

16-Bit

Architecture

XE166U Derivatives

16-Bit Single-Chip

Real Time Signal Controller

XC2000 Family / Compact Line

User's Manual

V1.1 2011-03

Microcontrollers

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Page	Subjects (major changes since last revision)
Page 8-2, Page 8-79, Page 8-150	SCU implementation section is removed and relevant contents are moved to the CGU, ESR and ERU sections.
Page 8-46, Page 8-49, Page 8-169	Notes are added to SCU interrupts that are enabled by default.
Page 8-55	SCU is not reset with an internal application reset.
Page 8-230	Reset types of TRAPSET, TRAPDIS and TRAPNP registers in SCU register overview table are corrected.
Page 9-16	IOCR register has to be configured when using analog pin functions of Ports 2 and 6.
Page 9-25	Newly added pin functions are shaded in the pin definitions and functions table.
Page 16-1, Page 16-110	Inconsistencies on the number of available channels are removed in the feature list and in the analog connections table.

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1 Introduction

The rapidly growing area of embedded control applications is representing one of the most time-critical operating environments for today's microcontrollers. Complex control algorithms have to be processed based on a large number of digital as well as analog input signals, and the appropriate output signals must be generated within a defined maximum response time. Embedded control applications also are often sensitive to board space, power consumption, and overall system cost.

Embedded control applications therefore require microcontrollers, which:

- offer a high level of system integration
- eliminate the need for additional peripheral devices and the associated software overhead
- provide system security and fail-safe mechanisms
- provide effective means to control (and reduce) the device's power consumption

Addressing these goals Infineon developed the XC2000 Family of 16/32-bit CMOS microcontrollers.

Information about specific versions and derivatives will be made available with the devices themselves. Contact your Infineon representative for up-to-date material or refer to <http://www.infineon.com/microcontrollers>.

About this Manual

This manual describes the functionality of a number of microcontroller types of the Infineon XE166U Derivatives - the **XE166U** derivatives. These microcontrollers provide identical functionality to a large extent, but each device type has specific unique features. The descriptions in this manual cover a superset of the provided features.

For simplicity, the various device types are referred to by the collective term **XE166U** throughout this manual. The complete Pro Electron conforming designations are listed in the respective Data Sheets.

For the features of a particular derivative please refer to the device datasheet.

Complete Development Support

For the development tool support of its microcontrollers, Infineon follows a clear third party concept. Currently around 120 tool suppliers world-wide, ranging from local niche manufacturers to multinational companies with broad product portfolios, offer powerful development tools for the Infineon C500, C800, XC800, C166, XC166, XC2000, XE166, and TriCore microcontroller families, providing a remarkable variety of price-performance classes as well as early availability of high quality key tools such as compilers, assemblers, simulators, debuggers or in-circuit emulators.

Infineon incorporates its strategic tool partners very early into the product development process, making sure embedded system developers get reliable, well-tuned tool

Introduction

solutions, which help them unleash the power of Infineon microcontrollers in the most effective way and with the shortest possible learning curve.

The tool environment for the Infineon 16/32-bit microcontrollers includes the following tools:

- Compilers (C/C++)
- Macro-assemblers, linkers, locators, library managers, format-converters
- Architectural simulators
- HLL debuggers
- Real-time operating systems
- VHDL chip models
- In-circuit emulators (based on bondout or standard chips)
- Plug-in emulators
- Emulation and clip-over adapters, production sockets
- Logic analyzer disassemblers
- Starter kits
- Evaluation boards with monitor programs
- Industrial boards
- Low level driver software
- Chip code generation tool (DAVE™)

1.1 Abbreviations

The following acronyms and terms are used within this document:

ADC	Analog Digital Converter
ALE	Address Latch Enable
ALU	Arithmetic and Logic Unit
ASC	Asynchronous/synchronous Serial Channel
CAN	Controller Area Network (License Bosch)
CAPCOM	CAPture and COMpare unit
CISC	Complex Instruction Set Computing
CMOS	Complementary Metal Oxide Silicon
CPU	Central Processing Unit
DAP	Device Access Port
DMU	Data Management Unit
EBC	External Bus Controller
ESFR	Extended Special Function Register
EVVR	Embedded Validated Voltage Regulator
Flash	Non-volatile memory that may be electrically erased
GPR	General Purpose Register
GPT	General Purpose Timer unit
HLL	High Level Language
IIC	Inter Integrated Circuit (Bus)
IIS	Inter Integrated Circuit Sound (Bus)
IO	Input/Output
JTAG	Joint Test Access Group
LIN	Local Interconnect Network
LPR	Low Power Reference
LQFP	Low Profile Quad Flat Pack
LXBus	Internal representation of the external bus
MAC	Multiply/Accumulate (unit)
MCDS	Multi Core Debug System
MPU	Memory Protection Unit

OCDS	On-Chip Debug Support
OTP	One-Time Programmable memory
PEC	Peripheral Event Controller
PLA	Programmable Logic Array
PLL	Phase Locked Loop
PMU	Program Management Unit
PVC	Power Validation Circuit
PWM	Pulse Width Modulation
RAM	Random Access Memory
RISC	Reduced Instruction Set Computing
ROM	Read Only Memory
RTC	Real Time Clock
SFR	Special Function Register
SoC	System on Chip
SSC	Synchronous Serial Channel
SWD	Supply Watchdog
UART	Universal Asynchronous Receiver/Transmitter
USIC	Universal Serial Interface Channel

1.2 Naming Conventions

The diverse bitfields used for control functions and status indication and the registers housing them are equipped with unique names wherever applicable. Thereby these control structures can be referred to by their names rather than by their location. This makes the descriptions by far more comprehensible.

To describe regular structures (such as ports) indices are used instead of a plethora of similar bit names, so bit 3 of port 5 is referred to as P5.3.

Where it helps to clarify the relation between several named structures, the next higher level is added to the respective name to make it unambiguous.

The term ADC0_GLOBCTR clearly identifies register GLOBCTR as part of module ADC0, the term SYSCON0.CLKSEL clearly identifies bitfield CLKSEL as part of register SYSCON0.

2 Architectural Overview

The diagram below shows the functional blocks and their basic connectivity within an XE166U System.

The system components are built around a C166SV2 CPU which is an enhanced member of Infineons C166 family of CPU cores. This evolutionary step of the CPU provides a mixed 16/32 bit instruction set compatible to the C166 instruction set. Additionally 32-bit DSP/MAC instructions are available. This ensures easy upgrade for existing C166 software and provides 32-bit performance assets.

Functional abstracts of the components contained in a XE166U are provided in the following subchapters.

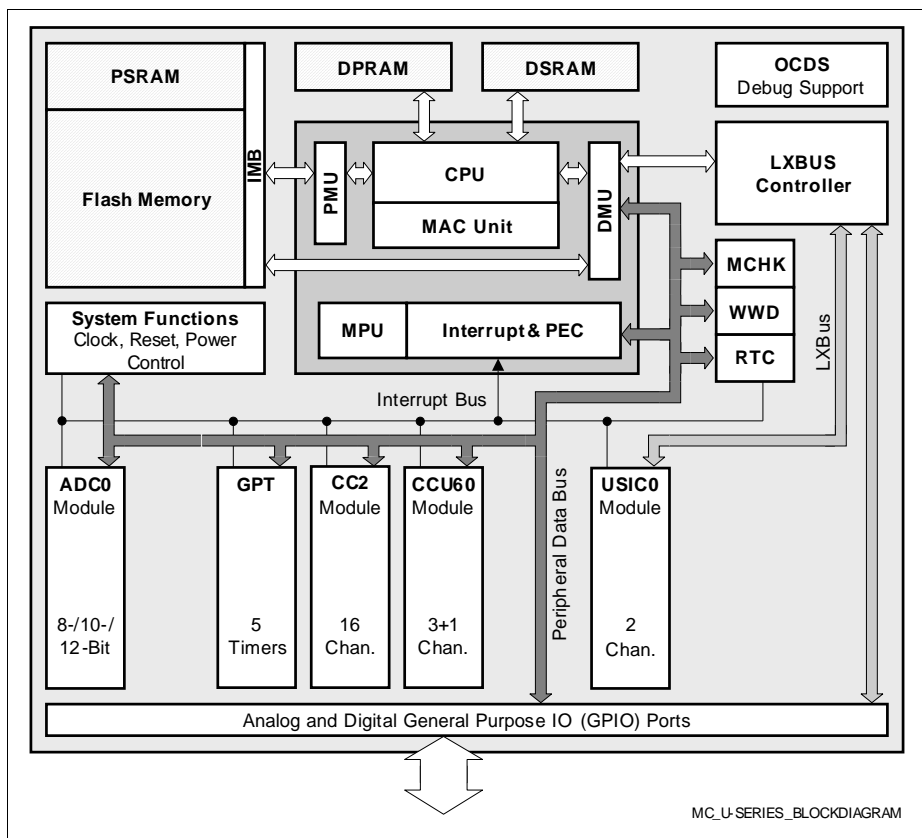


Figure 2-1 XE166U Functional Block Diagram

2.1 Summary of Features

The XE166U combines the extended functionality and performance of the C166SV2 Core with powerful on-chip peripheral subsystems and on-chip memory units. The following key features are available within the range of XE166U devices:

Intelligent On-Chip Peripheral Subsystems

- Synchronizable A/D Converters (ADC) with programmable resolution of 12-bit, 10-bit or 8-bit and conversion time of less than 1 μ s, up to 10 analog input channels, auto scan modes, channel injection, data reduction features
- Capture/Compare Unit (CC2) with 2 independent time bases, very flexible PWM unit/event recording unit with different operating modes, includes two 16-bit timers/counters, maximum resolution f_{SYS}
- One Capture/Compare Units (CCU6) for flexible PWM Signal Generation (3/6 Capture/Compare Channels and 1 Compare Channel)
- Two Multifunctional General Purpose Timer Units:
 - GPT1: three 16-bit timers/counters, maximum resolution $f_{SYS}/4$
 - GPT2: two 16-bit timers/counters, maximum resolution $f_{SYS}/2$
- One Universal Serial Interface Channel Units (USIC) providing 2 interface channels per unit, baud rate generator, receive/transmit FIFOs, programmable data length and shift direction, usable as UART, SPI-like, IIC, IIS, and LIN interface
- Real Time Clock (RTC) with alarm interrupt
- Window Watchdog Timer (WWD) with programmable time intervals and boundary window
- Bootstrap Loaders for flexible system initialization
- Protection management for system configuration and control registers

Integrated On-Chip Memories

- 2 Kbytes Dual-Port RAM (DPRAM) for variables, register banks, and stacks
- 2 Kbytes on-chip high-speed Data SRAM (DSRAM) for variables and stacks
- 4 Kbytes on-chip high-speed Program SRAM (PSRAM) for code and data
- Up to 64 Kbytes on-chip Flash Program Memory for instruction code or constant data

High Performance 16-bit CPU with Five-Stage Pipeline and MAC Unit

- Single clock cycle instruction execution for most instructions
- Single clock cycle multiplication (16-bit \times 16-bit)
- 4 + 17 clock cycles division (32-bit/16-bit), 4 cycles pipeline delay + 17 cycles background execution
- Single cycle multiply and accumulate instruction (MAC) execution
- 32-bit addition and 32-bit subtraction (MAC unit)
- 40-bit barrel shifter and 40-bit accumulator
- Automatic saturation or rounding included

- Multiple high bandwidth internal data buses
- Register-based design with multiple, memory mapped register banks
- Two additional local register banks
- Fast context switching support
- 16 Mbytes of linear address space for code and data (von Neumann architecture)
- System stack cache support with automatic stack overflow/underflow detection
- High performance branch, call, and loop processing
- Zero-cycle jump execution

Control Oriented Instruction Set with High Efficiency

- Bit, byte, and word data types
- Flexible and efficient addressing modes for high code density
- Enhanced boolean bit manipulation with direct addressability of 6 Kbits for peripheral control and user-defined flags
- Hardware traps to identify exception conditions during runtime
- HLL support for semaphore operations and efficient data access

Safety Support Features

- Memory Protection Unit (MPU)
- Memory Checker Module (MCHK) for CRC generation

Embedded Computing Features

- System Timer (STM) for real time clock support

Power Management Features

- Single IO power domain fulfills system requirements from 3 V to 5 V
- Embedded voltage regulator (core supply voltage 1.5V)
- Supply Watchdog (SWD)
- Core Power Validation (PVC)
- Separately controllable core power domains support wake-up via external triggers or on-chip timer while drastically reducing the power consumption
- Gated clock concept for improved power consumption and EMC
- Programmable system slowdown via clock generation unit
- Flexible management of peripherals, can be individually disabled
- Programmable frequency output

16-Priority-Level Interrupt System

- 46 interrupt nodes with separate interrupt vectors on 16 priority levels
- 7 cycles minimum interrupt latency in case of internal program execution
- Fast external interrupts

- Programmable external interrupt source selection
- Programmable vector table (start location and step-width)

8-Channel Peripheral Event Controller (PEC)

- Interrupt driven single cycle data transfer
- Programmable PEC interrupt request level, (15 down to 8)
- Transfer count option
(standard CPU interrupt after programmable number of PEC transfers)
- Separate interrupt level for PEC termination interrupts selectable
- Overhead from saving and restoring system state for interrupt requests eliminated
- Full 24-bit addresses for source and destination pointers, supporting transfers within the total address space

On-Chip Debug Support

- Communication through SPD interface (1-wire), DAP interface (2-wire) or JTAG interface (5-wire)
- On-chip debug controller with optional break interface
- Hardware, software and external pin breakpoints
- Up to 4 instruction pointer breakpoints
- Debug event control, e.g. with monitor call or CPU halt or trigger of data transfer
- Dedicated DEBUG instructions with control via SPD/DAP/JTAG interface
- Access to any internal register or memory location via SPD/DAP/JTAG interface
- Single step support and watchpoints with MOV-injection

Input/Output Lines With Individual Bit Addressability

- Tri-stated in input mode
- Push/pull or open drain output mode
- Programmable port driver control
- Single I/O power domain with a supply voltage range from 3.0 V to 5.5 V
(core-logic and oscillator input voltage is 1.5 V)

Various Temperature Ranges

- -40 to +85 °C
- -40 to +125 °C¹⁾

Infineon CMOS Process

- Low power CMOS technology enables power saving modes with flexible power management.

¹⁾ Not all derivatives are offered in all temperature ranges.

Green Plastic Packages

The XE166U devices use the package types:

- PG-VQFN (Plastic Green - Very Thin Profile Quad Flat Non-Leaded Package)
- PG-TSSOP (Plastic Green - Thin Shrink Small Outline Package)

Device packages are lead-free RoHS compliant surface mount device (SMD) types with 0.5 mm (10.7 mil) lead spacing. For details about package availability for a particular derivative please check the datasheet. For informations on available delivery options for assembly support and general package see <http://www.infineon.com/packages>

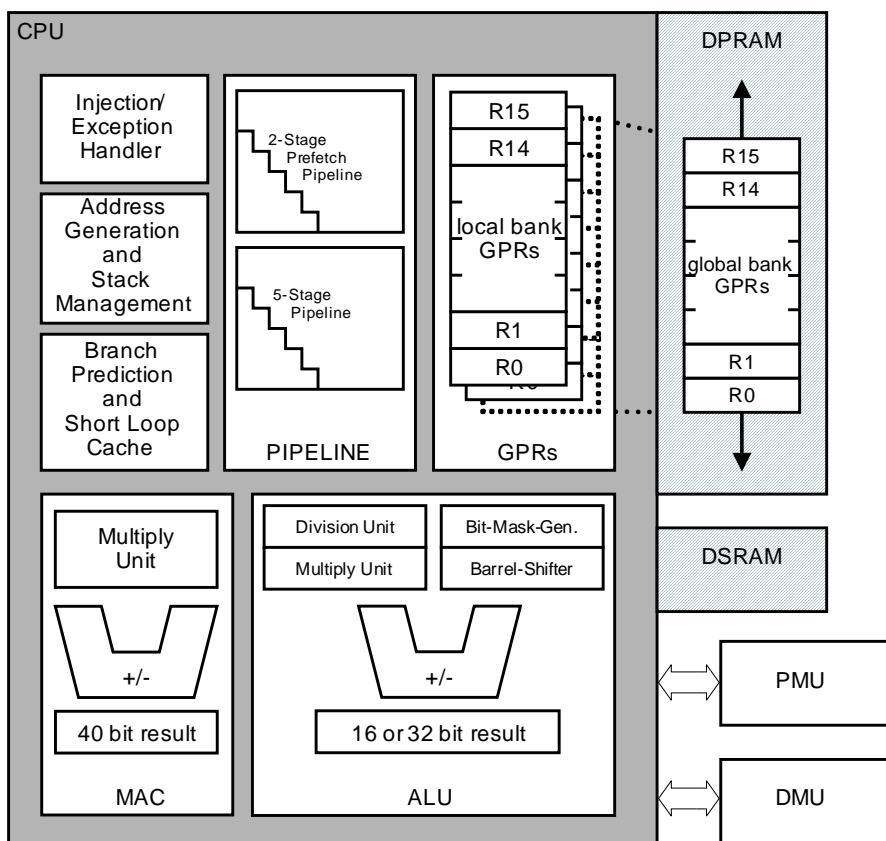
- PG-VQFN-48, 7 x 7 mm body
- PG-TSSOP-38, 9.7 x 4.4 mm body

2.2 System Core Components

The XE166U system core consists of the CPU with memory protection unit (MPU) and the memory interface blocks for program and data memories - PMU and DMU.

2.2.1 Central Processing Unit (CPU)

The CPU consists of a 5-stage execution pipeline with a 2-stage instruction-fetch pipeline, a 16/32-bit arithmetic and logic unit (ALU), a 40-bit multiply and accumulate unit (MAC), a register-file providing three register banks, and dedicated core (C)SFRs. The ALU features a multiply-and-divide unit, a bit-mask generator, and a barrel shifter.



CPU_OVERVIEW

Figure 2-2 CPU Overview

Architectural Overview

With this hardware most XE166U instructions can be executed in a single machine cycle of 15.2 ns with a 66-MHz CPU clock. For example, shift and rotate instructions are always processed during one machine cycle, no matter how many bits are shifted. Also, multiplication and most MAC instructions execute in one cycle. All multiple-cycle instructions have been optimized so that they can be executed very fast; for example, a 32-/16-bit division is started within 4 cycles while the remaining cycles are executed in the background. Another pipeline optimization, the branch target prediction, eliminates the execution time of branch instructions if the prediction was correct.

The CPU has a register context consisting of up to three register banks with 16 word-wide GPRs each at its disposal. One of these register banks is physically allocated within the on-chip DPRAM area. A Context Pointer (CP) register determines the base address of the active register bank accessed by the CPU at any time. The number of these register bank copies is only restricted by the available internal RAM space. For easy parameter passing, a register bank may overlap others.

A system stack of up to 32 Kwords is provided for storage of temporary data. The system stack can be allocated to any location within the address space (preferably in the on-chip RAM area); it is accessed by the CPU with the stack pointer (SP) register. Two separate SFRs, STKOV and STKUN, are implicitly compared with the stack pointer value during each stack access to detect stack overflow or underflow.

The high performance of the CPU hardware implementation can be best utilized by the programmer with the highly efficient XE166U instruction set. This includes the following instruction classes:

- Standard Arithmetic Instructions
- DSP-Oriented Arithmetic Instructions
- Logical Instructions
- Boolean Bit Manipulation Instructions
- Compare and Loop Control Instructions
- Shift and Rotate Instructions
- Prioritize Instruction
- Data Movement Instructions
- System Stack Instructions
- Jump and Call Instructions
- Return Instructions
- System Control Instructions
- Miscellaneous Instructions

The basic instruction length is either 2 or 4 bytes. Possible operand types are bits, bytes and words. A variety of direct, indirect or immediate addressing modes are provided to specify the required operands.

2.2.2 Memory Protection Unit (MPU)

The XE166U's Memory Protection Unit (MPU) protects user-specified memory areas from unauthorized read, write, or instruction fetch accesses. The MPU can protect the whole address space including the peripheral area. This completes established mechanisms such as the register security mechanism or stack overrun/underrun detection.

Four Protection Levels support flexible system programming where operating system, low level drivers, and applications run on separate levels. Each protection level permits different access restrictions for instructions and/or data.

Every access is checked (if the MPU is enabled) and an access violating the permission rules will be marked as invalid and leads to a protection trap.

A set of protection registers for each protection level specifies the address ranges and the access permissions. Applications requiring more than 4 protection levels can dynamically re-program the protection registers.

2.2.3 Programmable Multiple Priority Interrupt System

The XE166U provides 46 separate interrupt nodes that may be assigned to 16 priority levels with 8 group priorities on each level. Most interrupt sources are connected to a dedicated interrupt node. In some cases, multi-source interrupt nodes are incorporated for efficient use of system resources. These nodes can be activated by several source requests and are controlled via interrupt subnode control registers.

The following enhancements within the XE166U allow processing of a large number of interrupt sources:

- **Peripheral Event Controller (PEC):** This processor is used to off-load many interrupt requests from the CPU. It avoids the overhead of entering and exiting interrupt or trap routines by performing single-cycle interrupt-driven byte or word data transfers between any two locations with an optional increment of the PEC source pointer, the destination pointer, or both. Only one cycle is 'stolen' from the current CPU activity to perform a PEC service.
- **Multiple Priority Interrupt Controller:** This controller allows all interrupts to be assigned any specified priority. Interrupts may also be grouped, which enables the user to prevent similar priority tasks from interrupting each other. For each of the interrupt nodes, there is a separate control register which contains an interrupt request flag, an interrupt enable flag, and an interrupt priority bitfield. After being accepted by the CPU, an interrupt service can be interrupted only by a higher prioritized service request. For standard interrupt processing, each of the interrupt nodes has a dedicated vector location.
- **Multiple Register Banks:** Two local register banks for immediate context switching add to a locatable global register bank. The user can specify several register banks located anywhere in the internal DPRAM and made of up to sixteen general purpose

registers. A single instruction switches from one register bank to another (switching banks flushes the pipeline, changing the global bank requires a validation sequence).

The XE166U is capable of reacting very quickly to non-deterministic events because its interrupt response time is within a very narrow range of typically 7 clock cycles (in the case of internal program execution). Its fast external interrupt inputs are sampled every clock cycle and allow even very short external signals to be recognized.

The XE166U also provides an excellent mechanism to identify and process exceptions or error conditions that arise during run-time, so called 'Hardware Traps'. A hardware trap causes an immediate non-maskable system reaction which is similar to a standard interrupt service (branching to a dedicated vector table location). The occurrence of a hardware trap is additionally signified by an individual bit in the trap flag register (TFR). Unless another, higher prioritized, trap service is in progress, a hardware trap will interrupt any current program execution. In turn, a hardware trap service can normally not be interrupted by a standard or PEC interrupt.

Software interrupts are supported by means of the 'TRAP' instruction in combination with an individual trap (interrupt) number.

2.2.4 Interfaces to System Resources

The CPU of the XE166U interfaces to the system resources via several bus systems which contribute to the overall performance by transferring data concurrently.

The Dual Port RAM (DPRAM) and Data SRAM (DSRAM) are directly connected to the CPU and provide the best performance for data storage. Neither of these memories can be used for program execution.

The Program Management Unit (PMU) controls accesses to the on-chip program memory blocks such as the Flash module and the Program SRAM (PSRAM). The program memories can also be used for data storage.

The Data Management Unit (DMU) controls accesses to the on-chip peripherals connected to the peripheral data bus. Data accesses to peripherals connected to the on-chip LxBus are executed by the LxBus Controller.

2.3 On-Chip System Resources

The XE166U controllers provide a number of powerful system resources designed around the CPU. The combination of CPU and these resources results in the high performance of the members of this controller family.

2.3.1 Memory Areas

The memory space of the XE166U is configured in a Von Neumann architecture. This means that code memory, data memory, registers, and IO ports are organized within the same linear address space which covers up to 16 Mbytes. The entire memory space can be accessed byte-wise or word-wise. Particular portions of the on-chip memory have been made directly bit addressable as well.

Note: The actual memory sizes depend on the selected device type. This overview describes the maximum block sizes.

Up to 64 Kbytes of on-chip Flash memory store code or constant data. The on-chip Flash memory consists of up to 4 Flash modules, each built up from 4-Kbyte sectors. Each sector can be separately write protected¹⁾, erased and programmed (in blocks of 128 bytes). The complete Flash area can be read-protected. A user-defined password sequence temporarily unlocks protected areas. The Flash modules combine 128-bit read accesses with protected and efficient writing algorithms for programming and erasing. Dynamic error correction provides extremely high read data security for all read accesses. Accesses to different Flash modules can be executed in parallel.

Note: Program execution from on-chip program memory is the fastest of all possible alternatives and results in maximum performance. The size of the on-chip program memory depends on the chosen derivative. On-chip program memory also includes the PSRAM.

4 Kbytes of on-chip Program SRAM (PSRAM) are provided to store user code or data. The PSRAM is accessed via the PMU and is, therefore, optimized for code fetches. A section of the PSRAM with programmable size can be write-protected.

2 Kbytes of on-chip Data SRAM (DSRAM) are provided as a storage for general user data. The DSRAM is accessed via a separate interface and is, therefore, optimized for data accesses.

2 Kbytes of on-chip Dual-Port RAM (DPRAM) are provided as a storage for user defined variables, for the system stack, and in particular for general purpose register banks. A register bank can consist of up to 16 word-wide (R0 to R15) and/or byte-wide (RL0, RH0, ..., RL7, RH7) so-called General Purpose Registers (GPRs).

¹⁾ To save control bits, sectors are clustered for protection purposes, they remain separate for programming/erasing.

Architectural Overview

The upper 256 bytes of the DPRAM are directly bitaddressable. When used by a GPR, any location in the DPRAM is bitaddressable.

The CPU has an actual register context of up to 16 wordwide and/or byte-wide global GPRs at its disposal, which are physically located within the on-chip RAM area. A Context Pointer (CP) register determines the base address of the active global register bank to be accessed by the CPU at a time. The number of register banks is restricted only by the available internal RAM space. For easy parameter passing, a register bank may overlap other register banks.

A system stack of up to 32 Kwords is provided as storage for temporary data. The system stack can be located anywhere within the complete addressing range and it is accessed by the CPU via the Stack Pointer (SP) register and the Stack Pointer Segment (SPSEG) register. Two separate SFRs, STKOV and STKUN, are implicitly compared against the stack pointer value upon each stack access for the detection of a stack overflow or underflow. This mechanism also supports the control of a bigger virtual stack. Maximum performance for stack operations is achieved by allocating the system stack to internal data RAM areas (DPRAM, DSRAM).

Hardware detection of the selected memory space is placed at the internal memory decoders and allows the user to specify any address directly or indirectly and obtain the desired data without using temporary registers or special instructions.

For Special Function Registers three areas of the address space are reserved: The standard Special Function Register area (SFR) uses 512 bytes, while the Extended Special Function Register area (ESFR) uses the other 512 bytes. A range of 4 Kbytes is provided for the internal IO area (XSFR). SFRs are wordwide registers which are used for controlling and monitoring functions of the different on-chip units. Unused SFR addresses are reserved for future members of the XE166U Derivatives with enhanced functionality. Therefore, they should either not be accessed, or written with zeros, to ensure upward compatibility.

2.3.2 LxBus Interface

The LxBus controller controls accesses to the USIC module connected to the **on-chip LxBus**.

2.4 On-Chip Peripheral Blocks

The XE166U Derivatives clearly separates peripherals from the core. This structure permits the maximum number of operations to be performed in parallel and allows peripherals to be added or deleted from family members without modifications to the core. Each functional block processes data independently and communicates information over common buses. Peripherals are controlled by data written to the respective Special Function Registers (SFRs). These SFRs are located within either the standard SFR area (00'FE00_H ... 00'FFFF_H), the extended ESFR area (00'F000_H ... 00'F1FF_H), or within the internal IO area (00'E000_H ... 00'FFFF_H).

These built-in peripherals either allow the CPU to interface with the external world or provide functions on-chip that otherwise would need to be added externally in the respective system.

The XE166U generic peripherals are:

- **Memory Checker Unit (MCHK)**
- **General Purpose Timers (GPT)**
- **Window Watchdog Timer (WWD)**
- **Capture/Compare Unit CAPCOM (CC2)**
- **Capture/Compare Unit CCU6 (CCU6)**
- **Analog/Digital Converter (ADC)**
- **Real Time Clock (RTC)**
- **Parallel Ports**

The LxBus, which does not support bit-addressing, connects on-chip peripherals to the CPU:

- **Universal Serial Interface Channel Modules (USIC)**
-

Each peripheral also contains a set of Special Function Registers (SFRs) which control the functionality of the peripheral and temporarily store intermediate data results. Each peripheral has an associated set of status flags. Individually selected clock signals are generated for each peripheral from binary multiples of the master clock.

Note: The available peripherals for the different derivatives are listed in the respective datasheet.

Peripheral Interfaces

The on-chip peripherals generally have two different types of interfaces: a bus interface to the CPU and interface signals to other on-chip peripherals or to external hardware. Communication between the CPU and peripherals is performed through Special Function Registers (SFRs) and interrupts. The SFRs serve as control/status and data registers for the peripherals. Interrupt requests are generated by the peripherals based on specific events which occur during their operation, such as operation complete, error, etc.

To interface with external hardware, specific pins of the parallel ports are used, when an input or output function has been selected for a peripheral. During this time, the port pins are controlled either by the peripheral (when used as outputs) or by the external hardware which controls the peripheral (when used as inputs). This is called the 'alternate (input or output) function' of a port pin, in contrast to its function as a general purpose I/O pin.

Peripheral Timing

Internal operation of the CPU and peripherals is based on the system clock (f_{SYS}). The clock generation unit uses external (e.g. a crystal) or internal clock sources to generate the system clock signal. Peripherals can be disconnected from the clock signal either temporarily to save energy or permanently if they are not used in a specific application. Peripheral SFRs may be accessed by the CPU once per state. When an SFR is written to by software in the same state where it is also to be modified by the peripheral, the software write operation has priority. Further details on peripheral timing are included in the specific sections describing each peripheral.

Programming Hints

- **Access to SFRs:** The SFRs reside in various data pages of the memory space. The following addressing mechanisms allow access to the SFRs:
 - Indirect or direct addressing with **16-bit (mem) addresses** must guarantee that the used data page pointer (DPP0 ... DPP3) selects the corresponding data page.
 - Accesses via the Peripheral Event Controller (**PEC**) use the SRCPx and DSTPx pointers instead of the data page pointers.
 - **Short 8-bit (reg) addresses** to the standard SFR area do not use the data page pointers but directly access the registers within this 512-byte area.
 - **Short 8-bit (reg) addresses** to the extended **ESFR** area require switching to the 512-byte Extended SFR area. This is done via the EXTension instructions EXTR, EXTP(R), EXTS(R).
- **Byte Write Operations** to wordwide SFRs via indirect or direct 16-bit (mem) addressing or byte transfers via the PEC force zeros in the non-addressed byte. Byte write operations via short 8-bit (reg) addressing can access only the low byte of an SFR and force zeros in the high byte. It is therefore recommended, to use the bitfield

instructions (BFLDL and BFLDH) to write to any number of bits in either byte of an SFR without disturbing the non-addressed byte and the unselected bits.

- **Write Operations to Write-Only Bits/Registers** usually modify bits within other registers. In some cases this modification is controlled by state machines. Therefore, the effect of the write operation may not be visible, when the modified register is read immediately after the write access that triggers the modification.
- **Reserved Bits:** Some of the bits which are contained in the XE166U's SFRs are marked as 'Reserved'. User software should never write '1's to reserved bits. These bits are currently not implemented and may be used in future products to invoke new functions. In that case, the active state for those new functions will be '1', and the inactive state will be '0'. Therefore writing only '0's to reserved locations allows portability of the current software to future devices. After read accesses, reserved bits should be ignored or masked out.

Capture/Compare Unit CAPCOM (CC2)

The CAPCOM unit supports generation and control of timing sequences on up to 16 channels with a maximum resolution of 1 system clock cycle (8 cycles in staggered mode). The CAPCOM unit is typically used to handle high speed I/O tasks such as pulse and waveform generation, pulse width modulation (PMW), Digital to Analog (D/A) conversion, software timing, or time recording relative to external events.

Two 16-bit timers with reload registers provide two independent time bases for each capture/compare register.

The input clock for the timers is programmable to several prescaled values of the internal system clock, or may be derived from an overflow/underflow of timer T6 in module GPT2. This provides a wide range of variation for the timer period and resolution and allows precise adjustments to the application specific requirements. In addition, external count inputs allow event scheduling for the capture/compare registers relative to external events.

The capture/compare register array contains 16 dual purpose capture/compare registers, each of which may be individually allocated to either CAPCOM timer and programmed for capture or compare function.

All registers have each one port pin associated with it which serves as an input pin for triggering the capture function, or as an output pin to indicate the occurrence of a compare event.

When a capture/compare register has been selected for capture mode, the current contents of the allocated timer will be latched ('captured') into the capture/compare register in response to an external event at the port pin which is associated with this register. In addition, a specific interrupt request for this capture/compare register is generated. Either a positive, a negative, or both a positive and a negative external signal transition at the pin can be selected as the triggering event.

Architectural Overview

The contents of all registers which have been selected for one of the five compare modes are continuously compared with the contents of the allocated timers.

When a match occurs between the timer value and the value in a capture/compare register, specific actions will be taken based on the selected compare mode.

Table 2-1 Compare Modes

Compare Mode	Function
Mode 0	Interrupt-only compare mode; several compare interrupts per timer period are possible
Mode 1	Pin toggles on each compare match; several compare events per timer period are possible
Mode 2	Interrupt-only compare mode; only one compare interrupt per timer period is generated
Mode 3	Pin set '1' on match; pin reset '0' on compare timer overflow; only one compare event per timer period is generated
Double Register Mode	Two registers operate on one pin; pin toggles on each compare match; several compare events per timer period are possible
Single Event Mode	Generates single edges or pulses; can be used with any compare mode

Capture/Compare Unit CCU6 (CCU6)

The CCU6 units support generation and control of timing sequences on up to three 16-bit capture/compare channels plus one independent 16-bit compare channel.

In compare mode, the CCU6 units provide two output signals per channel which have inverted polarity and non-overlapping pulse transitions (deadtime control). The compare channel can generate a single PWM output signal and is further used to modulate the capture/compare output signals.

In capture mode the contents of compare timer T12 is stored in the capture registers upon a signal transition at pins CCx.

The output signals can be generated in edge-aligned or center-aligned PWM mode. They are generated continuously or in single-shot mode.

Compare timers T12 and T13 are free running timers which are clocked by the prescaled system clock.

For motor control applications (brushless DC-drives) both subunits may generate versatile multichannel PWM signals which are basically either controlled by compare timer T12 or by a typical hall sensor pattern at the interrupt inputs (block commutation). The latter mode provides noise filtering for the hall inputs and supports automatic rotational speed measurement.

The trap function offers a fast emergency stop without CPU activity. Triggered by an external signal (CTR_{AP}) the outputs are switched to selectable logic levels which can be adapted to the connected power stages.

Note: The number of available CCU6 units and channels depends on the selected device type.

General Purpose Timers (GPT)

The GPT12E unit represents a very flexible multifunctional timer/counter structure which may be used for many different time related tasks such as event timing and counting, pulse width and duty cycle measurements, pulse generation, or pulse multiplication.

The GPT12E unit incorporates five 16-bit timers which are organized in two separate blocks, GPT1 and GPT2. Each timer in each block may operate independently in a number of different modes, or may be concatenated with another timer of the same block.

Each of the three timers T2, T3, T4 of **block GPT1** can be configured individually for one of four basic modes of operation, which are Timer, Gated Timer, Counter, and Incremental Interface Mode. In Timer Mode, the input clock for a timer is derived from the system clock, divided by a programmable prescaler, while Counter Mode allows a timer to be clocked in reference to external events.

Pulse width or duty cycle measurement is supported in Gated Timer Mode, where the operation of a timer is controlled by the 'gate' level on an external input pin. For these purposes, each timer has one associated port pin (TxIN) which serves as gate or clock input. The maximum resolution of the timers in block GPT1 is 4 system clock cycles.

The count direction (up/down) for each timer is programmable by software or may additionally be altered dynamically by an external signal on a port pin (TxEUD) to facilitate e.g. position tracking.

In Incremental Interface Mode the GPT1 timers (T2, T3, T4) can be directly connected to the incremental position sensor signals A and B via their respective inputs TxIN and TxEUD. Direction and count signals are internally derived from these two input signals, so the contents of the respective timer Tx corresponds to the sensor position. The third position sensor signal TOP0 can be connected to an interrupt input.

Timer T3 has an output toggle latch (T3OTL) which changes its state on each timer overflow/underflow. The state of this latch may be output on pin T3OUT e.g. for time out monitoring of external hardware components. It may also be used internally to clock timers T2 and T4 for measuring long time periods with high resolution.

In addition to their basic operating modes, timers T2 and T4 may be configured as reload or capture registers for timer T3. When used as capture or reload registers, timers T2 and T4 are stopped. The contents of timer T3 is captured into T2 or T4 in response to a signal at their associated input pins (TxIN). Timer T3 is reloaded with the contents of T2 or T4 triggered either by an external signal or by a selectable state transition of its toggle latch T3OTL. When both T2 and T4 are configured to alternately reload T3 on opposite state transitions of T3OTL with the low and high times of a PWM signal, this signal can be constantly generated without software intervention.

With its maximum resolution of 2 system clock cycles, the **GPT2 block** provides precise event control and time measurement. It includes two timers (T5, T6) and a capture/reload register (CAPREL). Both timers can be clocked with an input clock which

Architectural Overview

is derived from the CPU clock via a programmable prescaler or with external signals. The count direction (up/down) for each timer is programmable by software or may additionally be altered dynamically by an external signal on a port pin (TxEUD). Concatenation of the timers is supported via the output toggle latch (T6OTL) of timer T6, which changes its state on each timer overflow/underflow.

The state of this latch may be used to clock timer T5, and/or it may be output on pin T6OUT. The overflows/underflows of timer T6 can additionally be used to clock the CAPCOM2 timers, and to cause a reload from the CAPREL register.

The CAPREL register may capture the contents of timer T5 based on an external signal transition on the corresponding port pin (CAPIN), and timer T5 may optionally be cleared after the capture procedure. This allows the XE166U to measure absolute time differences or to perform pulse multiplication without software overhead.

The capture trigger (timer T5 to CAPREL) may also be generated upon transitions of GPT1 timer T3's inputs T3IN and/or T3EUD. This is especially advantageous when T3 operates in Incremental Interface Mode.

Note: Not all timer modes may be available due to missing input pins.

Real Time Clock (RTC)

The Real Time Clock (RTC) module of the XE166U is directly clocked with a separate clock signal. Several internal and external clock sources can be selected via register RTCCCLKCON. It is, therefore, independent from the selected clock generation mode of the XE166U.

The RTC basically consists of a chain of divider blocks:

- Selectable 32:1 and 8:1 dividers (on - off)
- The reloadable 16-bit timer T14
- The 32-bit RTC timer block (accessible via registers RTCH and RTCL), made of:
 - a reloadable 10-bit timer
 - a reloadable 6-bit timer
 - a reloadable 6-bit timer
 - a reloadable 10-bit timer

All timers count up. Each timer can generate an interrupt request. All requests are combined to a common node request.

Note: The registers associated with the RTC are not affected by an application reset in order to maintain the contents even when intermediate resets are executed.

The RTC module can be used for different purposes:

- System clock to determine the current time and date
- Cyclic time based interrupt, to provide a system time tick independent of CPU frequency and other resources
- 48-bit timer for long term measurements
- Alarm interrupt for wake-up on a defined time

Analog/Digital Converter (ADC)

For analog signal measurement, the 12bit A/D converter (ADC0) with 10 multiplexed input channels including a sample and hold circuit have been integrated on-chip. It uses the method of successive approximation. The sample time (for loading the capacitors) and the conversion time are programmable and can thus be adjusted to the external circuitry. The A/D converter can also operate in 8-bit and 10-bit conversion modes, where the conversion time is further reduced.

Several independent conversion result registers, selectable interrupt requests, and highly flexible conversion sequences provide a high degree of programmability to fulfill the requirements of the respective application. Both modules can be synchronized to allow parallel sampling of two input channels.

For applications that require more analog input channels, external analog multiplexers can be controlled automatically.

For applications that require less analog input channels, the remaining channel inputs can be used as digital input port pins.

The A/D converter of the XE166U support two types of request sources which can be triggered by several internal and external events.

- Scan requests are activated at the same time and then executed in a predefined sequence.
- Queued requests are executed in a user-defined sequence.

In addition, the conversion of a specific channel can be inserted into a running sequence without disturbing this sequence. All requests are arbitrated according to the priority level that has been assigned to them.

Data reduction features, such as limit checking or result accumulation, reduce the number of required CPU accesses and so allow the precise evaluation of analog inputs (high conversion rate) even at low CPU speed.

The Peripheral Event Controller (PEC) may be used to control the A/D converter or to automatically store conversion results into a table in memory for later evaluation, without requiring the overhead of entering and exiting interrupt routines for each data transfer. Therefore, the A/D converter contains 8 result registers which can be concatenated to build a result FIFO. Wait-for-read mode can be enabled for each result register to prevent loss of conversion data.

In order to decouple analog inputs from digital noise and to avoid input trigger noise those pins used for analog input can be disconnected from the digital input stages under software control. This can be selected for each pin separately via registers Px_DIDIS (Port x Digital Input Disable).

The Auto-Power-Down feature of the A/D converters minimizes the power consumption when no conversion is in progress.

Note: The number of available analog channels depends on the selected device type.

Universal Serial Interface Channel Modules (USIC)

Each USIC module provides two communication channels which can be individually configured to match the application needs, e.g. the protocol can be selected or changed during run time without the need for a reset. The following protocols are supported:

- **UART** (ASC, asynchronous serial channel)
 - module capability: receiver/transmitter with max. baud rate $f_{\text{sys}}/4$
 - application target baud rate range: 1.2 kBaud to 3.5 MBaud
 - number of data bits per data frame 1 to 63
 - MSB or LSB first
- **LIN** Support by HW (low-cost network, baud rate up to 20 kBaud)
 - data transfers based on ASC protocol
 - baud rate detection possible by built-in capture event of baud rate generator
 - checksum generation under SW control for higher flexibility
- **SSC/SPI** (synchronous serial channel with or without slave select lines)
 - module capability: slave mode with max. baud rate f_{sys}
 - module capability: master mode with max. baud rate $f_{\text{sys}}/2$
 - application target baud rate range: 2 kBaud to 10 MBaud
 - number of data bits per data frame 1 to 63, more with explicit stop condition
 - MSB or LSB first
- **IIC** (Inter-IC Bus)
 - application baud rate 100 kBaud to 400 kBaud
 - 7-bit and 10-bit addressing supported
 - full master and slave device capability
- **IIS** (infotainment audio bus)
 - module capability: receiver with max. baud rate f_{sys}
 - module capability: transmitter with max. baud rate $f_{\text{sys}}/2$
 - application target baud rate range: up to 26 MBaud

In addition to the flexible choice of the communication protocol, the USIC structure has been designed to reduce the system load (CPU load) allowing efficient data handling. The following aspects have been considered:

- **Data buffer capability**
The standard buffer capability includes a double word buffer for receive data and a single word buffer for transmit data. This allows longer CPU reaction times (e.g. interrupt latency).
- **Additional FIFO buffer capability**
In addition to the standard buffer capability, the received data and the data to be transmitted can be buffered in a FIFO buffer structure. The size of the receive and the transmit FIFO buffer can be programmed independently. Depending on the application needs, a total buffer capability of 64 data words can be assigned to the receive and transmit FIFO buffers of a USIC module (the two channels of the USIC module share the 64 data word buffer).

In addition to the FIFO buffer, a bypass mechanism allows the introduction of high-priority data without flushing the FIFO buffer.

- **Transmit control information**

For each data word to be transmitted, a 5-bit transmit control information has been added to automatically control some transmission parameters, such as word length, frame length, or the slave select control for the SPI protocol. The transmit control information is generated automatically by analyzing the address where the user SW has written the data word to be transmitted (32 input locations = $2^5 = 5$ bit transmit control information).

This feature allows individual handling of each data word, e.g. the transmit control information associated to the data words stored in a transmit FIFO can automatically modify the slave select outputs to select different communication targets (slave devices) without CPU load. Alternatively, it can be used to control the frame length.

- **Flexible frame length control**

The number of bits to be transferred within a data frame is independent of the data word length and can be handled in two different ways. The first option allows automatic generation of frames up to 63 bits with a known length. The second option supports longer frames (even unlimited length) or frames with a dynamically controlled length.

- **Interrupt capability**

The events of each USIC channel can be individually routed to one of 4 service request outputs, depending on the application needs. Furthermore, specific start and end of frame indications are supported in addition to protocol-specific events.

- **Flexible interface routing**

Each USIC channel offers the choice between several possible input and output pins connections for the communications signals. This allows a flexible assignment of USIC signals to pins that can be changed without resetting the device.

- **Input conditioning**

Each input signal is handled by a programmable input conditioning stage with programmable filtering and synchronization capability.

- **Baud rate generation**

Each USIC channel contains an own baud rate generator. The baud rate generation can be based either on the internal module clock or on an external frequency input. This structure allows data transfers with a frequency that can not be generated internally, e.g. to synchronize several communication partners.

- **Transfer trigger capability**

In master mode, data transfers can be triggered events generated outside the USIC module, e.g. at an input pin or a timer unit (transmit data validation). This feature allows time base related data transmission.

- **Debugger support**

The USIC offers specific addresses to read out received data without interaction with the FIFO buffer mechanism. This feature allows debugger accesses without the risk of a corrupted receive data sequence.

Architectural Overview

To reach a desired baud rate, two criteria have to be respected, the module capability and the application environment. The module capability is defined with respect to the module's input clock frequency f_{sys} , being the base for the module operation. Although the module's capability being much higher (depending on the module clock and the number of module clock cycles needed to represent a data bit), the reachable baud rate is generally limited by the application environment. In most cases, the application environment limits the maximum reachable baud rate due to driver delays, signal propagation times, or due to EMI reasons.

Note: Depending on the selected additional functions (such as digital filters, input synchronization stages, sample point adjustment, data structure, etc.), the maximum reachable baud rate can be limited. Please also take care about additional delays, such as (internal or external) propagation delays and driver delays (e.g. for collision detection in ASC mode, for IIC, etc.).

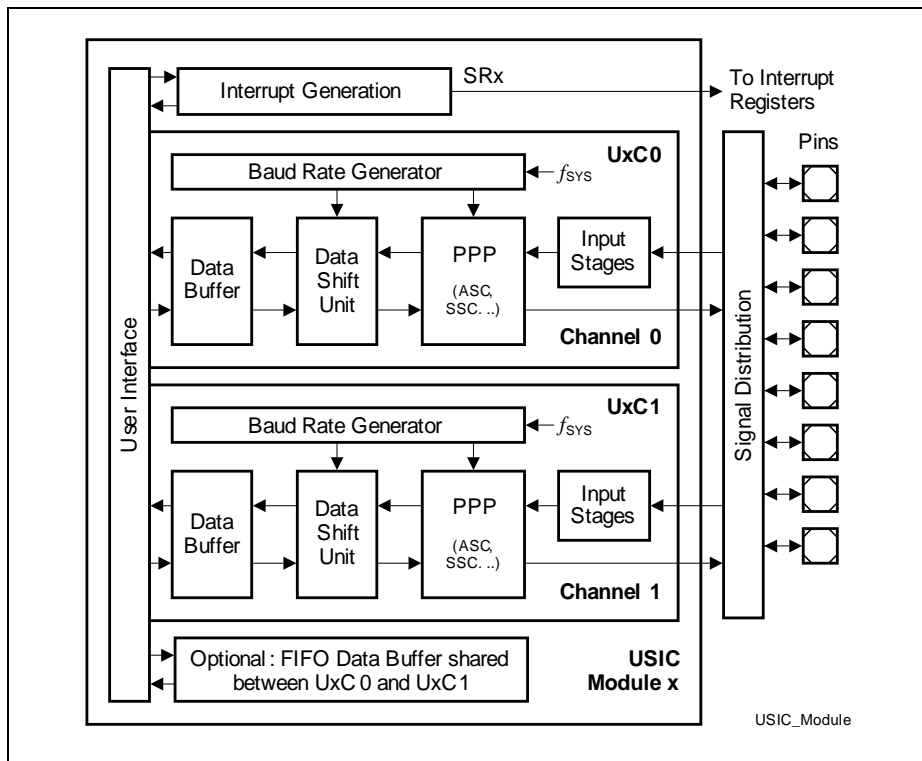


Figure 2-3 USIC Channel Structure

Architectural Overview

The USIC module contains two independent communication channels, with structure shown in **Figure 2-3**.

The data shift unit and the data buffering of each channel support full-duplex data transfers. The protocol-specific actions are handled by protocol pre-processors (PPP). In order to simplify data handling, an additional FIFO data buffer is optionally available for each USIC module to store transmit and receive data for each channel. This FIFO data buffer is not necessarily available in all devices (please refer to USIC implementation chapter for details).

Due to the independent channel control and baud rate generation, the communication protocol, baud rate and the data format can be independently programmed for each communication channel.

Window Watchdog Timer (WWD)

The Window Watchdog Timer represents one of the fail-safe mechanisms which have been implemented to prevent the controller from malfunctioning for longer periods of time. Throughout the user's manual, the Window Watchdog Timer is also referred to as the Watchdog Timer (WDT).

The Watchdog Timer is always enabled after a reset of the chip, and can be disabled and enabled at any time by executing instructions DISWDT and ENWDT. Thus, the chip's start-up procedure is always monitored. The software has to be designed to restart the Watchdog Timer before it overflows. If, due to hardware or software related failures, the software fails to do so, the Window Watchdog Timer overflows and generates a reset request.

The Watchdog Timer has a 'programmable window boundary', it disallows refresh during the Watchdog Timer's count-up. A refresh during this window boundary will cause the Watchdog Timer to also generate a reset request.

The Watchdog Timer is a 16-bit timer, clocked with either the system clock f_{SYS} or the independent wake-up oscillator clock f_{OSC_WU} divided by 16,384 or 256. The high byte of the Watchdog Timer register can be set to a prespecified reload value (stored in WDTREL) to allow further variation of the monitored time interval. Each time it is serviced by the application software, the high byte of the Watchdog Timer is reloaded and the low byte is cleared.

The following time intervals can be monitored with the Watchdog Timer (window boundary feature is disabled):

- Between 15.2 ns and 16.3 s (@ $f_{SYS} = 66$ MHz)
- Between 2.0 μ s and 2147.5 s (@ $f_{OSC_WU} = 500$ kHz)

The default Watchdog Timer interval after reset is 0.13 s (@ $f_{OSC_WU} = 500$ kHz).

Memory Checker Unit (MCHK)

The memory checker module (MCHK) of the XE166U supports checking the data consistency of memories, registers (e.g. configuration registers), or communication channels. It calculates a checksum on a block of data, often called cyclic redundancy code (CRC). It is implemented as a parallel signature generation based on a multi input linear feedback shift register (MISR). Being based on a linear feedback shift register (LFSR), it also can generate pseudo-random numbers and cyclic codes.

From the programmer's point of view, the MCHK is a set of registers associated with this peripheral. To communicate respective error or operation events, an interrupt line may be used for the signal "MISMATCH" to generate an internal event.

Parallel Ports

The port lines have programmable alternate input or output functions associated with them. These alternate functions can be assigned to various port pins to support the optimal utilization for a given application. Port lines that are not used for these alternate functions may be used as general purpose IO (GPIO) port lines.

All port lines are bit-addressable, and all input/output lines can be individually (bit-wise) configured via port control registers. This configuration selects the direction (input/output), push/pull or open-drain operation, and activation of pull devices for each pin. Edge characteristics (shape) and driver characteristics (output current) of the port drivers can be selected for groups of 4 pins. The I/O ports are true bidirectional ports which are switched to high impedance state when configured as inputs. During the internal reset, all port pins are configured as inputs without pull devices active.

The following table lists how many lines of each port are connected to package pins.

Table 2-2 Quantitative Ports Summary

Port	VQFN-48	TSSOP-38
P2	12	9
P5	6	5
P6	3	2
P10	12	12
Σ GPIO Ports	33	28

2.5 Clock Generation

The Clock Generation Unit uses a programmable on-chip PLL with multiple prescalers to generate the clock signals for the XE166U with high flexibility. The system clock f_{SYS} can be derived from several internal and external clock sources.

The on-chip high-precision oscillator (OSC_HP) can drive an external crystal or accepts an external clock signal. The oscillator clock frequency can be multiplied by the on-chip PLL (by a programmable factor) or can be divided by a programmable prescaler factor.

An internal clock source can provide a clock signal without requiring an external crystal.

The Oscillator Watchdog (OWD) supervises the input clock and enables an emergency clock if the input clock appears as not reliable.

2.6 Power Management

The XE166U can operate within a wide supply voltage range from 3 V to 5 V. The internal core supply voltage is generated via on-chip Embedded Voltage Regulators and is supervised by on-chip Power Validation Circuits.

The XE166U provides several means to control the power it consumes either at a given time or averaged over a certain timespan. Two mechanisms can be used (partly in parallel):

- **Clock Generation Management** controls the distribution and the frequency of internal and external clock signals. While the clock signals for currently inactive parts of logic are disabled automatically, the user can reduce the XE166U's CPU clock frequency which drastically reduces the consumed power. External circuitry can be controlled via the programmable frequency output EXTCLK.
- **Peripheral Management** permits temporary disabling of peripheral modules. Each peripheral can separately be disabled/enabled.

Wake-up from power reduction modes can be triggered either externally by signals generated by the external system, or internally by the on-chip wake-up timer, which supports intermittent operation of the XE166U by generating cyclic wake-up signals. This offers full performance to quickly react on action requests while the intermittent power-saving phases greatly reduce the average power consumption of the system.

Note: When selecting the clock generation management method, the required parameters must be carefully written to the respective bitfields, to avoid unintended intermediate states. Recommended sequences are provided which ensure the intended operation of the clock system.

2.7 On-Chip Debug Support (OCDS)

The On-Chip Debug Support system provides a broad range of debug and emulation features built into the XE166U. The user software running on the XE166U can thus be debugged within the target system environment.

The OCDS is controlled by an external debugging device via the debug interface and an optional break interface. The debugger controls the OCDS via a set of dedicated registers accessible via the debug interface. Additionally, the OCDS system can be controlled by the CPU, e.g. by a monitor program. An injection interface allows the execution of OCDS-generated instructions by the CPU.

Multiple breakpoints can be triggered by on-chip hardware, by software, or by an external trigger input. Single stepping is supported as well as the injection of arbitrary instructions and read/write access to the complete internal address space. A breakpoint trigger can be answered with a CPU-halt, a monitor call, a data transfer, or/and the activation of an external signal.

For the tool interface these variants can be used:

- JTAG (IEEE-1149.1-conforming) with 4 pins
- DAP (Device Access Port) with 2 pins
- SPD (Single Pin DAP) with 1 pin

The optional break interface uses another 1 or 2 pins.

3 Memory Organization

The memory space of the XE166U is configured in a “Von Neumann” architecture. This means that code and data are accessed within the same linear address space. All of the physically separated memory areas, including internal ROM and Flash, internal RAM, the internal Special Function Register Areas (SFRs and ESFRs), the internal IO area, and external memory are mapped into one common address space.

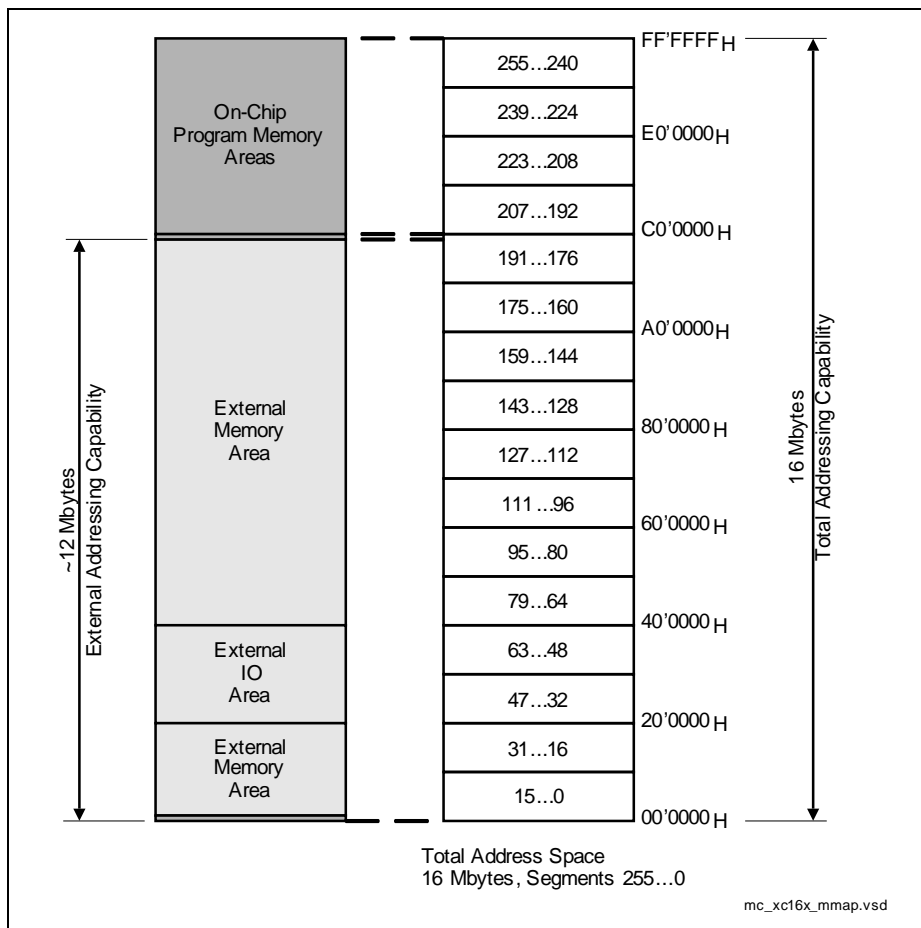


Figure 3-1 Address Space Overview

Memory Organization

The XE166U provides a total addressable memory space of 16 Mbytes. This address space is arranged as 256 segments of 64 Kbytes each, and each segment is again subdivided into four data pages of 16 Kbytes each (see [Figure 3-1](#)).

Bytes are stored at even or odd byte addresses. Words are stored in ascending memory locations with the low byte at an even byte address being followed by the high byte at the next odd byte address ("little endian"). Double words (code only) are stored in ascending memory locations as two subsequent words. Single bits are always stored in the specified bit position at a word address. Bit position 0 is the least significant bit of the byte at an even byte address, and bit position 15 is the most significant bit of the byte at the next odd byte address. Bit addressing is supported for a part of the Special Function Registers, a part of the internal RAM and for the General Purpose Registers.

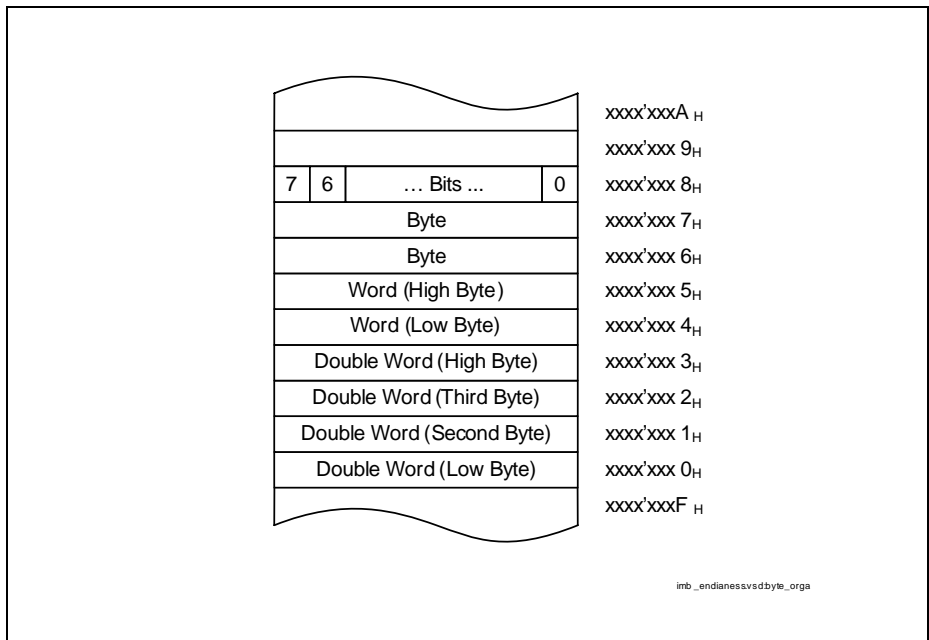


Figure 3-2 Storage of Words, Bytes and Bits in a Byte Organized Memory

Note: Byte units forming a single word or a double word must always be stored within the same physical (internal, external, ROM, RAM) and organizational (page, segment) memory area.

3.1 Address Mapping

All the various memory areas and peripheral registers (see [Table 3-1](#)) are mapped into one contiguous address space. All sections can be accessed in the same way. The memory map of the XE166U contains some reserved areas, so future derivatives can be enhanced in an upward-compatible fashion.

Note: [Table 3-1](#) shows the maximum available memory areas. The actual available memory areas depend on the selected device type.

Table 3-1 XE166U Memory Map¹⁾

Address Area	Start Loc.	End Loc.	Area Size ²⁾	Notes
IMB register space	FF'FF00 _H	FF'FFFF _H	256 Bytes	
Reserved	F0'0000 _H	FF'FEFF _H	< 1 Mbyte	Minus IMB registers
Reserved for EPSRAM	E8'1000 _H	EF'FFFF _H	508 Kbytes	Mirrors EPSRAM
Emulated PSRAM	E8'0000 _H	E8'0FFF _H	up to 4 Kbytes	With Flash timing
Reserved for PSRAM	E0'1000 _H	E7'FFFF _H	508 Kbytes	Mirrors PSRAM
PSRAM	E0'0000 _H	E0'0FFF _H	up to 4 Kbytes	Program SRAM
Reserved for Flash	C1'1000 _H	DF'FFFF _H	1980 Kbytes	
Flash 0	C0'0000 _H	C1'0FFF _H	68 Kbytes	
External memory area	40'0000 _H	BF'FFFF _H	8 Mbytes	
External IO area ³⁾	21'0000 _H	3F'FFFF _H	1,984 Kbytes	
Reserved	20'B400 _H	20'FFFF _H	19 Kbytes	
USIC0 alternate regs.	20'B000 _H	20'B3FF _H	1 Kbyte	Accessed via LxBus controller
Reserved	20'4800 _H	20'AFFF _H	26 Kbytes	
USIC0 registers	20'4000 _H	20'47FF _H	2 Kbytes	Accessed via LxBus controller
Reserved	20'0000 _H	20'3FFF _H	16 Kbytes	
External memory area	01'0000 _H	1F'FFFF _H	1984 Kbytes	
SFR area	00'FE00 _H	00'FFFF _H	0.5 Kbytes	
Dualport RAM (DPRAM)	00'F600 _H	00'FDFF _H	2 Kbytes	
Reserved for DPRAM	00'F200 _H	00'F5FF _H	1 Kbytes	
ESFR area	00'F000 _H	00'F1FF _H	0.5 Kbytes	
XSFR area	00'E000 _H	00'EFFF _H	4 Kbytes	

Table 3-1 XE166U Memory Map¹⁾ (cont'd)

Address Area	Start Loc.	End Loc.	Area Size ²⁾	Notes
Data SRAM (DSRAM)	00'D800 _H	00'DFFF _H	2 Kbytes	
Reserved for DSRAM	00'8000 _H	00'D7FF _H	22 Kbytes	
External memory area	00'0000H	00'7FFFH	32 Kbytes	

1) Accesses to the shaded areas are reserved. In devices with external bus interface these accesses generate external bus accesses.

2) The areas marked with "<" are slightly smaller than indicated, see column "Notes".

3) Several pipeline optimizations are not active within the external IO area.

3.2 Register Areas

The registers controlling the system and peripheral functions of the XE166U can be accessed through five address areas. The address areas differ in their access properties. Please refer to [Chapter 3.7](#) and the CPU chapter for further details.

The first three areas provide Special Function Registers (SFRs) access capabilities for controlling the system and peripheral functions of the XE166U:

- 512-byte SFR area (located above the DPRAM: 00'FFFF_H ... 00'FE00_H).
- 512-byte ESFR area (located below the DPRAM: 00'F1FF_H ... 00'F000_H).
- 4-Kbyte XSFR area (located below the ESFR area: 00'EFFF_H ... 00'E000_H).

The USIC registers are located within the external IO area:

- 64-Kbyte external IO area (located in: 20'0000_H ... 20'FFFF_H).

The IMB registers are located within a regular memory area. CPU pipeline effects must be regarded for access in this area:

- 256-byte IMB registers area (located in: FF'FF00_H ... FF'FFFF_H).

This arrangement provides upward compatibility with the derivatives of the C166 and XC166 families.

IMB Registers not in IO Area

Important to note is that IMB registers are not located within the IO area. Only in IO areas the CPU takes care that data accesses are executed exactly in the sequence of their appearance in the instruction stream. Outside of the IO areas the CPU ensures only that accesses to single addresses maintain their sequence. So special care must be taken when accessing the IMB register range. Two examples will help to understand this important issue:

1. Sequence: write to address A; read from address B.
2. Sequence: write to address C; read from address C.

If addresses A, B and C are located in IO areas then the sequence of memory accesses would resemble their sequence in the code.

If addresses A, B and C are located outside of IO areas, then pipeline effects could cause the read from address B in sequence 1 to be performed before the write to address A happens. The CPU will itself ensure that sequence 2 is executed in order. To work around this issue and to enforce sequence order, a read from address A or a write to address B should be performed after the write to address A — both ensure that the read from address B occurs after the write from address A.

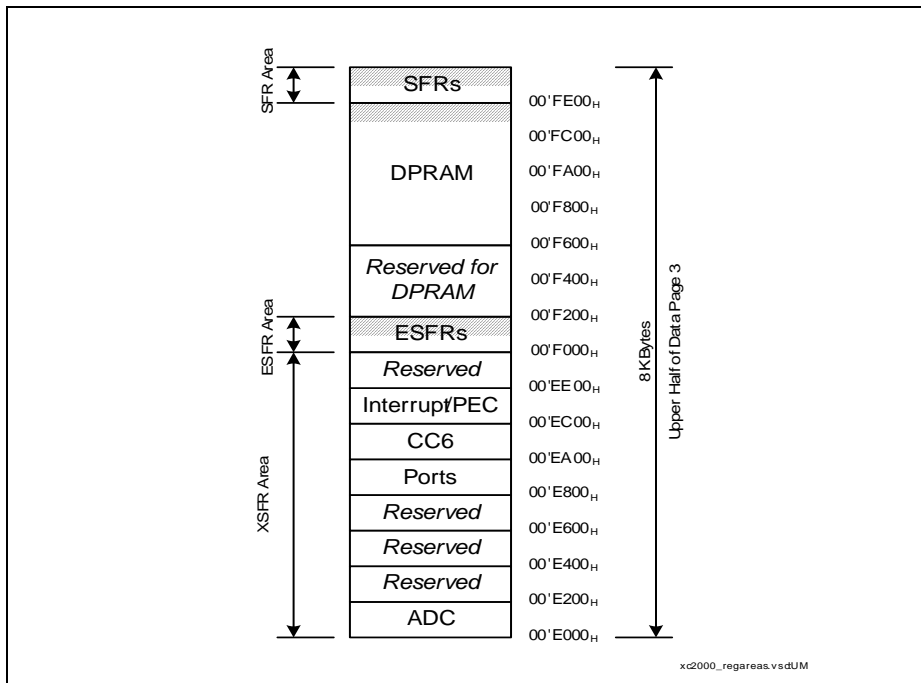


Figure 3-3 Special Function Register Mapping

Note: The upper 256 bytes of SFR area, ESFR area, and internal RAM are bit-addressable (see hatched blocks in [Figure 3-3](#)).

Special Function Registers

The functions of the CPU, the bus interface, the IO ports, and the on-chip peripherals of the XE166U are controlled via a number of Special Function Registers (SFRs).

All Special Function Registers can be addressed via indirect and long 16-bit addressing modes. The (word) SFRs and their respective low bytes in the SFR/ESFR areas can be addressed using an 8-bit offset together with an implicit base address. However, this **does not work** for the respective high bytes!

Note: Writing to any byte of an SFR causes the not addressed complementary byte to be cleared.

The upper half of the SFR-area (00'FFFF_H ... 00'FF00_H) and the ESFR-area (00'F1FF_H ... 00'F100_H) is bit-addressable, so the respective control/status bits can be modified directly or checked using bit addressing.

Memory Organization

When accessing registers in the ESFR area using 8-bit addresses or direct bit addressing, an Extend Register (EXTR) instruction is required beforehand to switch the short addressing mechanism from the standard SFR area to the Extended SFR area. This is not required for 16-bit and indirect addresses. The GPRs R15 ... R0 are duplicated, i.e. they are accessible within both register blocks via short 2-, 4-, or 8-bit addresses without switching.

ESFR_SWITCH_EXAMPLE:

```
EXTR  #4                      ;Switch to ESFR area for next 4 instr.
MOV   STMREL, #data16         ;STMREL uses 8-bit reg addressing
BFLDL STMCON, #mask, #data8 ;Bit addressing for bitfields
BSET  WUCR.CLRTG             ;Bit addressing for single bits
MOV   T8REL, R1               ;T8REL uses 16-bit mem address,
                              ;R1 is duplicated into the ESFR space
                              ;(EXTR is not required for this access)
;---- ;-----              ;The scope of the EXTR #4 instruction ...
                              ;... ends here!
MOV   T8REL, R1               ;T8REL uses 16-bit mem address,
                              ;R1 is accessed via the SFR space
```

In order to minimize the use of the EXTR instructions the ESFR area mostly holds registers which are mainly required for initialization and mode selection. Registers that need to be accessed frequently are allocated to the standard SFR area, wherever possible.

Note: The tools are equipped to monitor accesses to the ESFR area and will automatically insert EXTR instructions, or issue a warning in case of missing or excessive EXTR instructions.

Accesses to registers in the XSFR area use 16-bit addresses and require no specific addressing modes or precautions.

General Purpose Registers

The General Purpose Registers (GPRs) use a block of 16 consecutive words either within the global register bank or within one of the two local register banks. The bit-field BANK in register PSW selects the currently active register bank. The global register bank is mirrored to a section in the DPRAM, the Context Pointer (CP) register determines the base address of the currently active global register bank section. This register bank may consist of up to 16 Word-GPRs (R0, R1, ... R15) and/or of up to 16 byte-GPRs (RL0, RH0, ... RL7, RH7). The sixteen byte-GPRs are mapped onto the first eight Word GPRs (see [Table 3-2](#)).

In contrast to the system stack, a register bank grows from lower towards higher address locations and occupies a maximum space of 32 bytes. The GPRs are accessed via short 2-, 4-, or 8-bit addressing modes using the Context Pointer (CP) register as base

Memory Organization

address for the global bank (independent of the current DPP register contents). Additionally, each bit in the currently active register bank can be accessed individually.

Table 3-2 Mapping of General Purpose Registers to DPRAM Addresses

DPRAM Address	High Byte Registers	Low Byte Registers	Word Registers
<CP> + 1E _H	–	–	R15
<CP> + 1C _H	–	–	R14
<CP> + 1A _H	–	–	R13
<CP> + 18 _H	–	–	R12
<CP> + 16 _H	–	–	R11
<CP> + 14 _H	–	–	R10
<CP> + 12 _H	–	–	R9
<CP> + 10 _H	–	–	R8
<CP> + 0E _H	RH7	RL7	R7
<CP> + 0C _H	RH6	RL6	R6
<CP> + 0A _H	RH5	RL5	R5
<CP> + 08 _H	RH4	RL4	R4
<CP> + 06 _H	RH3	RL3	R3
<CP> + 04 _H	RH2	RL2	R2
<CP> + 02 _H	RH1	RL1	R1
<CP> + 00 _H	RH0	RL0	R0

The XE166U supports fast register bank (context) switching. Multiple global register banks can physically exist within the DPRAM at the same time. Only the global register bank selected by the Context Pointer register (CP) is active at a given time, however. Selecting a new active global register bank is simply done by updating the CP register. A particular Switch Context (SCXT) instruction performs register bank switching by automatically saving the previous context and loading the new context. The number of implemented register banks (arbitrary sizes) is limited only by the size of the available DPRAM.

Note: The local GPR banks are not memory mapped and the GPRs cannot be accessed using a long or indirect memory address.

PEC Source and Destination Pointers

The source and destination address pointers for data transfers on the PEC channels are located in the XSFR area.

Memory Organization

Each channel uses a pair of pointers stored in two subsequent word locations with the source pointer (SRCPx) on the lower and the destination pointer (DSTPx) on the higher word address ($x = 7 \dots 0$). An additional segment register stores the associated source and destination segments, so PEC transfers can move data from/to any location within the complete addressing range.

Whenever a PEC data transfer is performed, the pair of source and destination pointers (selected by the specified PEC channel number) accesses the locations referred to by these pointers independently of the current DPP register contents.

If a PEC channel is not used, the corresponding pointer locations can be used for other purposes.

Note: Writing to any byte of the PEC pointers causes the not addressed complementary byte to be cleared.

3.3 Data Memory Areas

The XE166U provides two on-chip RAM areas exclusively for data storage:

- The **Dual Port RAM (DPRAM)** can be used for global register banks (GPRs), system stack, storage of variables and other data, in particular for MAC operands.
- The **Data SRAM (DSRAM)** can be used for system stack (recommended), storage of variables and other data.

Note: Data can also be stored in the PSRAM (see [Section 3.11](#)). However, both data memory areas provide the fastest access.

Depending on the device additional on-chip memory areas may exist with the special purpose to retain data while the system power domain is switched off. The XE166U contains:

- The **Marker Memory (MKMEM)**.

Dual-Port RAM (DPRAM)

The XE166U provides 2 Kbytes of DPRAM (00'F600_H ... 00'FDFF_H). Any word or byte data in the DPRAM can be accessed via indirect or long 16-bit addressing modes, if the selected DPP register points to data page 3. Any word data access is made on an even byte address.

For PEC data transfers, the DPRAM can be accessed independent of the contents of the DPP registers via the PEC source and destination pointers.

The upper 256 bytes of the DPRAM (00'FD00_H through 00'FDFF_H) are provided for single bit storage, and thus they are bit addressable.

Note: Code cannot be executed out of the DPRAM.

Note: The locations 00'FBFE_H ... 00'FC01_H of the DPRAM may be altered during the initialization phase after a reset. This area, therefore, should not store data to be preserved beyond a reset.

An area of 3 Kbytes is dedicated to DPRAM (00'F200_H ... 00'FDFF_H). The locations without implemented DPRAM are reserved.

Data SRAM (DSRAM)

The XE166U provides 2 Kbytes of DSRAM (00'D800_H ... 00'DFFF_H). Any word or byte data in the DSRAM can be accessed via indirect or long 16-bit addressing modes, if the selected DPP register points to data page 3 (for the range 00'C000_H ... 00'DFFF_H) or to data page 2 (for the range 00'D800_H ... 00'BFFF_H). Any word data access is made on an even byte address.

For PEC data transfers, the DSRAM can be accessed independent of the contents of the DPP registers via the PEC source and destination pointers.

Note: Code cannot be executed out of the DSRAM.

Memory Organization

An area of 24 Kbytes is dedicated to DSRAM (00'8000_H ... 00'DFFF_H). The locations without implemented DSRAM are reserved.

Marker Memory (MKMEM)

The MKMEM provides 4 bytes of memory. It can be used to store system state information during power down.

The MKMEM consists of 2 16-bit SFRs that are accessible as all other SFRs. Details are described in the SCU chapter.

Note: Code cannot be executed out of the MKMEM.

3.4 Program Memory Areas

The XE166U provides two on-chip program memory areas for code/data storage:

- The **Program Flash/ROM** stores code and constant data. Flash memory is (re-) programmed by the application software or flash loaders, ROM is mask-programmed in the factory.
- The **Program SRAM (PSRAM)** stores temporary code sequences and other data. For example higher level boot loader software can be written to the PSRAM and then be executed to program the on-chip Flash memory.

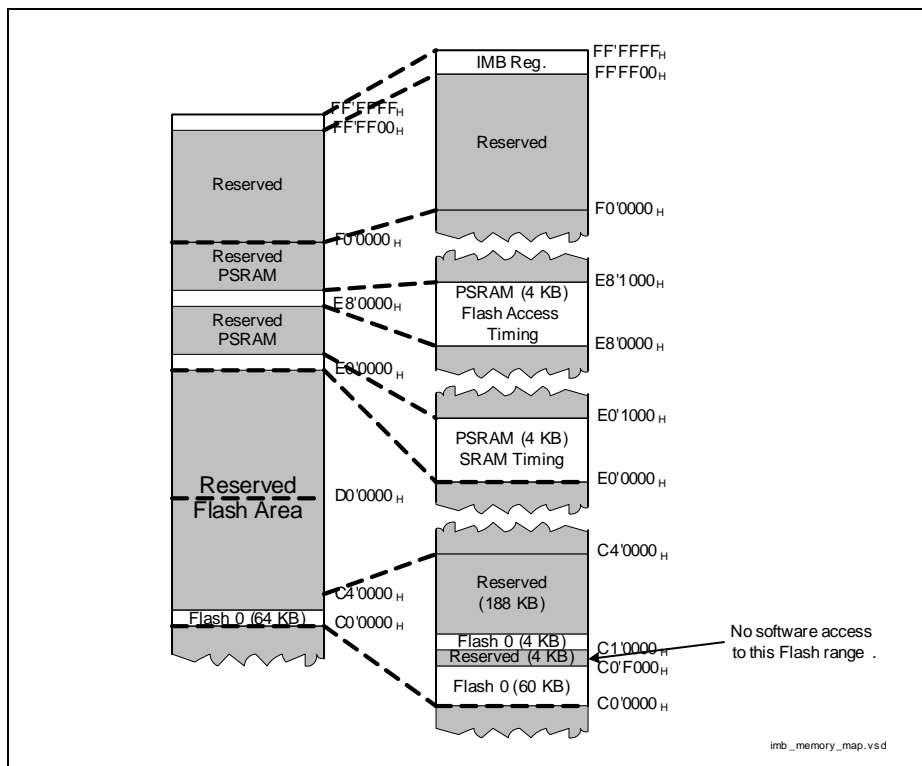


Figure 3-4 On-Chip Program Memory Mapping

3.4.1 Program/Data SRAM (PSRAM)

The XE166U provides up to 4 Kbytes of PSRAM (E0'0000_H ... E0'0FFF_H). The PSRAM provides fast code execution without initial delays. Therefore, it supports non-sequential code execution, for example via the interrupt vector table.

Any word or byte data in the PSRAM can be accessed via indirect or long 16-bit addressing modes, if the selected DPP register points to one of its data pages. Any word data access is made on an even byte address.

For PEC data transfers, the PSRAM can be accessed independent of the contents of the DPP registers via the PEC source and destination pointers.

Any data can be stored in the PSRAM. Because the PSRAM is optimized for code fetches, however, data accesses to the data memories provide higher performance.

Note: The PSRAM is not bit-addressable.

Note: The upper 256 Bytes of the PSRAM may be altered during the initialization phase after a reset. This area, therefore, should not store data to be preserved beyond a reset.

Also, during bootstrap loader operation, the serially received data is stored in the PSRAM starting at location E0'0000_H.

An area of 512 Kbytes is dedicated to PSRAM (E0'0000_H ... F7'FFFF_H). The locations without implemented PSRAM are reserved.

Flash Emulation

During code development the PSRAM will often be used for storing code or data that the production chip will later contain in the flash memory. In order to ensure similar execution time the PSRAM supports a second access path in the range E8'0000_H ... EF'FFFF_H with timing parameters that correspond to Flash timing. The number of wait-cycles is determined by the flash access timing configuration (see [IMB_IMBCTRL.WSFLASH](#)). Writes are always performed without wait-cycles.

This flash access timing imitation is nearly cycle accurate because the same read logic as for reading the flash memory is used¹⁾. Discrepancies might occur if the software uses the PSRAM for flash emulation and directly as PSRAM. During emulation access conflicts can cause a slightly different timing as in the product chip where these conflicts do not occur.

Another source of timing differences can be access conflicts at the flash modules in the product chip. Data reads and instruction fetches that target different flash modules can be executed concurrently whereas if they target the same flash module they are

1) The dual use of the flash read logic might cause unexpected behavior: while the IMB Core is busy with updating the protection configuration (after startup or after changing the security pages) read accesses to the flash emulation range of the PSRAM are blocked because Flash data reads would be blocked also.

executed sequentially with the data access as first. In the flash emulation this type of conflict can not occur. The data and the instruction access will both incur the defined number of wait-cycles (as if they would target different flash modules) and if they collide at the PSRAM interface the instruction fetch will see an additional wait-cycle.

Data Integrity

The PSRAM contains its own error control which can be switched between ECC and parity. Details are described in the SCU chapter.

Write Protection

As the PSRAM is often used to store timing critical code or constant data it is supplied with a write protection. After storing critical data in the PSRAM the register field **IMB_IMBCTRH.PSPROT** can be used to split the PSRAM into a read-only and a writable part. Write accesses to the read-only part are blocked and a trap can be activated.

3.4.2 Non-Volatile Program Memory (Flash)

The XE166U provides up to up to 64 Kbytes of program Flash starting at address C0'0000_H. Code and data fetches are always 64-bit aligned, using byte select lines for word and byte data.

Any word or byte data in the program memory can be accessed via indirect or long 16-bit addressing modes, if the selected DPP register points to one of the respective data pages. Any word data access is made on an even byte address.

For PEC data transfers, the program memory can be accessed independent of the contents of the DPP registers via the PEC source and destination pointers.

Note: The program memory is not bit-addressable.

An area of 2 Mbytes is dedicated to program memory (C0'0000_H ... DF'FFFF_H). The locations without implemented program memory are reserved.

A more detailed description can be found in **“Embedded Flash Memory” on Page 3-19**.

3.5 System Stack

The system stack may be defined anywhere within the XE166U's memory areas.

For all system stack operations the respective stack memory is accessed via a 24-bit stack pointer. The Stack Pointer (SP) register provides the lower 16 bits of the stack pointer (stack pointer offset), the Stack Pointer Segment (SPSEG) register adds the upper 8 bits of the stack pointer (stack segment). The system stack grows downward from higher towards lower locations as it is filled. Only word accesses are supported to the system stack.

Register SP is decremented before data is pushed on the system stack, and incremented after data has been pulled from the system stack. Only word accesses are supported to the system stack.

By using register SP for stack operations, the size of the system stack is limited to 64 KBytes. The stack must be located in the segment defined by register SPSEG.

The stack pointer points to the latest system stack entry, rather than to the next available system stack address.

A stack overflow (STKOV) register and a stack underflow (STKUN) register are provided to control the lower and upper limits of the selected stack area. These two stack boundary registers can be used both for protection against data corruption.

For best performance it is recommended to locate the stack to the DPRAM or to the DSRAM. Using the DPRAM may conflict with register banks or MAC operands.

3.6 Protected Bits

The XE166U provides a special mechanism to protect bits which can be modified by the on-chip hardware from being changed unintentionally by software accesses to related bits (refer also to section “Bit Manipulation Unit” in the CPU chapter). The “rwh” and “wh” bits and bfields of the following registers support bit protection:

Table 3-3 XE166U Protected Bits

Register	Component(s)	Notes
TFR	CPU	Trap Flag Register
PSW	CPU	Processor Status Word
PECISNC	CPU	PEC channel interrupt request flags
MPU_PRA	MPU	Protection Range Address
SCU_GSCSWREQ	SCU	Global State Control Software Request
RTC_ISNC	RTC	Interrupt node sharing request flags
CC2_OUT	CC2	Compare output bits
GPT12E_T2CON	GPT	GPT1 timer T2 flags
GPT12E_T3CON	GPT	GPT1 timer T3 flags and output toggle latch
GPT12E_T4CON	GPT	GPT1 timer T4 flags
GPT12E_T6CON	GPT	GPT2 timer T6 output toggle latch
xC	CPU, SCU and Peripheral units	All interrupt control registers. A complete list is given in the interrupt and exception control chapter
Px_OUT	Ports	All port output registers

3.7 IO Areas

The following areas of the XE166U's address space are marked as IO area:

- The **external IO area** is provided for the on-chip LxBus-peripherals, such as the USIC module. It is located from 20'0000_H to 3F'FFFF_H (2 Mbytes).
- The **internal IO area** provides access to the internal peripherals and is split into three blocks:
 - The SFR area, located from 00'FE00_H to 00'FFFF_H (512 bytes).
 - The ESFR area, located from 00'F000_H to 00'F1FF_H (512 bytes).
 - The XSFR area, located from 00'E000_H to 00'EFFF_H (4 Kbytes).

Note: The external IO area supports real byte accesses. The internal IO area does not support real byte transfers, the complementary byte is cleared when writing to a byte location.

The IO areas have special properties, because peripheral modules must be controlled in a different way than memories:

- Accesses are not buffered and cached, the write back buffers and caches are not used to store IO read and write accesses.
- Speculative reads are not executed, but delayed until all speculations are solved (e.g. pre-fetching after conditional branches).
- Data forwarding is disabled, an IO read access is delayed until all IO writes pending in the pipeline are executed, because peripherals can change their internal state after a write access.

3.8 Reserved Memory Areas

The memory map contains reserved memory areas where no memories nor registers are currently mapped to. Generally, such memory areas must never be accessed by the user program. Otherwise, the following behavior occurs when accessing unprotected reserved memory areas:

- In case of a read access, random data is returned;
- In case of a write access, the behavior is undefined. The reserved memory areas may be mirrored to existing memories. Therefore, one consequence may be that the other data is overwritten.

Reserved memory areas may be protected against access by using the MPU. Access protection mechanisms are also implemented for reserved Flash or PSRAM sections. If an access protection is detected, a trap is executed.

3.9 Crossing Memory Boundaries

The address space of the XE166U is implicitly divided into equally sized blocks of different granularity and into logical memory areas. Crossing the boundaries between these blocks (code or data) or areas requires special attention to ensure that the controller executes the desired operations.

Memory Areas are partitions of the address space assigned to different kinds of memory (if provided at all). These memory areas are the SFR areas, the on-chip program or data RAM areas, the on-chip ROM/Flash (if available), the on-chip LxBus-peripherals (if integrated), and the external memory (if available).

Accessing subsequent data locations which belong to different memory areas is no problem. However, when executing code, the different memory areas must be switched explicitly via branch instructions. Sequential boundary crossing is not supported and leads to erroneous results.

Note: Changing from the external memory area to the on-chip RAM area takes place within segment 0.

Segments are contiguous blocks of 64 Kbytes each. They are referenced via the Code Segment Pointer CSP for code fetches and via an explicit segment number for data accesses overriding the standard DPP scheme.

During code fetching, segments are not changed automatically, but rather must be switched explicitly. The instructions JMPS, CALLS and RETS will do this.

Data Pages are contiguous blocks of 16 Kbytes each. They are referenced via the data page pointers DPP3 ... DPP0 and via an explicit data page number for data accesses overriding the standard DPP scheme. Each DPP register can select one of the possible 1024 data pages. The DPP register which is used for the current access is selected via the two upper bits of the 16-bit data address. Therefore, subsequent 16-bit data addresses which cross the 16-Kbytes data page boundaries will use different data page pointers, while the physical locations need not be subsequent within memory.

3.10 Embedded Flash Memory

This chapter describes the embedded flash memory of the XE166U:

- **Section 3.10.1** defines the flash specific nomenclature and the structure of the flash memory.
- **Section 3.10.2** describes the operating modes.
- **Section 3.10.3** contains all operations.
- **Section 3.10.4** gives the details of operating sequences.
- The three sections **Section 3.10.7**, **Section 3.10.8** and **Section 3.10.9** look more into depth of maintaining data integrity and protection issues.
- **Section 3.10.10** discusses Flash EEPROM emulation.
- **Section 3.10.11** describes interrupt generation by the flash memory.

The **Chapter 3.11** describes how the flash memory is embedded into the memory architecture of the XE166U and lists all SFRs that affect its behavior.

3.10.1 Definitions

This section defines the nomenclature and some abbreviations as a base for the rest of the document. The used flash memory is a non-volatile memory ("**NVM**") based on a floating gate one-transistor cell. It is called "non-volatile" because the memory content is kept when the memory power supply is shut off.

Logical and Physical States

Flash memory content can not be changed directly as in SRAMs. Changing data is a complicated process with a typically much longer duration than reading.

- **Erasing:** The erased state of a cell is logical 0. Forcing an flash cell to this state is called "erasing". Erasing is possible with a minimum granularity of one page (see below). A device is delivered with completely erased flash memory.
- **Programming:** The programmed state of a cell is logical 1. Changing an erased cell to this state is called "programming". A page must only be programmed once and has to be erased before it can be programmed again.

The above listed processes have certain limitations:

- **Retention:** This is the time during which the data of a flash cell can be read reliably. The retention time is a statistical figure that depends on the operating conditions of the flash array (temperature profile) and the accesses to the flash array. With an increasing number of program/erase cycles (see endurance) the retention is lowered. Drain and gate disturbs decrease data retention as well.
- **Endurance:** As described above the data retention is reduced with an increasing number of program/erase cycles. A flash cell incurs one cycle whenever its page or sector is erased. This number is called "endurance". As said for the retention it is a statistical figure that depends on operating conditions and the use of the flash cells and not to forget on the required quality level.

Memory Organization

- **Drain Disturb:** Because of using a so called “one-transistor” flash cell each program access disturbs all pages of the same sector slightly. Over long these “drain disturbs” make 0 and 1 values indistinguishable and thus provoke read errors. This effect is again interrelated with the retention. A cell that incurred a high number of drain disturbs will have a lower retention. The physical sectors of the flash array are isolated from each other. So pages of a different sector do not incur a drain disturb. This effect must be therefor considered when the page erase feature is used.

The durations of programming and erasing as well as the limits for endurance, retention and drain disturbs are documented in the data sheet.

Attention: No means exist in the device that prevent the application from violating these limitation.

Array Structure

The flash memory is hierarchically structured:

- **Block:** A block consists of 128 user data bits (i.e. 16 bytes) and 9 ECC bits. One read access delivers one block.
- **Page:** A page consists of 8 blocks (i.e. 128 bytes). Programming changes always complete pages.
- **Sector:** A sector consists of 32 pages (i.e. 4096 bytes). The pages of one sector are affected by drain disturb as described above. The pages of different sectors are isolated from each other.
- **Array:** Each 256 KB array has 64 sectors¹⁾, a 128 KB array has 32, a 64 KB array has 16 and a 32 KB array has 8 sectors. Usually when referring to an “array” this contains as well all accompanying logic as assembly buffer, high voltage logic and the digital logic that allows to operate them in parallel.
- **Memory:** The complete flash memory of the XE166U consists of 1 flash array(s).

This structure of the 256 KB array is visualized in [Figure 3-5](#). The structure of the 64 KB array is analog.

1) If the Flash0 is a 256 KB array one sector is reserved for device internal purposes. It is not accessible by software, thus only 63 are usable.

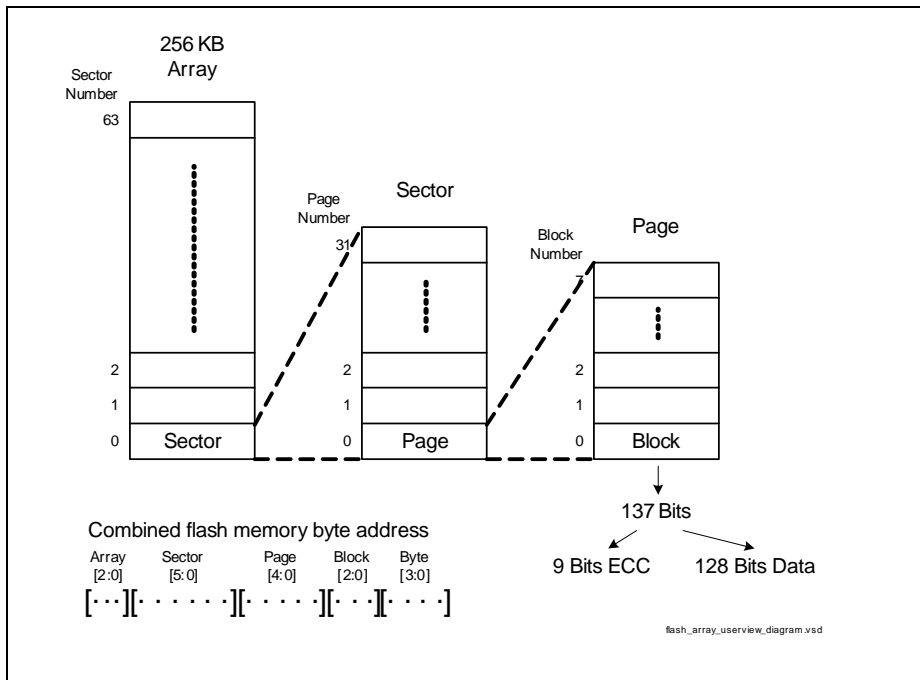


Figure 3-5 Flash Structure

3.10.2 Operating Modes

The IMB and the flash memory and each flash module have certain modes of operation. Some modes define clocking and power supply and the operating state of the analog logic as oscillators and voltage pumps. Overall system modes (e.g. startup mode) influence the behavior of the flash memory as well.

Other modes define the functional behavior. These will be discussed here.

3.10.2.1 Standard Read Mode

After reset and after performing a clean startup the flash memory with all its modules is in "standard read mode". In this mode it behaves as an on-chip ROM. This mode is entered:

- After reset when the complete start-up has been performed.
- After completion of a longer lasting command like "erase" or "program" which is acknowledged by clearing the "busy" flag.
- Immediately after each other command execution.

- In case of detecting an execution error like attempting to write to a write protected range, sending a wrong password, after all sequence errors.

For the long lasting commands the read mode stays active until the last command of the sequence is received and the operation is started.

3.10.2.2 Command Mode

After receiving the last command of a command sequence the addressed flash module (not the whole flash memory!) is placed into command mode. For most commands this will not be noticed by the user as the command executes immediately and afterwards the flash module is placed again into read mode. For the long lasting commands the flash module stays in command mode for several milliseconds. This is reported by setting the corresponding “busy” flag. The data of a busy flash module cannot be read but other not busy flash modules stay readable. New command sequences are generally not accepted and cause a sequence error until the running operation has finished. In certain cases however new command sequences are accepted in order to enable concurrent programming and erase of independent flash modules.

Read accesses to busy flash modules stall the CPU until the read mode is entered again. A stalled CPU responds only to the reset. As no interrupts can be handled this state must be avoided. Nevertheless this feature can be used to execute code from a flash module that erases or programs data in the same flash module.

Note: Because command sequences to busy flash memory are not always rejected by the hardware with a sequence error it is necessary to handle all commands more careful than in previous device generations that didn't support concurrent processes. A new command sequence shall be only be issued to a flash module after checking that it is not busy anymore. This is especially vital when using the “stall CPU when reading busy flash” feature. Further advice can be found in [Section 3.10.5](#) (sequence errors) and [Section 3.10.6](#) (concurrent processes).

3.10.2.3 Page Mode

The page mode is entered with the “[Enter Page Mode](#)” command. Please find its description below. A flash module that is in page mode can still be read (so it is concurrently in “read mode”). At a time only one flash module can be in page mode.

When the flash memory is in page mode — i.e. one of the flash modules is in page mode — some command sequences are not allowed. These are all erase sequences and the “change read margin” sequence. These are ignored and a sequence error is reported.

3.10.3 Operations

The flash memory supports the following operations:

- Instruction fetch.
- Data read.
- Command sequences to change data and control the protection.

3.10.3.1 Instruction Fetch from Flash Memory

Instructions are fetched by the PMU in groups of aligned 64 bits. These code requests are forwarded to the flash memory. It needs a varying number of cycles (depending on the system clock frequency) to perform the read access. The number of cycles must be known to the IMB Core because the flash does not signal data availability. The number of wait states is therefore stored in the **IMB_IMBCTRL** register.

The complete duration of a flash read access is: **IMB_IMBCTRL.WSFLASH** + 1 cycles. Consult the data sheet for correct values of **WSFLASH** dependent on the system clock frequency and device.

One read access to the flash memory delivers 128 data bits and a 9-bit ECC value. The ECC value is used to detect and possibly correct errors. The addressed 64-bit part of the 128-bit chunk is sent to the PMU. The complete 128 data bits and the 9 ECC bits are stored in the IMB Core with their address. If a succeeding fetch request matches this address the data is delivered from the buffer without performing a read access in the flash memory. The delivery from the buffer happens after one cycle. The flash read wait-cycles are not waited.

The stored data are a kind of instruction cache. In order to support self-modifying code (e.g. boot loaders) this cache is invalidated when the corresponding address is written (i.e. erased or programmed).

In addition to this fetch buffer the IMB Core has an additional performance increasing feature — the Linear Code Pre-Fetch. When this feature is enabled with **IMB_IMBCTRL.DLCPF** = 0 the IMB Core fetches autonomously the following instructions while the CPU executes from its own buffers or the fetch buffer. As this feature is fetching only the linear successors (it does not analyze the code stream) it is most effective for code with longer linear sequences. For code with a high density of jumps and calls it can even cause a reduction of performance and should be switched off.

3.10.3.2 Data Reads from Flash Memory

Data reads are issued by the DMU. Data is always requested in 16-bit words. The flash memory delivers for every read request 128 bits plus ECC as described in **“Instruction Fetch from Flash Memory” on Page 3-23**.

The IMB Core has to get all 128 bits to evaluate the ECC data. The requested 16 bits will be delivered to the DMU. All data and ECC bits are kept in the data register and their address is kept in the address register. For all following data reads the address is compared with the address register and in case of a match the data is delivered after one cycle from the data register. Every data read that is not delivered from this cache invalidates the cache content. When the requested data arrives the cache contains again valid data.

This small data cache is invalidated when a write (i.e. erase or program) access to this address happens.

For data reads the IMB Core does not perform any autonomous pre-fetching.

3.10.3.3 Data Writes to Flash Memory

Flash memory content can not be changed by directly writing data to this memory. Command sequences are used to execute all other operations in the flash except reading. Command sequences consist of data writes with certain data to the flash memory address range. All data moves targeting this range are interpreted as command sequences. If they do not match a defined one or if the IMB Core cannot accept a new one because it is busy a sequence error is reported.

3.10.3.4 Command Sequences

As described before changing data in the flash memory is performed with command sequences.

Table 3-4 Command Sequence Overview

Command Sequence	Description	Details on Page
Reset to Read	Reset Flash into read mode and clear error flags.	Page 3-27
Clear Status	Clear error and status flags.	Page 3-27
Change Read Margin	Change read margins.	Page 3-27
Enter Page Mode	Prepare page for programming.	Page 3-28
Enter Security Page Mode	Prepare security page for programming.	Page 3-29
Load Page Word	Load page with data.	Page 3-30
Program Page	Start page programming process.	Page 3-31
Erase Sector	Start sector erase process.	Page 3-32
Erase Page	Start page erase process.	Page 3-33
Erase Security Page	Start security page erase process.	Page 3-33
Disable Read Protection	Disable temporarily read protection with password.	Page 3-34
Disable Write Protection	Disable temporarily write protection with password.	Page 3-35
Re-Enable Read/Write Protection	Re-enable protection.	Page 3-36

3.10.4 Details of Command Sequences

The description defines the command sequence with pseudo assembler code. It is “pseudo” because all addresses are direct addresses which is generally not possible in real assembler code.

The commands are called by a sequence of one to six data moves into the flash memory range. The data moves must be of the “word” type, i.e. not byte move instructions. The following sections describe each command. The following abbreviations for addresses and data will be used:

- PA: “Page Address”. This is the base address of the destination page. For example the very first page has the address $C0'0000_H$. The page 13 of the second array has the $PA = C0'0000_H + 1 \cdot 256 \cdot 1024$ (for the array) $+ 0 \cdot 4 \cdot 1024$ (for the sector) $+ 13 \cdot 128$ (for the page) $= C4'0680_H$.
- SECPA: “Security Page Address”. This is the virtual address of a security page. It is “virtual” because SECPA is just used as argument of the command sequence to identify the security page but the physical storage of the security page is hidden. Two security pages are defined:
 SecP0: address $C0'0000_H$.
 SecP1: address $C0'0080_H$.
- WD: “Write Data”. This is a 16-bit data word that is written into the assembly buffer.
- SA: “Sector Address”. This is the physical sector number as defined in [Figure 3-6](#) based on the address of the flash module. Two examples as clarification:
 1. Physical sector number 16 of the first array that is based on $C0'0000_H$ is addressed with $SA = C0'0000_H + 16 \cdot 4 \cdot 1024 = C1'0000_H$.
 2. The second 256 KB array has the base address $C4'0000_H$ (as shown in [Table 3-1](#)). So its physical sector number 3 has the $SA = C4'0000_H + 3 \cdot 4 \cdot 1024 = C4'3000_H$.
- PWD: “Password”. This is a 64-bit password. It is transferred in 4 16-bit data words $PWD0 = PWD[15:0]$, $PWD1 = PWD[31:16]$, $PWD2 = PWD[47:32]$ and $PWD3 = PWD[63:48]$.
- Address XX followed by two hexadecimal digits, for example “XXAA_H”. If the command targets a certain flash module the XX must be translated to its base address. So “XXAA_H” means $C0'00AA_H$ for all commands addressing flash 0, $C4'00AA_H$ for flash 1 and $C8'00AA_H$ for flash 2. If a command (e.g. “Clear Status”) addresses the complete flash memory the base address of flash module 0 must be used.
- Data XX followed by two hexadecimal digits, e.g. XXA5_H. This is a “don’t care” data word where only the low byte must match a certain pattern. So in this example all data words like 12A5_H or 79A5_H can be used.
- MR: “Margin”. This 8-bit number defines the read margin. MR can take the values 00_H (normal read), 01_H (hard read 0), 02_H (alternate hard read 0), 05_H (hard read 1), 06_H (alternate hard read 1). All other values of MR are reserved.

Reset to Read

Arguments: –

Definition:

```
MOV XXAAH, XXF0H
```

Timing: One cycle command that does not set any “BUSY” flags. But note that an immediately following write access to the IMB Core is stalled for a few clock cycles during which the IMB Core is busy with aborting a previous command.

Description: The internal command state machine is reset to initial state and returns to read mode. An already started programming or erase operation is not affected and will be continued (the “**Reset to Read**” command — i.e. all commands — will anyhow not be accepted while the IMB Core is busy).

The “**Reset to Read**” command is a single cycle command. It can be used during a command sequence to reset the command interpreter and return the IMB Core into its initial state. It clears also all error flags in the Flash Status Register IMB_FSR and an active page mode is aborted. “**Reset to Read**” can not be used to abort an active command mode. When at least one flash module is busy this command is rejected with SQER¹.

This command clears: PROER, PAGE, SQER, OPER, ISBER, IDBER, DSBER, DDBER.

Clear Status

Arguments: –

Definition:

```
MOV XXAAH, XXF5H
```

Timing: 1-cycle command that does not set any busy flags.

Description: The flags OPER, SQER, PROER, ISBER, IDBER, DSBER, DDBER in Flash status register are cleared. Additionally, the process status bits (PROG, ERASE, POWER, MAR) are cleared.

This command must not be issued when any of the flash modules is in command mode. In this case it is ignored and a sequence error is reported.

Change Read Margin

Arguments: MR

1) In the XE166U there is one exception to this rule: when one flash module is busy with program or erase and the FAPI has received some but not all command cycles of a concurrently executable command sequence (“Erase Sector”, “Erase Page”, “Enter Page Mode”, “Load Page Word”, “Program Page”) then a Reset to Read is performed without issuing a sequence error.

Definition:

```
MOV XXAAH, XXB0H
MOV XX54H, XXMRH
```

Timing: 2-cycle command that sets “BUSY” of the addressed flash module for around 30 micro seconds.

Description: This command sequence changes the read margin of one flash module. The address XX of the second move identifies the targeted flash module. The flash module needs some time to change its read voltage. During this time BUSY is set and this flash module cannot be accessed. The other flash modules stay readable.

The argument “MR” defines the read margin:

- 00_H: normal read margin.
- 01_H: hard read 0 margin.
- 02_H: alternate hard read 0 margin.
- 05_H: hard read 1 margin.
- 06_H: alternate hard read 1 margin.
- Other values: reserved.

For understanding the read margins please refer to **“Margin Reads” on Page 3-41**.

This command must not be issued when the flash memory is in page mode or any of the flash modules is in command mode. In this case it is ignored and a sequence error is reported.

Note: As noted in **“Margin Control” on Page 3-68** the command sequences **“Program Page”**, **“Erase Sector”**, **“Erase Page”** and **“Erase Security Page”** reset the read margin back to 00_H, i.e. to the normal read margin. The same happens in case of a flash wake-up.

Enter Page Mode

Arguments: PA

Definition:

```
MOV XXAAH, XX50H
MOV PA, XXAAH
```

Timing: 2-cycle command that sets “BUSY” of the addressed flash module for around 20 clock cycles¹⁾.

Description: The page mode is entered to prepare a page programming operation on page address PA. (Write data are accepted only with the **“Load Page Word”** command.)

1) When this command is used to abort a page mode of an other flash module the duration increases to around 30 clock cycles.

Memory Organization

With this command, the IMB Core initializes the write pointer of its block assembly register to zero so that it points to the first word. The page mode is indicated in the status register IMB_FSR_BUSY with the PAGE bit, separately for each flash module. The page mode and the read mode are allowed in parallel at the same time and in the same flash module so the flash module stays readable. When the addressed page PA is read the content of the flash memory is delivered. The page mode can be aborted and the related PAGE bit in IMB_FSR_BUSY be cleared with the **“Reset to Read”** command. A new **“Enter Page Mode”** command during page mode aborts the actual page mode, which is indicated with the error flag SQER, and restarts a new page operation. So as mentioned above only one of the flash modules can be in page mode at a time. If one of the erase commands or the **“Change Read Margin”** command are received while in page mode it is ignored and a sequence error is reported.

The page mode can be entered in one flash module while others are busy with executing a user data erase or program command, i.e. not while programming or erasing security pages or other blocking sequences.

If write protection is installed for the sector to be programmed, the **“Enter Page Mode”** command is only accepted when write protection has before been disabled using the unlock command sequence **“Disable Write Protection”** with four passwords. If global write protection is installed with read protection, also the command **“Disable Read Protection”** can be used if no sector specific protection is installed. If write protection is not disabled when the **“Enter Page Mode”** command is received, the command is not executed, and the protection error flag PROER is set in the IMB_FSR_PROT.

Note: In previous device families (e.g. XC16x) the “Enter Page Mode” did not set “BUSY”. In these devices the “Load Page Word” could be sent directly after issuing “Enter Page Mode”. In XE166U it must be waited until “BUSY” clears before sending the “Load Page Word” command sequence.

Enter Security Page Mode

Arguments: SECPA

Definition:

```
MOV XXAAH, XX55H
MOV SECPA, XXAAH
```

Timing: 2-cycle command that sets “BUSY” of flash module 0 for around 100 clock cycles.

Description: This command is identical to the **“Enter Page Mode”** command (see above), with the following exceptions: The addressed page (SECPA) belongs to the security pages of the flash memory and not to the user flash range. This command can only be executed when neither flash write protection nor read protection are active (RPA = 0 and WPA = 0), otherwise it fails with PROER.

This command is refused with SQER when any of the flash modules is in command mode.

The use of this command to install passwords and to disable them again is described in **“Protection Handling Details” on Page 3-44**.

Load Page Word

Arguments: WD

Definition:

MOV XXF2_H, WD

Timing: 1-cycle command that does not set any “BUSY” flags. But note that an immediately following write access to the IMB Core or read from the flash memory is stalled for a few clock cycles if it arrives while the IMB Core is busy with copying its block assembly register content into the flash module assembly buffer. During this stall time the CPU can not perform any action! So either the user software can accept this stall time (which must be taken into account for the worst-case interrupt latency) or the software must avoid the blocking accesses.

Description: Load the IMB Core block assembly register with a 16-bit word and increment the write pointer. The 128 byte assembly buffer (i.e. a complete page) is filled by a sequence of 64 “Load Page Word” commands. The word address is not determined by the command but the **“Enter Page Mode”** command sets a write word pointer to zero which is incremented after each **“Load Page Word”** command.

This (sequential) data write access to the block assembly register belongs to and is only accepted in Page Mode. The command address of this single cycle command is always the same (F2_H). These low order address bits also identify the **“Load Page Word”** command and the sequential write data to be loaded into the block assembly register. The high order bits XX should address the target page. The IMB Core takes always the page address that was used by the last **“Enter Page Mode”** command.

When the 128-bit block assembly register of the IMB Core is filled completely after 8 **“Load Page Word”** commands the IMB Core calculates the 9 ECC bits and transfers the block into the assembly buffer of the flash module. After that it sets the write pointer of the block assembly register back to zero. The following 8 **“Load Page Word”** commands fill again the block. After all 8 blocks are filled the **“Program Page”** command can be used to trigger the program process that transfers the assembly buffer content into the flash array.

While the IMB Core transfers the completed block assembly register to the flash module it can not accept new data for a few cycles. A **“Load Page Word”** command arriving during this time is stalled by the IMB Core.

If **“Program Page”** is called before all blocks of the assembly buffer have received new data then the remaining bits are cleared.

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If more than 8 times 8 commands are used the additional data is lost. The overflow condition is indicated by the sequence error flag, but the execution of a following **“Program Page”** command is not suppressed (the page mode is not aborted).

When a **“Load Page Word”** command is received and the flash is not in page mode, a sequence error is reported in IMB_FSR_OP with SQER flag. In case of a new **“Enter Page Mode”** command or a **“Reset to Read”** command during page mode, or in case of an Application Reset, the write data in the assembly buffer is lost. The current page mode is aborted and in case of a new **“Enter Page Mode”** command entered again for the new address.

Program Page

Arguments: –

Definition:

```
MOV XXAAH, XXA0H  
MOV XX5AH, XXAAH
```

Timing: 2-cycle command that sets “BUSY” of the selected flash module for the whole programming duration. The IMB Core is blocked a few clock cycles after receiving this command and again a few clock cycles before finishing the programming. Write accesses to the flash memory range to execute another command sequence during these times stall the CPU.

Description: The assembly buffer of the flash module is programmed into the flash array. If the last block of data was not filled completely this command finalizes its ECC calculation and copies its data into the assembly buffer before it starts the program process. The selection of the flash module and the page to be programmed depends on the page address used by the last **“Enter Page Mode”** command. The user software should always address the targeted page.

The programming process is autonomously performed by the selected flash module. The CPU is not occupied and can continue with its application.

The **“Program Page”** command is only accepted if the addressed flash module is in Page Mode (otherwise, a sequence error is reported instead of execution). With the **“Program Page”** command, the page mode is terminated, indicated by resetting the related PAGE flag and the command mode is entered and the PROG flag in the status register IMB_FSR_OP is activated and the related BUSY flag is set in IMB_FSR_BUSY.

When the program process has finished BUSY is cleared but PROG stays set. It indicates which operation has finished and will be cleared by a Power-On Reset or by **“Clear Status”**.

Read accesses to the busy flash module are not possible. Reading a busy flash module stalls until the flash module becomes ready again.

If write protection is active for the sector to be programmed, the “**Program Page**” command is not accepted because the Flash is not in Page Mode (see description of the “**Enter Page Mode**” command).

If the page to be programmed is a security page (accepted only in security page mode), the new protection configuration (including keywords or protection confirmation code) is valid directly after execution of this command. During its execution all commands are rejected with a sequence error.

While the IMB Core reads the new protection configuration all DMU accesses to any flash module are stalled.

Erase Sector

Arguments: SA

Definition:

```
MOV XXAAH, XX80H
MOV XX54H, XXAAH
MOV SA, XX33H
```

Timing: 3-cycle command that sets BUSY of the addressed flash module for the whole erasing duration. The IMB Core is blocked a few clock cycles after receiving this command and again a few clock cycles before finishing the erasing. Write accesses to the flash memory range during these times stall the CPU.

Description: The addressed physical sector in the flash array is erased. Following data reads deliver all-zero data with correct ECC.

The erasing process is autonomously performed by the selected flash module. The CPU is not occupied and can continue with its application.

The sector to be erased is addressed by SA (sector address) in the last command cycle.

With the last cycle of the “**Erase Sector**” command, the command mode is entered, indicated by activation of the ERASE flag in IMB_FSR_OP and after start of erase operation also by the related busy flag in the status register IMB_FSR_BUSY. The BUSY flag is cleared after finishing the operation but ERASE stays set. It can be cleared by a Power-On Reset or the “**Clear Status**” command.

Read accesses to the busy flash module are not possible. Read accesses to the not busy flash module are especially supported. Reading a busy flash module stalls until the flash module becomes ready again.

If write protection is installed for the sector to be erased, the Erase Sector command is only accepted when write protection has before been disabled using the unlock command sequence “**Disable Write Protection**”. If global write protection is installed with read protection, also the command “**Disable Read Protection**” can be used if no sector specific protection is installed. If write protection is not disabled when the “**Erase**

Sector” command is received, the command is not executed, and the protection error flag PROER is set in the IMB_FSR_PROT.

This command must not be issued when the flash memory is in page mode. In this case it is ignored and a sequence error is reported.

Erase Page

Arguments: PA

Definition:

```
MOV XXAAH, XX80H
MOV XX54H, XXAAH
MOV PA, XX03H
```

Timing: 3-cycle command that sets BUSY of the addressed flash module for the whole erasing duration. The IMB Core is blocked a few clock cycles after receiving this command and again a few clock cycles before finishing the erasing. Write accesses to the flash memory range during these times stall the CPU.

Description: The addressed page is erased. Following data reads deliver all-zero data with correct ECC.

With the last cycle of the **“Erase Page”** command, the command mode is entered, indicated by activation of the ERASE flag in IMB_FSR_OP and after start of erase operation also by the related BUSY flag in the status register IMB_FSR_BUSY. BUSY is cleared automatically after finishing the operation but ERASE stays set. It is cleared by a Power-On Reset or the **“Clear Status”** command.

Read accesses to the busy flash array are not possible. Read accesses to the not busy flash modules are especially supported. Reading a busy flash module stalls until the flash module becomes ready again.

If the page to be erased belongs to a sector which is write protected, the command is only executed when write protection has before been disabled (see **“Erase Sector”** command).

In case of using the page erase care must be taken not to exceed the drain disturb limit of the other pages of the same sector.

This command must not be issued when the flash memory is in page mode. In this case it is ignored and a sequence error is reported.

Erase Security Page

Arguments: SECPA

Definition:

```
MOV XXAAH, XX80H
MOV XX54H, XXA5H
MOV SECPA, XX53H
```

Timing: 3-cycle command that sets BUSY of flash module 0 for the whole erasing duration.

Description: The addressed security page is erased.

This command is identical to the “**Erase Page**” command with the following exceptions: The addressed page (SecP0 or SecP1) belongs not to the user visible flash memory range. This command can only be executed after disabling of read protection and of sector write protection.

See “**Protection Handling Examples**” on **Page 3-51** for a detailed description of re-programming security pages.

The structure of the two security pages (SecP0 and SecP1) is described in “**Layout of the Security Pages**” on **Page 3-50**.

After erasing a security page the new protection configuration (including keywords or protection confirmation code) is valid directly after execution of this command.

While the IMB Core reads the protection configuration all DMU accesses to any flash module are stalled.

This command must not be issued when the flash memory is in page mode or any of the flash modules is in command mode. In this case it is ignored and a sequence error is reported.

Disable Read Protection

Arguments: PWD

Definition:

```
MOV XX3CH, XXXXH
MOV XX54H, PWD0
MOV XXAAH, PWD1
MOV XX54H, PWD2
MOV XXAAH, PWD3
MOV XX5AH, XX55H
```

Timing: 6-cycle command that does not set any busy flag.

Description: Disable temporarily Flash read protection and — if activated — global write protection of the whole flash memory. The RPA bit in IMB_IMBCTRH is reset.

This is a protected command sequence, using four user defined passwords to release this command or to check the programmed keywords. For every password one command cycle is required. If the second or fourth password represents the code of the “**Reset to Read**” command, it is interpreted as password and the reset is not executed. The 16-bit passwords are internally compared with the keywords out of the “Security Page 0”. If one or more passwords are not identical to their related keywords, the protected sectors remain in the locked state and a protection error (PROER) is indicated in the Flash status register. In this case, a new “**Disable Read Protection**” command or

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a “**Disable Write Protection**” command is only accepted after the next Application Reset.

Note: During execution of the “Disable Read” (or Write) Protection command a password compare error is only indicated after all four passwords have been compared with the related keywords.

Note: This command sequence is also used to check the correctness of keywords before the protection is confirmed in the Security Page 1. A wrong keyword is indicated by the IMB_FSR_PROT flag PROER.

After correct execution of this command, the whole flash memory is unlocked and the read protection disable bit RPRODIS is set in the Flash Status Register (IMB_FSR_PROT). Erase and program operations on all sectors are then possible, if the flash memory was also globally write protected (WPA=1), and if they are not separately write protected. The read protection (including global write protection, if so selected) remains disabled until the command “**Re-Enable Read/Write Protection**” is executed, or until the next Application Reset (including HW and SW reset).

This command must not be issued when any of the flash modules is in command mode. In this case it is ignored and a sequence error is reported.

Disable Write Protection

Arguments: PWD

Definition:

```
MOV XX3CH, XXXXH
MOV XX54H, PWD0
MOV XXAAH, PWD1
MOV XX54H, PWD2
MOV XXAAH, PWD3
MOV XX5AH, XX05H
```

Timing: 6-cycle command that does not set any busy flag.

Description: Disable temporarily the global flash write protection or/and the sector write protection of all protected sectors. The WPA bit in IMB_IMBCTR_H is reset.

This is a protected command sequence, using four user defined passwords to release this command (as described above for the “**Disable Read Protection**” command).

After correct execution of this command, all write-protected sectors are unlocked, which is indicated in the Flash Status Register (IMB_FSR_PROT) with the WPRODIS bit. Erase and program operations on all sectors are now possible, until

- The command “**Re-Enable Read/Write Protection**” is executed, or
- The next Application Reset (including HW and SW reset) is received.

This command must not be issued when any of the flash modules is in command mode. In this case it is ignored and a sequence error is reported.

Re-Enable Read/Write Protection

Arguments: –

Definition:

MOV XX5E_H, XXXX_H

Timing: 1-cycle command that does not set any busy flags.

Description: Flash read and write protection is resumed.

This single-cycle command clears RPRODIS and WPRODIS. The IMB Core is triggered to restore the protection states RPA and WPA from the content of the security page 0 as defined in [Table 3-6 “Flash State” Determining RPA and WPA” on Page 3-47](#). So in effect this command resumes all kinds of temporarily disabled protection installations.

This command is released immediately after execution.

This command must not be issued when any of the flash modules is in command mode. In this case it is ignored and a sequence error is reported.

3.10.5 Sequence Errors

A word (i.e. 16-bit) data move into the flash address range is interpreted by the command interpreter as command sequence. All byte moves are ignored and cause a sequence error which is reported by setting the bit SQER.

As soon the command interpreter detects that the data moves can't be executed as legal sequence it reports the sequence error.

Note: Data moves addressing not implemented flash areas or powered-down flash modules don't enter the command interpreter and consequently can't cause a sequence error. Usually the next correct command sequence will cause the sequence error because it is interpreted as continuation of the previous one. So instead of checking only for the absence of SQER the other flags (e.g. PAGE, PROG, ERASE) can be further evaluated. For an example see [Section 3.10.6](#).

Generally each data move received while at least one flash module is BUSY causes a sequence error. But in order to support concurrent execution of command sequences this is under certain conditions not done. A SQER is reported under the following conditions:

- If one of the flash modules is in command mode and the running command does not allow concurrent execution a SQER is reported immediately.
- If at least one of the flash modules is in command mode and the running command allows concurrent execution SQER is only reported when the new command targets a busy flash module.
- If at least one of the flash modules is in command mode SQER is reported as soon as a command cycle is detected that can not belong to a command sequence that allows concurrent execution (i.e. when the received data does not belong to “Enter Page Mode”, “Load Page Word”, “Program Page” or “Erase Page”).

The concurrency issues are summarized in [Table 3-5](#).

Table 3-5 Concurrency Issues

New sequence while any module is in mode:	Page Mode	Busy with normal erase or program	Busy with blocking sequence¹⁾
Reset to Read	Resets page mode	SQER ²⁾	SQER ²⁾
Enter Page Mode	SQER and Re-enters page mode	OK ³⁾	SQER
Enter Sec. Page Mode	SQER and Re-enters page mode	SQER	SQER
Load Page Word	OK	OK in page mode	SQER/ ⁴⁾
Program Page	OK	OK in page mode	SQER/ ⁴⁾
Erase Page/Sector	SQER	OK ³⁾	SQER
Erase Sec. Page	SQER	SQER	SQER
*Protection	OK	SQER	SQER
Clear Status	OK	SQER	SQER
Change Read Margin	SQER	SQER	SQER

1) "Blocking sequences" are: "Erase Security Page", "Program Page" for a security page, "Change Read Margin", "Enter Page Mode", "Enter Security Page Mode" only while these set busy.

2) As described in ["Reset to Read"](#) on [Page 3-27](#) there is one exception to this rule.

3) If the new command sequence targets a different flash module that is in read mode else SQER.

4) Situation can not occur because "Program Page" is only allowed in page mode and page mode could not be entered.

Other conditions that cause a sequence error were mentioned above in the command descriptions.

3.10.6 Instructions for Executing Program and Erase Jobs

Concurrently

All flash modules¹⁾ can be programmed and erased concurrently. This is however an exceptional case for high-speed flash programming. In the normal case at most one flash module shall be busy while the others can be read.

The limitations reported above in the command sequence descriptions enforce certain behavior for concurrent processes:

- A programming task shall be started in one not interrupted sequence: “Enter Page Mode”, then 64 “Load Page Word” and finally the “Program Page”. No other command sequence on any other flash module shall interrupt this sequence.
- All security page handling shall be done while all flash modules are in read mode.
- Clearing of error and status flags is as well only possible when all flash modules are in read mode. An exception is the flash module specific handling via **IMB_ECC_STAT**.
- The IMB Core can only finish an ongoing program or erase task successfully when it is not busy with interpreting a command sequence (i.e. the busy of the ongoing tasks is only cleared when the IMB Core is ready to accept a new command sequence and no new command sequence has been started but not completed).

So the required sequence for programming flash modules concurrently is as follows:

1. Send the “Erase Sector” command sequence to each flash module.
2. Wait until all “BUSY” flags are cleared. During this time the data for programming can be read from external.
3. Send “Enter Page Mode”, 64 “Load Page Word” and the “Program Page” to the first flash module. Continue this sequence with the other flash modules.
4. Wait until all “BUSY” flags are cleared. This time can be used to read the data for programming the next pages from external.
5. Verify the programmed data of all flash modules.
6. Continue the steps 3 to 5 until all pages of the erased sectors are programmed.
7. Continue the steps 1 to 6 until all sectors are programmed.

The recommend sequence which detects incorrect sequences as early as possible is as follows:

1. “Clear Status” and check that SQER is 0.
2. Send the “Erase Sector” command sequence to each flash module. Check for SQER after issuing each sequence.
3. Wait until all “BUSY” flags are cleared. During this time the data for programming can be read from external.
4. Check for SQER which would indicate an incorrectly issued command sequence.

1) Additional constraints may apply due to power supply and other device specific reasons. The allowed concurrent processes (including read) are described in the data sheet. This section describes only the logic hardware capabilities.

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5. "Clear Status" and check again for SQER. If SQER would be set after "Clear Status" a previous "Erase Sector" hasn't been completed.
6. Send "Enter Page Mode", check if the PAGE flag was set and check if SQER stays 0, send the 64 "Load Page Word" and the "Program Page" to the first flash module. Check if the PAGE flag is cleared and SQER stays cleared after "Program Page" is accepted. Continue this sequence with the other flash modules.
7. Wait until all "BUSY" flags are cleared. This time can be used to read the data for programming the next pages from external.
8. Verify the programmed data of all flash modules.
9. Continue the steps 6 to 8 until all pages of the erased sectors are programmed.
10. Continue the steps 1 to 9 until all sectors are programmed.

3.10.7 Data Integrity

This section describes means for detecting and preventing the inadvertent modification of data in the flash memory.

3.10.7.1 Error Correcting Codes (ECC)

With very low probability a flash cell can become disturbed or lose its data value faster than specified. In order to reach the defined overall device reliability each 128-bit block of flash data is accompanied with a 9-bit ECC value. This redundancy supplies SEC-DED capability, meaning “single error correction and double error detection”. All single bit errors are corrected (and the incident is detected), all double bit errors are detected and even most triple bit errors are detected but some of these escape as valid data or corrected data.

A detected error is reported in the register **IMB_FSR_PROT** and **IMB_ECC_STAT**. Software can select which type of error should trigger a trap by the means of register **IMB_INTCTR**. In the system control further means exist to modify the handling of errors (see “**SCU Trap Control Registers**” on **Page 8-254**). The enabled trap requests by the flash module are handled there as “Flash Access Trap”. In case of a double-bit error the read data is always replaced with a dummy data word.

3.10.7.2 Aborted Program/Erase Detection

Where the ECC should protect from intrinsic failures of the flash memory that affect usually only single bits; an interruption of a running program or erase process might cause massive data corruption:

- The erase process programs first all cells to 1 before it erases them. So depending on the time when it is interrupted the data might be in a different state. This can be the old data, all-one, a random value, a weak all-zero or finally all-zero.
- The program process programs all bits concurrently from 0 to 1. If it is interrupted not all set bits might read as 1 or contain a weak 1.

The register **IMB_FSR_OP** contains the bits ERASE and PROG. These bits stay set until the next “**Clear Status**” command or Power-On Reset. So if an erase or program process is interrupted by an Application Reset one of these bits is still set which allows to detect the interruption. It lies in the responsibility of the software to send the “**Clear Status**” command after a finalized program/erase process to enable this evaluation.

Another possible measure against aborted program/erase processes is to prevent resets by configuring the SCU appropriately.

If a program or erase process was aborted by a Power-On Reset (e.g. due to a power failure) there do not exist reliable means to detect this by reading the affected flash range. Even with margin reads an early or late aborted process might go unnoticed although it might in the long-term affect reliability.

Therefore the application must ensure that flash processes can perform uninterrupted and under the defined operating conditions, e.g. by early brown-out warning that prevents the software from starting flash processes.

After a flash process aborted the affected address range must be erased and re-programmed.

3.10.7.3 Margin Reads

Margin reads can be used to verify that flash data is readable with a certain margin. This is typically used as additional check directly after end-of-line programming. As explained above this is not a reliable method for detecting interrupted program or erase processes but the probability of detecting such cases can be increased.

Reading with “hard read 0 margin” returns weak 0s as 1s and reading with “hard read 1 margin” returns weak 1s as 0s. Changing the read margin is done with the command sequence “**Change Read Margin**” and is reported by the status register “**IMB_MAR0**”.

3.10.7.4 Protection Overview

The flash memory supports read and write protection for the whole memory and separate write protection for each logical sector. The logical sector structure is depicted in **Figure 3-6** for a 256 KB array. The logical sector structure of the smaller arrays is equivalent but if they are used as flash module 0 the missing physical sector 15 is added on top. Thus flash module 0 offers depending on its size the following sectors:

- 256 KB: physical sectors 0 – 14, 16 – 63. Logical sector numbers: 0 – 12, logical sector 6 is shortened to 12 KB.
- 128 KB: physical sectors 0 – 14, 16 – 32. Logical sector numbers: 0 – 10, logical sector 6 is shortened to 12 KB.
- 64 KB: physical sectors 0 – 14, 16. Logical sector numbers: 0 – 7, logical sector 6 is shortened to 12 KB.

Usable physical sector numbers in the other flash modules:

- 256 KB: physical sectors 0 – 63. Logical sector numbers: 0 – 12.
- 64 KB: physical sectors 0 – 15. Logical sector numbers: 0 – 6.
- 32 KB: physical sectors 0 – 7. Logical sector numbers: 0 – 4.

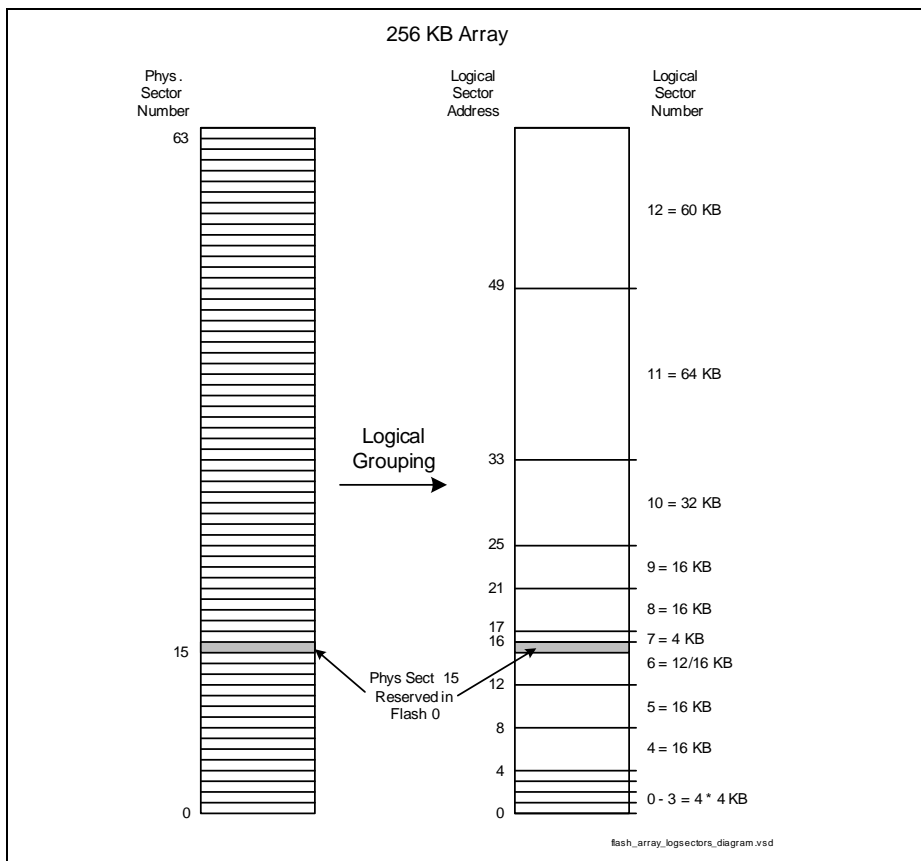


Figure 3-6 Logical Sectors

If read protection is installed and active, any flash read access is disabled in case of start after reset from internal RAM. Debug access is as well disabled and thus the execution of injected OCDS instructions. In case of start after reset in internal flash, all flash access operations are controlled by the flash-internal user code and are therefore allowed, as long as not especially disabled by the user, e.g. before enabling the debug interface.

Per default, the read protection includes a full (global) flash memory write protection covering all flash modules. This is necessary to eliminate the possibility to program a dump routine into the Flash, which reads the whole Flash and writes it out via a serial interface. Program and erase accesses to the flash during active read protection are only possible, if write protection is separately disabled. Flash write and read protection can be temporarily disabled, if the user authorizes himself with correct passwords.

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The device also features a sector specific write protection. Software locking of flash memory sectors is provided to protect code and data. This feature disables both program and erase operations for all protected sectors. With write protection it is supported to protect the flash memory or parts of it from unauthorized programming or erase accesses and to provide virus-proof protection for all sectors.

Read and write protection is installed by specific security configuration words which are programmed by the user directly into two "Security Pages" (SecP0/1). After any reset, the security configuration is checked by the command state machine (IMB Core) and installations are stored (and indicated) in related registers. If any protection is enabled also the security pages are especially protected.

For authorization of short-term disabling of read protection or/and of write protection a password checking feature is provided. Only with correct 64-bit password a temporary unprotected state is taken and the protected command sequences are enabled. If not finished by the command "**Re-Enable Read/Write Protection**", the unprotected state is terminated with the next reset. Password checking is based on four 16-bit keywords (together 64 bits) which are programmed by the user directly into the "Security Page 0" (SecP0).

Special support is provided to protect also the protection installation itself against any stressing or beaming aggressors. The codes of configuration bits are selected, so that in case of any violation in the flash array, on the read path or in registers the protected state is taken per default. In registers and security pages, protection control bits are coded always with two bits, having both codes, "00_B" and "11_B" as indication of illegal and therefore protected state.

3.10.8 Protection Handling Details

As shortly described in **“Protection Overview” on Page 3-41** the flash memory can be in different protection states. The protection handling can be separated into different layers that interact with each other (see **Figure 3-7**).

- The lowest layer consists of the physical content of the security pages SecP0 and SecP1. This information is used to initialize the protection system during startup.
- The next layer consists of registers that report the state of the physical layer (IMB_PROCONx) and the protection state (IMB_FSR_PROT). The protection state can be temporarily changed with command sequences which is reflected in the IMB_FSR_PROT.
- The highest layer is represented by 4 fields of the IMB_IMBCTR register. These fields define the protection rights of the customer software (are read or write accesses currently allowed or not).

The IMB Core controls the protection state of all connected flash modules centrally. In this position it can supervise all accesses that are issued by the CPU.

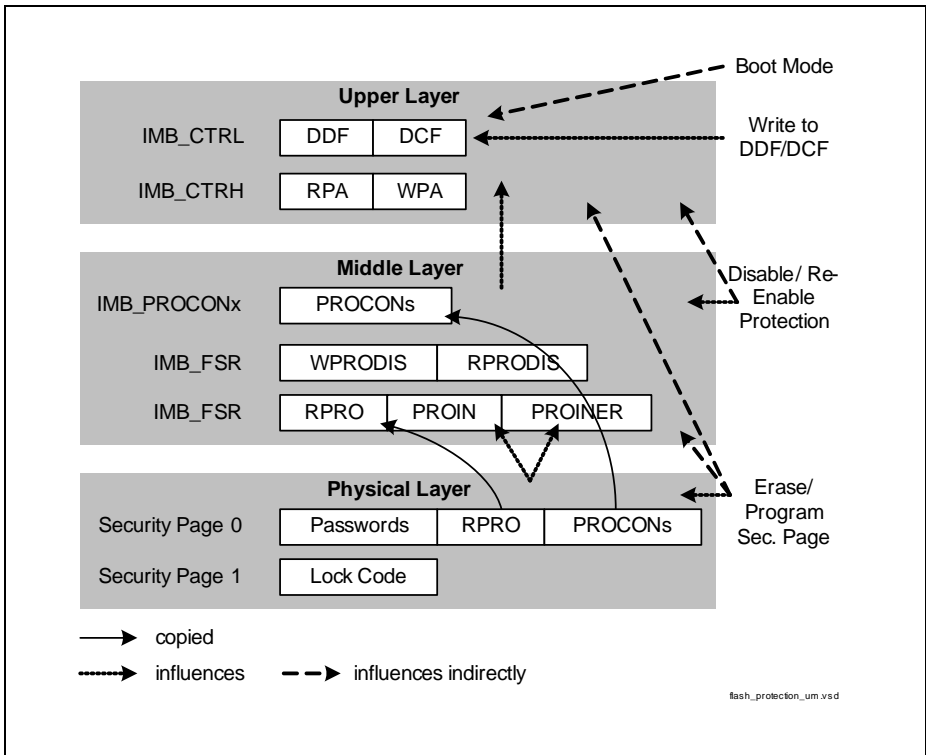


Figure 3-7 Protection Layers

3.10.8.1 The Lower Layer “Physical State”

After reset the protection state of the device is restored from the following information:

- The security page 1 contains a “lock code”. This consists of two words of data (32 bits). If it has the value AA55AA55_H then security page 0 determines the protection state. Otherwise (i.e. the lock code was not found) the device is in the “non-protected state”. The content of the security page 0 is still copied into the registers as described in **“The Middle Layer “Flash State”” on Page 3-46** but their values are ignored in the non-protected state.
- The security page 0 contains the RPRO double bit, the write protection bits SnU and 4 passwords. If the field RPRO contains a valid 01_B or 10_B entry the page is valid and the device is in the “protection installed state”. The page content determines the security settings after startup. If SecP0 contains an invalid RPRO entry the device is in the “errored protection” state.

To summarize: the content of the security pages determines if the device is in the “non-protected state”, “protection installed state” or “errored protection state”. These states are reflected in the register settings of the next layer.

The device is usually delivered in the “non-protected state”.

The exact layout of the security pages is described in [“Layout of the Security Pages” on Page 3-50](#).

3.10.8.2 The Middle Layer “Flash State”

The middle layer consists of the registers IMB_PROCONx and IMB_FSR_PROT and commands that manipulate them and the content of the security pages.

During startup the physical state is examined by the IMB Core and it is reflected in the following bit settings of IMB_FSR_PROT:

- “non-protected state”: PROIN = 0, PROINER = 0.
- “protection installed state”: PROIN = 1, PROINER = 0.
- “errored protection state”: PROIN = 0, ROINER = 1.

The fourth possible setting PROIN=1 and PROINER=1 is invalid and can not occur.

The IMB_PROCONx registers are initialized during startup with the content of the security page 0. The bits DSBERR and DDBERR indicate if an ECC error occurred. The customer software has thus the possibility to detect disturbed security pages and it can refresh their content.

Commands

Other bits of the IMB_FSR_PROT: RPRODIS, WPRODIS, PROER can be manipulated with command sequences and define together with the other bits the protection effective for the next layer. All three bits are 0 after system startup.

The command **“Disable Read Protection”** sets RPRODIS to 1 if the correct passwords that are stored in SecP0 are supplied. If incorrect passwords are entered the bit PROER is set and RPRODIS stays unchanged. As protection against “brute force attacks” that search the correct password the password detection is locked. So after supplying the first incorrect password all following passwords even the correct ones are rejected with PROER. This state is only left by an Application Reset or by erasing SecP0.

The disabled protection can be enabled again by the Application Reset or by the command **“Re-Enable Read/Write Protection”** which clears RPRODIS again.

The bit PROER can be reset by an Application Reset or by the commands **“Reset to Read”** and **“Clear Status”**.

The command **“Disable Write Protection”** sets WPRODIS to 1 if the correct passwords are supplied. It behaves analog to RPRODIS as described above.

The command **“Re-Enable Read/Write Protection”** clears RPRODIS and WPRODIS.

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The commands “**Enter Page Mode**”, “**Enter Security Page Mode**”, “**Erase Page**”, “**Erase Security Page**” and “**Erase Sector**” set PROER if the write access to the addressed range is not allowed. If a write access is allowed or not is determined by the next level.

Table 3-6 summarizes how the “Flash State” of protection determines the RPA and WPA fields of IMB_IMBCTRH. For the double bits a short notation is used here and in the following sections: 1 means active, 0 means inactive, ‘#’ means invalid and ‘—’ means do not care including invalid states. The symbol ‘|’ means logic or.

Table 3-6 “Flash State” Determining RPA and WPA

IMB_FSR. PROI N	IMB_FSR. PROI NER	IMB_FSR. RPR O	IMB_FSR. RPR ODIS	IMB_FSR. WPR ODIS	Resulting Security Level in RPA and WPA
0	0	—	—	—	Non-protected state: RPA = 0, WPA = 0.
1	0				Protection installed state (possibly disabled, see below):
		0	—	0	RPA = 0, WPA = 1.
		0	0	1	RPA = 0, WPA = 0.
		1 #	0	0	RPA = 1, WPA = 1.
		—	1	1	RPA = 0, WPA = 0 (all disabled).
		1 #	0	1	RPA = 1, WPA = 0.
		1 #	1	0	RPA = 0, WPA = 1.
0	1				Errored protection state (see below):
		—	0	0	RPA = 1, WPA = 1.
		—	0	1	RPA = 1, WPA = 0.
		—	1	0	RPA = 0, WPA = 1.
		—	1	1	RPA = 0, WPA = 0.

3.10.8.3 The Upper Layer “Protection State”

This layer consists mainly of the 4 fields DCF, DDF, WPA and RPA of the IMB_IMBCTRH register. These determine the effective protection state together with registers of the lower layers. Some of the above mentioned command sequences directly influence these fields as well. In order to increase the resistance against beaming or power supply manipulation all 4 fields are coded with 2 bits. Generally “01”

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means active, “10” inactive and the two other states “00” and “11” are invalid and are recognized as “attacked” state.

Effective Security Level

The effective security level based on these 4 double-bits is summarized in [Table 3-7](#) and [Table 3-8](#). For the double bits the same short notation is used as before: 1 means active, 0 means inactive, ‘#’ means invalid and ‘–’ means do not care including invalid states.

Table 3-7 Effective Read Security

RPA	DCF	DDF	Security Level
0	–	–	No read protection.
1 #	0	0	No read protection.
	–	1 #	Data reads prohibited.
	1 #	–	Code fetches prohibited.

Table 3-8 Effective Write Security

WPA	RPA	Security Level
0	–	No write protection
1 #	1 #	Global write protection.
1 #	0	Sector specific write protection depending on IMB_PROCONx.

To summarize:

- Read protection is always globally affecting the whole flash memory range. Code fetches and data reads can be separately controlled.
- Write protection can be global when the read protection is effective or it can be specific for each logical sector.

The lower and the middle security layers determine how the 4 effective IMB_IMBCTR fields are preset, changed and how software can access them. This is discussed in the following paragraphs.

Initialization of the Effective Security Level

After Application Reset protection is activated so that RPA, WPA, DDF and DCF are set. During startup the IMB Core determines the stored security level as described in [“The Lower Layer “Physical State”” on Page 3-45](#) and sets IMB_FSR_PROT.PROIN and IMB_FSR_PROT.PROINER and IMB_PROCONx as described in [“The Middle Layer](#)

“Flash State” on Page 3-46. The IMB Core further initializes the IMB_IMBCTRLH fields RPA and WPA according to the rules of **Table 3-6**.

The bits DDF and DCF of the IMB_IMBCTRL are not initialized by the IMB Core. During system startup they are initialized depending on the startup condition. If code fetching starts in the flash memory then they are set to the inactive state. In all other cases they are activated to prevent read access to the flash memory without proving password knowledge.

Changing the Effective Security Level

During run-time the effective security level can be changed. This can be done by directly writing to the IMB_IMBCTRL register or indirectly by changing the bits of the middle layer by commands as **“Disable Write Protection”** or even double indirectly by changing the content of the security pages which changes bits in the middle layer and influences the effective security level.

Writing directly to IMB_IMBCTRL:

- DCF and DDF can be deactivated only if RPA is inactive. They can always be activated.

Indirectly by using a command sequence:

- A successful **“Disable Read Protection”** sets RPRODIS and clears RPA.
- A successful **“Disable Write Protection”** sets WPRODIS and clears WPA.
- **“Re-Enable Read/Write Protection”** clears RPRODIS and WPRODIS and sets RPA and WPA according to **Table 3-6** depending on PROIN, PROINER and RPRO.

Double indirect by changing security pages. After executing a command sequence that changed the content of a security page the IMB Core immediately reads back the pages and determines all resulting security data as described for system startup in **“Initialization of the Effective Security Level” on Page 3-48**. The examples in **“Protection Handling Examples” on Page 3-51** will show how this can be used for installing and removing protection or changing passwords.

3.10.8.4 Reaction on Protection Violation

If software tries to violate the protection rules the following happens:

- Reading data when read protection is effective: The bit IMB_FSR_PROT.PROER is set and the Flash access trap can be triggered via the SCU if IMB_INTCTR.DPROTRP is 0. Default data is delivered.
- Fetching code when read protection is effective: the trap code “TRAP 15_D” is delivered instead.
- Programming or erasing memory ranges when they are write protected: PROER is set.

3.10.8.5 Layout of the Security Pages

The previous sections just mentioned the content of the security pages. This section depicts their exact layout. **Figure 3-8** depicts symbolically the layout of the security pages 0 and 1.

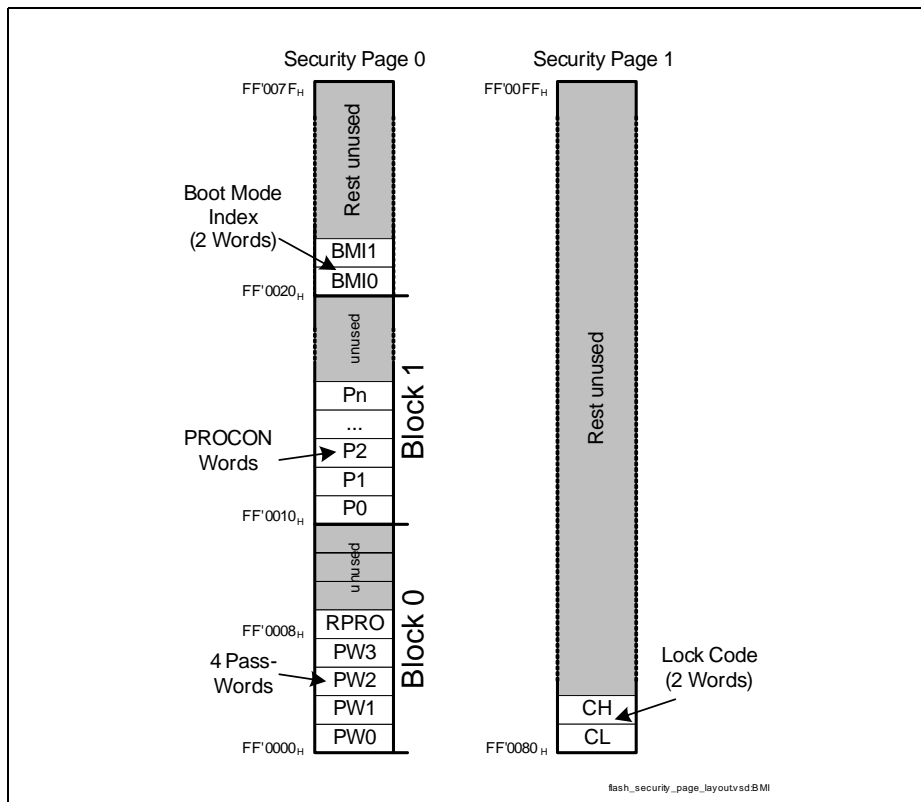


Figure 3-8 Layout of Security Pages

Generally the 16-bit words are stored as always in the XE166U in little endian format.

- The PWx words contain the passwords.
- The double bit RPRO is stored as in the related ISFR **IMB_FSR_PROT** in the bits 15 and 14. The other bits of this word are unused and should be kept all-zero.
- The PROCON data is stored as defined in the **IMB_PROCONx (x=0-0)** ISFR.
- The lock code consists of the two words CL and CH. Both contain "AA55_H" to form the correct lock code.

- The Boot Mode Index “BMI” words BMI0 and BMI1 are stored in block 2. Their usage is described in the Startup chapter.

All bytes of the used blocks of the security pages (block 0 and 1 of SecP0 and block 0 of SecP1) are to be considered as “reserved” and must be kept erased, i.e. with all-zero content. The unused blocks of the security pages (blocks 2 to 7 of SecP0 and blocks 1 to 7 of SecP1) shall be programmed with all-one data.

3.10.9 Protection Handling Examples

Some examples on how to work with the protection system.

Delivery State

The device is delivered in the “non-protected state”.

Security page 1 is erased (so it does not contain the “lock code” AA55AA55_H).

Security page 0 is erased and so “invalid” but because SecP1 is erased this data is anyhow not evaluated. Only its content is copied into corresponding the registers.

During startup the bits DDF and DCF are set depending on the start mode but as RPA and WPA are inactive all accesses to the flash memory are allowed.

The data sectors of the flash memory are delivered in the erased state as well. All sectors can be programmed. After uploading the software the customer can install write and read protection.

First Time Password Installation

In order to install a password generally the lock code in SecP1 has to be erased. In this case the code is not present.

After that SecP0 must be erased with “[Erase Security Page](#)” in order to be able to change RPRO. Erasing SecP0 clears RPRO to “00_B” which is an invalid state. After finishing the erase command the IMB Core restores the IMB_FSR_PROT and IMB_IMBCTRH fields from the flash data.

Because no lock code is present in SecP1 the invalid state of RPRO has no effect on the user visible protection. Still all parts of the flash memory can be written.

The second step is to program the information of SecP0 with the required security information. Again the IMB Core reads immediately back the stored data and initializes the security system. As SecP1 still does not contain the lock code the device stays in the “non-protected” mode.

The security pages cannot be read directly by customer software. The data programmed into SecP0 can therefore only be verified indirectly. The data of the RPRO and SnU fields can be checked by reading the IMB_PROCON and IMB_FSR_PROT registers. The passwords can be verified with the command “[Disable Read Protection](#)”. If the password does not match the bit PROER is set. But because of the erased SecP1 the

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flash memory stays writable. So after erasing SecP0 the correct password can be programmed again.

After the SecP0 was verified successfully SecP1 gets programmed with the lock code AA55AA55_H which enables the security settings of SecP0.

Because the password validation left RPRODIS set the command “**Re-Enable Read/Write Protection**” must be used to finally activate the new protection.

Changing Passwords or Security Settings

Changing the passwords is a delicate operation. The interrelation of the two security pages must be kept in mind.

Usually in the protected state the SecP1 contains the lock code. First write protection must be disabled with the correct passwords. Then the lock code in SecP1 is erased. If this operation was successful PROIN will be cleared by the IMB Core. Now SecP0 can be safely erased.

From this point on the security pages are in the factory delivery state and the new passwords and security settings can be installed as described above.

Attention: The number of times a security page may be changed is noted in the data sheet.

3.10.10 EEPROM Emulation

The flash memory of the XE166U is used for three purposes:

1. Storage of program code. Updates happen usually very seldom. The main criteria to be fulfilled is a retention of the life-time of the product.
2. Storage of constant data: this data is stored together with program code. So this data is very seldom updated. Endurance is of no issue here but retention identical to the code memory is required.
3. Data updated during run-time: this might be data with a very high frequency of updates like a mileage counter or access keys for key-less entry. Other data might be changed only in case of failures and other data might only be transferred from RAM to non-volatile memory before the system is powered down.

Especially for the third type of data the non-volatile memory needs EEPROM like characteristics:

- Fine program/erase granularity which is in EEPROMs typically 1 byte.
- Higher endurance than the intrinsic endurance of flash cells.
- Short program and erase duration per byte. Especially for storing data in an emergency (e.g. power failure) short latencies might be required.

A basic requirement for changing data during run-time is that code execution can still resume, especially interrupt requests must still be serviced. This requirement is fulfilled in all devices with more than one flash module because these work independently. If one is busy with program or erase then code can still be executed from the other.

In devices with only one flash module code would have to be executed from PSRAM while the flash module is busy.

The other requirements are more difficult to fulfill because the XE166U does not have an EEPROM available but only the flash memory with the already frequently mentioned limitations: big program/erase granularity, moderately long program/erase duration, limited cell endurance with reduced retention at high number of program/erase cycles, pages not isolated but affected by drain disturbs.

In order to alleviate these effects on run-time storage of data software is used to emulate EEPROM. There is quite a number of algorithms for efficiently using flash memory as EEPROM. The following section describes one (the most simple) of these algorithms.

It should be noted that the XE166U does not offer the customer any hardware means for EEPROM emulation. All of the following must be realized by software.

3.10.10.1 The Traditional EEPROM Emulation

The key point is to solve the limited endurance by storing data in N different physical places. In XE166U the algorithm could use N sequential pages or groups of pages. If data is currently stored in the page group "x" then the next program happens to the page group $(x+1) \bmod N$.

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After boot up the last correct page group must be found. This could be done by either evaluating a counter (from 0 to $2 \cdot N - 1$) or the old entries are invalidated by erasing the page after programming the new one. Additionally a CRC check could be performed over the group.

As all involved pages are re-used cyclically the endurance from customer perspective is increased by the factor N . N must be chosen high enough to fulfill endurance and retention requirements. Disturbs in the group of N pages are no issue because they incur at most $N - 1$ disturbs before they get written with new data. Care must be taken however if one sector accommodates different groups of pages with different update behavior. In this case the updates of one group of pages could exceed the disturb limits of the other group. So generally one sector should be used only by one such EEPROM cyclic buffer.

The algorithm keeps the old data until the new data is verified so power failure during programming can only destroy the last update but the older data is still available. There are still some issues with power failure that need special treatment:

- Power is cut during programming: the following boot-up might find an apparently correctly programmed page. However the cells might be not fully programmed and thus have a much lower retention or the read data is unstable (e.g. changing operating conditions cause read errors).
If the power is cut early the page can appear as erased although some cells are partly programmed. When programming different data to this apparently erased page read errors might occur.
- Power is cut during erase: the same as above can happen. Data may appear as erased but the retention is lowered. A power failure during a page-erase can inhibit readability of all data in its physical sector. Therefore an algorithm is advantageous that performs erases only in sectors that don't contain anymore current data.

The algorithm can be improved to be more robust against such cases, e.g. program always two pages, mark the end of an erase process by programming a page. But generally aborting flash processes is a forbidden "operating condition".

The main deficiency of the described algorithm is that the software designer is required to plan the use of the flash memory thoroughly. The user has to choose the correct value of N . Then all data has to be allocated to pages. Data sharing one page should have a similar or better identical update pattern (otherwise unchanged data is unnecessarily written). If one set of data does not fill a complete sector the available pages must be possibly left unused because they might incur too many drain disturbs.

There are other algorithms that try to alleviate these efforts by monitoring the flash usage and adapt automatically the assignment of data to flash cells.

3.10.11 Interrupt Generation

Long lasting processes (these are mainly: program page, erase page, erase sector and margin changes, but also enter page mode) set the `IMB_FSR_BUSY.BUSY` flag of one flash module when accepting the request and reset this flag after finishing the process. Software is required to poll the busy flag in order to determine the end of the operation. In order to release the software from this burden an interrupt can be generated. If the interrupt is enabled by `IMB_INTCTRL.IEN` then all transitions from 1 to 0 of one of the `IMB_FSR_BUSY.BUSY` flags send an interrupt request to the SCU. In the SCU (see **“SCU Interrupt Generation” on Page 8-217** in the SCU chapter) the interrupt request (noted as “PFI” Program Flash Interrupt) is multiplexed with other interrupt sources and is forwarded to one of four interrupt nodes. The selection of the interrupt node is done with the register field `INTNP1.PF`. The SCU contains its own set of interrupt status flags (`INTSTAT`), interrupt disable control (`INTDIS`) and registers for setting this interrupt (`INTSET`) and clearing it (`INTCLR`).

The **“Enter Page Mode”** command sets `BUSY` only for a few clock cycles. It is usually not advisable to enable the interrupt for this command.

The register `IMB_INTCTR` contains fields for the interrupt status “ISR”, an enable for the interrupt request “IEN” and fields for clearing the status flag “ICLR” or setting if “ISET”. It should be noted that the interrupt request is only sent when ISR becomes 1 and IEN was already 1. No interrupt is sent when IEN becomes 1 when ISR was already 1 or both are set to 1 at the same time.

3.10.12 Recommendations for Optimized Flash Usage

This section describes best practices for using the flash in certain application scenarios, e.g. how to use effectively ECC and margin reads. For a description of the hardware features consult **“Data Integrity” on Page 3-40**.

3.10.12.1 Programming Code and Constant Data

Code and constant data are programmed only few times during life-time of a device, e.g. end-of-line in ECU production or when service updates are performed. As the readability of this data is decisive for the product quality customers might want to implement the elaborate “best practice” advice.

Basic Advice

Always ensure correct operating conditions and prevent power failures during flash operation.

As basic protection against handling errors all data should be verified after programming. Single-bit ECC errors should be ignored. The appearance of small numbers of single-bit errors is a consequence of known physical effects.

Best Practice

This approach offers best possible quality but risks that programming steps need to be repeated even unnecessarily (“false negatives”):

- Use “Erase Sector” to erase complete sectors.
- Program the sector with data. A common protection against software crashes is to fill the unused part of the sector with trap codes.
- Change the read level to hard margin 0.
- Verify the programmed data, note comparison errors and double-bit ECC errors and count single-bit ECC errors. Take care to evaluate the ECC error flags only once per 128-bit data block and clear them afterwards.
- Repeat this check with hard margin 1.
- After programming all sectors:
 - Erase and re-program all sectors with comparison or double-bit ECC errors.
 - If a flash module contained more than a certain number (e.g. 10) of single-bit ECC errors it is recommended to erase and re-program the affected sectors (i.e. those containing at least one single-bit error).
 - Attention: a high number of single-bit errors indicates usually a violation of operating conditions.

The threshold of allowed single-bit errors could be increased for in-service updates in order to reduce the risk of false negatives.

3.10.12.2 EEPROM Emulation

For EEPROM emulation the goal is usually not readability over device life-time but highest possible robustness (against violated operating conditions, power failures, even failing flash pages e.g. due to over-cycling). The risk of false negatives should be minimized.

A good robustness is achieved with the following approach:

- Verify data after programming with the normal read level. Single-bit ECC errors should be ignored.
- In case of comparison error or double-bit ECC error the data should be programmed again to the next flash range (e.g. next page or sector).
- The number of re-programming trials should be limited (e.g. to 3) to protect against violated operating conditions.

Obviously this jumping over failed pages can be only used optimally when the algorithm does not expect data on fixed addresses.

Failing pages can prevent “Erase Sector” from erasing any data in the affected sector. The “Erase Page” command however could still erase all other pages. These other pages stay readable and programmable.

3.11 On-Chip Program Memory Control

The internal memory block “IMB” contains all memories of the so called “on-chip program memory area” in the address range from C0'0000_H to FF'FFFF_H. Included are the program SRAM, the embedded flash memories and central control logic called “IMB Core”.

In the XE166U device the IMB contains the following memories:

- up to 64 KB flash memory in one independent modules.
- up to 4 KB program SRAM (see [Section 3.4.1](#)).

The IMB connects these memories to the CPU data bus and the instruction fetch bus. Each memory can contain instruction code, data or a mixture of both. The IMB manages accesses to the memories and supports flash programming and erase.

3.11.1 Overview

The [Figure 3-9](#) shows how the IMB and its memories are integrated into the device architecture. Only the main data streams are included. The data buses are usually accompanied by address and control signals and check-sum data like parity or ECC.

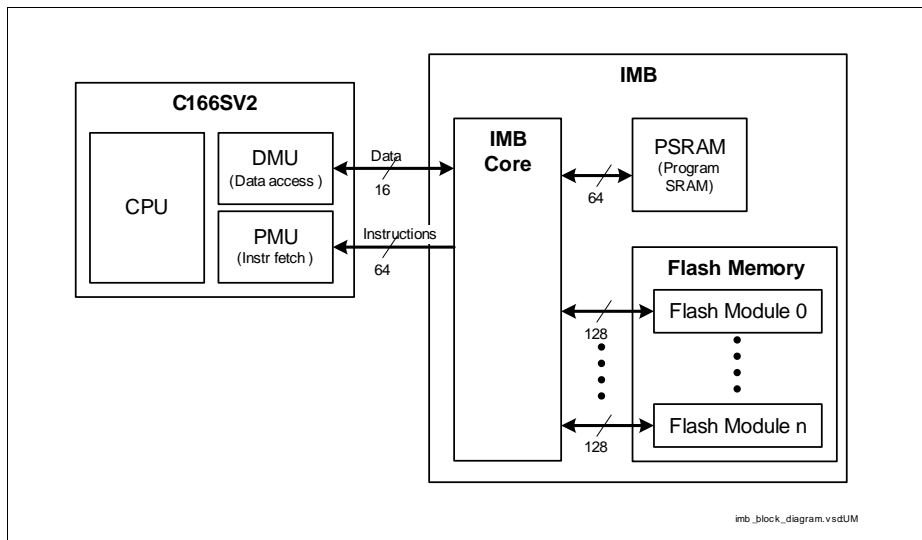


Figure 3-9 IMB Block Diagram

The CPU has two independent busses. The instruction fetch bus is controlled by the program management unit “PMU” of the CPU. It fetches instructions in aligned groups of 64 bits. The instruction fetch unit of the CPU predicts the outcome of jumps and fetches instructions on the predicted branch in advance. In case of a misprediction this interface

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can abort outstanding requests and continues fetching on the correct branch. As the CPU can consume up to one 32-bit instruction per clock cycle the performance of this interface determines the CPU performance.

The data bus is controlled by the data management unit "DMU" of the CPU. It reads data in words of 16 bits. Write accesses address as well 16-bit words but additional byte enables allow changing single bytes.

Because of the CPU's "von Neumann" architecture data and instructions (and "special function registers" to complete the list) share a common address range. When instructions are used as data (e.g. when copying code from an IO interface to the PSRAM) they are accessed via the data bus. The pipelined behavior of the CPU can cause that code fetches and data accesses are requested simultaneously. The IMB takes care that accesses can perform concurrently if they address different memories or flash modules.

Additional connections of the IMB to central system control units exist. These are not shown in the block diagram.

3.11.2 Register Interface

The **“IMB Registers” on Page 3-59** describes the special function registers of the IMB.

*Note: Some registers contain bit fields named ‘reserved’. They should be written with ‘0’.
Read data is unpredictable and should be ignored.*

3.11.2.1 IMB Registers

The section describes all IMB special function registers.

Table 3-9 Registers Overview

Register Short Name	Register Long Name	Offset Address	Page Number
IMB_IMBCTRL	IMB Control Low	FF FF00 _H	Page 3-60
IMB_IMBCTRH	IMB Control High	FF FF02 _H	Page 3-61
IMB_INTCTR	Interrupt Control	FF FF04 _H	Page 3-63
IMB_FSR_BUSY	Flash State Busy	FF FF06 _H	Page 3-64
IMB_FSR_OP	Flash State Operations	FF FF08 _H	Page 3-65
IMB_FSR_PROT	Flash State Protection	FF FF0A _H	Page 3-66
IMB_MAR0	Margin 0	FF FF0C _H	Page 3-68
IMB_PROCON0	Protection Configuration 0	FF FF10 _H	Page 3-69
IMB_ECC_TRAP	ECC Trap Control	FF FF20 _H	Page 3-70
IMB_ECC_STAT	ECC Status	FF FF22 _H	Page 3-71

IMB Control

Global IMB control.

Both IMB_IMBCTRL and IMB_IMBCTRH are reset by an Application Reset.

The write access to both registers is controlled by the register security mechanism as defined in the SCU chapter **“Register Control” on Page 8-282**. Please note that the register write-protection is not activated automatically again after an access to IMB_IMBCTR because this happens only for SCU internal registers.

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IMB_IMBCTRL

IMB Control Low

ISFR (FF FF00_H)

Reset value: 55AC_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DDF		DCF		reserved								DLC PF	WSFLASH		
rw		rw		r								rw	rw		

Field	Bits	Typ	Description
WSFLASH	[2:0]	rw	<p>Wait States for Flash Access</p> <p>Number of wait cycles after which the IMB expects read data from the flash memory is: $N_{WS} = WSFLASH$.</p> <p>This field determines as well the read timing of the PSRAM in the flash emulation address range. See “Flash Emulation” on Page 3-13.</p> <p>The correct setting of this field depends on the system clock frequency. The data sheet of the device describes this relation.</p> <p><i>Note: WSFLASH must not be 0. This value is forbidden!</i></p>
DLCPF	3	rw	<p>Disable Linear Code Pre-Fetch</p> <p>0_B “High Speed Mode”: When the next read request will be delivered from the buffer and so the flash memory would be idle, the IMB Core autonomously increments the last address and reads the next 128-bit block from the flash memory.</p> <p>1_B “Low Power Mode”: This feature is disabled. Usually for code with power minimization requirements or for code with short linear code sections this feature should be disabled (DLCPF = 1). Enabling this feature is only advantageous for code section with longer linear sequences. With lower values of WSFLASH the performance gain of DLCPF=0 is reduced. In case of low WSFLASH settings DLCPF=1 might even lead to better performance than with linear code pre-fetch.</p>

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Field	Bits	Typ	Description
DCF	[13:12]	rw	Disable Code Fetch from Flash Memory 01 _B Short notation DCF = 1. If RPA = 1 instructions cannot be fetched from flash memory. If RPA = 0 this field has no effect. 10 _B Short notation DCF = 0. Instructions can be fetched independent of RPA. 00 _B Illegal state. 11 _B Illegal state. Both illegal states have the same effect as "01". This state can only be left by an Application Reset. When RPA = 0 software can change this field to any value. Otherwise code fetch can only be disabled but not enabled anymore until the next Application Reset.
DDF	[15:14]	rw	Disable Data Read from Flash Memory 01 _B Short notation DDF = 1. If RPA = 1 data cannot be read from flash memory. If RPA = 0 this field has no effect. 10 _B Short notation DDF = 0. Data can be read independent of RPA. 00 _B Illegal state. 11 _B Illegal state. Both illegal states have the same effect as "01". This state can only be left by an Application Reset. When RPA = 0 software can change this field to any value. Otherwise data reads can only be disabled but not enabled anymore until the next Application Reset.

IMB control high word. The WPA and RPA fields are described in **"Protection Handling Details" on Page 3-44**.

IMB_IMBCTRH

IMB Control High

ISFR (FF FF02_H)

Reset value: 0005_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSPROT								0	0	0	0	RPA		WPA	
rw								r	r	r	r	rh		rh	

Field	Bits	Typ	Description
WPA	[1:0]	rh	Write Protection Activated 01 _B Short notation WPA = 1. The write protection of the flash memory is activated. 10 _B Short notation WPA = 0. The write protection is not activated. 00 _B Illegal state. 11 _B Illegal state. Both illegal states have the same effect as "01". This state can only be left by an Application Reset. This field is only changed by the IMB Core. Software writes are ignored.
RPA	[3:2]	rh	Read Protection Activated 01 _B Short notation RPA = 1. The read protection of the flash memory is activated. 10 _B Short notation RPA = 0. The read protection is not activated. 00 _B Illegal state. 11 _B Illegal state. Both illegal states have the same effect as "01". This state can only be left by an Application Reset. This field is only changed by the IMB Core. Software writes are ignored.
PSPROT	[15:8]	rw	PSRAM Write Protection This 8-bit field determines the address up to which the PSRAM is write protected. The start address of the writable range is E0'0000 _H + 1000 _H *PSPROT. The end address is determined by the implemented memory. The equivalent range in the PSRAM area with flash access timing is protected as well. Here the writable range starts at E8'0000 _H + 1000 _H *PSPROT. So with PSPROT=00 _H the complete PSRAM is writable.

Interrupt Control

Interrupt control and status.

Reset by Application Reset.

IMB_INTCTR

Interrupt Control

ISFR (FF FF04_H)

Reset value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ISR	PSE R	0	0	0	PSE RCLR	ISER	ICLR	0	0	0	0	DPR OTR P	DDD TRP	DIDT RP	IEN
rh	rh	r	r	r	w	w	w	r	r	r	r	rw	rw	rw	rw

Field	Bits	Typ	Description
IEN	0	rw	Interrupt Enable If set, the interrupt signal of the IMB gets activated when ISR is set.
DIDTRP	1	rw	Disable Instruction Fetch Double Bit Error Trap If set, a double bit ECC error does not cause the replacement of the fetched data by a trap instruction. See also IMB_ECC_TRAP .DITRPx.
DDTRP	2	rw	Disable Data Read Double Bit Error Trap If set, a double bit ECC error during data read does not send a “Flash Access Error” request to the SCU, i.e. no HW trap is generated and the read data is not replaced with default data. The error flags are still set in IMB_FSR_PROT and IMB_ECC_STAT. See also IMB_ECC_TRAP .DDTRPx.
DPROTRP	3	rw	Disable Protection Trap If set, a read request from read protected flash memory does not generate a “Flash Access Error” request to the SCU, i.e. no HW trap is generated.
ICLR	8	w	Interrupt Clear When written with 1 the ISR is cleared. Reading this bit delivers always 0. Writing a 0 is ignored.
ISER	9	w	Interrupt Set When written with 1 the ISR is set and if IEN is set the interrupt signal is activated. Reading this bit delivers always 0. Writing a 0 is ignored.
PSECLR	10	w	Clear PSRAM Error Flag When written with 1 the PSE is cleared. Reading this bit delivers always 0. Writing a 0 is ignored.

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Field	Bits	Typ	Description
PSER	14	rh	PSRAM Error Flag This flag is set when write requests to the write protected or not implemented PSRAM range are detected. This flag can be cleared by writing 1 to PSERCLR.
ISR	15	rh	Interrupt Service Request If set, it indicates that at least one IMB_FSR_BUSY.BUSY bit changed from 1 to 0. If IEN was set an interrupt request is sent to the interrupt controller. After servicing the interrupt the software handler clears this flag by writing a 1 to ICLR.

Flash State

Flash state. Split into 3 registers IMB_FSR_BUSY, IMB_FSR_OP, and IMB_FSR_PROT. The protection relevant fields of IMB_FSR_PROT are described in [“Protection Handling Details” on Page 3-44](#).

The registers are reset by the Application Reset with the exception of “ERASE”, “PROG”, and “OPER”. These three fields are only reset by a Power-On Reset.

IMB_FSR_BUSY

Flash State Busy

ISFR (FF FF06_H)

Reset value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	PAGE0	0	0	0	0	0	0	0	BUSY0
r	r	r	r	r	r	r	rh	r	r	r	r	r	r	r	rh

Field	Bits	Typ	Description
BUSY0	0	rh	Busy Flash 0 Flash module 0 is busy with a task. The task is indicated by the bits MAR, POWER, ERASE or PROG of IMB_FSR_OP. BUSY0 is automatically cleared when the task has finished. The corresponding task indication is not cleared in order to allow an interrupt handler to determine the finished task.

Memory Organization

Field	Bits	Typ	Description
PAGE0	8	rh	Page Mode Indication Flash 0 Set as long the flash module 0 is in page mode. Page mode is entered by the “Enter Page Mode” commands and finished by a “Program Page” command. The page mode can be also left by a “Reset to Read” command. Also an Application Reset clears this bit.

IMB_FSR_OP

Flash State Operations

ISFR (FF FF08_H)

Reset value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	OPE R	SQE R	MAR	POW ER	ERA SE	PRO G
r	r	r	r	r	r	r	r	r	r	rh	rh	rh	rh	rh	rh

Field	Bits	Typ	Description
PROG	0	rh	Program Task Indication This bit is set when a program task is started. The affected flash module is indicated by a BUSY bit. The PROG bit is not automatically reset but must be cleared by a “Clear Status” command. This bit is not cleared by an Application Reset but only by a Power-On Reset.
ERASE	1	rh	Erase Task Indication This bit is set when an erase task is started. The affected flash module is indicated by a BUSY bit. The ERASE bit is not automatically reset but must be cleared by a “Clear Status” command. This bit is not cleared by an Application Reset but only by a Power-On Reset.
POWER	2	rh	Power Change Indication This bit indicates that a flash module is in its startup phase or in a shutdown phase. The BUSY bits indicate which flash module is busy. This bit is not automatically reset but must be cleared by a “Clear Status” command.

Memory Organization

Field	Bits	Typ	Description
MAR	3	rh	Margin Change Indication If a read margin modification is requested this bit is set together with the corresponding BUSY bit. The BUSY bit is cleared when the margin change is effective and the flash module can be read again. The MAR bit must be cleared by a “ Clear Status ” command.
SQER	4	rh	Sequence Error This bit is set by a errored command sequence or a command that is not accepted. It is cleared by “ Clear Status ” and “ Reset to Read ”.
OPER	5	rh	Operation Error The IMB Core maintains internal bits that are set when starting a program or erase process. They are cleared when this process finishes. These bits are not reset by an Application Reset but only by a Power-On Reset. If one of these bits is set after Application Reset the IMB Core sets OPER. So this signals that a running erase or program process was interrupted by an Application Reset. The OPER is cleared by “ Reset to Read ”, “ Clear Status ” or a Power-On Reset.

IMB_FSR_PROT

Flash State Protection

ISFR (FF FF0A_H)

Reset value: x000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RPRO	0	0	DDB ER	DSB ER	IDBE R	ISBE R	0	0	0	PRO ER	WPR ODIS	RPR ODIS	PROI NER	PROI N	
rh	r	r	rh	rh	rh	rh	r	r	r	rh	rh	rh	rh	rh	

Field	Bits	Typ	Description
PROIN	0	rh	Flash Protection Installed Modified by the IMB Core. Cleared by Application Reset.
PROINER	1	rh	Flash Protection Installation Error Modified by the IMB Core. Cleared by Application Reset.

Memory Organization

Field	Bits	Typ	Description
RPRODIS	2	rh	Read Protection Disabled The read protection was temporarily disabled with the “ Disable Read Protection ” command. Modified by the IMB Core. Cleared by Application Reset.
WPRODIS	3	rh	Write Protection Disabled The write protection was temporarily disabled with the “ Disable Write Protection ” command. Modified by the IMB Core. Cleared by Application Reset.
PROER	4	rh	Protection Error Set by a violation of the installed protection. Reset by the “ Clear Status ” and “ Reset to Read ” commands or an Application Reset.
ISBER	8	rh	Instruction Fetch Single Bit Error Set if during instruction fetch a single-bit ECC error was detected (and corrected). Reset by “ Clear Status ” or “ Reset to Read ” commands or an Application Reset.
IDBER	9	rh	Instruction Fetch Double Bit Error Set if during instruction fetch a double-bit ECC error was detected (and not corrected). Reset by “ Clear Status ” or “ Reset to Read ” commands or an Application Reset.
DSBER	10	rh	Data Read Single Bit Error Same as ISBER for data reads.
DDBER	11	rh	Data Read Double Bit Error Same as IDBER for data reads.
RPRO	[15:14]	rh	Read Protection Configuration This field is copied by the IMB Core from the corresponding field in the security page 0. After Application Reset read protection is activated. See Table 3-6 and ff for interpreting this and other protection bit fields. 00 _B Invalid. 01 _B Active. 10 _B Inactive. 11 _B Invalid.

Margin Control

Read margin control. Each field corresponds to one flash module. A hard read 0 detects not completely erased cells. These are read as “1”. A hard read 1 detects not completely programmed cells. These are read as “0”. Read margin changes are caused by the command sequence “[Change Read Margin](#)”. The resulting read margin is reflected in this status register.

The command sequences “[Program Page](#)”, “[Erase Sector](#)”, “[Erase Page](#)” and “[Erase Security Page](#)” resets the read margin back to “normal”. The same happens in case of a flash wake-up.

Reset by Application Reset.

IMB_MAR0

Margin Control 0

ISFR (FF FF0C_H)

Reset value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		reserved			reserved			reserved			reserved			HREAD0	
r		r			r			r			r			rh	

Field	Bits	Typ	Description
HREAD0	[2:0]	rh	Hard Read 0 Active read margin of flash module 0. 000 _B Normal read. 001 _B Hard read 0. 010 _B Alternate hard read 0 (usually harder than 001). 101 _B Hard read 1. 110 _B Alternate hard read 1 (usually harder than 101). other codes:Reserved.

Protection Configuration

Protection configuration register of each implemented flash module. The logical sector numbering is depicted in [Figure 3-6](#).

Each bit of the PROCONs is related to a logical sector. If it is cleared the write access to the corresponding logical sector (this means to the range of physical sectors) is locked under the conditions that are documented in “[Protection Handling Details](#)” on [Page 3-44](#). The PROCON registers are exclusively modified by the IMB Core which copies them from the security page 0.

Memory Organization

For flash modules smaller than 256 KB the SsU bits corresponding to the not implemented flash range are reserved and shall be programmed to 0 in the security page.

Reset by Application Reset.

IMB_PROCONx (x=0-0)

Protection Configuration.

ISFR (FF FF10_H+2*x)

Reset value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	S12 U	S11 U	S10 U	S9U	S8U	S7U	S6U	S5U	S4U	S3U	S2U	S1U	S0U
r	r	r	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh

Field	Bits	Typ	Description
SsU (s=0-12)	s	rh	Sector s Unlock 0 _B Logical sector s of flash module x is write-protected. 1 _B Logical sector s of flash module x is not write-protected. <i>Note: In previous device families and the TriCore™ based products these are “lock” bits and not “unlock” bits!</i>

ECC Trap Control

ECC trap control register.

Reset by Application Reset.

The register IMB_ECC_TRAP allows to disable the double bit ECC error trap generation for selected flash modules in contrast to IMB_INTCTR which allows to switch this only globally. This selective control enables to operate part of the flash memory as quasi ROM with enabled error traps. But while a flash module is programmed or erased its trap generation can be switched off without affecting the “ROM” modules. Without this facility the traps would have to be globally disabled and the flash driver had to work from SRAM and all interrupts would have to be blocked.

IMB_ECC_TRAP

ECC Trap Control

ISFR (FF FF20_H)

Reset value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	DDT RP0	0	0	0	0	0	0	0	DITR P0
r	r	r	r	r	r	r	rw	r	r	r	r	r	r	r	rw

Field	Bits	Typ	Description
DITRP0	0	rw	Disable Instruction Fetch Double Bit ECC Trap 0 0 _B Replacing instructions by a trap code for double bit ECC errors when fetching from flash module 0 is handled globally via IMB_INTCTR.DIDTRP. 1 _B If set, a double bit ECC error does not cause the replacement of the fetched data by a trap instruction for fetches from flash module 0 independent of IMB_INTCTR.DIDTRP. Additionally IMB_FSR_PROT.ISBER/IDBER are not set for ECC errors from flash module 0.
DDTRP0	8	rw	Disable Data Read Double Bit ECC Trap 0 0 _B Double bit ECC error trap for data reads from flash module 0 are handled globally via IMB_INTCTR.DDDTRP. 1 _B Double bit ECC error for data reads from flash module 0 does not trigger the "Flash Access Error" trap independent of IMB_INTCTR.DDDTRP. Additionally IMB_FSR_PROT.DSBER/DDBER are not set for ECC errors from flash module 0 and the data from flash memory is delivered not default data. But the bits IMB_ECC_STAT.xBERx are still set for ECC errors.

ECC Status

ECC status register.

Reset by Application Reset.

Memory Organization

This register reports ECC data read single and double bit errors selectively per flash module. Each bit can be cleared independently. This enables to use part of the flash memory quasi as "ROM". In this part all errors trigger traps that are handled by a trap handler and trigger typically a reset of the application. However while flash modules are programmed or erased all ECC errors can be handled by a low-level driver without necessarily affecting the complete system.

IMB_ECC_STAT

ECC Status

ISFR (FF FF22_H)

Reset value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	DBE R0	0	0	0	0	0	0	0	SBE R0
r	r	r	r	r	r	r	rwh	r	r	r	r	r	r	r	rwh

Field	Bits	Typ	Description
SBER0	0	rwh	Data Read Single Bit Error 0 Set when a single bit ECC errors occurs when reading data from flash module 0. Cleared by Application Reset or by writing 1 to this bit.
DBER0	8	rwh	Data Read Double Bit Error 0 Set when a double bit ECC errors occurs when reading data from flash module 0. Cleared by Application Reset or by writing 1 to this bit.

3.11.3 Error Reporting Summary

The **Table 3-10** summarizes the types of detected errors and the possible reactions.

Table 3-10 IMB Error Reporting

Error	Reaction
Data read from PSRAM with parity error.	If PECON.PEENPS: HW trap (see Section 8.14.2).
Instruction fetch from PSRAM with parity error.	If PECON.PEENPS: HW trap (see Section 8.14.2).
Data read from flash memory with single bit error.	Silently corrected. Bit IMB_FSR_PROT.DSBER set.
Data read from flash memory with double bit error.	Bit IMB_FSR_PROT.DDBER set. If IMB_INTCTR.DDDTRP = 0: Flash access trap ¹⁾ and default data is delivered.
Instruction fetch from flash memory with single bit error.	Silently corrected. Bit IMB_FSR_PROT.ISBER set.
Instruction fetch from flash memory with double bit error.	Bit IMB_FSR_PROT.IDBER set. If IMB_INTCTR.DIDTRP = 0: "TRAP 15 _D " delivered instead of corrupted data.
Data read from protected flash memory.	IMB_FSR_PROT.PROER set. If IMB_INTCTR.DPROTRP = 0: Flash access trap ¹⁾ and default data is delivered.
Instruction fetch from protected flash memory.	"TRAP 15 _D " delivered.
Program/erase request of write protected flash range.	Only bit PROER in IMB_FSR_PROT set.
Data read or instruction fetch from busy flash memory.	Read access stalled until end of busy state.
Instruction fetch from ISFR addresses.	Default data ("TRAP 15 _D ") delivered.
Data read from not implemented ISFRs.	Default data delivered.
Data writes to not implemented ISFRs.	Silently ignored.
Data read from not implemented address range.	Unpredictable. Mirrored data from other memories might be returned or default values.

Table 3-10 IMB Error Reporting (cont'd)

Error	Reaction
Instruction fetch from not implemented address range.	Unpredictable. Mirrored data from other memories might be returned or default values.
Data written to not implemented PSRAM or write protected PSRAM address range (both determined by IMB_IMBCTRH.PSPROT).	Bit IMB_INTCTR.PSER set. Flash access trap ¹⁾ and no data is changed in the PSRAM.
Program or erase command targeting not implemented flash memory.	Unpredictable. Access is ignored ²⁾ or mirrored into implemented flash memory ³⁾ .
Data read from powered-down flash modules.	Considered as access to not-implemented memory range. Default data or data from implemented flash modules will be returned.
Instruction fetch from powered-down flash modules.	Considered as access to not-implemented memory range. Default data ("TRAP 15 _D ") will be returned or data from implemented flash modules.
Program or erase command targeting powered-down flash modules.	Silently ignored ²⁾ .
Shutdown or power-down request received while the command sequence interpreter is waiting for the last words of a command sequence.	The command interpreter is reset and a " Reset to Read " command sequence is executed.

1) More information about the Flash Access Trap can be found in chapter "SCU".

2) Attention: when an access (i.e. MOV) is ignored, the command sequence interpreter will still wait for this outstanding MOV. So the next command sequence might cause a SQER because it delivers an unexpected MOV.

3) The flash protection can not be by-passed by accessing the reserved memory ranges.

4 Memory Checker Module (MCHK)

The memory checker module (MCHK) of the XE166U supports checking the data consistency of memories, registers (e.g. configuration registers), or communication channels. It calculates a checksum on a block of data, often called cyclic redundancy code (CRC). It is implemented as a parallel signature generation based on a multi input linear feedback shift register (MISR). Being based on a linear feedback shift register (LFSR), it also can generate pseudo-random numbers and cyclic codes.

This chapter is structured as follows:

- An operational overview of the Memory Checker Module (see [Section 4.1](#))
- Functional description of the Memory Checker Module (see [Section 4.2](#))
- Description of the Memory Checker Module registers (see [Section 4.3](#))
- Interfaces of the Memory Checker Module (see [Section 4.4](#))

4.1 Operational Overview

From the programmer's point of view, the MCHK is a set of registers associated with this peripheral. To communicate respective error or operation events a port pin may be used for the signal "MATCH" to generate an external event and an interrupt line may be used for the signal "MISMATCH" to generate an internal event. The MCHK is reset together with the CPU so it can be used as a CPU coprocessor. This ensures a deterministic state of the MCHK after the CPU exits the reset state.

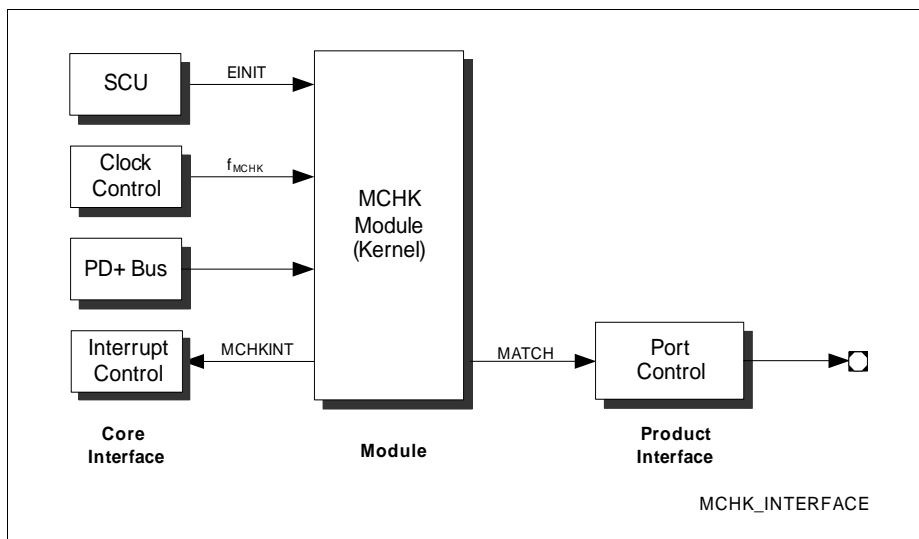


Figure 4-1 Interface Diagram

Note: The MATCH output is connected to an external port in packaged devices with 144 or more pins only.

4.2 Functional Description

Conventional digital processing systems generally are configured around volatile and non-volatile memory elements. These memories provide (store) the data and instructions to the CPU doing the main computing of an embedded system. This includes the administration of the system by coordinating the operation of various system units to perform system tasks.

Faults within these memories are in general critical for the safety and reliability of an embedded system. Therefore these memories have mechanisms to check for data consistency, e.g. parity or ECC (error correction code). These mechanisms can detect faults up to a certain amount (e.g. double bit faults) per word (bit line faults). Concatenated codes (block codes, word codes) can also detect multibit faults per word (word line faults), which increases the fault coverage.

The MCHK is a parallel signature compression circuitry that calculates a concatenated CRC block code to increase test coverage by code concatenation. This enables error detection within a block of data stored in memory, registers, or communicated e.g. via serial communication lines. The MCHK reduces the probability of error masking due to repeated error patterns by compressing parallel test inputs from a block of data to be tested. Furthermore, it can generate pseudo random numbers.

The MCHK uses a multiple input linear feedback shift register to generate a checksum (signature) of a block of data. A multiple input linear feedback shift register (MISR) is a shift register whose internal feedback input bit is driven by the exclusive-or (XOR) of some bits of the overall shift register value (LFSR: linear feedback shift register).

This generator includes an arithmetic circuitry to calculate the block code. This circuitry is implemented as an independent piece of hardware and, therefore, does not rely on the memories to be tested. Only for the configuration it requires initialization data out of the memories. To avoid the need of a multi master system (CPU, DMA, etc.), the CPU (e.g. PEC, subroutine) is used to handle the data read and write transactions. These transactions rely on the memories to be tested because they may contain the respective CPU instruction code. Therefore the MCHK implements additional measures to enable detection of erroneous data move operations by the CPU.

The following error scenarios are detected:

- The CPU configures the MCHK erroneously
- The CPU does not provide the data from the respective address range
- The CPU does not provide the correct amount of data
- The CPU is not able to check correctly the match of the online generated CRC block code and the expected offline (during development) generated CRC block code

The principle of this circuitry is to generate an external coded life signal of the CRC block code check. Furthermore the configuration of the circuitry cannot be changed without an external notification. The life signal is not a static signal, but changes polarity in a predefined manner to avoid static faults, e.g. open and short circuit in the output stages.

Memory Checker Module (MCHK)

The circuitry consists of the following components:

- An arithmetic circuitry calculating the CRC block code out of the data transferred into an input register of this circuitry.
- A compare unit to check if the value of the calculated CRC block code is correct. The MCHK compares the content of the CRC block code result registers to a fixed value (FADE'EDDA_H). Before calculating a CRC value, the result register is initialized with a specific value (magic word, seed), which results in a specific value after the CRC calculation. This so called magic word must be selected in a way that the block code ends up with the fixed value (FADE'EDDA_H). This works fine for linear code, e.g. the CRC block code.
- A method granting the CRC block code calculation over a given amount of data. Therefore functional redundancy is used to grant this. A local count register within the MCHK initiates the compare of the calculated CRC block code after a given amount of input data. Secondly the CPU reloads the magic word (seed) of the CRC block code when initiating a new CRC block code generation (loop variable within data move subroutine or count register within PEC).
- An internal service request generation to enable software recovery in case of a fault. This could be a software routine running out of a different flash block than the one that produced the error, e.g. to support a limb home function. There is a residual risk: The CPU could write dummy data into the memory checker within this error interrupt routine and then rewrite the COUNT register.
- All configuration registers are protected by a time redundant mechanism. So modifications of configuration registers are only possible following a specific sequence of write operations (EINIT protected). Additionally, the COUNT register is protected by a content dependent access scheme.
- An external MATCH signal is generated on every successful CRC block code generation and may be used to trigger an external window watchdog. This window watchdog may generate a reset in case too many or too few MATCH signal toggles fall into a specific time window. To grant a correctly working block code unit, the application must also perform from time to time a block code generation outside the watchdog time window by having an incorrect compare (no MATCH signal toggle). This will check the correct function of the compare circuitry, because in case of an erroneous compare circuitry a MATCH signal toggle is generated outside the watchdog time window.

4.2.1 Principle of the LFSR

The list of the bit positions that affect the internal feedback bit is called the tap sequence. **Figure 4-2** shows the principle of an LFSR. It assumes a tap sequence of [32, 26, 23, 22, 16, 12, 11, 10, 8, 7, 5, 4, 2, 1]. On activation, all bits in the LFSR are shifted left one bit position (in direction of the most significant bit). All bits on the tap position are exclusive-ORed and the result is fed into bit 0 as a feedback. On the next activation the same procedure is repeated.

The LFSR outputs that influence the internal feedback input are called taps (marked gray in **Figure 4-2**).

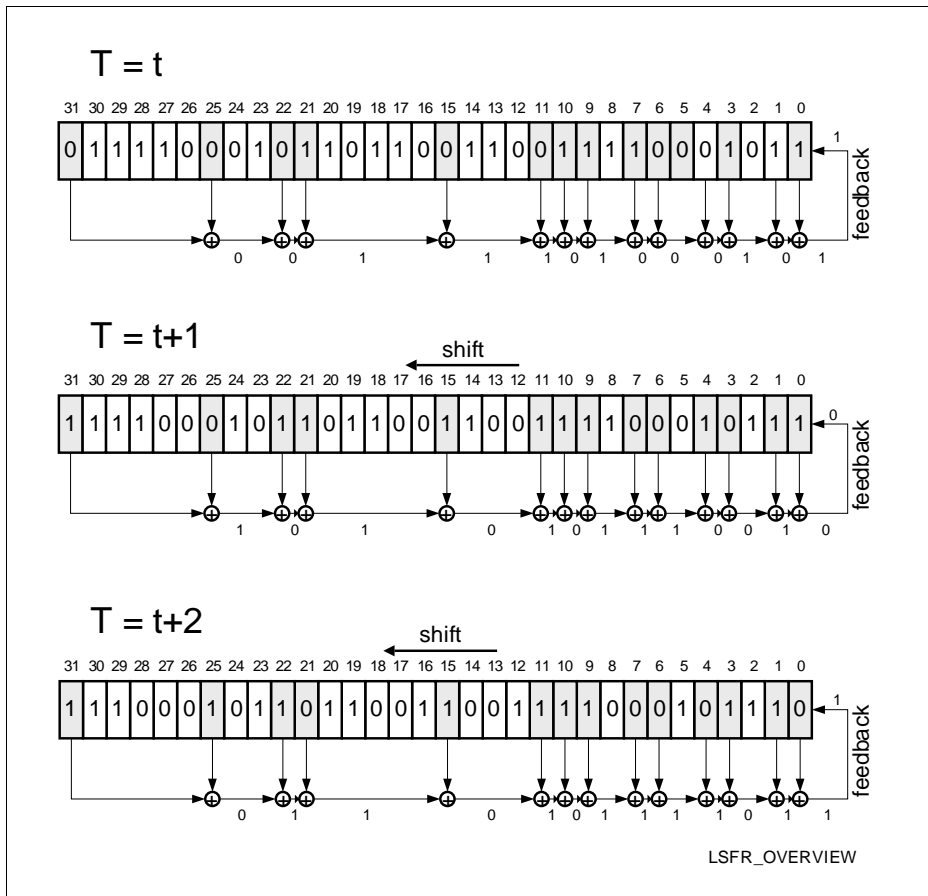


Figure 4-2 Principle of an LFSR

Memory Checker Module (MCHK)

The tap sequence of an LFSR can be represented as a polynomial mod 2. This means that the coefficients of the polynomial must be 0 in case a respective feedback is not implemented or 1 in case a feedback tap is implemented. This is called the feedback polynomial or characteristic polynomial. For example, if the taps are at the 32nd, 26th, 23rd, 22nd, 16th, 12th, 11th, 10th, 8th, 7th, 5th, 4th, and the 2nd bits (as below), the resulting LFSR polynomial is

$$G^{32} = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1 \quad (4.1)$$

The '+1' in the polynomial does not correspond to a tap. The powers of the terms represent the tapped bits, counting from the least significant bit. The polynomial may be represented by a binary number (binary representation). Every power of the terms represent a 1 in the binary format counting from the most significant bit. So for the polynomial listed above, the number would be:

$$G^{32} = 1000\ 0010\ 0110\ 0000\ 1000\ 1110\ 1101\ 1011_B = 8260'8EDB_H$$

The polynomial used by the MCHK is defined in the tap polynomial registers **TPRH** and **TPRL**.

4.2.2 Principle of the MISR

In parallel to the internal feedback input bit of the LFSR, 16 external bits may be loaded into the LFSR (multiple input).

These 16 input bits are exclusive-ORed with the bits shifted or fed back in the LFSR.

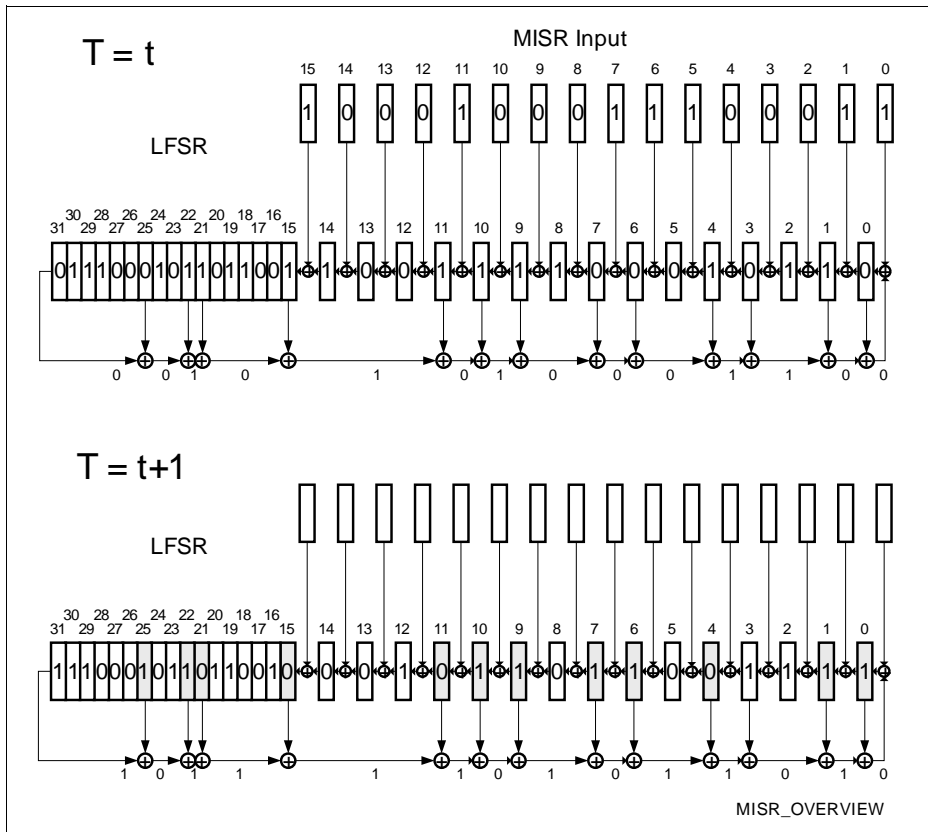


Figure 4-3 Principle of a MISR

The initial value of the LFSR/MISR is called the seed and may be defined by an initial write to the result registers **RRL** and **RRH**. Because the operation of the MISR is deterministic, the sequence of values produced by the MISR is completely determined by its current (or previous) states and inputs.

4.2.3 Commonly used Polynomials

Polynomials for cyclic codes as used in globally standardized systems have not been fully standardized themselves. Most cyclic codes in current use have some weakness with respect to strength or construction. Standardization of cyclic codes would allow for better designed cyclic codes to come into common use. The following table provides a list of common polynomials used for sequential CRC signature generation.

Table 4-1 Some Commonly used Polynomials

Name	Polynomial	Maximum Data Width	Normal (Reverse) of Reciprocal
CRC-8-ATM	x^8+x^2+x+1	8-bit	0000'0083 _H (0000'00C1 _H)
CRC-8-CCITT	$x^8+x^7+x^3+x^2+1$	8-bit	0000'00C6 _H
CRC-8-Dallas	$x^8+x^5+x^4+1$	8-bit	0000'0098 _H
CRC-8	$x^8+x^7+x^6+x^4+x^2+1$	8-bit	0000'00EA _H
CRC-8 SAE J1850	$x^8+x^4+x^3+x^2+1$	8-bit	0000'008E _H
CRC-1 (parity)	$x^8+x^7+x^6+x^5+x^4+x^3+x^2+x+1$	8-bit	0000'00FF _H
CRC-10	$x^{10}+x^9+x^5+x^4+x+1$	10-bit	0000'0319 _H (0000'0263 _H)
CRC-12	$x^{12}+x^{11}+x^3+x^2+x+1$	12-bit	0000'0C07 _H (0000'0E03 _H)
CRC-15-CAN	$x^{15}+x^{14}+x^{10}+x^8+x^7+x^4+x^3+1$	15-bit (13-bit)	0000'62CC _H (0000'19A3 _H)
CRC-1 (parity)	$x^{16}+x^{15}+x^{14}+x^{13}+x^{12}+x^{11}+x^{10}+x^9+x^8+x^7+x^6+x^5+x^4+x^3+x^2+x+1$	16-bit	0000'FFFF _H
CRC-16-CCITT	$x^{16}+x^{12}+x^5+1$	16-bit	0000'8810 _H
CRC-16-IBM	$x^{16}+x^{15}+x^2+1$	16-bit	0000'C002 _H
CRC-24- Radix-64	$x^{24}+x^{23}+x^{18}+x^{17}+x^{14}+x^{11}+x^{10}+x^7+x^6+x^5+x^4+x^3+x+1$	16-bit (24-bit polynomial)	00C3'267D _H (BE64'C300 _H)

Table 4-1 Some Commonly used Polynomials (cont'd)

Name	Polynomial	Maximum Data Width	Normal (Reverse) of Reciprocal
CRC-32-IEEE802.3/MPEG2	$x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^8+x^7+x^5+x^4+x^2+x+1$	16-bit (32-bit polynomial)	8260'8ED6 _H (DB71'0641 _H)
CRC-32C	$x^{32}+x^{28}+x^{27}+x^{26}+x^{25}+x^{23}+x^{22}+x^{20}+x^{19}+x^{18}+x^{14}+x^{13}+x^{11}+x^{10}+x^9+x^8+x^6+1$	16-bit (32/27-bit polynomial)	8F6E'37A0 _H (05EC'76F1 _H)

Note: The polynomials above are in general used for sequential signature generation (in general named as CRC), resulting in different signatures than the parallel signature generation algorithm used by the MCHK.

4.2.4 Architecture of the Memory Checker Module

The LFSR is represented by the Result Register High (**RRH**) and the Result Register Low (**RRL**). These may be used to initialize the MCHK with a seed value. When writing to register RRL, the MISR count register **COUNT** is reloaded with the last value written to register **COUNT**. The result registers **RRH** and **RRL** may be used to read the final or intermediate signature of a block of data loaded into the MCHK.

Data may be loaded into the MCHK by writing either 8-bit or 16-bit data into the MISR input register **IR**. Each write access to register IR decrements the content of the MISR count register **COUNT**.

The polynomial is defined by writing the binary normal reciprocal value into the TAP Polynomial Register High (**TPRH**) and TAP Polynomial Register Low (**TPRL**). The TAP polynomial registers and the result registers are combined by a binary AND. If the amount of ones in the result of this AND operation is odd, a 1_B is fed back, else a 0_B. The effectiveness of the Memory Checker Module is significantly reduced if a polynomial is used with a the most significant 1_B bit position in the TAP Polynomial register being smaller than the most significant 1_B in the data fed into the Memory Checker Module. So in general the content of the TAP polynomial register must be larger than 80_H for 8-bit data and larger than 8000_H for 16-bit data.

If the content of the MISR count register **COUNT** is decremented from 0001_H to 0000_H, a service request signal is generated in case the content of the LFSR result register high (**RRH**) is not equal FADE_H or the content of the LFSR result register low (**RRL**) is not equal EDDA_H. If the content of the LFSR result registers equals FADE'EDDA_H, the external MATCH signal is toggled. **Figure 4-4** summarizes the architecture of the checksum circuit.

Memory Checker Module (MCHK)

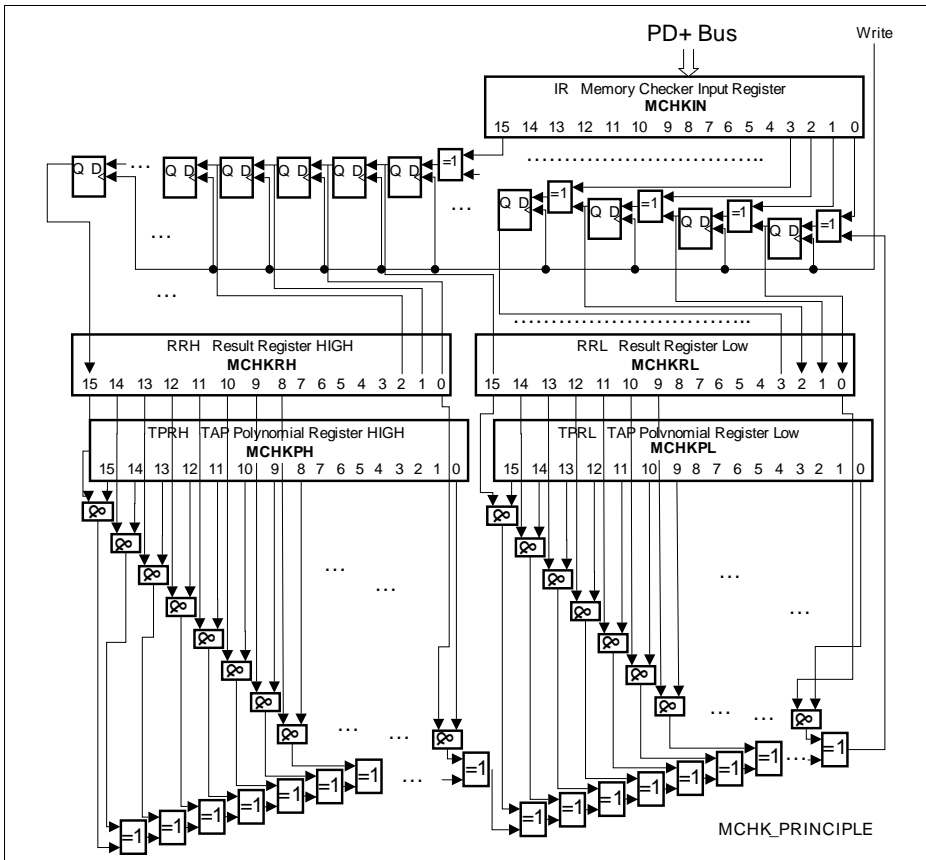


Figure 4-4 Implementation of the MCHK Checksum Circuit

4.2.5 Preferable Usage of the Memory Checker Module

Preferably the MCHK is used together with the CPU. The CPU reads the data block from the selected address area and writes it to the input register **IR**. Alternatively the PEC may be configured to move the data block to input register **IR** using 8-bit or 16-bit moves (PECCx.BWT = 0: 16-bit; PECCx.BWT = 1: 8-bit). Each write operation to register **IR** triggers a intermediate polynomial checksum calculation and the result of the calculation is stored in the result registers **RRL** and **RRH**. Furthermore, every write operation to register **IR** decrements the content of count register **COUNT**.

In order to start a memory check sequence, the result register must be initialized with a seed (e.g. written with the desired start value) and a CPU or PEC transaction must be set up (start address, length, etc.).

When the defined data block is completely written to register **IR**, an interrupt may be generated if the contents of the LFSR result registers **RRH** and **RRL** does not equal FADE'EDDA_H.

The MCHK may use e.g. the standard Ethernet (IEEE802.3/MPEG2) polynomial, which is given by:

$$G^{32} = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1 \quad (4.2)$$

Note: Although the polynomial above is used for generation, the result of the parallel signature generation (MISR) differs from the sequential signature generation (LFSR) used by the Ethernet protocol.

4.2.6 Calculation of Seed Values (Magic Word)

To achieve a successful CRC calculation and MATCH or MISMATCH signal on a block of non volatile data, a data specific seed value, the so called magic word, has to be loaded into the LFSR result registers **RRH** and **RRL** prior to the CRC calculation. This magic word should be calculated during development of the respective data. Such a magic word can only be generated, if the order of the TAP polynomial is equal order 32 (most significant bit of TAP polynomial **TPRH** must be equal 1). Otherwise the higher order bits are non equal to the required end result FADE EDDA_H. The following program sketches the principle of the program. It uses VBA (Microsoft Visual Basic) syntax. The Data_Array contains all the 16-bit data the CRC is to be calculated. COUNT passes the number of data the CRC is to be calculated, to the subroutine, as defined in the Memory Checker count register **COUNT**. The magical word is passed back to the calling routine through **RRH** and **RRL**, as it has to be written into the Result Register High (**RRH**) and the LFSR Result Register Low (**RRL**) as seed value. Because VBA has no unsigned integer format, a long integer format has been used within this demonstration code.

```
Sub MagicWord(ByRef Data_Array() As Long, _
              ByVal COUNT, TPRH, TPRL as Long, _
              ByRef RRH, RRL As Long)
```

Memory Checker Module (MCHK)

```

Dim i, j, order, feedback_bit As Integer
Dim temp As Long
    RRH = &HFADE
    RRL = &HEDDA
For j = COUNT To 1 Step -1
    If TPRH <> 0 Then                                ' order of polynomial > 16
        order = 31
        Do While TPRH< 2 ^ (order - 16) ' calculate order of polynomial,
            order = order - 1           ' determines bit position
        Loop                           ' "rolled" out of LFSR
    Else                                ' order of polynomial < 17
        order = 15
        Do While TPRL< 2 ^ order        ' calculate order of polynomial,
            order = order - 1           ' determines bit position
        Loop                           ' "rolled" out of LFSR
    End If
    RRL = RRL Xor Data_Array(j)         ' MISR XOR Input
    feedback_bit = RRL And 1            ' Extract CRC feedback bit
    RRL = RRL \ 2                       ' 32 bit shift right (LFSR)
    RRL = RRL + (RRH And 1) * 2 ^ 15
    RRH = RRH \ 2
    temp = (RRH And TPRH) _
           Xor (RRL And TPRL)          ' generate 32 TAP Bits
For i = 0 To 15
    feedback_bit = feedback_bit _
                 Xor ((temp \ (2 ^ i)) And 1)
Next i                                ' XOR TAP bits to bit
If feedback_bit <> 0 Then              ' TAP feedback bit is equal 1
    If order > 16 Then
        RRH = RRH Or (2 ^ (order - 16))
    Else
        RRL = RRL Xor (2 ^ order)
    End If
End If
Next j                                ' calculate CRC of all data
End Sub

```

4.2.7 Example Application

Assuming MCHK is to be used to detect faults within a set of twenty one 16 bit Data. The Memory Checker Module uses the standard Ethernet (IEEE802.3/MPEG2) polynomial, which is given by:

$$G^{32} = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1 \quad (4.3)$$

The Polynomial is therefore 8260 8EDB_H and is written to **TPRH** and **TPRL**. Next the magical word of this set of data has to be calculated offline using a respective program as described in **Section 4.2.6: “Calculation of Seed Values (Magic Word)” on Page 4-11**. For the given data in **Table 4-2**, a magical word = AA1F ED4E_H is calculated and written to **RRH** and **RRL**.

Table 4-2 Example for a CRC Check

User Action	Data Value	Content of Register				
		COUNT	RRH	RRL	TPRH	TPRL
TAP Polynomial written to TPRH	8260 _H	xxxx	xxxx	xxxx	8260 _H	xxxx
TAP Polynomial written to TPRL	8EDB _H	xxxx	xxxx	xxxx	8260 _H	8EDB _H
Magical Word written into RRH	AA1F _H	0015 _H	AA1F _H	xxxx	8260 _H	8EDB _H
Magical Word written into RRL	ED4E _H	0015 _H	AA1F _H	ED4E _H	8260 _H	8EDB _H
Data Amount written to COUNT	0015 _H	0015 _H	xxxx	xxxx	8260 _H	8EDB _H
Data 1 written into IR	8BED _H	0014 _H	543F _H	5171 _H	8260 _H	8EDB _H
Data 2 written into IR	AA61 _H	0013 _H	A87E _H	0883 _H	8260 _H	8EDB _H
Data 3 written into IR	C64E _H	0012 _H	50FC _H	D749 _H	8260 _H	8EDB _H
Data 4 written into IR	17E4 _H	0011 _H	A1F9 _H	B976 _H	8260 _H	8EDB _H
Data 5 written into IR	A329 _H	0010 _H	43F3 _H	D1C5 _H	8260 _H	8EDB _H
Data 6 written into IR	66B5 _H	000F _H	87E7 _H	C53E _H	8260 _H	8EDB _H
Data 7 written into IR	422A _H	000E _H	0FCF _H	C857 _H	8260 _H	8EDB _H
Data 8 written into IR	4FF6 _H	000D _H	1F9F _H	DF58 _H	8260 _H	8EDB _H
Data 9 written into IR	4046 _H	000C _H	3F3F _H	FEF6 _H	8260 _H	8EDB _H
Data 10 written into IR	911C _H	000B _H	7E7F _H	6CF0 _H	8260 _H	8EDB _H
Data 11 written into IR	1FA0 _H	000A _H	FCFE _H	C640 _H	8260 _H	8EDB _H

Memory Checker Module (MCHK)

Table 4-2 Example for a CRC Check (cont'd)

User Action	Data Value	Content of Register				
		COUNT	RRH	RRL	TPRH	TPRL
Data 12 written into IR	BF38 _H	0009 _H	F9FD _H	33B9 _H	8260 _H	8EDB _H
Data 13 written into IR	9FE3 _H	0008 _H	F3FA _H	F891 _H	8260 _H	8EDB _H
Data 14 written into IR	44DD _H	0007 _H	E7F5 _H	B5FE _H	8260 _H	8EDB _H
Data 15 written into IR	749A _H	0006 _H	CFEB _H	1F67 _H	8260 _H	8EDB _H
Data 16 written into IR	8C09 _H	0005 _H	9FD6 _H	B2C7 _H	8260 _H	8EDB _H
Data 17 written into IR	D0F5 _H	0004 _H	3FAD _H	B57A _H	8260 _H	8EDB _H
Data 18 written into IR	DC5F _H	0003 _H	7F5B _H	B6AB _H	8260 _H	8EDB _H
Data 19 written into IR	DB06 _H	0002 _H	FEB7 _H	B651 _H	8260 _H	8EDB _H
Data 20 written into IR	4604 _H	0001 _H	FD6F _H	2AA7 _H	8260 _H	8EDB _H
Data 21 written into IR	B894 _H	0000 _H	FADE _H	EDDA _H	8260 _H	8EDB _H

Memory Checker Module (MCHK)

4.3 Memory Checker Module Registers

From the programmer's point of view, the MCHK is composed of a set of SFRs as summarized below.

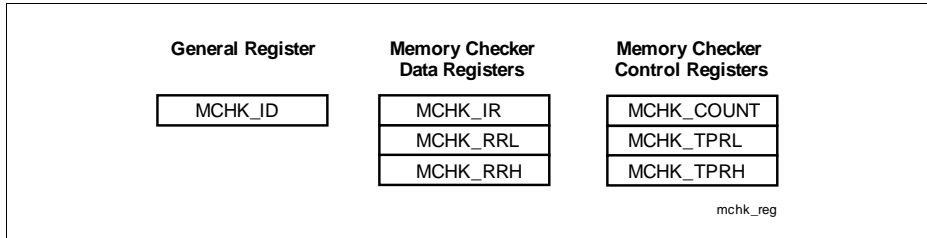


Figure 4-5 Memory Checker Module Kernel Registers

The following tables show the MCHK registers and their addresses.

Table 4-3 Registers Address Space

Module	Base Address	End Address	Note
MCHK	0000 _H		

Table 4-4 Registers Overview

Register Short Name	Register Long Name	Offset Address	Page Number
ID	Module Identification Register	FFE0 _H	Page 4-16
IR	Input Register	FE58 _H	Page 4-17
RRL	Result Register Low	F058 _H	Page 4-17
RRH	Result Register High	F05A _H	Page 4-18
COUNT	Count Register	FE5A _H	Page 4-20
TPRL	Polynomial Register Low	F05C _H	Page 4-21
TPRH	Polynomial Register High	F05E _H	Page 4-21

Note: All registers are reset by the same reset class as the CPU is reset.

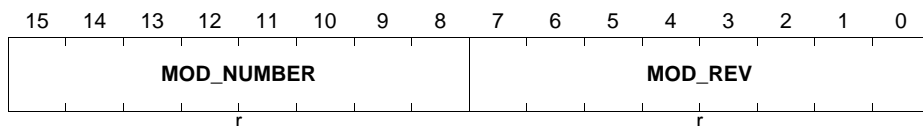
Memory Checker Module (MCHK)

4.3.1 General Register

The ID register is a read-only register used for MCHK module identification purposes. It provides 8 bits for module identification and 8 bits for revision numbering.

ID

Module Identification Register (FFE0_H) **Reset Value: 3BXX_H**

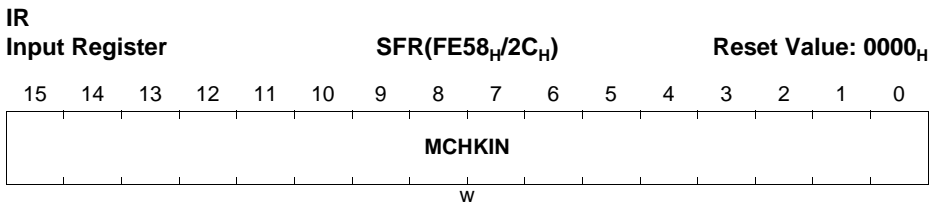


Field	Bits	Type	Description
MOD_REV	[7:0]	r	Module Revision Number Value Bits 7-0 bits are used for module revision numbering. The value of the module revision number starts with 01 _H (first revision).
MOD_NUMBER	[15:8]	r	Module Identification Number Value Bits 15-8 are used for module identification. The MCHK has the module number 3B _H .

Memory Checker Module (MCHK)

4.3.2 Memory Checker Data Register

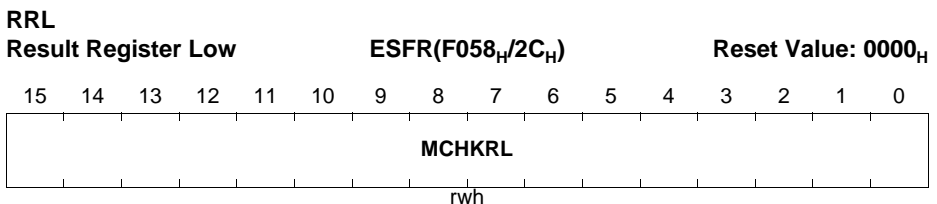
The input register receives the data written to the MCHK for checksum calculation. If the CPU moves to register MCHK_IR are 8-bit wide, the unused register bits of the 16-bit MCHKIN value are taken as 0s for the current result calculation.



Field	Bits	Type	Description
MCHKIN	[15:0]	w	Memory Checker Module Input The value written to MCHKIN is used for the next checksum calculation. Any read action will deliver 0000 _H .

Note: MCHK_IR is a write-only register. Any read action will deliver 0000_H.

The result registers contain the signature (result) of the memory check operation. Before starting a checksum calculation operation, they should be written with the initial checksum calculation value (seed).



Field	Bits	Type	Description
MCHKRL	[15:0]	rwh	Memory Checker Result Low This bit field contains the least significant 16 bits of the current result of the 32-bit checksum calculation operation.

Memory Checker Module (MCHK)

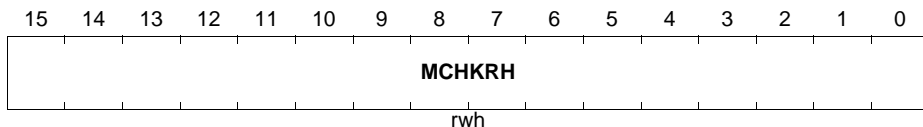
Note: Writing to the RRL.MCHKRL will reset (reload) the MCHKCNT.COUNT register to the last data written to this register MCHKCNT.COUNT value. Therefore writing to RRL will immediately initialize a new CRC calculation cycle.

RRH

Result Register High

ESFR(F05A_H/2D_H)

Reset Value: 0000_H



Field	Bits	Type	Description
MCHKRH	[15:0]	rwh	Memory Checker Result High This bit field contains the most significant 16 bits of the current result of the 32-bit checksum calculation operation.

4.3.3 Memory Checker Control Register

The count register COUNT is decremented on each write access to the input register. If the count register is decremented to 0000_H, a service request (interrupt) is generated if the content of the result registers is non equal FADE'EDDA_H, or instead the output signal MATCH is toggled if the result registers are equal FADE'EDDA_H. The count register is reloaded with the last value written to it, when the CPU transfers a new seed value (magic word) to the LFSR result register low ([RRL](#)).

When the CPU or PEC writes to register COUNT and its content is not equal to the last value written to it, the service request (interrupt) is generated and the output signal MATCH is toggled. This enables detection of software not correctly handling the MCHK, e.g. due to an erroneous program memory. The timely correct toggling of the MATCH signal may be used as a life signal e.g. by an external window watchdog. The reset value of the MATCH signal = 0_B.

Because register COUNT controls a safety critical system function, it is protected by a special register security mechanism so this vital system function cannot be changed inadvertently after executing the EINIT instruction.

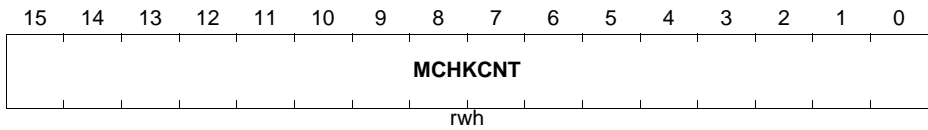
Memory Checker Module (MCHK)

COUNT

Count Register

SFR(FE5A_H/2D_H)

Reset Value: 0000_H



Field	Bits	Type	Description
MCHKCNT	[15:0]	rwh	Memory Checker Count MCHKCNT indicates the number of remaining data in the current data block to be entered into MCHK. 0001 _H One remaining data to be written to register IR to trigger the compare for the MATCH signal, interrupt signal NOMATCH. 0002 _H Two remaining data to be written to register IR FFFE _H 65534 remaining data to be written to register IR . FFFF _H 65535 remaining data to be written to register IR . 0000 _H 65536 remaining data to be written to register IR to trigger the compare for the MATCH signal, interrupt signal NOMATCH.

Note: Register COUNT should only be written if MCHKCNT is equal to the last value written to this register. Otherwise, a service request (interrupt) will be triggered and the MATCH signal will be toggled.

*Modify register COUNT only after writing to register **RRL**, which reloads COUNT to the previously written value (see also **Table 4-2**).*

Note: COUNT is write protected after the execution of EINIT by the register security mechanism.

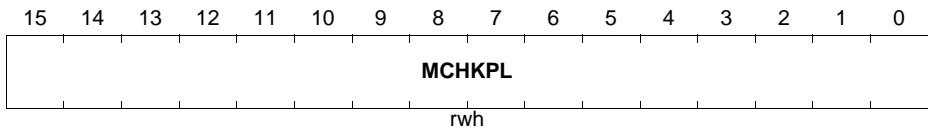
Memory Checker Module (MCHK)

The polynomial registers contain the LFSR polynomial of the checksum calculation operation.

Because the polynomial registers control a safety critical system function, they are protected by a special register security mechanism so this vital system function cannot be changed inadvertently after executing the EINIT instruction.

TPRL

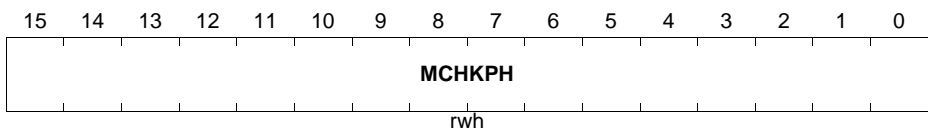
Tap Polynomial Register Low ESFR(F05C_H/2E_H) Reset Value: FFFF_H



Field	Bits	Type	Description
MCHKPL	[15:0]	rwh	Memory Checker Polynomial Low This bit field contains the least significant 16 bits of the binary tap polynomial format.

TPRH

Tap Polynomial Register High ESFR(F05E_H/2F_H) Reset Value: FFFF_H



Field	Bits	Type	Description
MCHKPH	[15:0]	rwh	Memory Checker Polynomial High This bit field contains the most significant 16 bits of the binary tap polynomial format.

Note: TPRH and TPRL is write protected after the execution of EINIT by the register security mechanism.

4.4 Interfaces of the MCHK Module

The MCHK module can generate an interrupt request and an external life signal.

The interrupt request signal is connected to the SCU and can be routed to one of the SCU's interrupt nodes.

The MATCH output is connected to an external pin in packaged devices with 144 or more pins only.

Table 4-5 MCHK Digital Connections in XE166U

Signal	from/to Module	I/O to MCHK
MATCH	not connected	O
INT (MISMATCH)	SCU	O
MCHKIN_Write_Access	Write trigger from MCHKIN	I ¹⁾
MCHKCNT_Write_Access	Write trigger from MCHKCNT	I ¹⁾
EINIT	SCU	I

1) This signal is generated within the module itself and is not present at the module boundary.

5 Central Processing Unit (CPU)

Basic tasks of the Central Processing Unit (CPU) are to fetch and decode instructions, to supply operands for the Arithmetic and Logic unit (ALU) and the Multiply and Accumulate unit (MAC), to perform operations on these operands in the ALU and MAC, and to store the previously calculated results. As the CPU is the main engine of the XE166U microcontroller, it is also affected by certain actions of the peripheral subsystem.

Because a five-stage processing pipeline (plus 2-stage fetch pipeline) is implemented in the XE166U, up to five instructions can be processed in parallel. Most instructions of the XE166U are executed in one single clock cycle due to this parallelism.

This chapter describes how the pipeline works for sequential and branch instructions in general, and the hardware provisions which have been made to speed up execution of jump instructions in particular. General instruction timing is described, including standard timing, as well as exceptions.

The on-chip peripheral units of the XE166U operate independently of the CPU. Data and control information are interchanged between the CPU and these peripherals via Special Function Registers (SFRs) or shared memory areas.

Whenever peripherals need a non-deterministic CPU action, an on-chip Interrupt Controller compares all pending peripheral service requests against each other and prioritizes one of them. If the priority of the current CPU operation is lower than the priority of the selected peripheral request, an interrupt will occur.

There are two basic types of interrupt processing:

- **Standard interrupt processing** forces the CPU to save the current program status and return address on the stack before branching to the interrupt vector jump table.
- **PEC interrupt processing** steals only one machine cycle from the current CPU activity to perform a single data transfer via the on-chip Peripheral Event Controller (PEC).

System errors detected during program execution (hardware traps) and external non-maskable interrupts are also processed as standard interrupts with a very high priority.

In contrast to other on-chip peripherals, there is a closer conjunction between the watchdog timer and the CPU. If enabled, the watchdog timer expects to be serviced by the CPU within a programmable period of time, otherwise it will reset the chip. Thus, the watchdog timer is able to prevent the CPU from going astray when executing erroneous code. The CPU provides a set of instructions for enabling (ENWDT), disabling (DISWDT) and servicing (SRVWDT) the watchdog timer.

In addition to its active operation state, the CPU can enter idle mode by executing the IDLE instruction. In idle mode the CPU stops program execution but still reacts to interrupt or PEC requests. Transition to the active state can be forced by an interrupt request or a hardware reset.

Central Processing Unit (CPU)

The PWRDN instruction is not enabled in the XE166U. If executed a NOP will be performed instead. System power state transitions are controlled by the System Control Unit (SCU).

A set of Special Function Registers is dedicated to the CPU core (CSFRs):

- CPU Status Indication and Control: **PSW, CPUCON1, CPUCON2**
- Code Access Control: **IP, CSP**
- Data Paging Control: **DPP0, DPP1, DPP2, DPP3**
- Global GPRs Access Control: **CP**
- System Stack Access Control: **SP, SPSEG, STKUN, STKOV**
- Multiply and Divide Support: **MDL, MDH, MDC**
- Indirect Addressing Offset: **QR0, QR1, QX0, QX1**
- MAC Address Pointers: **IDX0, IDX1**
- MAC Status Indication and Control: **MCW, MSW, MAH, MAL, MRW**
- ALU Constants Support: **ZEROS, ONES**
- CPU identification: **CPUID**

The CPU also uses CSFRs to access the General Purpose Registers (GPRs). Since all CSFRs can be controlled by any instruction capable of addressing the SFR/CSFR memory space, there is no need for special system control instructions.

However, to ensure proper processor operation, certain restrictions on the user access to some CSFRs must be imposed. For example, the instruction pointer (CSP, IP) cannot be accessed directly at all. These registers can only be changed indirectly via branch instructions. Registers PSW, SP, and MDC can be modified not only explicitly by the programmer, but also implicitly by the CPU during normal instruction processing.

Note: Note that any explicit write request (via software) to an CSFR supersedes a simultaneous modification by hardware of the same register.

Central Processing Unit (CPU)

All CSFRs may be accessed wordwise, or bytewise (some of them even bitwise). Reading bytes from word CSFRs is a non-critical operation. Any write operation to a single byte of a CSFR clears the non-addressed complementary byte within the specified CSFR.

Attention: Reserved CSFR bits must not be modified explicitly, and will always supply a read value of 0. If a byte/word access is preferred by the programmer or is the only possible access the reserved CSFR bits must be written with 0 to provide compatibility with future versions.

Central Processing Unit (CPU)

5.1 Components of the CPU

The high performance of the CPU results from the cooperation of several units which are optimized for their respective tasks (see [Figure 5-1](#)). **Prefetch Unit** and **Branch Unit** feed the pipeline minimizing CPU stalls due to instruction reads. The **Address Unit (ADU)** supports sophisticated addressing modes avoiding additional instructions needed otherwise. **Arithmetic and Logic Unit (ALU)** and **Multiply and Accumulate Unit (MAC)** handle differently sized data and execute complex operations. **Three memory interfaces** and **Write Buffer (WB)** minimize CPU stalls due to data transfers.

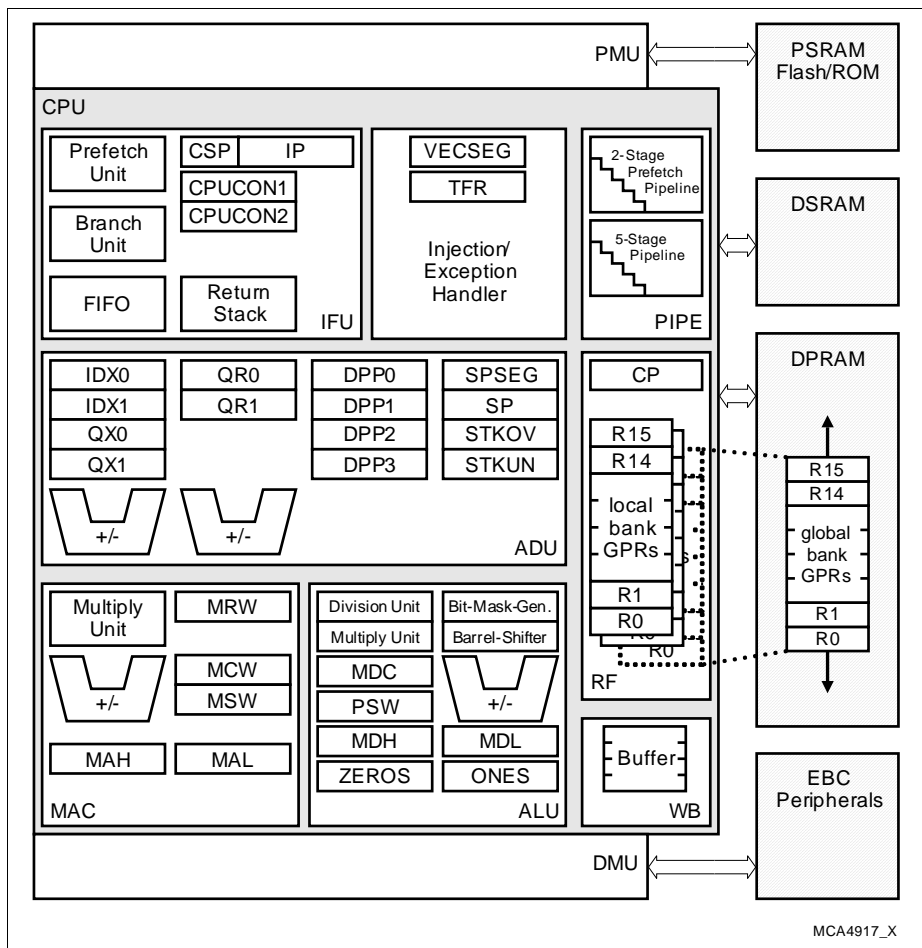


Figure 5-1 CPU Block Diagram

Central Processing Unit (CPU)

In general the instructions move through 7 pipeline stages ([Section 5.3](#)). The stages can be grouped as follows:

- **2 stages fetch pipeline** - receives instructions from program memory and stores them into an instruction FIFO. Fetch pipeline stages can be bypassed.
- **5 stages processing pipeline** - executes each instruction received from fetch stages.

Because passing through one pipeline stage takes at least one clock cycle and because the fetch pipeline stages can be bypassed, any isolated instruction takes at least five clock cycles to be completed. Pipelining, however, allows parallel (i.e. simultaneous) processing of up to five instructions (with branches up to six instructions). Therefore, most of the instructions appear to be processed during one clock cycle as soon as the pipeline has been filled once after reset.

The pipelining increases the average instruction throughput considered over a certain period of time.

5.2 Instruction Fetch and Program Flow Control

The Instruction Fetch Unit (IFU) prefetches and preprocesses instructions to provide a continuous instruction flow. The IFU can fetch simultaneously at least two instructions via a 64-bit wide bus from the Program Management Unit (PMU). The prefetched instructions are stored in an instruction FIFO.

Preprocessing of branch instructions enables the instruction flow to be predicted. While the CPU is in the process of executing an instruction fetched from the FIFO, the prefetcher of the IFU starts to fetch a new instruction at a predicted target address from the PMU. The latency time of this access is hidden by the execution of the instructions which have already been buffered in the FIFO. Even for a non-sequential instruction execution, the IFU can generally provide a continuous instruction flow. The IFU contains two pipeline stages: the Prefetch Stage and the Fetch Stage.

During the prefetch stage, the Branch Detection and Prediction Logic analyzes up to three prefetched instructions stored in the first Instruction Buffer (can hold up to six instructions). If a branch is detected, then the IFU starts to fetch the next instructions from the PMU according to the prediction rules. After having been analyzed, up to three instructions are stored in the second Instruction Buffer (can hold up to three instructions) which is the input register of the Fetch Stage.

In the case of an incorrectly predicted instruction flow, the instruction fetch pipeline is bypassed to reduce the number of dead cycles.

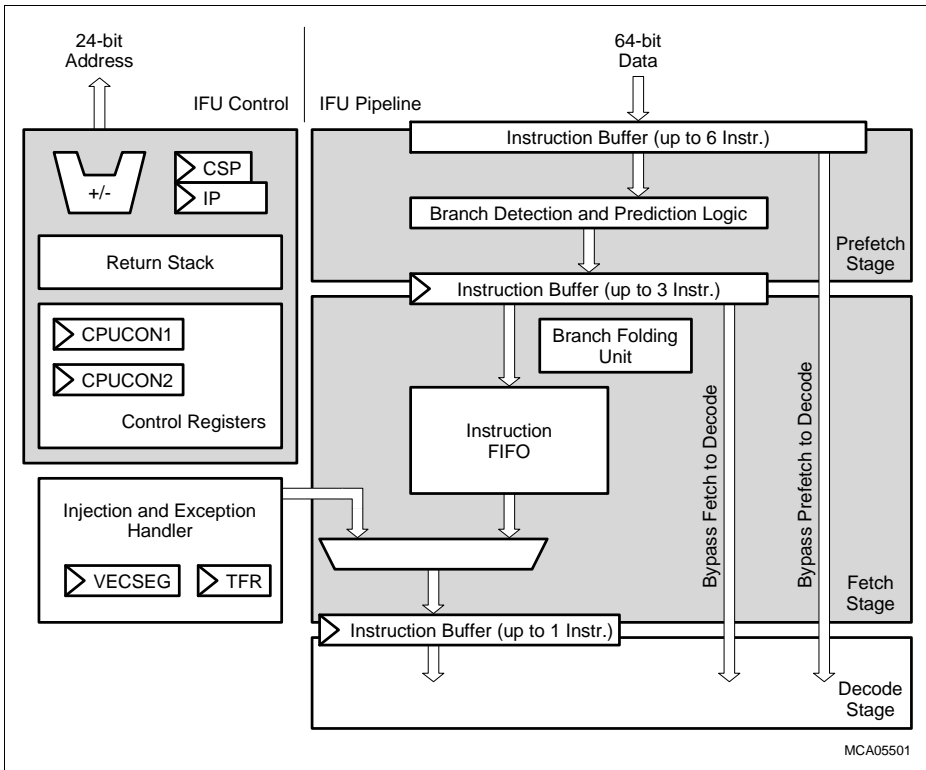


Figure 5-2 IFU Block Diagram

On the Fetch Stage, the prefetched instructions are stored in the instruction FIFO. The Branch Folding Unit (BFU) allows processing of branch instructions in parallel with preceding instructions. To achieve this the BFU preprocesses and reformats the branch instruction. First, the BFU defines (calculates) the absolute target address. This address — after being combined with branch condition and branch attribute bits — is stored in the same FIFO step as the preceding instruction. The target address is also used to prefetch the next instructions.

For the Processing Pipeline, both instructions are fetched from the FIFO again and are executed in parallel. If the instruction flow was predicted incorrectly (or FIFO is empty), the two stages of the IFU can be bypassed.

Note: Pipeline behavior in case of a incorrectly predicted instruction flow is described in the following sections.

5.2.1 Branch Detection and Branch Prediction Rules

The Branch Detection Unit preprocesses instructions and classifies detected branches. Depending on the branch class, the Branch Prediction Unit predicts the program flow using the following rules:

Table 5-1 Branch Classes and Prediction Rules

Branch Instruction Classes	Instructions	Prediction Rule (Assumption)
Inter-segment branch instructions	JMPS seg, caddr CALLS seg, caddr	The branch is always taken
Branch instructions with user programmable branch prediction	JMPA- xcc, caddr JMPA+ xcc, caddr CALLA- xcc, caddr CALLA+ xcc, caddr	User-specified ¹⁾ via bit 8 ('a') of the instruction long word: ...+: branch 'taken' (a = 0) ...-: branch 'not taken' (a = 1)
Indirect branch instructions	JMPI cc, [Rw] CALLI cc, [Rw]	Unconditional: branch 'taken' Conditional: 'not taken'
Relative branch instructions with condition code	JMPR cc, rel	Unconditional or backward: branch 'taken' Conditional forward: 'not taken'
Relative branch instructions without condition code	CALLR rel	The branch is always taken
Branch instructions with bit-condition	JB(C) bitaddr, rel JNB(S) bitaddr, rel	Backward: branch 'taken' Forward: 'not taken'
Return instructions	RET, RETP RETS, RETI	The branch is always taken

1) This bit can be also set/cleared automatically by the Assembler for generic JMPA and CALLA instructions depending on the jump condition

5.2.2 Zero-Cycle Jumps

The **"Zero-Cycle Jumps"** are one of the advanced XE166U specifics, which becomes possible due to the complex pipelined structure for processing instruction-flow.

This feature allows, under some circumstances, jumps to be executed in "null time". In fact, a jump is "hooked" to the previous instruction and the two instructions pass through the pipeline as one instruction. This can be only possible, if the jump instruction does not need any of the pipeline resources needed by the predecessor. Hence, the following rules are essential:

- a jump can not be hooked onto another jump instruction, as the pipeline resource "target IP" can not be shared between the two;

Central Processing Unit (CPU)

- a jump can not be executed in zero-cycle if it requires any memory access, as basically any predecessor instruction might access a memory.

The above are only preliminary conditions, needed to make a jump zero-cycle. But would this really happen, it's not reliable enough to predict: it also depends on the exact instruction sequence, speed of the program memory etc.

What can be summarized is:

- only **JMPA**, **JMPR** and **JMPS** Instructions **can be** converted to zero-cycle; if the immediately preceding instruction **is not** a branch (any **JMP**, **CALL** or **RET**).
- If a Jump is executed as zero-cycle, in fact the address of this Jump will not be assigned to the Instruction Pointer.

*Note: No IP-Breakpoint must be set over an instruction, which satisfies the two prepositions above for a zero-cycle Jump. Otherwise, if set, it is **very possible** this Breakpoint will be missed by the debug module.*

5.2.3 Atomic and Extend Instructions

The atomic and extend instructions (**ATOMIC**, **EXTR**, **EXTP**, **EXTS**, **EXTPR**, **EXTSR**) disable standard and PEC interrupts and class A traps until completion of the immediately following sequence of instructions. The number of instructions in the sequence may vary from 1 to 4. It is coded in the 2-bit constant field **#irang2** and takes values from 0 to 3. The **EXTENDED** instructions additionally change the addressing mechanism during this sequence (see instruction description).

ATOMIC and **EXTENDED** instructions become active immediately, so no additional **NOPs** are required. All instructions requiring multi cycles or hold states for execution are considered to be one instruction. The **ATOMIC** and **EXTENDED** instructions can be used with any instruction type.

If a branch instruction following immediately after an atomic sequence is executed as zero-cycle jump, then this branch is part of the atomic sequence as well. If the branch instruction is not a part of the **ATOMIC** sequence, it should not be hooked on to the atomic sequence, a **NOP** could be inserted in between.

*Note: If a class B trap interrupt occurs during an **ATOMIC** or **EXTENDED** sequence, then the sequence is terminated, an interrupt lock is removed, and the standard condition is restored before the trap routine is executed. The remaining instructions of the terminated sequence executed after returning from the trap routine will run under standard conditions.*

*Note: When using nested **ATOMIC** and **EXTENDED** instructions. There is only one counter to control the length of the sequence, i.e. issuing an **ATOMIC** or **EXTENDED** instruction within a sequence will reload the counter with the value of the new instruction.*

5.3 Instruction Processing Pipeline

The XE166U uses five pipeline stages to execute an instruction. All instructions pass through each of the five stages of the instruction processing pipeline. The pipeline stages are listed here together with the 2 stages of the fetch pipeline:

1st -> PREFETCH: This stage prefetches instructions from the PMU in the predicted order. The instructions are preprocessed in the branch detection unit to detect branches. The prediction logic decides if the branches are assumed to be taken or not.

2nd -> FETCH: The instruction pointer of the next instruction to be fetched is calculated according to the branch prediction rules. For zero-cycle branch execution, the Branch Folding Unit preprocesses and combines detected branches with the preceding instructions. Prefetched instructions are stored in the instruction FIFO. At the same time, instructions are transported out of the instruction FIFO to be executed in the instruction processing pipeline.

3rd -> DECODE: The instructions are decoded and, if required, the register file is accessed to read the GPR used in indirect addressing modes.

4th -> ADDRESS: All the operand addresses are calculated. Register SP is decremented or incremented for all instructions which implicitly access the system stack.

5th -> MEMORY: All the required operands are fetched.

6th -> EXECUTE: An ALU or MAC-Unit operation is performed on the previously fetched operands. The condition flags are updated. All explicit write operations to CPU-SFRs and all auto-increment/auto-decrement operations of GPRs used as indirect address pointers are performed.

7th -> WRITE BACK: All external operands and the remaining operands within the internal DPRAM space are written back. Operands located in the internal SRAM are buffered in the Write Back Buffer.

Specific so-called injected instructions are generated internally to provide the time needed to process instructions requiring more than one CPU cycle for processing. They are automatically injected into the decode stage of the pipeline, then they pass through the remaining stages like every standard instruction. Program interrupt, PEC transfer, and debug operations are also performed by means of injected instructions. Although these internally injected instructions will not be noticed in reality, they help to explain the operation of the pipeline.

The performance of the CPU (pipeline) is decreased by bandwidth limitations (same resource is accessed by different stages) and data dependencies between instructions. The XE166U's CPU has dedicated hardware to detect and to resolve different kinds of dependencies. Some of those dependencies are described in the following section.

Because up to five different instructions are processed simultaneously, additional hardware has been dedicated to deal with dependencies which may exist between instructions in different pipeline stages. This extra hardware supports 'forwarding' of the operand read and write values and resolves most of the possible conflicts — such as

multiple usage of buses — in a time optimized way without performance loss. This makes the pipeline unnoticeable for the user in most cases. However, there are some cases in which the pipeline requires attention by the programmer.

5.3.1 Access to the IO Area

Read or write accesses to the IO Areas of the XE166U memory space enforce particular pipeline behavior. Thus the requirements of peripheral devices with registers located in these areas are handled appropriately.

The following typical properties of peripheral device registers are considered:

- Upon a write to a peripheral register the contents of any (also multiple) peripheral register(s) may change as a consequence of the write.
- Upon a read from a peripheral register the contents of the same register may change as a consequence of the read (e.g. read buffer of a serial channel)

These cases are handled by following pipeline measures:

Write before read execution enforced

If the instructions in the pipeline contain a write action followed by a read action both to the IO areas then the read action is delayed (held in memory stage) until the write action has passed through the writeback stage. Thus the write action will always be scheduled before a read action.

Attention: Due to additional system delay this does not guarantee that a write will become effective before a read at the target registers.

Additional system delay is accumulated by the bus system or caused by the peripheral itself. In case the additional read delay differs from the write delay the read may overtake the write. However since the on-chip delays are similar the programmer must take care about this in particular when using off-chip peripherals allocating IO area through the EXTBUS.

Prevention of buffered writes

Write access to the IO area is not buffered in the writeback buffer.

5.3.2 Pipeline Conflicts

The following examples describe the pipeline behavior in special cases and give provide rules to optimize performance by instruction re-ordering.

Note: The XE166U has a fully interlocked pipeline, which means that pipeline conflicts do not cause any malfunction. Instruction re-ordering is only required for performance reasons.

5.3.2.1 Using General Purpose Registers

The GPRs are the working registers of the CPU and there are a lot of possible dependencies between instructions using GPRs. A high-speed five-port register file prevents bandwidth conflicts. Dedicated hardware is implemented to detect and resolve the data dependencies. Special forwarding buses are used to forward GPR values from one pipeline stage to another. In most cases, this allows the execution of instructions without any delay despite of data dependencies.

Conflict_GPRs_Resolved:

```
In      ADD R0,R1      ;Compute new value for R0
In+1    ADD R3,R0      ;Use R0 again
In+2    ADD R6,R0      ;Use R0 again
In+3    ADD R6,R1      ;Use R6 again
```

Table 5-2 Resolved Pipeline Dependencies Using GPRs

Stage	T _n	T _{n+1}	T _{n+2}	T _{n+3}	T _{n+4} ¹⁾	T _{n+5} ²⁾
DECODE	I _n = ADD R0, R1	I _{n+1} = ADD R3, R0	I _{n+2} = ADD R6, R0	I _{n+3} = ADD R6, R1	I _{n+4}	I _{n+5}
ADDRESS	I _{n-1}	I _n = ADD R0, R1	I _{n+1} = ADD R3, R0	I _{n+2} = ADD R6, R0	I _{n+3} = ADD R6, R1	I _{n+4}
MEMORY	I _{n-2}	I _{n-1}	I _n = ADD R0, R1	I _{n+1} = ADD R3, R0	I _{n+2} = ADD R6, R0	I _{n+3} = ADD R6 , R1
EXECUTE	I _{n-3}	I _{n-2}	I _{n-1}	I _n = ADD R0 , R1	I _{n+1} = ADD R3, R0	I _{n+2} = ADD R6 , R0
WR.BACK	I _{n-4}	I _{n-3}	I _{n-2}	I _{n-1}	I _n = ADD R0 , R1	I _{n+1} = ADD R3, R0

1) R0 forwarded from WRITE BACK to MEMORY.

2) R6 forwarded from EXECUTE to MEMORY.

However, if a GPR is used for indirect addressing the address pointer (i.e. the GPR) will be required already in the DECODE stage. In this case the instruction is stalled in the address stage until the operation in the ALU is executed and the result is forwarded to the address stage.

Conflict_GPRs_Pointer_Stall:

```
In      ADD R0,R1      ;Compute new value for R0
In+1    MOV R3,[R0]    ;Use R0 as address pointer
In+2    ADD R6,R0
In+3    ADD R6,R1
```

Table 5-3 Pipeline Dependencies Using GPRs as Pointers (Stall)

Stage	T _n	T _{n+1}	T _{n+2} ¹⁾	T _{n+3} ²⁾	T _{n+4}	T _{n+5}
DECODE	I _n = ADD R0, R1	I _{n+1} = MOV R3, [R0]	I _{n+2}	I _{n+2}	I _{n+2}	I _{n+3}
ADDRESS	I _{n-1}	I _n = ADD R0, R1	I _{n+1} = MOV R3, [R0]	I _{n+1} = MOV R3, [R0]	I _{n+1} = MOV R3, [R0]	I _{n+2}
MEMORY	I _{n-2}	I _{n-1}	I _n = ADD R0, R1	–	–	I _{n+1} = MOV R3, [R0]
EXECUTE	I _{n-3}	I _{n-2}	I _{n-1}	I _n = ADD R0 , R1	–	–
WR.BACK	I _{n-4}	I _{n-3}	I _{n-2}	I _{n-1}	I _n = ADD R0, R1	–

1) New value of R0 not yet available.

2) R0 forwarded from EXECUTE to ADDRESS (next cycle).

To avoid these stalls, one multicycle instruction or two single cycle instructions may be inserted. These instructions must not update the GPR used for indirect addressing.

Conflict_GPRs_Pointer_NoStall:

```

In    ADD R0,R1      ;Compute new value for R0
In+1  ADD R6,R0      ;R0 is not updated, just read
In+2  ADD R6,R1
In+3  MOV R3,[R0]    ;Use R0 as address pointer

```

Table 5-4 Pipeline Dependencies Using GPRs as Pointers (No Stall)

Stage	T _n	T _{n+1}	T _{n+2}	T _{n+3} ¹⁾	T _{n+4}	T _{n+5}
DECODE	I _n = ADD R0, R1	I _{n+1} = ADD R6, R0	I _{n+2} = ADD R6, R1	I _{n+3} = MOV R3, [R0]	I _{n+4}	I _{n+5}
ADDRESS	I _{n-1}	I _n = ADD R0, R1	I _{n+1} = ADD R6, R0	I _{n+2} = ADD R6, R1	I _{n+3} = MOV R3, [R0]	I _{n+4}
MEMORY	I _{n-2}	I _{n-1}	I _n = ADD R0, R1	I _{n+1} = ADD R6, R0	I _{n+2} = ADD R6, R1	I _{n+3} = MOV R3, [R0]
EXECUTE	I _{n-3}	I _{n-2}	I _{n-1}	I _n = ADD R0 , R1	I _{n+1} = ADD R6, R0	I _{n+2} = ADD R6, R1
WR.BACK	I _{n-4}	I _{n-3}	I _{n-2}	I _{n-1}	I _n = ADD R0, R1	I _{n+1} = ADD R6, R0

1) R0 forwarded from EXECUTE to ADDRESS (next cycle).

5.3.2.2 Using Indirect Addressing Modes

In the case of read accesses using indirect addressing modes, the Address Generation Unit uses a speculative addressing mechanism. The read data path to one of the different memory areas (DPRAM, DSRAM, etc.) is selected according to a history table before the address is decoded. This history table has one entry for each of the GPRs. The entries store the information of the last accessed memory area using the corresponding GPR. In the case of an incorrect prediction of the memory area, the read access must be restarted.

It is recommended that the GPRs used for indirect addressing always point to the same memory area. If an updated GPR points to a different memory area, the next read operation will access the wrong memory area. The read access must be repeated, which leads to pipeline stalls.

Conflict_GPRs_Pointer_WrongHistory:

```

In    ADD R3,[R0]      ;R0 points to DPRAM (e.g.)
In+1  MOV R0,R4
...
Ii    MOV DPPX, ...    ;change DPPx
...
Im    ADD R6,[R0]      ;R0 now points to SRAM (e.g.)
Im+1  MOV R6,R1

```

Table 5-5 Pipeline Dependencies with Pointers (Valid Speculation)

Stage	T _n	T _{n+1}	T _{n+2}	T _{n+3}	T _{n+4}	T _{n+5}
DECODE	I _n = ADD R3, [R0]	I _{n+1} = MOV R0, R4	I _{n+2}	I _{n+3}	I _{n+4}	I _{n+5}
ADDRESS	I _{n-1}	I _n = ADD R3, [R0]	I _{n+1} = MOV R0, R4	I _{n+2}	I _{n+3}	I _{n+4}
MEMORY	I _{n-2}	I _{n-1}	I _n = ADD R3, [R0]	I _{n+1} = MOV R0, R4	I _{n+2}	I _{n+3}
EXECUTE	I _{n-3}	I _{n-2}	I _{n-1}	I _n = ADD R3, [R0]	I _{n+1} = MOV R0, R4	I _{n+2}
WR.BACK	I _{n-4}	I _{n-3}	I _{n-2}	I _{n-1}	I _n = ADD R3, [R0]	I _{n+1} = MOV R0, R4

Table 5-6 Pipeline Dependencies with Pointers (Invalid Speculation)

Stage	T_m	T_{m+1}	T_{m+2} ¹⁾	T_{m+3}	T_{m+4}	T_{m+5}
DECODE	$I_m = \text{ADD R6, [R0]}$	$I_{m+1} = \text{MOV R6, R1}$	$I_{m+1} = \text{MOV R6, R1}$	I_{m+2}	I_{m+3}	I_{m+4}
ADDRESS	I_{m-1}	$I_m = \text{ADD R6, [R0]}$	$I_m = \text{ADD R6, [R0]}$	$I_{m+1} = \text{MOV R6, R1}$	I_{m+2}	I_{m+3}
MEMORY	I_{m-2}	I_{m-1}	—	$I_m = \text{ADD R6, [R0]}$	$I_{m+1} = \text{MOV R6, R1}$	I_{m+2}
EXECUTE	I_{m-3}	I_{m-2}	I_{m-1}	—	$I_m = \text{ADD R6, [R0]}$	$I_{m+1} = \text{MOV R6, R1}$
WR.BACK	I_{m-4}	I_{m-3}	I_{m-2}	I_{m-1}	—	$I_m = \text{ADD R6, [R0]}$

1) Access to location [R0] must be repeated due to wrong history (target area was changed).

5.3.2.3 Due to Memory Bandwidth

Memory bandwidth conflicts can occur if instructions in the pipeline access the same memory area at the same time. Special access mechanisms are implemented to minimize conflicts. The DPRAM of the CPU has two independent read/write ports; this allows parallel read and write operation without delays. Write accesses to the DSRAM can be buffered in a Write Back Buffer until read accesses are finished.

All instructions except the CoXXX instructions can read only one memory operand per cycle. A conflict between the read and one write access cannot occur because the DPRAM has two independent read/write ports. Only other pipeline stall conditions can generate a DPRAM bandwidth conflict. The DPRAM is a synchronous pipelined memory. The read access starts with the valid addresses on the address stage. The data are delivered in the Memory stage. If a memory read access is stalled in the Memory stage and the following instruction on the Address stage tries to start a memory read, the new read access must be delayed as well. But, this conflict is hidden by an already existing stall of the pipeline.

The CoXXX instructions are the only instructions able to read two memory operands per cycle. A conflict between the two read and one pending write access can occur if all three operands are located in the DPRAM area. This is especially important for performance in the case of executing a filter routine. One of the operands should be located in the DSRAM to guarantee a single-cycle execution of the CoXXX instructions.

Conflict_DPRAM_Bandwidth:

```

In      ADD op1,R1
In+1    ADD R6,R0
In+2    CoMAC [IDX0],[R0]
```

I_{n+3} `MOV R3, [R0]`

Table 5-7 Pipeline Dependencies in Case of Memory Conflicts (DPRAM)

Stage	T_n	T_{n+1}	T_{n+2}	T_{n+3}	T_{n+4} ¹⁾	T_{n+5}
DECODE	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$	$I_{n+2} = \text{CoMAC ...}$	$I_{n+3} = \text{MOV R3, [R0]}$	I_{n+4}	I_{n+4}
ADDRESS	I_{n-1}	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$	$I_{n+2} = \text{CoMAC ...}$	$I_{n+3} = \text{MOV R3, [R0]}$	$I_{n+3} = \text{MOV R3, [R0]}$
MEMORY	I_{n-2}	I_{n-1}	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$	$I_{n+2} = \text{CoMAC ...}$	$I_{n+2} = \text{CoMAC ...}$
EXECUTE	I_{n-3}	I_{n-2}	I_{n-1}	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$	—
WR.BACK	I_{n-4}	I_{n-3}	I_{n-2}	I_{n-1}	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$

1) CoMAC instruction stalls due to memory bandwidth conflict.

The DSRAM is a single-port memory with one read/write port. To reduce the number of bandwidth conflict cases, a Write Back Buffer is implemented. It has three data entries. Only if the buffer is filled and a read access and a write access occur at the same time, must the read access be stalled while one of the buffer entries is written back.

Conflict_DSRAM_Bandwidth:

I_n `ADD op1, R1`
 I_{n+1} `ADD R6, R0`
 I_{n+2} `ADD R6, op2`
 I_{n+3} `MOV R3, R2`

Table 5-8 Pipeline Dependencies in Case of Memory Conflicts (DSRAM)

Stage	T_n	T_{n+1}	T_{n+2}	T_{n+3}	T_{n+4} ¹⁾	T_{n+5}
DECODE	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$	$I_{n+2} = \text{ADD R6, op2}$	$I_{n+3} = \text{MOV R3, R2}$	I_{n+4}	I_{n+4}
ADDRESS	I_{n-1}	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$	$I_{n+2} = \text{ADD R6, op2}$	$I_{n+3} = \text{MOV R3, R2}$	$I_{n+3} = \text{MOV R3, R2}$
MEMORY	I_{n-2}	I_{n-1}	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$	$I_{n+2} = \text{ADD R6, op2}$	$I_{n+2} = \text{ADD R6, op2}$
EXECUTE	I_{n-3}	I_{n-2}	I_{n-1}	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$	—

Table 5-8 Pipeline Dependencies in Case of Memory Conflicts (DSRAM)

Stage	T_n	T_{n+1}	T_{n+2}	T_{n+3}	T_{n+4} ¹⁾	T_{n+5}
WR.BACK	I_{n-4}	I_{n-3}	I_{n-2}	I_{n-1}	$I_n = \text{ADD op1, R1}$	$I_{n+1} = \text{ADD R6, R0}$
WB.Buffer	full	full	full	full	full	full

1) ADD R6, op2 instruction stalls due to memory bandwidth conflict.

5.3.2.4 Caused by CPU-SFR Updates

CPU-SFRs control the CPU functionality and behavior. Changes and updates of CSFRs influence the instruction flow in the pipeline. Therefore, special care is required to ensure that instructions in the pipeline always work with the correct CSFR values. CSFRs are updated late on the EXECUTE stage of the pipeline. Meanwhile, without conflict detection, the instructions in the DECODE, ADDRESS, and MEMORY stages would still work without updated register values. The CPU detects conflict cases and stalls the pipeline to guarantee a correct execution. For performance reasons, the CPU differentiates between different classes of CPU-SFRs. The flow of instructions through the pipeline can be improved by following the given rules used for instruction re-ordering.

There are three classes of CPU-SFRs:

- CSFRs not generating pipeline conflicts (ONES, ZEROS, MCW)
- CSFR result registers updated late in the EXECUTE stage, causing one stall cycle
- CSFRs affecting the whole CPU or the pipeline, causing a pipeline cancellation

CSFR Result Registers

The CSFR result registers MDH, MDL, MSW, MAH, MAL, and MRW of the ALU and MAC-Unit are updated late in the EXECUTE stage of the pipeline. If an instruction (except CoSTORE) accesses these registers in the MEMORY stage, the value cannot be forwarded. The instruction must be stalled for one cycle on the MEMORY stage.

Conflict_CSFR_Update_Stall:

```

 $I_n$       MUL  R0,R1
 $I_{n+1}$     MOV  R6,MDL
 $I_{n+2}$     ADD  R6,R1
 $I_{n+3}$     MOV  R3,[R0]
```

Table 5-9 Pipeline Dependencies with Result CSFRs (Stall)

Stage	T_n	T_{n+1}	T_{n+2}	$T_{n+3}^{1)}$	T_{n+4}	T_{n+5}
DECODE	$I_n = \text{MUL } R0, R1$	$I_{n+1} = \text{MOV } R6, MDL$	$I_{n+2} = \text{ADD } R6, R1$	$I_{n+3} = \text{MOV } R3, [R0]$	$I_{n+3} = \text{MOV } R3, [R0]$	I_{n+4}
ADDRESS	I_{n-1}	$I_n = \text{MUL } R0, R1$	$I_{n+1} = \text{MOV } R6, MDL$	$I_{n+2} = \text{ADD } R6, R1$	$I_{n+2} = \text{ADD } R6, R1$	$I_{n+3} = \text{MOV } R3, [R0]$
MEMORY	I_{n-2}	I_{n-1}	$I_n = \text{MUL } R0, R1$	$I_{n+1} = \text{MOV } R6, MDL$	$I_{n+1} = \text{MOV } R6, MDL$	$I_{n+2} = \text{ADD } R6, R1$
EXECUTE	I_{n-3}	I_{n-2}	I_{n-1}	$I_n = \text{MUL } R0, R1$	–	$I_{n+1} = \text{MOV } R6, MDL$
WR.BACK	I_{n-4}	I_{n-3}	I_{n-2}	I_{n-1}	$I_n = \text{MUL } R0, R1$	–

1) Cannot read MDL here.

By reordering instructions, the bubble in the pipeline can be filled with an instruction not using this resource.

Conflict_CSFR_Update_Resolved:

```

 $I_n$       MUL  R0, R1
 $I_{n+1}$     MOV  R3, [R0]
 $I_{n+2}$     MOV  R6, MDL
 $I_{n+3}$     ADD  R6, R1

```

Table 5-10 Pipeline Dependencies with Result CSFRs (No Stall)

Stage	T_n	T_{n+1}	T_{n+2}	T_{n+3}	$T_{n+4}^{1)}$	T_{n+5}
DECODE	$I_n = \text{MUL } R0, R1$	$I_{n+1} = \text{MOV } R3, [R0]$	$I_{n+2} = \text{MOV } R6, MDL$	$I_{n+3} = \text{ADD } R6, R1$	I_{n+4}	I_{n+5}
ADDRESS	I_{n-1}	$I_n = \text{MUL } R0, R1$	$I_{n+1} = \text{MOV } R3, [R0]$	$I_{n+2} = \text{MOV } R6, MDL$	$I_{n+3} = \text{ADD } R6, R1$	I_{n+4}
MEMORY	I_{n-2}	I_{n-1}	$I_n = \text{MUL } R0, R1$	$I_{n+1} = \text{MOV } R3, [R0]$	$I_{n+2} = \text{MOV } R6, MDL$	$I_{n+3} = \text{ADD } R6, R1$
EXECUTE	I_{n-3}	I_{n-2}	I_{n-1}	$I_n = \text{MUL } R0, R1$	$I_{n+1} = \text{MOV } R3, [R0]$	$I_{n+2} = \text{MOV } R6, MDL$
WR.BACK	I_{n-4}	I_{n-3}	I_{n-2}	I_{n-1}	$I_n = \text{MUL } R0, R1$	$I_{n+1} = \text{MOV } R3, [R0]$

1) MDL can be read now, no stall cycle necessary.

CSFRs Affecting the Whole CPU

Some CSFRs affect the whole CPU or the pipeline before the Memory stage. The CPU-SFRs CPUCON1/2, CP, SP, STKUN, STKOV, VECSEG, TFR, and PSW affect the overall CPU function, while the CPU-SFRs IDX0, IDX1, QX1, QX0, DPP0, DPP1, DPP2, and DPP3 only affect the DECODE, ADDRESS, and MEMORY stage when they are modified **explicitly**. In this case the pipeline behavior depends on the instruction and addressing mode used to modify the CSFR.

In the case of modification of these CSFRs by “POP CSFR” or by instructions using the reg,#data16 addressing mode, a special mechanism is implemented to improve performance during the initialization.

For further explanation, the instruction which modifies the CSFR can be called “instruction_modify_CSFR”. This special case is detected in the DECODE stage when the instruction_modify_CSFR enters the processing pipeline. Further on, instructions described in the following list are held in the DECODE stage (all other instructions are not held):

- Instructions using long addressing mode (mem)
- Instructions using indirect addressing modes ($[R_w]$, $[R_w+]$...), except JMPL and CALLI
- ENWDT, DISWDT, EINIT
- All CoXXX instructions

If the CPUCON1/2, CP, SP, STKUN, STKOV, VECSEG, TFR, or the PSW are modified and the instruction_modify_CSFR reaches the EXECUTE stage, the pipeline is canceled. The modification affects the entire pipeline and the instruction prefetch. A clean cancel and restart mechanism is required to guarantee a correct instruction flow. In case of modification of IDX0, IDX1, QX1, QX0, DPP0, DPP1, DPP2, or DPP3 only the DECODE, ADDRESS, and MEMORY stages are affected and the pipeline needs not to be canceled. The modification does not affect the instructions in the ADDRESS, MEMORY stage because they are not using this resource. Other kinds of instructions are held in the DECODE stage until the CSFR is modified.

The following example shows a case in which the pipeline is stalled. The instruction “MOV R6, R1” after the “MOV IDX1, #12” instruction which modifies the CSFR will be held in DECODE Stage until the IDX1 register is updated. The next example shows an optimized initialization routine.

Conflict_Canceling:

```
In      MOV  IDX1, #12
In+1    MOV  R6, mem
In+2    ADD  R6, R1
In+3    MOV  R3, [R0]
```

Table 5-11 Pipeline Dependencies with Control CSFRs (Canceling)

Stage	T _n	T _{n+1}	T _{n+2}	T _{n+3}	T _{n+4}	T _{n+5}
DECODE	I _n = MOV IDX1, #12	I _{n+1} = MOV R6, mem	I _{n+1} = MOV R6, mem	I _{n+1} = MOV R6, mem	I _{n+1} = MOV R6, mem	I _{n+2} = ADD R6, R1
ADDRESS	I _{n-1}	I _n = MOV IDX1, #12	–	–	–	I _{n+1} = MOV R6, mem
MEMORY	I _{n-2}	I _{n-1}	I _n = MOV IDX1, #12	–	–	–
EXECUTE	I _{n-3}	I _{n-2}	I _{n-1}	I _n = MOV IDX1, #12	–	–
WR.BACK	I _{n-4}	I _{n-3}	I _{n-2}	I _{n-1}	I _n = MOV IDX1, #12	–

Conflict_Canceling_Optimized:

```

In      MOV  IDX1, #12
In+1    MOV  MAH, #23
In+2    MOV  MAL, #25
In+3    MOV  R3, #08

```

Table 5-12 Pipeline Dependencies with Control CSFRs (Optimized)

Stage	T _n	T _{n+1}	T _{n+2}	T _{n+3}	T _{n+4}	T _{n+5}
DECODE	I _n = MOV IDX1, #12	I _{n+1} = MOV MAH, #23	I _{n+2} = MOV MAL, #25	I _{n+3} = MOV R3, #08	I _{n+4}	I _{n+5}
ADDRESS	I _{n-1}	I _n = MOV IDX1, #12	I _{n+1} = MOV MAH, #23	I _{n+2} = MOV MAL, #25	I _{n+3} = MOV R3, #08	I _{n+4}
MEMORY	I _{n-2}	I _{n-1}	I _n = MOV IDX1, #12	I _{n+1} = MOV MAH, #23	I _{n+2} = MOV MAL, #25	I _{n+3} = MOV R3, #08
EXECUTE	I _{n-3}	I _{n-2}	I _{n-1}	I _n = MOV IDX1, #12	I _{n+1} = MOV MAH, #23	I _{n+2} = MOV MAL, #25
WR.BACK	I _{n-4}	I _{n-3}	I _{n-2}	I _{n-1}	I _n = MOV IDX1, #12	I _{n+1} = MOV MAH, #23

For all the other instructions that modify this kind of CSFR, a simple stall and cancel mechanism guarantees the correct instruction flow.

A possible explicit write-operation to this kind of CSFRs is detected on the MEMORY stage of the pipeline. The following instructions on the ADDRESS and DECODE Stage are stalled. If the instruction reaches the EXECUTE stage, the entire pipeline and the Instruction FIFO of the IFU are canceled. The instruction flow is completely re-started.

Conflict_Canceling_Completely:

```
In      MOV PSW, R4
In+1    MOV R6, R1
In+2    ADD R6, R1
In+3    MOV R3, [R0]
```

Table 5-13 Pipeline Dependencies with Control CSFRs (Cancel All)

Stage	T _{n+1}	T _{n+2}	T _{n+3}	T _{n+4}	T _{n+5}	T _{n+6}
DECODE	I _{n+1} = MOV R6, R1	I _{n+2} = ADD R6, R1	I _{n+2} = ADD R6, R1	–	–	I _{n+1} = MOV R6, R1
ADDRESS	I _n = MOV PSW, R4	I _{n+1} = MOV R6, R1	I _{n+1} = MOV R6, R1	–	–	–
MEMORY	I _{n-1}	I _n = MOV PSW, R4	–	–	–	–
EXECUTE	I _{n-2}	I _{n-1}	I _n = MOV PSW, R4	–	–	–
WR.BACK	I _{n-3}	I _{n-2}	I _{n-1}	I _n = MOV PSW, R4	–	–

5.3.3 Pipeline clean up

When either IDLE or SRST instruction is executed the CPU provides pipeline and writeback buffer flushing.

For the following code example the CPU will make sure that the write to DSRAM is completed before reset state is entered.

```
MOV <some DSRAM location>, R2
SRST
```

Note: If you need to write to other on-chip memory or peripherals it depends on the system latency whether the write will complete. In this case it is advisable to take additional software measures to ensure the expected behavior.

5.4 CPU Configuration Registers

The CPU configuration registers select a number of general features and behaviors of the XE166U's CPU core. In general these registers are only written by the startup software and not altered during application software run time.

Note: The CPU configuration registers are protected by the register security mechanism after the EINIT instruction has been executed.

CPUCON1

CPU Control Register 1

SFR (FE18_H/0C_H)

Reset Value: 0007_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0									VECSC		WDT CTL	SGT DIS	INTS CXT	BP	ZCJ
r									rw		rw	rw	rw	rw	rw

Field	Bits	Type	Description
0	[15:7]	r	Reserved Read as 0, should be written 0
VECSC	[6:5]	rw	Scaling Factor of Vector Table 00 _B Space between two vectors is 2 words ¹⁾ 01 _B Space between two vectors is 4 words 10 _B Space between two vectors is 8 words 11 _B Space between two vectors is 16 words
WDTCTL	4	rw	Configuration of Watchdog Timer 0 _B DISWDT executable only until End Of Init ²⁾ 1 _B DISWDT/ENWDT always executable (enhanced WDT mode)
SGTDIS	3	rw	Segmentation Disable/Enable Control 0 _B Segmentation enabled 1 _B Segmentation disabled
INTSCXT	2	rw	Enable Interruptibility of Switch Context 0 _B Switch context is not interruptible 1 _B Switch context is interruptible
BP	1	rw	Enable Branch Prediction Unit 0 _B Branch prediction disabled 1 _B Branch prediction enabled
ZCJ	0	rw	Enable Zero-Cycle Jump Function 0 _B Zero-cycle jump function disabled 1 _B Zero-cycle jump function enabled

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- 1) The default value (2 words) is compatible with the vector distance defined in the C166 Family architecture.
- 2) The DISWDT (executed after EINIT) and ENWDT instructions are internally converted in a NOP instruction.

CPUCON2

CPU Control Register 2

SFR (FE1A_H/0D_H)

Reset Value: 8FBB_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FIFODEPTH			FIFOFED			BYP PF	BYP F	1	STE N	LFIC	OV RUN	RET ST	FAS TBL	1	SL
rw			rw			rw	rw	r	rw	rw	rw	rw	rw	r	rw

Field	Bits	Type	Description
FIFODEPTH	[15:12]	rw	FIFO Depth Configuration 0 _H No FIFO (entries) 1 _H One FIFO entry ... 8 _H Eight FIFO entries 9 _H reserved ... F _H reserved
FIFOFED	[11:10]	rw	FIFO Fed Configuration 00 _B FIFO disabled 01 _B FIFO filled with up to one instruction per cycle 10 _B FIFO filled with up to two instructions per cycle 11 _B FIFO filled with up to three instruction per cycle
BYP PF	9	rw	Prefetch Bypass Control 0 _B Bypass path from prefetch to decode disabled 1 _B Bypass path from prefetch to decode available
BYPF	8	rw	Fetch Bypass Control 0 _B Bypass path from fetch to decode disabled 1 _B Bypass path from fetch to decode available
1	7	r	Reserved Read as 1, should be written 1
STEN	6	rw	Stall Instruction Enable (for debug purposes) 0 _B Stall Instruction disabled 1 _B Stall Instruction enabled (see example below)
LFIC	5	rw	Linear Follower Instruction Cache 0 _B Linear Follower Instruction Cache disabled 1 _B Linear Follower Instruction Cache enabled

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Field	Bits	Type	Description
OVRUN	4	rw	Pipeline Control 0_B Overrun of pipeline bubbles not allowed 1_B Overrun of pipeline bubbles allowed
RETST	3	rw	Enable Return Stack 0_B Return Stack is disabled 1_B Return Stack is enabled
FASTBL	2	rw	Enables the fast injection of block transfers 0_B Direct injection disabled 1_B Direct injection enabled
1	1	r	Reserved Read as 1, should be written 1
SL	0	rw	Enables Short Loop Mode 0_B Short loop mode disabled 1_B Short loop mode enabled

Note: This register must only be modified when explicitly documented - e.g. in an errata sheet.

5.5 Use of General Purpose Registers

The CPU provides three banks of sixteen dedicated registers R0, R1, R2, ... R15, called General Purpose Registers (GPRs), which can be accessed in one CPU cycle. The GPRs are the working registers of the arithmetic and logic units and many also serve as address pointers for indirect addressing modes.

The register banks are accessed via the 5-port register file providing the high access speed required for the CPU's performance. The register file is split into three independent physical register banks. There are **two types of register banks**:

- **Two local register banks** which are a part of the register file
- **One global register bank** which is memory-mapped and cached in the register file

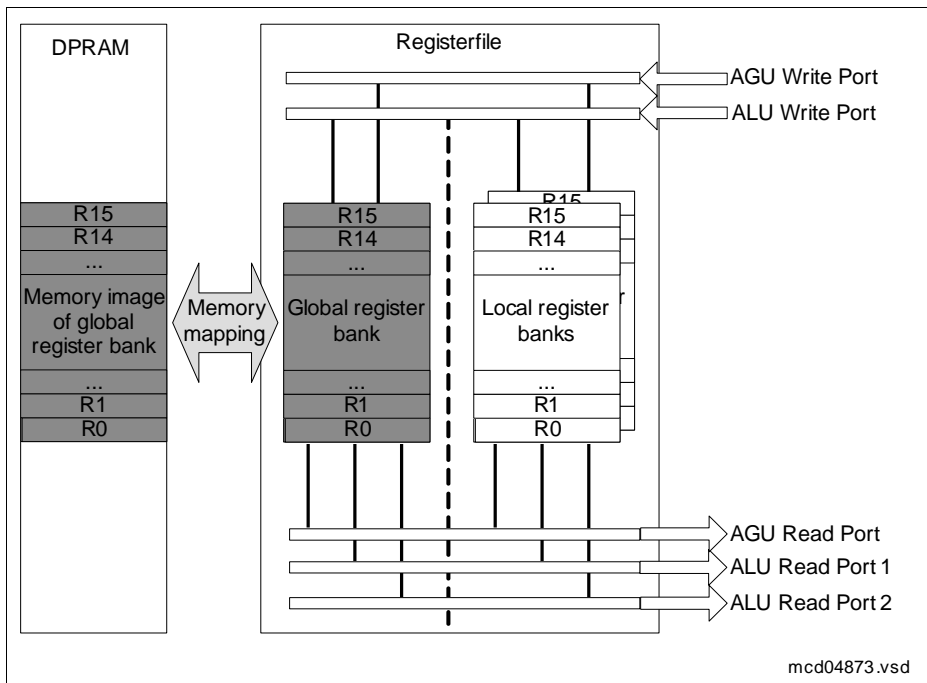


Figure 5-3 Register File

Bitfield **BANK** in register **PSW** selects which of the three physical register banks is activated. The selected bank can be changed explicitly by any instruction which writes to the **PSW**, or implicitly by a **RET1** instruction, an interrupt or hardware trap. In case of an interrupt, the selection of the register bank is configured via registers **BNKSELx** in the Interrupt Controller **ITC**. Hardware traps always use the global register bank.

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The local register banks are built of dedicated physical registers, while the global register bank represents a cache. Multiple global banks can be mapped to the internal DPRAM. Each of these banks uses a block of 16 consecutive words. A Context Pointer (CP) register determines the base address of the current selected bank. To provide the required access speed, the GPRs located in the DPRAM are cached in the 5-port register file (only one memory-mapped GPR bank can be cached at the time). If the global register bank is activated, the cache will be validated before further instructions are executed. After validation, all further accesses to the GPRs are redirected to the global register bank.

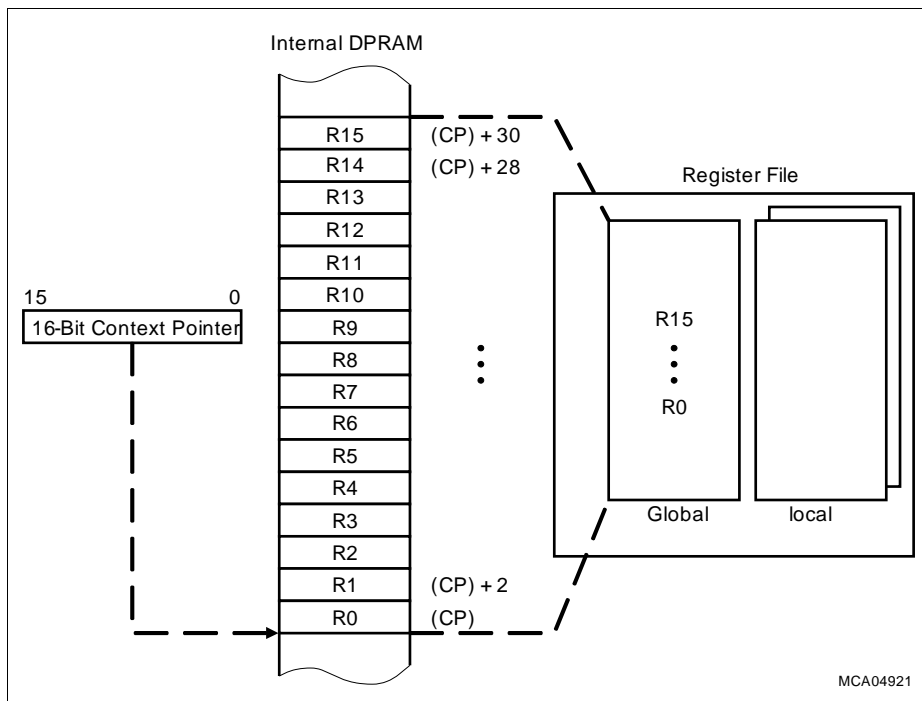


Figure 5-4 Register Bank Selection via Register CP

5.5.1 GPR Addressing Modes

Because the GPRs are the working registers and are accessed frequently, there are three possible ways to access a register bank:

- **Short GPR Address** (mnemonic: Rw or Rb)
- **Short Register Address** (mnemonic: reg or bitoff)
- **Long Memory Address** (mnemonic: mem), for the global bank only

Short GPR Addresses specify the register offset within the current register bank (selected via bitfield BANK). Short 4-bit GPR addresses can access all sixteen registers, short 2-bit addresses (used by some instructions) can access the lower four registers.

Depending on whether a register word (Rw) or byte (Rb) address is specified, the short GPR address is either multiplied by two (Rw) or not (Rb) before it is used to physically access the register bank. Thus, both byte and word GPR accesses are possible in this way.

Note: GPRs used as indirect address pointers are always accessed wordwise.

For the local register banks the resulting offset is used directly, for the global register bank the resulting offset is logically added to the contents of register CP which points to the memory location of the base of the current global register bank (see [Figure 5-5](#)).

Short 8-Bit Register Addresses within a range from $F0_H$ to FF_H interpret the four least significant bits as short 4-bit GPR addresses, while the four most significant bits are ignored. The respective physical GPR address is calculated in the same way as for short 4-bit GPR addresses. For single bit GPR accesses, the GPR's word address is calculated in the same way. The accessed bit position within the word is specified by a separate additional 4-bit value.

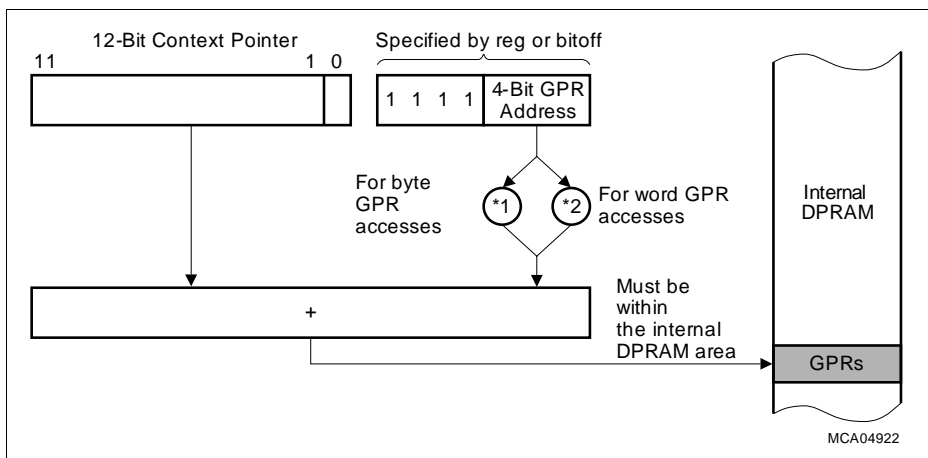


Figure 5-5 Implicit CP Use by Logical Short GPR Addressing Modes

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24-Bit Memory Addresses can be directly used to access GPRs located in the DPRAM (not applicable for local register banks). In case of a memory read access, a hit detection logic checks if the accessed memory location is cached in the global register bank. In case of a cache hit the read is redirected to the global register bank. The data that is read from cache will be used and the read from memory will be discarded. This leads to a delay of one CPU cycle (MOV R4, **mem** [CP ≤ mem ≤ CP + 31]). In case of a memory write access, the hit detection logic determines a cache hit in advance. Nevertheless, the address conversion needs one additional CPU cycle. The value is directly written into the global register bank without further delay (MOV **mem**, R4).

Note: The 24-bit GPR addressing mode requires an extra cycle for the read and write access.

Table 5-14 Addressing Modes to Access GPRs

Word Registers ¹⁾		Byte Registers		Short Address ²⁾		
Name	Mem. Addr. ³⁾	Name	Mem. Addr. ³⁾	8-Bit	4-Bit	2-Bit
R0	(CP) + 0	RL0	(CP) + 0	F0 _H	0 _H	0 _H
R1	(CP) + 2	RH0	(CP) + 1	F1 _H	1 _H	1 _H
R2	(CP) + 4	RL1	(CP) + 2	F2 _H	2 _H	2 _H
R3	(CP) + 6	RH1	(CP) + 3	F3 _H	3 _H	3 _H
R4	(CP) + 8	RL2	(CP) + 4	F4 _H	4 _H	---
R5	(CP) + 10	RH2	(CP) + 5	F5 _H	5 _H	---
R6	(CP) + 12	RL3	(CP) + 6	F6 _H	6 _H	---
R7	(CP) + 14	RH3	(CP) + 7	F7 _H	7 _H	---
R8	(CP) + 16	RL4	(CP) + 8	F8 _H	8 _H	---
R9	(CP) + 18	RH4	(CP) + 9	F9 _H	9 _H	---
R10	(CP) + 20	RL5	(CP) + 10	FA _H	A _H	---
R11	(CP) + 22	RH5	(CP) + 11	FB _H	B _H	---
R12	(CP) + 24	RL6	(CP) + 12	FC _H	C _H	---
R13	(CP) + 26	RH6	(CP) + 13	FD _H	D _H	---
R14	(CP) + 28	RL7	(CP) + 14	FE _H	E _H	---
R15	(CP) + 30	RH7	(CP) + 15	FF _H	F _H	---

1) The first 8 GPRs (R7 ... R0) may also be accessed byte-wise. Writing to a GPR byte does not affect the other byte of the respective GPR.

2) Short addressing modes are usable for all register banks.

3) Long addressing mode only usable for the memory mapped global bank.

5.5.2 Context Switching

When a task scheduler of an operating system activates a new task or an interrupt service routine is called or terminated, the working context (i.e. the registers) of the left task must be saved and the working context of the new task must be restored. The CPU context can be changed in two ways:

- Switching the selected register bank
- Switching the context of the global register bank

Switching the Selected Physical Register Bank

By updating bitfield BANK in register PSW the active register bank is switched immediately. It is possible to switch between the current memory-mapped GPR bank cached in the global register bank (BANK = 00_B), local register bank 1 (BANK = 10_B), and local register bank 2 (BANK = 11_B).

In case of an interrupt service, the bank switch can be automatically executed by updating bitfield BANK from registers BNKSELx in the interrupt controller. By executing a RETI instruction, bitfield BANK will automatically be restored and the context will be switched to the original register bank.

The switch between the three physical register banks of the register file can also be executed by writing to bitfield BANK. Because of pipeline dependencies an explicit change of register PSW must cancel the pipeline.

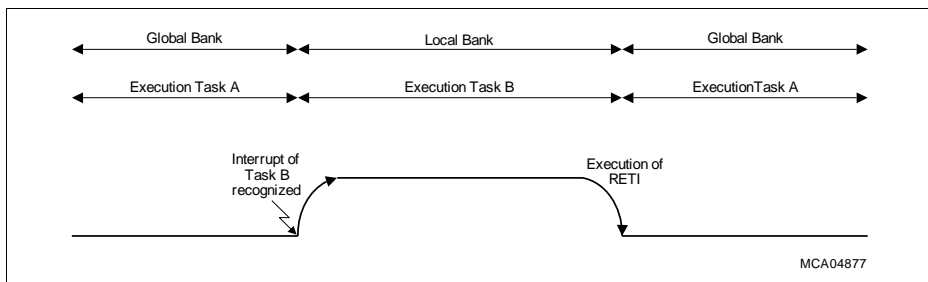


Figure 5-6 Context Switch by Changing the Physical Register Bank

After a switch to a local register bank, the new bank is immediately available. After switching to the global register bank, the cached memory-mapped GPRs must be valid before any further instructions can be executed. If the global register bank is not valid at this time (in case if the context switch process has been interrupted), the cache validation process is started automatically.

Switching the Context of the Global Register Bank

The contents of the global register bank are switched by changing the base address of the memory-mapped GPR bank. The base address is given by the contents of the Context Pointer (CP).

After the CP has been updated, a state machine starts to store the old contents of the global register bank and to load the new one. The store and load algorithm is executed in nineteen CPU cycles: the execution of the cache validation process takes sixteen cycles plus three cycles to stall an instruction execution to avoid pipeline conflicts upon the completion of the validation process. The context switch process has two phases:

- **Store phase:** The contents of the global register bank¹⁾ is stored back into the DPRAM by executing eight injected STORE instructions. After the last STORE instruction the contents of the global register bank are invalidated.
- **Load phase:** The global register bank is loaded with the new context by executing eight injected LOAD instructions. After the last LOAD instruction the contents of the global register bank are validated.

The code execution is stopped until the global register bank is valid again. A hardware interrupt can occur during the validation process. The way the validation process is completed depends on the type of register bank selected for this interrupt:

- If the interrupt also uses a global register bank the validation process is finished before executing the service routine (see [Figure 5-7](#)).
- If the interrupt uses a local register bank the validation process is interrupted and the service routine is executed immediately (see [Figure 5-8](#)). After switching back to the global register bank, the validation process is finished:
 - If the interrupt occurred during the store phase, the entire validation process is restarted from the very beginning.
 - If the interrupt occurred during the load phase, only the load phase is repeated.

If a local-bank interrupt routine (Task B in [Figure 5-9](#)) is again interrupted by a global-bank interrupt (Task C), the suspended validation process must be finished before code of Task C can be executed. This means that the validation process of Task A does not affect the interrupt latency of Task B but the latency of Task C.

Note: If Task C would immediately interrupt Task A, the register bank validation process of Task A would be finished first. The worst case interrupt latency is identical in both cases (see [Figure 5-7](#) and [Figure 5-9](#)).

¹⁾ During the store phase of the context switch the complete register bank is written to the DPRAM even if the application only uses a part of this register bank. A register bank must not be located above FDE0_H, otherwise the store phase will overwrite SFRs (beginning at FE00_H).

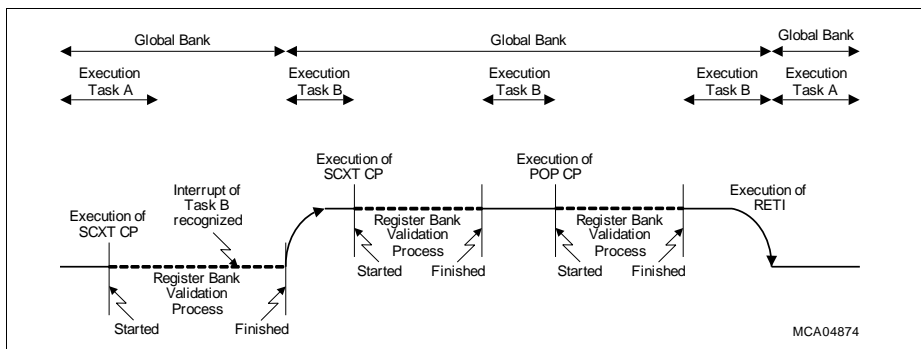


Figure 5-7 Validation Process Interrupted by Global-Bank Interrupt

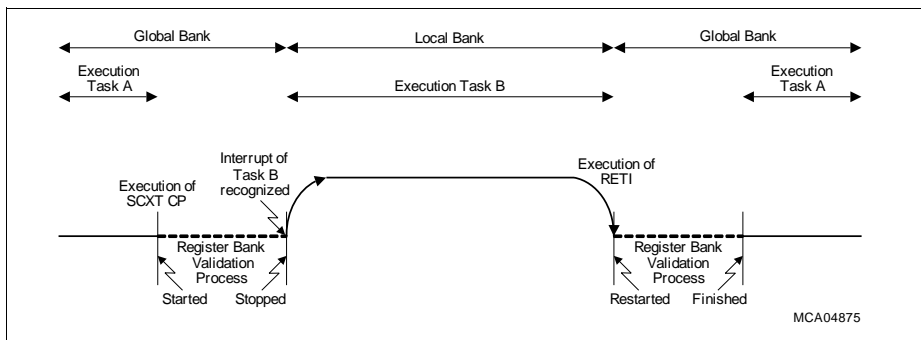


Figure 5-8 Validation Process Interrupted by Local-Bank Interrupt

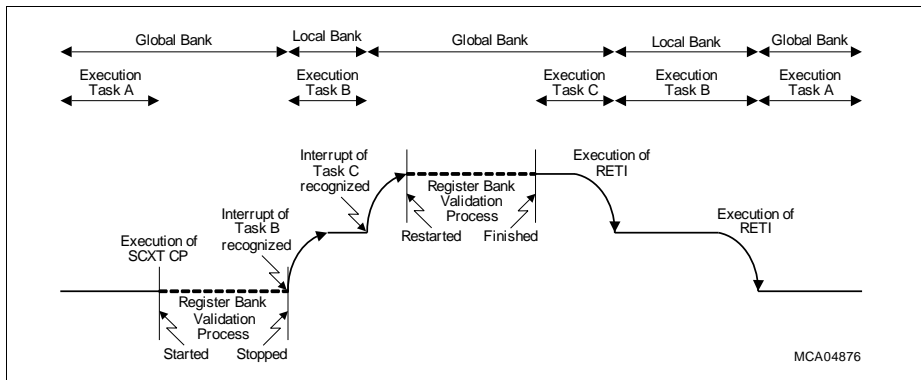


Figure 5-9 Validation Process Interrupted by Local- and Global-Bank Intr.

5.5.2.1 The Context Pointer (CP)

This non-bit-addressable register selects the current global register bank context. It can be updated via any instruction capable of modifying SFRs.

CP

Context Pointer				SFR (FE10 _H /08 _H)								Reset Value: FC00 _H			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	CP											
r	r	r	r	rw								r			

Field	Bits	Type	Description
1	15, 14, 13, 12	r	Fixed part of CP Read as 1
CP	[11:1]	rw	Modifiable part of CP Specifies bits [11:1] of the 16-bit base address of the current global (memory-mapped) register bank. When writing a value to register CP with bits CP[11:9] = 000 _B , bits CP[11:10] are set to 11 _B by hardware.
0	0	r	Fixed part of CP Read as 0

Note: It is the user's responsibility to ensure that the physical GPR address specified via CP register plus short GPR address is always an internal DPRAM location. If this condition is not met, unexpected results may occur. Do not set CP below the internal DPRAM start address. Do not set CP above FDE0_H, otherwise the store phase will overwrite SFRs (beginning at FE00_H).

The XE166U switches the complete memory-mapped GPR bank with a single instruction. After switching, the service routine executes within its own separate context.

The instruction "SCXT CP, #New_Bank" pushes the value of the current context pointer (CP) into the system stack and loads CP with the immediate value "New_Bank", which selects a new register bank. The service routine may now use its "own registers". This memory register bank is preserved when the service routine terminates, i.e. its contents are available on the next call.

Before returning from the service routine (RETI), the previous CP is simply popped from the system stack which returns the registers to the original bank.

Note: Due to the internal instruction pipeline, a write operation to the CP register stalls the instruction flow until the register file context switch is really executed. The

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instruction immediately following the instruction that updates CP register can use the new value of the changed CP.

5.6 Code Addressing

The XE166U provides a total addressable memory space of 16 Mbytes. This address space is arranged as 256 segments of 64 Kbytes each. A dedicated 24-bit code address pointer is used to access the memories for instruction fetches. This pointer has two parts: an 8-bit code segment pointer CSP and a 16-bit offset pointer called Instruction Pointer (IP). The concatenation of the CSP and IP results directly in a correct 24-bit physical memory address.

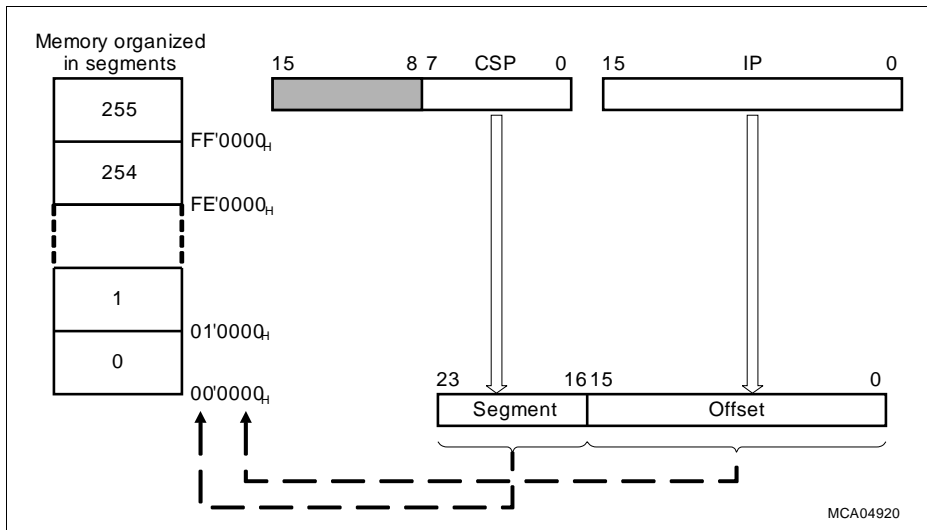


Figure 5-10 Addressing via the Code Segment and Instruction Pointer

The Code Segment Pointer CSP selects the code segment being used at run-time to access instructions. The lower 8 bits of register CSP select one of up to 256 segments of 64 Kbytes each, while the higher 8 bits are reserved for future use. The hardware reset value is 0000_H, but immediately after reset it is loaded with the contents of the VECSEG register due to an injected MOVCSIP instruction.

Note: Register CSP can only be read but cannot be written by data operations.

In segmented memory mode (default after reset), register CSP is modified either directly by JMPS and CALLS instructions, or indirectly via the stack by RETS and RETI instructions.

In non-segmented memory mode (selected by setting bit SGTDIS in register CPUCON1), CSP is fixed to the segment of the instruction that disabled segmentation. Modification by inter-segment CALLs or RETurns is no longer possible.

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For processing an accepted interrupt or a TRAP, register CSP is automatically loaded with the segment of the vector table (defined in register VECSEG).

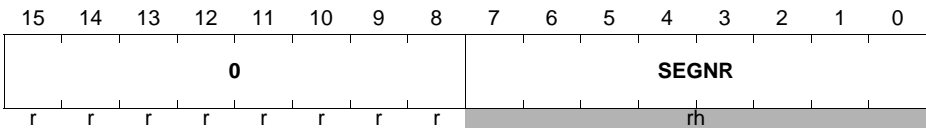
Note: For the correct execution of interrupt tasks in non-segmented memory mode, the contents of VECSEG must select the same segment as the current value of CSP, i.e. the vector table must be located in the segment pointed to by the CSP.

CSP

Code Segment Pointer

SFR (FE08_H/04_H)

Reset Value: 0000_H



Field	Bits	Type	Description
0	[15:8]	r	Reserved Read as 0, should be written 0
SEGNR	[7:0]	rh	Segment Number Specifies the code segment from which the current instruction is to be fetched.

Note: After a reset, register CSP is automatically loaded from register VECSEG.

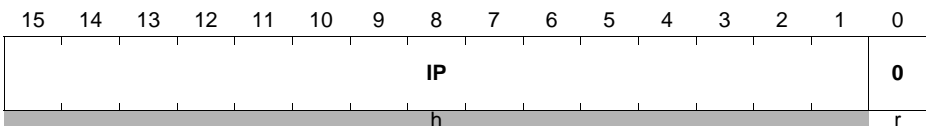
The Instruction Pointer IP determines the 16-bit intra-segment address of the currently fetched instruction within the code segment selected by the CSP register. Register IP is not mapped into the XE166U's address space; thus, it is not directly accessible by the programmer. However, the IP can be modified indirectly via the stack by means of a return instruction. IP is implicitly updated by the CPU for branch instructions and after instruction fetch operations.

IP

Instruction Pointer

(not addressable)

Reset Value: 0000_H



Field	Bits	Type	Description
IP	[15:1]	h	Instruction Pointer Specifies bits [15:1] of the intra segment offset from which the current instruction is to be fetched. IP refers to the current segment <SEGNR>.
0	0	r	Fixed part of IP Read as 0

5.7 Data Addressing

The Address Data Unit (ADU) contains two independent arithmetic units to generate, calculate, and update addresses for data accesses, the Standard Address Generation Unit (SAGU) and the DSP Address Generation Unit (DAGU). The ADU performs the following major tasks:

- Standard Address Generation (SAGU)
- DSP Address Generation (DAGU)
- Data Paging (SAGU)
- Stack Handling (SAGU)

The SAGU supports linear arithmetic for the indirect addressing modes and also generates the address in case of all other short and long addressing modes.

The DAGU contains an additional set of address pointers and offset registers which are used in conjunction with the CoXXX instructions only.

The CPU provides a lot of powerful addressing modes (short, long, indirect) for word, byte, and bit data accesses. The different addressing modes use different formats and have different scopes.

5.7.1 Short Addressing Modes

Short addressing modes allow access to the GPR, SFR or bit-addressable memory space. All of these addressing modes use an offset (8/4/2 bits) together with an implicit base address to specify a 24-bit physical address:

Table 5-15 Short Addressing Modes

Mnemonic	Base Address ¹⁾	Offset	Short Address Range	Scope of Access
Rw	(CP)	$2 \times \text{Rw}$	0 ... 15	GPRs (word)
Rb	(CP)	$1 \times \text{Rb}$	0 ... 15	GPRs (byte)
reg	00'FE00 _H 00'F000 _H (CP) (CP)	$2 \times \text{reg}$ $2 \times \text{reg}$ $2 \times (\text{reg} \wedge 0\text{F}_{\text{H}})$ $1 \times (\text{reg} \wedge 0\text{F}_{\text{H}})$	00 _H ... EF _H 00 _H ... EF _H F0 _H ... FF _H F0 _H ... FF _H	SFRs (word, low byte) ESFRs (word, low byte) GPRs (word) GPRs (bytes)
bitoff	00'FD00 _H 00'FF00 _H 00'F100 _H (CP)	$2 \times \text{bitoff}$ $2 \times (\text{bitoff} \wedge 7\text{F}_{\text{H}})$ $2 \times (\text{bitoff} \wedge 7\text{F}_{\text{H}})$ $2 \times (\text{bitoff} \wedge 0\text{F}_{\text{H}})$	00 _H ... 7F _H 80 _H ... EF _H 80 _H ... EF _H F0 _H ... FF _H	RAM Bit word offset SFR Bit word offset ESFR Bit word offset GPR Bit word offset
bitaddr	Bit word see bitoff	Immediate bit position	0 ... 15	Any single bit

1) Accesses to general purpose registers (GPRs) may also access local register banks, instead of using CP.

Physical Address = Base Address + $\Delta \times$ Short Address

Note: Δ is 1 for byte GPRs, Δ is 2 for word GPRs.

Rw, Rb: Specifies direct access to any GPR in the currently active context (global register bank or local register bank). Both 'Rw' and 'Rb' require four bits in the instruction format. The base address of the global register bank is determined by the contents of register CP. 'Rw' specifies a 4-bit word GPR address, 'Rb' specifies a 4-bit byte GPR address within a local register bank or relative to (CP).

reg: Specifies direct access to any (E)SFR or GPR in the currently active context (global or local register bank). The 'reg' value requires eight bits in the instruction format. Short 'reg' addresses in the range from 00_H to EF_H always specify (E)SFRs. In that case, the factor ' Δ ' equates 2 and the base address is 00'FE00_H for the standard SFR area or 00'F000_H for the extended ESFR area. The 'reg' accesses to the ESFR area require a preceding EXT*R instruction to switch the base address. Depending on the opcode, either the total word (for word operations) or the low byte (for byte operations) of an SFR can be addressed via 'reg'. Note that the high byte of an SFR cannot be accessed via the 'reg' addressing mode. Short 'reg' addresses in the range from F0_H to FF_H always specify GPRs. In that case, only the lower four bits of 'reg' are significant for physical address generation and, therefore, it is identical to the address generation described for the 'Rb' and 'Rw' addressing modes.

bitoff: Specifies direct access to any word in the bit addressable memory space. The 'bitoff' value requires eight bits in the instruction format. The specified 'bitoff' range selects different base addresses to generate physical addresses (see [Table 5-15](#)). The 'bitoff' accesses to the ESFR area require a preceding EXT*R instruction to switch the base address.

bitaddr: Any bit address is specified by a word address within the bit addressable memory space (see 'bitoff') and a bit position ('bitpos') within that word. Therefore, 'bitaddr' requires twelve bits in the instruction format.

5.7.2 Long Addressing Modes

Long addressing modes specify 24-bit addresses and, therefore, can access any word or byte data within the entire address space. Long addresses can be specified in different ways to generate the full 24-bit address:

- **Use one of the four Data Page Pointers (DPP registers):** The used 16-bit pointer selects a DPP with bits 15 ... 14, bits 13 ... 0 specify the 14-bit data page offset (see [Figure 5-11](#)).
- **Select the used data page directly:** The data page is selected by a preceding EXTP(R) instruction, bits 13 ... 0 of the used 16-bit pointer specify the 14-bit data page offset.
- **Select the used segment directly:** The segment is selected by a preceding EXT(S) instruction, the used 16-bit pointer specifies the 16-bit segment offset.

Note: Word accesses on odd byte addresses are not executed. A hardware trap will be triggered.

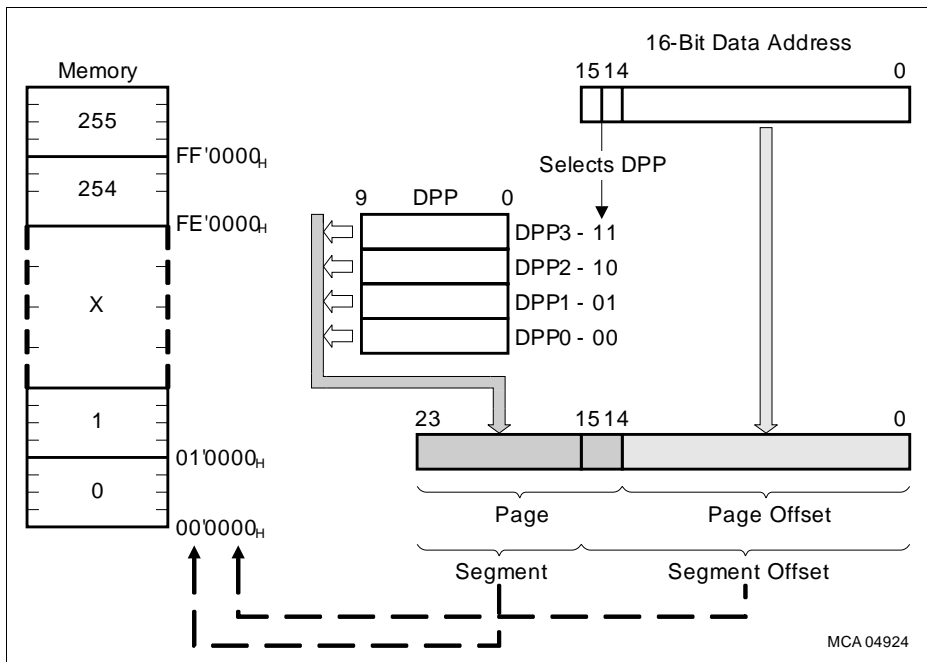


Figure 5-11 Data Page Pointer Addressing

5.7.2.1 Data Page Pointers DPP0, DPP1, DPP2, DPP3

These four non-bit-addressable registers select up to four different data pages to be active simultaneously at run-time. The lower 10 bits of each DPP register select one of the 1024 possible 16-Kbyte data pages; the upper 6 bits are reserved for future use.

DPP0

Data Page Pointer 0 **SFR (FE00_H/00_H)** **Reset Value: 0000_H**

DPP1

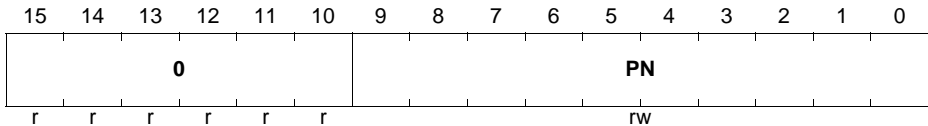
Data Page Pointer 1 **SFR (FE02_H/01_H)** **Reset Value: 0001_H**

DPP2

Data Page Pointer 2 **SFR (FE04_H/02_H)** **Reset Value: 0002_H**

DPP3

Data Page Pointer 3 **SFR (FE06_H/03_H)** **Reset Value: 0003_H**



Field	Bits	Type	Description
0	[15:8]	r	Reserved Read as 0, should be written 0
PN	[9:0]	rw	Data Page Number of DPPx Specifies the data page selected via DPPx.

The DPP registers allow access to the entire memory space in pages of 16 Kbytes each. The DPP registers are implicitly used whenever data accesses to any memory location are made via indirect or direct long 16-bit addressing modes (except for override accesses via EXTended instructions and PEC data transfers). After reset, the Data Page Pointers are initialized in such a way that all indirect or direct long 16-bit addresses result in identical 18-bit addresses. This allows access to data pages 3 ... 0 within segment 0 as shown in [Figure 5-11](#). If the user does not want to use data paging, no further action is required.

Data paging is performed by concatenating the lower 14 bits of an indirect or direct long 16-bit address with the contents of the DPP register selected by the upper two bits of the 16-bit address. The contents of the selected DPP register specify one of the 1024 possible data pages. This data page base address together with the 14-bit page offset forms the physical 24-bit address (even if segmentation is disabled).

A DPP register can be updated via any instruction capable of modifying an SFR.

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Note: Due to the internal instruction pipeline, a write operation to the DPPx registers could stall the instruction flow until the DPP is actually updated. The instruction that immediately follows the instruction which updates the DPP register can use the new value of the changed DPPx.

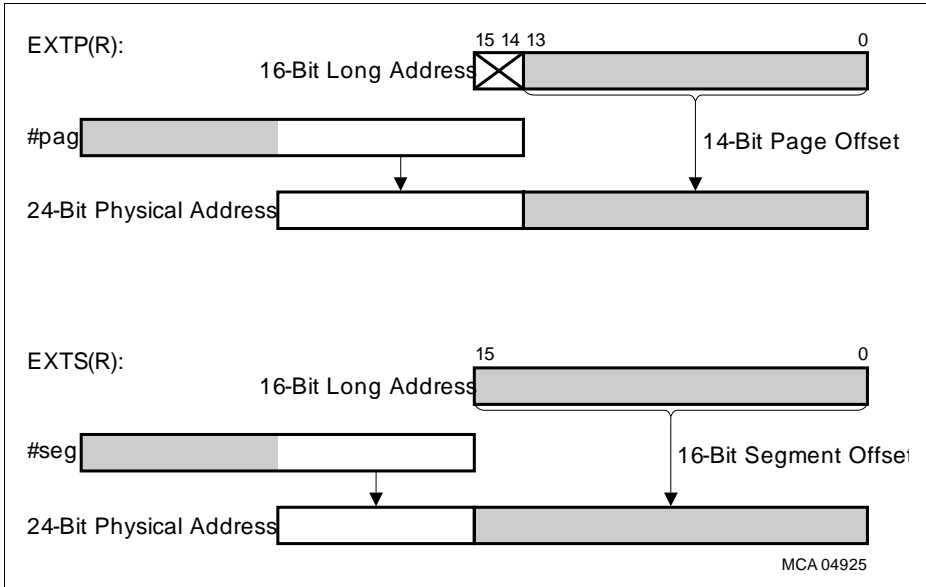


Figure 5-12 Overriding the DPP Mechanism

Note: The overriding page or segment may be specified as a constant (#pag, #seg) or via a word GPR (Rw).

Table 5-16 Long Addressing Modes

Mnemonic	Base Address ¹⁾	Offset	Scope of Access
mem	(DPPx)	mem \wedge 3FFF _H	Any Word or Byte
mem	pag	mem \wedge 3FFF _H	Any Word or Byte
mem	seg	mem	Any Word or Byte

1) Represents either a 10-bit data page number to be concatenated with a 14-bit offset, or an 8-bit segment number to be concatenated with a 16-bit offset.

5.7.3 Indirect Addressing Modes

Indirect addressing modes can be considered as a combination of short and long addressing modes. This means that the “long” 16-bit pointer is provided indirectly by the contents of a word GPR which itself is specified directly by a short 4-bit address ($'Rw' = 0 \dots 15$).

There are indirect addressing modes, which add a constant value to the GPR contents before the long 16-bit address is calculated. Other indirect addressing modes can decrement or increment the indirect address pointers (GPR contents) by 2 or 1 (referring to words or bytes) or by the contents of the offset registers QR0 or QR1.

Table 5-17 Generating Physical Addresses from Indirect Pointers

Step	Executed Action	Calculation	Notes
1	Calculate the address of the indirect pointer (word GPR) from its short address	GPR Address = $2 \times \text{Short Addr.} [+ (CP)]$	see Table 5-15
2	Pre-decrement indirect pointer ($'Rw'$) depending on datatype ($\Delta = 1$ or 2 for byte or word operations)	(GPR Address) = (GPR Address) - Δ	Optional step, executed only if required by addressing mode
3	Adjust the pointer by a constant value ($'Rw + \text{const16}'$)	Pointer = (GPR Address) + Constant	Optional step, executed only if required by addressing mode
4	Calculate the physical 24-bit address using the resulting pointer	Physical Addr. = Page/Segment + Pointer offset	Uses DPPs or page/segment override mechanisms, see Table 5-16
5	Post-in/decrement indirect pointer ($'Rw \pm'$) depending on datatype ($\Delta = 1$ or 2 for byte or word operations), or depending on offset registers ($\Delta = \text{QRx}$) ¹⁾	(GPR Address) = (GPR Address) $\pm \Delta$	Optional step, executed only if required by addressing mode

1) Post-decrement and QRx-based modification is provided only for CoXXX instructions.

Note: Some instructions only use the lowest four word GPRs (R3 ... R0) as indirect address pointers, which are specified via short 2-bit addresses in that case.

The following indirect addressing modes are provided:

Table 5-18 Indirect Addressing Modes

Mnemonic	Particularities
[Rw]	Most instructions accept any GPR (R15 ... R0) as indirect address pointer. Some instructions accept only the lower four GPRs (R3 ... R0).
[Rw+]	The specified indirect address pointer is automatically post-incremented by 2 or 1 (for word or byte data operations) after the access.
[-Rw]	The specified indirect address pointer is automatically pre-decremented by 2 or 1 (for word or byte data operations) before the access.
[Rw + #data16]	The specified 16-bit constant is added to the indirect address pointer, before the long address is calculated.
[Rw-]	The specified indirect address pointer is automatically post-decremented by 2 (word data operations) after the access.
[Rw + QRx]	The specified indirect address pointer is automatically post-incremented by QRx (word data operations) after the access.
[Rw - QRx]	The specified indirect address pointer is automatically post-decremented by QRX (word data operations) after the access.

5.7.3.1 Offset Registers QR0 and QR1

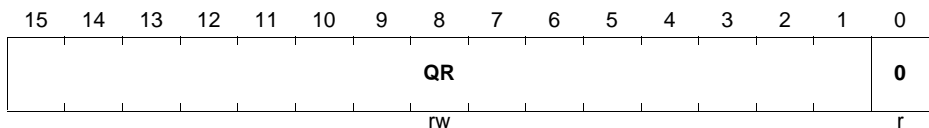
The non-bit-addressable offset registers QR0 and QR1 are used with CoXXX instructions. For possible instruction flow stalls refer to [Section 5.3.2.4](#).

QR0

Offset Register **ESFR (F004_H/02_H)** **Reset Value: 0000_H**

QR1

Offset Register **ESFR (F006_H/03_H)** **Reset Value: 0000_H**



Field	Bits	Type	Description
QR	[15:1]	rw	Modifiable part of QRx Specifies the 16-bit offset address for indirect addressing modes (LSB always zero).
0	0	r	Fixed part of QRx Read as 0

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There are indirect addressing modes which allow parallel data move operations before the long 16-bit address is calculated (see [Figure 5-14](#) for an example). Other indirect addressing modes allow decrementing or incrementing the indirect address pointers (IDXx contents) by 2 or by the contents of the offset registers QX0 and QX1 (used in conjunction with the IDX pointers).

QX0

Offset Register

ESFR (F000_H/00_H)

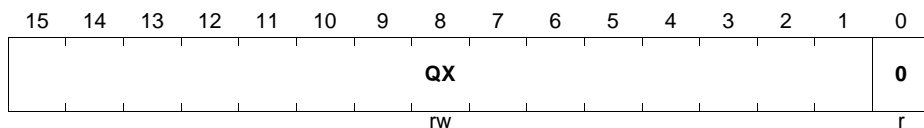
Reset Value: 0000_H

QX1

Offset Register

ESFR (F002_H/01_H)

Reset Value: 0000_H



Field	Bits	Type	Description
QX	[15:1]	rw	Modifiable part of QXx Specifies the 16-bit word offset for indirect addressing modes
0	0	r	Fixed part of QXx Read as 0

Note: During the initialization of the QX registers, instruction flow stalls are possible. For the proper operation, refer to [Section 5.3.2.4](#).

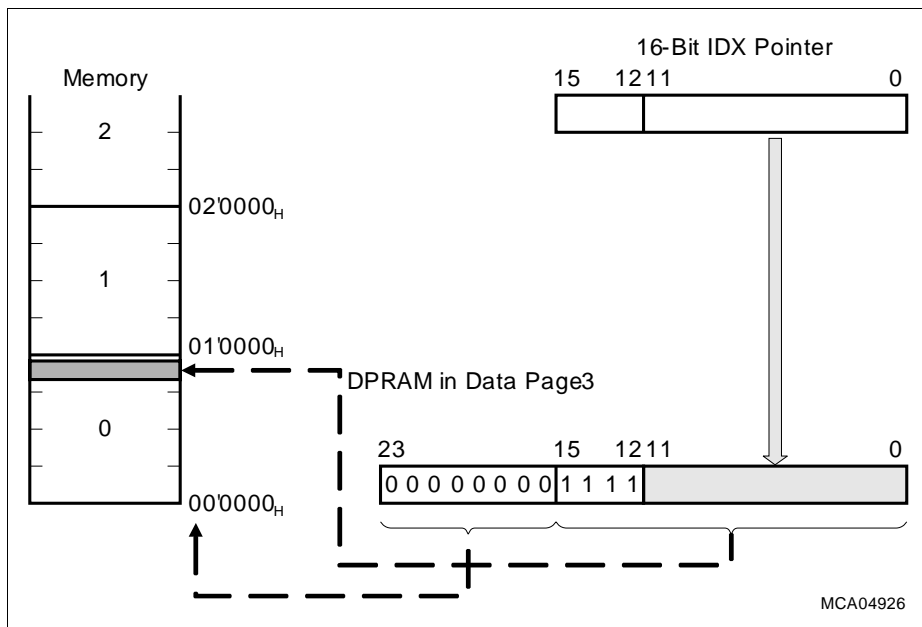


Figure 5-13 Arithmetic MAC Operations and Addressing via the IDX Pointers

Table 5-19 Generating Physical Addresses from Indirect Pointers (IDXx)

Step	Executed Action	Calculation	Notes
1	Determine the used IDXx pointer	---	—
2	Calculate an intermediate long address for the parallel data move operation and in/decrement indirect pointer ('IDXx±') by 2 ($\Delta = 2$), or depending on offset registers ($\Delta = QXx$)	Interm. Addr. = (IDXx Address) $\pm \Delta$	Optional step, executed only if required by instruction CoXXXM and addressing mode
3	Calculate long 16-bit address	Long Address = (IDXx Pointer)	—

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Table 5-19 Generating Physical Addresses from Indirect Pointers (IDXx) (cont'd)

Step	Executed Action	Calculation	Notes
4	Calculate the physical 24-bit address using the resulting pointer	Physical Addr. = Page/Segment + Pointer offset	Uses DPPs or page/segment override mechanisms, see Table 5-16 and Figure 5-13
5	Post-in/decrement indirect pointer ('IDXx±') by 2 ($\Delta = 2$), or depending on offset registers ($\Delta = QXx$)	(IDXx Pointer) = (IDXx Pointer) $\pm \Delta$	Optional step, executed only if required by addressing mode

The following indirect addressing modes are provided:

Table 5-20 DSP Addressing Modes

Mnemonic	Particularities
[IDXx]	Most CoXXX instructions accept IDXx (IDX0, IDX1) as an indirect address pointer.
[IDXx+]	The specified indirect address pointer is automatically post-incremented by 2 after the access.
with parallel data move	In case of a CoXXXM instruction, the address stored in the specified indirect address pointer is automatically pre-decremented by 2 for the parallel move operation. The pointer itself is not pre-decremented. Then, the specified indirect address pointer is automatically post-incremented by 2 after the access.
[IDXx-]	The specified indirect address pointer is automatically post-decremented by 2 after the access.
with parallel data move	In case of a CoXXXM instruction, the address stored in the specified indirect address pointer is automatically pre-incremented by 2 for the parallel move operation. The pointer itself is not pre-incremented. Then, the specified indirect address pointer is automatically post-decremented by 2 after the access.
[IDXx + QXx]	The specified indirect address pointer is automatically post-incremented by QXx after the access.
with parallel data move	In case of a CoXXXM instruction, the address stored in the specified indirect address pointer is automatically pre-decremented by QXx for the parallel move operation. The pointer itself is not pre-decremented. Then, the specified indirect address pointer is automatically post-incremented by QXx after the access.

Table 5-20 DSP Addressing Modes (cont'd)

Mnemonic	Particularities
[IDXx - QXx]	The specified indirect address pointer is automatically post-decremented by QXx after the access.
with parallel data move	In case of a CoXXXM instruction, the address stored in the specified indirect address pointer is automatically pre-incremented by QXx for the parallel move operation. The pointer itself is not pre-incremented. Then, the specified indirect address pointer is automatically post-decremented by QXx after the access.

Note: An example for parallel data move operations can be found in [Figure 5-14](#).

The CoREG Addressing Mode

The CoSTORE instruction utilizes the special CoREG addressing mode for immediate storage of the MAC-Unit register after a MAC operation. The address of the MAC-Unit register is coded in the CoSTORE instruction format as described in [Table 5-21](#):

Table 5-21 Coding of the CoREG Addressing Mode

Mnemonic	Register	Coding of www:w bits [31:27]
MSW	MAC-Unit Status Word	00000 _B
MAH	MAC-Unit Accumulator High Word	00001 _B
MAS	Limited MAC-Unit Accumulator High Word	00010 _B
MAL	MAC-Unit Accumulator Low Word	00100 _B
MCW	MAC-Unit Control Word	00101 _B
MRW	MAC-Unit Repeat Word	00110 _B

The example in [Figure 5-14](#) shows the complex operation of CoXXXM instructions with a parallel move operation based on the descriptions about addressing modes given in [Section 5.7.3 \(Indirect Addressing Modes\)](#) and [Section 5.7.4 \(DSP Addressing Modes\)](#).

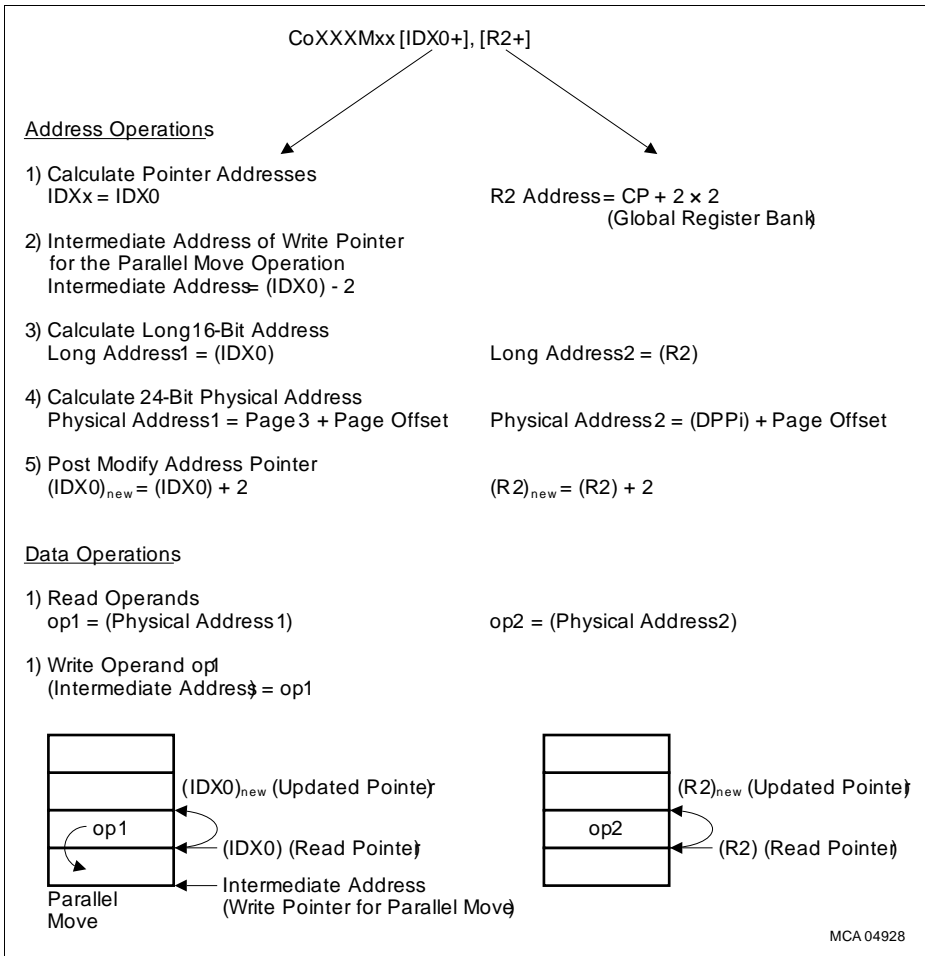


Figure 5-14 Arithmetic MAC Operations with Parallel Move

5.7.5 The System Stack

The XE166U supports a system stack of up to 64 Kbytes. The stack can be located in one of the on-chip memories. The 16-bit Stack Pointer register (SP) addresses the stack within a 64-Kbyte segment selected by the Stack Pointer Segment register (SPSG). A virtual stack (usually bigger than 64 Kbytes) can be implemented by software. This mechanism is supported by the Stack Overflow register STKOV and the Stack Underflow register STKUN (see descriptions below).

5.7.5.1 The Stack Pointer Registers SP and SPSEG

Register SPSEG (not bit addressable) selects the segment being used at run-time to access the system stack. The lower eight bits of register SPSEG select one of up to 256 segments of 64 Kbytes each, while the higher 8 bits are reserved for future use.

The Stack Pointer SP (not bit addressable) points to the top of the system stack (TOS). SP is pre-decremented whenever data is pushed onto the stack, and it is post-incremented whenever data is popped from the stack. Therefore, the system stack grows from higher towards lower memory locations.

System stack addresses are generated by directly extending the 16-bit contents of register SP by the contents of register SPSEG, as shown in [Figure 5-15](#).

The system stack cannot cross a 64-Kbyte segment boundary.

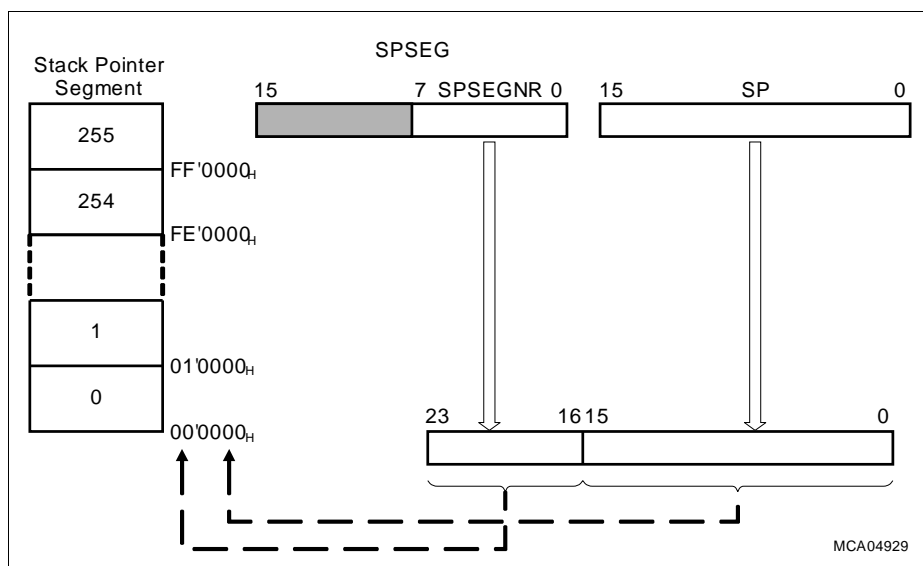


Figure 5-15 Addressing via the Stack Pointer

SP

Stack Pointer

SFR (FE12_H/09_H)

Reset Value: FC00_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SP															0
rw															r

Field	Bits	Type	Description
SP	[15:1]	rw	Modifiable part of SP Specifies bits [15:1] of the 16-bit system stack pointer intra segment address
0	0	r	Fixed part of SP Read as 0

SPSEG

Stack Pointer Segment

SFR (FF0C_H/86_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0								SPSEGNR							
r	r	r	r	r	r	r	r	rw							

Field	Bits	Type	Description
0	[15:8]	r	Reserved Read as 0, should be written 0
SPSEGNR	[7:0]	rw	Stack Pointer Segment Number Specifies the segment where the stack is located.

Note: SPSEG and SP can be updated via any instruction capable of modifying a 16-bit SFR. Due to the internal instruction pipeline, a write operation to SPSEG or SP stalls the instruction flow until the register is really updated. The instruction immediately following the instruction updating SPSEG or SP can use the new value.

5.7.5.2 The Stack Overflow/Underflow Pointers STKOV/STKUN

These limit registers (not bit-addressable) supervise the stack pointer. A trap is generated when the stack pointer reaches its upper or lower limit. The Stack Pointer Segment Register SPSG is not taken into account for the stack pointer comparison. The system stack cannot cross a 64-Kbyte segment.

STKOV is compared with SP before each implicit write operation which decrements the contents of SP (instructions CALLA, CALLI, CALLR, CALLS, PCALL, TRAP, SCXT, or PUSH). If the contents of SP are equal to the contents of STKOV a stack overflow trap is triggered.

STKUN is compared with SP before each implicit read operation which increments the contents of SP (instructions RET, RETS, RETP, RETI, or POP). If the contents of SP are equal to the contents of STKUN a stack underflow trap is triggered.

The Stack Overflow/Underflow Traps may be used in two different ways:

- **Fatal error indication** treats the stack overflow as a system error and executes the associated trap service routine.
In case of a stack overflow trap, data in the bottom of the stack may have been overwritten by the status information stacked upon servicing the trap itself.
- **Virtual stack control** allows the system stack to be used as a 'Stack Cache' for a bigger (external) user stack: flush cache in case of an overflow, refill cache in case of an underflow.

Scope of Stack Limit Control

The stack limit control implemented by the register pair STKOV and STKUN detects cases in which the Stack Pointer (SP) crosses the defined stack area as a result of an implicit change.

If the stack pointer was explicitly changed as a result of move or arithmetic instruction, SP is not compared to the contents of STKOV and STKUN. In this case, a stack violation will not be detected if the modified stack pointer is on or outside the defined limits, i.e. below (STKOV) or above (STKUN). Stack overflow/underflow is detected only in case of implicit SP modification.

SP may be operated outside the permitted SP range without triggering a trap. However, if SP reaches the limit of the permitted SP range from outside the range as a result of an implicit change (PUSH or POP, for example), the respective trap will be triggered.

Note: STKOV and STKUN can be updated via any instruction capable of modifying an SFR. If a stack overflow or underflow event occurs in an ATOMIC/EXT sequence, the stack operations that are part of the sequence are completed. The trap is issued after the completion of the entire ATOMIC/EXT sequence.

STKOV

Stack Overflow Pointer

SFR (FE14_H/0A_H)

Reset Value: FA00_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STKOV															0
rw															r

Field	Bits	Type	Description
STKOV	[15:1]	rw	Modifiable part of STKOV Specifies the segment offset address of the lower limit of the system stack.
0	0	r	Fixed part of STKOV Read as 0

STKUN

Stack Underflow Pointer

SFR (FE16_H/0B_H)

Reset Value: FC00_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STKUN															0
rw															r

Field	Bits	Type	Description
STKUN	[15:1]	rw	Modifiable part of STKUN Specifies the segment offset address of the upper limit of the system stack.
0	0	r	Fixed part of STKUN Read as 0

5.8 Standard Data Processing

All standard arithmetic, shift-, and logical operations are performed in the 16-bit ALU. In addition to the standard functions, the ALU of the XE166U includes a bit-manipulation unit and a multiply and divide unit. Most internal execution blocks have been optimized to perform operations on either 8-bit or 16-bit numbers. After the pipeline has been filled, most instructions are completed in one CPU cycle. The status flags are automatically updated in register PSW after each ALU operation and reflect the current state of the microcontroller. These flags allow branching upon specific conditions. Support of both signed and unsigned arithmetic is provided by the user selectable branch test. The status flags are also preserved automatically by the CPU upon entry into an interrupt or trap routine. Another group of bits represents the current CPU interrupt status. Two separate bits (USR0 and USR1) are provided as general purpose flags.

PSW

Processor Status Word						SFR (FF10 _H /88 _H)						Reset Value: 0000 _H				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
ILVL				IEN	HLD EN_ PL1	BANK		USR 1	USR 0	PL0	E	Z	V	C	N	
rwh				rw	rwh	rwh		rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	

Field	Bits	Type	Description
ILVL	[15:12]	rwh	CPU Priority Level 0 _H Lowest Priority ... F _H Highest Priority
IEN	11	rw	Global Interrupt/PEC Enable Bit 0 _B Interrupt/PEC requests are disabled 1 _B Interrupt/PEC requests are enabled
HLDEN_PL1	10	rwh	Hold Enable/Protection Level selection 1 0 _B external bus arbitration disabled or protection level 0/1 (refer to Table 5-23) 1 _B external bus arbitration enabled or protection level 2/3 (refer to Table 5-23). Enabling bus arbitration is not supported for this device. Setting the HLDEN bit may yield unexpected results.

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Field	Bits	Type	Description
BANK	[9:8]	rwh	Reserved for Register File Bank Selection 00 _B Global register bank 01 _B Reserved 10 _B Local register bank 1 11 _B Local register bank 2
USR1	7	rwh	General Purpose Flag Can be used by application software. Also set when using repeated MAC instructions (Section 5.9.11)
USR0	6	rwh	General Purpose Flag Can be used by application software. Also set when using repeated MAC instructions (Section 5.9.11)
PL0	5	rwh	Protection Level selection 0 0 _B Protection level 0/2 (refer to Table 5-23) 1 _B Protection level 1/3 (refer to Table 5-23)
E	4	rwh	End of Table Flag 0 _B Source operand is neither 8000 _H nor 80 _H 1 _B Source operand is 8000 _H or 80 _H
Z	3	rwh	Zero Flag 0 _B ALU result is not zero 1 _B ALU result is zero
V	2	rwh	Overflow Flag 0 _B No Overflow produced 1 _B Overflow produced
C	1	rwh	Carry Flag 0 _B No carry/borrow bit produced 1 _B Carry/borrow bit produced
N	0	rwh	Negative Result 0 _B ALU result is not negative 1 _B ALU result is negative

ALU/MAC Status (N, C, V, Z, E)

The condition flags (N, C, V, Z, E) within the PSW indicate the ALU status after the most recently performed ALU operation. They are set by most of the instructions according to specific rules which depend on the ALU or data movement operation performed by an instruction.

After execution of an instruction which explicitly updates the PSW register, the condition flags cannot be interpreted as described below because any explicit write to the PSW register supersedes the condition flag values which are implicitly generated by the CPU.

Central Processing Unit (CPU)

Explicitly reading the PSW register supplies a read value which represents the state of the PSW register after execution of the immediately preceding instruction.

Note: After reset, all of the ALU status bits are cleared.

N-Flag: For most of the ALU operations, the N-flag is set to 1, if the most significant bit of the result contains a 1; otherwise, it is cleared. In the case of integer operations, the N-flag can be interpreted as the sign bit of the result (negative: $N = 1$, positive: $N = 0$). Negative numbers are always represented as the 2's complement of the corresponding positive number. The range of signed numbers extends from -8000_H to $+7FFF_H$ for the word data type, or from -80_H to $+7F_H$ for the byte data type. For Boolean bit operations with only one operand, the N-flag represents the previous state of the specified bit. For Boolean bit operations with two operands, the N-flag represents the logical XORing of the two specified bits.

C-Flag: After an addition, the C-flag indicates that a carry from the most significant bit of the specified word or byte data type has been generated. After a subtraction or a comparison, the C-flag indicates a borrow which represents the logical negation of a carry for the addition.

This means that the C-flag is set to 1, if **no** carry from the most significant bit of the specified word or byte data type has been generated during a subtraction, which is performed internally by the ALU as a 2's complement addition, and, the C-flag is cleared when this complement addition caused a carry.

The C-flag is always cleared for logical, multiply and divide ALU operations, because these operations cannot cause a carry.

For shift and rotate operations, the C-flag represents the value of the bit shifted out last. If a shift count of zero is specified, the C-flag will be cleared. The C-flag is also cleared for a prioritize ALU operation, because a 1 is never shifted out of the MSB during the normalization of an operand.

For Boolean bit operations with only one operand, the C-flag is always cleared. For Boolean bit operations with two operands, the C-flag represents the logical ANDing of the two specified bits.

V-Flag: For addition, subtraction, and 2's complementation, the V-flag is always set to 1 if the result exceeds the range of 16-bit signed numbers for word operations (-8000_H to $+7FFF_H$), or 8-bit signed numbers for byte operations (-80_H to $+7F_H$). Otherwise, the V-flag is cleared. Note that the result of an integer addition, integer subtraction, or 2's complement is not valid if the V-flag indicates an arithmetic overflow.

For multiplication and division, the V-flag is set to 1 if the result cannot be represented in a word data type; otherwise, it is cleared. Note that a division by zero will always cause an overflow. In contrast to the result of a division, the result of a multiplication is valid whether or not the V-flag is set to 1.

Because logical ALU operations cannot produce an invalid result, the V-flag is cleared by these operations.

Central Processing Unit (CPU)

The V-flag is also used as a 'Sticky Bit' for rotate right and shift right operations. With only using the C-flag, a rounding error caused by a shift right operation can be estimated up to a quantity of one half of the LSB of the result. In conjunction with the V-flag, the C-flag allows evaluation of the rounding error with a finer resolution (see [Table 5-22](#)).

For Boolean bit operations with only one operand, the V-flag is always cleared. For Boolean bit operations with two operands, the V-flag represents the logical ORing of the two specified bits.

Table 5-22 Shift Right Rounding Error Evaluation

C-Flag	V-Flag	Rounding Error Quantity
0	0	No rounding error
0	1	$0 < \text{Rounding error} < \frac{1}{2} \text{ LSB}$
1	0	$\text{Rounding error} = \frac{1}{2} \text{ LSB}$
1	1	$\text{Rounding error} > \frac{1}{2} \text{ LSB}$

Z-Flag: The Z-flag is normally set to 1 if the result of an ALU operation equals zero, otherwise it is cleared.

For the addition and subtraction with carry, the Z-flag is only set to 1, if the Z-flag already contains a 1 and the result of the current ALU operation also equals zero. This mechanism is provided to support multiple precision calculations.

For Boolean bit operations with only one operand, the Z-flag represents the logical negation of the previous state of the specified bit. For Boolean bit operations with two operands, the Z-flag represents the logical NORing of the two specified bits. For the prioritize ALU operation, the Z-flag indicates whether the second operand was zero.

E-Flag: End of table flag. The E-flag can be altered by instructions which perform ALU or data movement operations. The E-flag is cleared by those instructions which cannot be reasonably used for table search operations. In all other cases, the E-flag value depends on the value of the source operand to signify whether the end of a search table is reached or not. If the value of the source operand of an instruction equals the lowest negative number which is representable by the data format of the corresponding instruction (8000_H for the word data type, or 80_H for the byte data type), the E-flag is set to 1; otherwise, it is cleared.

General Control Functions (USR0, USR1, BANK, HLDEN)

A few bits in register PSW are dedicated to general control functions. Thus, they are saved and restored automatically upon task switches and interrupts.

USR0/USR1-Flags: These bits can be set automatically during the execution of repeated MAC instructions. These bits can also be used as general flags by an application.

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BANK: Bitfield BANK selects the currently active register bank (local or global). Bitfield BANK is updated implicitly by hardware upon entering an interrupt service routine, and by a RETI instruction. It can be also modified explicitly via software by any instruction which can write to PSW.

HLDEN_PL1: When the **MPU is disabled** this bit controls the external bus arbitration bit (HLDEN). Enabling bus arbitration is not supported for this device. Setting the bit may yield unexpected results. When the **MPU is enabled** the bit represents the high bit (PL1) of the MPU protection level.

Protection Level (PL0, PL1)

These flags specify the current protection level of the system. This information is needed for systems implementing memory protection (i.e. MPU). Four different protection levels are defined according to the table below. Refer to the Memory Protection (MPU) chapter for more information on how the protection system works.

Table 5-23 Decoding of Protection Level

PL1	PL0	Protection Level
0	0	Protection Level 0
0	1	Protection Level 1
1	0	Protection Level 2
1	1	Protection Level 3

Note: A write into bit PSW.10 will be interpreted as a write into PL1 when the MPU is enabled or as a write into HLDEN when the MPU is disabled.

CPU Interrupt Status (IEN, ILVL)

IEN: The Interrupt Enable bit allows interrupts to be globally enabled (IEN = 1) or disabled (IEN = 0).

ILVL: The four-bit Interrupt Level field (ILVL) specifies the priority of the current CPU activity. The interrupt level is updated by hardware on entry into an interrupt service routine, but it can also be modified via software to prevent other interrupts from being acknowledged. If an interrupt level 15 has been assigned to the CPU, it has the highest possible priority; thus, the current CPU operation cannot be interrupted except by hardware traps or external non-maskable interrupts.

After reset, all interrupts are globally disabled, and the lowest priority (ILVL = 0) is assigned to the initial CPU activity.

5.8.1 16-bit Adder/Subtractor, Barrel Shifter, and 16-bit Logic Unit

All standard arithmetic and logical operations are performed by the 16-bit ALU. In case of byte operations, signals from bits 6 and 7 of the ALU result are used to control the condition flags. Multiple precision arithmetic is supported by a "CARRY-IN" signal to the ALU from previously calculated portions of the desired operation.

A 16-bit barrel shifter provides multiple bit shifts in a single cycle. Rotations and arithmetic shifts are also supported.

5.8.2 Bit Manipulation Unit

The XE166U offers a large number of instructions for bit processing. These instructions are typically used to -

- manipulate software bit flags within CPU registers, GPRs or DPRAM
- control on-chip +Bus peripherals and port logic via control bits of their respective bit addressable (E)SFRs.

The bit manipulation instructions allow short addressing mode with bitoff operands only (see [Chapter 5.7.1](#)).

Note: All GPRs are bit-addressable independently from the allocation of the register bank via the Context Pointer (CP). Even GPRs which are allocated to non-bit-addressable RAM locations provide this feature.

Instructions BSET, BCLR, BAND, BOR, BXOR, BMOV, BMOVN explicitly set or clear specific bits. The bitfield instructions BFLDL and BFLDH allow masked manipulation of up to 8 bits of a specific byte at one time. The instructions JBC and JNBS implicitly clear or set the specified bit when the jump is taken. The instructions JB and JNB evaluate the specified bit to determine if the jump is to be taken.

Note: Bit operations on undefined bit locations will always read a bit value of '0', while the write access will not affect the respective bit location.

Bit protection using mask protected write

Instructions that manipulate single bits or bit groups either use a read-modify-write sequence or mask protected write to execute the operation.

The read-modify-write sequence accesses the whole word containing the specified bit(s). The read-modify-write approach may be critical with hardware affected bits of type 'rwh' or 'wh'. In these cases, the hardware may change other bits of the register while the read-modify-write operation is in progress. Thus the writeback could overwrite the new bit value generated by the hardware.

To handle this side effect operations on **bit addressable (E)SFR registers** support the bit protection mechanism using a mask protected write.

Example:

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BCLR EOPIC.EOPIE ; disable 'end of PEC' interrupts

The instruction will clear the interrupt enable bit EOPIE while the 'rwh' bit EOPIR will be mask protected. This ensures that an EOP interrupt occurring exactly at the same time will be correctly flagged.

Note: For the BFLD(LH) instructions the protection mask must be supplied by the programmer.

*Note: If a direct conflict occurs between a bit manipulation generated by hardware and an intended software access on the **same** bit, the software access has priority and determines the final value of the respective bit.*

5.8.3 Multiply and Divide Unit

The XE166U's multiply and divide unit has two separated parts. One is the fast 16×16 -bit multiplier that executes a multiplication in one CPU cycle. The other one is a division sub-unit which performs the division algorithm in 18 ... 21 CPU cycles (depending on the data and division types). The divide instruction requires four CPU cycles to be executed. For performance reasons, the rest of the division algorithm runs in the background during the following seventeen CPU cycles, while further instructions are executed in parallel. Interrupt tasks can also be started and executed immediately without any delay. If an instruction (from the original instruction stream or from the interrupt task) tries to use the unit while a division is still running, the execution of this new instruction is stalled until the previous division is finished.

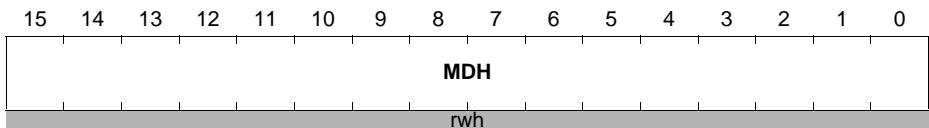
To avoid these stalls, the multiply and division unit should not be used during the first fourteen CPU cycles of the interrupt tasks. For example, this requires up to fourteen one-cycle instructions to be executed between the interrupt entry and the first instruction which uses the multiply and divide unit again (worst case).

Multiplications and divisions implicitly use the 32-bit multiply/divide register MD (represented by the concatenation of the two non-bit-addressable data registers MDH and MDL) and the associated control register MDC. This bit-addressable 16-bit register is implicitly used by the CPU when it performs a division or multiplication in the ALU.

After a multiplication, MD represents the 32-bit result. For long divisions, MD must be loaded with the 32-bit dividend before the division is started. After any division, register MDH represents the 16-bit remainder, register MDL represents the 16-bit quotient.

MDH

Multiply Divide High Word **SFR (FE0C_H/06_H)** **Reset Value: 0000_H**



Field	Bits	Type	Description
MDH	[15:0]	rwh	High Part of MD The high order sixteen bits of the 32-bit multiply and divide register MD.

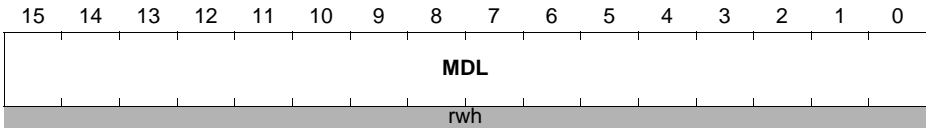
Central Processing Unit (CPU)

MDL

Multiply Divide Low Word

SFR (FE0E_H/07_H)

Reset Value: 0000_H



Field	Bits	Type	Description
MDL	[15:0]	rwh	Low Part of MD The low order sixteen bits of the 32-bit multiply and divide register MD.

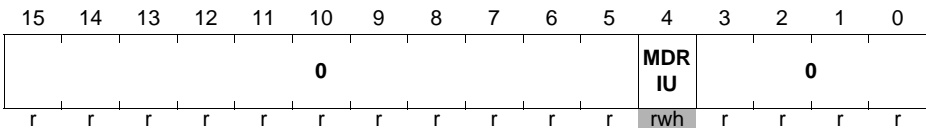
Whenever MDH or MDL is updated via software, the Multiply/Divide Register In Use flag (MDRIU) in the Multiply/Divide Control register (MDC) is set to '1'. The MDRIU flag is cleared, whenever register MDL is read via software.

MDC

Multiply Divide Control

SFR (FF0E_H/87_H)

Reset Value: 0000_H



Field	Bits	Type	Description
MDRIU	4	rwh	Multiply/Divide Register In Use 0 _B Cleared when MDL is read via software. 1 _B Set when MDL or MDH is written via software, or when a multiply or divide instruction is executed.
0	[15:5], [3:0]	r	Reserved Read as 0, should be written 0

Note: The MDRIU flag indicates the usage of register MD (MDL and MDH). In this case MD must be saved prior to a new multiplication or division operation.

5.9 DSP Data Processing (MAC Unit)

The CoXXX arithmetic instructions are executed by the MAC unit. It provides single-instruction-cycle, non-pipelined, 32-bit additions; 32-bit subtraction; right and left shifts; 16-bit by 16-bit multiplication; and multiplication with cumulative subtraction/addition. The MAC unit includes the following major components also shown in [Figure 5-16](#):

- 16-bit by 16-bit signed/unsigned multiplier with signed result¹⁾
- Concatenation Unit
- Scaler (one-bit left shifter) for fractional computing
- 40-bit Adder/Subtractor
- 40-bit Signed Accumulator
- Data Limiter
- Accumulator Shifter
- Repeat Counter

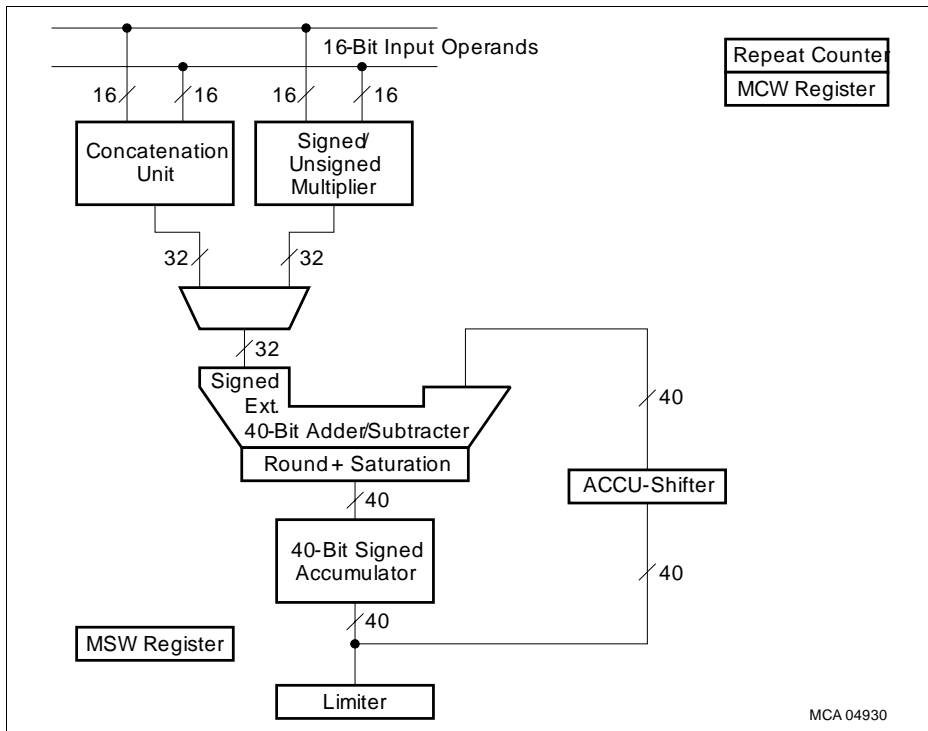


Figure 5-16 Functional MAC Unit Block Diagram

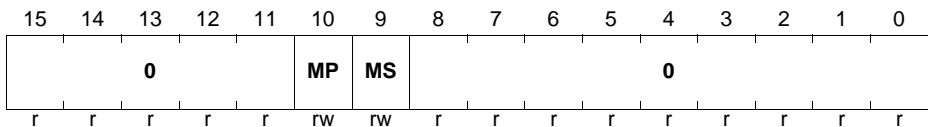
1) The same hardware-multiplier is used in the ALU.

5.9.1 MAC Unit Control

The working register of the MAC unit is a dedicated 40-bit accumulator register. A set of consistent flags is automatically updated in status register MSW after each MAC operation. These flags allow branching on specific conditions. Unlike the PSW flags, these flags are not preserved automatically by the CPU upon entry into an interrupt or trap routine. All dedicated MAC registers must be saved on the stack if the MAC unit is shared between different tasks and interrupts. General properties of the MAC unit are selected via the MAC control word MCW.

MCW

MAC Control Word **SFR (FFDC_H/EE_H)** **Reset Value: 0000_H**



Field	Bits	Type	Description
MP	10	rw	One-Bit Scaler Control 0 _B Multiplier product shift disabled 1 _B Multiplier product shift enabled for signed multiplications
MS	9	rw	Saturation Control 0 _B Saturation disabled 1 _B Saturation to 32-bit value enabled
0	[15:11] , [8:0]	r	Reserved Read as 0, should be written 0

5.9.2 Representation of Numbers and Rounding

The XE166U supports the 2's complement representation of binary numbers. In this format, the sign bit is the MSB of the binary word. This is set to zero for positive numbers and set to one for negative numbers. Unsigned numbers are supported only by multiply/multiply-accumulate instructions which specify whether each operand is signed or unsigned.

In 2's complement fractional format, the N-bit operand is represented using the 1.[N-1] format (1 signed bit, N-1 fractional bits). Such a format can represent numbers between -1 and +1 - 2^{-[N-1]}. This format is supported when bit MP of register MCW is set.

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The XE166U implements 2's complement rounding. With this rounding type, one is added to the bit to the right of the rounding point (bit 15 of MAL), before truncation (MAL is cleared).

5.9.3 The 16-bit by 16-bit Signed/Unsigned Multiplier and Scaler

The multiplier executes 16-bit by 16-bit parallel signed/unsigned fractional and integer multiplication in one CPU-cycle. The multiplier allows the multiplication of unsigned and signed operands. The result is always presented in a signed fractional or integer format. The result of the multiplication feeds a one-bit scaler to allow compensation for the extra sign bit gained in multiplying two 16-bit 2's complement numbers.

5.9.4 Concatenation Unit

The concatenation unit enables the MAC unit to perform 32-bit arithmetic operations in one CPU cycle. The concatenation unit concatenates two 16-bit operands to a 32-bit operand before the 32-bit arithmetic operation is executed in the 40-bit adder/subtractor. The second required operand is always the current accumulator contents. The concatenation unit is also used to pre-load the accumulator with a 32-bit value.

5.9.5 One-bit Scaler

The one-bit scaler can shift the result of the concatenation unit or the output of the multiplier one bit to the left. The scaler is controlled by the executed instruction for the concatenation or by control bit MP in register MCW.

If bit MP is set the product is shifted one bit to the left to compensate for the extra sign bit gained in multiplying two 16-bit 2's-complement numbers. The enabled automatic shift is performed only if both input operands are signed.

5.9.6 The 40-bit Adder/Subtractor

The 40-bit Adder/Subtractor allows intermediate overflows in a series of multiply/accumulate operations. The Adder/Subtractor has two input ports. The 40-bit port is the feedback of the accumulator output through the ACCU-Shifter to the Adder/Subtractor. The 32-bit port is the input port for the operand coming from the one-bit Scaler. The 32-bit operands are signed and extended to 40 bits before the addition/subtraction is performed.

The output of the Adder/Subtractor goes to the accumulator. It is also possible to round the result and to saturate it on a 32-bit value automatically after every accumulation. The round operation is performed by adding $00'0000'8000_H$ to the result. Automatic saturation is enabled by setting the saturation control bit MS in register MCW.

When the accumulator is in the overflow saturation mode and an overflow occurs, the accumulator is loaded with either the most positive or the most negative value

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representable in a 32-bit value, depending on the direction of the overflow as well as on the arithmetic used. The value of the accumulator upon saturation is either 00'7FFF'FFFF_H (positive) or FF'8000'0000_H (negative).

5.9.7 The Data Limiter

Saturation arithmetic is also provided to selectively limit overflow when reading the accumulator by means of a **CoSTORE <destination>**, **MAS** instruction. Limiting is performed on the MAC-Unit accumulator. If the contents of the accumulator can be represented in the destination operand size without overflow, then the data limiter is disabled and the operand is not modified. If the contents of the accumulator cannot be represented without overflow in the destination operand size, the limiter will substitute a "limited" data as explained in [Table 5-24](#):

Table 5-24 Limiter Output

ME-flag	MN-flag	Output of Limiter
0	x	unchanged
1	0	7FFF _H
1	1	8000 _H

Note: In this particular case, both the accumulator and the status register are not affected. MAS is readable by means of a CoSTORE instruction only.

5.9.8 The Accumulator Shifter

The accumulator shifter is a parallel shifter with a 40-bit input and a 40-bit output. The source accumulator shifting operations are:

- No shift (Unmodified)
- Up to 16-bit Arithmetic Left Shift
- Up to 16-bit Arithmetic Right Shift

Notice that bits ME, MSV, and MSL in register MSW are affected by left shifts; therefore, if the saturation mechanism is enabled (MS) the behavior is similar to the one of the Adder/Subtractor.

Note: Certain precautions are required in case of left shift with saturation enabled. Generally, if MAE contains significant bits, then the 32-bit value in the accumulator is to be saturated. However, it is possible that left shift may move some significant bits out of the accumulator. The 40-bit result will be misinterpreted and will be either not saturated or saturated incorrectly. There is a chance that the result of left shift may produce a result which can saturate an original positive number to the minimum negative value, or vice versa.

5.9.9 The 40-bit Signed Accumulator Register

The 40-bit accumulator consists of three concatenated registers MAE, MAH, and MAL. MAE is 8 bits wide, MAH and MAL are 16 bits wide. MAE is the Most Significant Byte of the 40-bit accumulator. This byte performs a guarding function. MAE is accessed as the lower byte of register MSW.

When MAH is written, the value in the accumulator is automatically adjusted to signed extended 40-bit format. That means MAL is cleared and MAE will be automatically loaded with zeros for a positive number (the most significant bit of MAH is 0), and with ones for a negative number (the most significant bit of MAH is 1), representing the extended 40-bit negative number in 2's complement notation. One may see that the extended 40-bit value is equal to the 32-bit value without extension. In other words, after this extension, MAE does not contain significant bits. Generally, this condition is present when the highest 9 bits of the 40-bit signed result are the same.

During the accumulator operations, an overflow may happen and the result may not fit into 32 bits and MAE will change. The extension flag "E" in register MSW is set when the signed result in the accumulator has exceeded the 32-bit boundary. This condition is present when the highest 9 bits of the 40-bit signed result are not the same, i.e. MAE contains significant bits.

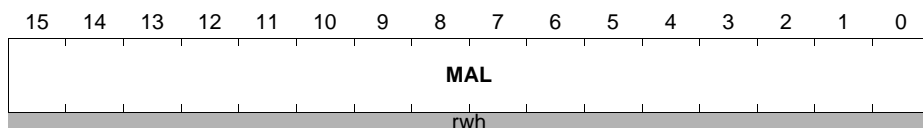
Most CoXXX operations specify the 40-bit accumulator register as a source and/or a destination operand.

MAL

Accumulator Low Word

SFR (FE5C_H/2E_H)

Reset Value: 0000_H



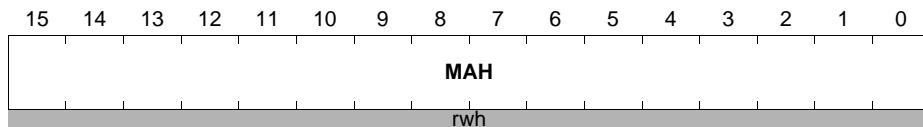
Field	Bits	Type	Description
MAL	[15:0]	rwh	Low Part of Accumulator The 40-bit accumulator is completed by the accumulator high word (MAH) and bitfield MAE

MAH

Accumulator High Word

SFR (FE5E_H/2F_H)

Reset Value: 0000_H



Field	Bits	Type	Description
MAH	[15:0]	rwh	High Part of Accumulator The 40-bit accumulator is completed by the accumulator low word (MAL) and bitfield MAE

5.9.10 The MAC Unit Status Word MSW

The upper byte of register MSW (bit-addressable) shows the current status of the MAC Unit. The lower byte of register MSW represents the 8-bit MAC accumulator extension, building the 40-bit accumulator together with registers MAH and MAL.

MSW

MAC Status Word

SFR (FFDE_H/EF_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	MV	MSL	ME	MSV	MC	MZ	MN					MAE			
r	rwh	rwh	rwh	rwh	rwh	rwh	rwh					rwh			

Field	Bits	Type	Description
0	15	r	Reserved Read as 0, should be written 0
MV	14	rwh	Overflow Flag 0 _B No Overflow produced 1 _B Overflow produced
MSL	13	rwh	Sticky Limit Flag 0 _B Result was not saturated 1 _B Result was saturated
ME	12	rwh	MAC Extension Flag 0 _B MAE does not contain significant bits 1 _B MAE contains significant bits
MSV	11	rwh	Sticky Overflow Flag 0 _B No Overflow occurred 1 _B Overflow occurred
MC	10	rwh	Carry Flag 0 _B No carry/borrow produced 1 _B Carry/borrow produced
MZ	9	rwh	Zero Flag 0 _B MAC result is not zero 1 _B MAC result is zero
MN	8	rwh	Negative Result 0 _B MAC result is positive 1 _B MAC result is negative

Field	Bits	Type	Description
MAE	[7:0]	rwh	MAC Accumulator Extension The most significant bits of the 40-bit accumulator, completing registers MAH and MAL

MAC Unit Status (MV, MN, MZ, MC, MSV, ME, MSL)

These condition flags indicate the MAC status resulting from the most recently performed MAC operation. These flags are controlled by the majority of MAC instructions according to specific rules. Those rules depend on the instruction managing the MAC or data movement operation.

After execution of an instruction which explicitly updates register MSW, the condition flags may no longer represent an actual MAC status. An explicit write operation to register MSW supersedes the condition flag values implicitly generated by the MAC unit. An explicit read access returns the value of register MSW after execution of the immediately preceding instruction. Register MSW can be accessed via any instruction capable of accessing an SFR.

Note: After reset, all MAC status bits are cleared.

MN-Flag: For the majority of the MAC operations, the MN-flag is set to 1 if the most significant bit of the result contains a 1; otherwise, it is cleared. In the case of integer operations, the MN-flag can be interpreted as the sign bit of the result (negative: MN = 1, positive: MN = 0). Negative numbers are always represented as the 2's complement of the corresponding positive number. The range of signed numbers extends from 80'0000'0000_H to 7F'FFFF'FFFF_H.

MZ-Flag: The MZ-flag is normally set to 1 if the result of a MAC operation equals zero; otherwise, it is cleared.

MC-Flag: After a MAC addition, the MC-flag indicates that a "Carry" from the most significant bit of the accumulator extension MAE has been generated. After a MAC subtraction or a MAC comparison, the MC-flag indicates a "Borrow" representing the logical negation of a "Carry" for the addition. This means that the MC-flag is set to 1 if **no** "Carry" from the most significant bit of the accumulator has been generated during a subtraction. Subtraction is performed by the MAC Unit as a 2's complement addition and the MC-flag is cleared when this complement addition caused a "Carry".

For left-shift MAC operations, the MC-flag represents the value of the bit shifted out last. Right-shift MAC operations always clear the MC-flag. The arithmetic right-shift MAC operation can set the MC-flag if the enabled round operation generates a "Carry" from the most significant bit of the accumulator extension MAE.

MSV-Flag: The addition, subtraction, 2's complement, and round operations always set the MSV-flag to 1 if the MAC result exceeds the maximum range of 40-bit signed numbers. If the MSV-flag indicates an arithmetic overflow, the MAC result of an operation is not valid.

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The MSV-flag is a 'Sticky Bit'. Once set, other MAC operations cannot affect the status of the MSV-flag. Only a direct write operation can clear the MSV-flag.

ME-Flag: The ME-flag is set if the accumulator extension MAE contains significant bits, that means if the nine highest accumulator bits are not all equal.

MSL-Flag: The MSL-flag is set if an automatic saturation of the accumulator has happened. The automatic saturation is enabled if bit MS in register MCW is set. The MSL-Flag can be also set by instructions which limit the contents of the accumulator. If the accumulator has been limited, the MSL-Flag is set.

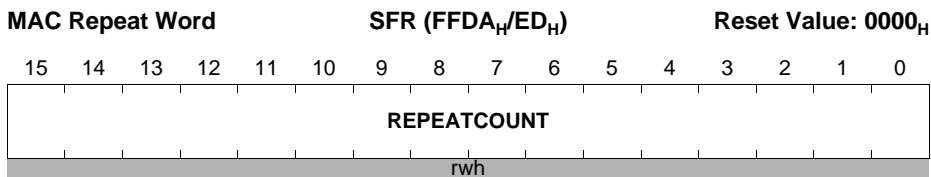
The MSL-Flag is a 'Sticky Bit'. Once set, it cannot be affected by the other MAC operations. Only a direct write operation can clear the MSL-flag.

MV-Flag: The addition, subtraction, and accumulation operations set the MV-flag to 1 if the result exceeds the maximum range of signed numbers (80'0000'0000_H to 7F'FFFF'FFFF_H); otherwise, the MV-flag is cleared. Note that if the MV-flag indicates an arithmetic overflow, the result of the integer addition, integer subtraction, or accumulation is not valid.

5.9.11 The Repeat Counter MRW

The Repeat Counter MRW controls the number of repetitions a loop must be executed. The register must be pre-loaded before it can be used with -USRx CoXXX operations. MAC operations are able to decrement this counter. When a -USRx CoXXX instruction is executed, MRW is checked for zero **before** being decremented. If MRW equals zero, bit USRx is set and MRW is not further decremented. Register **MRW** can be accessed via any instruction capable of accessing a SFR.

MRW



Field	Bits	Type	Description
REPEATCOUNT	[15:0]	rwh	MAC repeat counter

All CoXXX instructions have a 3-bit wide repeat control field 'rrr' (bit positions [31:29]) in the operand field to control the MRW repeat counter. [Table 5-25](#) lists the encoding.

Table 5-25 Encoding of MAC Repeat Word Control

Code in 'rrr'	Effect on Repeat Counter
000 _B	regular CoXXX instruction
001 _B	RESERVED
010 _B	'-USR0 CoXXX' instruction, decrements repeat counter and sets bit USR0 if MRW is zero
011 _B	'-USR1 CoXXX' instruction, decrements repeat counter and sets bit USR1 if MRW is zero
1XX _B	RESERVED

Note: Bit USR0 has been a general purpose flag also in previous architectures. To prevent collisions due to using this flag by programmer or compiler, use '-USR0 CoXXX' instructions very carefully.

The following example shows a loop which is executed 20 times. Every time the CoMACM instruction is executed, the MRW counter is decremented.

```

MOV      MRW, #19           ;Pre-load loop counter
loop01:
-USR1    CoMACM [IDX0+], [R0+] ;Calculate and decrement MSW
ADD      R2, #0002H
JMPA     cc_nusr1, loop01 ;Repeat loop until USR1 is set

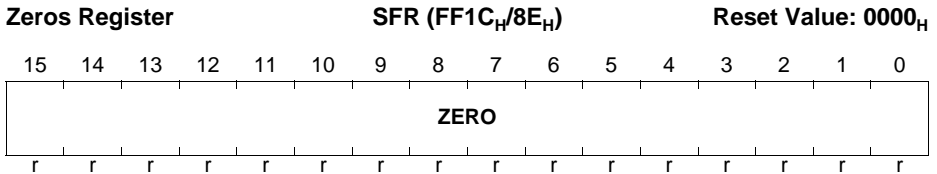
```

Note: Because correctly predicted JMPA is executed in 0-cycle, it offers the functionality of a repeat instruction.

5.10 Constant Registers

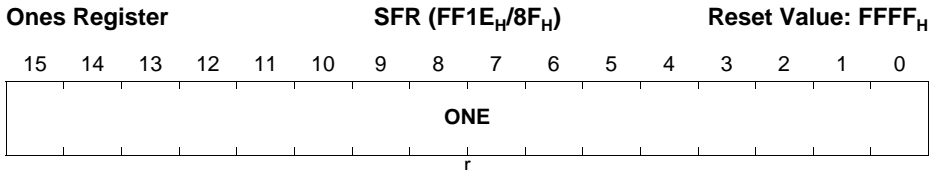
All bits of these bit-addressable registers are fixed to 0 or 1 by hardware. These registers can be read only. Register ZEROS/ONES can be used as a register-addressable constant of all zeros or all ones, for example for bit manipulation or mask generation. The constant registers can be accessed via any instruction capable of addressing an SFR.

ZEROS



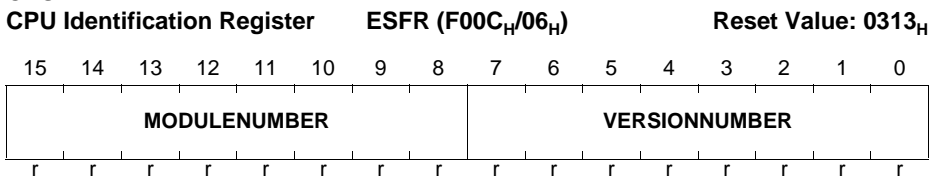
Field	Bits	Type	Description
ZERO	[15:0]	r	Constant Zero Bits

ONES



Field	Bits	Type	Description
ONE	[15:0]	r	Constant One Bits

CPUID



Field	Bits	Type	Description
MODULENUMBER	[15:8]	r	C166 Family CPU Module Number (C166S-V2)

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Field	Bits	Type	Description
VERSIONNUMBER	[7:0]	r	C166S-V2 CPU Version Number

6 Memory Protection Unit (MPU)

The Memory Protection Unit (MPU) provides the hardware mechanisms needed for implementing memory protection. The MPU allows detection of unauthorized accesses (read, write or instruction fetch) in user-defined memory ranges. It offers protection for the complete address space, including the peripheral area.

The MPU can be used to support the encapsulation of different applications or software components running on the processor. This encapsulation provides the means to ensure integrity and fault isolation capabilities in today's complex systems relying on multiple-sources software.

6.1 Functional Overview

Different protection levels are usually needed to support a programming system where for example an operating system or software kernel runs and controls different application and low level drivers parts. One level can be associated to the operating system and for the other tasks that need protection against each other or against the operating system, other levels can be used. For every protection level different address ranges with different access permissions for instructions and/or data can be defined. When a piece of code is executed and the memory protection is enabled, the permissions associated to its protection level are selected and every time a memory access is performed it will be checked if the access is outside of the specified ranges or violates the access permissions. In this case the access may not be performed but marked as invalid and a protection trap routine can be executed.

The basic MPU functionality is shown in [Figure 6-1](#).

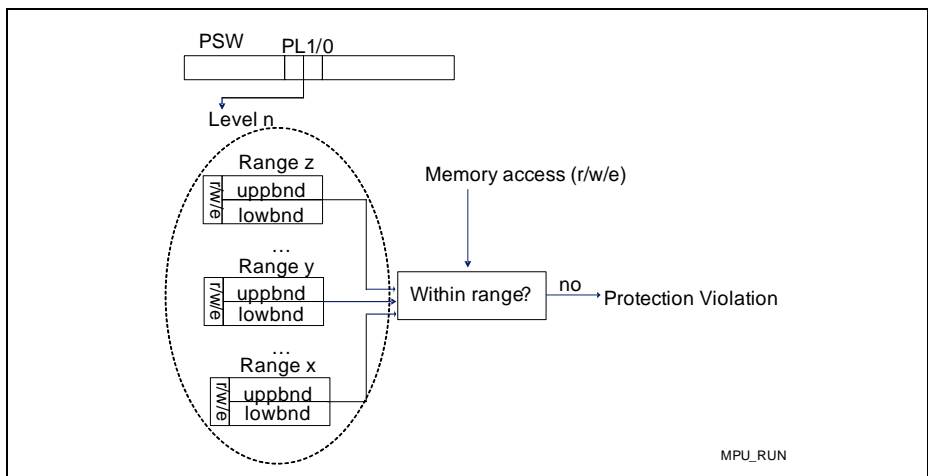


Figure 6-1 MPU Operation

Memory Protection Unit (MPU)

Four Protection Levels can coexist during run time in this architecture. Two bits in the Processor Status Word (PSW) are used to select which protection level is active at a given time. If an application requires more than 4 protection levels, a re-mapping of all the levels to the 4 possible values has to be performed and during run time re-programming of the protection register sets when switching levels is needed.

A protection register set is associated to every protection level, every set contains all the address ranges and the access permissions associated to the corresponding protection level. Every protection register set can contain a programmable number of range registers. All together, a maximum of 12 ranges is supported. Associated to every code or data range, a protection mode register defines the permissions for this range. Refer to the next chapters for a detailed explanation of the MPU registers needed for the protection system and its usage.

6.2 Memory Protection Registers

A protection register set consists of a variable number of Protection Range register pairs (PRUx/PRLx) and the corresponding number of Protection Mode registers (PMx). The PMx registers are located in the SFRs area and are accessed through the Peripheral Data Bus -PD-Bus-. The PRUx/PRLx registers are not memory mapped, their access mechanism is supported through the memory mapped registers Protection Range Address register (PRA) and Protection Range Data register (PRD).

Table 6-1 Registers Address Space

Module	Base Address	End Address	Note
MPU	0 _H		

Table 6-2 Registers Overview

Register Short Name	Register Long Name	Offset Address	Page Number
PRUx (x =0-11)	Protection Range Register x Upper Bound	none _H	6-4
PRLx (x =0-11)	Protection Range Register x Lower Bound	none _H	6-4
PM5	Protection Mode Register 5	FFD2 _H	6-7
PM4	Protection Mode Register 4	FFD0 _H	6-7
PM3	Protection Mode Register 3	FFCE _H	6-7
PM2	Protection Mode Register 2	FFCC _H	6-7
PM1	Protection Mode Register 1	FFCA _H	6-7
PM0	Protection Mode Register 0	FFC8 _H	6-7
PRD	Protection Range Data	FFC6 _H	6-8
PRA	Protection Range Address	FFC4 _H	6-9

6.2.1 Protection Range Registers

The PRUx/PRLx pairs are 16-bits registers and specify the upper 16 bits of the physical addresses, upper and lower bound, for data and/or code for all the allowed ranges (12 is the maximum supported). Only these upper 16 bits of the physical addresses are considered in the address comparisons, as a consequence, the minimum granularity of the ranges is 256 bytes and all the ranges are aligned to this size.

The PRUx and PRLx registers specify respectively the Upper and Lower addresses of a Range. If due to a programming error PRLx specifies a value bigger than PRUx, the corresponding range will not specify a correct address range, and as a consequence the corresponding range is useless (i.e. ignored). Note that due to the 256 byte range

Memory Protection Unit (MPU)

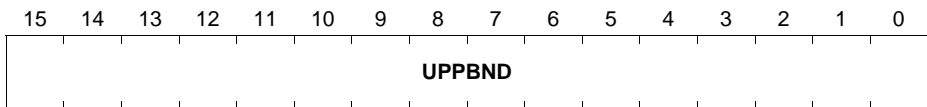
granularity, to program a range of this smallest size, both upper and lower range need to be program with the same value, i.e. the 16-bits base address of the range.

For programming a protection range in the PRUx/PRLx registers, it has to be selected first which range is going to be written by programming the address into PRA, then the data write operation can be performed by writing the data into PRD. In a similar way, a read operation has to be performed by selecting first which range is going to be read (by programming the address into PRA) and then the read operation can be performed by reading PRD. Programming a PRUx/PRLx register requires then two write operations. Similarly, reading a PRUx/PRLx register requires also two operations (one write and one read). For continuous accesses and when using the auto increment feature only one initialization into PRA is needed, afterwards only the PRD register needs to be written/read every time. Registers PRD and PRA are described in [Chapter 6.2.3](#) and [Chapter 6.2.4](#) respectively.

PRUx (x =0-11)

Protection Range Register x Upper Bound

Reset Value: 0000_H

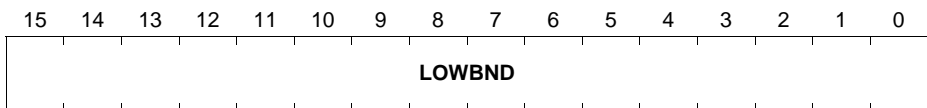


Field	Bits	Type	Description
UPPBND	[15:0]	rw	Upper Boundary Address (upper 16 bits)

PRLx (x =0-11)

Protection Range Register x Lower Bound

Reset Value: 0000_H



Field	Bits	Type	Description
LOWBND	[15:0]	rw	Lower Boundary Address (lower 16 bits)

6.2.2 Protection Mode Registers

All the control information associated to every address range is contained in the Protection Mode registers. Access permissions (execute, read and/or write) are defined here and also the range-to-level mapping. Every range can be individually enabled to be used for any protection level, even can be used for more than one level (but with the same access permissions). Also the field used to enable the protection system is implemented in one of the protection mode registers.

Note that no hardware mechanism is implemented to flush the pipeline upon a modification of these registers. This is usually not a problem because a (re-)programming of the MPU configuration registers should be anyhow performed having the protection disabled. Also the configuration affecting a particular protection level will be usually (re-)programmed from another level meaning that even at the point when protection is enabled the software currently running will not be affected by the configuration change (the configuration change is usually seen once the protection level is changed according to the procedure described in [Chapter 6.4.2](#)). For special cases where the change will and needs to be immediately seen, the software has to take care that the write is effective before executing the next affected instruction (by reading for example the latest written register).

The bit fields of the PMx registers in the description below use generic Range names (A, B), their mapping to the physical ranges is given after the PMx register name where they belong to. Given a Protection Mode register x, the range named A is addressing the physical range $2 \cdot x$ and range named B the range $2 \cdot x + 1$.

The PMx registers are EINIT protected.

PM0

Protection Mode Register 0 **SFR (FFC8_H)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3E B	L2E B	L1E B	L0E B	WEB	REB	XEB	0	L3E A	L2E A	L1E A	L0E A	WEA	REA	XEA	PRO TEN
rw	rw	rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
PROTEN	0	rw	Protection Enable bit This bit enables the Protection mechanism 0 _B Protection not enabled 1 _B Protection enabled

Memory Protection Unit (MPU)

Field	Bits	Type	Description
XEA, XEB	1, 9	rw	Execute Enable 0_B Instruction fetch accesses to associated address range (A, B) not permitted 1_B Instruction fetch accesses to associated address range (A, B) permitted
REA, REB	2, 10	rw	Read Enable 0_B Data read accesses to associated address range (A, B) not permitted 1_B Data read accesses to associated address range (A, B) permitted
WEA, WEB	3, 11	rw	Write Enable 0_B Data write accesses to associated address range (A, B) not permitted 1_B Data write accesses to associated address range (A, B) permitted
L0EA, L0EB	4, 12	rw	Level 0 Enable 0_B Range (A, B) not enabled for Protection Level 0 1_B Range (A, B) enabled for Protection Level 0
L1EA, L1EB	5, 13	rw	Level 1 Enable 0_B Range (A, B) not enabled for Protection Level 1 1_B Range (A, B) enabled for Protection Level 1
L2EA, L2EB	6, 14	rw	Level 2 Enable 0_B Range (A, B) not enabled for Protection Level 2 1_B Range (A, B) enabled for Protection Level 2
L3EA, L3EB	7, 15	rw	Level 3 Enable 0_B Range (A, B) not enabled for Protection Level 3 1_B Range (A, B) enabled for Protection Level 3
0	8	r	Reserved field

The field PROTEN exists only in the Protection Mode Register 0.

Memory Protection Unit (MPU)

PMx (x =1-5)

Protection Mode Register x

SFR (FFC8_H+2*x)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3E B	L2E B	L1E B	L0E B	WEB	REB	XEB	0	L3E A	L2E A	L1E A	L0E A	WEA	REA	XEA	0
rw	rw	rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	r

Field	Bits	Type	Description
0	0	r	Reserved field
XEA, XEB	1, 9	rw	Execute Enable 0 _B Instruction fetch accesses to associated address range (A, B) not permitted 1 _B Instruction fetch accesses to associated address range (A, B) permitted
REA, REB	2, 10	rw	Read Enable 0 _B Data read accesses to associated address range (A, B) not permitted 1 _B Data read accesses to associated address range (A, B) permitted
WEA, WEB	3, 11	rw	Write Enable 0 _B Data write accesses to associated address range (A, B) not permitted 1 _B Data write accesses to associated address range (A, B) permitted
L0EA, L0EB	4, 12	rw	Level 0 Enable 0 _B Range (A, B) not enabled for Protection Level 0 1 _B Range (A, B) enabled for Protection Level 0
L1EA, L1EB	5, 13	rw	Level 1 Enable 0 _B Range (A, B) not enabled for Protection Level 1 1 _B Range (A, B) enabled for Protection Level 1
L2EA, L2EB	6, 14	rw	Level 2 Enable 0 _B Range (A, B) not enabled for Protection Level 2 1 _B Range (A, B) enabled for Protection Level 2

Memory Protection Unit (MPU)

Field	Bits	Type	Description
L3EA, L3EB	7, 15	rw	Level 3 Enable 0 _B Range (A, B) not enabled for Protection Level 3 1 _B Range (A, B) enabled for Protection Level 3
0	8	r	Reserved field

6.2.3 Protection Range Data Register

The Protection Range Data register contains the 16 bits data value needed to program the content of the Protection Range Registers. It also contains the data read during the last read access on the Protection Range Registers. A write into PRD triggers immediately a write into the corresponding PRUx/PRLx register (the one that is currently selected by the write pointer -in PRA register-). Also a read into PRD delivers the corresponding PRUx/PRLx data immediately (the one that is currently selected by the read pointer -in PRA register-).

The PRD register is EINIT protected.

PRD

Protection Range Data

SFR (FFC6_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA															
rwh															

Field	Bits	Type	Description
DATA	[15:0]	rwh	Data Value for/from PRUx/PRLx

6.2.4 Protection Range Address Register

The Protection Range Address register contains two access pointers, one used for write operations and the other for read operations. With every 5-bit pointer it is possible to select a PRUx/PRLx register from a set of 24 register (the 24 PRUx/PRLx registers needed to implement 12 protection ranges).

An auto increment capability can be enabled for the access pointers (controlled by WMOD and RMOD fields), after every write or read into/from PRD the write or read pointers are incremented respectively. This feature enables a faster programming of the protection range registers. When the auto increment mode is active, the access pointers automatically do a wrap around (i.e. initialized to 0) after reaching its maximum value.

Memory Protection Unit (MPU)

The occurrence of a wrap around is shown in the status bits WWA or RWA. The software can then check if this situation has happened taking the corresponding action and resetting the corresponding flag.

Special care has to be taken when programming the PRA register in order not to modify one of the pointers unintentionally. It is recommended to use bit instructions for that (bit field instructions for example). Also when using the auto increment feature and during debugging it has to be considered that a debugger access can also modify the pointer values, the debugger software should then take care of restoring the original status of this register.

The PRA register is EINIT protected.

PRA

Protection Range Address					SFR (FFC4 _H)					Reset Value: 0000 _H					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RMO D	RWA	0	RPTR				WM OD	WW A	0	WPTR					
rw	rwh	r	rwh				rw	rwh	r	rwh					

Field	Bits	Type	Description
WPTR	[4:0]	rwh	Write Pointer Selects the Protection Range Register to be written 00000 _B Selects PRL0 00001 _B Selects PRU0 00010 _B Selects PRL1 00011 _B Selects PRU1 00100 _B Selects PRL2 00101 _B Selects PRU2 ... 11110 _B Selects PRL15 11111 _B Selects PRU15
0	5	r	Reserved field
WWA	6	rwh	Write Wrap Around Status 0 _B No WPTR Wrap Around occurred on last Write 1 _B A WPTR Wrap Around occurred on last Write Bit to be cleared by SW
WMOD	7	rw	Auto increment Write Mode 0 _B No increment WPTR on every Write 1 _B Auto increment WPTR on every Write

Memory Protection Unit (MPU)

Field	Bits	Type	Description
RPTR	[12:8]	rwh	Read Pointer Selects the Protection Range Register to be read 00000 _B Selects PRL0 00001 _B Selects PRU0 00010 _B Selects PRL1 00011 _B Selects PRU1 00100 _B Selects PRL2 00101 _B Selects PRU2 ... 11110 _B Selects PRL15 11111 _B Selects PRU15
0	13	r	Reserved field
RWA	14	rwh	Read Wrap Around Status 0 _B No RPTR Wrap Around occurred on last Read 1 _B A RPTR Wrap Around occurred on last Read Bit to be cleared by SW
RMOD	15	rw	Auto increment Read Mode 0 _B No increment RPTR on every Read 1 _B Auto increment RPTR on every Read

6.3 Functional Description

6.3.1 Enabling Protection

Protection has to be globally enabled per software, bit PM0.PROTEN implements this functionality, refer to chapter [Chapter 6.2.2](#).

6.3.2 Protection Levels

The bits PSW.PL1/0 select the current protection level, i.e the protection register set currently active. The decoding of PL1/0 is as follows:

Table 6-3 Decoding of Protection Level

PL1	PL0	Protection Level
0	0	Protection Level 0
0	1	Protection Level 1
1	0	Protection Level 2
1	1	Protection Level 3

Memory Protection Unit (MPU)

PL1 and PL0 bits are mapped into PSW.10 and PSW.5 bits respectively. Note that due to the shared functionality implemented on the bit PSW.10, a write on this bit will be interpreted as a write on the PSW.PL1 only when the MPU is itself enabled (PM0.PROTEN is 1). When the MPU is not enabled a write on this bit will be interpreted as a write on the HLDEN flag. For consistency, the flag PSW.PL0 is handled in a similar way, a write on PSW.PL0 is only effective when the MPU is enabled.

6.3.2.1 Protection Level 0

For the protection mechanism to work properly, the MPU has to be operated under a kind of privileged mode, programming and changing the protection information should only be allowed during this mode. Even if the C166 family architecture does not support directly this operation mode (only the one associated to the initialization phase ended by the EINIT execution), the privileged mode can be defined in this context as the mode entered when the processor runs with protection Level 0. This is the level entered after reset and the level automatically entered after an interrupt/trap is taken. Level 0 should be then the level used by the operating system, software kernel or the software components needing access to the whole system resources (specially to system control registers and peripheral area).

But note that defining and programming address ranges and permissions is still needed for Level 0 (even if it is the whole space). Per default (i.e. after reset), no access in any address range is allowed, also not for this level.

Note: The need to program Level 0 allows in special occasions to give restricted access also to this level. Restriction sometimes needed to probe reliability of the software running under this level.

6.3.3 Intersecting Memory Ranges

The permission to access a memory location is the OR of the memory range permissions. When two or more ranges intersect, the intersecting region has the permission of the most permissive range.

6.3.4 Protection of the MPU registers

As mentioned in [Chapter 6.3.2.1](#), the MPU registers need to be protected. A protection mechanism comes automatically with the use of the MPU and the fact that the whole address space, including SFRs, is under control of the MPU, see also [Chapter 6.3.5](#). Once protection is enabled, changing protection information can then only be performed from a protection level which has access to the corresponding SFR area (i.e. to the protection registers).

In addition to this inherited protection mechanism, the protection control registers are also EINIT protected. The EINIT protection creates some overhead during dynamic re-programming, however it adds an additional protection level that may be needed in case

different software component need to be executed at the same protection level (the one having access to these control registers -usually level 0-).

6.3.5 Accessing SFRs and GPRs

Once the protection system is activated, a task is not free anymore to access per software any special function register (SFR) unless this is explicitly covered by the address ranges and permissions assigned to this task. This applies to the internal IO area (SFR, ESFR, XSFR) and also to the external IO area (on chip LxBus peripherals or external peripherals). Since the minimum granularity of the address ranges is 256 bytes, the IO space is partitioned into blocks. A task will have access either to one of these blocks with its full set of registers or to none. For example the SFR/ESFR area (1 Kbyte), is divided into four blocks (F000h...F0FFh, F100h...F1FFh, FE00h...FEFFh, FF00h...FFFFh). For the XSFRs area, 4 Kbyte, the space is divided in 16 blocks.

CSFRs are also handled by the protection scheme, but exceptions are required for those CSFRs that are user registers. CSFR that are kept under the protection scheme are:

- PSW (partly), CPUCON1/2, CP, CSP, SP, SPSEG, STKUN, STKOV, TFR, VECSEG.

The USR0/1 bits of PSW, that are user bits, are excluded from the protection scheme. Also the PSW condition flags are excluded. Instructions like JBC/JNBS on the PSW conditions flags can then still be used in user mode. Read accesses to all the PSW fields are allowed.

CSFR that are excluded from the protection mechanism are:

- DPP0/1/2/3, MDL, MDH, MSW, MDC, MAH, MAL, MRW, MCW, QR0/1, QX0/1, IDX0/1, ZEROS, ONES, CPUID.

The DPP registers are handled as user registers to support its re-programming during run time (practice needed for code optimization purposes). When used in this way, it will be responsibility of the software to ensure their right handling, for example saving and restoring them in task switches. CPUID is not strictly a user register, however it is not required to define it as protected since it is anyhow not writable.

GPRs are excluded from the memory protection mechanism. Protection on the DPRAM is however guaranteed since the CP itself is protected. Similarly, GPRs mapped into the Local Register Banks are excluded from the protection mechanism.

6.3.6 Interrupts and PECs Handling

Any interrupt taken by the CPU will switch automatically the protection level to 0. This is valid for peripheral interrupts, debugger interrupts, hardware and software traps. As a consequence Interrupt Service Routines (ISRs) are always started with protection level 0, having usually access to all the system resources. The ISR itself can afterwards reduce the protection level and execute user code with protection restrictions.

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Interrupt requests can be also serviced through PEC transfers, that is, fast data transfers between two memory locations. PEC transfers will be executed by the CPU without protection. Protection can still be ensured through the programming of the PEC control registers that should be only performed under the right protection level, usually in privileged mode (i.e. protection level 0). At the configuration time the software should then check for the correctness of the PEC source and destination pointers (according to the permissions allowed) and the PEC control register. Special care has to be taken when using continuous mode, in this case the software can not take care at the configuration time if the PEC will not violate an area in the future. Additional run time checks may be needed to support this mode (executed by the privileged software) or this mode will have to be avoided.

6.3.7 Special handling of RETI instruction

The PSW and specially the Protection Level selection flags (PSW.PLO/1) are handled under the protection scheme: explicit writes on the PSW are detected by the hardware and checked if they are triggered under the right protection level. In case the access is not allowed, a trap will be generated and the modification of the PSW will be avoided by the protection logic.

But the PSW can also be modified implicitly by the hardware and this hardware update can hardly be managed by the protection logic. Hardware updates on the PSW.PLO/1 field are triggered by the execution of a RETI instruction. These PSW hardware updates are in principle not critical as long as the PSW (and PSW.PLO/1) value that is taken from the Stack has not been manipulated by any user code. But since there is no possibility to prohibit user code from this possible manipulations (user code may make use of local stacks with write access to it) the only work around is to prohibit un-trusted user code from using the RETI instruction. RETI will be then specially handled as a kind of protected instruction that can only be executed when the protection level 0. This handling is consistent with the fact that interrupts are handled under protection level 0, returning from interrupts should then also be performed under the same level.

6.3.8 Context Switch operations

The Context Switch mechanism is executed in the core with the help of internal instructions that are auto-injected in the pipeline. Usually auto-injected instructions should run with the same protection level as the instruction causing the auto injection. However, due to the fact that the context switch is an interruptible operation and its completion may be delayed in certain situations, these context switch auto injected instructions have to be executed without considering protection. That means, while they are executed, the protection checks are not performed and/or are ignored. As a consequence only the CP update operation, that is not performed by the auto-injected instruction but by the context switch instruction itself, is performed under the protection scheme. The saving procedure of registers into DPRAM or the read of GPRs from

Memory Protection Unit (MPU)

DPRAM is not performed under the protection scheme. DPRAM protection in this case will have to be ensured, in case it is needed, by the software, the software can check if the region addressed by the values programmed into CP are allowed.

6.3.9 Debugger Access Permissions

The debugger must be able to access all the memory space even if memory protection is active, this includes also the IO space (i.e. SFRs). The OCDS/Cerberus implements basically 2 mechanisms for accessing the system resources:

- triggering the CPU to execute a Monitor Routine that contains the code to access the resources (Call a Monitor)
- Injecting any instruction that can by itself access any resource

When using the first mechanism, that is started by the injection of an ITRAP instruction, the debugger will automatically run in privileged mode, i.e. with protection level 0. As defined in [Chapter 6.3.2.1](#), this is the level automatically entered after an interrupt (in this case after the injection of the debug TRAP instruction).

When using the second mechanism (also if the CPU is halted) the injected instruction will run without protection. The CPU keeps track of the fact that an instruction was injected by the Debugger and disables the protection check for that instruction.

With respect to accessing OCDS/Cerberus/MCDS SFRs by the debugger it just needs to be ensured that the debug monitor (used to program the debug logic) can access these registers with minimum overhead and without any impact on the user code. Since the debug monitor routine will always be executed with protection level 0, it is expected that all the memory space is then allowed. Also accessing these registers via injecting instructions can be performed without restrictions as explained above.

6.3.10 Invalid Access Traps

If an access is performed in a protected area an invalid access trap will be generated. Three traps are defined for this purpose:

MPR Memory Protection, Read

MPW Memory Protection, Write

MPX Memory Protection, Execute

They are defined as Class B traps. They are mapped to TFR.10,9,8 respectively (MPR is TFR.10, MPW is TFR.9 and MPX is TFR.8). Refer to the Hardware Traps description chapter for the complete description of the TFR register.

Note that no trap must be performed on accesses that are performed speculatively, this is why these traps can just be generated when it is known that the instruction is not cancelled anymore (this is, when the instruction goes into the Execute stage).

Memory Protection Unit (MPU)

The already existing trap PRTFLT Protection Fault Trap is also used to indicate the execution of a RETI instruction from a protection level different to 0. Even when RETI causes a protection fault trap, it is normally executed.

6.3.10.1 Cancelling operations

Instructions causing a protection violation will be detected by the MPU but its full execution can not be suppressed, only the writes operations causing a protection fault or derived from an instruction causing a protection fault will be cancelled. Read operations can not be cancelled since they are triggered very soon in the pipeline (sometimes speculatively), however, the read data will not be written by the corresponding instruction in any memory mapped address.

There are some exceptions to the above general rule of cancelling writes operations, in particular, for instructions performing 2 write operations sometimes the first write can not be cancelled. These are the concrete cases:

- SCXT instruction. The write into the Stack can not be avoided when a Read protection violation on the mem operand is detected (for SCXT reg, mem) or a Write protection violation on the reg operand.
- CALLS, PCALL instruction. The first write into the Stack (CSP, or reg in case of PCALL) can not be avoided when a Write protection violation on the second Stack address is detected (where the IP should be pushed). This situation assumes that the Stack has grown over the limit of an allowed area right while executing this instruction (first stack push in an allowed area, second stack push in a non-allowed area).

As a consequence of the fact that Read operations can not be cancelled, destructive reads on the IO space can be still performed even if the MPU detects a protection violation.

As a consequence of the fact that Execute operations can not be cancelled, system instructions and their corresponding actions may be still executed even if they trigger an Execute protection violation. For example an IDLE instruction may still put the CPU in idle mode before the corresponding hardware trap routine can be executed (once the idle mode is left).

6.4 Initializing and using the MPU**6.4.1 Installing Protection**

This chapter describes briefly the SW sequences needed for initializing and using the protection system. It also analyses the overhead created (real time performance). The implementation with 12 ranges is analyzed.

Memory Protection Unit (MPU)

The initialization sequence that can be used for installing protection is:

- Disable Protection in case it is not (after reset protection is disabled), 1 write into PM0.
- Program the Range Registers, 1 PRA write, 24 writes into PRD (absolute maximum value, assumes that all ranges are used).
- Program Protection Mode Registers, 6 PMx writes.
- Enable protection, 1 write into PM0. This last write can be performed together with the write into the PM0 above, but in this case care should be taken to write this register at the end.

When the applications or software components using different protection levels can exactly be mapped to the protection sets implemented, this code sequence would set up the system and no additional overhead when using the MPU would exist during run time. After the initialization phase, whenever a change in the protection level is needed, the corresponding protection set has to be selected (changing PSW.PL). This is the only additional operation during run time.

This initialization, and in general any change in the protection registers, should be performed always having the protection disabled and usually will be executed from protection level 0. Note that in cases where the protection configuration and its activation needs to be immediately seen, the software has to take care that the latest write activating the protection is effective before executing the next affected instruction (by reading for example the latest written register). This is because as explained in [Chapter 6.2.2](#), there is no hardware mechanism to flush the pipeline when the protection is activated.

In case the protection needs can not be mapped into the implemented protection sets, some re-programming during run time is needed. The worst case scenario is that the ranges have to be re-programmed, then a sequence similar to the one during the initialization is needed. However it may be that only some already defined Ranges needs to be activated/deactivated, in this case only the Protection Mode Registers will need to be re-programmed. This assumes that at every moment it is known which ranges are used, so the PSW.PL1/0 has to be read before deciding what to change. An additional overhead during reprogramming is coming from the EINIT protection. After EINIT execution, reprogramming of the PMU registers is only allowed by releasing temporarily this protection by going to an unprotected mode (a command sequence of 4 write instructions with the use of a password is needed for that). After the re-programming the EINIT-protection has to be of course restored (again a command sequence of 4 write instructions). Note that reprogramming of protection registers that are currently not active (i.e. selected through PSW.PL) and do not become active through the reprogramming, is still possible without having to disable protection.

6.4.2 Changing Protection Level

Special care has to be taken when changing the protection level by writing explicitly into PSW. This is because any write into PSW takes effect immediately. If the privileged code handling protection would write into the PSW before performing a code/task switch, the level of the privileged code would be itself changed and eventually the code/task switch (function call for example) couldn't be performed. For avoiding this immediate effect when writing into the PSW some tricks have to be used: stack manipulation and calling functions using the RETI/RETP instructions. The value of the new PSW with the new protection level has to be then stored in the stack, instead of writing the PSW explicitly. The RET instruction will then update the PSW associated to the new task with the correct protection level and at the right time.

6.4.3 Executing privileged code from non-privileged one

It is possible for a non-privileged (un-trusted) software to invoke a privileged software component (trusted). The non-privileged part has to give control to a privileged part, this can be performed by executing a software TRAP instruction. Automatically this instruction will change the protection level to 0. This mechanism allows for example invoking low level drivers from an application software and also returning from the user part of an ISR to the ISR itself, i.e. to the part handle by the OS or software kernel.

6.4.4 Fast task switches

Any task switch that is not controlled by the OS or software kernel will be handled as a trusted task with respect to the software that is invoking it. This is because if the switch is not performed under a software running with enough protection level (usually level 0), there is no possibility to change the protection level explicitly for this task.

6.4.5 Register Bank Selection

Since PSW.BANK field is now handled within the protection scheme, the register bank selection (global or local 1/2) will have to be settled by the software running with enough access permissions, i.e. enough protection level (usually level 0). The bank selection should then be done in the part of the ISR running on level 0 (starting level of all ISRs).

6.4.6 Debugger Use Cases

This chapter documents how to debug the system when memory protection is in use.

The following 4 use cases are identified:

- user wants to find the reason for a MPU trap
- user wants to debug the MPU trap routine
- user doesn't want to debug, he just wants to poll a variable with Cerberus
- user wants to debug without any irregular influence from the protection system

Memory Protection Unit (MPU)

For the first use case, the standard debugging resources (OCDS) can be used for setting an IP breakpoint on the ISR/s handling the trap. Once there, it will be known which access type causes the trap, either implicitly because there are different trap routines depending on the exception type or explicitly by reading the TFR flags. Also the protection level causing the violation can be obtained by reading the stacked PSW. With respect to the IP causing the trap, there is no direct access to it but to the linear following one, that is also stored in the stack.

The second use case, i.e. the debugging of the MPU trap routine, can be done similarly to the debugging of any trap routine and will be started probably also by setting an IP breakpoint on the corresponding ISR.

With respect the third use case, the variable polling action can be performed at any time independently of if the MPU is enabled or not. The debugger has always access to all the system resources even if the MPU is enabled.

The fourth use case, i.e. debugging without influence from the PMU, can be covered by disabling explicitly the MPU (PM0.PROTEN) via the debugger. Since the debugger does not know when the application will enable the MPU after the reset of the system, the debugger will have to monitor the status of the MPU (PMU0.PROTEN) and re-disable it once enabled. This use case is however rather strange because debugging is intended to be done with the real system behavior, if an application causes a MPU exception, this should also be seen during debugging.

7 Interrupt and Exception Control

The architecture of the XE166U supports several mechanisms for fast and flexible response to service requests from various sources internal or external to the micro controller. Different kinds of exceptions are handled in a similar way:

- Interrupts generated by the Interrupt Controller (ITC)
- DMA transfers issued by the Peripheral Event Controller (PEC)
- Traps caused by the TRAP instruction or issued by faults or specific system states

Normal Interrupt Processing

The CPU temporarily suspends the current program execution and branches to an interrupt service routine in order to service an interrupt requesting device. As a result, the current program status (IP, PSW, and, in segmentation mode, also CSP) is saved on the system stack. A prioritization scheme with sixteen priority levels specifies the execution order of multiple interrupt requests.

PEC Interrupt Processing

A faster alternative to normal interrupt processing is the use of the XE166U's integrated **Peripheral Event Controller** (PEC) to service an interrupt requesting device. Triggered by an interrupt request, the PEC performs a single word or byte data transfer between any two memory locations. During a PEC transfer, the normal program execution of the CPU is interrupted only for the data transfer. No internal program status information needs to be saved. The same prioritization scheme is used for PEC service as for normal interrupt processing.

Trap Functions

Trap Functions are activated in response to special conditions that occur during the execution of instructions. A trap can also be caused externally by the External Service Request pins ESRx (e.g. used to implement NMI like behavior). Several hardware trap functions are provided for handling erroneous conditions and exceptions that arise during the program execution. Hardware traps always have highest priority and cause immediate system reaction. The software trap function is invoked by the TRAP instruction that generates a software interrupt for a specified interrupt vector. For all types of traps, the current program status is saved on the system stack.

External Interrupt Processing

The XE166U does not provide dedicated external interrupt input pins but rather allows to configure a subset of its input pins as interrupt inputs. Interrupt (trap) input pins can be chosen from standard inputs or External Service Request pins ESRx. The available options are detailed in the **External Interrupts** section.

Interrupt Sources and Routing

To activate and correctly route an interrupt source programming of the following on-chip components must be considered:

- Interrupt control of each peripheral
- IMB memory controller Interrupt Generation
- SCU External Request Unit (ERU)
- SCU Interrupt Generation

Additionally the port programming must be considered if external interrupt sources are to be used.

7.1 Interrupt System Structure

The XE166U provides 46 separate interrupt nodes assignable to 16 priority levels, with 8 sub-levels (group priority) on each level. In order to support modular and consistent software design techniques, most sources of an interrupt or PEC request are supplied with a separate interrupt control register and an interrupt vector. The control register contains the interrupt request flag, the interrupt enable bit, and the interrupt priority of the associated source. Each source request is then activated by one specific event, determined by the selected operating mode of the respective device. For efficient resource usage, multi-source interrupt nodes are also incorporated. These nodes can be activated by several source requests, such as by different kinds of errors in the serial interfaces. However, specific status flags which identify the type of error are implemented in the respective peripheral control registers. Additional sharing of interrupt nodes is supported via [Interrupt Node Sharing](#).

The XE166U provides a vectored interrupt system. In this system specific vector locations in the memory space are reserved for the reset, trap, and interrupt service functions. Whenever a request occurs, the CPU branches to the location that is associated with the respective interrupt source. The Class B hardware traps all share the same interrupt vector. The status flags in the Trap Flag Register (TFR) can then be used to determine which exception caused the trap. For the special software TRAP instruction, the vector address is specified by the operand field of the instruction, which is a seven bit trap number.

The reserved vector locations build a jump table in the low end of a segment (selected by register VECSEG) in the XE166U's address space. The jump table consists of the appropriate jump instructions which transfer control to the interrupt or trap service routines and which may be located anywhere within the address space. The entries of the jump table are located at the lowest addresses in the selected code segment. Each entry occupies 2, 4, 8, or 16 words (selected by bitfield VECSC in register CPUCON1), providing room for at least one double word instruction. The respective vector location results from multiplying the trap number by the selected step width ($2^{(VECSC+2)}$).

All pending interrupt requests are arbitrated. The arbitration winner is indicated to the CPU together with its priority level and action request. The CPU triggers the corresponding action based on the required functionality (normal interrupt, PEC, jump table cache, etc.) of the arbitration winner.

An action request will be accepted by the CPU if the requesting source has a higher priority than the current CPU priority level and interrupts are globally enabled. If the requesting source has a lower (or equal) interrupt level priority than the current CPU task, it remains pending.

Interrupt and Exception Control

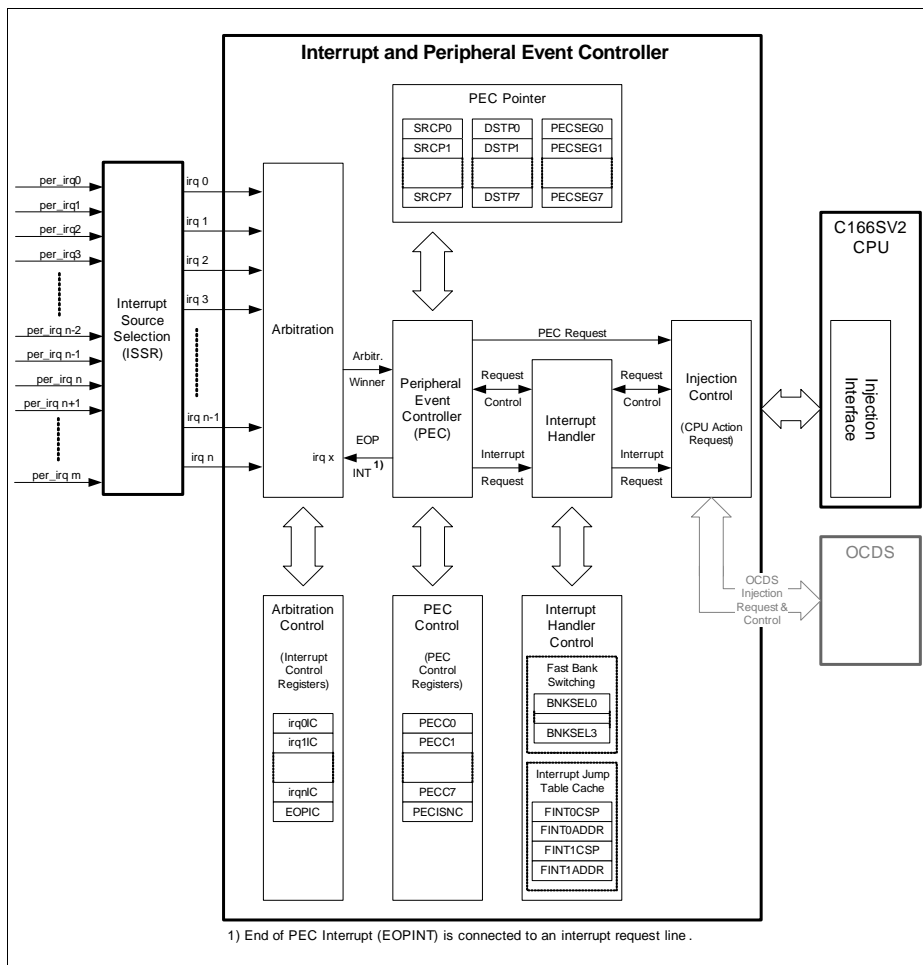


Figure 7-1 Block Diagram of the Interrupt and PEC Controller

7.2 Interrupt Arbitration

The XE166U interrupt arbitration system can handle interrupt requests from up to 46 sources. Interrupt requests may be triggered either by the internal peripherals or by external inputs. The “End of PEC” interrupt for supporting enhanced PEC functionality is connected internally to one of the interrupt request lines.

The arbitration process starts with an enabled interrupt request and stays active for as long as an enabled interrupt request is pending.

Each interrupt request line is controlled by its interrupt control register `xxIC` (here and below `xx` stands for the mnemonic of the respective interrupt source). An interrupt request event sets the interrupt request flag in the corresponding interrupt control register (bit `xxIC.IR`). The interrupt request can also be triggered by the software if the program sets the respective interrupt request bit.

If the request bit has been set and this interrupt request is enabled by the interrupt enable bit of the same control register (bit `xxIC.IE`), an arbitration cycle starts with the next clock cycle. However, if an arbitration cycle is currently in progress, the new interrupt request will be delayed until the next arbitration cycle. If an interrupt request (or PEC request) is accepted by the core, the respective interrupt request flag is cleared automatically.

All interrupt requests pending at the beginning of a new arbitration cycle are considered simultaneous. Within the arbitration cycle, the arbitration is independent of the actual request time.

The XE166U uses a three-stage interrupt prioritization scheme for interrupt arbitration as shown in [Figure 7-2](#).

Interrupt and Exception Control

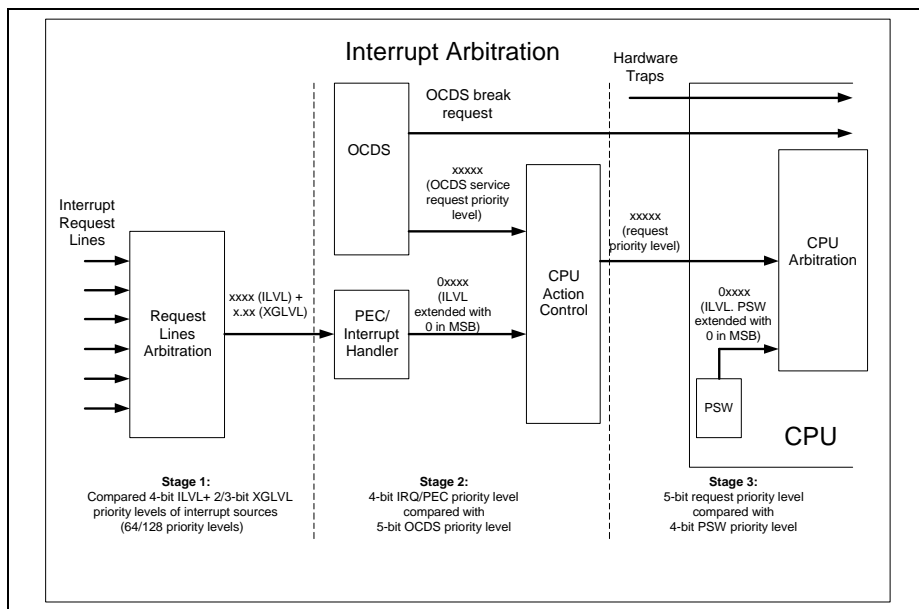


Figure 7-2 Interrupt Arbitration

The first arbitration stage compares the priority levels of interrupt request lines. The priority level of each requestor consists of interrupt priority level and group priority level. An interrupt priority level is programmed for each interrupt request line by the 4-bit bitfield ILVL of respective xxIC register. The group priority level is programmed for each interrupt request line by the 2-bit bitfield GLVL and the extension bit GPX of the register xxIC. Both together, GPX and GLVL form the 3-bit (extended) group priority level XGLVL, controlling up to eight interrupt sub-priorities within one of the 16 interrupt levels.

Note: All interrupt request sources that are enabled and programmed to the same interrupt priority level (ILVL) must have different group priority levels. Otherwise, an incorrect interrupt vector may be generated.

The second arbitration stage compares the priority of the first stage winner with the priority of OCDS service requests. OCDS service requests bypass the first stage of arbitration and go directly to the CPU Action Control Unit. The CPU Action Control Unit disregards the group priority level of interrupt/PEC requests and deals only with interrupt priority levels (ILVL). To compare with OCDS service request priority programmed by 5-bit value, the 4-bit ILVL of the interrupt/PEC request is extended to a 5-bit value with MSB equal to 0. This means that any OCDS request with MSB=1 will always win the second stage arbitration. However, if there is an OCDS request with MSB=0 conflicting with the same priority interrupt/PEC request, the latter is sent to the CPU.

Interrupt and Exception Control

On the third arbitration stage, the priority level of the second stage winner is compared with the priority of the current CPU task. An action request will be accepted by the CPU if the requesting source has a higher priority level than the current CPU priority level (bits ILVL of the PSW register) and interrupts are globally enabled by the global interrupt enable flag IEN in PSW. The CPU denies all requests in case of a cleared IEN flag. To compare with the 5-bit priority level of the second stage winner, the 4-bit ILVL.PSW is extended to a 5-bit value with MSB equal to 0. This means that any request with MSB=1 will always win the arbitration against any CPU level. If the requester has a lower or equal priority level than current CPU task, the request stays pending.

Note: Priority level 0000_B is the default level of the CPU. Therefore, a request on interrupt priority level 0000_B will be arbitrated, but the CPU will never accept an action request on this level. However, every enabled interrupt request (including a denied interrupt request and a priority level 0000_B request) triggers a CPU wake-up from idle state independent of setting the global interrupt enable bit PSW.IEN.

7.3 Interrupt Control

This section describes:

- interrupt control registers
- how to temporarily or selectively disable interrupts
- concept of interrupt class management

7.3.1 Interrupt Control Registers

All interrupt control registers are organized identically. The lower nine bits of an interrupt control register contain the complete interrupt control and status information of the associated source required during one round of prioritization (arbitration cycle). The upper seven bits of the respective register are reserved. All interrupt control registers are bit addressable and all control bits can be read or written via software. Therefore, each interrupt source can be programmed or modified with just one instruction. In the case of reading the interrupt control registers with instructions that operate with word data types, the upper 7 bits (15...9) will return zeros. It is recommended to always write zeros to these bit positions.

The IR bit of any IC register is of type “rwh” and is set by hardware upon occurrence of an interrupt. If the software requires to write to the IC register while the interrupt source is enabled the software write may conflict with a hardware access to bit IR. To address this conflict scenario all xxIC registers are located in the bit addressable memory area. The use of C166 bit modification instructions is therefore possible and recommended. These instructions provide a special “protection mask” feature which allows to protect IR bit from unintended software write. Refer to CPU Bit Manipulation Unit chapter for details.

The layout of the interrupt control registers shown below is applicable to all xxIC registers.

xxIC															
Interrupt Control Register										(E)SFR (xxxx _H)			Reset Value: 0000 _H		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	GPX	IR	IE	ILVL			GLVL		
r	r	r	r	r	r	r	rw	rwh	rw	rw			rw		

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit

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Field	Bits	Type	Description
IR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
IE	6	rw	Interrupt Enable Control Bit (individually enables/disables a specific source) 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level
0	[15:9]	r	Reserved read as 0; should be written with 0.

When accessing interrupt control registers through instructions which operate on word data types, their upper 7 bits (15 ... 9) will return zeros when read, and will discard written data. It is recommended to always write zeros to these bit positions.

The **Interrupt Request Flag** is set by hardware whenever a service request from its respective source occurs. It is cleared automatically upon entry into the interrupt service routine or upon a PEC service. In the case of PEC service, the Interrupt Request flag remains set if the COUNT field in register PECCx of the selected PEC channel decrements to zero and bit EOPINT is cleared. This allows a normal CPU interrupt to respond to a completed PEC block transfer on the same priority level.

Note: Modifying the Interrupt Request flag via software causes the same effects as if it had been set or cleared by hardware.

The **Interrupt Enable Control Bit** determines whether the respective interrupt node takes part in the arbitration process (enabled) or not (disabled). The associated request flag will be set upon a source request in any case. The occurrence of an interrupt request can so be polled via xxIR even while the node is disabled.

Note: In this case the interrupt request flag xxIR is not cleared automatically but must be cleared via software.

7.3.2 Interrupt Priority Level and Group Level

The four bits of bitfield ILVL specify the priority level of a service request for the arbitration of simultaneous requests. The priority increases with the numerical value of ILVL: so, 0000_B is the lowest and 1111_B is the highest priority level.

When more than one interrupt request on a specific level becomes active at the same time, the values in the respective bitfields GPX and GLVL are used for second level arbitration to select one request to be serviced. Again, the group priority increases with the numerical value of the concatenation of bitfields GPX and GLVL, so 000_B is the lowest and 111_B is the highest group priority.

Note: All interrupt request sources enabled and programmed to the same priority level must always be programmed to different group priorities. Otherwise, an incorrect interrupt vector will be generated.

Upon entry into the interrupt service routine, the priority level of the source that won the arbitration and whose priority level is higher than the current CPU level, is copied into bitfield ILVL of register PSW after pushing the old PSW contents onto the stack.

The interrupt system of the XE166U allows nesting of up to 15 interrupt service routines of different priority levels (level 0 cannot be arbitrated).

Interrupt requests programmed to priority levels 15 ... 8 (i.e., ILVL = 1XXX_B) can be serviced by the PEC if the associated PEC channel is properly assigned and enabled (please refer to [Section 7.10.5](#)). Interrupt requests programmed to priority levels 7 through 1 will always be serviced by normal interrupt processing.

7.3.3 General Interrupt Control Functions in Register PSW

The acceptance of an interrupt request depends on the current CPU priority level (bitfield ILVL in register PSW) and the global interrupt enable control bit IEN in register PSW (see CPU Chapter).

CPU Priority ILVL defines the current level for the operation of the CPU. This bitfield reflects the priority level of the routine currently executed. Upon entry into an interrupt service routine, this bitfield is updated with the priority level of the request being serviced. The PSW is saved on the system stack before the request is serviced. The CPU level determines the minimum interrupt priority level which will be serviced. Any request on the same or a lower level will not be acknowledged. The current CPU priority level may be adjusted via software to control which interrupt request sources will be acknowledged. PEC transfers do not really interrupt the CPU, but rather “steal” a single cycle, so PEC services do not influence the ILVL field in the PSW.

Hardware traps switch the CPU level to maximum priority (i.e. 15) so no interrupt or PEC requests will be acknowledged while an exception trap service routine is executed.

Note: The TRAP instruction does not change the CPU level, so software invoked trap service routines may be interrupted by higher requests.

Interrupt and Exception Control

Interrupt Enable bit IEN globally enables or disables PEC operation and the acceptance of interrupts by the CPU. When IEN is cleared, no new interrupt requests are accepted by the CPU. When IEN is set to 1, all interrupt sources, which have been individually enabled by the interrupt enable bits in their associated control registers, are globally enabled. Traps are non-maskable and are, therefore, not affected by the IEN bit.

Note: To generate requests, interrupt sources must be also enabled by the interrupt enable bits in their associated control register.

Register Bank Select bitfield BANK defines the currently used register bank for the CPU operation. When the CPU enters an interrupt service routine, this bitfield is updated to select the register bank associated with the serviced request:

- Requests on priority levels 15 ... 12 use the register bank pre-selected via the respective bitfield GPRSELx in the corresponding BNKSEL register
- Requests on priority levels 11 ... 1 always use the global register bank, i.e. BANK = 00_B
- Hardware traps always use the global register bank, i.e. BANK = 00_B
- The TRAP instruction does not change the current register bank

7.3.4 Selective Interrupt Disabling

Interrupt requests may be temporarily disabled and enabled during the execution of the software. This may be required to exclude specific interrupt sources based on the current status of the application. In particular, this is necessary to achieve a deterministic execution of time-critical code sequences.

Interrupt requests in the XE166U can be disabled and enabled on three different levels:

- Disable all interrupt requests for a certain code sequence
- Disable all interrupt requests globally
- Disable single interrupt requests

The ATOMIC and EXTend instructions automatically disable all interrupt requests for the duration of the following 1 ... 4 instructions. This is useful for semaphore handling, for example, and does not require to re-enable the interrupt system after the inseparable instruction sequence.

Global interrupt control is achieved with a single instruction:

```
BCLR IEN ;Clear IEN flag (causes pipeline restart)
```

Specific interrupt control is achieved by controlling the enable bits in the associated interrupt control registers.

```
BCLR T2IE ;Clear enable flag to disable intr.node
```

Due to pipeline effects, however, an interrupt request may be executed after the corresponding node was disabled, if the request coincides with clearing the enable flag.

If the application must avoid this, the following sequence can be used, ensuring that no interrupt requests from this source will be serviced after disabling the interrupt node:

Interrupt and Exception Control

```

BCLR IEN                ;Globally disable interrupts
BCLR T2IE               ;Disable Timer 2 interrupt node
JNB T2IE, Next          ;Any instruction reading T2IC can be used
Next:                   ;(assures that T2IC is written by BCLR
                        ;before being read by JNB or other instr.)
BSET IEN                ;Globally enable interrupts again

```

Please note that the sequence above blindly controls the global enable flag. If the global setting must not be changed, the code sequence can be enhanced, as shown below:

```

JNB IEN, GlobalIntOff
BCLR IEN                ;Globally disable interrupts
BCLR T2IE               ;Disable Timer 2 interrupt node
JNB T2IE, Next          ;Any instruction reading T2IC can be used
Next:                   ;(assures that T2IC is written by BCLR
                        ;before being read by JNB or other instr.)
BSET IEN                ;Globally enable interrupts again
JMPR cc_uc, Continue
GlobalIntOff:           ;Interrupts are globally disabled anyway
BCLR T2IE               ;Disable Timer 2 interrupt node

JNB T2IE, Continue      ;Reading T2IC can be omitted if the next
Continue:               ;few instructions do not set IEN
...

```

The same function can easily be implemented as a C macro:

```

#define Disable_One_Interrupt(IE_bit) \
{if(IEN) {IEN=0; IE_bit=0; while (IE_bit); IEN=1;} else \
{IE_bit=0; while IE_bit);}}

```

Usage Example:

```

Disable_One_Interrupt(T2IE) ; // T2 interrupt enable flag

```

ATOMIC or EXTend sequences preserve the status of the interrupt arbitration when they begin. An accepted request is processed after the ATOMIC/EXTend sequence. Therefore, the following code sequence may not produce the desired result:

```

AvoidThis:
ATOMIC #3
NOP
BCLR T2IE                ;Disable Timer 2 interrupt node
NOP                      ;Timer 2 request may be processed
                        ;after this instruction!!!

```

7.3.5 Interrupt Class Management

An interrupt class covers a set of interrupt sources with the same importance, i.e. the same priority from the system's viewpoint. Interrupts of the same class must not interrupt each other. The XE166U supports this function with two features:

- **Classes with up to eight members** can be established by using the same interrupt priority (ILVL) and assigning a dedicated group level to each member. This functionality is built-in and handled automatically by the interrupt controller.
- **Classes with more than eight members** can be established by using a number of adjacent interrupt priorities (ILVL) and the respective group levels (eight per ILVL). Each interrupt service routine within this class sets the CPU level to the highest interrupt priority within the class. All requests from the same or any lower level are blocked now, i.e. no request of this class will be accepted.

The example shown below establishes 3 interrupt classes which cover 2 or 3 interrupt priorities, depending on the number of members in a class. A level 6 interrupt disables all other sources in class 2 by changing the current CPU level to 8, which is the highest priority (ILVL) in class 2. Class 1 requests or PEC requests are still serviced, in this case.

In this way, the interrupt sources (excluding PEC requests) are assigned to 3 classes of priority rather than to 7 different levels, as the hardware support would do.

Table 7-1 Software Controlled Interrupt Classes (Example)

ILVL (Priority)	Group Level								Interpretation
	7	6	5	4	3	2	1	0	
15									PEC service on up to 8 channels
14									
13									
12	X	X	X	X	X	X	X	X	Interrupt Class 1 9 sources on 2 levels
11	X								
10									
9									Interrupt Class 2 17 sources on 3 levels
8	X	X	X	X	X	X	X	X	
7	X	X	X	X	X	X	X	X	
6	X								
5	X	X	X	X	X	X	X	X	Interrupt Class 3 9 sources on 2 levels
4	X								
3									
2									

Interrupt and Exception Control

Table 7-1 Software Controlled Interrupt Classes (Example) (cont'd)

ILVL (Priority)	Group Level								Interpretation
	7	6	5	4	3	2	1	0	
1									
0									No service!

7.4 Interrupt Vector Table

The XE166U provides a vectored interrupt system. This system reserves a set of specific memory locations, which are accessed automatically upon the respective trigger event. Entries for the following events are provided:

- Reset (hardware, software, watchdog)
- Traps (hardware-generated by fault conditions or via TRAP instruction)
- Interrupt service requests

Whenever a request is accepted, the CPU branches to the location associated with the respective trigger source. This vector position directly identifies the source causing the request, with the following exceptions:

- Class B hardware traps all share the same interrupt vector. The status flags in the Trap Flag Register (TFR) are used to determine which exception caused the trap. For details, see [Section 7.9](#).
- An interrupt node may be shared by several interrupt requests, e.g. within a module. Additional flags identify the requesting source, so the software can handle each request individually. For details, see [Section 7.14.2](#).
- The interrupt jump cache feature is used. For details, see [Section 7.5](#)

The reserved vector locations build a vector table located in the address space of the XE166U. The vector table usually contains the appropriate jump instructions that transfer control to the interrupt or trap service routines. These routines may be located anywhere within the address space. The location and organization of the vector table is programmable.

The Vector Segment register VECSEG defines the segment of the Vector Table (can be located in all segments, except for reserved areas).

Bitfield VECSC in register CPUCON1 defines the space between two adjacent vectors (can be 2, 4, 8, or 16 words). For a summary of register CPUCON1, please refer to CPU Chapter.

Each vector location has an offset address to the segment base address of the vector table (given by VECSEG). The offset can be easily calculated by multiplying the vector number with the vector space programmed in bitfield VECSC.

Table 7-9 lists all sources capable of requesting interrupt or PEC service in the XE166U, the associated interrupt vector locations, the associated vector numbers, and the associated interrupt control registers.

Note: Interrupt nodes which are not used by their associated modules or are not connected to a module in the actual derivative may be used to generate software controlled interrupt requests by setting the respective IR flag.

Interrupt and Exception Control

VECSEG

Vector Segment Pointer

SFR(FF12_H)

Reset Value: 00XX_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0								
r	r	r	r	r	r	r	r								

VECSEG

rwh

Field	Bits	Type	Description
VECSEG	[7:0]	rwh	Segment number of the Vector Table
0	[15:8]	r	Reserved read as 0; should be written with 0.

The initial user value of register VECSEG is configured according to settings made for [Startup Configuration and Bootstrap Loading](#).

7.5 Interrupt Jump Table Cache

The mechanism that uses the vector table location as the entry point for the interrupt service routines can be overwritten by the Interrupt Controller (ITC). For a very fast interrupt response time, the XE166U offers the Interrupt Jump Table Cache (also called “fast interrupt”). The ITC can transfer to the CPU a 24-bit vector which is directly used as a start address for the service routine. This feature skips the path through the vector table which normally saves the execution of at least one branch. Therefore, avoiding the vector table may significantly improve interrupt response time. However, the number of 24-bit vectors in the ITC is limited.

Fast interrupt is available for two interrupt sources with interrupt priority levels greater than or equal to 12. The Interrupt Jump Table Cache skips the instruction fetches from the interrupt vector table and executes a direct jump to the interrupt service routines entry point. This feature is controlled by a set of two interrupt jump table cache registers (FINTxCSP, FINTxADDR) for each of the two jump table entries.

Every interrupt jump table cache entry contains an enable bit, an associated arbitration priority level (ILVL and GLVL), and the 24-bit address of the interrupt service routine. Note that only the two lower bits of the interrupt priority level are selectable in the respective control registers. The two upper bits of the interrupt priority level are fixed to 11_B, which limits the allowed interrupt priority level to be greater than or equal to 12.

FINT0CSP

Fast Interrupt Control 0 XSFR(EC00_H) Reset Value: 0000_H

FINT1CSP

Fast Interrupt Control 1 XSFR(EC04_H) Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	0	0	GPX	ILVL	GLVL	SEG									
rw	r	r	rw	rw	rw	rw									

Field	Bits	Type	Description
EN	15	rw	Fast Interrupt Enable 0 _B The interrupt jump table cache is disabled. No fast interrupt is used. 1 _B The interrupt jump table cache is enabled. A fast interrupt (direct jump to the interrupt service routine) is used instead of the normal fetch from the interrupt vector table.

Interrupt and Exception Control

Field	Bits	Type	Description
GPX	12	rw	Group Priority Extension This bit together with bitfield GLVL selects the group priority level (XGLVL) of the associated interrupt jump table cache entry.
ILVL	[11:10]	rw	Interrupt Priority Level This bitfield selects the lower two bits of the interrupt priority level associated with this interrupt jump table cache entry. <i>Note: The two upper bits of the interrupt priority level are fixed to 11_B, which ends in an interrupt priority level greater than or equal to 12.</i>
GLVL	[9:8]	rw	Group Priority Level This bitfield together with GPX-bit selects the group priority level (XGLVL) of the associated interrupt jump table cache entry.
SEG	[7:0]	rw	Segment Number of Interrupt Service Routine Address bits 23:16 of the interrupt service routine's entry point.
0	[14:13]	r	Reserved read as 0; should be written with 0.

FINT0ADDR

Fast Interrupt Address 0

XSFR (EC02_H)

Reset Value: 0000_H

FINT1ADDR

Fast Interrupt Address 1

XSFR (EC06_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDR															0
rw															r

Field	Bits	Type	Description
ADDR	[15:1]	rw	Address of Interrupt Service Routine Address bits 15:1 of the interrupt service routine's entry point.

Interrupt and Exception Control

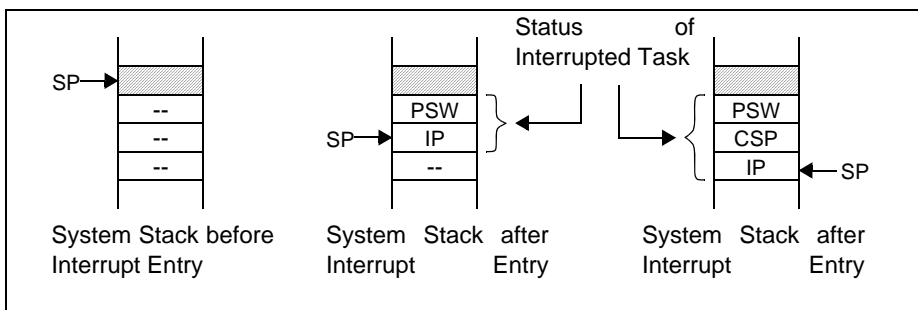
Field	Bits	Type	Description
0	0	r	Interrupt Service Routine Address Bit 0 LSB of the interrupt service routine's entry point address. This address bit is always 0 because of the program code's word alignment.

7.6 CPU Status Saving

Before an interrupt request that has been arbitrated is actually serviced, the status of the current task is automatically saved on the system stack. The CPU status (PSW) is saved together with the location at which execution of the interrupted task is to be resumed after returning from the service routine. This return location is specified through the Instruction Pointer (IP) and, in the case of a segmented memory model, the Code Segment Pointer (CSP). Bit SGTDIS in register CPUCON1 controls how the return location is stored.

- The system stack receives the PSW first, followed by the IP (unsegmented), or followed by CSP and then IP (segmented mode). This optimizes the usage of the system stack if segmentation is disabled.
- The CPU priority field (ILVL in PSW) is updated with the priority of the interrupt request to be serviced, so the CPU now executes on the new level.
- The register bank select field (BANK in PSW) is changed to select the register bank associated with the interrupt request. The association between interrupt requests and register banks are partly pre-defined and can partly be programmed.
- The interrupt request flag of the source being serviced is cleared. IP and CSP are loaded with the vector associated with the requesting source, and the first instruction of the service routine is fetched from the vector location which is expected to branch to the actual service routine (except when the interrupt jump table cache is used). All other CPU resources, such as data page pointers and the context pointer, are not affected.

When the interrupt service routine is exited (RETI is executed), the status information is popped from the system stack in the reverse order, taking into account the value of bit SGTDIS.



Task Status saved on the System Stack

7.7 CPU Context Switch

An interrupt service routine usually saves all the registers it uses on the stack and restores them before returning. To ease this process the XE166U allows switching the complete bank of CPU registers (GPRs) either automatically or with a single instruction, so that the service routine executes within its own separate context (see also CPU Chapter).

There are two ways to switch context:

1. **Context switch on interrupt** automatically updates bitfield PSW.BANK to select one of the two local register banks or the current global register bank, so the service routine may now use its “own registers” directly. This local register bank is preserved when the service routine is terminated; thus, its contents are available on the next call. For interrupt priority levels 15 ... 12 the target register bank can be pre-selected. The register bank selection registers BNKSELx provide a 2-bit field for each priority level. The respective bitfield is then copied to bitfield BANK in register PSW to select the register bank, as soon as the respective interrupt request is accepted.
2. **Explicit context switch by software** is initiated by a write to CP or PSW registers.
 - a) A write to PSW.BANK bitfields allows to switch between global and local banks.
 - b) A write to CP allows to relocate the memory mapped global bank to another memory location.

For example the instruction “SCXT CP, #New_Bank” pushes the contents of the context pointer (CP) on the system stack and loads CP with the immediate value “New_Bank”. The new CP value sets a new global register bank. The service routine may now use its “own registers”. This global register bank is preserved when the service routine is terminated, i.e. its contents are available for the next call. Before returning (RETI), the previous CP simply be restored from the system stack using “POP CP”.

Note: Other resources used by an interrupting program (like DPP registers) must be saved and restored separately.

Note: There are certain timing restrictions during context switching associated with pipeline behavior.

7.8 Fast Bank Switching

The interrupt handler supports an additional enhanced feature (compared to the C166 family) for normal interrupts called Fast Bank Switching. To speed up interrupt handling, the core can use fast General Purpose Register (GPR) bank switching for interrupts with an interrupt level greater or equal than 12. For every arbitration priority level with $[ILVL = '15_D'-'12_D$ and $XGLVL = '7_D'-'0_D']$, the register bank can be selected with two bits. The select-bits are located in the four register bank selection registers BNKSELx (x = 0...3).

The following table identifies the arbitration priority level assignment to the respective bit fields within the four register bank selection registers:

Table 7-2 Register Bank Assignment

ILVL	XGLVL	Assigned GPRSELx Register	ILVL	XGLVL	Assigned GPRSELx Register
15	7	BNKSEL3.GPRSEL7	13	7	BNKSEL2.GPRSEL7
15	6	BNKSEL3.GPRSEL6	13	6	BNKSEL2.GPRSEL6
15	5	BNKSEL3.GPRSEL5	13	5	BNKSEL2.GPRSEL5
15	4	BNKSEL3.GPRSEL4	13	4	BNKSEL2.GPRSEL4
15	3	BNKSEL1.GPRSEL7	13	3	BNKSEL0.GPRSEL7
15	2	BNKSEL1.GPRSEL6	13	2	BNKSEL0.GPRSEL6
15	1	BNKSEL1.GPRSEL5	13	1	BNKSEL0.GPRSEL5
15	0	BNKSEL1.GPRSEL4	13	0	BNKSEL0.GPRSEL4
14	7	BNKSEL3.GPRSEL3	12	7	BNKSEL2.GPRSEL3
14	6	BNKSEL3.GPRSEL2	12	6	BNKSEL2.GPRSEL2
14	5	BNKSEL3.GPRSEL1	12	5	BNKSEL2.GPRSEL1
14	4	BNKSEL3.GPRSEL0	12	4	BNKSEL2.GPRSEL0
14	3	BNKSEL1.GPRSEL3	12	3	BNKSEL0.GPRSEL3
14	2	BNKSEL1.GPRSEL2	12	2	BNKSEL0.GPRSEL2
14	1	BNKSEL1.GPRSEL1	12	1	BNKSEL0.GPRSEL1
14	0	BNKSEL1.GPRSEL0	12	0	BNKSEL0.GPRSEL0

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BNKSEL0

Register Bank Selection 0 **XSFR(EC20_H)** **Reset Value: 0000_H**

BNKSEL1

Register Bank Selection 1 **XSFR(EC22_H)** **Reset Value: 0000_H**

BNKSEL2

Register Bank Selection 2 **XSFR(EC24_H)** **Reset Value: 0000_H**

BNKSEL3

Register Bank Selection 3 **XSFR(EC26_H)** **Reset Value: 0000_H**



Field	Bits	Type	Description
GPRSEL0, GPRSEL1, GPRSEL2, GPRSEL3, GPRSEL4, GPRSEL5, GPRSEL6, GPRSEL7	[1:0], [3:2], [5:4], [7:6], [9:8], [11:10], [13:12], [15:14]	rw	Register Bank Selection 00 _B Global register bank 01 _B Reserved 10 _B Local register bank 1 11 _B Local register bank 2

Note: The GPRSELx value of the current triggered interrupt is automatically transferred into the Program Status Word (PSW).

:

7.9 Trap Functions

The C166SV2 CPU supports software and hardware trap functions.

7.9.1 Software Traps

The TRAP instruction is used to cause a software call to an interrupt service routine. The trap number specified in the operand field of the trap instruction determines which vector location of the vector table will be used.

The TRAP instruction has an effect similar to an interrupt request at the same vector. PSW, CSP (in segmentation mode), and IP are pushed into the system stack and then a jump is taken to the specified vector location. When a software trap is executed, the CSP for the trap service routine is loaded with the value of the VECSEG register. No Interrupt Request flags are affected by the TRAP instruction. The interrupt service routine called by a TRAP instruction must be terminated with a RETI (return from interrupt) instruction to ensure correct operation.

Note: The CPU priority level and the selected register bank in PSW register are not modified by the TRAP instruction; so, the service routine is executed with the same priority level as the interrupt task. Therefore, the service routine entered by the TRAP instruction can be interrupted by other traps or by higher priority interrupts, unless triggered by a real hardware event. The service routine also works with an unchanged register bank. If the hardware triggers the same service routine, register bank can be selected by the ITC and may be different.

Note: Software traps are also generated and issued, when data reads from the internal program memory space are requested which are not allowed, e.g. a user-read access to the protected Flash.

7.9.2 Hardware Traps

Hardware Traps are issued by faults or specific system states that occur during runtime (not identified at assembly time). The XE166U distinguishes twelve different hardware trap functions. When a hardware trap condition has been detected, the CPU branches to the trap vector location for the respective trap condition. The instruction causing the trap event is completed before the trap handling routine is entered.

Hardware traps are not-maskable and always have a priority higher than any other CPU task. If several hardware trap conditions are detected within the same instruction cycle, the highest priority trap is serviced (see [Table 7-3](#)). In case of a hardware trap, the injection unit injects a ITRAP instruction into the pipeline. The ITRAP instruction performs the following actions:

- Push PSW, CSP (in segmented mode) and IP into the System Stack
- Set CPU level in the PSW register to the highest possible priority level, which disables all interrupts and PEC transfers
- Select the global register bank for the trap service routine
- Branch to the trap vector location specified by the trap number of the trap condition

The hardware trap functions of the core are divided in two classes.

Class A traps are

- System Request 0 (SR0)
- Stack Overflow
- Stack Underflow
- Software Break

These traps share the same trap priority, but have an individual vector address.

Class B traps are

- System Request 1 (SR1)
- Memory Protection
- Undefined Opcode
- Memory Access Error
- Protection Fault
- Illegal Word Operand Access

The Class B traps share the same interrupt node and interrupt vector. The bit addressable Trap Flag Register (TFR) allows a trap service routine to identify the trap which caused the exception.

Note: The trap service routine must clear the respective trap flag; otherwise, a new trap will be requested after exiting the service routine. Setting a trap request flag by software causes the same effects as if it had been set by hardware.

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The reset functions (hardware, software, watchdog) may be also regarded as a type of trap. Reset functions have the highest priority (trap priority III). Class A traps have the second highest priority (trap priority II), on the 3rd rank are class B traps (trap priority I); thus, a class A trap can interrupt a class B trap (for priority see also [Table 7-3](#)).

Class A Traps

Class A traps are generated by the high priority system request SR0 or by special CPU events such as the software break, a stack overflow, or an underflow event. Class A traps are not used to indicate hardware failures. After a class A event, a dedicated service routine is called to react to the events. Each class A trap has its own vector location in the vector table. After finishing the service routine, the instruction flow must be further correctly executed. This explains why class A traps cannot interrupt atomic/extend sequences and IO accesses in progress. For example, an interrupted extend sequence cannot be restarted.

All class A traps are generated in the pipeline during the execution of instructions, with the exception of SR0, which is an asynchronous external event. It is not possible for two different instructions in the pipeline to generate traps in the same CPU cycle. Class A trap events can be generated only during the memory stage of execution. An execution of instruction which caused a class A trap event is always completed. In the case of a class A trap, the pipeline is directly canceled and the IP of the instruction following the last executed one is pushed into the stack. In the case of an atomic/extend sequence or IO read access in progress, the execution continues till the sequence completion. Upon completion of the sequence, the IP of the instruction following the last one executed is pushed into the stack. Therefore, in the case of a class A trap, the stack always contains the IP of the first not-executed instruction in the instruction flow.

Note: The Branch Folding Unit allows an execution of branch instructions in parallel with the preceding instruction. The pre-processed branch instruction is combined with the preceding instruction. The branch is executed together with the instruction which caused the Class A trap. The IP of the first following not-executed instruction in the instruction flow is then pushed into the stack.

If more than one Class A trap occurs at a same time, they are prioritized internally. The SR0 trap has the highest priority and the software break has the lowest.

Note: In the case of two different class A trap occurring simultaneously, both trap flags are set. The IP of the instruction following the last one executed is pushed into the stack. The trap with the higher priority is executed. After return from the service routine, the IP is popped from the stack and immediately pushed again because of the other pending class A trap (unless the trap related to the second trap flag in TFR has been cleared by the first trap service routine).

Class B Traps

Class B traps are generated by unrecoverable hardware failures. In the case of a hardware failure, the CPU must immediately start a failure service routine. Class B traps can interrupt an atomic/extend sequence and an IO read access. After finishing the class B service routine, a restoration of the interrupted instruction flow is not possible.

All Class B traps have the same priority (trap priority I). When several class B traps become active at the same time, the corresponding flags in the TFR register are set and the trap service routine is entered. Because all class B traps have the same vector, the priority of service of simultaneously occurring class B traps is determined by the software in the trap service routine.

All class B traps are synchronous to instruction execution; most of them are generated in the pipeline during the execution of instructions. It is not possible for two different instructions in the pipeline to generate class A and class B traps in the same CPU cycle. Class B trap events can be generated only during memory stage execution. SR1 and ACER are exceptions, because they are generated by the SCU.

Instructions which caused a class B trap event are always executed. In the case of a class B trap, the pipeline is directly canceled and the IP of the instruction following the one which caused the trap is pushed on the stack. Therefore, the stack always contains the IP of the first following not executed instruction in the instruction flow.

Note: The Branch Folding Unit allows the execution of branch instructions in parallel with the preceding instruction. The pre-processed branch instruction is combined with the preceding instruction. The branch is executed together with the instruction causing the Class B trap. The IP of the first following not executed instruction in the instruction flow is pushed into the stack.

During execution of a class A trap service routine, any class B trap will not be serviced until the class A trap service routine is exited with a RETI instruction. In this case, the class B trap condition is stored in the TFR register, but the IP value of the instruction which caused this trap will be lost.

Note: If a class A trap occurs simultaneously with a class B trap, both trap flags are set. The IP of the instruction following the one which caused the trap is pushed into the stack, and the class A trap is executed. If this occurs during execution of an atomic/extend sequence or IO read access in progress, then the presence of the class B trap breaks the protection of atomic/extend operations and the class A trap will be executed immediately without waiting for the sequence completion. After return from the service routine, the IP is popped from the system stack and immediately pushed again because of the other pending class B trap. In this situation, the restoration of the interrupted instruction flow is not possible.

- **System Request 0 Trap (A):** The control signal is generated by the SCU. See chapter SCU Trap Generation.

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- **Stack Overflow Trap (A):** Whenever the stack pointer is implicitly decremented and if the stack pointer was equal to the value in the stack overflow register STKOV, the STKOF flag in register TFR is set and the CPU will enter the stack overflow trap routine.
- **Stack Underflow Trap (A):** Whenever the stack pointer is implicitly incremented and if the stack pointer was equal to the value in the stack underflow register STKUN, the STKUF flag is set in register TFR, and the CPU will enter the stack underflow trap routine.
- **Software Break Trap (A):** When the instruction currently being executed by the CPU is a SBRK instruction, the SOFTBRK flag is set in register TFR and the CPU enters the software break debug routine. The flag generation of the software break instruction can be disabled by an On-chip Emulation Module. In this case, the instruction only breaks the instruction flow and signals this event to the debugger. The flag is not set and the trap will not be executed.
- **System Request 1 Trap (B):** The control signal is generated by the SCU. See chapter SCU Trap Generation.
- **Memory Protection Traps (B):** When an access violation outside the permitted address ranges is detected. Depending on the access type it is differentiated between Read (MPR), Write (MPW) and Execute (MPX) violations.
- **Undefined Opcode Trap (B):** When the instruction currently being decoded by the CPU does not contain a valid C166SV2 opcode, the UNDOPC flag is set in register TFR and the CPU enters the undefined opcode trap routine. The instruction which causes the undefined opcode trap is executed as a NOP.
- **Memory Access Error (B):** The control signal is generated by the SCU. See chapter SCU Trap Generation.
- **Protection Fault Trap (B):** Whenever one of the special protected instructions is executed where the opcode of that instruction is not repeated twice in the second word of the instruction and the byte following the opcode is not the complement of the opcode, the PRTFLT flag in register TFR is set and the CPU enters the protection fault trap routine. The protected instructions include DISWDT, EINIT, IDLE, PWRDN, SRST, ENWDT and SRVWDT. The instruction which causes the protection fault trap is executed as a NOP. For products supporting MPU, RETI is also defined as a protected instruction in the sense that its execution is only allowed for privileged code, i.e. code executed with protection level 0. This flag is then used to indicate that a RETI instruction was tried to be executed from a protection level different to 0. Note that RETI will be still executed even if it causes a protection fault trap (it is not executed as a NOP).
- **Illegal Word Operand Access Trap (B):** Whenever a word operand read or write access (including Flash commands!) is attempted to an odd byte address, the ILLOPA flag in register TFR is set and the CPU enters the illegal word operand access trap routine.

Interrupt and Exception Control

Trap Vector Locations

Table 7-3 lists the vector locations for hardware traps and the corresponding status flags in register TFR. It also lists the priorities of trap service for those cases in which more than one trap condition might be detected within the same instruction. After any reset (hardware reset, software reset instruction SRST, or reset by watchdog timer overflow) program execution starts at the reset vector at location xx'0000H. Reset conditions have priority over every other system activity and, therefore, have the highest priority (trap priority III).

Software traps may be initiated to any defined vector location. A service routine entered via a software TRAP instruction is always executed on the current CPU priority level which is indicated in bitfield ILVL in register PSW. This means that routines entered via the software TRAP instruction can be interrupted by all hardware traps or higher level interrupt requests.

Table 7-3 Hardware Trap Summary

Exception Condition	Trap Flag	Trap Vector	Vector Location ¹⁾	Vector Number	Trap Priority
Application Reset	—	RESET	xx'0000 _H	00 _H	III
Class A Hardware Traps:					
• System Request 0	SR0	SR0TRAP	xx'0008 _H	02 _H	II
• Stack Overflow	STKOF	STOTRAP	xx'0010 _H	04 _H	II
• Stack Underflow	STKUF	STUTRAP	xx'0018 _H	06 _H	II
• Software Break	SOFTBRK	SBRKTRAP	xx'0020 _H	08 _H	II
Class B Hardware Traps:					
• System Request 1	SR1	BTRAP	xx'0028 _H	0A _H	I
• Memory Protection	MPR/W/X	BTRAP	xx'0028 _H	0A _H	I
• Undefined Opcode	UNDOPC	BTRAP	xx'0028 _H	0A _H	I
• Memory Access Error	ACER	BTRAP	xx'0028 _H	0A _H	I
• Protected Instruction Fault	PRTFLT	BTRAP	xx'0028 _H	0A _H	I
• Illegal Word Operand Access	ILLOPA	BTRAP	xx'0028 _H	0A _H	I

1) Register VECSEG defines the segment where the vector table is located to.

Bitfield VECSC in register CPUCON1 defines the distance between two adjacent vectors. This table represents the default setting, with a distance of 4 (two words) between two vectors.

Interrupt and Exception Control

7.9.2.1 The Trap Flag Register TFR

The XE166U provides a number of trap vectors (class A and class B) which are indicated in the trap flag register TFR.

TFR

Trap Flag Register

SFR(FFAC_H/D6_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SR0	STK OF	STK UF	SOFT BRK	SR1	MPR	MPW	MPX	UND OPC	0	0	AC ER	PRT FLT	ILL OPA	0	0
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	r	r	rwh	rwh	rwh	r	r

Field	Bits	Type	Description
SR0	15	rwh	System request flag 0 0 _B No trigger detected 1 _B The selected condition has been detected
STKOF	14	rwh	Stack overflow flag 0 _B No stack overflow event detected 1 _B The current stack pointer value falls below the contents of register STKOV
STKUF	13	rwh	Stack underflow flag 0 _B No stack underflow event detected 1 _B The current stack pointer value exceeds the contents of register STKUN
SOFTBRK	12	rwh	Software Break 0 _B No software break event detected 1 _B Software break event detected
SR1	11	rwh	System request flag 1 0 _B No trigger detected 1 _B The selected condition has been detected
MPR	10	rwh	Memory Protection Read 0 _B No read protection violation detected 1 _B Read protection violation detected
MPW	9	rwh	Memory Protection Write 0 _B No write protection violation detected 1 _B Write protection violation detected

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Field	Bits	Type	Description
MPX	8	rwh	Memory Protection Execute 0_B No execute protection violation detected 1_B Execute protection violation detected
UNDOPC	7	rwh	Undefined Opcode 0_B No undefined opcode event detected 1_B The currently decoded instruction has no valid opcode
ACER	4	rwh	Memory Access Error 0_B No access error event detected 1_B Illegal or erroneous access detected
PRTFLT	3	rwh	Protection Fault 0_B No protection fault event detected 1_B A protected instruction with an illegal format has been detected
ILLOPA	2	rwh	Illegal word operand access 0_B No illegal word operand access event detected 1_B A word operand access (read or write) to an odd address has been attempted
0	[6:5], [1:0]	r	Reserved read as 0; should be written with 0.

Note: Flags TFR.15, TFR.11 and TFR.4 are generated via SCU. TFR.8, TFR.9 and TFR.10 are generated via MPU. Other flags are generated by the CPU.

7.10 Peripheral Event Controller

The "PEC" feature provides a DMA-like data transfer functionality.

7.10.1 PEC Functionality

The XE166U's Peripheral Event Controller (PEC) provides 8 PEC service channels which can be used to perform the following tasks:

- Repeatable DMA-like data transfers with
 - selectable byte or word data type
 - automatic increment of source and/or destination pointers
 - support of channel linking using two alternating channels
- Interrupt request upon data transfer completion programmable to the
 - interrupt node associated with the PEC channel
 - "End of PEC" interrupt node shared by all PEC channels

Each single PEC transfer is triggered by an interrupt service request. Because of this it is executed only if its priority level is higher than current CPU priority level.

A PEC transfer is the fastest possible interrupt response. In many cases it is sufficient to service peripheral requests (for example, serial channels, etc.). PEC transfers are fast because they are executed by the CPU "on-the-fly". The program flow is not changed by the PEC action itself. Therefore the current program status and context needs not to be saved and restored as with standard interrupts.

7.10.2 Source and Destination Pointers

The PEC channels source and destination pointers specify the locations between which the data is to be moved.

All pointers x are 24-bits wide. The 24-bit source address is stored in the register SRCP x (lower 16 bits of address) and in the high byte of register PECSEG x (highest 8 address bits). The 24-bit destination address is stored in the register DSTP x (lower 16 bits of address) and in the low byte of register PECSEG x (highest 8 address bits).

Only the lower 16 bits of the PEC address pointers (segment offset) can be modified by the PEC Increment Control hardware (programmed by PECC x .INC). The highest 8 bits, which represent the segment number, are not modified by hardware. Therefore, the PEC pointers may be incremented within the address space of one segment and may not cross the segment border. If the offset address pointer reaches FFFF $_H$ in case of byte transfers (BWT = 1) or FFFE $_H$ in case of word transfers (BWT = 0), the next increment will be disregarded. The address register will keep one of these maximum values and no overflow will happen. This behavior protects subsequent memory from unintentional overwriting. No explicit error event is generated by the system in case of address pointer(s) saturation; therefore, it is the user's responsibility to handle this condition.

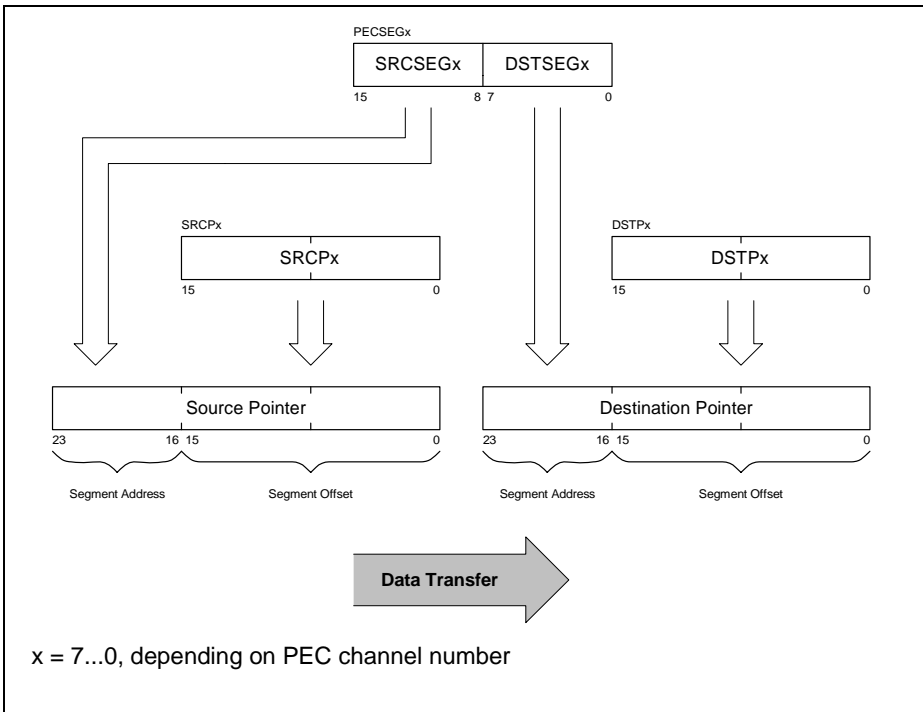


Figure 7-3 PEC Pointer Address Composition

Note: PEC data transfers do not use the data page pointers DPP3...DPP0.

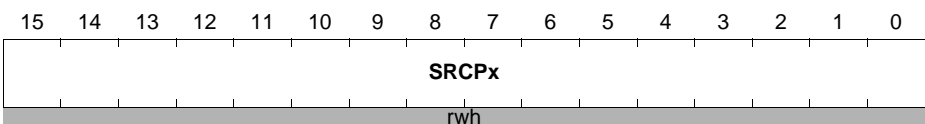
Note: If a word data transfer is selected for a specific PEC channel (i.e. BWT = 0), the respective source and destination pointers must both contain a valid word address which points to an even byte boundary. Otherwise, the Illegal Word Operand Access trap will be invoked when this channel is used.

SRCP_x (x=0-7)

PEC Source Pointer x

XSFR(EC40_H+4*x)

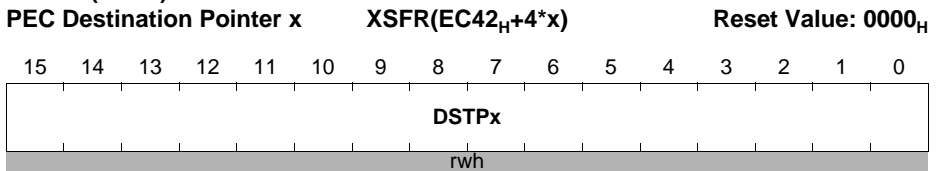
Reset Value: 0000_H



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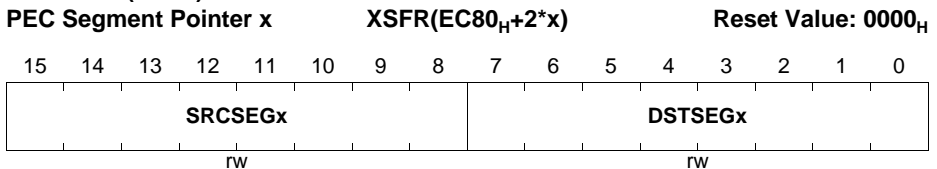
Field	Bits	Type	Description
SRCPx	[15:0]	rwh	Source Pointer Offset of Channel x Source address bits 15 ... 0

DSTPx (x=0-7)



Field	Bits	Type	Description
DSTPx	[15:0]	rwh	Destination Pointer Offset of Channel x Destination address bits 15 ... 0

PECSEGx (x=0-7)



Field	Bits	Type	Description
SRCSEGx	[15:8]	rw	Source Pointer Segment of Channel x Source address bits 23 ... 16
DSTSEGx	[7:0]	rw	Destination Pointer Segment Address of Channel x Destination address bits 23 ... 16

7.10.3 Functional Control

Each PEC channel x is controlled by its respective PEC control register PECCx. The registers are used to program the PECs functional operation mode and associated options. The following operation modes are supported:

- **Short Transfer Mode**
- **Channel Link Mode for Data Chaining**

PECCx (x=0-7)

PEC Channel Control x						SFR(FEC0 _H +2*x)						Reset Value: 0000 _H					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0		
0	EOP INT	PLEV	CL	INC	BWT												
r	rw	rw	rw	rw	rw												

Field	Bits	Type	Description
0	15	r	Reserved read as 0; should be written with 0.
EOPINT	14	rw	End of PEC Interrupt Selection 0 _B End of PEC interrupt with the same level as the PEC transfer is triggered 1 _B End of PEC interrupt is serviced by a separate interrupt node with programmable interrupt level (EOPIC) and interrupt sharing control register (PECISNC)
PLEV	[13:12]	rw	PEC Level Selection 00 _B Interrupt Levels 15 and 14 selected 01 _B Interrupt Levels 13 and 12 selected 10 _B Interrupt Levels 11 and 10 selected 11 _B Interrupt Levels 9 and 8 selected
CL	11	rw	Channel Link Control 0 _B PEC channels work independent 1 _B Pairs of channels are linked together

Interrupt and Exception Control

Field	Bits	Type	Description
INC	[10:9]	rw	Increment Control (Modification of source and destination pointer after PEC transfer) 00 _B No modification 01 _B Increment of destination pointer DSTPx by 1 (BWT = 1) or by 2 (BWT = 0) 10 _B Increment of source pointer SRCPx by 1 (BWT = 1) or by 2 (BWT = 0) 11 _B Increment of destination pointer DSTPx and source pointer SRCPx by 1 (BWT = 1) or by 2 (BWT = 0)
BWT	8	rw	Byte/Word Transfer Selection 0 _B Transfer a word 1 _B Transfer a byte
COUNT	[7:0]	rwh	PEC Short Transfer Count Counts PEC transfers and influences the channel's action (see Table 7-4)

Short Transfer Mode

The PEC transfer count field COUNT controls directly the action of the associated PEC channel according to [Table 7-4](#). Besides the option to have continuous transfers this mode supports up to 254 consecutive transfers.

Table 7-4 Short Transfer Mode Channel Actions

Previous COUNT field value	Modified COUNT field value	Action of PEC Channel and Comments
FF _H	FF _H	Move a Byte/Word Continuous transfer mode, i.e. COUNT is not modified
FE _H ...02 _H	FD _H ...01 _H	Move a Byte/Word and decrement COUNT
01 _H	00 _H	Move a Byte/Word Depending on bit EOPINT, one of two different actions are taken: EOPINT=0 The service request flag (xxIC.IR) of the respective interrupt remains set (it is cleared for all other COUNT values). Therefore, an additional interrupt request is triggered on the next arbitration cycle with a COUNT field value of 00 _H (see next row) EOPINT=1 The service request flag (xxIC.IR) of the respective interrupt is cleared. Additionally, the interrupt request flag of the EOP sub node control register PECISNC.CxIR is set. Furthermore, the interrupt request flag of the end of PEC interrupt node (EOPIC.EOPIR) is automatically set if the sub node request is enabled PECISNC.CxIE = 1'.
00 _H	00 _H	No PEC action! A normal interrupt is requested instead of a PEC data transfer.

Channel Link Mode for Data Chaining

Channel linking, if enabled, links two channels together to commonly serve the same data transfer task.

The whole data transfer (for example a peripheral message) is divided into separately controlled and chained block transfers. The two PEC channels which are linked together, handle chained block transfers alternately to each other. At the end of a data block transfer, controlled by one PEC channel, automatically the other (linked) PEC channel is started to continue the transfer with the next data block.

Channel linking and thus data (block) chaining is supported within pairs of PEC channels (channels 0&1, 2&3 a.s.o.). Each data block is controlled by one PEC channel of the channel pair. While one of the two channels is active, the CPU can update the pointer and counter values of the other channel to prepare it for continuation of data transfer after next channel linking.

Channel linking is enabled, if in the active PEC channel of the channel pair the Channel Link Control Bit "CL" in its PECCx register is set to 1. The data transfer of linked channels is started always with the even numbered channel of the channel pair. If in Channel Link mode (at least one CL bit of the pair is set) the channel's data block is completely transferred the PEC service request processing is automatically switched to the other PEC channel of the channel-pair.

Channel linking and thus the switching from one channel to the other channel is performed, when the CL bit of first (active) channel is set (in its PEC control register) and its transfer count is changed from one to zero with the last transfer. If the channel link flag CL of the first (terminated) PEC control register is found to be zero or if the count field of linked channel is zero, the whole data transfer is finished.

Note: The CL-flags are fully controlled by software and should be cleared by SW when the whole data transfer shall be finished and the termination of transfer shall be executed. Because termination can also be entered with a zero-value of the transfer count field of linked channel, termination of whole data transfer is automatically performed if the channels count field was not updated after the last channel link interrupt for this channel.

When a data block of a linked channel is completely transferred and PEC servicing switches to the other channel of channel pair, a channel specific channel link interrupt is generated (for the old channel) to inform the CPU that the channel is inactive now and may be configured for its next block transfer. The channel link interrupt is requested, indicated and enabled in the respective PEC Interrupt Subnode Control Register (PECISNC), which is also used for the channel's End of PEC interrupt. Thus, all channel link interrupts are also controlled with the one EOP Interrupt Control register EOPIC and therefore with the same interrupt priority level as the EOP interrupt. This service request node requests CPU interrupt service in case of one or more pending channel link interrupt requests or End of PEC interrupt requests, if the respective enable control bit(s)

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is (are) set in the PEC interrupt subnode control register PECISNC and in the interrupt control register EOPIC.

Note: The generation of Channel Link/EOP interrupt is automatically enabled, if the CL-bit of the active (terminated) channel is set. If it is not set, either a standard interrupt or an EOP interrupt is initiated according to the EOPINT bit in the channel's PEC Control Register. The channel is not switched in this case, because a missing CL flag defines the last block of data transfer.

Note: If Channel Link mode is active (at least one of the pair's CL bits is set), interrupt requests connected to the odd channel (via priority levels) will trigger only a standard interrupt but no PEC transfer.

Note: The start of data transfer on linked channels is always performed with the even numbered PEC channel of the channel pair.

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7.10.4 End of PEC Interrupt Control

The EOPIE register is the interrupt control register of the End Of PEC interrupt.

EOPIC

End Of PEC Interrupt Control **ESFR(F19E_H/CF_H)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	GPX	EOP IR	EOP IE	ILVL			GLVL		
r	r	r	r	r	r	r	rw	rwh	rw	rw			rw		

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit
EOPIR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B The source has raised an interrupt request
EOPIE	6	rw	Interrupt Enable Control Bit 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level
0	[15:9]	r	Reserved read as 0; should be written with 0.

PEC Interrupt Sub Node Control Register

The Register PECISNC contains flags of the “End of PEC” interrupt node. This node is used when control bit PECCx.EOPINT=1.

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PECISNC

PEC Interrupt Sub Node Control SFR(FFD8_H/EC_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
C7IR	C7IE	C6IR	C6IE	C5IR	C5IE	C4IR	C4IE	C3IR	C3IE	C2IR	C2IE	C1IR	C1IE	C0IR	C0IE
rwh	rw	rwh	rw	rwh	rw	rwh	rw	rwh	rw	rwh	rw	rwh	rw	rwh	rw

Field	Bits	Type	Description
CxIR (x=0-7)	2*x+1	rwh	Interrupt Sub Node Request Flag of PEC Channel x 0 _B No special end of PEC interrupt request is pending for PEC channel x 1 _B PEC channel x has raised an end of PEC interrupt request
CxIE (x=0-7)	2*x	rw	Interrupt Sub Node Enable Control Bit of PEC Channel x ¹⁾ (individually enables/disables a specific source) 0 _B End of PEC interrupt request of PEC channel x is disabled 1 _B End of PEC interrupt request of PEC channel x is enabled

- 1) It is recommended to clear an interrupt request flag (CxIR) before setting the respective enable flag (CxIE). Otherwise, former requests still pending will immediately trigger an interrupt request after setting the enable bit.

Note: The “End of PEC” sub-node interrupt request flags are not cleared by hardware when entering the interrupt service routine (interrupt has been accepted by the CPU), unlike the interrupt request flags of the interrupt nodes (request flags xxIC.xxIR). The interrupt service routine must check the request flags and clear them before executing the RETI instruction.

Generation of the “End of PEC” interrupt

As shown in [Figure 7-4](#) the request flag of the “End of PEC” interrupt EOPIC.IR can be generated from any of the PEC sub nodes. Single or multiple sub node event(s) produce a single EOPIC.IR trigger. The EOPIC interrupt service routine therefore must evaluate (and reset) all sub node request flags.

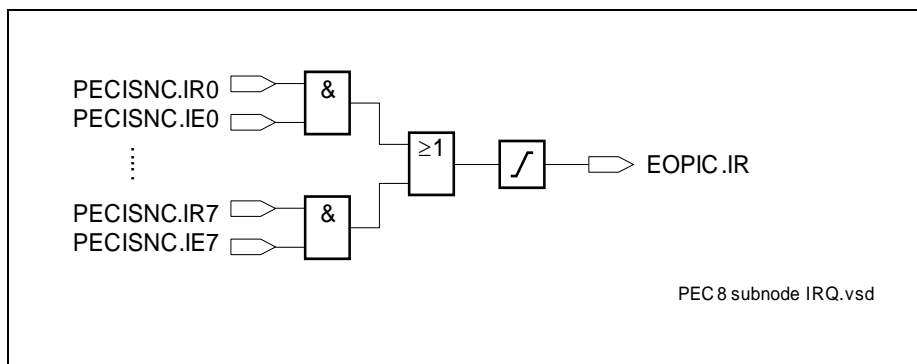


Figure 7-4 End of PEC Interrupt Sub Node

7.10.5 Channel Assignment

All interrupt requests with interrupt priority levels 8 to 15 can be associated with the PEC functionality. The PEC channel used for executing the transfer depends on the programming of the interrupt, group and PEC levels.

Note that the programming of the PEC level (PECC.PLEV - see [Section 7.10.3](#)) and Interrupt level (**xxIC.ILVL**) must match to make the assignment valid. All interrupt requests not assigned to a PEC channel go to the interrupt service routine handler.

The following table lists the possible channel assignments.

Table 7-5 PEC Channel Assignment

ICx.GPX	ICx.ILVL(0)	ICx.GLVL	Assigned PEC Channel
0 _B	1 _B	11 _B	7
0 _B	1 _B	10 _B	6
0 _B	1 _B	01 _B	5
0 _B	1 _B	00 _B	4
0 _B	0 _B	11 _B	3
0 _B	0 _B	10 _B	2

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Table 7-5 PEC Channel Assignment (cont'd)

ICx.GPX	ICx.ILVL(0)	ICx.GLVL	Assigned PEC Channel
0 _B	0 _B	01 _B	1
0 _B	0 _B	00 _B	0

7.11 External Interrupts

Although the XE166U has no dedicated interrupt input pins, it supports many possibilities to react to external asynchronous events by providing a number of IO lines which can be selected as interrupt inputs.

7.11.1 External Request Unit

Please refer to the External Request Unit (ERU) chapter. The ERU provides routing capabilities and allows to define advanced trigger conditions for the interrupt input signals. The resulting ERU interrupt requests are forwarded to the interrupt controller registers ERU_0IC ... ERU_3IC.

7.11.2 Using Peripheral Pins

The interrupt function of some peripheral pins may be either combined with the pin's main function or used instead of it if the main pin function is not required.

Table 7-6 Pins Usable as External Interrupt Inputs

Port Pin	Original Function	Control Register
P2.10-3/CC23-16IO	CAPCOM Register 23-16 Capture Input ¹⁾	CC23-CC16 ¹⁾
P2.10/CAPIN	GPT2 capture input pin ²⁾	T5CON

1) Pin P2.10 overlays two possible input functions.

For each of these pins, either a positive, a negative, or both a positive and a negative external transition can be selected to cause an interrupt or PEC service request. The edge selection is performed in the control register of the peripheral device associated with the respective port pin. The peripheral must be programmed to a specific operating mode to allow generation of an interrupt by the external signal. The priority of the interrupt request is determined by the interrupt control register of the respective peripheral interrupt source, and the interrupt vector of this source will be used to service the external interrupt request.

Note: In order to use any of the listed pins as an external interrupt input, it must be switched to input mode via its port control register.

When port pins CCxIO are to be used as external interrupt input pins, bitfield CCMODx in the control register of the corresponding capture/compare register CCx must select capture mode. When CCMODx is programmed to 001_B, the interrupt request flag CCxIR in register CCxIC will be set on a positive external transition at pin CCxIO. When CCMODx is programmed to 010_B, a negative external transition will set the interrupt request flag. When CCMODx = 011_B, both a positive and a negative transition will set the request flag. In all three cases, the contents of the allocated CAPCOM timer will be latched into capture register CCx, independent of whether or not the timer is running.

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When the interrupt enable bit CCxIE is set, a PEC request or an interrupt request for vector CCxINT will be generated.

Pin CAPIN can be used as external interrupt input pin without affecting peripheral functions. When the capture mode enable bit T5SC in register T5CON is cleared to '0', signal transitions on pin CAPIN will only set the interrupt request flag CRIR in register CRIC, and the capture function of register CAPREL is not activated.

So register CAPREL can still be used as reload register for GPT2 timer T5, while pin CAPIN serves as external interrupt input. Bitfield CI in register T5CON selects the effective transition of the external interrupt input signal. When CI is programmed to 01_B, a positive external transition will set the interrupt request flag. CI = 10_B selects a negative transition to set the interrupt request flag, and with CI = 11_B, both a positive and a negative transition will set the request flag. When the interrupt enable bit CRIE is set, an interrupt request for vector CRINT or a PEC request will be generated.

7.12 OCDS Requests

The OCDS module issues high-priority break requests or standard service requests. The break requests are routed directly to the CPU (like the hardware trap requests) and are prioritized there. Therefore, break requests ignore the standard interrupt arbitration and receive highest priority.

The standard OCDS service requests are routed to the CPU Action Control Unit together with the arbitrated interrupt/PEC requests. The service request with the higher priority is sent to the CPU to be serviced. If both the interrupt/PEC request and the OCDS request have the same priority level, the interrupt/PEC request wins.

This approach ensures precise break control, while affecting the system behavior as little as possible.

The CPU Action Control Unit also routes back request acknowledges and denials from the core to the corresponding requestor.

7.13 Service Request Latency

The numerous service requests of the XE166U (requests for interrupt or PEC service) are generated asynchronously with respect to the execution of the instruction flow. Therefore, these requests are arbitrated and are inserted into the current instruction stream. This decouples the service request handling from the currently executed instruction stream, but also leads to a certain latency.

The request latency is the time from activating a request signal at the interrupt controller (ITC) until the corresponding instruction reaches the pipeline's execution stage.

Table 7-7 lists the consecutive steps required for this process.

Table 7-7 Steps Contributing to Service Request Latency

Description of Step	Interrupt Response	PEC Response
Request arbitration in 3 stages, leads to acceptance by the CPU (see Section 7.2)	3 cycles	3 cycles
Injection of an internal instruction into the pipeline's instruction stream	4 cycles	4 cycles
The first instruction fetched from the interrupt vector table reaches the pipeline's execution stage	4 cycles / 0 ¹⁾	- - -
Resulting minimum request latency	11/7 cycles	7 cycles

1) Can be saved by using the interrupt jump table cache (see [Section 7.5](#)).

Sources for Additional Delays

Because the service requests are inserted into the current instruction stream, the properties of this instruction stream can influence the request latency.

Table 7-8 Additional Delays Caused by System Logic

Reason for Delay	Interrupt Response	PEC Response
Interrupt controller busy, because the previous interrupt request is still in process	max. 7 cycles	max. 7 cycles
Pipeline is stalled, because instructions preceding the injected instruction in the pipeline need to write/read data to/from a peripheral or memory	$2 \times T_{\text{ACCmax}}^{1)}$	$2 \times T_{\text{ACCmax}}$
Pipeline cancelled, because instructions preceding the injected instruction in the pipeline update core SFRs	4 cycles	4 cycles
Memory access for stack writes (if not to DPRAM or DSRAM)	$2/3 \times T_{\text{ACC}}^{2)}$	- - -
Memory access for vector table read (except for intr. jump table cache)	$2 \times T_{\text{ACC}}$	- - -

1) This is the longest possible access time within the XE166U system.

2) Depending on segmentation off/on.

The actual response to an interrupt request may be delayed further depending on programming techniques used by the application. The following factors can contribute:

- Actual interrupt service routine is only reached via a JUMP from the interrupt vector table.
Time-critical instructions can be placed directly into the interrupt vector table, followed by a branch to the remaining part of the interrupt service routine. The space between two adjacent vectors can be selected via bitfield VECSC in register CPUCON1.
- Context switching is executed before the intended action takes place (see [Section 7.7](#))
Time-critical instructions can be programmed “non-destructive” and can be executed before switching context for the remaining part of the interrupt service routine.

7.14 Interrupt Nodes

This section describes the available physical interrupt nodes and how some of the nodes are shared among selected peripherals.

7.14.1 Physical Interrupt Nodes

The full set of enabled and used modules integrated in the XE166U would require more than the 46 interrupt nodes provided by the C166SV2 interrupt controller. Therefore some of the physically available interrupt nodes are shared between selected modules.

The sources selected by ISSR.ISSx are listed in [Section 7.14.2](#).

The following table summarizes the 46 physical interrupt nodes with their related

- trap number
- vector location
- control register name and address
- node sharing information

Table 7-9 XE166U Interrupt Nodes

Source of Interrupt or PEC Service Request	Trap Number	Vector ¹⁾ Location	Control Register	Register Address
selected by SCU_ISSR.ISS0	10 _H	xx'0040 _H	CC2_CC16IC	F1C0 _H
selected by SCU_ISSR.ISS1	11 _H	xx'0044 _H	CC2_CC17IC	F1C2 _H
selected by SCU_ISSR.ISS2	12 _H	xx'0048 _H	CC2_CC18IC	F1C4 _H
selected by SCU_ISSR.ISS3	13 _H	xx'004C _H	CC2_CC19IC	F1C6 _H
selected by SCU_ISSR.ISS4	14 _H	xx'0050 _H	CC2_CC20IC	F1C8 _H
selected by SCU_ISSR.ISS5	15 _H	xx'0054 _H	CC2_CC21IC	F1CA _H
selected by SCU_ISSR.ISS6	16 _H	xx'0058 _H	CC2_CC22IC	F1CC _H
selected by SCU_ISSR.ISS7	17 _H	xx'005C _H	CC2_CC23IC	F1CE _H
selected by SCU_ISSR.ISS8	18 _H	xx'0060 _H	CC2_CC24IC	F1D0 _H
selected by SCU_ISSR.ISS9	19 _H	xx'0064 _H	CC2_CC25IC	F1D2 _H
selected by SCU_ISSR.ISS10	1A _H	xx'0068 _H	CC2_CC26IC	F1D4 _H
selected by SCU_ISSR.ISS11	1B _H	xx'006C _H	CC2_CC27IC	F1D6 _H
selected by SCU_ISSR.ISS12	1C _H	xx'0070 _H	CC2_CC28IC	F1D8 _H
selected by SCU_ISSR.ISS13	1D _H	xx'0074 _H	CC2_CC29IC	F1DA _H
selected by SCU_ISSR.ISS14	1E _H	xx'0078 _H	CC2_CC30IC	F1DC _H
selected by SCU_ISSR.ISS15	1F _H	xx'007C _H	CC2_CC31IC	F1DE _H
GPT1 Timer 2	20 _H	xx'0080 _H	GPT12E_T2IC	FF60 _H

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Table 7-9 XE166U Interrupt Nodes (cont'd)

Source of Interrupt or PEC Service Request	Trap Number	Vector¹⁾ Location	Control Register	Register Address
GPT1 Timer 3	21 _H	xx'0084 _H	GPT12E_T3IC	FF62 _H
GPT1 Timer 4	22 _H	xx'0088 _H	GPT12E_T4IC	FF64 _H
GPT2 Timer 5	23 _H	xx'008C _H	GPT12E_T5IC	FF66 _H
GPT2 Timer 6	24 _H	xx'0090 _H	GPT12E_T6IC	FF68 _H
GPT2 CAPREL	25 _H	xx'0094 _H	GPT12E_CRIC	FF6A _H
CAPCOM2 Timer 7	26 _H	xx'0098 _H	CC2_T7IC	FF6C _H
CAPCOM2 Timer 8	27 _H	xx'009C _H	CC2_T8IC	FF6E _H
A/D Converter Request 0	28 _H	xx'00A0 _H	ADC_0IC	FF70 _H
A/D Converter Request 1	29 _H	xx'00A4 _H	ADC_1IC	FF72 _H
A/D Converter Request 2	2A _H	xx'00A8 _H	ADC_2IC	FF74 _H
A/D Converter Request 3	2B _H	xx'00AC _H	ADC_3IC	FF76 _H
CCU60 Request 0	30 _H	xx'00C0 _H	CCU60_0IC	F160 _H
CCU60 Request 1	31 _H	xx'00C4 _H	CCU60_1IC	F162 _H
CCU60 Request 2	32 _H	xx'00C8 _H	CCU60_2IC	F164 _H
CCU60 Request 3	33 _H	xx'00CC _H	CCU60_3IC	F166 _H
USIC0 CH0 SR0	50 _H	xx'0140 _H	U0C0_0IC	F120 _H
USIC0 CH0 SR1	51 _H	xx'0144 _H	U0C0_1IC	F122 _H
USIC0 CH0 SR2	52 _H	xx'0148 _H	U0C0_2IC	F124 _H
USIC0 CH1 SR0	53 _H	xx'014C _H	U0C1_0IC	F126 _H
USIC0 CH1 SR1	54 _H	xx'0150 _H	U0C1_1IC	F128 _H
USIC0 CH1 SR2	55 _H	xx'0154 _H	U0C1_2IC	F12A _H
SCU External Request 0	68 _H	xx'01A0 _H	ERU_0IC	F190 _H
SCU External Request 1	69 _H	xx'01A4 _H	ERU_1IC	F192 _H
SCU External Request 2	6A _H	xx'01A8 _H	ERU_2IC	F194 _H
SCU Interrupt 1	6B _H	xx'01AC _H	SCU_1IC	F196 _H
SCU Interrupt 0	6C _H	xx'01B0 _H	SCU_0IC	F198 _H
SCU External Request 3	6D _H	xx'01B4 _H	ERU_3IC	F19A _H
RTC	6E _H	xx'01B8 _H	RTC_IC	F19C _H
End of PEC Subchannel	6F _H	xx'01BC _H	EOPIC	F19E _H

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- 1) Register VECSEG defines the segment where the vector table is located to.
Bitfield VECSC in register CPUCON1 defines the distance between two adjacent vectors. This table represents the default setting, with a distance of 4 (two words) between two vectors.

7.14.2 Interrupt Node Sharing

Interrupt source selection is adjustable to the application focus. The concept described in this chapter allows to adjust the focus to be more on control (CAPCOM2) or on communication (USIC) side.

Interrupt node sharing is controlled by SCU register ISSR.

Shared Nodes controlled by ISSR

The following figure visualizes the sharing principle controlled by ISSR register. The default interrupt source is CAPCOM2. The alternate source selections are the SCU interrupts 2 and 3 and the SR3 requests of all USIC channels.

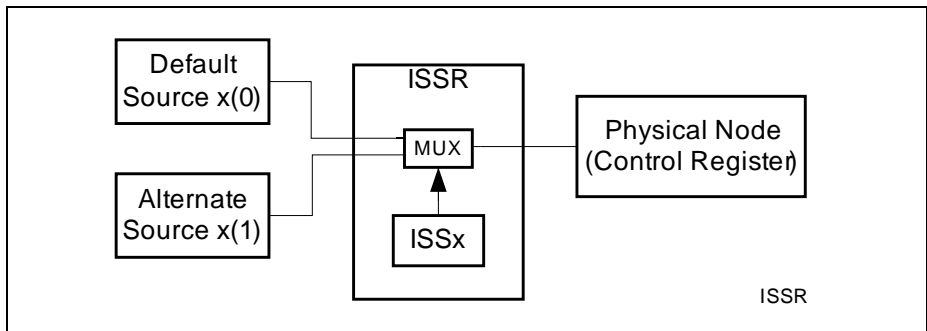


Figure 7-5 Node Sharing Principle controlled by ISSR

The table below lists the possible selections of interrupt request sources to the physical interrupt nodes (Control Register). Selection is controlled through ISSx bits of the ISSR register.

Table 7-10 Nodes Sharing controlled by ISSR

Control Register	Select Bit	Default Source (ISSx=0)	Alternate Source (ISSx=1)
CC2_CC16IC	ISS0	CAPCOM2 Request 16	(not assigned)
CC2_CC17IC	ISS1	CAPCOM2 Request 17	(not assigned)
CC2_CC18IC	ISS2	CAPCOM2 Request 18	(not assigned)
CC2_CC19IC	ISS3	CAPCOM2 Request 19	(not assigned)
CC2_CC20IC	ISS4	CAPCOM2 Request 20	USIC0 CH0 SR3
CC2_CC21IC	ISS5	CAPCOM2 Request 21	USIC0 CH1 SR3
CC2_CC22IC	ISS6	CAPCOM2 Request 22	(not assigned)
CC2_CC23IC	ISS7	CAPCOM2 Request 23	(not assigned)

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Table 7-10 Nodes Sharing controlled by ISSR (cont'd)

Control Register	Select Bit	Default Source (ISSx=0)	Alternate Source (ISSx=1)
CC2_CC24IC	ISS8	CAPCOM2 Request 24	(not assigned)
CC2_CC25IC	ISS9	CAPCOM2 Request 25	(not assigned)
CC2_CC26IC	ISS10	CAPCOM2 Request 26	(not assigned)
CC2_CC27IC	ISS11	CAPCOM2 Request 27	(not assigned)
CC2_CC28IC	ISS12	CAPCOM2 Request 28	(not assigned)
CC2_CC29IC	ISS13	CAPCOM2 Request 29	(not assigned)
CC2_CC30IC	ISS14	CAPCOM2 Request 30	SCU Interrupt 2
CC2_CC31IC	ISS15	CAPCOM2 Request 31	SCU Interrupt 3

7.15 Interrupt Source Select Registers

In order to map the interrupt request sources in the complete system to the available interrupt nodes, interrupt nodes are shared between selected modules.

SCU_ISSR

Interrupt Source Select Register

SFR (FF2E_H/97_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ISS 15	ISS 14	ISS 13	ISS 12	ISS 11	ISS 10	ISS 9	ISS 8	ISS 7	ISS 6	ISS 5	ISS 4	ISS 3	ISS 2	ISS 1	ISS 0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
ISS0	0	rw	Interrupt Source Select for CC2_CC16IC 0 _B CC2 channel 16 interrupt is selected 1 _B No interrupt source assigned
ISS1	1	rw	Interrupt Source Select for CC2_CC17IC 0 _B CC2 channel 17 interrupt is selected 1 _B No interrupt source assigned
ISS2	2	rw	Interrupt Source Select for CC2_CC18IC 0 _B CC2 channel 18 interrupt is selected 1 _B No interrupt source assigned
ISS3	3	rw	Interrupt Source Select for CC2_CC19IC 0 _B CC2 channel 19 interrupt is selected 1 _B No interrupt source assigned
ISS4	4	rw	Interrupt Source Select for CC2_CC20IC 0 _B CC2 channel 20 interrupt is selected 1 _B USIC0 channel 0 SR3 is selected
ISS5	5	rw	Interrupt Source Select for CC2_CC21IC 0 _B CC2 channel 21 interrupt is selected 1 _B USIC0 channel 1 SR3 is selected
ISS6	6	rw	Interrupt Source Select for CC2_CC22IC 0 _B CC2 channel 22 interrupt is selected 1 _B No interrupt source assigned
ISS7	7	rw	Interrupt Source Select for CC2_CC23IC 0 _B CC2 channel 23 interrupt is selected 1 _B No interrupt source assigned

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Field	Bits	Type	Description
ISS8	8	rw	Interrupt Source Select for CC2_CC24IC 0 _B CC2 channel 24 interrupt is selected 1 _B No interrupt source assigned
ISS9	9	rw	Interrupt Source Select for CC2_CC25IC 0 _B CC2 channel 25 interrupt is selected 1 _B No interrupt source assigned
ISS10	10	rw	Interrupt Source Select for CC2_CC26IC 0 _B CC2 channel 26 interrupt is selected 1 _B No interrupt source assigned
ISS11	11	rw	Interrupt Source Select for CC2_CC27IC 0 _B CC2 channel 27 interrupt is selected 1 _B No interrupt source assigned
ISS12	12	rw	Interrupt Source Select for CC2_CC28IC 0 _B CC2 channel 28 interrupt is selected 1 _B No interrupt source assigned
ISS13	13	rw	Interrupt Source Select for CC2_CC29IC 0 _B CC2 channel 29 interrupt is selected 1 _B No interrupt source assigned
ISS14	14	rw	Interrupt Source Select for CC2_CC30IC 0 _B CC2 channel 30 interrupt is selected 1 _B SCU Interrupt 2 is selected
ISS15	15	rw	Interrupt Source Select for CC2_CC31IC 0 _B CC2 channel 31 interrupt is selected 1 _B SCU Interrupt 3 is selected

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7.16 Interrupt Control Registers per Module

ADC_xIC (x=0-3)

ADC Interrupt Control x

SFR(FF70_H+ 2*x)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	GPX	IR	IE	ILVL			GLVL		
r	r	r	r	r	r	r	rw	rwh	rw	rw			rw		

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit
IR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
IE	6	rw	Interrupt Enable Control Bit (individually enables/disables a specific source) 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level
0	[15:9]	r	Reserved read as 0; should be written with 0.

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U0C0_xIC (x=0-2)

USIC0 Channel 0 IC x

ESFR(F120_H+ 2*x)

Reset Value: 0000_H

U0C1_xIC (x=0-2)

USIC0 Channel 1 IC x

ESFR(F126_H+ 2*x)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	GPX	IR	IE		ILVL				GLVL
r	r	r	r	r	r	r	rw	rwh	rw		rw				rw

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit
IR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
IE	6	rw	Interrupt Enable Control Bit (individually enables/disables a specific source) 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level
0	[15:9]	r	Reserved read as 0; should be written with 0.

CCU60_xIC (x=0-3)

CCU60 Interrupt Control x

ESFR(F160_H+ 2*x)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	GPX	IR	IE		ILVL				GLVL
r	r	r	r	r	r	r	rw	rwh	rw		rw				rw

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Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit
IR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
IE	6	rw	Interrupt Enable Control Bit (individually enables/disables a specific source) 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level
0	[15:9]	r	Reserved read as 0; should be written with 0.

GPT12E_TxIC (x=2-6)

GPT12 TIMER x IC

SFR(FF5C_H + 2*x)

Reset Value: 0000_H

GPT12E_CRIC

GPT12 CAPREL IC

SFR(FF6A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	GPX	IR	IE	ILVL			GLVL	
r	r	r	r	r	r	r	r	rw	rwh	rw	rw			rw	

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit
IR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request

Interrupt and Exception Control

Field	Bits	Type	Description
IE	6	rw	Interrupt Enable Control Bit (individually enables/disables a specific source) 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level
0	[15:9]	r	Reserved read as 0; should be written with 0.

CC2_T7IC

CAPCOM TIMER 7 IC

SFR(FF6C_H)

Reset Value: 0000_H

CC2_T8IC

CAPCOM TIMER 8 IC

SFR(FF6E_H)

Reset Value: 0000_H

CC2_CCxIC (x=16-31)

CAPCOM Interrupt Control x **ESFR(F1A0_H+ 2*x)**

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	GPX	IR	IE		ILVL			GLVL	
r	r	r	r	r	r	r	rw	rwh	rw		rw			rw	

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit
IR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
IE	6	rw	Interrupt Enable Control Bit (individually enables/disables a specific source) 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled

Interrupt and Exception Control

Field	Bits	Type	Description
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level
0	[15:9]	r	Reserved read as 0; should be written with 0.

RTC_IC

Real Time Clock IC

ESFR(F19C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	GPX	IR	IE		ILVL			GLVL	
r	r	r	r	r	r	r	rw	rwh	rw		rw			rw	

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit
IR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
IE	6	rw	Interrupt Enable Control Bit (individually enables/disables a specific source) 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level

Interrupt and Exception Control

Field	Bits	Type	Description
0	[15:9]	r	Reserved read as 0; should be written with 0.

ERU_0IC

External Request Unit 0 IC **ESFR(F190_H)** **Reset Value: 0000_H**

ERU_1IC

External Request Unit 2 IC **ESFR(F192_H)** **Reset Value: 0000_H**

ERU_2IC

External Request Unit 2 IC **ESFR(F194_H)** **Reset Value: 0000_H**

ERU_3IC

External Request Unit 3 IC **ESFR(F19A_H)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	GPX	IR	IE		ILVL			GLVL	
r	r	r	r	r	r	r	rw	rwh	rw		rw			rw	

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit
IR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
IE	6	rw	Interrupt Enable Control Bit (individually enables/disables a specific source) 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level
0	[15:9]	r	Reserved read as 0; should be written with 0.

Interrupt and Exception Control

SCU_0IC

SCU Interrupt 0 IC

ESFR(F198_H)

Reset Value: 0000_H

SCU_1IC

SCU Interrupt 1 IC

ESFR(F196_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	GPX	IR	IE		ILVL				GLVL
r	r	r	r	r	r	r	rw	rwh	rw		rw				rw

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension Defines the value of high-order group level bit
IR	7	rwh	Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
IE	6	rw	Interrupt Enable Control Bit (individually enables/disables a specific source) 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
ILVL	[5:2]	rw	Interrupt Priority Level F _H Highest priority level ... 0 _H Lowest priority level
GLVL	[1:0]	rw	Group Priority Level 3 _H Highest priority level ... 0 _H Lowest priority level
0	[15:9]	r	Reserved read as 0; should be written with 0.

Interrupt and Exception Control

7.17 Interrupt and PEC Configuration Registers

The following table lists all registers used to configure the interrupt and PEC behavior of the XE166U. Registers are ordered by address. The Interrupt Control registers `xxIC`, assigned to each interrupt request, are listed separately (see [Section 7.14](#)).

Bit addressable SFRs are marked with the letter “b” in column “Name”.

Table 7-11 Register Overview Interrupt and PEC - ordered by address

Name	Physical Address	8-bit Address	Description	Reset Value
FINT0CSP	EC00 _H	--	Fast Interrupt 0 CSP Register	0000 _H
FINT0ADDR	EC02 _H	--	Fast Interrupt 0 Address Register	0000 _H
FINT1CSP	EC04 _H	--	Fast Interrupt 1 CSP Register	0000 _H
FINT1ADDR	EC06 _H	--	Fast Interrupt 1 Address Register	0000 _H
BNKSEL0	EC20 _H	--	Bank Selection Register 0	0000 _H
BNKSEL1	EC22 _H	--	Bank Selection Register 1	0000 _H
BNKSEL2	EC24 _H	--	Bank Selection Register 2	0000 _H
BNKSEL3	EC26 _H	--	Bank Selection Register 3	0000 _H
SRCP0	EC40 _H	--	PEC Channel 0 Source Pointer	0000 _H
DSTP0	EC42 _H	--	PEC Channel 0 Destination Pointer	0000 _H
SRCP1	EC44 _H	--	PEC Channel 1 Source Pointer	0000 _H
DSTP1	EC46 _H	--	PEC Channel 1 Destination Pointer	0000 _H
SRCP2	EC48 _H	--	PEC Channel 2 Source Pointer	0000 _H
DSTP2	EC4A _H	--	PEC Channel 2 Destination Pointer	0000 _H
SRCP3	EC4C _H	--	PEC Channel 3 Source Pointer	0000 _H
DSTP3	EC4E _H	--	PEC Channel 3 Destination Pointer	0000 _H
SRCP4	EC50 _H	--	PEC Channel 4 Source Pointer	0000 _H
DSTP4	EC52 _H	--	PEC Channel 4 Destination Pointer	0000 _H
SRCP5	EC54 _H	--	PEC Channel 5 Source Pointer	0000 _H
DSTP5	EC56 _H	--	PEC Channel 5 Destination Pointer	0000 _H
SRCP6	EC58 _H	--	PEC Channel 6 Source Pointer	0000 _H
DSTP6	EC5A _H	--	PEC Channel 6 Destination Pointer	0000 _H
SRCP7	EC5C _H	--	PEC Channel 7 Source Pointer	0000 _H
DSTP7	EC5E _H	--	PEC Channel 7 Destination Pointer	0000 _H

Interrupt and Exception Control

Table 7-11 Register Overview Interrupt and PEC - ordered by address (cont'd)

Name	Physical Address	8-bit Address	Description	Reset Value
PECSEG0	EC80 _H	--	PEC Pointer 0 Segment Address	0000 _H
PECSEG1	EC82 _H	--	PEC Pointer 1 Segment Address	0000 _H
PECSEG2	EC84 _H	--	PEC Pointer 2 Segment Address	0000 _H
PECSEG3	EC86 _H	--	PEC Pointer 3 Segment Address	0000 _H
PECSEG4	EC88 _H	--	PEC Pointer 4 Segment Address	0000 _H
PECSEG5	EC8A _H	--	PEC Pointer 5 Segment Address	0000 _H
PECSEG6	EC8C _H	--	PEC Pointer 6 Segment Address	0000 _H
PECSEG7	EC8E _H	--	PEC Pointer 7 Segment Address	0000 _H
PECISNC b	FFD8 _H	EC _H	PEC Interrupt Subnode Control	0000 _H
PECC0	FEC0 _H	60 _H	PEC Channel 0 Control Register	0000 _H
PECC1	FEC2 _H	61 _H	PEC Channel 1 Control Register	0000 _H
PECC2	FEC4 _H	62 _H	PEC Channel 2 Control Register	0000 _H
PECC3	FEC6 _H	63 _H	PEC Channel 3 Control Register	0000 _H
PECC4	FEC8 _H	64 _H	PEC Channel 4 Control Register	0000 _H
PECC5	FECA _H	65 _H	PEC Channel 5 Control Register	0000 _H
PECC6	FECC _H	66 _H	PEC Channel 6 Control Register	0000 _H
PECC7	FECE _H	67 _H	PEC Channel 7 Control Register	0000 _H

8 System Control Unit (SCU)

The System Control Unit (SCU) of the XE166U handles all system control tasks besides the debug related tasks which are controlled by the OCDS/Cerberus. All functions described in this chapter are tightly coupled, thus, they are conveniently handled by one unit, the SCU.

The SCU contains the following functional sub-blocks:

- Clock Generation (see [Chapter 8.1](#))
- System Timer (see [Chapter 8.2](#))
- Wake-up Timer (see [Chapter 8.3](#))
- Reset Operation (see [Chapter 8.4](#))
- External Service Requests (see [Chapter 8.5](#))
- Power Supply and Control (see [Chapter 8.6](#))
- Global State Control (see [Chapter 8.7](#))
- Software Boot Support (see [Chapter 8.8](#))
- External Request Unit (see [Chapter 8.9](#))
- Interrupt Generation (see [Chapter 8.10](#))
- Window Watchdog Timer (see [Chapter 8.11](#))
- Trap Generation (see [Chapter 8.12](#))
- Memory Content Protection (see [Chapter 8.13](#))
- Register Access Control (see [Chapter 8.14](#))
- Miscellaneous System Registers (see [Chapter 8.15](#))
- SCU Registers and Address map (see [Chapter 8.16](#))

Important Information: Register Programming

Some of XE166U registers are initialized during the startup procedure with values different from their reset-content (defined into respective registerdescriptions). They are listed in section “Registers modified by the Startup Procedure”.

The System Control Unit contains special function registers, which can not be programmed in an arbitrary order in particular due to the usage of an internal voltage regulator. In order to prevent critical system conditions because of an improper setup and to provide means for easy and quick configuration and control of sensitive features such as power supply and clock generation, recommendations and examples for the programming sequence of the registers will be given in the Programmer's Guide.

In particular the registers listed below have to be updated with care:

- Clock Generation Unit: WUOSCCON, HPOSCCON, PLLOSCCON, PLLCONx
- Power Supply: EVRMCON0, EVRMSET15VHP, EVRMSET15VLP, PVCMMCON0, SWDCON0, SEQCON
- System: STEP0, SYSCON0

8.1 Clock Generation Unit

The Clock Generation Unit (CGU) allows a very flexible clock generation for the XE166U. During user program execution the frequency can be programmed for an optimal ratio between performance and power consumption in the actual application state.

8.1.1 Overview

The CGU can convert a low-frequency external clock to a high-speed system clock or can create a high-speed system clock without external input.

The CGU consists of a Clock Generator and a Clock Control Unit (CCU).

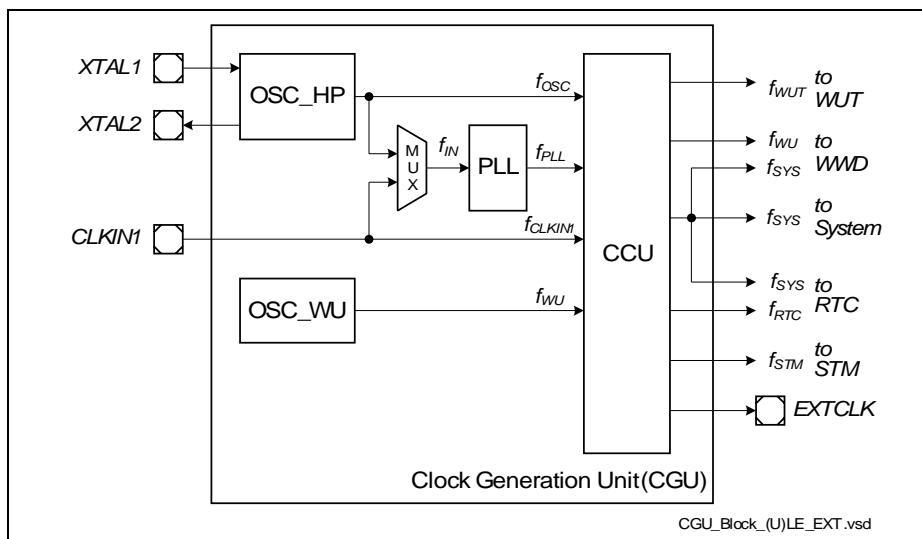


Figure 8-1 Clock Generation Unit Block Diagram

Note: For 38 pin package, XTAL1 and XTAL2 pins are not available.

The following table shows the input connection of the CGU.

Table 8-1 CGU Input Connection

Input	Connected to
XTAL 1	XTAL 1
XTAL 2	XTAL 2
CLKIN1	Port 2.6
CLKIN2	Reserved, not connected

The following clock signals are generated:

- System clock f_{SYS}
- RTC count clock f_{RTC}
- Wake-Up Timer (WUT) clock f_{WUT}
- STM clock f_{STM}
- External clock f_{EXT}

Chapter 8.1.5 and **Chapter 8.1.6** describe which clock signals are generated out of which selectable clocks.

Register Overview

The CGU is controlled by a number of registers shown in the following figure.

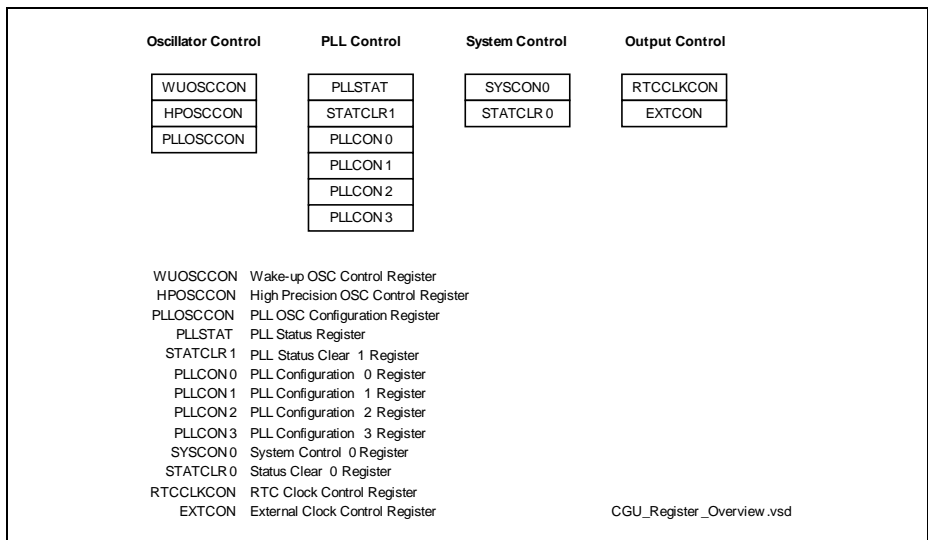


Figure 8-2 Clock Generation Unit Register Overview

The following sections describe the different parts of the CGU.

8.1.2 Trimmed Current Controlled Wake-Up Clock (OSC_WU)

The trimmed current controlled wake-up clock source provides a clock to control internal operations independent of the standard clock supplies and requires no external components. Its output frequency f_{WU} is configured via bit field **WUOSCON.FREQSEL**.

8.1.3 High Precision Oscillator Circuit (OSC_HP)

The high precision oscillator circuit can drive an external crystal or accepts an external clock source. It consists of an inverting amplifier with XTAL1 as input, and XTAL2 as output.

Figure 8-4 and **Figure 8-3** show the recommended external circuitries for both operating modes, External Crystal Mode and External Input Clock Mode.

Note: For 38 pin package, XTAL1 and XTAL2 pins are not available.

8.1.3.1 External Input Clock Mode

An external clock signal is supplied directly not using an external crystal and bypassing the amplifier of the oscillator. The maximum allowed input frequency depends on the characteristics of pin XTAL1.

When using an external clock signal it must be connected to XTAL1. XTAL2 is left open (unconnected).

Note: Voltages on XTAL1 must comply to the voltage defined in the data sheet.

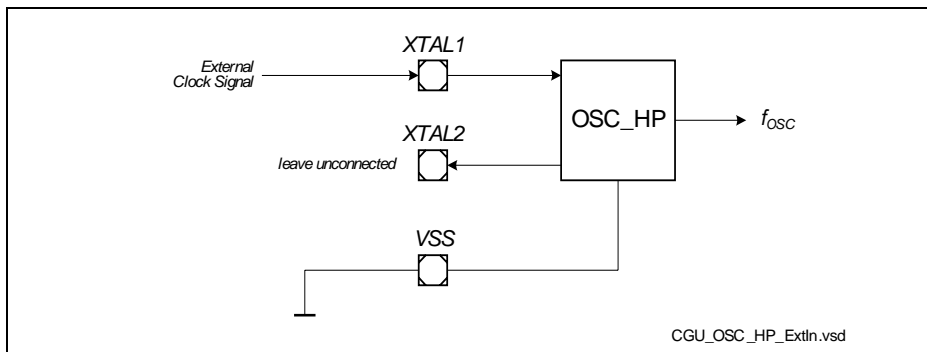


Figure 8-3 XE166U External Clock Input Mode for the High-Precision Oscillator

8.1.3.2 External Crystal Mode

An external oscillator load circuitry must be used, connected to both pins, XTAL1 and XTAL2. It consists normally of the two load capacitances C1 and C2. For some crystals a series damping resistor might be necessary. The exact values and related operating

range depend on the crystal and have to be determined and optimized together with the crystal vendor using the negative resistance method.

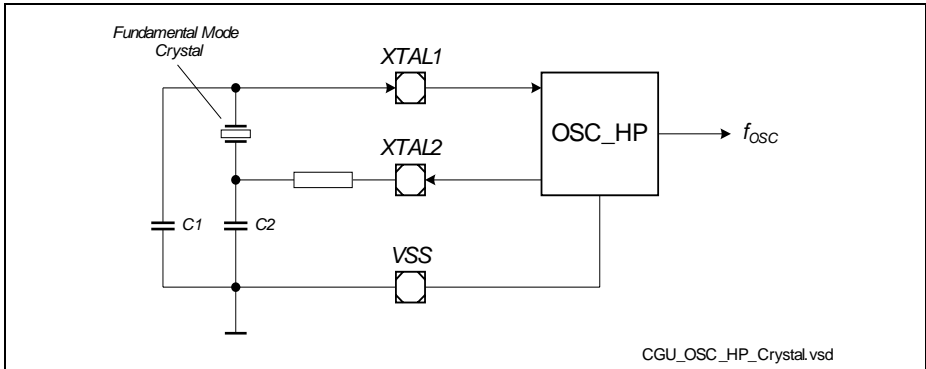


Figure 8-4 XE166U External Crystal Mode Circuitry for the High-Precision Oscillator

Support for Start-up Control of an External Crystal

The first time before the system clock is generated based on an external crystal 1000 cycles of the crystal clock should be waited before the clock control system is changed to External Crystal Mode. Bit **PLLSTAT.OSCLOCK** indicates if the oscillator OSC_HP operates for at least 2^{11} periods. Bit **PLLSTAT.OSCSTAB** indicates if OSC_HP operates for at least 2^{15} periods.

Oscillator Gain Control

The oscillator starts with a high drive level (gain) during and after a Power-on Reset to ensure safe start-up behavior in the beginning (force the crystal oscillation). When a stable oscillation has been reached after oscillation start-up (**PLLSTAT.OSCSTAB** = 1), the gain of the oscillator can be reduced. This reduces the power consumption of the oscillator, which is especially important in the power saving modes. This gain reduction is selected by **HPOSCCON.GAINSEL**.

Note: Choosing the gain setting is only possible with detailed consideration of parasitics, external circuitry, frequency range and quality of the applied crystal and has to be verified by testing together with the crystal manufacturer.

8.1.4 Phase-Locked Loop (PLL) Module

The PLL can convert a low-frequency external clock signal to a high-speed system clock for maximum performance. The PLL also has fail-safe logic that detects degenerate external clock behavior such as abnormal frequency deviations or a total loss of the external clock. It can execute emergency actions if it loses its lock on the external clock.

This module is a phase locked loop for integer frequency synthesis. It allows the use of input and output frequencies of a wide range by varying the different divider factors.

8.1.4.1 Features

Here is a brief overview of the functions that are offered by the PLL.

- VCO lock detection
- 4-bit input divider **P**: (divide by PDIV+1)
- 6-bit feedback divider **N**: (multiply by NDIV+1)
- 10-bit output divider **K2**: (divide K2DIV+1)
- 10-bit VCO bypass divider **K1**: (divide by either by K1DIV+1)
- Oscillator run detection and Watchdog
- Different operating modes
 - Prescaler Mode
 - Unlocked Mode
 - Normal Mode
- Different power saving modes
 - Power Down
 - Sleep Mode (VCO Power Down)
- Glitchless programming of output divider K2 and VCO bypass divider K1
- Glitchless switching between Normal Mode and Prescaler Mode
- Trimmed current controlled clock source

8.1.4.2 PLL Functional Description

The PLL consists of a Voltage Controlled Oscillator (VCO) with a feedback path. A divider in the feedback path (N-Divider) divides the VCO frequency. The resulting frequency is then compared with the divided external frequency (P-Divider). The phase detection logic determines the difference between the two clocks and accordingly controls the frequency of the VCO (f_{VCO}). A PLL lock detection unit monitors and signals this condition. The phase detection logic continues to monitor the two clocks and adjusts the VCO clock if required. The PLL output clock f_{PLL} is derived from the VCO clock using the K2-Divider or from the oscillator clock using the K1-Divider.

The following figure shows the PLL block structure.

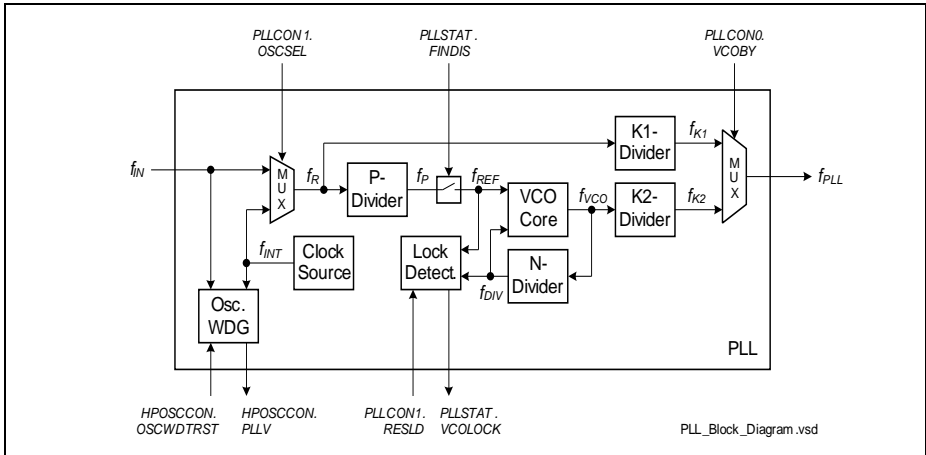


Figure 8-5 PLL Block Diagram

Clock Source Control

The reference frequency f_R can be selected to be either taken from the trimmed current controlled clock source f_{INT} or from an external clock source f_{IN} .

PLL Modes

The PLL clock f_{PLL} is generated from f_R in one of the following software selectable modes:

- Normal Mode
- Prescaler Mode
- Unlocked Mode

In Normal Mode the reference frequency f_R is divided by a factor P, multiplied by a factor N and then divided by a factor K2. The output frequency is given by

(8.1)

$$f_{PLL} = \frac{N}{P \cdot K2} \cdot f_R$$

System Control Unit (SCU)

In Prescaler Mode the reference frequency f_R is divided by a factor K1. The output frequency is given by

(8.2)

$$f_{\text{PLL}} = \frac{f_R}{K1}$$

In Unlocked Mode the base output frequency of the Voltage Controlled Oscillator (VCO) f_{VCObase} is divided by a factor K2. The output frequency is given by

(8.3)

$$f_{\text{PLL}} = \frac{f_{\text{VCObase}}}{K2}$$

PLL Power Saving Modes

PLL Power Down Mode The PLL offers a Power Down Mode to save power if the PLL is not needed at all. While the PLL is in Power Down Mode no PLL output frequency is generated.

PLL Sleep Mode The PLL offers a Sleep Mode (also called VCO Power Down Mode) to save power within the PLL. While the PLL is in Sleep Mode only the Prescaler Mode can be used.

8.1.4.3 Configuration and Operation of the PLL Modes

The following section describes the configuration and the operation of the different PLL modes.

Configuration and Operation of the Unlocked Mode

In Unlocked Mode, the PLL is running at its VCO base frequency and f_{PLL} is derived from f_{VCO} by the K2-Divider.

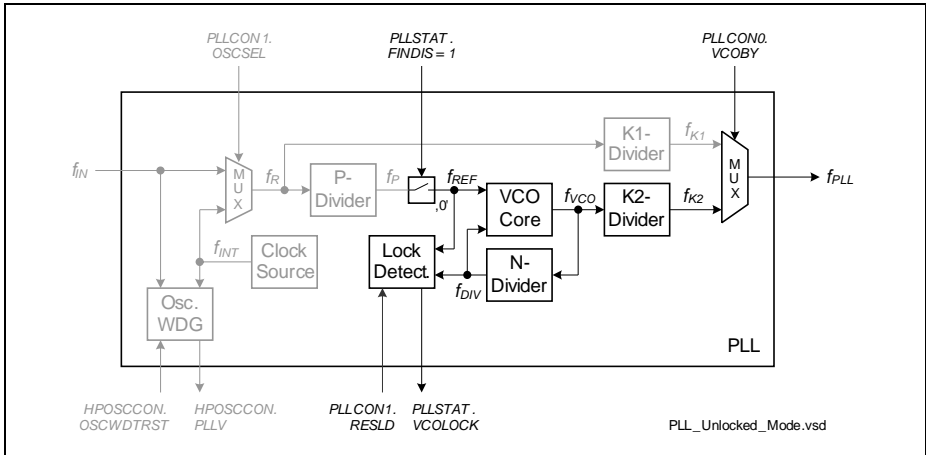


Figure 8-6 PLL Unlocked Mode Diagram

The Unlocked Mode is selected by the following settings:

- STATCLR1.SETFINDIS = 1
- PLLCON0.VCOBY = 0

The Unlocked Mode is entered when all following conditions are true:

- PLLSTAT.FINDIS = 1
- PLLSTAT.VCOBYST = 1

Operation in Unlocked Mode does not require an input clock f_{IN} . The Unlocked Mode is automatically entered on a PLL VCO Loss-of-Lock event if bit PLLCON1.EMFINDISEN is cleared. This mechanism allows a fail-safe operation of the PLL as in emergency cases still a clock is available.

The frequency of the Unlocked Mode $f_{VCObase}$ is listed in the Data Sheet.

Note: Changing the system operation frequency by changing the value of the K2-Divider or the VCO range has a direct influence on the power consumption of the device. Therefore, this has to be done carefully.

Configuration and Operation of the Normal Mode

In Normal Mode, the PLL is running at frequency f_{PLL} , where f_R is divided by a factor P, multiplied by a factor N and then divided by a factor K2.

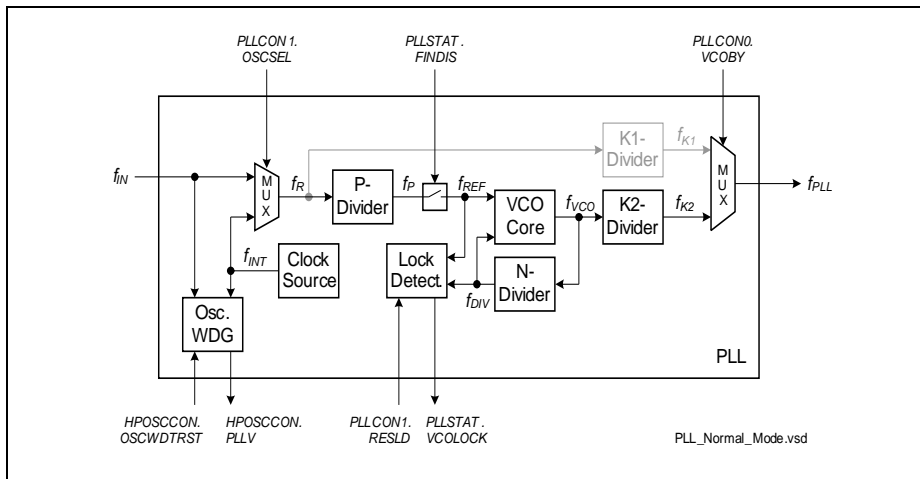


Figure 8-7 PLL Normal Mode Diagram

The Normal Mode is selected by the following settings:

- PLLCON0.VCOBY = 0
- STATCLR1.CLRFINDIS = 1

The Normal Mode is entered when all following conditions are true:

- PLLSTAT.FINDIS = 0
- PLLSTAT.VCOBYST = 1
- PLLSTAT.VCOLOCK = 1
- HPOSCCON.PLLV = 1

Operation in Normal Mode requires a clock frequency of f_R . When f_{IN} is selected as source for f_R it is recommended to check and monitor if an input frequency f_R is available at all by checking HPOSCCON.PLLV.

The system operation frequency in Normal Mode is controlled by the values of the three dividers: P, N, and K2. A modification of the two dividers P and N has a direct influence on the VCO frequency and leads to a loss of the VCO Lock status. A modification of the K2-divider has no impact on the VCO Lock status but changes the PLL output frequency.

Note: Changing the system operation frequency by changing the value of the K2-Divider has a direct influence on the power consumption of the device. Therefore, this has to be done carefully.

To modify or enter the Normal Mode frequency, follow the sequence described below:

Configure and enter Prescaler Mode. For more details see the Prescaler Mode.

Disable the trap generation for the VCO Lost-of-Lock.

System Control Unit (SCU)

While the Prescaler Mode is used the Normal Mode can be configured and checked for a positive VCO Lock status. The first target frequency of the Normal Mode should be selected in a way that it matches or is only slightly higher as the one used in the Prescaler Mode. This avoids big changes in the system operation frequency and, therefore, the power consumption when switching later from Prescaler Mode to Normal Mode. The P and N dividers should be selected in the following way:

- Selecting P and N in a way that f_{VCO} is in the lower area of its allowed values leads to a slightly reduced power consumption but to a slightly increased jitter
- Selecting P and N in a way that f_{VCO} is in the upper area of its allowed values leads to a slightly increased power consumption but to a slightly reduced jitter

After the P, and N dividers are updated for the first configuration, the indication of the VCO Lock status (PLLSTAT.VCOLOCK = 1) should be awaited.

Note: It is recommended to reset the VCO Lock detection (PLLCON1.RESLD = 1) after the new values of the dividers have been configured to get a defined VCO lock check time.

When this happens the switch from Prescaler Mode to Normal Mode can be done. Normal Mode is requested by clearing PLLCON0.VCOBY. The Normal Mode is entered when the status bit PLLSTAT.VCOBYST is set.

Now the Normal Mode is entered. The trap status flag for the VCO Lock trap should be cleared and then enabled again.

The intended PLL output target frequency can be configured by changing only the K2-Divider. Depending on the selected divider value of the K2-Divider, the duty cycle of the clock is selected. This can have an impact on the operation with an external communication interface. In order to avoid too big frequency changes it might be necessary to change the K2-Divider in multiple steps. When the value of the K2-Divider was changed the next update of this value should not be done before bit PLLSTAT.K2RDY is set.

Note: The Programmers's Guide describes a smooth frequency stepping to achieve an appropriate load regulation of the internal voltage regulator.

PLL VCO Lock Detection

The PLL has a lock detection that supervises the VCO part of the PLL in order to detect instable VCO circuit behavior. The lock detector marks the VCO circuit and therefore the output f_{VCO} of the VCO as instable if the two inputs f_{REF} and f_{DIV} differ too much. Changes in one or both input frequencies below a level are not marked by a loss of lock because the VCO can handle such small changes without any problem for the system.

PLL VCO Loss-of-Lock Event

The PLL may become unlocked, caused by a break of the crystal or the external clock line. In such a case, a trap is generated if the according trap is enabled. Additionally, the clock f_R is disconnected from the PLL VCO to avoid unstable operation due to noise or

Note: Changing the system operation frequency by changing the value of the K1-Divider has a direct influence on the power consumption of the device. Therefore, this has to be done carefully.

The duty cycle of the clock signal depends on the selected value of the K1-Divider. This can have an impact for the operation with an external communication interface.

The Prescaler Mode is requested from the Unlocked or Normal Mode by setting bit PLLCON0.VCOBY. The Prescaler Mode is entered when the status bit PLLSTAT.VCOBYST is cleared.

Before the Prescaler Mode is requested the K1-Divider should be configured with a value generating a PLL output frequency f_{PLL} that matches the one generated by the Unlocked or Normal Mode as much as possible. In this way the frequency change resulting out of the mode change is reduced to a minimum.

The Prescaler Mode is requested to be left by clearing bit PLLCON0.VCOBY. The Prescaler Mode is left when the status bit PLLSTAT.VCOBYST is set.

Configuration and Operation of the PLL Power Down Mode

The Power Down Mode is entered by setting bit PLLCON0.PLLPWD. While the PLL is in Power Down Mode no PLL output frequency is generated.

Configuration and Operation of the PLL Sleep Mode

The Sleep Mode (also called VCO Power Down Mode) is entered by setting bit PLLCON0.VCOPWD. While the PLL is in Sleep Mode only the Prescaler Mode is operable. Selecting the Sleep Mode does not automatically switch to the Prescaler Mode. Therefore, before the Sleep Mode is entered the Prescaler Mode must be active.

8.1.4.4 Power Regulator

The analog parts of the PLL (VCO, trimmed current controlled clock source) are running on a dedicated supply generated by a dedicated regulator integrated within the PLL unit.

The regulator has to be enabled separately before the analog blocks of the PLL are activated, i.e. trimmed current controlled clock source and VCO must be kept off until the supply is stable. After activation, the PLL regulator will need its ramp-up time to properly ramp-up the analog PLL supply.

When the regulator shall be disabled in conjunction with a power down of the PLL digital part, it has to be taken into account that the digital part needs an active clock at the output of the PLL to ramp down. In case this clock is generated by one of the PLL oscillators, power down of PLL must be entered before the regulator is disabled. VCO and trimmed current controlled clock source may be activated or switched off together.

8.1.4.5 Divider Handshake

The PLL provides several handshake interfaces for dividers. This section describes how a handshake is to be conducted upon a change of configuration.

The general conduction of the handshake is the same for all interfaces. However, a sample sequence is described here in conjunction with re-programming of a divider.

Note: The described handshake only works if the new setting (e.g. divider value) changes the current value upon the handshake.

The handshake should be done in the the following steps:

1. Clear acknowledge bit together with setting the new divider value
2. Poll on ready bit to be 0
3. Set acknowledge bit
4. Poll on ready bit to be 1

This approach will even work in case the handshake has not been properly served before, and ready is already at 0 from the beginning. In any case, a change of the divider value will set ready to 0.

8.1.4.6 Trimmed Current Controlled Clock

The trimmed current controlled clock source provides a clock f_{INT} for the PLL.

Note: The clock f_{INT} is also required for the operation of the oscillator watchdog.

8.1.4.7 Input Clock Selection

The reference clock f_R can be provided by the PLL input clock source f_{IN} or by the trimmed current controlled clock source f_{INT} . This is selected via bit **PLLCON1.OSCSEL**.

The PLL input clock f_{IN} can be selected to be either taken from the high-precision oscillator clock source f_{OSC} or from the direct clock input f_{CLKIN1} . This is configured by **PLLCON1.INSEL**.

8.1.4.8 Oscillator Watchdog

The oscillator watchdog continuously monitors the input clock f_{IN} . If the input frequency becomes too low or if the input clock fails, this oscillator fail condition is indicated by **HPOSCCON.PLLV** = 0 and an interrupt request is generated.

By setting bit **HPOSCCON.OSCWDTRST** the detection can be restarted without a reset of the complete PLL, e.g. in case of a VCO loss-of-lock condition.

*Note: The oscillator watchdog requires the trimmed current controlled clock f_{INT} as a reference. Therefore, it can only be used (**HPOSCCON.PLLV** is valid) while the clock source is active.*

8.1.4.9 Switching PLL Parameters

The following restriction applies when changing PLL parameters inside the PLLCON0 to PLLCON3 registers:

- The VCO bypass switch may be used at any time, however, it has to be ensured that the maximum operating frequency of the device (see data sheet) will not be exceeded.
- Prescaler Mode should be selected.
- After switching to Prescaler Mode, NDIV and PDIV can be adjusted.
- Before deselecting the Prescaler Mode, the RESLD bit has to be set and then the VCOLOCK flag has to be checked. Only when the VCOLOCK flag is set again, the Prescaler Mode may be deselected.
- Before changing VCOSEL, the Prescaler Mode must be selected.

Note: PDIV and NDIV can also be switched in Normal Mode. When changing NDIV, it must be regarded that the VCO clock f_{VCO} may exceed the target frequency until the PLL becomes locked. After changing PDIV or NDIV, it must be waited for the PLL lock condition. This procedure is typically used for increasing the VCO clock step-by-step.

8.1.5 Clock Control Unit

The Clock Control Unit selects the current clock sources for the clock signals used in the XE166U. It generates the following clocks:

- System clock f_{SYS}
- RTC count clock f_{RTC}
- WUT clock f_{WUT}
- System timer clock f_{STM}
- Output clock f_{EXT}

The following clock sources can be selected:

- PLL clock f_{PLL}
- The oscillator clock (OSC_HP) $f_{OSC}^{1)}$
- Wake-up clock f_{WU}
- Input CLKIN1 as Direct Clock Input f_{CLKIN1}

8.1.5.1 Clock Generation

Different clock sources can be selected for the generated clock signals.

Note: The selected clock sources are affected by the start-up procedure. See chapter Device Status after Start-up for the register values set by the different start-up procedures.

1) There are no XTAL1 and XTAL2 pins in the 38 pin package and oscillator clock, f_{OSC} , will not be available.

System Clock Generation

The system clock f_{SYS} can be selected from the following clock sources in the CCU:

- Wake-up clock f_{WU}
- The oscillator clock (OSC_HP) f_{OSC}
- PLL clock f_{PLL}
- Input CLKIN1 as Direct Clock Input f_{CLKIN1}

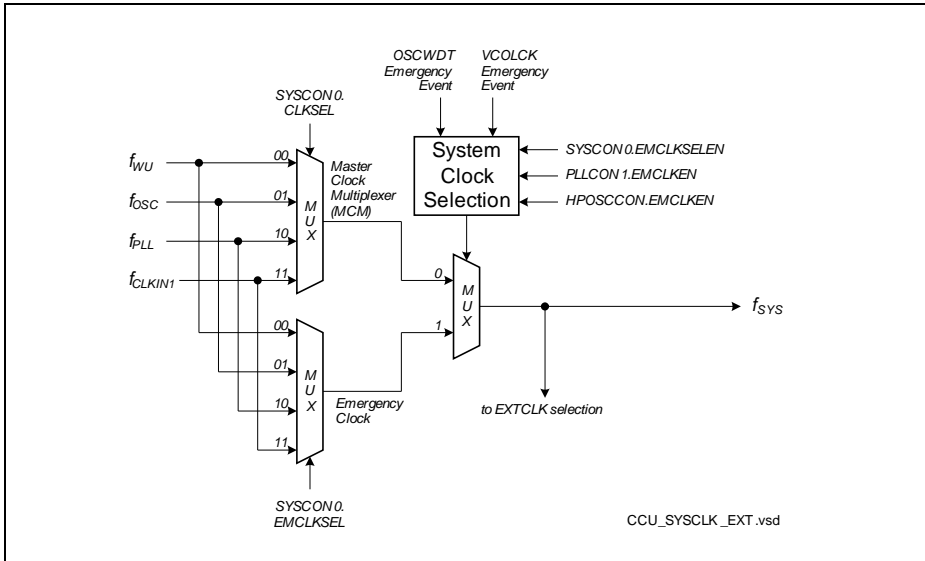


Figure 8-9 Clock Control Unit, System Clock Generation

RTC Clock Generation

For the RTC module it is possible to select the operation in synchronous or asynchronous mode in the module itself. The asynchronous clock for the RTC can be selected out of following clock sources in the CCU:

- PLL clock f_{PLL}
- The oscillator clock (OSC_HP) f_{OSC}
- Wake-up clock f_{WU}

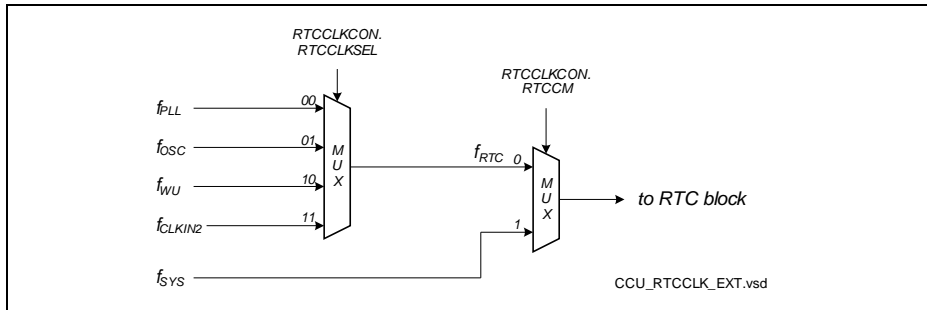


Figure 8-10 Clock Control Unit, RTC Clock Generation

Note: For the XE166U pin CLKIN2 is not available.

System Timer (STM) Clock Generation

The system timer clock can be selected out of following clock sources:

- The Direct Clock from oscillator OSC_HP f_{OSC}
- PLL clock f_{PLL}
- Input CLKIN1 as Direct Clock Input f_{CLKIN1}
- Wake-up clock f_{WU}

Then the selected clock can be divided by the factor defined in **STMCON.CLKDIV** (see [Chapter 8.2.1.2](#)).

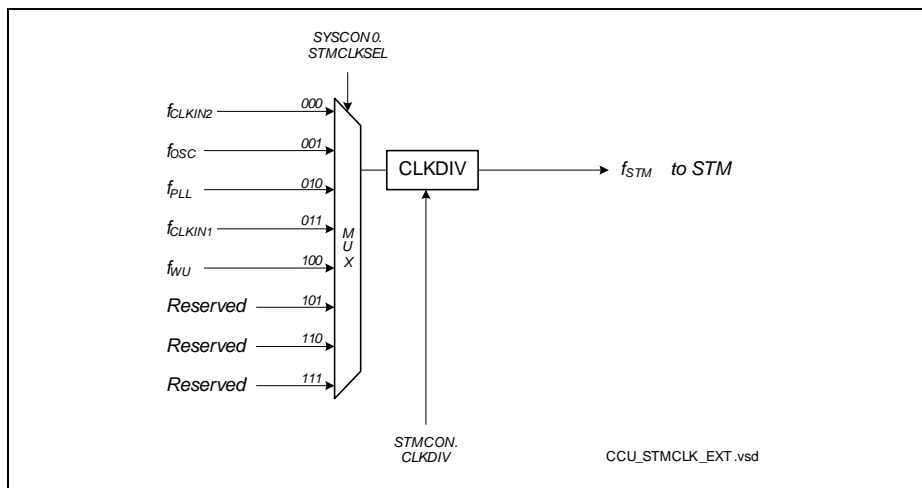


Figure 8-11 Clock Control Unit, STM Clock Generation

Note: For the XE166U pin CLKIN2 is not available.

Wake-up Timer (WUT) Clock Generation

The wake-up timer clock can be selected out of following clock sources in the CCU:

- Wake-up clock f_{WU}
- The Direct Clock from oscillator OSC_HP f_{OSC}
- PLL clock f_{PLL}
- Input CLKIN1 as Direct Clock Input f_{CLKIN1}

Then the selected clock can be divided by the factor defined in **WUCR.CLKDIV** (see [Chapter 8.3.2.2](#)).

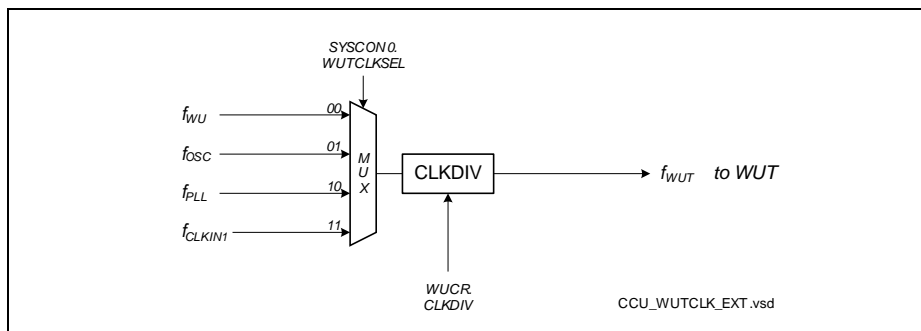


Figure 8-12 Clock Control Unit, WUT Clock Generation

Window Watchdog (WWD) Clock Generation

The clock source of WWD module can be selected out of the following clock source in the CCU:

- System clock f_{SYS}
- Wake-up Oscillator output signal f_{WU}

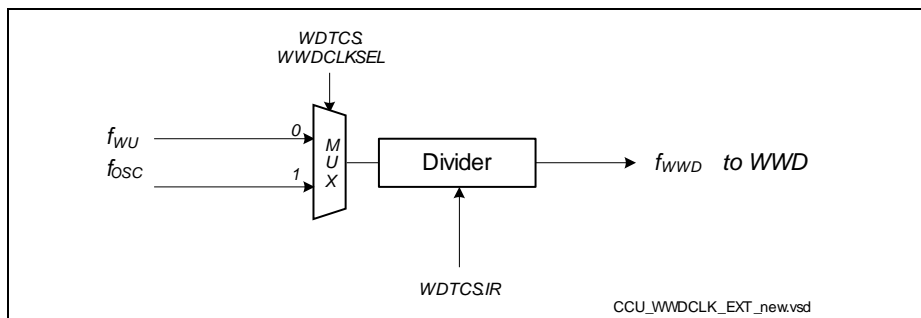


Figure 8-13 Clock Control Unit, WWD Clock Generation

8.1.5.2 Selecting and Changing the Operating Frequency

When selecting the clock source and the clock generation method, the required parameters must be carefully written to the respective bit fields, to avoid unintended intermediate states.

Many applications change the frequency of the system clock f_{SYS} during operation to optimize performance and power consumption of the system. Modifying the operating frequency changes the consumed switching current, which influences the power supply. Therefore, while the core voltage is generated by the on-chip Embedded Voltage Regulators (EVRs), the operating frequency may only be changed according to the rules given in the data sheet.

Note: To avoid the indicated problems, specific sequences are recommended that ensure the intended operation of the clock system interacting with the power system. Please refer to the document Programmer's Guide.

8.1.5.3 System Clock Emergency Handling

The generation of the system clock f_{SYS} can be affected, if either the PLL is no more locked to its input signal f_{IN} , or if the input clock f_{IN} is no more active. Both events can be detected and are indicated to the application software. The clock system takes appropriate actions where necessary, so the device and the application is never left without an alternate clock signal.

Oscillator Watchdog Event

If the clock frequency of the external source drops below a limit value the oscillator watchdog (OSCWDTC) (see [Chapter 8.1.4.8](#)) then the clock source for the system clock f_{SYS} is switched to an alternate clock source, if enabled (HPOSCCON.EMCLKEN = 1). In this case following information is available:

- The oscillator watchdog trap flag (TRAPSTAT.OSCWDTC) is set and a trap request to the CPU is activated, if enabled (TRAPDIS.OSCWDTC = 0).
- Bit HPOSCCON.PLLV = 0, while the clock f_{IN} is missing
- Bit SYSCON0.EMSOSC is set, if SYSCON0.EMCLKSELEN is set
- The source of the system clock f_{SYS} is switched to alternate clock source selected by SYSCON0.EMCLKSEL, if enabled (SYSCON0.EMCLKSELEN = 1). This is indicated by bit SYSCON0.SELSTAT = 1.

PLL VCO Loss-of-Lock Event

If the PLL output frequency is no longer locked to its input frequency f_{IN} , the PLL switches from PLL Normal mode to the Unlocked mode, if enabled (PLLCON1.EMFINDISEN = 1). In this case following information is available:

- The PLL VCO loss of lock trap flag (TRAPSTAT.VCOLCKT) is set and a trap request to the CPU is activated, if enabled (TRAPDIS.VCOLCKT = 0).

System Control Unit (SCU)

- Bit PLLSTAT.VCOLOCK = 0, while the PLL is not locked
- Bit SYSCON0.EMSVCO is set, if SYSCON0.EMCLKSELEN is set
- The PLL VCO clock input is disconnected (PLLSTAT.FINDIS = 1) and the PLL clock slows down to its VCO base frequency.

System Behavior

Emergency routines can be executed with the alternate clock (emergency clock or VCO base frequency). The application can then enter a safe status and stop operation, or it can switch to an emergency operating mode, where a reduced performance and/or feature set is provided.

The Programmer's Guide describes both, how to enable these features, and how to react properly on each of the two events.

8.1.6 External Clock Output

An external clock output can be provided via pin EXTCLK to clock an external system or to observe one of the selectable device clocks. This external clock is enabled by setting bit EXTCON.EN and by selecting the clock signal as alternate output function at pin EXTCLK. Following clocks can be selected by EXTCON.SEL for external clock f_{EXT} :

- System clock f_{SYS}
- Programmable clock output f_{OUT}
- Direct Clock from oscillator OSC_HP f_{OSC}
- Direct Clock Input f_{CLKIN1}
- PLL clock f_{PLL}
- Wake-up clock f_{WU}
- RTC clock f_{RTC}

Note: Changing bit field EXTCON.SEL can lead to spikes at pin EXTCLK.

Note: There are no XTAL1 and XTAL2 pins in 38 pin package and oscillator clock, f_{OSC} , will not be available.

Note: In XE166U, the clock output may not support a full voltage swing if the clock frequency is more than 10 MHz.

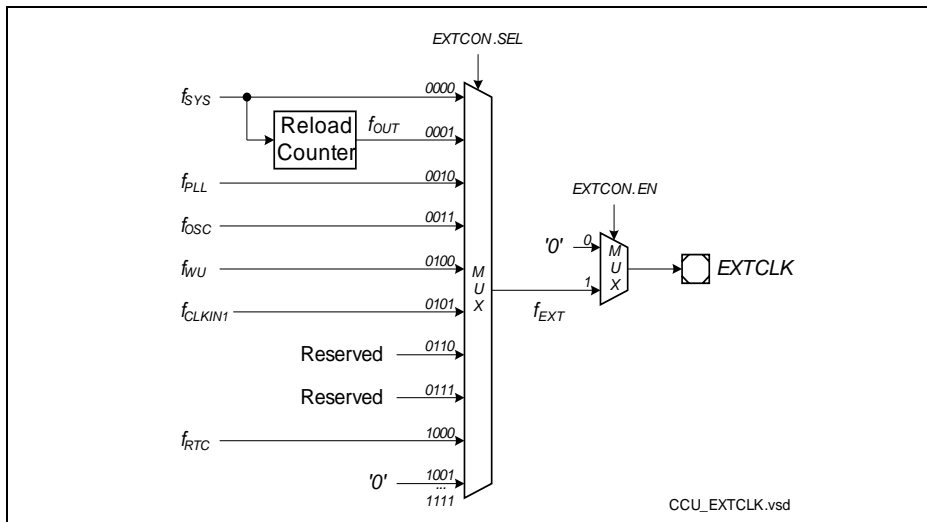


Figure 8-14 EXTCLK Generation

8.1.6.1 Programmable Frequency Output

The programmable frequency output f_{OUT} can be selected as clock output (EXTCLK). This clock can be controlled via software, and so can be adapted to the requirements of the connected external circuitry. The programmability also extends the power management to a system level, as also circuitry (peripherals, etc.) outside the XE166U can be run at a scalable frequency or can temporarily be left without a clock.

Clock f_{OUT} is generated via a reload counter, so the output frequency can be selected in small steps.

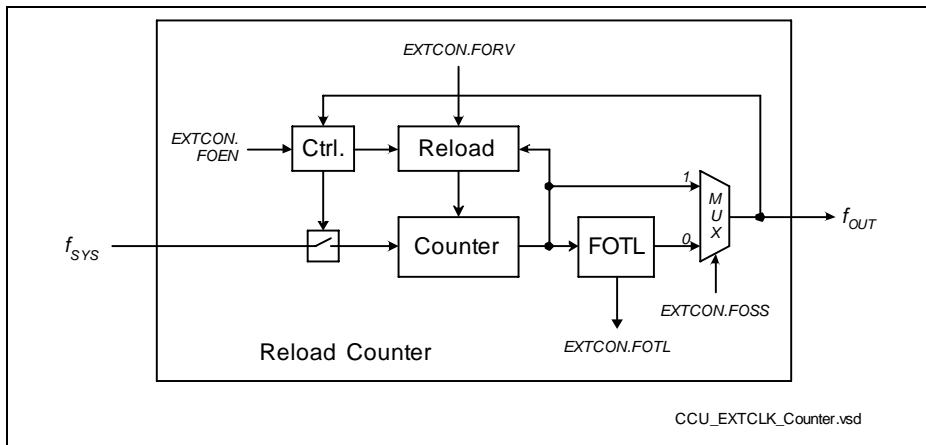


Figure 8-15 Programmable Frequency Output Generation

f_{OUT} always provides complete output periods (provided f_{SYS} is available):

- When f_{OUT} is started (EXTCON.FOEN is set) counter FOCNT is loaded from EXTCON.FORV
- When OUT is stopped (EXTCON.FOEN is cleared) counter FOCNT is stopped when f_{OUT} has reached (or is) '0'.

Register EXTCON provides control over the output generation (frequency, waveform, activation) as well as all status information (EXTCON.FOTL).

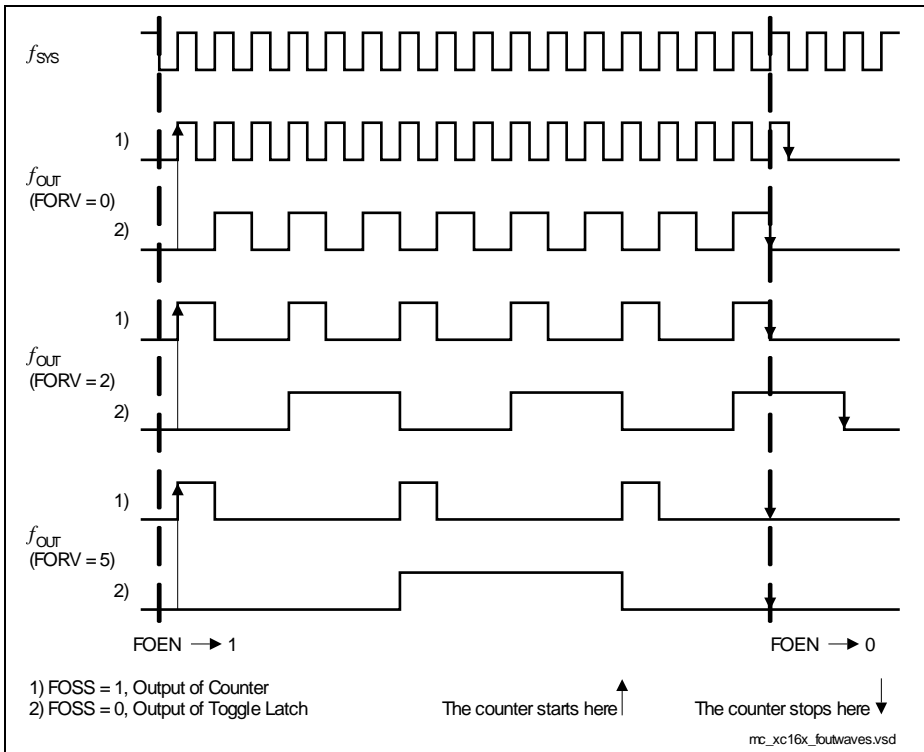


Figure 8-16 Output Waveforms Examples

Note: The output (for $\text{EXTCON.FOSS} = 1$) is high for the duration of one f_{sys} cycle for all reload values $\text{EXTCON.FORV} > 0$. For $\text{EXTCON.FORV} = 0$ the output frequency corresponds to f_{sys} . When a reference clock is required (e.g. for the bus interface), f_{sys} must be selected directly.

8.1.7 CGU Registers

8.1.7.1 Wake-up Clock Register

This register controls the settings of OSC_WU.

WUOSCCON

Wake-up OSC Control Register ESFR (F1AE_H/D7_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0											DIS	0	FREQSEL		
r											rw	rw	rw		

Field	Bits	Type	Description
FREQSEL	[1:0]	rw	Frequency Selection The values for the different settings are listed in the data sheet. <i>Note: This value must not be changed while f_{WU} is used as clock source for any logic.</i>
0	[3:2]	rw	Reserved Do not change this value when writing to this register
DIS	4	rw	Clock Disable 0 _B The oscillator is switched on and the clock is enabled 1 _B The oscillator is switched off and the clock is disabled
0	[15:5]	r	Reserved Read as 0; should be written with 0.

8.1.7.2 High Precision Oscillator Register

This register controls the setting of OSC_HP.

Note: There are no XTAL1 and XTAL2 pins in 38 pin package and oscillator clock, f_{OSC} , will not be available.

HPOSCCON

High Precision OSC Control Register

ESFR (F1B4_H/DA_H)

Reset Value: 053C_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			OSC 2 L0	OSC 2 L1	EM FIN DIS EN	EM CLK EN	SH BY	X1D EN	X1D	GAINSEL	MODE	OSC WDT RST	PLL V		
r			rh	rh	rw	rw	rw	rw	rh	rw	rw	w	rh		

Field	Bits	Type	Description
PLLV	0	rh	Oscillator for PLL Valid Status Bit This bit indicates whether the frequency output of OSC_HP is usable. This is checked by the Oscillator Watchdog of the PLL. 0 _B The OSC_HP frequency is not usable. The frequency is below the limit. 1 _B The OSC_HP frequency is usable. The frequency is not below the limit. For more information see Chapter 8.1.4.8 .
OSCWDTRST	1	w	Oscillator Watchdog Reset 0 _B No action 1 _B The Oscillator Watchdog of the PLL is reset and restarted <i>Note: This bit is always read as 0.</i>
MODE	[3:2]	rw	Oscillator Mode 00 _B The oscillator is active (External Crystal Mode) 01 _B Reserved, do not use 10 _B External Input Clock Mode; oscillator is in power-saving mode 11 _B OSC_HP is disabled and in power-saving mode

System Control Unit (SCU)

Field	Bits	Type	Description
GAINSEL	[5:4]	rw	Oscillator Gain Selection 00 _B Supply current is typically 300 µA (not tested) 01 _B Supply current is typically 530 µA (not tested) 10 _B Supply current is typically 450 µA (not tested) 11 _B Supply current is typically 610 µA (not tested)
X1D	6	rh	XTAL1 Data Value This bit reflects the inverted level of pin XTAL1. This bit is sampled with f_{SYS} while X1DEN is set. <i>Note: Voltages on XTAL 1 must comply to the voltage defined in the data sheet.</i>
X1DEN	7	rw	XTAL1 Data Enable 0 _B Bit X1D is not updated 1 _B Bit X1D can be updated
SHBY	8	rw	Shaper Bypass The shaper forms a proper signal from the input signal. This bit must be 0 for proper operation. 0 _B The shaper is not bypassed 1 _B The shaper is bypassed
EMCLKEN	9	rw	OSCWDT Emergency System Clock Source Select Enable This bit requests the master clock multiplexer (MCM) to switch to an alternate clock (selected by bit field SYSCON0.EMCLKSEL) in an OSCWDT emergency case. 0 _B MCM remains controlled by SYSCON0.CLKSEL 1 _B MCM is controlled by SYSCON0.EMCLKSEL
EMFINDISEN	10	rw	Emergency Input Clock Disconnect Enable This bit defines if bit PLLSTAT.FINDIS is set in an OSCWDT emergency case. 0 _B No action 1 _B PLLSTAT.FINDIS is set in an emergency case <i>Note: Please refer to the Programmer's Guide for a description of the proper handling.</i>

System Control Unit (SCU)

Field	Bits	Type	Description
OSC2L1	11	rh	OSC_HP Not Usable Frequency Event This sticky bit indicates if bit PLLV has been cleared since OSC2L1 has last been cleared (by writing 1 to bit STATCLR1.OSC2L1CLR). 0 _B No change of PLLV detected 1 _B Bit PLLV has been cleared at least once
OSC2L0	12	rh	OSC_HP Usable Frequency Event This sticky bit indicates if bit PLLV has been set since OSC2L0 has last been cleared (by writing 1 to bit STATCLR1.OSC2L0CLR). 0 _B No change of PLLV detected 1 _B PLLV has been set at least once
0	[15:13]	r	Reserved Read as 0; should be written with 0.

8.1.7.3 Trimmed Current Controlled Clock Control Register

This register controls the trimmed current controlled clock source.

PLLOSCCON

PLL OSC Control Register

ESFR (F1B6 _H /DB _H)										Reset Value: 0000 _H					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						OSCTRIM									OSC PD
r						rw									rw

Field	Bits	Type	Description
OSCPD	0	rw	Clock Source Power Saving Mode 0 _B Trimmed current controlled clock source is active 1 _B Trimmed current controlled clock source is off
OSCTRIM	[9:1]	rw	Clock Source Trim Configuration This value is used to adjust the frequency range of the current controlled clock source. Do not change this value when writing to this register.
0	[15:10]	r	Reserved Read as 0; should be written with 0.

8.1.7.4 PLL Registers

PLLSTAT

PLL Status Register

ESFR (F0BC_H/5E_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OSC LOC K	OSC STA B	0	REG STA T	VCO L1	VCO L0	FIN DIS	K2 RDY	K1 RDY	N RDY	P RDY	0	VCO LOC K	OSC SEL ST	PWD STA T	VCO BY ST
rh	rh	r	rh	rh	rh	rh	rh	rh	rh	rh	r	rh	rh	rh	rh

Field	Bits	Type	Description
VCObYST	0	rh	VCO Bypass Status 0 _B The PLL clock is derived from divider K1 (Prescaler Mode) 1 _B The PLL clock is derived from divider K2 (Normal / Unlocked Mode) <i>Note: Coding of PLLCON0.VCOBY and VCObYST are different.</i>
PWDSTAT	1	rh	PLL Power-saving Mode Status 0 _B The PLL is operable 1 _B The digital part of the PLL is disabled
OSCSELST	2	rh	Oscillator Input Selection Status 0 _B External input clock source for the PLL (f_{IN}) 1 _B Internal input clock source for the PLL
VCOLOCK	3	rh	PLL VCO Lock Status 0 _B The frequency difference of f_{REF} and f_{DIV} is greater than allowed. The PLL cannot lock. 1 _B The PLL clock f_{PLL} is locked to f_{REF} and is stable. <i>Note: In case of a loss of lock, the VCO frequency f_{VCO} approaches to the upper/lower boundary of the selected VCO band if the reference frequency is higher/lower than possible for locking.</i>
PRDY	5	rh	P-Divider Ready Status 0 _B Bit field PLLCON1.PDIV has been changed, new K1 divider value not yet used. 1 _B The P-Divider operates with the value defined in bit field PLLCON1.PDIV.

System Control Unit (SCU)

Field	Bits	Type	Description
NRDY	6	rh	N-Divider Ready Status 0_B Bit field PLLCON0.NDIV has been changed, new K1 divider value not yet used. 1_B The P-Divider operates with the value defined in bit field PLLCON0.NDIV.
K1RDY	7	rh	K1-Divider Ready Status 0_B Bit field PLLCON2.K1DIV has been changed, new K1 divider value not yet used. 1_B The K1-Divider operates with the value defined in bit field PLLCON2.K1DIV.
K2RDY	8	rh	K2-Divider Ready Status 0_B Bit field PLLCON3.K2DIV has been changed, new K2 divider value not yet used. 1_B The K2-Divider operates with the value defined in bit field PLLCON3.K2DIV.
FINDIS	9	rh	Input Clock Disconnect Select Status 0_B The VCO is connected to the reference clock 1_B The VCO is disconnected from the reference clock <i>Note: Software can control this bit by writing 1 to bits SETFINDIS or CLRFINDIS in register STATCLR1.</i>
VCOL0	10	rh	VCO Lock Detection Lost Status This sticky bit indicates if bit VCOLOCK has been cleared since VCOL0 has last been cleared (by writing 1 to bit STATCLR1.VCOL0CLR). 0_B No falling edge detected 1_B PLLV has been cleared at least once (VCO lock was lost)
VCOL1	11	rh	VCO Lock Detection Reached Status This sticky bit indicates if bit VCOLOCK has been set since VCOL1 has last been cleared (by writing 1 to bit STATCLR1.VCOL1CLR). 0_B No rising edge detected 1_B VCO lock was reached

System Control Unit (SCU)

Field	Bits	Type	Description
VCOL1CLR	1	w	VCOL1 Clear Trigger 0 _B No action 1 _B Bit PLLSTAT.VCOL1 is cleared
OSC2L1CLR	2	w	OSC2L1 Clear Trigger 0 _B No action 1 _B Bits HPOSCCON.OSC2L1 is cleared
OSC2L0CLR	3	w	OSC2L0 Clear Trigger 0 _B No action 1 _B Bit HPOSCCON.OSC2L0 is cleared
SETFINDIS	4	w	Set Status Bit PLLSTAT.FINDIS 0 _B No action 1 _B Bit PLLSTAT.FINDIS is set. The VCO input clock is disconnected.
CLRFINDIS	5	w	Clear Status Bit PLLSTAT.FINDIS 0 _B No action 1 _B Bit PLLSTAT.FINDIS is cleared. The VCO input clock is connected.
0	[15:6]	r	Reserved Read as 0; should be written with 0.

Note: Bits of type w are always read as 0.

These registers control the configuration of the PLL.

PLLCON0

PLL Configuration 0 Register **ESFR (F1B8_H/DC_H)** **Reset Value: 1302_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
N ACK	0				NDIV			0	IN SEL	REG EN SET	REG EN CLR	VCOSEL	VCO PWD	VCO BY	
rw	r				rw			r	rw	w	w	rw	rw	rw	

Field	Bits	Type	Description
VCOBY	0	rw	VCO Bypass 0_B Select divider K2 for PLL clock (Normal / Unlocked Mode) 1_B Select divider K1 for PLL clock (Prescaler Mode, i.e. VCO is bypassed) Bit PLLSTAT.VCOBYST shows the actually selected divider. <i>Note: Coding of VCOBY and PLLSTAT.VCOBYST are different.</i>
VCOPWD	1	rw	VCO Power Saving Mode 0_B Normal behavior 1_B The VCO is put into a power saving mode and can no longer be used. Only the Prescaler Mode is active if previously selected.
VCOSEL	[3:2]	rw	VCO Range Select The values for the different settings are listed in the data sheet.
REGENCLR	4	w	Power Regulator Enable Clear 0_B No action 1_B Switch off the PLL's power regulator. The PLL is not powered (no operation possible). <i>Note: This bit is always read as 0.</i>
REGENSET	5	w	Power Regulator Enable Set 0_B No action 1_B Switch on the PLL's power regulator. The PLL is powered (operation possible). <i>Note: This bit is always read as 0.</i>

System Control Unit (SCU)

Field	Bits	Type	Description
INSEL	6	rw	Input Select 0_B f_{OSC} is selected as input for the PLL 1_B f_{CLKIN1} is selected as input for the PLL <i>Note: f_{OSC} is not available in the 38 pin package.</i>
NDIV	[13:8]	rw	N-Divider Value The value the N-Divider operates is NDIV+1. Only values between N = 8 and N = 28 are allowed for VCOSEL = 00_B . Only values between N = 16 and N = 40 are allowed for VCOSEL = 01_B . Outside of this range, stable operation cannot be ensured.
NACK	15	rw	N-Divider Ready Acknowledge Setting this bit provides the acknowledge signal to NRDY.
0	7, 14	r	Reserved Read as 0; should be written with 0.

PLLCON1

PLL Configuration 1 Register ESFR (F1BA_H/DD_H)

Reset Value: 000A_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
P ACK		0				PDIV		0	EM FIN DIS EN	EM CLK EN	0	A OSC SEL	RES LD	OSC SEL	PLL PWD
rw		r				rw		r	rw	rw	r	rw	w	rw	rw

Field	Bits	Type	Description
PLLPWD	0	rw	PLL Power Saving Mode 0 _B Normal behavior 1 _B Complete PLL block is put into a power saving mode and no longer operates
OSCSEL	1	rw	Oscillator Input Selection 0 _B Select external clock as input for PLL 1 _B Select trimmed current controlled clock as input for PLL
RESLD	2	w	Restart VCO Lock Detection Setting this bit will reset bit PLLSTAT.VCOLOCK and restart the VCO lock detection. <i>Note: This bit is always read as 0.</i>
AOSCSEL	3	rw	Asynchronous Oscillator Input Selection This bit overrules the setting of bit OSCSEL. 0 _B Configuration is controlled via bit OSCSEL 1 _B Select asynchronously trimmed current controlled clock as input for PLL
EMCLKEN	5	rw	VCOLCK Emergency System Clock Source Select Enable This bit requests the master clock multiplexer (MCM) to switch to an alternate clock (selected by bit field SYSCON0.EMCLKSEL) in a VCOLCK emergency case. 0 _B MCM remains controlled by SYSCON0.CLKSEL 1 _B MCM is controlled by SYSCON0.EMCLKSEL

System Control Unit (SCU)

Field	Bits	Type	Description
EMFINDISEN	6	rw	Emergency Input Clock Disconnect Enable This bit defines if bit PLLSTAT.FINDIS is set in a VCOLCK emergency case. 0 _B No action 1 _B PLLSTAT.FINDIS is set in a VCOLCK emergency case <i>Note: Please refer to the Programmer's Guide for a description of the proper handling.</i>
PDIV	[11:8]	rw	P-Divider Value The value the P-Divider operates is PDIV+1.
PACK	15	rw	P-Divider Ready Acknowledge Setting this bit provides the acknowledge to PRDY.
0	4, 7, [14:12]	r	Reserved Read as 0; should be written with 0.

PLLCON3

PLL Configuration 3 Register **ESFR (F1BE_H/DF_H)** **Reset Value: 00CB_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
K2 ACK			0												
rw			r												
									K2DIV						
										rw					

Field	Bits	Type	Description
K2DIV	[9:0]	rw	K2-Divider Value The value the K2-Divider operates is K2DIV+1.
K2ACK	15	rw	K2-Divider Ready Acknowledge¹⁾ Setting this bit provides the acknowledge to K2RDY.
0	[14:10]	r	Reserved Read as 0; should be written with 0.

1) Please refer to the Programmer's Guide for a description of the proper handling.

8.1.7.5 System Clock Control Registers

These registers control the system level clock behavior.

Note: Oscillator clock, f_{OSC} , is not available in the 38 pin package.

SYSCON0

System Control 0 Register

SFR (FF4A_H/A5_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEL STA T	0	EMS VCO	EMS OSC	STM CLKSEL		WUT CLKSEL		EM CLK SEL EN	0	EM CLKSEL		0	CLKSEL		
rh	r	rh	rh	rw		rw		rw	r	rw		r	rw		

Field	Bits	Type	Description
CLKSEL	[1:0]	rw	Clock Select This bit field defines the clock source that is used as system clock for normal operation. 00 _B The Wake-up clock f_{WU} is used 01 _B The oscillator clock (OSC_HP) f_{OSC} is used 10 _B The PLL clock f_{PLL} is used 11 _B CLKIN1 as direct input clock f_{CLKIN1} is used
EMCLKSEL	[4:3]	rw	Emergency Clock Select This bit field defines the clock source that is used as system clock in case of an OSCWDT or VCOLCK emergency event. 00 _B The Wake-up clock f_{WU} is used 01 _B The oscillator clock (OSC_HP) f_{OSC} is used 10 _B The PLL clock f_{PLL} is used 11 _B CLKIN1 as direct input clock f_{CLKIN1} is used
EMCLKSELEN	6	rw	Emergency Clock Select Enable Controls switching the system clock to an alternate source in case of an OSCWDT or VCOLCK event. 0 _B The switching is disabled 1 _B The switching is enabled

System Control Unit (SCU)

Field	Bits	Type	Description
WUTCLKSEL	[8:7]	rw	WUT Clock Select This bit field defines the clock source that is used as wake-up timer clock for operation. 00 _B The Wake-up clock f_{WU} is used 01 _B The oscillator clock (OSC_HP) f_{OSC} is used 10 _B The PLL clock f_{PLL} is used 11 _B CLKIN1 as direct Input clock, f_{CLKIN1} is used
STMCLKSEL	[11:9]	rw	STM Clock Select This bit field defines the clock source that is used as STM clock for operation. 000 _B Reserved, do not use this combination 001 _B The oscillator clock (OSC_HP) f_{OSC} is used 010 _B The PLL clock f_{PLL} is used 011 _B CLKIN1 as direct Input clock f_{CLKIN1} is used 100 _B The Wake-up clock f_{WU} is used 101 _B Reserved, do not use this combination 110 _B Reserved, do not use this combination 111 _B Reserved, do not use this combination
EMSOSC	12	rh	OSCWDT Emergency Event Source Status 0 _B No OSCWDT emergency event occurred since EMSOSC has been cleared last 1 _B An OSCWDT emergency event has occurred <i>Note: This bit is only set if EMCLKSELEN is set.</i>
EMSVCO	13	rh	VCOLCK Emergency Event Source Status 0 _B No VCOLCK emergency event occurred since EMSVCO has been cleared last 1 _B A VCOLCK emergency event has occurred <i>Note: This bit is only set if EMCLKSELEN is set.</i>
SELSTAT	15	rh	Clock Select Status 0 _B The standard configuration from bit field CLKSEL is used currently 1 _B The configuration from bit field EMCLKSEL is used currently
0	2, 5, 14	r	Reserved Read as 0; should be written with 0.

STATCLR0

Status Clear 0 Register

ESFR (F0E0_H/70_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		EMC VCO	EMC OSC	0											
r		w	w							r					

Field	Bits	Type	Description
EMCOSC	12	w	EMSOSC Clear Trigger 0 _B No action 1 _B Bit SYSCON0.EMSOSC is cleared <i>Note: This bit is always read as 0.</i>
EMCVCO	13	w	EMSVCO Clear Trigger 0 _B No action 1 _B Bit SYSCON0.EMSVCO is cleared <i>Note: This bit is always read as 0.</i>
0	[11:0], [15:14]	r	Reserved Read as 0; should be written with 0.

8.1.7.6 RTC Clock Control Register

Note: Only change register RTCCLKCON while the RTC is off.

Note: Oscillator clock, f_{OSC} , is not available in the 38 pin package.

RTCCLKCON

RTC Clock Control Register

SFR (FF4E_H/A7_H)

Reset Value: 0006_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
						0							RTC CM	RTC CLKSEL	
						r							rw	rw	

Field	Bits	Type	Description
RTCCLKSEL	[1:0]	rw	RTC Clock Select This bit field defines the count clock source for the RTC. 00 _B The PLL clock f_{PLL} is used 01 _B The oscillator clock (OSC_HP) f_{OSC} is used 10 _B The Wake-up clock signal f_{WU} is used 11 _B Reserved, do not use this combination
RTCCM	2	rw	RTC Clocking Mode 0 _B Asynchronous Mode: The RTC internally operates with f_{RTC} . No register access is possible. 1 _B Synchronous Mode: The RTC internally operates with f_{SYS} clock. Registers can be read and written.
0	[15:3]	r	Reserved Read as 0; should be written with 0.

8.1.7.7 External Clock Control Register

This register control the setting of external clock for pin 2.8.

Note: Oscillator clock, f_{OSC} , is not available in the 38 pin package.

EXTCON

External Clock Control Register SFR (FF5E_H/AF_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FO EN	FO SS	FORV					0	FO TL	0	SEL				EN	
rw	rw	rw					r	rh	r	rw				rw	

Field	Bits	Type	Description
EN	0	rw	External Clock Enable 0 _B No external clock signal is provided. The signal is tied to zero. 1 _B The configured external clock signal is provided as alternate output signal
SEL	[4:1]	rw	External Clock Select Selects the clock signal to be routed to the EXTCLK pin: 0000 _B System clock f_{SYS} 0001 _B Programmable clock signal f_{OUT} 0010 _B PLL output clock f_{PLL} 0011 _B Oscillator clock f_{OSC} 0100 _B Wake-up clock f_{WU} 0101 _B Direct Input clock f_{CLKIN1} 1000 _B RTC count clock f_{RTC} All other combination are reserved, do not use.
FOTL	6	rh	Frequency Output Toggle Latch Toggled upon each underflow of FOCNT.
FORV	[13:8]	rw	Frequency Output Reload Value Copied to FOCNT upon each underflow of FOCNT.
FOSS	14	rw	Frequency Output Signal Select 0 _B Output of the toggle latch 1 _B Output of the reload counter: duty cycle depends on FORV

System Control Unit (SCU)

Field	Bits	Type	Description
FOEN	15	rw	Frequency Output Enable 0_B Frequency output generation stops when f_{OUT} is/becomes low. 1_B FOCNT is running, f_{OUT} is gated to pin. First reload after 0 - 1 transition.
0	5, 7	r	Reserved Read as 0; should be written with 0.

8.2 System Timer Function (STM)

The System Timer equips the device with a real time counter function

The STM function can operate on the clock sources described in **System Timer (STM) Clock Generation**.

The STM consists of a 16-bit counter that is able to generate up to two interrupts. Driven by a clock source the counter can be used to count time based events and upon an interrupt trigger based on a time generated out of a clock different than the remaining of the system. A clock function can easily be implemented based on these interrupts in software.

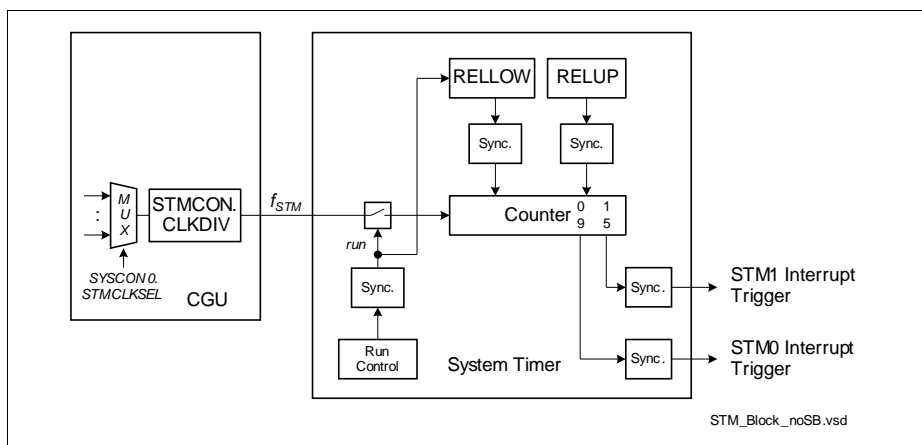


Figure 8-17 STM Block Diagram

*Note: The STM0 and STM1 interrupts are enabled by default upon a reset (register $INTDIS = 0000_{\text{H}}$). It may lead to interrupt requests being triggered at an inappropriate time as described in **Chapter 8.10**. Hence, it is advised to disable interrupt sources that will not be used via the $INTDIS$ register. In addition, pending request flags ($SCU_xIC.IR$) need to be cleared before enabling interrupts in interrupt controller.*

8.2.1 STM Registers

8.2.1.1 Register STMREL

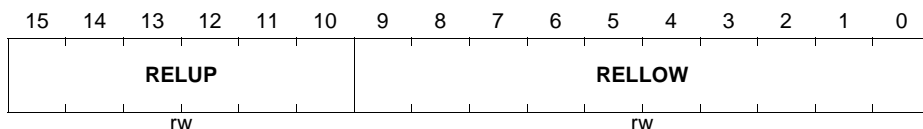
Via this register, the reload value and therefore the period of the STM is defined.

STMREL

STM Reload Register

ESFR (F1A8_H/D4_H)

Reset Value: 0000_H



Field	Bits	Type	Description
RELOW	[9:0]	rw	Reload Lower Value The counter counts up and issues an interrupt trigger when bit 9 changes from 1 _B to 0 _B . Upon this trigger the counter is loaded with the reload value defined by this bit field.
RELUP	[15:10]	rw	Reload Upper Value The counter counts up and issues an interrupt trigger when bit 15 changes from 1 _B to 0 _B . Upon this trigger the counter is loaded with the reload value defined by this bit field and by bit field RELOW.

8.2.1.2 Register STMCON

This register holds the status and control bits for the STM.

STMCON

STM Control Register

ESFR (F1AA_H/D5_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0											CLKDIV			RUN	
r											rw			rw	

Field	Bits	Type	Description
RUN	0	rw	Run Control 0 _B STM is stopped 1 _B STM is operating By setting this bit the STM is started and the reload value STMREL.REL is loaded into the counter.
CLKDIV	[4:1]	rw	Clock Divider for the STM Clock This bit field defines the divider factor of the STM clock input. The selected input clock is divided by $2^{<CLKDIV>}$.
0	[15:5]	r	Reserved Read as 0; should be written with 0.

8.3 Wake-up Timer (WUT)

The Wake-up Timer provides a very compact (and, therefore, power-saving) mean of re-activating the system from certain power saving modes automatically after a specific period of time.

The Wake-up Timer function can operate on the clock sources described in [Wake-up Timer \(WUT\) Clock Generation](#).

The wake-up timer clock f_{WUT} drives a simple counter. All functions are controlled by register WUCR.

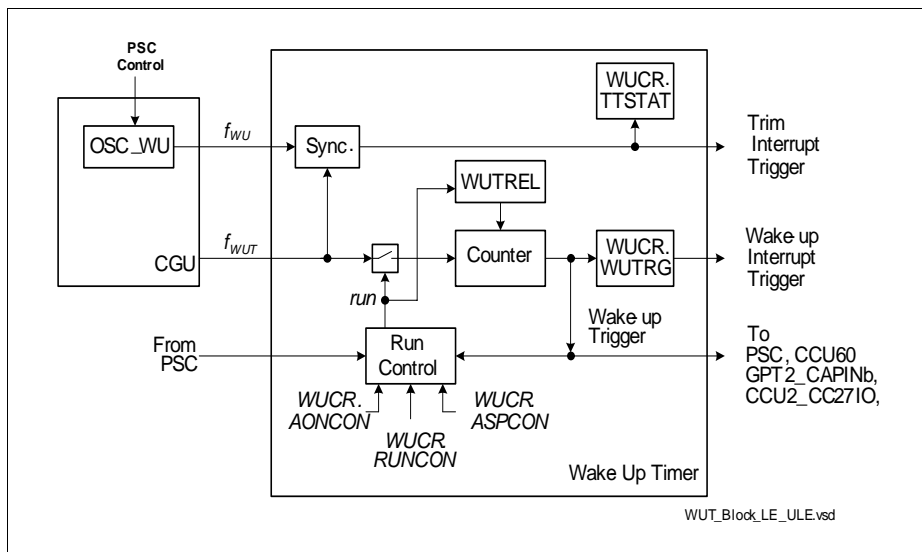


Figure 8-18 Wake-up Timer Logic

8.3.1 Wake-up Timer Operation

The Wake-up Timer start and stop is controlled by the Run Control logic. The timer can be started in the following way:

- bit **WUCR.AON** is set AND the Power State Controller (PSC, see [Chapter 8.6.5](#)) generates a start trigger
- bit **WUCR.RUN** is set

When the timer is started the prescaler is reset and the counter starts to count down.

The wake-up interval counter is clocked with f_{WUT} and counts down until it reaches zero. It then generates a wake-up trigger and sets bit **WUCR.WUTRG**.

The timer is stopped in the following ways:

- bit WUCR.RUN is cleared
- bit WUCR.ASP is set AND a wake-up trigger is generated

If the counter is not stopped by its zero trigger it continues counting down from WUTREL.

Determination of Wake-up Period

The actual frequency of the trimmed current controlled wake-up clock (OSC_WU) can be measured prior to entering power-save mode in order to adjust the number of clock cycles to be counted (reload value written to the counter) and so to define the time until wake-up. The period of the the OSC_WU can be measured by evaluating the (synchronized) trigger that can generate interrupt requests or can be monitored with bit WUCR.TTSTAT.

As using an interrupt together with software contain some uncertainty, there is a second way to determine the wake-up period using the CCU60 capture input that is connected to the wake-up trigger output. A CCU60 capture event will be triggered when a WUT wake-up trigger is generated as shown in [Figure 8-18](#). With the CCU60 running on an accurate system clock, the actual wake-up period and therefore, the actual OSC_WU frequency, can be determined using the captured counter value. The WUT reload value can then be adjusted based on the actual frequency.

Besides CCU60, the wake-up trigger output is also connected to GPT2 and CCU2 and the same approach can be used for the wake-up period evaluation. Since OSC_WU is one of the clock input for WWD, the same approach could be used to adjust the number of counts needed for the window watchdog timer period as described in [Determination of WWD Period when fIN = fWU](#).

Note: The Wake-up Timer interrupts are enabled by default upon a reset (register INTDIS = 0000_H). It may lead to interrupt requests being triggered at an inappropriate time as described in [Chapter 8.10](#). Hence, it is advised to disable interrupt sources that will not be used via the INTDIS register. In addition, pending request flags (SCU_xIC.IR) need to be cleared before enabling interrupts in interrupt controller.

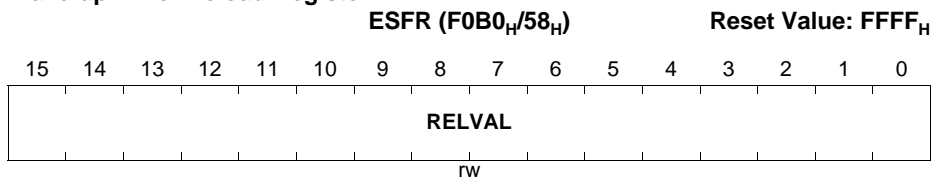
8.3.2 WUT Registers

8.3.2.1 Register WUTREL

This register configures the reload value of the counter.

WUTREL

Wake-up Timer Reload Register



Field	Bits	Type	Description
RELVAL	[15:0]	rw	Wake-up Timer Reload Value The WUT counter is reloaded with this value and starts to count down when the timer is started.

8.3.2.2 Register WUCR

This register the status and control bits for the WUT.

WUCR

Wake-up Control Register

ESFR (F1B0_H/D8_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WU TRG		TTS TAT		CLKDIV		ASP	AON	RUN	CLR TRG	0	ASP CON	AON CON	RUN CON		
rh		rh		rw		rh	rh	rh	w	r	w	w	w		

Field	Bits	Type	Description
RUNCON	[1:0]	w	Control Field for RUN 00 _B No action 01 _B Set bit RUN 10 _B Clear bit RUN 11 _B Reserved, do not use this combination <i>Note: This bit is always read as 0.</i>
AONCON	[3:2]	w	Control Field for AON 00 _B No action 01 _B Set bit AON 10 _B Clear bit AON 11 _B Reserved, do not use this combination <i>Note: This bit is always read as 0.</i>
ASPCON	[5:4]	w	Control Field for ASP 00 _B No action 01 _B Set bit ASP 10 _B Clear bit ASP 11 _B Reserved, do not use this combination <i>Note: This bit is always read as 0.</i>
CLRTRG	7	w	Clear Bit WUTRG 0 _B No action 1 _B Clear bit WUTRG <i>Note: This bit is always read as 0.</i>

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Field	Bits	Type	Description
RUN	8	rh	Run Indicator 0_B Wake-up counter is stopped 1_B Wake-up counter is counting down <i>Note: Clearing this bit via a write action to bit field RUNCON stops the WUT after four cycles of f_{WUT}.</i>
AON	9	rh	Auto-Start Indicator 0_B Wake-up counter is started by software only 1_B Wake-up counter can be started by the PSC mechanism <i>Note: This bit is cleared by writing 01_B to bit field AONCON.</i>
ASP	10	rh	Auto-Stop Indicator 0_B Wake-up counter runs continuously 1_B Wake-up counter stops after generating a trigger when reaching zero
CLKDIV	[13:11]	rw	Clock Divider for the WUT Clock This bit field defines the divider factor of the WUT clock input. The selected input clock is divided by $2^{<CLKDIV>}$.
TTSTAT	14	rh	Trim Trigger Status 0_B No trim trigger event is active. No trim interrupt trigger is generated. 1_B A trim trigger event is active. A trim interrupt trigger is generated. <i>Note: This bit is not valid if $f_{WUT} = f_{WU}$ is configured by SYSCON0.WUTCLKSEL</i>
WUTRG	15	rh	WUT Trigger Indicator 0_B No trigger event has occurred since WUTRG has been cleared last. No interrupt trigger is generated. 1_B A wake-up trigger event has occurred. A wake-up interrupt trigger is generated.
0	6	r	Reserved Read as 0; should be written with 0.

Note: The bits in the upper byte of register WUCR indicate the current status of the wake-up counter logic. They are not influenced by a write access, but are

System Control Unit (SCU)

controlled by their associated control fields (lower byte) or by hardware.

The control bit(field)s in the lower byte of register WUCR determine the state of the status bits (upper byte) of the wake-up counter logic. Setting bits by software triggers the associated action, writing 0 has no effect.

8.4 Reset Operation

All resets are generated by the Reset Control Block. It handles the control of the reset triggers as well as the length of a reset and the reset timing. A reset leads the system, or a part of the system depending on the reset, to a initialization into a defined state.

8.4.1 Reset Architecture

The XE166U contains a very sophisticated reset architecture to offer the greatest amount of flexibility for the support of different applications. The reset architecture supports the different power domains.

Different reset types for the complete system are supported.

8.4.1.1 Device Reset Hierarchy

The device reset hierarchy is divided according to the power domains (see [Chapter 8.6](#)) into following linked levels:

Level 1: I/O domain (power domain DMP_B)

Level 2: Core domain (power domain DMP_M)

If a power domain (level) is deactivated all resets of the deactivated level and all resets of all lower power domains are asserted.

8.4.1.2 Reset Types

The following summary shows the different reset types.

Power Reset

- **Power-on Reset**
This reset leads to a defined state of the complete system. This reset should only be requested on a real power-on event and not by any non power related event.
- **Power Reset for DMP_M core domain**
This reset regains data consistency upon a power loss in the core domain. In addition, this reset could also be triggered on a watchdog timer reset request.

Functional / User Reset

- **Debug Reset**
This reset leads to a defined state of the complete debug system.
- **Internal Application Reset**
This reset leads to a defined state of the complete application system with the following parts: all peripherals (except the RTC and SCU), the CPU and the flash memory.

System Control Unit (SCU)

- **Application Reset**

This reset leads to a defined state of the complete application system with the following parts: all peripherals (except the Ports and the RTC), the CPU and partially the SCU and the flash memory.

After a reset has been executed, the Reset Status registers RSTSTATx indicate the latest reset that has occurred.

To identify the type and the trigger of the latest reset registers **RSTSTAT0**, **RSTSTAT1** and **SWDCON1** may be evaluated according to **Table 8-2**. The latest reset that has occurred is always the reset of the highest type. If two reset triggers of the same type are indicated, this means that the two triggers have been active at the same time. If two or more reset triggers of a different type are reported, always the reset of the highest type is the latest one.

Table 8-2 Identification of a Reset

Type of Reset (in hierarchical order, highest on top)	Identification
Power-on Reset	SWDCON1.PON = 1 _B RSTSTAT1.STM = 11 _B Further action: clear PON bit to be able to identify a Power Reset for DMP_M core domain.
Power Reset for DMP_M core domain	SWDCON1.PON = 0 _B (unchanged after clearing) RSTSTAT1.STM = 11 _B
Internal Application Reset	RSTSTAT1.STM = 00 _B any bit field y in RSTSTATx.y = 10 _B (except RSTSTAT1.STM)
Application Reset	RSTSTAT1.STM = 00 _B any bit field y in RSTSTATx.y = 11 _B (except RSTSTAT1.STM)

The algorithm depicted in **Figure 8-19** shows a sequence to detect the type of the reset comprising the conditions in **Table 8-2**.

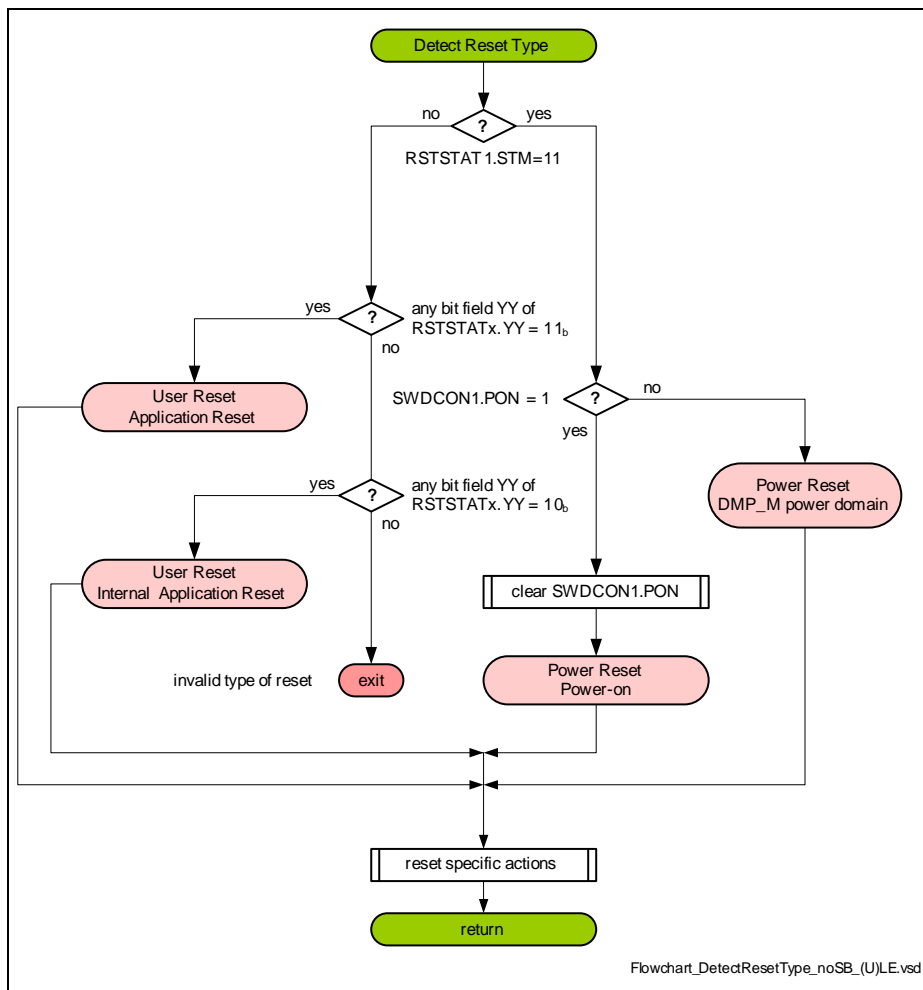


Figure 8-19 Algorithm for the Detection of the Type of a Reset

8.4.2 General Reset Operation

A reset is generated if an enabled reset request trigger is asserted. Most reset request triggers can be configured for the reset type it should initiate. No action (disabled) is one possible configuration and can be selected for a reset request trigger by setting the respective bit field in a Reset Configuration Register to 00_B. The debug reset can only be requested by dedicated reset request triggers and can not be selected via a Reset Configuration Register. For more information see also registers **RSTCON0** and **RSTCON1**.

The duration of a reset is defined by two independent counters. One counter for the System and Application Reset types and one separate counter for the debug reset. A separate counter for the debug reset was implemented to allow a non-intrusive adaptation of the reset length to the debugger needs without modification of the application setting.

8.4.2.1 Reset Counters (RSTCNTA and RSTCNTD)

RSTCNTA is the reset counter that controls the reset length for all application relevant resets (Internal Application Reset, and Application Reset). RSTCNTD is the reset counter that controls the reset length for the debug reset.

The reset counters control the length of the internal resets. This can be used to configure the duration of a reset output via the ESRx pins, so this matches with the reset input requirements of external blocks connected to these signals.

A reset counter RSTCNT is an 8-bit counter counting down from the reload value defined by **RSTCNTCON.RELx** (x = A or D). The counter is started by the reset control block as soon as a reset request trigger condition becomes active (for more information see **Table 8-3** and **Table 8-4**). Whether the counter has to be started or not depends on the reset request trigger and whether the counter is already active or not. In case of that the counter is inactive, not counting down, it is always started. While the counter is already active it depends on the reset type of the new reset request trigger that was asserted anew if the counter is restarted or not. This behavior is summarized in **Table 8-3** and **Table 8-4**.

Table 8-3 Restart of RSTCNTA

Reset Active	New Reset Trigger			
	Power-On	Debug Reset	Internal Application Reset	Application Reset
Internal Application Reset	Restart with default delay	No Change	No Change	No Change
Application Reset	Restart with default delay	No Change	Restart with defined delay	No Change

Table 8-4 Restart of RSTCNTD

Reset Active	New Reset Trigger			
	Power-On	Debug Reset	Internal Application Reset	Application Reset
Debug Reset	Restart with default delay	No Change	No Change	No Change

The reset counters RSTCNTx ensure a configurable minimum duration of a generated reset. If a reset request trigger remains asserted after the respective counter has counted down, the counter is not started again, instead the reset control block keeps the reset asserted until the reset request trigger is deasserted.

8.4.2.2 De-assertion of a Reset

The reset of a dedicated type is de-asserted when all of the following conditions are fulfilled:

- The reset counter has been expired (reached zero).
- No reset request trigger that is configured to generate a reset of the dedicated type (or higher) is currently asserted.

Example1

Reset request trigger A is asserted and leads to an Application Reset. If the reset request trigger is de-asserted before RSTCNTA reached zero the Application Reset is de-asserted when RSTCNTA reaches zero. If the reset request trigger is de-asserted after RSTCNTA reached zero the Application Reset is de-asserted when the reset request trigger is de-asserted.

Example2

Reset request trigger A is asserted and leads to an Application Reset. Reset request trigger A is de-asserted before RSTCNTA reached zero. Reset request trigger B is asserted after reset request trigger A but before RSTCNTA reaches zero. Reset request trigger B is also configured to result in a Application Reset. If the reset request trigger B is de-asserted before RSTCNTA reached zero the Application Reset is de-asserted when RSTCNTA reaches zero. If the reset request trigger B is de-asserted after RSTCNTA reached zero the Application Reset is de-asserted when the reset request trigger B is de-asserted.

8.4.3 Debug Reset Assertion

Unlike the other reset types a Debug Reset can only be asserted if the following two conditions are valid:

- A reset request trigger is asserted that request a debug reset
- An Application Reset is already active in the system

8.4.4 Coupling of Reset Types

The different reset types are coupled for a better usage:

- The assertion of a Power-on Reset automatically asserts also the following reset types:
 - Debug Reset
 - Internal Application Reset
 - Application Reset
- The assertion of an Internal Application Reset automatically asserts also the following reset type:
 - Application Reset

8.4.5 Reset Request Trigger Sources

The following overview summarizes the different reset request trigger sources within the system.

Power-On Reset Pin $\overline{\text{PORST}}$

A Power-on Reset is requests asynchronously, by driving the $\overline{\text{PORST}}$ pin low.

Supply Watchdog (SWD)

If the power supply for I/O domain is below the value required for proper functionality, a non-synchronized power-on reset request is generated if the SWD reset generation is enabled. This ensures a reproducible behavior in the case of power-fail. This can also be used to restart the system without the usage of the $\overline{\text{PORST}}$ pin. As long as the I/O power domain does not get the required voltage level the system is held in the reset.

Core Power Validation (PVC_M)

If the core power supply is below the value required for proper functionality of the core power domain, a reset request trigger can be forwarded to the system. The generation of a Power Reset in core domain is configured by bit $\text{PVCMCN0.L1RSTEN} = 1_{\text{B}}$. If the bit $\text{PVCMCN0.L1RSTEN} = 1_{\text{B}}$ a request trigger is asserted for PVC_M1 upon a level check match. If the bit $\text{PVCMCN0.L2RSTEN} = 1_{\text{B}}$ a request trigger is asserted for PVC_M2 upon a level check match.

For more information about the Power Validation Circuit see [Chapter 8.6.2](#).

$\overline{\text{ESRx}}$

An $\overline{\text{ESRx}}$ reset request trigger leads to a configurable reset. The type of reset can be configured via [RSTCON1.ESRx](#).

The pins $\overline{\text{ESRx}}$ can serve as an external reset input as well as a reset output (open drain) for Internal Application and Application Resets. Furthermore, several GPIO pad triggers, that can be enabled additionally via register ESREXCONx ($x = 1, 2$), interfere with the ESR pin function. GPIO and ESRx pin triggers can be enabled/disabled individually and are combined for the reset trigger generation.

If pin $\overline{\text{ESRx}}$ is enabled as reset output and the input level is low while the output stage is disabled (indicating that it is still driven low externally), the reset circuitry holds the chip in reset until a high level is detected on $\overline{\text{ESRx}}$. Minimum value for RSTCNTCON.RELA must be the reset value.

Note: The reset output is only driven low for the duration the reset counter RSTCNTA is active. During a possible reset extension the reset output is no longer driven.

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Note: In XE166U, dedicated $\overline{ESR0}$, $\overline{ESR1}$ and $\overline{ESR2}$ pins are not available. However, $\overline{ESR1}$ and $\overline{ESR2}$ are provided as alternate input functions on pins with shared functions.

Software

A software reset request trigger leads to a configurable reset. The type of reset can be configured via **RSTCON0.SW**.

Window Watchdog Timer (WWD)

A WWD reset request trigger leads to a configurable reset. The type of reset can be configured via **RSTCON1.WDT**. A WWD reset is requested on a WWD overflow event or an out of boundary window refresh event. For more information see **Chapter 8.11**.

CPU

A CPU reset request trigger leads to a configurable reset. The type of reset can be configured via **RSTCON0.CPU**. A CPU reset is requested when instruction SRST is executed.

Memory Parity

A MP reset request trigger leads to a configurable reset. The type of reset can be configured via **RSTCON1.MP**. For more information see **Chapter 8.13.2**.

OCDS Block

The OCDS block has several options to request different reset types:

1. A Debug Reset either via the OCDS reset function or via bit CBS_OJCONF.RSTCL1 AND CBS_OJCONF.RSTCL3
2. An Internal Application Reset via bit CBS_OJCONF.RSTCL2
3. An Application Reset via bit CBS_OJCONF.RSTCL3

8.4.5.1 Reset Sources Overview

The connection of the reset sources and the activated reset types are shown in **Table 8-5**.

Table 8-5 Effects of Reset Types for Reset Activation

Reset Request Trigger	Application Reset	Internal Application Reset	Debug Reset
PORST	Activated	Activated	Activated
SWD	Activated	Activated	Activated
PVC_M1	Activated	Activated	Activated
PVC_M2	Activated	Activated	Activated
ESR0	Configurable	Configurable	Not Activated
ESR1	Configurable	Configurable	Not Activated
ESR2	Configurable	Configurable	Not Activated
WWD	Configurable	Configurable	Not Activated
SW	Configurable	Configurable	Not Activated
CPU	Configurable	Configurable	Not Activated
MP	Configurable	Configurable	Not Activated
OCDS Reset	Not Activated	Not Activated	Activated ¹⁾
CBS_OJCONF.RSTCL1	Not Activated	Not Activated	Activated ¹⁾
CBS_OJCONF.RSTCL2	Activated	Activated	Not Activated
CBS_OJCONF.RSTCL3	Activated	Not Activated	Not Activated

1) Only if an Application Reset is active or is requested in parallel.

8.4.6 Module Reset Behavior

Table 8-6 lists how the various functions of the XE166U are affected through a reset depending on the reset type. A “X” means that this block has at least some register/bits that are affected by this reset type.

Table 8-6 Effect of Reset on Device Functions

Module / Function	Application Reset	Internal Application Reset	Debug Reset
CPU Core	X	X	X
Peripherals (except SCU and RTC)	X	X	X

Table 8-6 Effect of Reset on Device Functions (cont'd)

Module / Function		Application Reset	Internal Application Reset	Debug Reset
SCU		X	Not affected	Not affected
RTC		Not affected	Not affected	X
On-chip Static RAMs¹⁾	DPRAM	Not affected, reliable	Not affected, reliable	Not affected, reliable
	PSRAM	Not affected, reliable	Not affected, reliable	Not affected, reliable
	DSRAM	Not affected, reliable	Not affected, reliable	Not affected, reliable
Flash Memory		X ²⁾	X ²⁾	Not affected, reliable
JTAG Interface		Not affected	Not affected	Not affected
OCDS		Not affected	Not affected	X
Oscillator, PLL		Not affected	Not affected	Not affected
Port Pins		Not affected ³⁾	X	Not affected

1) Reliable here means that also the redundancy is not affected by the reset.

2) Parts of the flash memory block are only reset by a Power-on Reset. For more detail see the flash chapter.

3) The reset of the internal peripherals can change the data driven on the outputs, see also description of port behavior in section "Reset Behavior" in chapter "Parallel Ports".

8.4.7 Reset Controller Registers

8.4.7.1 Status Registers

After a reset has been executed, the Reset Status registers provide information on the type of the last reset. The reset status registers are updated upon each reset.

RSTSTAT0

Reset Status 0 Register

ESFR (F0B2_H/59_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SW		CPU		0											
rh		rh		r											

Field	Bits	Type	Description
CPU	[13:12]	rh	CPU Reset Type Status 00 _B The CPU reset trigger was not relevant for the last reset 01 _B Reserved 10 _B The CPU reset trigger was relevant for the last reset. Internal Application and Application Resets were generated. 11 _B The CPU reset trigger was relevant for the last reset. Application Reset was generated.
SW	[15:14]	rh	Software Reset Type Status 00 _B The Software reset trigger was not relevant for the last reset 01 _B Reserved 10 _B The Software reset trigger was relevant for the last reset. Internal Application and Application Resets were generated. 11 _B The Software reset trigger was relevant for the last reset. Application Reset was generated.
0	[11:0]	r	Reserved Read as 0; should be written with 0.

RSTSTAT1

Reset Status 1 Register

ESFR (F0B4_H/5A_H)

Reset Value: F000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	STM	0	MP	WDT	ESR2	ESR1	ESR0								
r	rh	r	rh	rh	rh	rh	rh								

Field	Bits	Type	Description
ESR0	[1:0]	rh	ESR0 Reset Status 00 _B The <u>ESR0</u> reset trigger was not relevant for the last reset 01 _B Reserved 10 _B The <u>ESR0</u> reset trigger was relevant for the last reset. Internal Application, and Application Resets were generated. 11 _B The <u>ESR0</u> reset trigger was relevant for the last reset. Application Reset was generated.
ESR1	[3:2]	rh	ESR1 Reset Status 00 _B The <u>ESR1</u> reset trigger was not relevant for the last reset 01 _B Reserved 10 _B The <u>ESR1</u> reset trigger was relevant for the last reset. Internal Application, and Application Resets were generated. 11 _B The <u>ESR1</u> reset trigger was relevant for the last reset. Application Reset was generated.
ESR2	[5:4]	rh	ESR2 Reset Status 00 _B The <u>ESR2</u> reset trigger was not relevant for the last reset 01 _B Reserved 10 _B The <u>ESR2</u> reset trigger was relevant for the last reset. Internal Application, and Application Resets were generated. 11 _B The <u>ESR2</u> reset trigger was relevant for the last reset. Application Reset was generated.

System Control Unit (SCU)

Field	Bits	Type	Description
WDT	[7:6]	rh	WWD Reset Status 00 _B The WWD reset trigger was not relevant for the last reset 01 _B Reserved 10 _B The WWD reset trigger was relevant for the last reset. Internal Application, and Application Resets were generated. 11 _B The WWD reset trigger was relevant for the last reset. Application Reset was generated. <i>Note: There is no indication of the WWD reset status that a WWD triggered power reset for DMP_M (RSTCON1.WDT = 01_B) has occurred. This bit will be reset to 00_B after the reset.</i>
MP	[9:8]	rh	MP Reset Status 00 _B The MP reset trigger was not relevant for the last reset 01 _B Reserved 10 _B The MP reset trigger was relevant for the last reset. Internal Application, and Application Resets were generated. 11 _B The MP reset trigger was relevant for the last reset. Application Reset was generated.
STM	[13:12]	rh	Power Reset for DMP_M Reset Status 00 _B The power reset for DMP_M reset trigger was not relevant for the last reset 01 _B The power reset for DMP_M reset trigger was not relevant for the last reset 10 _B The power reset for DMP_M reset trigger was not relevant for the last reset 11 _B The power reset for DMP_M reset trigger was relevant for the last reset
1	[15:14]	rh	Reserved Read as 1; should be written with 1.
0	[11:10]	r	Reserved Read as 0; should be written with 0.

RSTSTAT2

Reset Status 2 Register

ESFR (F0B6_H/5B_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						OJCONF3		OJCONF2		OJCONF1		OJCONF0		DB	
r						rh		rh		rh		rh		rh	

Field	Bits	Type	Description
DB	[1:0]	rh	Debug Reset Status 00 _B The DB reset trigger was not relevant for the last reset 01 _B The DB reset trigger was not relevant for the last reset 10 _B The DB reset trigger was not relevant for the last reset 11 _B The DB reset trigger was relevant for the last reset
OJCONF0	[3:2]	rh	OJCONF0 Reset Status Value undefined; should be written with 0.
OJCONF1	[5:4]	rh	OJCONF1 Reset Status 00 _B The OJCONF1 reset trigger was not relevant for the last reset 01 _B The OJCONF1 reset trigger was not relevant for the last reset 10 _B The OJCONF1 reset trigger was not relevant for the last reset 11 _B The OJCONF1 reset trigger was relevant for the last reset. Debug Reset was generated.
OJCONF2	[7:6]	rh	OJCONF2 Reset Status 00 _B The OJCONF2 reset trigger was not relevant for the last reset 01 _B The OJCONF2 reset trigger was not relevant for the last reset 10 _B The OJCONF2 reset trigger was relevant for the last reset. Internal Application, and Application Resets were generated. 11 _B The OJCONF2 reset trigger was not relevant for the last reset

System Control Unit (SCU)

Field	Bits	Type	Description
OJCONF3	[9:8]	rh	OJCONF3 Reset Status 00 _B The OJCONF3 reset trigger was not relevant for the last reset 01 _B The OJCONF3 reset trigger was not relevant for the last reset 10 _B The OJCONF3 reset trigger was not relevant for the last reset 11 _B The OJCONF3 reset trigger was relevant for the last reset. Application Reset was generated.
0	[3:2], [15:10]	r	Reserved Read as 0; should be written with 0.

8.4.7.2 Configuration Registers

These registers allow the behavioral configuration for the various reset trigger sources.

RSTCON0

Reset Configuration 0 Register ESFR (F0B8_H/5C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SW		CPU		0											
rw		rw		rw											

Field	Bits	Type	Description
CPU	[13:12]	rw	CPU Reset Type Selection This bit field defines which reset types are generated by a CPU reset request trigger. 00 _B No reset is generated 01 _B Reserved, do not use this combination 10 _B Internal Application, and Application Resets are generated 11 _B Application Reset is generated
SW	[15:14]	rw	Software Reset Type Selection This bit field defines which reset types are generated by a software reset request trigger. 00 _B No reset is generated 01 _B Reserved, do not use this combination 10 _B Internal Application, and Application Resets are generated 11 _B Application Reset is generated
0	[11:0]	rw	Reserved Must be written with reset value 0.

RSTCON1

Reset Configuration 1 Register ESRF (F0BA_H/5D_H)

Reset Value: 0002_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						MP		WDT		ESR2		ESR1		ESR0	
rw						rw		rw		rw		rw		rw	

Field	Bits	Type	Description
ESR0	[1:0]	rw	ESR0 Reset Type Selection This bit field defines which reset types are generated by a ESR0 reset request trigger. 00 _B No reset is generated 01 _B Reserved, do not use this combination 10 _B Internal Application, and Application Resets are generated 11 _B Application Reset is generated
ESR1	[3:2]	rw	ESR1 Reset Type Selection This bit field defines which reset types are generated by a ESR1 reset request trigger. 00 _B No reset is generated 01 _B Reserved, do not use this combination 10 _B Internal Application, and Application Resets are generated 11 _B Application Reset is generated
ESR2	[5:4]	rw	ESR2 Reset Type Selection This bit field defines which reset types are generated by a ESR2 reset request trigger. 00 _B No reset is generated 01 _B Reserved, do not use this combination 10 _B Internal Application, and Application Resets are generated 11 _B Application Reset is generated

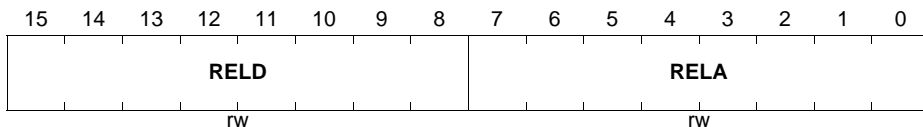
System Control Unit (SCU)

Field	Bits	Type	Description
WDT	[7:6]	rw	WWD Reset Type Selection This bit field defines which reset types are generated by a WWD reset request trigger. 00 _B No reset is generated 01 _B Power reset for DMP_M core domain 10 _B Internal Application, and Application Resets are generated 11 _B Application Reset is generated <i>Note: Setting of WDT bit is changed to 01_B before entering user code.</i>
MP	[9:8]	rw	MP Reset Type Selection This bit field defines which reset types are generated by a MP reset request trigger. 00 _B No reset is generated 01 _B Reserved, do not use this combination 10 _B Internal Application, and Application Resets are generated 11 _B Application Reset is generated
0	[15:10]	rw	Reserved Should be written with 0.

RSTCNTCON

Reset Counter Control RegisterESFR (F1B2_H/D9_H)

Reset Value: 0A0A_H



Field	Bits	Type	Description
RELA	[7:0]	rw	Application Reset Counter Reload Value This bit field defines the reload value of RSTCNTA. This value is always used when counter RSTCNTA is started. This counter value is used for Internal Application, and Application Resets. In case of an ESRx reset the counter value must be not less than the reset value.
RELD	[15:8]	rw	Debug Reset Counter Reload Value This bit field defines the reload value of RSTCNTD. This value is always used when counter RSTCNTD is started. This counter value is used for the Debug Reset. In case of an ESRx reset the counter value must be not less than the reset value.

Software Reset Control Register

This register controls the software reset operation.

SWRSTCON

Software Reset Control RegisterESFR (F0AE_H/57_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWCFG								0				SW RST REQ		SW BOO T	
rw								r				w		rw	

Field	Bits	Type	Description
SWBOOT	0	rw	Software Boot Configuration Selection 0 _B Bit field STSTAT.HWCFG is not updated with the content of SWCFG upon an Application Reset 1 _B Bit field STSTAT.HWCFG is updated with the content of SWCFG upon an Application Reset
SWRSTREQ	1	w	Software Reset Request 0 _B No software reset is requested 1 _B A software reset request trigger is generated <i>Note: This bit is always read as 0.</i>
SWCFG	[15:8]	rw	Software Boot Configuration A valid software boot configuration (also different from the external applied hardware configuration) can be specified with these bits. The configuration encoding is equal to the HWCFG encoding in register STSTAT.
0	[7:2]	r	Reserved Read as 0; should be written with 0.

8.5 External Service Request (ESR) Pins

The $\overline{\text{ESR}}$ pins serve as multi-functional pins for an amount of different options:

- Act as reset trigger input
- Act as trap input
- Act as wake-up trigger from a power saving mode
- Act as trigger input for the GSC
- Overlay with other product functions
- Independent pad configuration

Note: In XE166U, dedicated $\overline{\text{ESR0}}$, $\overline{\text{ESR1}}$ and $\overline{\text{ESR2}}$ pins are not available. However, $\overline{\text{ESR1}}$ and $\overline{\text{ESR2}}$ are provided as alternate input functions on pins with shared functions.

8.5.1 General Operation

Each $\overline{\text{ESR}}$ pin is equipped with an edge detection that allows the selection of the edges used as triggers. One, both, or no edge can be selected via bit field ESRCFGx.AEDCON if no clock is active in the DMP_M core domain (see [Section 8.6](#)), and ESRCFGx.SEDCON if a clock is active. Additionally, there is a digital (3-stage median) filter (DF) to suppress spikes. The signal at $\overline{\text{ESRx}}$ pin has to be held at the active signal level for at least 2 system clock cycles (f_{SYS}) in order to generate a trigger. If the core power domain is not clocked then the filter is not taken into account. The digital filter can be disabled by clearing bit ESRCFGx.DFEN .

Each $\overline{\text{ESRx}}$ pin can be individually configured.

If an $\overline{\text{ESR}}$ trigger is generated please note that triggers for all purposes (reset, trap, PSC, GSC, and non SCU module functions) are generated. If some of the actions resulting out of such a trigger should not occur this has to be disabled by each feature for its own.

The pins that should be used as trigger input for an ESR operation have to be configured as input pin.

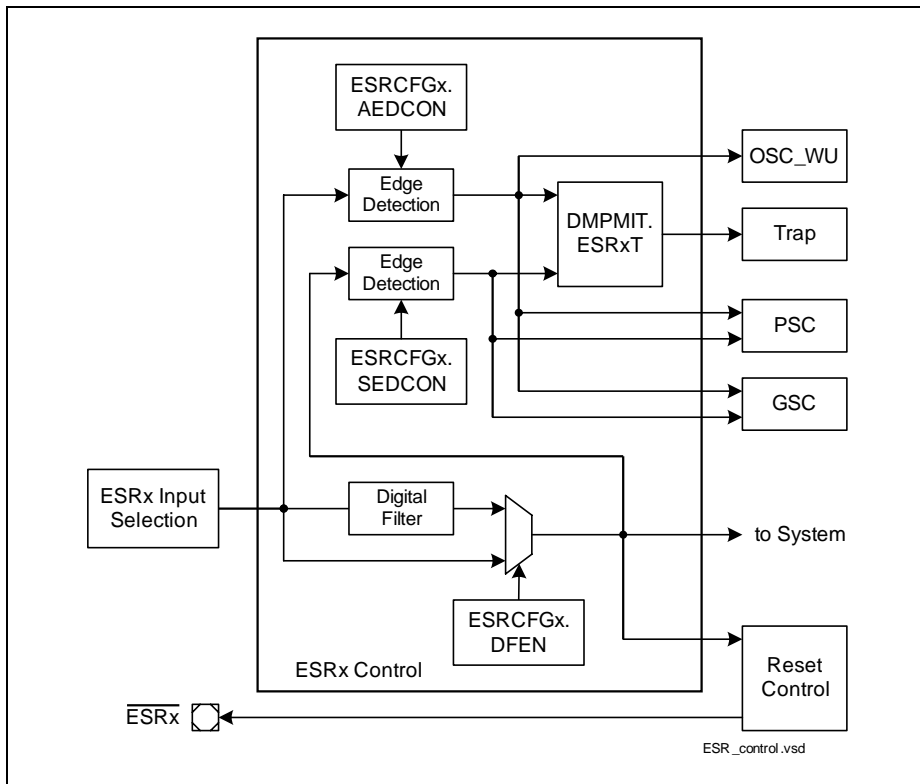


Figure 8-20 ESRx Control

Furthermore, an overlay with other product functions (i.e. inputs of serial interfaces) can be configured via register ESREXCONx to trigger ESR operations. The conjunction of the inputs (logically AND) are used for the trigger generation. Thus, if more than one pin shall be used for ESR trigger generation, then any signal at the respective pin must have an inactive high level. In addition, it is possible to invert some inputs to support active high levels.

To extend the overlay possibilities the conjugated inputs of the ESRx input selection structure are combined to one common event in a second AND gate level with the ESR input stage and the output of the combined inputs of the other input conjugation block, if enabled (ESREXCONx.ESRIN12EN). This allows all possible inputs to trigger an ESR function even if the second ESR logic is used for other purposes.

Pin $\overline{\text{ESR0}}$ does not offer an overlay with other product functions.

For information which other peripheral input signal is on an ESR overlay pin see [Chapter 8.5.1.5](#).

The following figure shows the the ESR Input selection function for $\overline{\text{ESR1}}$ and $\overline{\text{ESR2}}$.

Note: In XE166U, $\overline{\text{ESR1}}$ and $\overline{\text{ESR2}}$ does not have a dedicated pin. $\overline{\text{ESR1}}$ and $\overline{\text{ESR2}}$ are provided as alternate input functions on pins with shared functions.

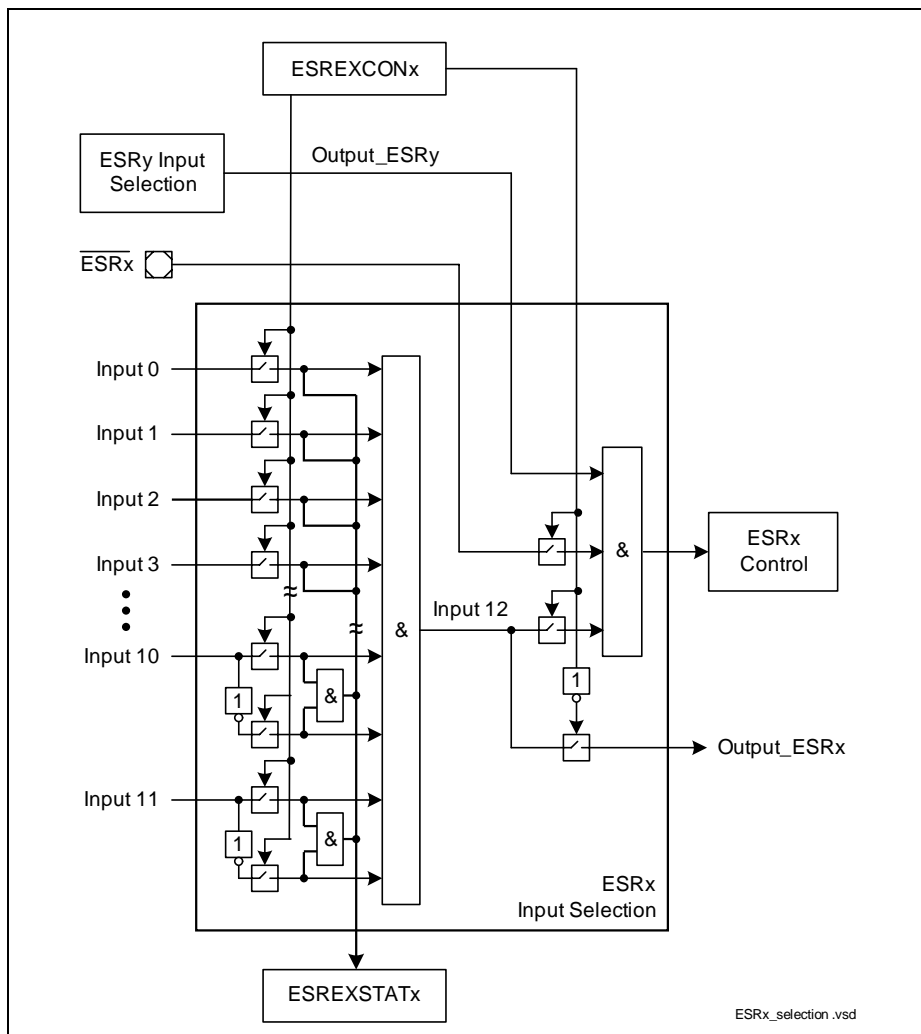


Figure 8-21 ESRx Input Selection

System Control Unit (SCU)

Up to three $\overline{\text{ESR}}$ pins ($\overline{\text{ESR0}}/\overline{\text{ESR1}}/\overline{\text{ESR2}}$) are available. The availability of pins $\overline{\text{ESR0}}$, $\overline{\text{ESR1}}$ and $\overline{\text{ESR2}}$ is device and package dependent and is described in the data sheet.

Even if pin $\overline{\text{ESR1}}$ or $\overline{\text{ESR2}}$ are not available in the device an overlay with other product functions (i.e. inputs of serial interfaces) can be configured via register **ESREXCON1** **ESREXCON2** to trigger ESR operations.

8.5.1.1 $\overline{\text{ESR}}$ as Reset Input

The pins $\overline{\text{ESRx}}$ can serve as an external reset input as well as a reset output (open drain) for Internal Application and Application Resets. Additionally several GPIO pad triggers that can be enabled additionally via register ESREXCONx interfere with the ESR pin function. GPIO and $\overline{\text{ESR}}$ pin triggers can be enabled/disabled individually and are combined for the reset trigger generation. For more information about the reset system see [Chapter 8.4](#).

Note: The reset output is only asserted for the duration the reset counter RSTCNTA is active. During a possible reset extension the reset output is not longer asserted.

8.5.1.2 $\overline{\text{ESR}}$ as Trap Trigger

The $\overline{\text{ESR}}$ can request traps. The control mechanism if and which trap is requested is located in the trap control logic. For more information see [Chapter 8.12](#).

8.5.1.3 $\overline{\text{ESR}}$ as Wake-up Trigger for the PSC

When the device is currently in a power save state, the $\overline{\text{ESR}}$ pin can be used as a wake-up trigger.

For the $\overline{\text{ESR}}$ trigger configuration the following options are available:

- Share $\overline{\text{ESR1}}$ and $\overline{\text{ESR2}}$ with serial IO function(s)
For information which other peripheral input signal is on an ESR overlay pin see [Chapter 8.5.1.5](#).
- Select active edge(s)
- Enable / disable filter
- Control other ESR functions

For more information see [Chapter 8.6.5](#) and the Programmer's Guide.

Note: The Asynchronous Edge Detection (ESRCFGx.AEDCON) needs special care in case of a parallel clock-off switching and an external wake-up. A wake-up trigger before the clock is switched off will not be recognized. Any wake-up trigger occurring after the clock has been switched off will wake-up the device in any case. A wake-up pulse of 1 ms or at least two wake-up pulses within a time period of 1 ms ensure a wake-up.

8.5.1.4 $\overline{\text{ESR}}$ as Trigger Input for the GSC

The $\overline{\text{ESR}}$ can be used to request a change in the Control Mode. For more information see [Chapter 8.7](#).

8.5.1.5 Overlay with other Product Functions

Additionally other port inputs (e.g. serial communication input) can be used to generate ESR operations. For pins ESR1 and ESR2 an overlay with the ESRx inputs listed in [Table 8-7](#) and [Table 8-8](#) is possible. Even if an ESRx pin is not available an overlay with the $\overline{\text{ESR}}_x$ inputs listed in the tables is possible. The ESRx logic part is fully functional. Pin $\overline{\text{ESR}}_0$ does not offer an overlay with other product functions.

Input from not available ESRx pins is tied to fixed value ("1" - value defined by ESRCFGx.PC).

Note: In XE166U, dedicated $\overline{\text{ESR}}_0$, $\overline{\text{ESR}}_1$ and $\overline{\text{ESR}}_2$ pins are not available. However, $\overline{\text{ESR}}_1$ and $\overline{\text{ESR}}_2$ are provided as alternate input functions on pins with shared functions.

Table 8-7 ESR1 Input Connection

Input	Connected to
Input 0	Port 2.4
Input 1	Reserved, not connected
Input 2	Port 10.0
Input 3	Reserved, not connected
Input 4	Reserved, not connected
Input 5	Port 2.1 (Reserved, not connected in TSSOP-38)
Input 6	Port 6.1
Input 7	Reserved, not connected
Input 8	Reserved, not connected
Input 9	Port 10.4
Input 10	Port 2.5
Input 11	Reserved, not connected

Table 8-8 ESR2 Input Connection

Input	Connected to
Input 0	Port 2.3
Input 1	Reserved, not connected

Table 8-8 ESR2 Input Connection

Input	Connected to
Input 2	Reserved, not connected
Input 3	Reserved, not connected
Input 4	Reserved, not connected
Input 5	Port 2.2 (Reserved, not connected in TSSOP-38)
Input 6	Port 2.6
Input 7	Port 2.7
Input 8	Reserved, not connected
Input 9	XTAL 1 (Reserved, not connected in TSSOP-38)
Input 10	Reserved, not connected
Input 11	Port 10.8

This feature can be used for various applications:

- Wake-up from a Clock-off Mode on an external Interrupt or CCU6x trigger and on a USIC operation
- Request to enter a Clock-off Mode on an external Interrupt or CCU6x trigger and on a USIC operation
- Stop input for the CCU6x modules on an external event

For more information about the external interrupt trigger see [Chapter 8.9](#).

8.5.2 ESR Control Registers

8.5.2.1 Configuration Registers

ESR External Control Register

The ESR External Control registers contain enable/disable bits for the different inputs that can lead to an ESR action. For ESR0 this option is not available.

ESREXCON1

ESR1 External Control Register

SFR (FF32_H/99_H)

Reset Value: 0000_H

ESREXCON2

ESR2 External Control Register

SFR (FF34_H/9A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ESR N IN11 EN	ESR N IN10 EN	ESR IN12 EN	ESR IN11 EN	ESR IN10 EN	ESR IN9 EN	ESR IN8 EN	ESR IN7 EN	ESR IN6 EN	ESR IN5 EN	ESR IN4 EN	ESR IN3 EN	ESR IN2 EN	ESR IN1 EN	ESR IN0 EN	ESR EN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
ESREN	0	rw	<u>ESRy</u> Pin Enable This bit enables/disables the <u>ESRy</u> pin for the activation of all <u>ESRy</u> related actions. 0 _B The input from pin <u>ESRy</u> is disabled 1 _B The input from pin <u>ESRy</u> is enabled
ESRINxEN (x = 0-11)	x+1	rw	<u>ESR</u> Input X Enable This bit enables/disables the input x for the activation of all <u>ESRy</u> related actions. 0 _B The input is disabled 1 _B The input is enabled

Field	Bits	Type	Description
ESRIN12EN	13	rw	ESR Input 12 Enable This bit enables/disables the input 12 for the activation of all ESRy related actions. 0_B The input 12 is disabled for the activation of all ESRy related actions. It is used in the second conjugation stage of the other ESRz Input Selection. 1_B The input 12 is enabled for the activation of all ESRy related actions.
ESRNIN10EN	14	rw	Negated ESR Input 10 Enable This bit enables/disables the negated input 10 for the activation of all ESRy related actions. 0_B The input is disabled 1_B The input is enabled
ESRNIN11EN	15	rw	Negated ESR Input 11 Enable This bit enables/disables the negated input 11 for the activation of all ESRy related actions. 0_B The input is disabled 1_B The input is enabled

ESREXSTAT1

ESR1 External Status Register SFR (FF36_H/9B_H) **Reset Value: 0000_H**

ESREXSTAT2

ESR2 External Status Register SFR (FF38_H/9C_H) **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			IN11	IN10	IN9	IN8	IN7	IN6	IN5	IN4	IN3	IN2	IN1	IN0	ESR
r			rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh

Field	Bits	Type	Description
ESR	0	rh	Input ESRy Status This bit is set upon a trigger on input x if ESREXCONy.ESREN was set. This bit can be cleared only by software. 0 _B No trigger for input ESRy occurred 1 _B A trigger for ESRy occurred since it was cleared last time
INx (x = 0-11)	x+1	rh	Input x Status This bit is set upon a trigger on input x if ESREXCONy.ESRINxEN was set for ESRy. This bit can be cleared only by software. 0 _B No trigger for input x occurred 1 _B A trigger for input x occurred since it was cleared last time
0	[15:13]	r	Reserved Read as 0; should be written with 0.

CLRESREXSTAT1

Clear ESR1 External Status RegisterSFR (FF3A_H/9D_H)

Reset Value: 0000_H

CLRESREXSTAT2

Clear ESR2 External Status RegisterSFR (FF3C_H/9E_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			IN11	IN10	IN9	IN8	IN7	IN6	IN5	IN4	IN3	IN2	IN1	IN0	ESR
r			w	w	w	w	w	w	w	w	w	w	w	w	w

Field	Bits	Type	Description
ESR	0	w	Clear Input ESRy Status Setting this bit clears the bit ESREXSTATy.ESR. This bit always read as zero. 0 _B No effect 1 _B Bit ESREXSTATy.ESR is cleared <i>Note: This bit is always read as 0.</i>
INx (x = 0-11)	x+1	w	Clear Input x Status Setting this bit clears the associated bit ESREXSTATy.INx. This bit always read as zero. 0 _B No effect 1 _B Bit ESREXSTATy.INx is cleared <i>Note: This bit is always read as 0.</i>
0	[15:13]	r	Reserved Read as 0; should be written with 0.

System Control Unit (SCU)

ESR Configuration Register

The ESR configuration registers contains bits required for the behavioral control of the ESR pins.

Note: If an ESRx pin is not available then writing to ESRCFGx.PC has no impact on the ESRx Input Selection. Reading ESRCFGx.IN will return 1. ESRCFGx.OUT is not used as output value.

ESRCFG1

ESR1 Configuration Register ESFR (F102_H/81_H) Reset Value: 0002_H

ESRCFG2

ESR2 Configuration Register ESFR (F104_H/82_H) Reset Value: 0002_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0					AEDCON		SEDCON		IN	OUT	DF EN	PC			
r					rw		rw		rh	rh	rw	rw			

Field	Bits	Type	Description
PC	[3:0]	rw	Pin Control of ESRx This bit field controls the behavior of the associated ESRx pin.
DFEN	4	rw	Digital Filter Enable This bit defines if the 3-stage median filter of the ESRx is used or bypassed. 0 _B The filter is bypassed 1 _B The filter is used
OUT	5	rh	Data Output This bit can be used as output value for the associated ESRx pin. 0 _B If selected, the output level is 0 1 _B If selected, the output level is 1
IN	6	rh	Data Input This bit monitors the input value at the associated ESRx pin.

Field	Bits	Type	Description
SEDCON	[8:7]	rw	Synchronous Edge Detection Control This bit field defines the edges that lead to an $\overline{\text{ESRx}}$ trigger of the synchronous path. 00 _B No trigger is generated 01 _B A trigger is generated upon a raising edge 10 _B A trigger is generated upon a falling edge 11 _B A trigger is generated upon a raising AND falling edge Other combinations than 00 _B are only allowed if bit field AEDCON is configured to 00 _B .
AEDCON	[10:9]	rw	Asynchronous Edge Detection Control This bit field defines the edges that lead to an $\overline{\text{ESRx}}$ trigger of the asynchronous path. 00 _B No trigger is generated 01 _B A trigger is generated upon a raising edge 10 _B A trigger is generated upon a falling edge 11 _B A trigger is generated upon a raising AND falling edge Other combinations than 00 _B are only allowed if bit field SEDCON is configured to 00 _B .
0	[15:11]	r	Reserved Read as 0; should be written with 0.

8.6 Power Supply and Control

The XE166U can run from a single external power supply. The core supply voltage is generated by on-chip Embedded Voltage Regulator (EVR).

Power Domains

There are 2 power domains in XE166U. All the I/O pads are located in pad I/O power domain (DMP_B). The core, memories, on-chip oscillators, PLL and peripherals are located in the core power domain (DMP_M).

Power Supply and Control Functions

The power supply and control is divided into following parts:

- monitoring of the supply voltage
- controlling and adjusting the supply voltage

The supply voltage of pad IO domain is monitored by a Supply Watchdog (SWD, see [Chapter 8.6.1](#)).

The core voltage for the core supply domain is supervised by a Power Validation Circuit (PVC) that provides two monitoring levels. Each monitoring level can request an interrupt (e.g. power-fail warning) or a reset depending on the voltage level. A PVC is used to detect under voltage due to an external short (see [Chapter 8.6.2](#)).

Table 8-9 XE166U Power Domains Supply and Control

Power Domain	Supply Source	Supply Voltage [V]	Supply Checked by
Pad IO domain (DMP_B)	External supply	V_{DDPB} : 3.0 ... 5.5 typ See data sheet	SWD
Core domain (DMP_M)	EVR_M	V_{DDIM} : 1.5 typ See data sheet	PVC_M

8.6.1 Supply Watchdog (SWD)

The supply voltage of the pad I/O domain for systems and communication I/Os (DMP_B) is monitored to validate the overall power supply. The external supply voltage is monitored for following purposes:

- **POR**
Detecting the ramp-up of the external supply voltage, so the device can be started without requiring an external power-on reset ($\overline{\text{PORST}}$).
- **Brown-out**
Detecting the ramp-down of the external supply voltage, so the device can be brought into a save state without requiring an external power-on reset ($\overline{\text{PORST}}$).
- Monitoring the external power supply allows the usage of a low-cost regulator without additional status signals (standard 3-pin device).
- Guarantee that the supply voltage for the EVRs is sufficient to generate a valid core voltage under every operating condition

Feature list

The following list is a summary of the SWD functions.

- Trigger a power-on reset whenever the supply falls and as long as the supply remains below V_{VAL}
- Two completely independent threshold levels and comparators
- 16 selectable threshold levels
- Power Saving Mode (only V_{VAL} detection active)

Operating the SWD

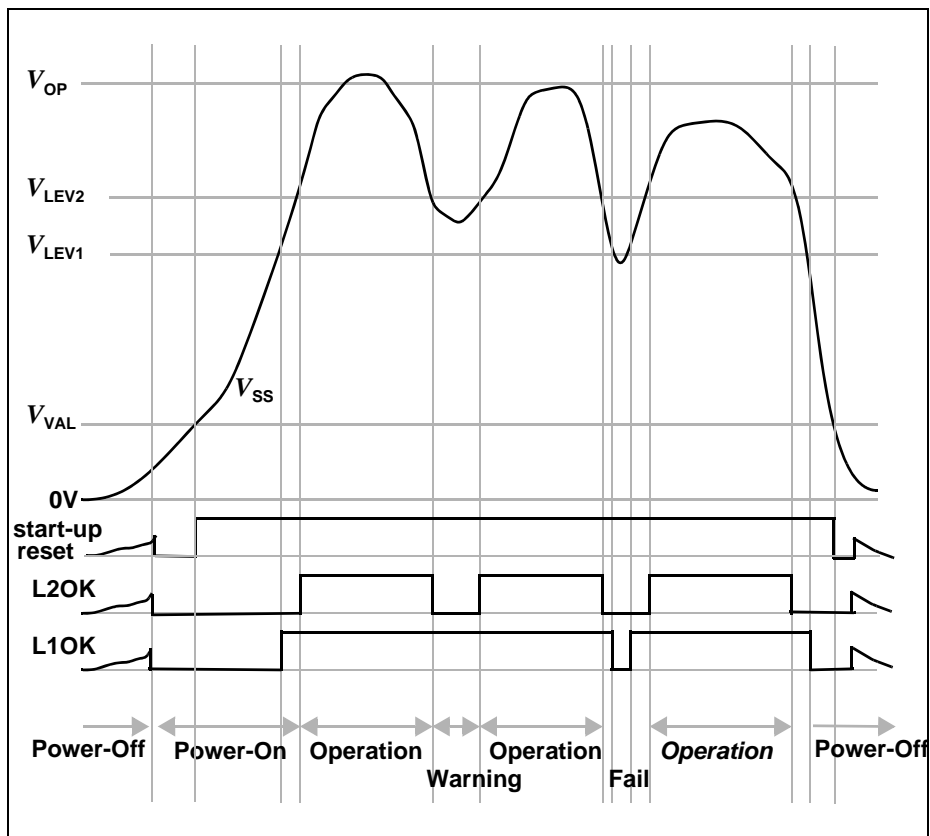


Figure 8-22 SWD Power Validation Example

V_{VAL} defines the fixed internal threshold where the device is held in reset. If V_{VAL} has not been reached, the device is held in reset. When V_{DDPB} raises above V_{VAL} , bit **SWDCON1.PON** is set.

The SWD provides two adjustable threshold levels (LEV1 and LEV2) that can be individually programmed, via **SWDCON0.LEV1V** and **SWDCON0.LEV2V**, and deliver a compare value each. The two compare results can be monitored via bits **SWDCON0.L1OK** and **SWDCON0.L2OK**. A reset or interrupt request can be generated while the voltage level is below or equal/above the configured level of a threshold. If an action and which action is triggered by each threshold can be configured via bits **SWDCON0.LxRSTEN** and **SWDCON0.LxINTEN** and bit field **SWDCON0.LxALEV** ($x = 1, 2$).

System Control Unit (SCU)

The SWD control (programming of the threshold levels) is done by software only.

With these features, an external supply watchdog, e.g. integrated in some external VR, can be replaced. It detects the minimum specified supply voltage level and can be configured to monitor other voltage levels.

Note: If the \overline{PORST} pin is used it has the same functionality as the min-power detection of the SWD.

Power-Saving Mode of the SWD

The two configurable thresholds can be disabled if not needed. This is called the SWD Power Saving Mode. The minimum operating voltage detection (POR/Brown-out detection) can not be disabled and it is always active. The SWD Power Saving Mode is entered by setting bit **SWDCON1.POWENSET** and exit by setting bit **SWDCON1.POWENCLR**. If the SWD Power Saving Mode is active is indicated by bit **SWDCON1.POWEN**.

Note: The reset request and interrupt request action should be switched off before entering power-save mode.

8.6.1.1 SWD Control Registers

The following registers are the software interface for the SWD.

SWDCON0

SWD Control 0 Register

ESFR (F080_H/40_H)

Reset Value: 0941_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L2 A LEV	L2 RST EN	L2 INT EN	L2 OK	LEV2V				L1 A LEV	L1 RST EN	L1 INT EN	L1 OK	LEV1V			
rw	rw	rw	rh	rw				rw	rw	rw	rh	rw			

Field	Bits	Type	Description
LEV1V	[3:0]	rw	Level Threshold 1 Voltage This bit field defines the voltage level that is used as threshold 1 check level. The values of the level thresholds are listed in the data sheet.
L1OK	4	rh	Level Threshold 1 Check Result 0 _B The supply voltage is below the Level Threshold 1 voltage LEV1V 1 _B The supply voltage is equal or above the Level Threshold 1 voltage LEV1V
L1INTEN	5	rw	Level Threshold 1 Interrupt Request Enable This bit field defines if an interrupt is requested if the supply voltage comparison matches the action level L1ALEV. 0 _B No interrupt is requested 1 _B An interrupt is requested
L1RSTEN	6	rw	Level Threshold 1 Reset Request Enable This bit field defines if a reset is requested if the supply voltage comparison matches the action level L1ALEV. 0 _B No reset is requested 1 _B An reset is requested

Field	Bits	Type	Description
L1ALEV	7	rw	Level Threshold 1 Action Level 0_B When the supply voltage is below the Level Threshold 1 voltage LEV1V the actions configured by bits L1INTEN and L1RSTEN are requested 1_B When the supply voltage is equal or above the Level Threshold 1 voltage LEV1V the actions configured by bits L1INTEN and L1RSTEN are requested
LEV2V	[11:8]	rw	Level Threshold 2 Voltage This bit field defines the voltage level that is used as check level threshold 2. The values of the level thresholds are listed in the data sheet.
L2OK	12	rh	Level Threshold 2 Check Result 0_B The supply voltage is below the Level Threshold 2 voltage LEV2V 1_B The supply voltage is equal or above the Level Threshold 2 voltage LEV2V
L2INTEN	13	rw	Level Threshold 2 Interrupt Request Enable This bit field defines if an interrupt is requested if the supply voltage comparison matches the action level L2ALEV. 0_B No interrupt is requested 1_B An interrupt is requested
L2RSTEN	14	rw	Level Threshold 2 Reset Request Enable This bit field defines if a reset is requested if the supply voltage comparison matches the action level L2ALEV. 0_B No reset is requested 1_B An reset is requested

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Field	Bits	Type	Description
L2ALEV	15	rw	Level Threshold 2 Action Level 0_B When the supply voltage is below the Level Threshold 2 voltage LEV2V the actions configured by bits L2INTEN and L2RSTEN are requested 1_B When the supply voltage is equal or above the Level Threshold 2 voltage LEV2V the actions configured by bits L2INTEN and L2RSTEN are requested

SWDCON1

SWD Control 1 Register

ESFR (F082_H/41_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
											CLR PON	PON	POW EN	POW EN SET	POW EN CLR
											w	rh	rh	w	w

Field	Bits	Type	Description
POWENCLR	0	w	SWD Power Saving Mode Enable Clear 0 _B No action 1 _B Bit POWEN is cleared <i>Note: This bit is always read as 0.</i>
POWENSET	1	w	SWD Power Saving Mode Enable Set 0 _B No action 1 _B Bit POWEN is set <i>Note: This bit is always read as 0.</i>
POWEN	2	rh	SWD Power Saving Mode Enable 0 _B All SWD functions are enabled 1 _B The SWD Power Saving Mode is enabled. Comparators are disabled.
PON	3	rh	Power-On Status Flag 0 _B No power-on event occurred 1 _B A power-on event occurred (V_{DDP} became greater than V_{VAL}).
CLRPON	4	w	Clear Power-On Status Flag 0 _B No action 1 _B Bit PON is cleared <i>Note: This bit is always read as 0.</i>
0	[15:5]	r	Reserved Read as 0; should be written with 0.

8.6.2 Monitoring the Voltage Level of Core Domain

A Power Validation Circuit (PVC_M) monitors the internal core supply voltage of core domain. It can be configured to monitor two programmable independent voltage levels.

Feature list

The following list summarizes the features of a PVC.

- Two independent comparators
- Threshold levels selectable
- Shut-off, which disables the complete module
- Configurable action level

A PVC provides two adjustable threshold levels (LEV1 and LEV2) that can be individually programmed via PVCICON0.LEV1V and PVCICON0.LEV2V. The current supply level of a domain is compared with the threshold values. The two compare results can be monitored via bits PVCICON0.LEV1OK and PVCICON0.LEV2OK.

Note: The PVC has a build in Hysteresis in the range of 40..50mV. The threshold level given in the data-sheet represents the lower corner of the hysteresis.

A core domain power reset or interrupt request can be generated in case the core domain voltage level is below or equal / above the configured threshold level. An interrupt is requested if bit PVCICON0.L1INTEN and / or PVCICON0.L2INTEN is set. A reset is requested if bit PVCICON0.L1RSTEN and / or PVCICON0.L2RSTEN is set.

Note: For a single threshold both interrupt and reset request generation should not be enabled at the same time.

Note: Due to variations of the tolerance of the EVR and the PVC levels, the LEV2V interrupt can be triggered inadvertently, even though the core voltage is within the normal range. Hence, it is recommended not to use this warning level.

8.6.2.1 PVC Status and Control Registers

These registers are the software interface for PVC_M.

PVCMCON0

PVC_M Control Step 0 Register

MEM (F1E4_H/--)

Reset Value: 0544_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L2 AS EN	L2 RST EN	L2 INT EN	L2 A LEV	LEV 2 OK	LEV2V			L1 AS EN	L1 RST EN	L1 INT EN	L1 A LEV	LEV 1 OK	LEV1V		
rw	rw	rw	rw	rh	rw			rw	rw	rw	rw	rh	rw		

Field	Bits	Type	Description
LEV1V	[2:0]	rw	Level Threshold 1 Voltage This bit field defines the Level Threshold 1 that is compared with the DMP_M core supply voltage. The values for the different configurations are listed in the data sheet.
LEV1OK	3	rh	Level Threshold 1 Check Result 0 _B The core supply voltage of the DMP_M is below Level Threshold 1 voltage LEV1V 1 _B The core supply voltage of the DMP_M is equal or above the Level Threshold 1 voltage LEV1V
L1ALEV	4	rw	Level Threshold 1 Action Level 0 _B When the core supply voltage is below Level Threshold 1 voltage LEV1V the action configured by bits L1INTEN, L1RSTEN, and L1ASEN are requested 1 _B When the core supply voltage is equal or above Level Threshold 1 voltage LEV1V the actions configured by bits L1INTEN, L1RSTEN, and L1ASEN are requested
L1INTEN	5	rw	Level Threshold 1 Interrupt Request Enable This bit defines if an interrupt request trigger is requested if the comparison check was successful. When a check is successful is defined via bit L1ALEV. 0 _B No interrupt is requested 1 _B An interrupt is requested

Field	Bits	Type	Description
L1RSTEN	6	rw	Level Threshold 1 Reset Request Enable This bit defines if a reset request trigger is requested if the comparison check was successful. When a check is successful is defined via bit L1ALEV. 0 _B No reset is requested 1 _B A reset is requested
L1ASEN	7	rw	Level Threshold 1 Asynchronous Action Enable This bit defines if asynchronous action can be performed if the comparison check was successful. When a check is successful is defined via bit L1ALEV. 0 _B No asynchronous actions are performed 1 _B Asynchronous actions can be performed
LEV2V	[10:8]	rw	Level Threshold 2 Voltage This bit field defines the Level Threshold 2 that is compared with the DMP_M core supply voltage. The values for the different configurations are listed in the data sheet.
LEV2OK	11	rh	Level Threshold 2 Check Result 0 _B The core supply voltage of the DMP_M is below Level Threshold 2 voltage LEV2V 1 _B The core supply voltage of the DMP_M is equal or above the Level Threshold 2 voltage LEV2V
L2ALEV	12	rw	Level Threshold 2 Action Level 0 _B When the core supply voltage is below the Level Threshold 2 voltage LEV2V the action configured by bits L2INTEN, L2RSTEN, and L2ASEN are requested 1 _B When the core supply voltage is equal or above the Level Threshold 2 voltage LEV2V the action configured by bits L2INTEN, L2RSTEN, and L2ASEN are requested
L2INTEN	13	rw	Level Threshold 2 Interrupt Request Enable This bit defines if an interrupt request trigger is requested if the comparison check was successful. When a check is successful is defined via bit L2ALEV. 0 _B No interrupt is requested 1 _B An interrupt is requested

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Field	Bits	Type	Description
L2RSTEN	14	rw	Level Threshold 2 Reset Request Enable This bit defines if a reset request trigger is requested if the comparison check was successful. When a check is successful is defined via bit L2ALEV. 0 _B No reset is requested 1 _B A reset is requested
L2ASEN	15	rw	Level Threshold 2 Asynchronous Action Enable This bit defines if asynchronous action can be performed if the comparison check was successful. When a check is successful is defined via bit L2ALEV. 0 _B No asynchronous actions are performed 1 _B Asynchronous actions can be performed

8.6.3 Controlling the Voltage Level of Core Domain

The core power can be controlled within certain limits. The voltage level is controlled by the **Embedded Voltage Regulator** (EVR_M).

8.6.3.1 Embedded Voltage Regulator

The main part of the device logic operates at a typical voltage level of 1.5 V. This supply voltage is generated by the Embedded Power Regulator (EVR) out of the pad voltage. External buffer caps are required for stable regulation.

Feature list:

- Core voltage generation either based on a Low Power Reference or on a High Precision Bandgap
- Core current limit

The EVR configurations to select the desired voltage and reference pair are combined within EVR settings EVRxSETyyV (x = M and yy = 15). Each setting contains a bit field (VRSEL) to select the reference and a bit field to fine-tune the voltage level (VLEV). One out of the possible settings is used to control the EVR. The EVR either use a low power reference or a High Precision Bandgap (HP) as reference.

The BG voltage of each setting can be adjusted to compensate application and environmental influences by the bit field EVRxSETyyV.VLEV. VLEV is set by default or trimmed by each device during production test to reach the default setting targets.

High Precision Bandgap (HP)

The HP bandgap of the system is used for following purposes:

- Provide a very stable reference for the EVR
- Provide an accurate reference for the flash memory. For more information see the flash memory description.

The HP bandgap can be enabled / disabled via the bit **EVARMCON1.HPEN**.

EVR Status and Control Registers

EVRMCON0

EVR_M Control 0 Register

ESFR (F084_H/42_H)

Reset Value: 0D20_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EVR DIS	0	CC DIS	CCLEV	LPR DIS	1	0	ULP EVR ON	LPRLEV	0						
rh	r	rh	rw	rh	rw	rw	rw	rw			rw			r	

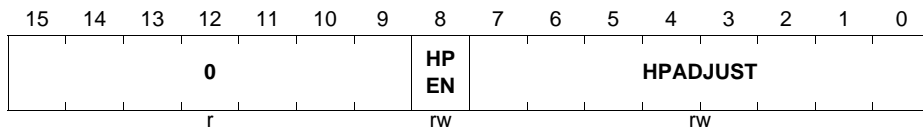
Field	Bits	Type	Description
LPRLEV	[5:3]	rw	Reserved Do not change this value when writing to this register
ULPEVRON	6	rw	Reserved Do not change this value when writing to this register
0	7	rw	Reserved Do not change this value when writing to this register
1	8	rw	Reserved Do not change this value when writing to this register
LPRDIS	9	rh	Low Power Reference Disable 0 _B The LPR is enabled 1 _B The LPR is disabled This bit is updated by bit EVRMSETy.LPRDIS.
CCLEV	[11:10]	rw	Current Control Level This bit field is required for enabling/disabling the current control (CCDIS). Valid values are described in the Programmer's Guide.
CCDIS	12	rh	Current Control Disable 0 _B The current control is enabled 1 _B The current control is disabled This bit is updated by bit EVRMSETy.CCDIS.
EVRDIS	15	rh	EVR_M Disable 0 _B The EVR_M is enabled 1 _B The EVR_M is disabled This bit is updated by bit EVRMSETy.EVRDIS.
0	[2:0], [14:13]	r	Reserved Read as 0; should be written with 0.

EVRMCON1

EVR_M Control 1 Register

ESFR (F086_H/43_H)

Reset Value: 0101_H



Field	Bits	Type	Description
HPADJUST	[7:0]	rw	HP Bandgap Adjustment This bit field is a device specific trimmvalue for the HP bandgap. Do not change this value when writing to this register.
HPEN	8	rw	HP Bandgap Enable 0 _B The HP bandgap is disabled 1 _B The HP bandgap is enabled
0	[15:9]	r	Reserved Read as 0; should be written with 0.

EVRMSET15VLP

EVR_M Setting for 1.5 V LP Register

ESFR (F094_H/4A_H)

Reset Value: 00DB_H

EVRMSET15VHP

EVR_M Setting for 1.5 V HP Register

ESFR (F096_H/4B_H)

Reset Value: 001B_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EVR DIS	0	CC DIS	0	LPR DIS	0	VRSEL						VLEV			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
VLEV	[5:0]	rw	Voltage Level Adjust This bit field adjusts the BG voltage and is trimmed by each device during production test to reach the default setting targets. Do not change this value when writing to this register.
VRSEL	[7:6]	rw	Voltage Reference Selection 00 _B 15VHP - Full Voltage with high precision bandgap selected 01 _B Reserved, do not use this combination 10 _B Reserved, do not use this combination 11 _B 15VLP - Full Voltage with low power reference selected <i>Note: The reset value should always be written to this bit field.</i>
LPRDIS	9	rw	Reserved Do not change this value when writing to this register
CCDIS	12	rw	Current Control Disable 0 _B The current control is enabled 1 _B The current control is disabled This bit updates bit EVRMCON0.CCDIS. <i>Note: Before switching off the current control the CCLEV setting in EVRMCON0 has to be set to 00_B.</i>
0	14	rw	Reserved Do not change this value when writing to this register

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Field	Bits	Type	Description
EVRDIS	15	rw	EVR_M Disable 0 _B The EVR_M is enabled 1 _B The EVR_M is disabled This bit updates bit EVR1CON0.EVRDIS.
0	8, [11:10], 13	rw	Reserved Should be written with 0.

8.6.3.2 Sources for Core Supply Voltage

The on-chip EVR can generate the XE166U's core supply voltage from the (externally supplied) IO voltage.

Core Supply via On-chip EVR

Generating the core supply voltage via the integrated EVR is advantageous because it saves an additional external voltage regulator. The integrated EVR is fed from supply voltage V_{DDPB} .

Proper operation of the EVR requires external buffer capacitances. Please refer to the respective Data Sheet for the recommended values. The current is delivered by the integrated pass devices.

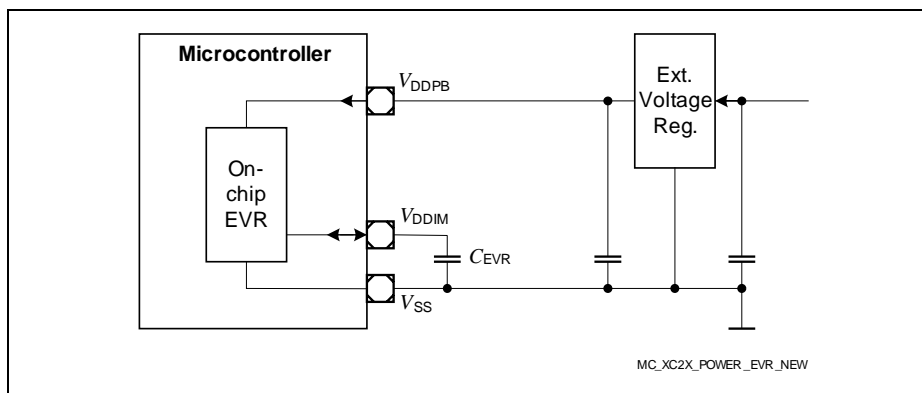


Figure 8-23 Selecting the EVR for Core Supply

Generating the core supply voltage with on-chip resources provides full control of power reduction modes, so the application can control and minimize the energy consumption of the XE166U using built-in mechanisms without requiring additional external circuitry.

8.6.4 Handling the Power System

Using the power system correctly is the key to power saving. Depending on the application different operating states can be defined in order to save maximal power. The XE166U supports following power saving mechanisms:

- Reduction of the system performance
 - the power consumption depends directly on the frequency of the system
 - the system performance is controlled with the clock operation mechanism
- Stopping single unused peripheral
 - a peripheral not needed for an application can be disabled
 - the module operation is controlled via register MOD_KSCCFG
- Stopping multiple unused peripherals
 - peripherals not needed for an application can be disabled
 - system peripheral operation is controlled via the Global State Controller (GSC)
- Stopping single unused analog parts
 - an analog part not needed for an application can be stopped
 - the operation is controlled via register either located in the SCU (PLL, clocks, PVCs, SWD) or the ADC

8.6.5 Power State Controller (PSC)

The Power State Controller (PSC) controls the operation of the EVR and PVC and handle changes in the different control values during the entry and exit of power saving mode.

8.6.5.1 General Overview

Entry and exit of a power saving mode can be achieved using a sequence of power transition. It defines how EVR and their associated PVC are controlled and modified when a power transition is requested from the system.

Two sets of configuration data are needed to handle the transitions:

- Sequence A is used to enter power saving mode
- Sequence B is used to exit power saving mode

Sequence A; it is invoked if a software trigger bit SEQBTRG in register SEQCON is set.

Sequence B; it is invoked if at least one valid wake-up trigger is asserted. For sequence B, it is required to be pre-configured by the software when a power saving state is entered where no software can be executed. Sequence B can only be started after a sequence A was performed. If no sequence A was performed, the trigger for the sequence B is treated as pending until a sequence A was performed.

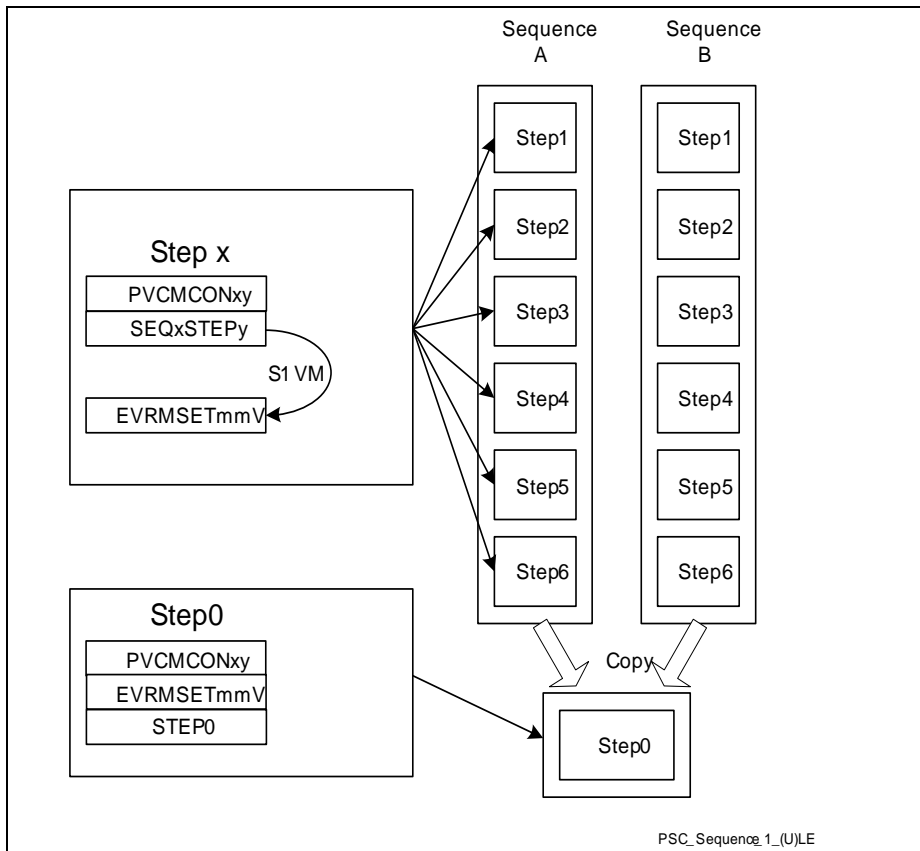


Figure 8-24 Transition Sequence Overview

8.6.5.2 Sequence Configuration

Each of the two sequences is built of six configuration data sets defining up to six steps. Each step of the sequence is controlled by its dedicated configuration data set.

Step 0 reflects the current power settings. Step 1 to 6 store the different settings which are applied to the power system whilst a transition. At the end of each transition, the values from the last enabled step are copied to step 0.

8.6.5.3 Transition Sequence Controlling

The PSC have to be pre-configured before the transition sequence is started. For a transition sequence using sequence B, the control registers SEQBSTPx and

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PVCMCONBx has to be pre-configured for the wake-up transition before the first transition is started.

A transition sequence is started if a wake-up trigger is asserted. A transition sequence is only started if no transition is currently running. The transition sequence itself is controlled by the sequence control registers SEQzSTEPx.

Note: With the start of a sequence, a trigger for the WUT is generated. Therefore, the WUT can be started if configured to be triggered by PSC (WUCR.AON = 1).

Skipping a Step

If a step is skipped the next not skipped step is executed without any time penalty. If a step is skipped or not is configured via bit SEQzSTEPx.SEN.

Stopping the System Clock for a Power Domain

One of the way to reduce power consumption is to stop the system clock. Stopping the clock is a transition step to enter power saving mode. If the system clock has to be stopped the PSC requests so and the asynchronous continuation has to be selected.

If the system clock is not stopped, synchronous continuation is selected.

If the system clock is stopped, asynchronous continuation is selected.

This configuration is ignored if the step is configured to be skipped.

The system clock is enabled again as soon as the selected trigger condition (bit field TRGSEL in the associated register) is valid again. If no trigger was selected (TRGSEL = 0000_b) the system clock is not disabled at all.

This feature is controlled via bits SEQzSTEPx.CLKENM, and SEQzSTEPx.TRGSEL.

Connection to the GSC

In order to stop or activate the operation of peripherals, the GSC is used. For this purpose, the PSCx exit and PSCx entry GSC triggers are used (x = sequence A or B). If the system clock should be stopped, the PSCA entry is used to bring all blocks in this domain into a state where the system clock can be stopped. If the system clock should be active, the PSCB exit is used to reactivate the clock system again. Unless disabled via bit SEQCON.GSCBY, the entry request is generated at the start of a sequence (before the first step is executed). Unless disabled via bit SEQCON.GSCBY, the exit request is generated at the end of a sequence (after the last step is executed).

Asynchronous/Synchronous Continuation

An asynchronous continuation event is defined if both selected PVC OK signals (from PVC_M) match their configured action level.

A synchronous continuation event is defined by the system clock divided by the value of bit field SEQzSTEPx.SYSDIV. Each time a step is started with the system clock enabled

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for DMP_M a synchronous continuation trigger is generated after SYSDIV system clock cycles.

Whenever the required continuation event occurs the next step is executed.

This configuration is ignored if the step is configured to be skipped.

8.6.5.4 Trigger Handling during a Power Transition

A power transition is an atomic operation. This means that it has to be finished before any new activity can be performed. Triggers that request another power transition while PSC is performing a power transition are stored automatically. It will be triggered immediately after the currently one is finished.

8.6.6 Operating a Power Transition

Performing a power transfer requires several steps that need to be executed involving both hardware and software operation. The transfers between the different Operating Modes are described in the Programmer's Guide.

8.6.7 Power Control Registers

8.6.7.1 PSC Status and Control Registers

SEQCON

Sequence Control Register

SFR (FEE4_H/72_H)

Reset Value: 8008_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GSC BY	SEQ B OSC DIS	SEQ A OSC DIS	STM 1 EN	ESR 2 EN	ESR 1 EN	ESR 0 EN	WUT EN	0	STM 0 EN	0	IDLE EN	SEQ B EN	SEQ A EN	SEQ B TRG	SEQ A TRG
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	rw	rwh	rwh	w	w

Field	Bits	Type	Description
SEQATR	0	w	Sequence A Trigger Setting this bit trigger a power transition defined by sequence A 0 _B No action 1 _B Sequence A is started Sequence A is only started if Sequence B is not currently active.
SEQBTR	1	w	Sequence B Trigger Setting this bit trigger a power transition defined by sequence B 0 _B No action 1 _B Sequence B is started Sequence B is only started if Sequence A is not currently active.
SEQAEN	2	rwh	Sequence A Enable 0 _B Sequence A is never started 1 _B Sequence A is started if requested Sequence A is only started if Sequence B is not currently active. This bit is automatically cleared after the sequence was started.

Field	Bits	Type	Description
SEQBEN	3	rwh	Sequence B Enable 0_B Sequence B is never started 1_B Sequence B is started if requested Sequence B is only started if Sequence A is not currently active. This bit is automatically cleared after the sequence was started.
IDLEEN	4	rw	IDLE Trigger Enable This bit defines if the IDLE instruction can trigger sequence A or not. 0_B Sequence A is never triggered by the IDLE instruction 1_B Sequence A is triggered by the IDLE instruction
STM0EN	6	rw	STM Trigger 0 Enable This bit defines if a STM 0 event can trigger sequence B or not. 0_B Sequence B is never triggered by a STM 0 event 1_B Sequence B is triggered by a STM 0 event
WUTEN	8	rw	WUT Trigger Enable This bit defines if an WUT event can trigger sequence B or not. 0_B Sequence B is never triggered by an WUT event 1_B Sequence B is triggered by an WUT event
ESR0EN	9	rw	ESR0 Trigger Enable This bit defines if an $\overline{\text{ESR0}}$ event can trigger sequence B or not. 0_B Sequence B is never triggered by an $\overline{\text{ESR0}}$ event 1_B Sequence B is triggered by $\overline{\text{ESR0}}$ event
ESR1EN	10	rw	ESR1 Trigger Enable This bit defines if an $\overline{\text{ESR1}}$ event can trigger sequence B or not. 0_B Sequence B is never triggered by an $\overline{\text{ESR1}}$ event 1_B Sequence B is triggered by $\overline{\text{ESR1}}$ event

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Field	Bits	Type	Description
ESR2EN	11	rw	ESR2 Trigger Enable This bit defines if an ESR2 event can trigger sequence B or not. 0_B Sequence B is never triggered by an $\overline{\text{ESR2}}$ event 1_B Sequence B is triggered by $\overline{\text{ESR2}}$ event
STM1EN	12	rw	STM Trigger 1 Enable This bit defines if a STM 1 event can trigger sequence B or not. 0_B Sequence B is never triggered by a STM 1 event 1_B Sequence B is triggered by a STM 1 event
SEQAOSCDIS	13	rw	Sequence A OSC_WU Disable This bit defines if the OSC_WU is disabled with the end of the sequence A. 0_B The enable setting for OSC_WU is left unchanged 1_B OSC_WU is disabled
SEQBOSCDIS	14	rw	Sequence B OSC_WU Disable This bit defines if the OSC_WU is disabled with the end of the sequence B. 0_B The enable setting for OSC_WU is left unchanged 1_B OSC_WU is disabled
GSCBY	15	rw	GSC Bypass This bit defines if an PSC event can trigger GSC action or not. 0_B The normal GSC action is requested 1_B No GSC action is started
0	5, 7	r	Reserved Read as 0; should be written with 0.

PSCSTAT

PSC Status Register

SFR (FFE8_H/F4_H)

Reset Value: 0C20_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	-		LST SEQ				-					PSMSTAT		B ACT	A ACT
	r		rh				r					rh		rh	rh

Field	Bits	Type	Description
AACT	0	rh	Sequence A Active This bit indicates if currently sequence A is active or not. 0 _B Sequence A is not active 1 _B Sequence A is active
BACT	1	rh	Sequence B Active This bit indicates if currently sequence B is active or not. 0 _B Sequence B is not active 1 _B Sequence B is active
PSMSTAT	[4:2]	rh	Power State Machine Status This bit field shows the status of the controlling power state machine. 000 _B Idle, no power transfer action is currently active. WUT start trigger is generated. OSC_WU is enabled. 001 _B PSC Entry; the system is request to enter a state where a power switch does not cause any harm. OSC_WU is enabled. 010 _B Transition; the power transition defined by the content of the SEQxSTEP registers is executed. OSC_WU is enabled. 011 _B PSC Exit; the system is request to enter a state where it can continue of the application. OSC_WU is enabled. 100 _B Ready; the power transfer is finished; OSC_WUT is disabled if the sequence related bit SEQxOSCDIS in register SEQCON is set. 101 _B Reserved 110 _B Reserved 111 _B Reserved;

System Control Unit (SCU)

Field	Bits	Type	Description
LSTSEQ	12	rh	Last Sequence Performed This bit shows the sequence that was performed. This bit is updated with PSMSTATE = 100 _B . 0 _B Sequence A was the last performed one 1 _B Sequence B was the last performed one
0	[15:13]	rw	Reserved Read as 0; should be written with 0.

STEP0

Step 0 Register

SFR (FEF2_H/79_H)

Reset Value: C043_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	Rese rved	PVC M OFF	SYS DIV	TRGSEL				Reserved		V1			VM		
rw	rw	rw	rw	rw				rw		rw			rw		

Field	Bits	Type	Description
VM	[2:0]	rw	EVR Configuration for core voltage This bit defines the configuration for EVR_M. 000 _B Full Voltage with HP bandgap selected 011 _B Full Voltage with LPR selected Others Reserved, do not use this combinations
V1	[5:3]	rw	Clock Configuration This bit defines the system clock configuration. 000 _B No change to system clock configuration 110 _B System clock is enabled, reading returns 000 _B 111 _B System clock is disabled, reading returns 000 _B Others Reserved, do not use this combinations
TRGSEL	[11:8]	rw	Trigger Selection This bit field defines the which of the four possible OK signals from PVC_M is used for validating the power transition. XX00 _B Non of the signals is used XX01 _B OK 1 from PVC_M is used XX10 _B OK 2 from PVC_M is used XX11 _B OK 1 from PVC_M AND OK 2 from PVC_M is used

System Control Unit (SCU)

Field	Bits	Type	Description
SYSDIV	12	rwh	System Clock Divider This bit defines the number of system clock cycles f_{SYS} before the sequence is continued. 0_{B} The sequence is continued after 1 f_{SYS} cycles 1_{B} The sequence is continued after 64 f_{SYS} cycles
PVCMOFF	13	rwh	PVC_M Disabled This bit defines whether the PVC_M generates any valid check results or not. The PVC_M can be disabled in order to save power. 0_{B} The PVC_M is enabled and delivers valid results 1_{B} The PVC_M is disabled and deliver no valid results
Reserved	[7:6], 14	rwh	Reserved Should be written with reset value.
1	15	rwh	Reserved Read as 1; should be written with 1. This bit is updated by the SEN bit of the sequence registers.

SEQASTEP1

Sequence Step 1 for Set A Register

SFR (FEE6_H/73_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEN	Reserved	PVC M OFF	SYS DIV	TRGSEL				Reserved		V1			VM		
rw	rw	rw	rw	rw				rw	rw	rw			rw		

Field	Bits	Type	Description
VM	[2:0]	rw	EVR Configuration for core voltage This bit defines the configuration for EVR_M. 000 _B Full Voltage with HP bandgap selected 011 _B Full Voltage with LPR selected Others Reserved, do not use this combinations
V1	[5:3]	rw	Clock Configuration This bit defines the system clock configuration. 000 _B No change to system clock configuration 110 _B System clock is enabled, reading returns 000 _B 111 _B System clock is disabled, reading returns 000 _B Others Reserved, do not use this combinations
TRGSEL	[11:8]	rw	Trigger Selection This bit field defines the which of the four possible OK signals from PVC_M is used for validating the power transition. XX00 _B Non of the signals is used XX01 _B OK 1 from PVC_M is used XX10 _B OK 2 from PVC_M is used XX11 _B OK 1 from PVC_M AND OK 2 from PVC_M is used
SYSDIV	12	rw	System Clock Divider This bit defines the number of system clock cycles f_{SYS} before the sequence is continued. 0 _B The sequence is continued after 1 f_{SYS} cycles 1 _B The sequence is continued after 64 f_{SYS} cycles

System Control Unit (SCU)

Field	Bits	Type	Description
PVCMOFF	13	rw	PVC_M Disabled This bit defines whether the PVC generates any valid check results or not for this step. The PVC can be disabled in order to save power. 0 _B The PVC_M is enabled and delivers valid results 1 _B The PVC_M is disabled and deliver no valid results
SEN	15	rw	Step Enable This bit defines the operation that is connected with step n of the transition is skipped or not. 0 _B Step is skipped 1 _B Step is executed
Reserved	7	rw	Reserved Should be written with 0; same reset value in STEP0 register
Reserved	6, 14	rw	Reserved Should be written with 1; same reset value in STEP0 register

SEQASTEP2

Sequence Step 2 for Set A Register

SFR (FEE8_H/74_H)

Reset Value: 0000_H

SEQASTEP3

Sequence Step 3 for Set A Register

SFR (FEEA_H/75_H)

Reset Value: 0000_H

SEQASTEP4

Sequence Step 4 for Set A Register

SFR (FEEC_H/76_H)

Reset Value: 0000_H

SEQASTEP5

Sequence Step 5 for Set A Register

SFR (FEEE_H/77_H)

Reset Value: 0000_H

SEQASTEP6

Sequence Step 6 for Set A Register

SFR (FEF0_H/78_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEN	Reserved	PVC M OFF	SYS DIV	TRGSEL			Reserved			V1			VM		
rw	rw	rw	rw	rw			rw			rw			rw		

Field	Bits	Type	Description
VM	[2:0]	rw	EVR Configuration for core voltage This bit defines the configuration for EVR_M. 000 _B Full Voltage with HP bandgap selected 011 _B Full Voltage with LPR selected Others Reserved, do not use this combinations
V1	[5:3]	rw	Clock Configuration This bit defines the system clock configuration. 000 _B No change to system clock configuration 110 _B System clock is enabled, reading returns 000 _B 111 _B System clock is disabled, reading returns 000 _B Others Reserved, do not use this combinations

System Control Unit (SCU)

Field	Bits	Type	Description
TRGSEL	[11:8]	rw	Trigger Selection This bit field defines the which of the four possible OK signals from PVC_M is used for validating the power transition. XX00 _B Non of the signals is used XX01 _B OK 1 from PVC_M is used XX10 _B OK 2 from PVC_M is used XX11 _B OK 1 from PVC_M AND OK 2 from PVC_M is used
SYSDIV	12	rw	System Clock Divider This bit defines the number of system clock cycles f_{SYS} before the sequence is continued. 0 _B The sequence is continued after 1 f_{SYS} cycles 1 _B The sequence is continued after 64 f_{SYS} cycles
PVCMOFF	13	rw	PVC_M Disabled This bit defines whether the PVC generates any valid check results or not for this step. The PVC can be disabled in order to save power. 0 _B The PVC_M is enabled and delivers valid results 1 _B The PVC_M is disabled and deliver no valid results
SEN	15	rw	Step Enable This bit defines the operation that is connected with step n of the transition is skipped or not. 0 _B Step is skipped 1 _B Step is executed
Reserved	7	rw	Reserved Should be written with 0; same reset value in STEP0 register
Reserved	6, 14	rw	Reserved Should be written with 1; same reset value in STEP0 register

SEQBSTEP1

Sequence Step 1 for Set B Register

SFR (FEF4_H/7A_H)

Reset Value: 88DB_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEN	Reserved	PVC M OFF	SYS DIV	TRGSEL			Reserved			V1			VM		
rw	rw	rw	rw	rw			rw			rw			rw		

Field	Bits	Type	Description
VM	[2:0]	rw	EVR Configuration for core voltage This bit defines the configuration for EVR_M. 000 _B Full Voltage with HP bandgap selected 011 _B Full Voltage with LPR selected Others Reserved, do not use this combinations
V1	[5:3]	rw	Clock Configuration This bit defines the system clock configuration. 000 _B No change to system clock configuration 110 _B System clock is enabled, reading returns 000 _B 111 _B System clock is disabled, reading returns 000 _B Others Reserved, do not use this combinations
TRGSEL	[11:8]	rw	Trigger Selection This bit field defines the which of the four possible OK signals from PVCM is used for validating the power transition. XX00 _B Non of the signals is used XX01 _B OK 1 from PVC_M is used XX10 _B OK 2 from PVC_M is used XX11 _B OK 1 from PVC_M AND OK 2 from PVC_M is used
SYSDIV	12	rw	System Clock Divider This bit defines the number of system clock cycles f_{SYS} before the sequence is continued. 0 _B The sequence is continued after 1 f_{SYS} cycles 1 _B The sequence is continued after 64 f_{SYS} cycles

System Control Unit (SCU)

Field	Bits	Type	Description
PVCMOFF	13	rw	PVC_M Disabled This bit defines whether the PVC generates any valid check results or not for this step. The PVC can be disabled in order to save power. 0 _B The PVC_M is enabled and delivers valid results 1 _B The PVC_M is disabled and deliver no valid results
SEN	15	rw	Step Enable This bit defines the operation that is connected with step n of the transition is skipped or not. 0 _B Step is skipped 1 _B Step is executed
Reserved	7	rw	Reserved Should be written with 0; same reset value in STEP0 register
Reserved	6, 14	rw	Reserved Should be written with 1; same reset value in STEP0 register

SEQBSTEP2

Sequence Step 2 for Set B Register

SFR (FEF6_H/7B_H)

Reset Value: 80EB_H

SEQBSTEP3

Sequence Step 3 for Set B Register

SFR (FEF8_H/7C_H)

Reset Value: 80F3_H

SEQBSTEP4

Sequence Step 4 for Set B Register

SFR (FEFA_H/7D_H)

Reset Value: 0000_H

SEQBSTEP5

Sequence Step 5 for Set B Register

SFR (FEFC_H/7E_H)

Reset Value: 0000_H

SEQBSTEP6

Sequence Step 6 for Set B Register

SFR (FEFE_H/7F_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEN	Reserved	PVC M OFF	SYS DIV	TRGSEL			Reserved			V1			VM		
rw	rw	rw	rw	rw			rw			rw			rw		

Field	Bits	Type	Description
VM	[2:0]	rw	EVR Configuration for core voltage This bit defines the configuration for EVR_M. 000 _B Full Voltage with HP bandgap selected 011 _B Full Voltage with LPR selected Others Reserved, do not use this combinations
V1	[5:3]	rw	Clock Configuration This bit defines the system clock configuration. 000 _B No change to system clock configuration 110 _B System clock is enabled, reading returns 000 _B 111 _B System clock is disabled, reading returns 000 _B Others Reserved, do not use this combinations

System Control Unit (SCU)

Field	Bits	Type	Description
TRGSEL	[11:8]	rw	Trigger Selection This bit field defines the selection of OK signals from PVC_M that could be used for validating the power transition. XX00 _B Non of the signals is used XX01 _B OK 1 from PVC_M is used XX10 _B OK 2 from PVC_M is used XX11 _B OK 1 from PVC_M AND OK 2 from PVC_M is used
SYSDIV	12	rw	System Clock Divider This bit defines the number of system clock cycles f_{SYS} before the sequence is continued. 0 _B The sequence is continued after 1 f_{SYS} cycles 1 _B The sequence is continued after 64 f_{SYS} cycles
PVCMOFF	13	rw	PVC_M Disabled This bit defines whether the PVC generates any valid check results or not for this step. The PVC can be disabled in order to save power. 0 _B The PVC_M is enabled and delivers valid results 1 _B The PVC_M is disabled and deliver no valid results
SEN	15	rw	Step Enable This bit defines the operation that is connected with step n of the transition is skipped or not. 0 _B Step is skipped 1 _B Step is executed
Reserved	7	rw	Reserved Should be written with 0; same reset value in STEP0 register
Reserved	6, 14	rw	Reserved Should be written with 1; same reset value in STEP0 register

PVCMCONA1

PVC_M Control for Step 1 Set A Register

MEM (F1E6_H/--)

Reset Value: 0000_H

PVCMCONA2

PVC_M Control for Step 2 Set A Register

MEM (F1E8_H/--)

Reset Value: 0000_H

PVCMCONA3

PVC_M Control for Step 3 Set A Register

MEM (F1EA_H/--)

Reset Value: 0000_H

PVCMCONA4

PVC_M Control for Step 4 Set A Register

MEM (F1EC_H/--)

Reset Value: 0000_H

PVCMCONA5

PVC_M Control for Step 5 Set A Register

MEM (F1EE_H/--)

Reset Value: 0000_H

PVCMCONA6

PVC_M Control for Step 6 Set A Register

MEM (F1F0_H/--)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L2 AS EN	L2 RST EN	L2 INT EN	L2 A LEV	0	LEV2V			L1 AS EN	L1 RST EN	L1 INT EN	L1 A LEV	0	LEV1V		
rw	rw	rw	rw	rw		rw		rw	rw	rw	rw	rw		rw	

Field	Bits	Type	Description
LEV1V	[2:0]	rw	Level Threshold 1 Voltage Configuration This bit field defines the level of threshold 1 that is compared with the DMP_M core voltage. The values for the different configurations are listed in the data sheet.
L1ALEV	4	rw	Level Threshold 1 Action Level 0 _B The action configured by bits L1INTEN, L1RSTEN, and L1ASEN are requested when the voltage is below LEV1V. Otherwise no action is requested. 1 _B The action configured by bits L1INTEN, L1RSTEN, and L1ASEN are requested when the voltage is equal or above LEV1V. Otherwise no action is requested.

Field	Bits	Type	Description
L1INTEN	5	rw	Level Threshold 1 Interrupt Request Enable This bit defines if an interrupt request trigger is requested if the comparison check was successful. When a check is successful is defined via bit L1ALEV. 0 _B No interrupt is requested 1 _B An interrupt is requested
L1RSTEN	6	rw	Level Threshold 1 Reset Request Enable This bit defines if a reset request trigger is requested if the comparison check was successful. When a check is successful is defined via bit L1ALEV. 0 _B No reset is requested 1 _B An reset is requested
L1ASEN	7	rw	Level Threshold 1 Asynchronous Action Enable This bit defines if asynchronous action can be performed if the comparison check was successful. When a check is successful is defined via bit L1ALEV. 0 _B No asynchronous actions are performed 1 _B Asynchronous actions can be performed
LEV2V	[10:8]	rw	Level Threshold 2 Voltage Configuration This bit field defines the level of threshold 2 that is compared with the DMP_M core voltage. The values for the different configurations are listed in the data sheet.
L2ALEV	12	rw	Level Threshold 2 Action Level 0 _B The action configured by bits L2INTEN, L2RSTEN, and L2ASEN are requested when the voltage is below LEV2V. Otherwise no action is requested. 1 _B The action configured by bits L2INTEN, L2RSTEN, and L2ASEN are requested when the voltage is equal or above LEV2V. Otherwise no action is requested.

Field	Bits	Type	Description
L2INTEN	13	rw	Level Threshold 2 Interrupt Request Enable This bit defines if an interrupt request trigger is requested if the comparison check was successful. When a check is successful is defined via bit L2ALEV. 0 _B No interrupt is requested 1 _B An interrupt is requested
L2RSTEN	14	rw	Level Threshold 2 Reset Request Enable This bit defines if a reset request trigger is requested if the comparison check was successful. When a check is successful is defined via bit L2ALEV. 0 _B No reset is requested 1 _B An reset is requested
L2ASEN	15	rw	Level Threshold 2 Asynchronous Action Enable This bit defines if asynchronous action can be performed if the comparison check was successful. When a check is successful is defined via bit L2ALEV. 0 _B No asynchronous actions are performed 1 _B Asynchronous actions can be performed
0	3, 11	rw	Reserved Should be written with 0.

PVCMCONB1

PVC_M Control for Step 1 Set B Register

MEM (F1F4_H/--)

Reset Value: 0544_H

PVCMCONB2

PVC_M Control for Step 2 Set B Register

MEM (F1F6_H/--)

Reset Value: 0544_H

PVCMCONB3

PVC_M Control for Step 3 Set B Register

MEM (F1F8_H/--)

Reset Value: 0544_H

PVCMCONB4

PVC_M Control for Step 4 Set B Register

MEM (F1FA_H/--)

Reset Value: 0544_H

PVCMCONB5

PVC_M Control for Step 5 Set B Register

MEM (F1FC_H/--)

Reset Value: 0544_H

PVCMCONB6

PVC_M Control for Step 6 Set B Register

MEM (F1FE_H/--)

Reset Value: 0544_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L2 AS EN	L2 RST EN	L2 INT EN	L2 A LEV	0	LEV2V			L1 AS EN	L1 RST EN	L1 INT EN	L1 A LEV	0	LEV1V		
rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw		

Field	Bits	Type	Description
LEV1V	[2:0]	rw	Level 1 Voltage Configuration This bit field defines the level that is used by the comparator 1 in the PVC. The values for the different configurations are listed in the data sheet.
L1ALEV	4	rw	Level 1 Action Level 0 _B The action configured by bits L1INTEN, L1RSTEN, and L1ASEN are requested when the voltage is below LEV1V. Otherwise no action is requested. 1 _B The actions configured by bits L1INTEN, L1RSTEN, and L1ASEN are requested when the voltage is equal or above LEV1V. Otherwise no action is requested.

Field	Bits	Type	Description
L1INTEN	5	rw	Level 1 Interrupt Request Enable This bit defines if an interrupt request trigger is requested if the comparison level check was successful. When a check is successful is defined via bit L1ALEV. 0_B No interrupt is requested 1_B An interrupt is requested
L1RSTEN	6	rw	Level 1 Reset Request Enable This bit defines if a reset request trigger is requested if the comparison level check was successful. When a check is successful is defined via bit L1ALEV. 0_B No reset is requested 1_B An reset is requested
L1ASEN	7	rw	Level 1 Asynchronous Action Enable This bit defines if asynchronous action can be performed if the comparison level check was successful. When a check is successful is defined via bit L1ALEV. 0_B No asynchronous actions are performed 1_B Asynchronous actions can be performed
LEV2V	[10:8]	rw	Level 2 Voltage Configuration This bit field defines the level that is used by the comparator 2 in the PVC. The values for the different configurations are listed in the data sheet.
L2ALEV	12	rw	Level 2 Action Level 0_B The action configured by bits L2INTEN, L2RSTEN, and L2ASEN are requested when the voltage is below LEV2V. Otherwise no action is requested. 1_B The action configured by bits L2INTEN, L2RSTEN, and L2ASEN are requested when the voltage is equal or above LEV2V. Otherwise no action is requested.

Field	Bits	Type	Description
L2INTEN	13	rw	Level 2 Interrupt Request Enable This bit defines if an interrupt request trigger is requested if the comparison level check was successful. When a check is successful is defined via bit L2ALEV. 0 _B No interrupt is requested 1 _B An interrupt is requested
L2RSTEN	14	rw	Level 2 Reset Request Enable This bit defines if a reset request trigger is requested if the comparison level check was successful. When a check is successful is defined via bit L2ALEV. 0 _B No reset is requested 1 _B An reset is requested
L2ASEN	15	rw	Level 2 Asynchronous Action Enable This bit defines if asynchronous action can be performed if the comparison level check was successful. When a check is successful is defined via bit L2ALEV. 0 _B No asynchronous actions are performed 1 _B Asynchronous actions can be performed
0	3, 11	rw	Reserved Should be written with 0.

8.7 Global State Controller (GSC)

Mode Control for the system peripherals provides besides power saving modes and the clock management an additional opportunity for configuring the system to the application needs.

Mode Control is described in detail in this chapter and is implemented by the Global State Controller (GSC). The GSC enables the user to configure one operating mode in a fast and easy way, reacting fast and explicit to needs of an application.

Feature Overview

The following functions are handled by the GSC:

- Control of peripheral clock operation
- Suspend control for debugging
- Arbitration between the different request sources

According to the requests coming from the OCDS, the SWD pre-warning detection or other blocks, the GSC does an internal prioritization. The result is forwarded as command request broadcast to all peripherals. The GSC internal prioritization scheme for the implemented request sources is shown in [Table 8-10](#).

8.7.1 GSC Control Flow

The sequence begins when at least one request source asserts its trigger in order to request a mode change in the SoC. If several requests are pending there is an arbitration mechanism that treats this issue. Request triggers are not stored by the GSC, therefore a trigger source has to assert its trigger until the trigger is no longer valid or needed.

A request trigger is kept asserted as long as either the request is still pending or the resulting command of the request was entered and acknowledged by the system. The communication of the GSC and the peripherals is based on commands. Three different commands are defined resulting in three modes:

- Wake-up command: requests Normal Mode
- Clock-off command: requests Stop Mode
- Debug command: requests Suspend Mode

The specific behavior in these three modes is defined for each peripheral in its module register `mod_KSCCFG`.

8.7.1.1 Request Source Arbitration

The highest priority for the arbitration is zero (see [Table 8-10](#)).

Each system clock cycle a new arbitration round is started. The winner of an arbitration round requests the next command towards the SoC. Please note that winning an arbitration does not lead automatically to a new command raised. Only if currently no command is broadcast in the SoC a new command can be generated and broadcast. If

the winner of the arbitration round is the same request trigger as in the previous round or if no winner was detected no new command request is generated.

Table 8-10 Connection of the Request Sources

Request Source	Priority
OCDS exit	4
ESR1	6
ESR2	7
WUT	8
ITC	9
GPT12E	10
SW1	11
SW2	12
OCDS entry	14

8.7.1.2 Generation of a New Command

When a new request trigger was detected and arbitrated a new command request is generated if currently no command request is broadcast that is not received by all slaves.

Table 8-11 Request Source and Command Request Coupling

Request Source	Command Description
OCDS exit	Wake-up; Normal Mode
ESR1	Wake-up; Normal Mode
ESR2	Clock-off; Stop Mode
WUT	Wake-up; Normal Mode
ITC	Wake-up; Normal Mode
GPT12E	Wake-up; Normal Mode
SW1	Wake-up; Normal Mode
SW2	Clock-off; Stop Mode
OCDS entry	Debug; Suspend Mode

8.7.1.3 Usage of Commands

The complete control mechanism for the different operation modes of the various slaves is divided into two parts:

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- A central control and configuration part; the Global State Controller (GSC)
- One local control part in each slave; the Kernel State Controller (KSC)

Via the GSC either different hardware sources (e.g. the WUT or the OCDS) or the software can request the system to enter a specific mode. The parts that are affected by the mode can be pre-defined locally for each part via the KSC. For each command a specific reaction can be pre-configured in each KSC for each individual part.

Note: Requesting a peripheral to be permanently shut off by clearing `mod_KSCCFG.MODEN` to 0 does not start a GSC run. However, a GSC run triggered in parallel to the ramp down of this peripheral will have the finite state machine of the GSC waiting for an acknowledge also of this peripheral as long as the peripheral does not deliver its acknowledge or the respective bit in `GSCPERSTATEN` is cleared.

The proposal is either to disable automatic GSC runs (by setting `GSCEN` respectively) in case the application needs the information of the shutdown acknowledge of the peripheral or to disable the respective bit in `GSCPERSTATEN`, so that the missing acknowledge is not taken into account.

Note: When a GSC mode request has been successfully entered, the GSC arbiter is open for any new request. In case a request occurs to enter the current mode, this request is pipelined and remains pending.

*It is recommended to request a command by a software trigger. In particular the clock-off command should be triggered by SW2. The usage of commands requested by hardware has to be done carefully. Only hardware resources requesting Normal Mode should be selected. If the software has detected a wake-up then pending mode change requests can be removed by clearing the bits of the selected sources in **GSCEN** and then enabling the bits in `GSCEN` again.*

8.7.1.4 Terminating a Request Trigger

A request trigger is no longer taken into account for the arbitration after the de-assertion of the request trigger, if it is not enabled or when its respective enable bit is cleared.

8.7.1.5 Suspend Control Flow

The suspend feature is controlled by the OCDS block. The GSC operates only as control and communication interface towards the system. The suspend feature is composed out of two requirements:

The mode that has to be entered when the Suspend Mode is requested.

The mode that has to be entered when the Suspend Mode is left.

The request to enter Suspend Mode is forwarded from the OCDS. When the Suspend Mode is requested the system is expected to be stopped as soon as possible in an idle state where no internal process is pending and in a way that this system state does not lead to any damage internally or externally and can also be left without any damage.

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Therefore all peripherals in the system are requested to enter a mode where the clock can be stopped. This is done by sending a debug command.

Leaving the Suspend Mode should serve the goal that debugging is a non-intrusive operation. Therefore leaving the Suspend Mode can not lead to only one dedicated system mode, instead it leads to the system mode the system left when it was requested to exit the Suspend Mode. The system mode is stored when a Suspend Mode request is detected by the GSC and is used as target system mode when a leave Suspend Mode trigger is detected by the GSC.

8.7.1.6 Error Feedback for a Mode Transition

In case at least one peripheral reports an error the error flag in register GSCSTAT is set. If no error is currently detected upon a new assertion of a system mode by the GSC the error flag is cleared. To inform the system of this erroneous state an interrupt can be generated.

8.7.2 GSC Registers

8.7.2.1 GSC Control and Status Registers

The following register control and configure the behavior of the GSC.

GSCSWREQ

GSC Software Request Register

SFR (FF14_H/8A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
							0							SW TRG 2	SW TRG 1
							r							rwh	rwh

Field	Bits	Type	Description
SWTRG1	0	rwh	Software Trigger 1 (SW1) 0 _B No SW1 request trigger is generated 1 _B A SW1 request trigger is generated This bit is automatically cleared if the SW1 request trigger wins the arbitration and was broadcast to the system.
SWTRG2	1	rwh	Software Trigger 2 (SW2) 0 _B No SW2 request trigger is generated 1 _B A SW2 request trigger is generated This bit is automatically cleared if the SW2 request trigger wins the arbitration and was broadcast to the system.
0	[15:2]	r	Reserved Read as 0; should be written with 0.

GSCEN

GSC Enable Register

SFR (FF16_H/8B_H)

Reset Value: 7FFF_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	OCD SEN EN	1	SW2 EN	SW1 EN	GPT EN	ITC EN	WUT EN	ESR 2 EN	ESR 1 EN	ESR 0 EN	OCD SEX EN	PSC AEN EN	PSC AEX EN	PSC BEN EN	PSC BEX EN
r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
PSCBEXEN	0	rw	Reserved Must be written with 0 _B .
PSCBENEN	1	rw	Reserved Must be written with 0 _B .
PSCAEXEN	2	rw	Reserved Must be written with 0 _B .
PSCAENEN	3	rw	Reserved Must be written with 0 _B .
OCDSEXEN	4	rw	OCDS Exit Request Trigger Enable 0 _B OCDS exit request trigger is not taken into account (disabled) 1 _B OCDS exit request trigger is taken into account (enabled)
ESR0EN	5	rw	Reserved Must be written with 0 _B .
ESR1EN	6	rw	ESR1 Request Trigger Enable 0 _B ESR1 request trigger is not taken into account (disabled) 1 _B ESR1 request trigger is taken into account (enabled)
ESR2EN	7	rw	ESR2 Request Trigger Enable 0 _B ESR2 request trigger is not taken into account (disabled) 1 _B ESR2 request trigger is taken into account (enabled)

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Field	Bits	Type	Description
WUTEN	8	rw	WUT Request Trigger Enable 0_B WUT request trigger is not taken into account (disabled) 1_B WUT request trigger is taken into account (enabled)
ITCEN	9	rw	ITC Request Trigger Enable 0_B ITC request trigger is not taken into account (disabled) 1_B ITC request trigger is taken into account (enabled)
GPTEN	10	rw	GTP12E Request Trigger Enable 0_B GPT12E request trigger is not taken into account (disabled) 1_B GPT12E request trigger is taken into account (enabled)
SW1EN	11	rw	Software 1 Request Trigger Enable 0_B SW1 request trigger is not taken into account (disabled) 1_B SW1 request trigger is taken into account (enabled)
SW2EN	12	rw	Software 2 Request Trigger Enable 0_B SW2 request trigger is not taken into account (disabled) 1_B SW2 request trigger is taken into account (enabled)
1	13	rw	Reserved Read as 1; should be written with 1.
OCDSENEN	14	rw	OCDS Entry Request Trigger Enable 0_B OCDS entry request trigger is not taken into account (disabled) 1_B OCDS entry request trigger is taken into account (enabled) OCDS entry is the request source belonging to the according connector interface.
0	15	r	Reserved Read as 0; should be written with 0.

GSCSTAT

GSC Status Register

SFR (FF18_H/8C_H)

Reset Value: 3C00_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		SOURCE				PEN	ERR	0		NEXT		0	CURRENT		
r		rh				rh	rh	r		rh		r	rh		

Field	Bits	Type	Description
CURRENT	[1:0]	rh	Currently used Command This bit field states the currently used system mode.
NEXT	[5:4]	rh	Next to use Command This bit field states the next to be used system mode.
ERR	8	rh	Error Status Flag This bit flags if with the last command that was broadcast was acknowledge with at least one error. This bit is automatically cleared when a new command is broadcast.
PEN	9	rh	Command Pending Flag This flag states if currently a command is pending or not. A command is pending after the broadcast as long as no all blocks acknowledge that they finished the operation requested by the command.

Field	Bits	Type	Description
SOURCE	[13:10]	rh	Requesting Source Status This bit field monitors the source that triggered the last request. 0000 _B Reserved 0001 _B Reserved 0010 _B Reserved 0011 _B Reserved 0100 _B OCDS exit 0101 _B Reserved 0110 _B <u>ESR1</u> 0111 _B <u>ESR2</u> 1000 _B WUT 1001 _B ITC 1010 _B GPT12E 1011 _B SW1 1100 _B SW2 1101 _B Reserved, do not use this combination 1110 _B OCDS entry 1111 _B Reserved, do not use this combination
0	[3:2], [7:6], [15:14]	r	Reserved Read as 0; should be written with 0.

GSCPERSTATEN

GSC Peripheral Status Enable Register

SFR (FF04_H/82_H)

Reset Value: FFFF_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	USIC 0	FL	MEM	RTC	1	1	1	CCU 60	1	CC2	1	GPT 12E	ADC	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Field	Bits	Type	Description
ADC	0	rw	ADC Acknowledge Enable This bit defines if the acknowledge status of ADC modules is taken into account and displayed or ignored. 0 _B The ADC modules acknowledge is ignored, it is treated as always asserted 1 _B The ADC modules acknowledge is used
GPT12E	1	rw	GPT12E Acknowledge Enable This bit defines if the acknowledge status of GPT12E module is taken into account and displayed or ignored. 0 _B The GPT12E module acknowledge is ignored, it is treated as always asserted 1 _B The GPT12E module acknowledge is used
CC2	3	rw	CC2 Acknowledge Enable This bit defines if the acknowledge status of CC2 module is taken into account and displayed or ignored. 0 _B The CC2 module acknowledge is ignored, it is treated as always asserted 1 _B The CC2 module acknowledge is used
1	4	rw	Reserved Read as 1; should be written with 1 _B .

Field	Bits	Type	Description
CCU60	5	rw	CCU60 Acknowledge Enable This bit defines if the acknowledge status of CCU60 module is taken into account and displayed or ignored. 0 _B The CCU60 module acknowledge is ignored, it is treated as always asserted 1 _B The CCU60 module acknowledge is used
1	8	rw	Reserved Read as 1; should be written with 1 _B .
RTC	9	rw	RTC Acknowledge Enable This bit defines if the acknowledge status of RTC module is taken into account and displayed or ignored. 0 _B The RTC module acknowledge is ignored, it is treated as always asserted 1 _B The RTC module acknowledge is used
MEM	10	rw	C166SV2 Subsystem Acknowledge Enable This bit defines if the acknowledge status of C166SV2 Subsystem module is taken into account and displayed or ignored. 0 _B The C166SV2 Subsystem module acknowledge is ignored, it is treated as always asserted 1 _B The C166SV2 Subsystem module acknowledge is used
FL	11	rw	Flash Acknowledge Enable This bit defines if the acknowledge status of Flash module is taken into account and displayed or ignored. 0 _B The Flash module acknowledge is ignored, it is treated as always asserted 1 _B The Flash module acknowledge is used
USIC0	12	rw	USIC0 Acknowledge Enable This bit defines if the acknowledge status of USIC0 module is taken into account and displayed or ignored. 0 _B The USIC0 module acknowledge is ignored, it is treated as always asserted 1 _B The USIC0 module acknowledge is used

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Field	Bits	Type	Description
1	2, 4, [8:6], [15:13]	rw	Reserved Read as 1; should be written with 1 _B .

GSCPERSTAT
GSC Peripheral Status Register

SFR (FF1A_H/8D_H)

Reset Value: FFFF_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
-	-	-	USIC 0	FL	MEM	RTC	-	-	-	CCU 60	-	CC2	-	GPT 12E	ADC
-	-	-	rh	rh	rh	rh	-	-	rh	-	rh	-	rh	rh	rh

Field	Bits	Type	Description
ADC	0	rh	ADC Acknowledge Status This bit shows the acknowledge status of the modules ADC. 0 _B The modules ADC change currently their kernel state. Their acknowledge has not been received. 1 _B Acknowledge of the modules ADC is taken into account and has been received or is not relevant.
GPT12E	1	rh	GPT12E Acknowledge Status This bit shows the acknowledge status of the modules GPT12E. 0 _B The module GPT12E changes currently its kernel state. Its acknowledge has not been received. 1 _B Acknowledge of the module GPT12E is taken into account and has been received or is not relevant.
CC2	3	rh	CC2 Acknowledge Status This bit shows the acknowledge status of the module CC2. 0 _B The module CC2 changes currently its kernel state. Its acknowledge has not been received. 1 _B Acknowledge of the module CC2 is taken into account and has been received or is not relevant.

Field	Bits	Type	Description
CCU60	5	rh	CCU60 Acknowledge Status This bit shows the acknowledge status of the module CCU60. 0_B The module CCU60 changes currently its kernel state. Its acknowledge has not been received. 1_B Acknowledge of the module CCU60 is taken into account and has been received or is not relevant.
RTC	9	rh	RTC Acknowledge Status This bit shows the acknowledge status of the module RTC. 0_B The module RTC changes currently its kernel state. Its acknowledge has not been received. 1_B Acknowledge of the module RTC is taken into account and has been received or is not relevant.
MEM	10	rh	C166SV2 Subsystem Acknowledge Status This bit shows the acknowledge status of the module C166SV2 Subsystem. 0_B The module C166SV2 Subsystem changes currently its kernel state. Its acknowledge has not been received. 1_B Acknowledge of the module C166SV2 Subsystem is taken into account and has been received or is not relevant.
FL	11	rh	Flash Acknowledge Status This bit shows the acknowledge status of the module Flash. 0_B The module Flash changes currently its kernel state. Its acknowledge has not been received. 1_B Acknowledge of the module Flash is taken into account and has been received or is not relevant.

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Field	Bits	Type	Description
USIC0	12	rh	USIC0 Acknowledge Status This bit shows the acknowledge status of the module USIC0. 0_B The module USIC0 changes currently its kernel state. Its acknowledge has not been received. 1_B Acknowledge of the module USIC0 is taken into account and has been received or is not relevant.

The acknowledge status bit is set, if acknowledge of the module x is taken into account and has been received or is not relevant. The acknowledge of the module x is not relevant if the acknowledge of the module x is not taken into account or the module x currently does not undergo a change of kernel state mode. In these cases the acknowledge is assumed to be received.

8.9 External Request Unit (ERU)

The External Request Unit (ERU) is a versatile event and pattern detection unit. Its major task is the **generation of interrupts based on selectable trigger events at different inputs**, e.g. to generate external interrupt requests if an edge occurs at an input pin.

The detected events can also be used by other modules to trigger or to gate module-specific actions, such as conversions of the ADC module.

8.9.1 Introduction

The ERU of the XE166U can be split in three main functional parts:

- 4 independent **Input Channels x** for input selection and conditioning of trigger or gating functions
- Event distribution: A **Connecting Matrix** defines the events of the Input Channel x that lead to a reaction of an Output Channel y.
- 4 independent **Output Channels y** for combination of events, definition of their effects and distribution to the system (interrupt generation, ADC conversion triggers)

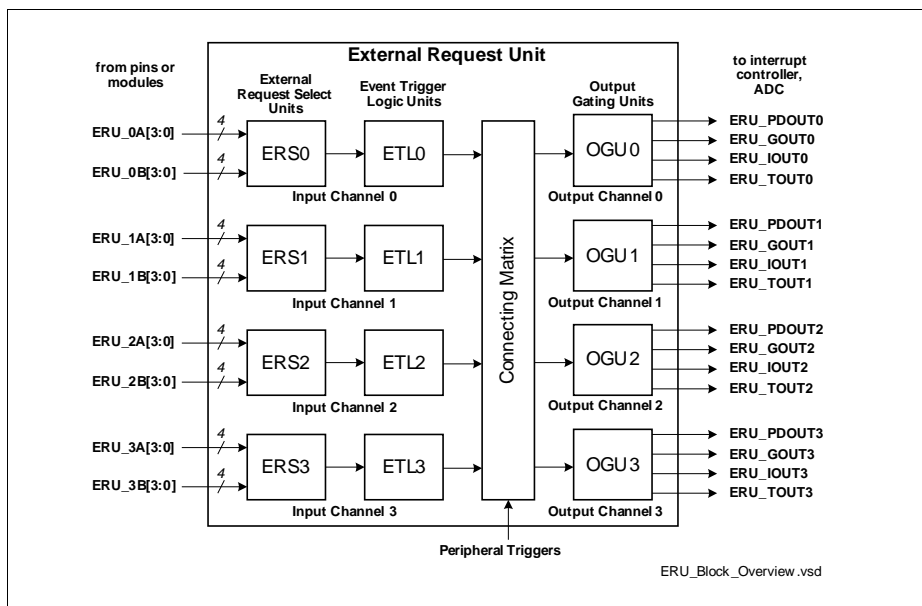


Figure 8-25 External Request Unit Overview

These tasks are handled by the following building blocks:

- An **External Request Select Unit (ERSx)** per Input Channel allows the selection of one out of two or a logical combination of two input signals (ERU_xA, ERU_xB) to a

System Control Unit (SCU)

common trigger. For each of these two signals, an input vector of 4 possible inputs is available (e.g. the actual input ERU_xA can be selected from one of the ERU inputs ERU_xA[3:0], similar for ERU_xB).

- An **Event Trigger Logic (ETLx)** per Input Channel allows the definition of the transition (edge selection, or by software) that lead to a trigger event and can also store this status. Here, the input levels of the selected signals are translated into events (event detected = event flag becomes set, independent of the polarity of the original input signals).
- The **Connecting Matrix** distributes the events and status flags generated by the Input Channels to the Output Channels. Additionally, some Peripheral Trigger signals from other modules (e.g. CC2) are made available and can be combined with the triggers generated by the Input Channels of the ERU.
- An **Output Gating Unit (OGUy)** per Output Channel that combines the available trigger events and status information from the Input Channels. An event of one Input Channel can lead to reactions of several Output Channels, or also events of several Input Channels can be combined to a reaction of one Output Channel (pattern detection).

Different types of reactions are possible, e.g. interrupt generation (based on signals ERU_IOUTy), triggering of ADC conversions (based on signals ERU_TOUTy), or gating of ADC conversions (based on signals ERU_GOUTy).

The ERU is controlled by a number of registers, shown in **Figure 8-26**, and described in **Section 8.9.8**.

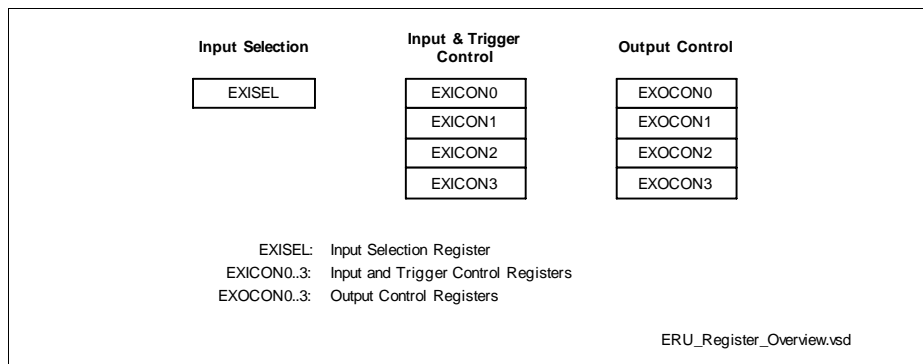


Figure 8-26 ERU Registers Overview

8.9.2 ERU Input Connections

The inputs to the ERU can be selected from a large number of input signals. While some of the inputs come directly from a pin, other inputs use signals from various peripheral modules, such as the USIC (signals named with prefix UxCy to indicate the communication channel). These signals are input signals from the pin that has been selected as input for a USIC function. The selection of the input is made within the respective USIC module.

Usually, such signals would be selected for an ERU function when the input function to the USIC module is not used otherwise, or the module is not used at all. However, it is also possible to select a input which is actually needed in a USIC module, and to use it also in the ERU to provide a certain trigger functions, eventually combined with other signals (e.g. to generate an interrupt trigger in case a start of frame is detected at a selected communication).

With this structure, the number of possible input pins is significantly increased, because not only the selection capability of the ERU is used, but also the selection capability of the communication modules.

Note: All functional inputs of the ERU are synchronized to f_{SYS} before they can affect the internal logic. The resulting delay of $2/f_{SYS}$ and an uncertainty of $1/f_{SYS}$ have to be taken into account for precise timing calculation.

An edge of an input can only be correctly detected if both, the high phase and the low phase of the input are each longer than $1/f_{SYS}$.

The following figure shows the ERU input connections, either directly with pins or via communication modules, such as USIC. These communication modules provide their input signals (e.g. USIC data, clock, or control inputs) that have been selected in these modules.

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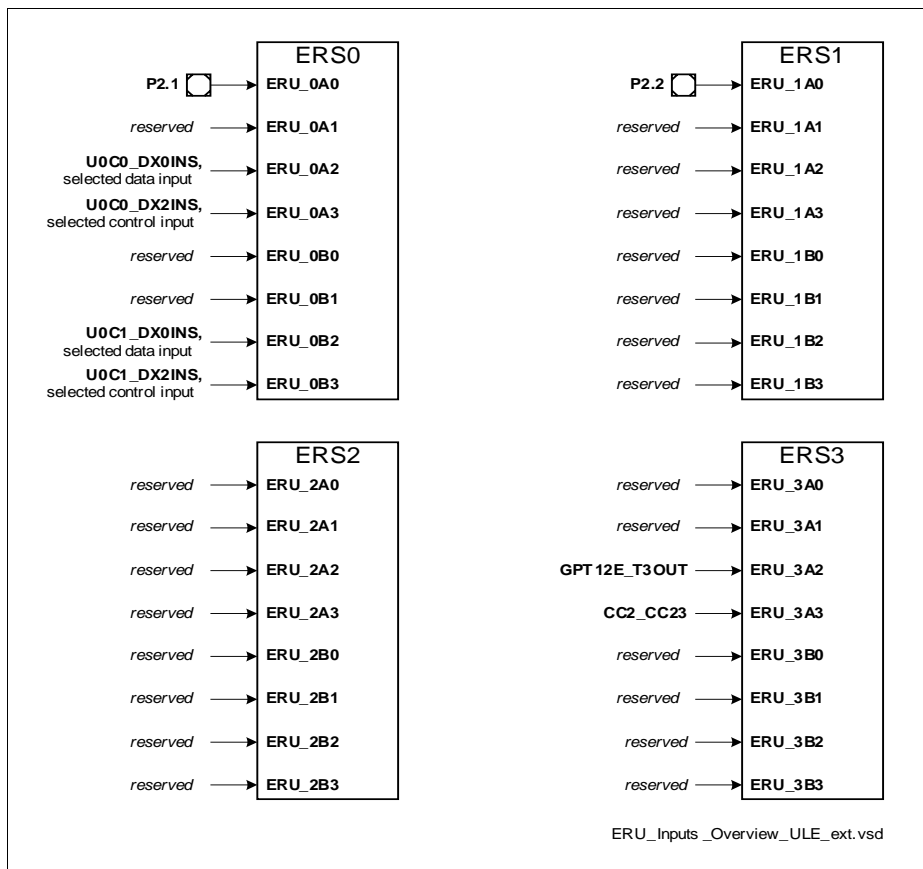


Figure 8-27 ERU Inputs Overview

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The following table describes the ERU input connections for the ERSx stages. The selection is defined by the bit fields in register **EXISEL**.

Table 8-12 ERSx Connections in XE166U

Input	from/to Module	I/O to ERSx	Can be used to/as
-------	-------------------	----------------	-------------------

ERS0 Inputs

ERU_0A0	P2.1	I	ERS0 input A
ERU_0A1	0	I	
ERU_0A2	U0C0_DX0INS	I	
ERU_0A3	U0C0_DX2INS	I	
ERU_0B0	0	I	ERS0 input B
ERU_0B1	0	I	
ERU_0B2	U0C1_DX0INS	I	
ERU_0B3	U0C1_DX2INS	I	

ERS1 Inputs

ERU_1A0	P2.2	I	ERS1 input A
ERU_1A1	0	I	
ERU_1A2	0	I	
ERU_1A3	0	I	
ERU_1B0	0	I	ERS1 input B
ERU_1B1	0	I	
ERU_1B2	0	I	
ERU_1B3	0	I	

ERS2 Inputs

ERU_2A0	0	I	ERS2 input A
ERU_2A1	0	I	
ERU_2A2	0	I	
ERU_2A3	0	I	

Table 8-12 ERSx Connections in XE166U (cont'd)

Input	from/to Module	I/O to ERSx	Can be used to/as
ERU_2B0	0	I	ERS2 input B
ERU_2B1	0	I	
ERU_2B2	0	I	
ERU_2B3	0	I	

ERS3 Inputs

ERU_3A0	0	I	ERS3 input A
ERU_3A1	0	I	
ERU_3A2	GPT12E_T3OUT	I	
ERU_3A3	CC2_CC23	I	
ERU_3B0	0	I	ERS3 input B
ERU_3B1	0	I	
ERU_3B2	0	I	
ERU_3B3	0	I	

8.9.3 External Request Select Unit (ERSx)

For each Input Channel x ($x = 0-3$), an ERS x unit handles the input selection for the associated ETL x unit. Each ERS x performs a logical combination of two signals (A_x , B_x) to provide one combined output ERS x O to the associated ETL x . Input A_x can be selected from 4 options of the input vector ERU_xA[3:0] and can be optionally inverted. A similar structure exists for input B_x (selection from ERU_xB[3:0]).

In addition to the direct choice of either input A_x or B_x or their inverted values, the possible logical combinations for two selected inputs are a logical AND or a logical OR.

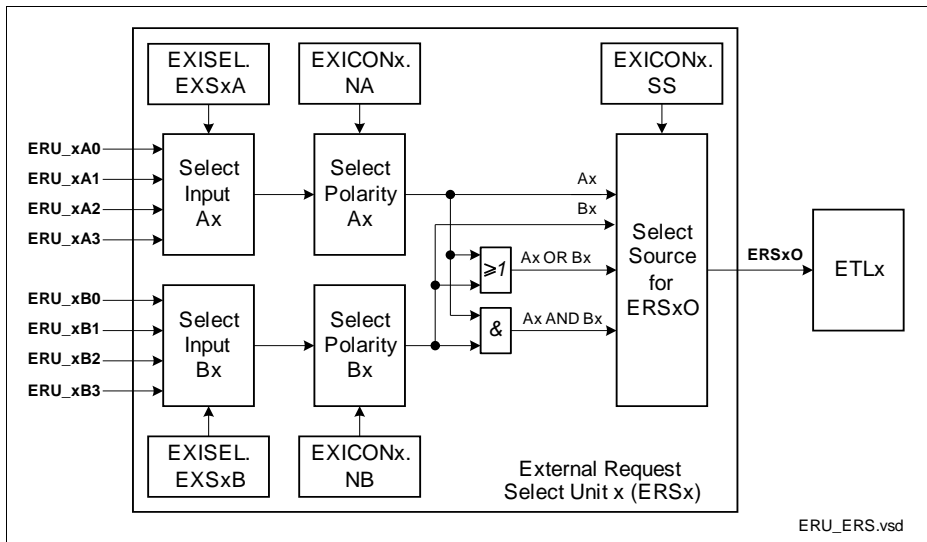


Figure 8-28 External Request Select Unit Overview

The ERS units are controlled via register **EXISEL** (one register for all four ERS x units) and registers EXICON x (one register for each ERS x and associated ETL x unit, e.g. **EXICON0** for Input Channel 0).

8.9.4 Event Trigger Logic (ETLx)

For each Input Channel x ($x = 0-3$), an event trigger logic ETLx derives a trigger event and a status from the input ERUxO delivered by the associated ERSx unit. Each ETLx is based on an edge detection block, where the detection of a rising or a falling edge can be individually enabled. Both edges lead to a trigger event if both enable bits are set (e.g. to handle a toggling input).

Each of the four ETLx units has an associated EXICONx register, that controls all options of an ETLx (the register also holds control bits for the associated ERSx unit, e.g. **EXICON0** to control ESR0 and ETLO).

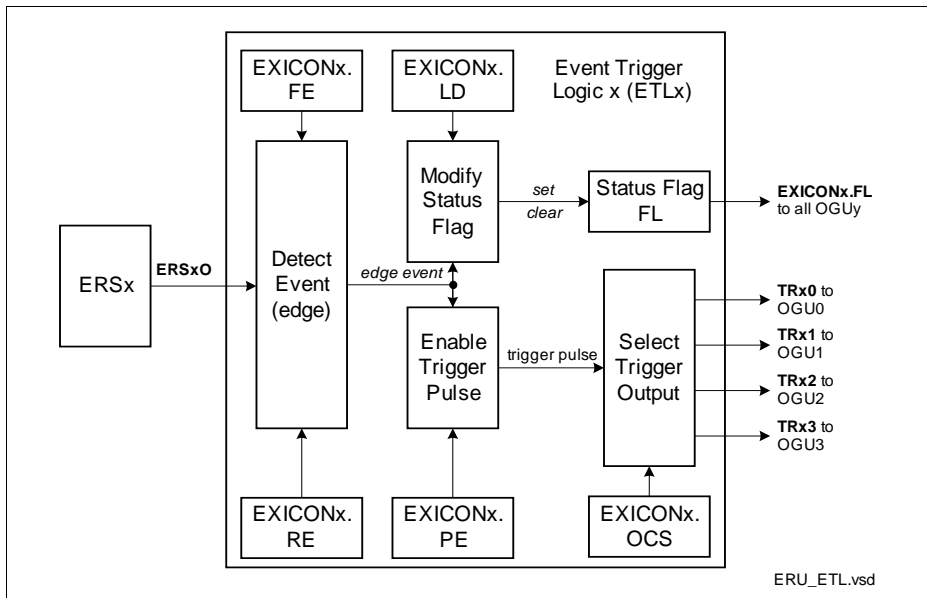


Figure 8-29 Event Trigger Logic Overview

When the selected event (edge) is detected, the status flag EXICONx.FL becomes set. This flag can also be modified by software (set or clear). Two different operating modes are supported by this status flag.

It can be used as “sticky” flag, that is set by hardware when the desired event has been detected and has to be cleared by software. In this operating mode, it indicates that the event has taken place, but without indicating the actual status of the input.

In the second operating mode, it is cleared automatically if the “opposite” event is detected. For example, if only the falling edge detection is enabled to set the status flag, it is cleared when the rising edge is detected. In this mode, it can be used for pattern

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detection where the actual status of the input is important (enabling both edge detections is not useful in this mode).

The output of the status flag is connected to all following Output Gating Units (OGUy) in parallel (see [Figure 8-30](#)) to provide **pattern detection capability of all OGUy** units based on different or the same status flags.

In addition to the modification of the status flag, a trigger pulse output TRxy of ETLx can be enabled (by bit EXICONx.PE) and selected to **trigger actions in one of the OGUy** units. The target OGUy for the trigger is selected by bit field EXICON.OCS.

The trigger becomes active when the selected edge event is detected, independently from the status flag EXICONx.FL.

8.9.5 Connecting Matrix

The connecting matrix distributes the trigger signals (TRxy) and status signals (EXICONx.FL) from the different ETLx units between the OGUy units. In addition, it receives peripheral trigger signals that can be OR-combined with the ETLx trigger signals in the OGUy units. **Figure 8-30** provides a complete overview of the connections between the ETLx and the OGUy units.

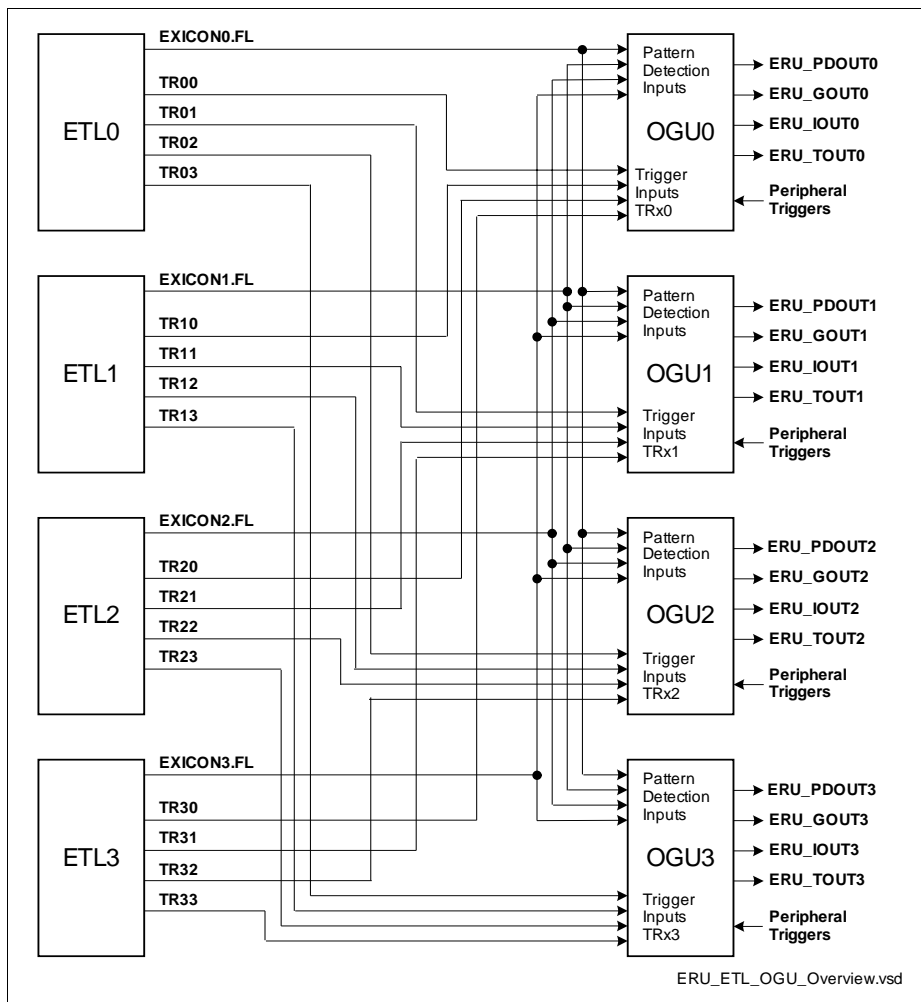


Figure 8-30 Connecting Matrix between ETLx and OGUy

8.9.6 Output Gating Unit (OGUy)

Each OGUy (y = 0-3) unit combines the available trigger events and status flags from the Input Channels and distributes the results to the system. **Figure 8-31** illustrates the logic blocks within an OGUy unit. All functions of an OGUy unit are controlled by its associated EXOCONy register, e.g. **EXOCON0** for OGU0. The function of an OGUy unit can be split into two parts:

- **Trigger combination** (see **Section 8.9.6.1**):
 All trigger signals TRxy from the Input Channels that are enabled and directed to OGUy, a selected peripheral-related trigger event, and a pattern change event (if enabled) are logically OR-combined.
- **Pattern detection** (see **Section 8.9.6.2**):
 The status flags EXICONx.FL of the Input Channels can be enabled to take part in the pattern detection. A pattern match is detected while all enabled status flags are set.

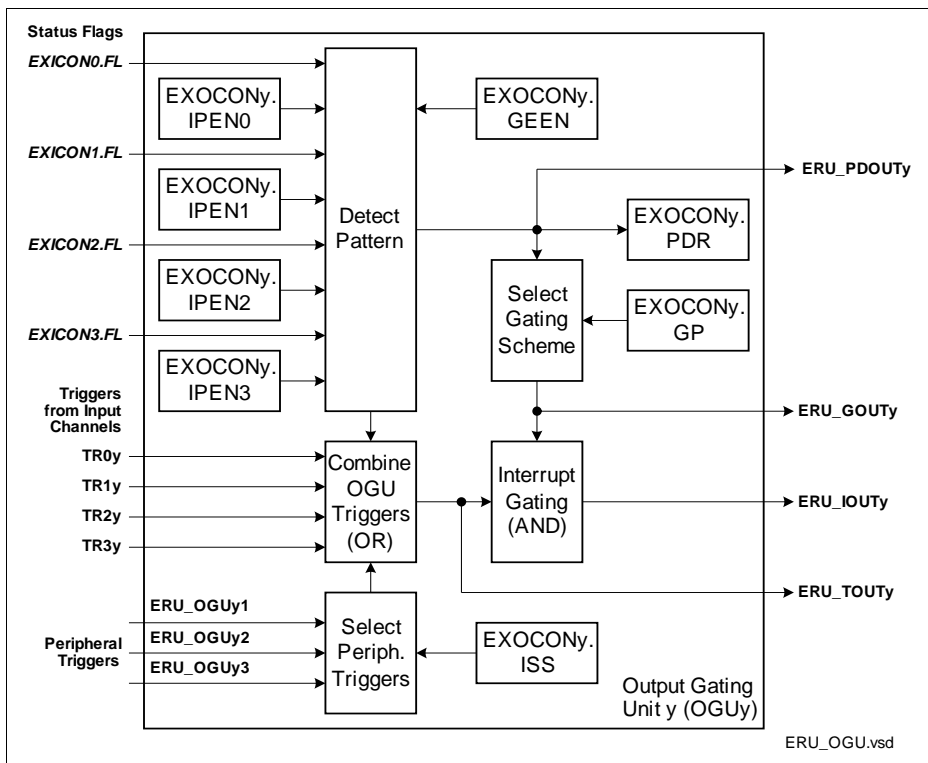


Figure 8-31 Output Gating Unit for Output Channel y

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Each OGUy unit generates 4 output signals that are distributed to the system (not all of them are necessarily used, please refer to [Section 8.9.7](#)):

- **ERU_PDOUTy** to directly output the pattern match information for gating purposes in other modules (pattern match = 1).
- **ERU_GOUTy** to output the pattern match or pattern miss information (inverted pattern match), or a permanent 0 or 1 under software control for gating purposes in other modules.
- **ERU_TOUTy** as combination of a peripheral trigger, a pattern detection result change event, or the ETLx trigger outputs TRxy to trigger actions in other modules.
- **ERU_IOUTy** as gated trigger output (ERU_GOUTy logical AND-combined with ERU_TOUTy) to trigger interrupts (e.g. the interrupt generation can be gated to allow interrupt activation during a certain time window).

Note: An unexpected falling edge on ERU_PDOUTx could trigger a trap interrupt in CCU6 if using an improper initialization sequence. Therefore, initialize ERU_PDOUTx prior to the configuration of other modules (e.g. CCU6 and ADC).

8.9.6.1 Trigger Combination

The trigger combination logically OR-combines different trigger inputs to form a common trigger ERU_TOUTy. Possible trigger inputs are:

- In each ETLx unit of the **Input Channels**, the trigger output TRxy can be enabled and the trigger event can be directed to one of the OGUy units.
- One out of three **peripheral trigger** signals per OGUy can be selected as additional trigger source. These peripheral triggers are generated by on-chip peripheral modules, such as capture/compare or timer units. The selection is done by bit field EXOCONy.ISS.
- In the case that at least one **pattern detection** input is enabled (EXOCONy.IPENx) and a change of the pattern detection result from pattern match to pattern miss (or vice-versa) is detected, a trigger event is generated to indicate a pattern detection result event (if enabled by ECOCONy.GEEN).

The trigger combination offers the possibility to program different trigger criteria for several input signals (independently for each Input Channel) or peripheral signals, and to combine their effects to a single output, e.g. to generate an interrupt or to start an ADC conversion. This combination capability allows the generation of an interrupt per OGU that can be triggered by several inputs (multitude of request sources -> one reaction).

The following table describes the peripheral trigger connections for the OGUy stages.

The selection is defined by the bit fields ISS in registers **EXOCON0** (for OGU0), **EXOCON1** (for OGU1), **EXOCON2** (for OGU2), or **EXOCON3** (for OGU3).

Table 8-13 OGUy Peripheral Trigger Connections in XE166U

Input	from/to Module	I/O to OGUy	Can be used to/as
-------	----------------	-------------	-------------------

OGU0 Inputs

ERU_OGU01	CCU60_MCM_ST	I	Peripheral triggers for OGU0
ERU_OGU02	CCU60_T13_PM	I	
ERU_OGU03	CC2_28	I	

OGU1 Inputs

ERU_OGU11	0	I	Peripheral triggers for OGU1
ERU_OGU12	0	I	
ERU_OGU13	CC2_29	I	

OGU2 Inputs

ERU_OGU21	0	I	Peripheral triggers for OGU2
ERU_OGU22	0	I	
ERU_OGU23	CC2_30	I	

OGU3 Inputs

ERU_OGU31	0	I	Peripheral triggers for OGU3
ERU_OGU32	0	I	
ERU_OGU33	CC2_31	I	

8.9.6.2 Pattern Detection

The pattern detection logic allows the combination of the status flags of all ETLx units. Each status flag can be individually included or excluded from the pattern detection for each OGUy, via control bits EXOCONy.IPENx. The pattern detection block outputs the following pattern detection results:

- **Pattern match** (EXOCONy.PDR = 1 and ERU_PDOUTy = 1):
A pattern match is indicated while all status flags FL that are included in the pattern detection are 1.
- **Pattern miss** (EXOCONy.PDR = 0 and ERU_PDOUTy = 0):
A pattern miss is indicated while at least one of the status flags FL that are included in the pattern detection is 0.

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In addition, the pattern detection can deliver a trigger event if the pattern detection result changes from match to miss or vice-versa (if enabled by EXOCONy.GEEN = 1). The pattern result change event is logically OR-combined with the other enabled trigger events to support interrupt generation or to trigger other module functions (e.g. in the ADC). The event is indicated when the pattern detection result changes and EXOCONy.PDR becomes updated.

The interrupt generation in the OGUy is based on the trigger ERU_TOUTy that can be gated (masked) with the pattern detection result ERU_PDOUTy. This allows an automatic and reproducible generation of interrupts during a certain time window, where the request event is elaborated by the trigger combination block and the time window information (gating) is given by the pattern detection. For example, interrupts can be issued on a regular time base (peripheral trigger input from capture/compare unit is selected) while a combination of input signals occurs (pattern detection based on ETLx status bits).

A programmable gating scheme introduces flexibility to adapt to application requirements and allows the generation of interrupt requests ERU_IOUTy under different conditions:

- **Pattern match** (EXOCONy.GP = 10_B):
An interrupt request is issued when a trigger event occurs while the pattern detection shows a pattern match.
- **Pattern miss** (EXOCONy.GP = 11_B):
An interrupt request is issued when the trigger event occurs while the pattern detection shows a pattern miss.
- **Independent** of pattern detection (EXOCONy.GP = 01_B):
In this mode, each occurring trigger event leads to an interrupt request. The pattern detection output can be used independently from the trigger combination for gating purposes of other peripherals (independent use of ERU_TOUTy and ERU_PDOUTy with interrupt requests on trigger events).
- **No interrupts** (EXOCONy.GP = 00_B, default setting)
In this mode, an occurring trigger event does not lead to an interrupt request. The pattern detection output can be used independently from the trigger combination for gating purposes of other peripherals (independent use of ERU_TOUTy and ERU_PDOUTy without interrupt requests on trigger events).

8.9.7 ERU Output Connections

The following table describes the connections of the ERU output signals for gating or triggering other module functions, as well as the connections to the interrupt control registers.

Table 8-14 ERU Output Connections in XE166U

Output	from/to Module	I/O to OGUy	Can be used to/as
---------------	---------------------------	------------------------	--------------------------

OGU0 Outputs

ERU_PDOUT0	ADC0 (REQGT0E) ADC0 (REQGT1E) ADC0 (REQGT2E)	O	Pattern detection output
ERU_GOUT0	not connected	O	Gated pattern detection output
ERU_TOUT0	not connected	O	Trigger output
ERU_IOUT0	ITC (SCU_ERU_0IC)	O	Interrupt output

OGU1 Outputs

ERU_PDOUT1	ADC0 (REQGT0F) ADC0 (REQGT1F) ADC0 (REQGT2F)	O	Pattern detection output
ERU_GOUT1	not connected	O	Gated pattern detection output
ERU_TOUT1	ADC0 (REQTR0B) ADC0 (REQTR1B) ADC0 (REQTR2B)	O	Trigger output
ERU_IOUT1	ITC (SCU_ERU_1IC)	O	Interrupt output

OGU2 Outputs

ERU_PDOUT2	CCU60 (CTRAPD)	O	Pattern detection output
ERU_GOUT2	not connected	O	Gated pattern detection output
ERU_TOUT2	not connected	O	Trigger output
ERU_IOUT2	ITC (SCU_ERU_2IC)	O	Interrupt output

OGU3 Outputs

ERU_PDOUT3	not connected	O	Pattern detection output
ERU_GOUT3	not connected	O	Gated pattern detection output

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Table 8-14 ERU Output Connections in XE166U (cont'd)

Output	from/to Module	I/O to OGUy	Can be used to/as
ERU_TOUT3	not connected	O	Trigger output
ERU_IOUT3	ITC (SCU_ERU_3IC)	O	Interrupt output

8.9.8 ERU Registers

8.9.8.1 External Input Selection Register EXISEL

This register selects the A and B inputs for all four ERS units. The possible input signals are given in [Table 8-12](#).

EXISEL

External Input Select Register ESFR (F1A0_H/D0_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXS3B		EXS3A		EXS2B		EXS2A		EXS1B		EXS1A		EXS0B		EXS0A	
rw		rw		rw		rw		rw		rw		rw		rw	

Field	Bits	Type	Description
EXS0A	[1:0]	rw	External Source Select for A0 (ERS0) This bit field defines which input is selected for A0. 00 _B Input ERU_0A0 is selected 01 _B Input ERU_0A1 is selected 10 _B Input ERU_0A2 is selected 11 _B Input ERU_0A3 is selected
EXS0B	[3:2]	rw	External Source Select for B0 (ERS0) This bit field defines which input is selected for B0. 00 _B Input ERU_0B0 is selected 01 _B Input ERU_0B1 is selected 10 _B Input ERU_0B2 is selected 11 _B Input ERU_0B3 is selected
EXS1A	[5:4]	rw	External Source Select for A1 (ERS1) This bit field defines which input is selected for A1. 00 _B Input ERU_1A0 is selected 01 _B Input ERU_1A1 is selected 10 _B Input ERU_1A2 is selected 11 _B Input ERU_1A3 is selected
EXS1B	[7:6]	rw	External Source Select for B1 (ERS1) This bit field defines which input is selected for B1. 00 _B Input ERU_1B0 is selected 01 _B Input ERU_1B1 is selected 10 _B Input ERU_1B2 is selected 11 _B Input ERU_1B3 is selected

Field	Bits	Type	Description
EXS2A	[9:8]	rw	External Source Select for A2 (ERS2) This bit field defines which input is selected for A2. 00 _B Input ERU_2A0 is selected 01 _B Input ERU_2A1 is selected 10 _B Input ERU_2A2 is selected 11 _B Input ERU_2A3 is selected
EXS2B	[11:10]	rw	External Source Select for B2 (ERS2) This bit field defines which input is selected for B2. 00 _B Input ERU_2B0 is selected 01 _B Input ERU_2B1 is selected 10 _B Input ERU_2B2 is selected 11 _B Input ERU_2B3 is selected
EXS3A	[13:12]	rw	External Source Select for A3 (ERS3) This bit field defines which input is selected for A3. 00 _B Input ERU_3A0 is selected 01 _B Input ERU_3A1 is selected 10 _B Input ERU_3A2 is selected 11 _B Input ERU_3A3 is selected
EXS3B	[15:14]	rw	External Source Select for B3 (ERS3) This bit field defines which input is selected for B3. 00 _B Input ERU_3B0 is selected 01 _B Input ERU_3B1 is selected 10 _B Input ERU_3B2 is selected 11 _B Input ERU_3B3 is selected

8.9.8.2 External Input Control Registers EXICONx

These registers control the inputs of the ERSx unit and the trigger functions of the ETLx units (x = 0..3).

EXICON0

External Input Control 0 Register

ESFR (F030_H/18_H)

Reset Value: 0000_H

EXICON1

External Input Control 1 Register

ESFR (F032_H/19_H)

Reset Value: 0000_H

EXICON2

External Input Control 2 Register

ESFR (F034_H/1A_H)

Reset Value: 0000_H

EXICON3

External Input Control 3 Register

ESFR (F036_H/1C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0				NB	NA	SS		FL	OCS		FE	RE	LD	PE	
r				rw	rw	rw		rwh	rw		rw	rw	rw	rw	rw

Field	Bits	Type	Description
PE	0	rw	Output Trigger Pulse Enable for ETLx This bit enables the generation of an output trigger pulse at TRxy when the selected edge is detected (set condition for the status flag FL). 0 _B The trigger pulse generation is disabled 1 _B The trigger pulse generation is enabled

Field	Bits	Type	Description
LD	1	rw	Rebuild Level Detection for Status Flag for ETLx This bit selects if the status flag FL is used as “sticky” bit or if it rebuilds the result of a level detection. 0 _B The status flag FL is not cleared by hardware and is used as “sticky” bit. Once set, it is not influenced by any edge until it becomes cleared by software. 1 _B The status flag FL rebuilds a level detection of the desired event. It becomes automatically set with a rising edge if RE = 1 or with a falling edge if FE = 1. It becomes automatically cleared with a rising edge if RE = 0 or with a falling edge if FE = 0.
RE	2	rw	Rising Edge Detection Enable ETLx This bit enables/disables the rising edge event as edge event as set condition for the status flag FL or as possible trigger pulse for TRxy. 0 _B A rising edge is not considered as edge event 1 _B A rising edge is considered as edge event
FE	3	rw	Falling Edge Detection Enable ETLx This bit enables/disables the falling edge event as edge event as set condition for the status flag FL or as possible trigger pulse for TRxy. 0 _B A falling edge is not considered as edge event 1 _B A falling edge is considered as edge event
OCS	[6:4]	rw	Output Channel Select for ETLx Output Trigger Pulse This bit field defines which Output Channel OGUy is targeted by an enabled trigger pulse TRxy. 000 _B Trigger pulses are sent to OGU0 001 _B Trigger pulses are sent to OGU1 010 _B Trigger pulses are sent to OGU2 011 _B Trigger pulses are sent to OGU3 1XX _B Reserved, do not use this combination
FL	7	rwh	Status Flag for ETLx This bit represents the status flag that becomes set or cleared by the edge detection. 0 _B The enabled edge event has not been detected 1 _B The enabled edge event has been detected

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Field	Bits	Type	Description
SS	[9:8]	rw	Input Source Select for ERSx This bit field defines which logical combination is taken into account as ESRxO. 00 _B Input A without additional combination 01 _B Input B without additional combination 10 _B Input A OR input B 11 _B Input A AND input B
NA	10	rw	Input A Negation Select for ERSx This bit selects the polarity for the input A. 0 _B Input A is used directly 1 _B Input A is inverted
NB	11	rw	Input B Negation Select for ERSx This bit selects the polarity for the input B. 0 _B Input B is used directly 1 _B Input B is inverted
0	[15:12]	r	Reserved Read as 0; should be written with 0.

8.9.8.3 Output Control Registers EXOCONy

These registers control the outputs of the Output Gating Unit y (y = 0..3).

EXOCON0

External Output Trigger Control 0 Register

SFR (FE30_H/18_H)

Reset Value: 0008_H

EXOCON1

External Output Trigger Control 1 Register

SFR (FE32_H/19_H)

Reset Value: 0008_H

EXOCON2

External Output Trigger Control 2 Register

SFR (FE34_H/1A_H)

Reset Value: 0008_H

EXOCON3

External Output Trigger Control 3 Register

SFR (FE36_H/1B_H)

Reset Value: 0008_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IPEN 3	IPEN 2	IPEN 1	IPEN 0	0						GP		PDR	GE EN	ISS	
rw	rw	rw	rw	r						rw		rh	rw	rw	

Field	Bits	Type	Description
ISS	[1:0]	rw	Internal Trigger Source Selection This bit field defines which input is selected as peripheral trigger input for OGUy. The possible input signals are given in Table 8-13 . 00 _B The peripheral trigger function is disabled 01 _B Input ERU_OGUy1 is selected 10 _B Input ERU_OGUy2 is selected 11 _B Input ERU_OGUy3 is selected
GEEN	2	rw	Gating Event Enable Bit GEEN enables the generation of a trigger event when the result of the pattern detection changes from match to miss or vice-versa. 0 _B The event detection is disabled 1 _B The event detection is enabled
PDR	3	rh	Pattern Detection Result Flag This bit represents the pattern detection result. 0 _B A pattern miss is detected 1 _B A pattern match is detected

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Field	Bits	Type	Description
GP	[5:4]	rw	Gating Selection for Pattern Detection Result This bit field defines the gating scheme for the interrupt generation (relation between the OGU output ERU_PDOUTy and ERU_GOUTy). 00 _B ERU_GOUTy is always disabled and ERU_IOUTy can not be activated 01 _B ERU_GOUTy is always enabled and ERU_IOUTy becomes activated with each activation of ERU_TOUTy 10 _B ERU_GOUTy is equal to ERU_PDOUTy and ERU_IOUTy becomes activated with an activation of ERU_TOUTy while the desired pattern is detected (pattern match PDR = 1) 11 _B ERU_GOUTy is inverted to ERU_PDOUTy and ERU_IOUTy becomes activated with an activation of ERU_TOUTy while the desired pattern is not detected (pattern miss PDR = 0)
IPENx (x = 0-3)	12+x	rw	Pattern Detection Enable for ETLx Bit IPENx defines whether the trigger event status flag EXICONx.FL of ETLx takes part in the pattern detection of OGUy. 0 _B Flag EXICONx.FL is excluded from the pattern detection 1 _B Flag EXICONx.FL is included in the pattern detection
0	[11:6]	r	Reserved Read as 0; should be written with 0.

8.10 SCU Interrupt Generation

The interrupt structure of the SCU is shown in **Figure 8-32**.

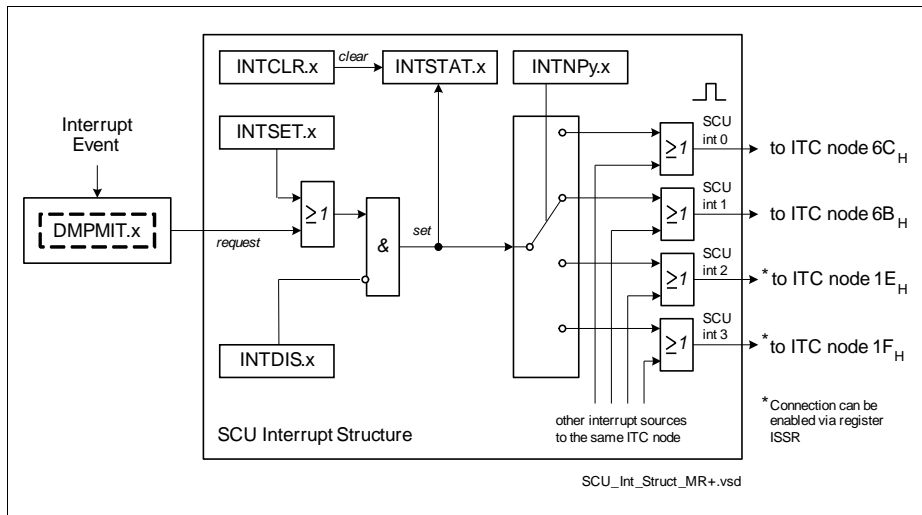


Figure 8-32 SCU Interrupt Structure

If enabled by the corresponding bit in register **INTDIS**, an interrupt is triggered either by the incoming interrupt request line, or by a software set of the respective bit in register **INTSET**. The trigger sets the respective flag in register **INTSTAT** and is gated to one of the interrupt nodes, selected by the node pointer registers **INTNP0** or **INTNP1**.

The interrupt flag can be cleared by software by writing to the corresponding bit in register **INTCLR**.

If more than one interrupt source is connected to the same interrupt node pointer (in register **INTNPx**), the requests are combined to one common line.

Attention: *Following a reset, the SCU interrupts are enabled by default (register **INTDIS** = 0000_H). This may lead to interrupt requests being triggered in the SCU immediately, even before user software has begun to execute. In the SCU, multiple interrupt sources are 'ORed' to a common interrupt node of the CPU interrupt controller. Due to the "ORing" of multiple interrupt sources, only one interrupt request to the interrupt controller will be generated if multiple sources at the input of this OR gate are active at the same time. If user software enables an interrupt in the interrupt controller (SCU_xIC) which shares the same node as the SCU interrupt request active after reset, it may lead to the effect of suppressing the intended interrupt source. So, for all SCU interrupt*

sources which will not be used, make sure to disable the interrupt source (SCU_INTDIS) and clear any pending request flags (SCU_xIC.IR) before enabling interrupts in interrupt controller.

Interrupt Node Assignment

The interrupt sources of the SCU module can be mapped to the dedicated interrupt node 6C_H or 6B_H by programming the interrupt node pointer registers INTNP0 and INTNP1.

Furthermore, If the CAPCOM2 interrupts for channels 30 or 31 are not used the SCU interrupts can be mapped via register ISSR to the interrupt nodes 1E_H or 1F_H which are assigned to the CAPCOM2 interrupts. So for the SCU interrupts can be selected the interrupt node 6C_H, 6B_H, or in addition via register ISSR the node 1E_H or 1F_H.

The default assignment of the interrupt sources to the nodes and their corresponding control registers are shown in [Table 8-15](#).

8.10.1 Interrupt Support

Some of the interrupt requests are first fed through a sticky flag register in the DMP_M domain. These flags are set with a trigger to generate an interrupt.

The list of interrupt requests with a sticky flag in register [DMPMIT](#) is described in [Table 8-15](#).

Note: When servicing an SCU interrupt request, make sure that all related request flags are cleared after the identified request has been handled. To clear an interrupt request that is stored in register DMPMIT, first clear the request source of the source (e.g. WUTRG), clear the request within DMP_M via [DMPMITCLR](#), and then clear the request via INTCLR.

8.10.2 SCU Interrupt Sources

The SCU receives the interrupt request lines listed in [Table 8-15](#).

Table 8-15 SCU Interrupt Overview

Source of Interrupt	Short Name	Sticky Flag in DMPMIT	Default Interrupt Node Assignment in INTNPx
SWD OK 1 Interrupt	SWDI1	yes	6C _H
SWD OK 2 Interrupt	SWDI2	yes	6B _H
PVC_M OK 1 Interrupt	PVCM1	yes	6C _H
PVC_M OK 2 Interrupt	PVCM2	yes	6B _H
Wake-up Timer Interrupt	WUI	yes	6B _H
Wake-up Timer Trim Interrupt	WUTI	yes	6C _H

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Table 8-15 SCU Interrupt Overview (cont'd)

Source of Interrupt	Short Name	Sticky Flag in DMPMIT	Default Interrupt Node Assignment in INTNPx
GSC Interrupt	GSCI	yes	6C _H
STM0 Interrupt	STM0I	yes	6B _H
STM1 Interrupt	STM1I	yes	6C _H
MCHK Interrupt	MCHKI	---	6B _H
Program Flash Interrupt	PFI	---	6C _H

8.10.3 Interrupt Control Registers

8.10.3.1 Register INTSTAT

This register contains the status flags for all interrupt request trigger sources of the SCU. For setting and clearing of these status bits by software see registers INTSET and INTCLR, respectively.

INTSTAT

Interrupt Status Register

SFR (FF00_H/80_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	PF I	M CHK I	STM 1 I	STM 0 I	GSC I	0	WU I	WUT I	0	0	PVC M I2	PVC M I1	SWD I2	SWD I1	
rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh

Field	Bits	Type	Description
SWDI1	0	rh	SWD Interrupt Request Flag 1 This bit is set if bit DMPMIT.SWDI1 is set. 0 _B No SWDI1 interrupt trigger has occurred since this bit was cleared the last time 1 _B A SWDI1 interrupt trigger has occurred since this bit was cleared the last time
SWDI2	1	rh	SWD Interrupt Request Flag 2 This bit is set if bit DMPMIT.SWDI2 is set. 0 _B No SWDI2 interrupt trigger has occurred since this bit was cleared the last time 1 _B A SWDI2 interrupt trigger has occurred since this bit was cleared the last time
PVCMI1	2	rh	PVC_M Interrupt Request Flag 1 This bit is set if bit DMPMIT.PVCMI1 is set. 0 _B No PVCMI1 interrupt trigger has occurred since this bit was cleared the last time 1 _B A PVCMI1 interrupt trigger has occurred since this bit was cleared the last time

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Field	Bits	Type	Description
PVCM12	3	rh	PVC_M Interrupt Request Flag 2 This bit is set if bit DMPMIT.PVCM12 is set. 0 _B No PVCM12 interrupt trigger has occurred since this bit was cleared the last time 1 _B A PVCM12 interrupt trigger has occurred since this bit was cleared the last time
WUTI	6	rh	Wake-up Timer Trim Interrupt Request Flag This bit is set if the WUT trim trigger event occur and bit is INTDIS.WUTI = 0. 0 _B No WUT interrupt trigger has occurred since this bit was cleared the last time 1 _B A WUT interrupt trigger has occurred since this bit was cleared the last time
WUI	7	rh	Wake-up Timer Interrupt Request Flag This bit is set if the WU trigger event occur and bit is INTDIS.WUI = 0. 0 _B No WU interrupt trigger has occurred since this bit was cleared the last time 1 _B A WU interrupt trigger has occurred since this bit was cleared the last time
GSCI	9	rh	GSC Interrupt Request Flag This bit is set if the GSC error bit is set and bit is INTDIS.GSCI = 0. 0 _B No GSC interrupt trigger has occurred since this bit was cleared the last time 1 _B A GSC interrupt trigger has occurred since this bit was cleared the last time
STM0I	10	rh	STM Interrupt 0 Request Flag This bit is set if the STM interrupt trigger 0 is set and bit is INTDIS.STM0I = 0. 0 _B No STM0 interrupt trigger has occurred since this bit was cleared the last time 1 _B A STM0 interrupt trigger has occurred since this bit was cleared the last time

Field	Bits	Type	Description
STM1I	11	rh	STM Interrupt 1 Request Flag This bit is set if the STM interrupt trigger 1 is set and bit is INTDIS.STM1I = 0. 0 _B No STM1 interrupt trigger has occurred since this bit was cleared the last time 1 _B A STM1 interrupt trigger has occurred since this bit was cleared the last time
MCHKI	12	rh	MCHK Interrupt Request Flag This bit is set if the MCHK interrupt trigger is set and bit is INTDIS.MCHKI = 0. 0 _B No MCHK interrupt trigger has occurred since this bit was cleared the last time 1 _B A MCHK interrupt trigger has occurred since this bit was cleared the last time
PFI	13	rh	Program Flash Interrupt Request Flag This bit is set if the Program Flash interrupt trigger is set and bit is INTDIS.PFI = 0. 0 _B No PF interrupt trigger has occurred since this bit was cleared the last time 1 _B A PF interrupt trigger has occurred since this bit was cleared the last time
0	[5:4], 8, [15:14]	rh	Reserved Read as 0; should be written with 0.

8.10.3.2 Register INTCLR

This register contains the software clear option for all status flags of all interrupt request trigger sources of the SCU.

INTCLR

Interrupt Clear Register

SFR (FE82_H/41_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	PF I	M CHK I	STM 1 I	STM 0 I	GSC I	0	WU I	WUT I	0	0	PVC M I2	PVC M I1	SWD I2	SWD I1	
W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W

Field	Bits	Type	Description
SWDI1	0	w	Clear SWD Interrupt Request Flag 1 0 _B No action 1 _B Bit INTSTAT.SWDI1 is cleared
SWDI2	1	w	Clear SWD Interrupt Request Flag 2 0 _B No action 1 _B Bit INTSTAT.SWDI2 is cleared
PVCMI1	2	w	Clear PVC_M Interrupt Request Flag 1 0 _B No action 1 _B Bit INTSTAT.PVCMI1 is cleared
PVCMI2	3	w	Clear PVC_M Interrupt Request Flag 2 0 _B No action 1 _B Bit INTSTAT.PVCMI2 is cleared
WUTI	6	w	Clear Wake-up Timer Trim Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.WUTI is cleared
WUI	7	w	Clear Wake-up Timer Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.WUI is cleared
GSCI	9	w	Clear GSC Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.GSCI is cleared
STM0I	10	w	Clear STM0 Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.STM0I is cleared

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Field	Bits	Type	Description
STM1I	11	w	Clear STM1 Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.STM1I is cleared
MCHKI	12	w	Clear MCHK Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.MCHKI is cleared
PFI	13	w	Clear Program Flash Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.PFI is cleared
0	[5:4], 8, [15:14]	w	Reserved Must be written with 0.

Note: These bits are always read as 0.

8.10.3.3 Register INTSET

This register contains the software set option for all status flags of all interrupt request trigger sources of the SCU.

INTSET

Interrupt Set Register

SFR (FE80_H/40_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	PF I	M CHK I	STM 1 I	STM 0 I	GSC I	0	WU I	WUT I	0	0	PVC M I2	PVC M I1	SWD I2	SWD I1	
W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W

Field	Bits	Type	Description
SWDI1	0	w	Set SWD Interrupt Request Flag 1 0 _B No action 1 _B Bit INTSTAT.SWDI1 is set
SWDI2	1	w	Set SWD Interrupt Request Flag 2 0 _B No action 1 _B Bit INTSTAT.SWDI2 is set
PVCMI1	2	w	Set PVC_M Interrupt Request Flag 1 0 _B No action 1 _B Bit INTSTAT.PVCMI1 is set
PVCMI2	3	w	Set PVC_M Interrupt Request Flag 2 0 _B No action 1 _B Bit INTSTAT.PVCMI2 is set
WUTI	6	w	Set Wake-up Timer Trim Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.WUTI is set
WUI	7	w	Set Wake-up Timer Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.WUI is set
GSCI	9	w	Set GSC Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.GSCI is set
STM0I	10	w	Set STM0 Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.STM0I is set

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Field	Bits	Type	Description
STM1I	11	w	Set STM1 Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.STM1I is set
MCHKI	12	w	Set MCHK Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.MCHKI is set
PFI	13	w	Set Program Flash Interrupt Request Flag 0 _B No action 1 _B Bit INTSTAT.PFI is set
0	[5:4], 8, [15:14]	w	Reserved Must be written with 0.

Note: These bits are always read as 0.

8.10.3.4 Register INTDIS

This register contains the software disable control for all interrupt request trigger sources of the SCU.

INTDIS

Interrupt Disable Register

SFR (FE84_H/42_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	PF I	M CHK I	STM 1 I	STM 0 I	GSC I	0	WU I	WUT I	0	0	PVC M I2	PVC M I1	SWD I2	SWD I1	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
SWDI1	0	rw	Disable SWD Interrupt Request 1 0 _B SWDI1 interrupt request enabled 1 _B SWDI1 interrupt request disabled
SWDI2	1	rw	Disable SWD Interrupt Request 2 0 _B SWDI2 interrupt request enabled 1 _B SWDI2 interrupt request disabled
PVCMI1	2	rw	Disable PVC_M Interrupt Request 1 0 _B PVCMI1 interrupt request enabled 1 _B PVCMI1 interrupt request disabled
PVCMI2	3	rw	Disable PVC_M Interrupt Request 2 0 _B PVCMI2 interrupt request enabled 1 _B PVCMI2 interrupt request disabled
WUTI	6	rw	Disable Wake-up Timer Trim Interrupt Request 0 _B WUT interrupt request enabled 1 _B WUT interrupt request disabled
WUI	7	rw	Disable Wake-up Timer Interrupt Request 0 _B WU interrupt request enabled 1 _B WU interrupt request disabled
GSCI	9	rw	Disable GSC Interrupt Request 0 _B GSC interrupt request enabled 1 _B GSC interrupt request disabled
STM0I	10	rw	Disable STM0 Interrupt Request 0 _B STM0 interrupt request enabled 1 _B STM0 interrupt request disabled

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Field	Bits	Type	Description
STM1I	11	rw	Disable STM1 Interrupt Request 0 _B STM1 interrupt request enabled 1 _B STM1 interrupt request disabled
MCHKI	12	rw	Disable MCHK Interrupt Request 0 _B MCHK interrupt request enabled 1 _B MCHK interrupt request disabled
PFI	13	rw	Disable Program Flash Interrupt Request 0 _B PF interrupt request enabled 1 _B PF interrupt request disabled
0	[5:4], 8, [15:14]	rw	Reserved Should be written with 0.

8.10.3.5 Registers INTNP0 and INPNP1

These registers contain the control for the interrupt node pointers of all interrupt request trigger sources of the SCU.

INTNP0

Interrupt Node Pointer 0 Register

SFR (FE86_H/43_H)

Reset Value: 4444_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WU		WUT		-		PVCM2		PVCM1		SWD2		SWD1			
rw		rw		-		rw		rw		rw		rw			

Field	Bits	Type	Description
SWD1	[1:0]	rw	Interrupt Node Pointer for SWD 1 Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.SWDI1 (if enabled by bit INTDIS.SWDI1). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)
SWD2	[3:2]	rw	Interrupt Node Pointer for SWD 2 Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.SWDI2 (if enabled by bit INTDIS.SWDI2). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)

Field	Bits	Type	Description
PVCM1	[5:4]	rw	Interrupt Node Pointer for PVC_M 1 Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.PCVMI1 (if enabled by bit INTDIS.PVCM11). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)
PVCM2	[7:6]	rw	Interrupt Node Pointer for PVC_M 2 Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.PCVMI2 (if enabled by bit INTDIS.PVCMI2). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)
WUT	[13:12]	rw	Interrupt Node Pointer for Wake-up Timer Trim Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.WUTI (if enabled by bit INTDIS.WUTI). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)
WU	[15:14]	rw	Interrupt Node Pointer for Wake-up Timer Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.WUI (if enabled by bit INTDIS.WUI). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)

INTNP1

Interrupt Node Pointer 1 Register

SFR (FE88_H/44_H)

Reset Value: 1111_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
-				PF	MCHK	STM1	STM0	GSC	-						
-				rw	rw	rw	rw	rw	-						

Field	Bits	Type	Description
GSC	[3:2]	rw	Interrupt Node Pointer for GSC Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.GSCI (if enabled by bit INTDIS.GSCI). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)
STM0	[5:4]	rw	Interrupt Node Pointer for STM0 Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.STM0I (if enabled by bit INTDIS.STM0I). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)
STM1	[7:6]	rw	Interrupt Node Pointer for STM1 Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.STM1I (if enabled by bit INTDIS.STM1I). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)

Field	Bits	Type	Description
MCHK	[9:8]	rw	Interrupt Node Pointer for MCHK Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.MCHKI (if enabled by bit INTDIS.MCHKI). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)
PF	[11:10]	rw	Interrupt Node Pointer for Program Flash Interrupts This bit field defines the interrupt node, which is requested due to the set condition for bit INTSTAT.PFI (if enabled by bit INTDIS.PFI). 00 _B Interrupt node 6C _H is selected 01 _B Interrupt node 6B _H is selected 10 _B Interrupt node 1E _H is selected if enabled by bit ISSR.ISS14 (bit is set) 11 _B Interrupt node 1F _H is selected if enabled by bit ISSR.ISS15 (bit is set)

8.10.3.6 Register DMPMIT

This register contains additional sticky interrupt and trap flags within the DMP_M power domain.

DMPMIT

DMP_M Interrupt and Trap Trigger Register

SFR (FE96_H/4B_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RA T	0	ESR 2 T	ESR 1 T	0	STM 1	STM 0	GSC	WU I	WUT I	0	0	PVC M I2	PVC M I1	SWD I2	SWD I1
rh	r	rh	rh	r	rh	rh	rh	rh	rh	r	r	rh	rh	rh	rh

Field	Bits	Type	Description
SWDI1	0	rh	SWD Interrupt Request Flag 1 This bit is set if bit SWDCON0.L1OK matches the action level defined by SWDCON0.L1ALEV and SWDCON0.L1INTEN = 1 _B . 0 _B No SWDI1 interrupt was requested since this bit was cleared the last time 1 _B A SWDI1 interrupt was requested since this bit was cleared the last time
SWDI2	1	rh	SWD Interrupt Request Flag 2 This bit is set if bit SWDCON0.L2OK matches the action level defined by SWDCON0.L2ALEV and SWDCON0.L2INTEN = 1 _B . 0 _B No SWDI2 interrupt was requested since this bit was cleared the last time 1 _B A SWDI2 interrupt was requested since this bit was cleared the last time
PVCMI1	2	rh	PVC_M Interrupt Request Flag 1 This bit is set if bit PVCICON0.LEV1OK is cleared and PVCICON0.L1INTEN = 1 _B . 0 _B No PVCMI1 interrupt was requested since this bit was cleared the last time 1 _B A PVCMI1 interrupt was requested since this bit was cleared the last time

Field	Bits	Type	Description
PVCM12	3	rh	PVC_M Interrupt Request Flag 2 This bit is set if bit PVCMCON0.LEV2OK is cleared and PVCMCON0.L2INTEN = 1 _B . 0 _B No PVCM12 interrupt was requested since this bit was cleared the last time 1 _B A PVCM12 interrupt was requested since this bit was cleared the last time
WUTI	6	rh	Wake-up Timer Trim Interrupt Request Flag This bit is set if a wake-up timer trim trigger occurs. 0 _B No WUT interrupt was requested since this bit was cleared the last time 1 _B A WUT interrupt was requested since this bit was cleared the last time
WUI	7	rh	Wake-up Timer Interrupt Request Flag This bit is set if a wake-up timer trigger occurs. 0 _B No WU interrupt was requested since this bit was cleared the last time 1 _B A WU interrupt was requested since this bit was cleared the last time
GSC	8	rh	GSC Interrupt Request Flag This bit is set if a GSC trigger occurs. 0 _B No GSC interrupt was requested since this bit was cleared the last time 1 _B A GSC interrupt was requested since this bit was cleared the last time
STM0	9	rh	STM0 Interrupt Request Flag This bit is set if a STM0 trigger occurs. 0 _B No STM0 interrupt was requested since this bit was cleared the last time 1 _B A STM0 interrupt was requested since this bit was cleared the last time
STM1	10	rh	STM1 Interrupt Request Flag This bit is set if a STM1 trigger occurs. 0 _B No STM1 interrupt was requested since this bit was cleared the last time 1 _B A STM1 interrupt was requested since this bit was cleared the last time

Field	Bits	Type	Description
ESR1T	12	rh	ESR1 Trap Request Flag This bit is set if pin ESR1 is asserted. 0 _B No ESR1 trap was requested since this bit was cleared the last time 1 _B An ESR1 trap was requested since this bit was cleared the last time
ESR2T	13	rh	ESR2 Trap Request Flag This bit is set if pin ESR2 is asserted. 0 _B No ESR2 trap was requested since this bit was cleared the last time 1 _B An ESR2 trap was requested since this bit was cleared the last time
RAT	15	rh	Register Access Trap Request Flag This bit is set a protected register is written by an non-authorized access. 0 _B No RA trap was requested since this bit was cleared the last time 1 _B A RA trap was requested since this bit was cleared the last time
0	[5:4], 11, 14	r	Reserved Read as 0; should be written with 0.

8.10.3.7 Register DMPMITCLR

This register contains the software clear option for all sticky status flags of all interrupt and trap request trigger sources of the DMP_M power domain.

DMPMITCLR

DMP_M Interrupt and Trap Clear Register

SFR (FE98_H/4C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RA T	0	ESR 2 T	ESR 1 T	0	STM 1	STM 0	GSC	W UI	WUT I	0	0	PVC M I2	PVC M I1	SWD I2	SWD I1
w	r	w	w	r	w	w	w	w	w	r	r	w	w	w	w

Field	Bits	Type	Description
SWDI1	0	w	Clear SWD1 Interrupt Request Flag 1 0 _B No action 1 _B Bit DMPMIT.SWDI1 is cleared
SWDI2	1	w	Clear SWD Interrupt Request Flag 2 0 _B No action 1 _B Bit DMPMIT.SWDI2 is cleared
PVCMI1	2	w	Clear PVC_M Interrupt Request Flag 1 0 _B No action 1 _B Bit DMPMIT.PVCMI1 is cleared
PVCMI2	3	w	Clear PVC_M Interrupt Request Flag 2 0 _B No action 1 _B Bit DMPMIT.PVCMI2 is cleared
WUTI	6	w	Clear Wake-up Trim Interrupt Request Flag 0 _B No action 1 _B Bit DMPMIT.WUTI is cleared
WUI	7	w	Clear Wake-up Interrupt Request Flag 0 _B No action 1 _B Bit DMPMIT.WUI is cleared
GSC	8	w	Clear GSC Interrupt Request Flag 0 _B No action 1 _B Bit DMPMIT.GSCI is cleared
STM0	9	w	Clear STM0 Interrupt Request Flag 0 _B No action 1 _B Bit DMPMIT.STM0I is cleared

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Field	Bits	Type	Description
STM1	10	w	Clear STM1 Interrupt Request Flag 0 _B No action 1 _B Bit DMPMIT.STM1I is cleared
ESR1T	12	w	Clear ESR1 Trap Request Flag 0 _B No action 1 _B Bit DMPMIT.ESR1T is cleared
ESR2T	13	w	Clear ESR2 Trap Request Flag 0 _B No action 1 _B Bit DMPMIT.ESR2T is cleared
RAT	15	w	Clear Register Access Trap Request Flag 0 _B No action 1 _B Bit DMPMIT.RAT is cleared
0	[5:4], 11,14	r	Reserved Read as 0; should be written with 0.

Note: The bits of type w are always read as 0.

8.11 Window Watchdog Timer (WWD)

The following part describes the Window Watchdog Timer (WWD) and its functionality.

8.11.1 Introduction

The Window Watchdog Timer (WWD) is a secure mechanism to overcome deadlocks. An enabled WWD generates a configurable reset for the system if not serviced in a configured time frame. Power reset in the core domain is one of the selectable reset that could reset the core system and all registers.

Features

The following list is a summary of the WWD functions:

- 16-bit Watchdog Timer
- Selectable clock source for WWD clock input f_{IN} : f_{SYS} or f_{WU}
- Selectable operating frequency: f_{IN} , $f_{IN} / 4$, $f_{IN} / 256$ or $f_{IN} / 16384$
- Programmable Window Boundary
- Individual disable for timer functionality

Figure 8-33 provides an overview on the registers of the Watchdog Timer.

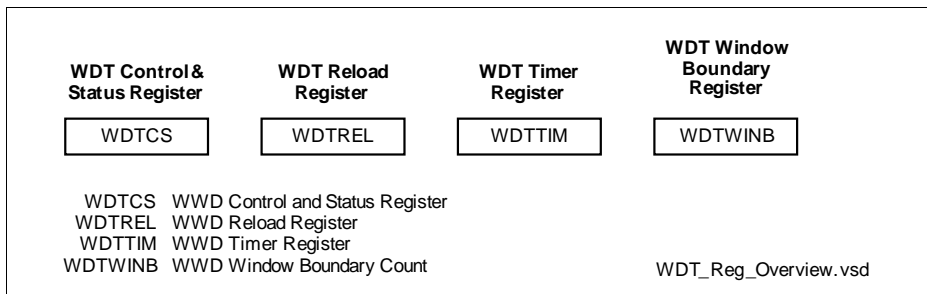


Figure 8-33 Watchdog Timer Register Overview

8.11.2 Overview

The Window Watchdog Timer (WWD) provides a highly reliable and secure way to detect and recover from software or hardware failure. The WWD helps to abort an accidental malfunction of the XE166U in a user-specified time period. When enabled, the WWD will cause the XE166U system to be reset if the WWD is not serviced within a user-programmable time period. The CPU must service the WWD within this time interval to prevent the WWD from causing a WWD reset request trigger. Hence, regular service of the WWD confirms that the system is functioning properly.

The Watchdog Timer has a 'programmable window boundary', it disallows refresh during the Watchdog Timer's count-up. A refresh during this window-boundary will cause the

Watchdog Timer to activate a WWD reset. The window boundary is from 0000_H to WINB. This feature can be enabled by bit WWDBE in register WDTCS. If the Window-Boundary feature of the Watchdog Timer is enabled, the period between servicing the Watchdog Timer and the next overflow is shortened if WINB is greater than RELV. See also [Figure 8-34](#). In order for this feature to be useful, WINB cannot be smaller than RELV.

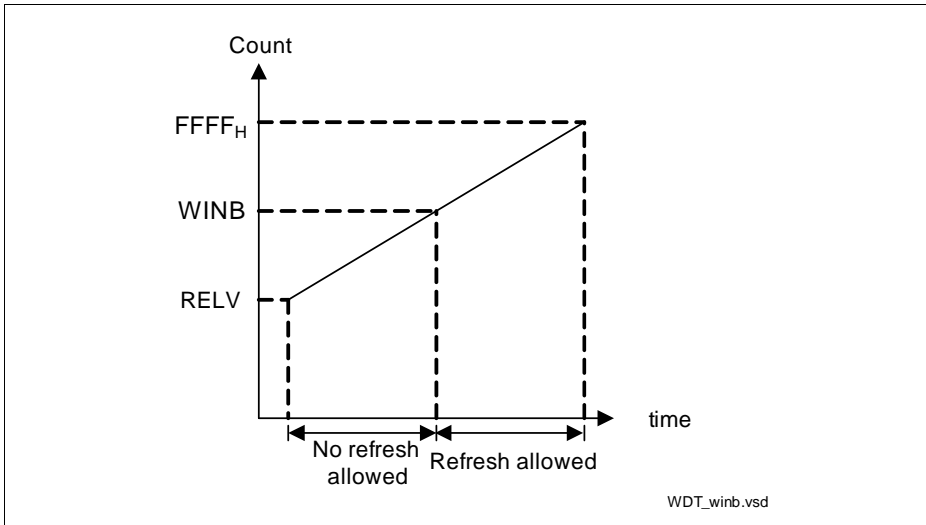


Figure 8-34 Window Watchdog Timer Timing Diagram

8.11.3 Functional Description

The following describes all functions of the WWD.

8.11.3.1 Timer Operation

The timer is enabled when instruction ENWDT (Enable Watchdog Timer) is executed correctly.

The WWD uses an input clock f_{IN} , which is either equal to the system clock f_{sys} or the OSC_WU clock f_{WU} . The clock source is selected using bit WDCLKSEL. A clock divider in front of the WWD timer provides four output frequencies, f_{IN} , $f_{IN} / 4$, $f_{IN} / 256$ or $f_{IN} / 16384$. The selection of the counting rate is done via bit [WDTCS.IR](#).

WWD Periods

The general formula to calculate a Watchdog period is:

$$\text{period} = \frac{(2^{16} - \text{startvalue}) \cdot 4 \cdot 2^{(2 - \text{IR})} \cdot 6}{f_{\text{IN}}} \quad \text{for IR} = 0, 1 \text{ and } 2 \quad (8.4)$$

$$\text{period} = \frac{(2^{16} - \text{startvalue})}{f_{\text{IN}}} \quad \text{for IR} = 3 \quad (8.5)$$

The parameter <startvalue> represents the user-programmable reload value WDTREL.RELV (default value FFFC_{H}) for the calculation of the period in Normal Mode. If the window boundary function is enabled, the user-programmable boundary value WINB is the <startvalue>.

WWD Timer Reload

The timer is reloaded when one of the following conditions occurs:

- A successful access to register **WDTREL**
- WWD is serviced in the refresh allowed boundary via instruction SRVWDT
- WWD overflow condition
- The Disable Mode is entered (when instruction DISWDT is executed)
- Upon any reset

Determination of WWD Period when $f_{\text{IN}} = f_{\text{WU}}$

The actual frequency of the trimmed current controlled wake-up clock (OSC_WU) can be measured prior to the enabling of WWD in order to adjust the number of clock cycles to be counted (reload value written to the counter) and so to define the time until WWD overflow. An accurate way to determine the WWD period is to use the CCU60 capture input and the WUT wake-up trigger output as described in **Determination of Wake-up Period**. A CCU60 capture event will be triggered when a WUT wake-up trigger is generated as shown in **Figure 8-18**. With the CCU60 running on an accurate system clock, the actual WUT wake-up period and therefore, the actual OSC_WU frequency, can be determined using the captured counter value. The WWD reload value or WINB boundary value can then be adjusted based on the actual OSC_WU frequency.

Besides CCU60, the wake-up trigger output is also connected to GPT2 and CCU2 and the same approach can be used for the WWD period evaluation.

8.11.3.2 Timer Modes

The Watchdog Timer provides following modes:

- Normal Mode
- Disable Mode

Figure 8-35 provides a state diagram of the different Timer Modes and the transition possibilities. Please refer to the description of the conditions for changing from one mode to the other.

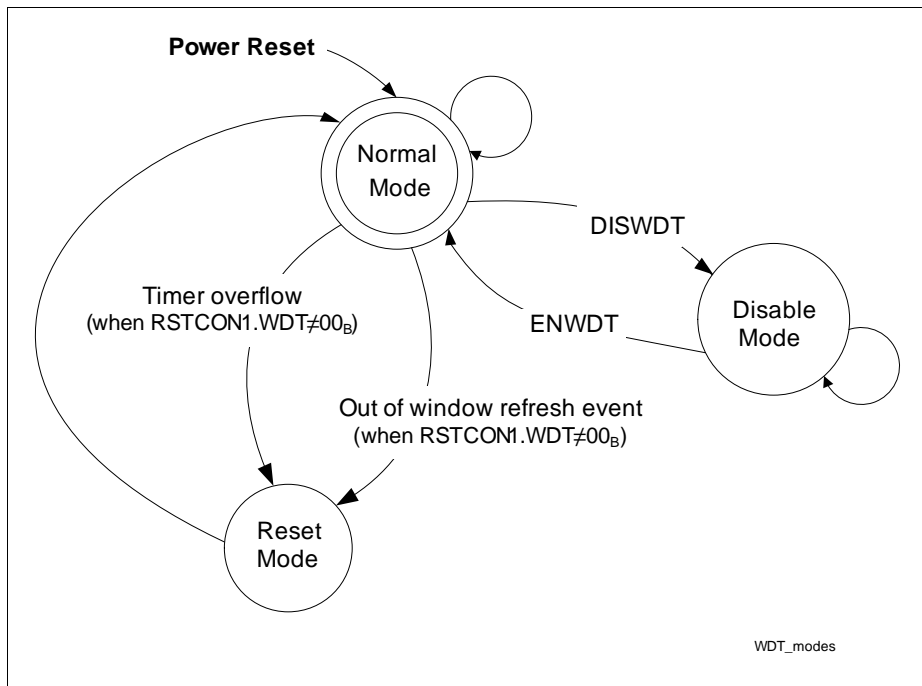


Figure 8-35 State Diagram of the Timer Modes

Normal Mode

Normal Mode is the default mode after any type of system resets.

The timer is loaded with RELV when the Normal Mode is entered, and it starts counting upwards. After reset the timer is loaded with FFFC_H (default value of RELV).

It has to be serviced before the counter overflows. Servicing is performed by the CPU via instructions SRVWDT and/or ENWDT. If the WWD is not serviced before the timer overflows, a system malfunction is assumed and a WWD reset of the XE166U is

System Control Unit (SCU)

imminent and can no longer be stopped. When the window boundary function is enabled, WWD need to be serviced within the boundary limits from WINB to FFFF_H to prevent the activation of a WWD reset.

The type of system resets that are triggered during a WWD reset is configurable by using bit WDT in register RSTCON1. The default setting is to trigger a power reset for DMP_1 core domain during an overflow event. This type of reset is able to reset all the registers to the default setting.

Note: Updating the setup of WWD such as the reload value, window boundary value and clock related configurations are not advisable when the WWD is in Normal Mode. User should configure the register settings when WWD is in the Disable Mode before entering Normal Mode.

Disable Mode

Disable Mode is provided for applications that do not require the Watchdog Timer function. Disable Mode is entered when instruction DISWDT is executed, either before End-of-Init, if CPUCON1.WDTCTL = 0, or at any time, if CPUCON1.WDTCTL = 1.

The timer is reloaded with the value of WDTREL.RELV when Disable Mode is entered.

A transition from Disable Mode to Normal Mode is performed when instruction ENWDT is executed while CPUCON1.WDTCTL = 1.

8.11.3.3 Suspend Mode Support

In an enabled and active debug session, the Watchdog functionality can lead to unintended resets. Therefore, to avoid these resets, the OCDS can control whether the WWD is enabled or disabled (default after reset). This is done via bit CBS_IOSR.DB.

Table 8-16 OCDS Behavior of WWD

WDTCS.DS	CBS_DBGSR.DBGEN	CBS_IOSR.DB	WWD Action
1	X	X	Stopped
0	0	X	Running
0	1	0	Stopped
0	1	1	Running

8.11.4 WWD Kernel Registers

8.11.4.1 WWD Reload Register

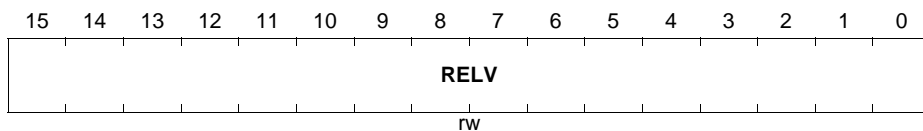
This register defines the WWD reload value.

WDTREL

WWD Reload Register

ESFR (F0C8_H/64_H)

Reset Value: FFFC_H



Field	Bits	Type	Description
RELV	[15:0]	rw	Reload Value for the Watchdog Timer This bit field defines the reload value for the WWD.

8.11.4.2 WWD Control and Status Register

The Control and Status Register can only be accessed in Secured Mode.

WDTCS

WWD Control and Status Register

ESFR (F0C6 _H /63 _H)										Reset Value: 0000 _H					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						IR		0		WW DBE	WWD CLK SEL	0		DS	OE
r						rw		r		rw	rw	r		rh	rh

Field	Bits	Type	Description
OE	0	rh	Overflow Error Status Flag 0 _B No WWD overflow error 1 _B A WWD overflow error has occurred. This bit is only cleared through: <ul style="list-style-type: none"> any Power Reset an executed SRVWDT or ENWDT instruction <i>Note: The WWD is always enabled by ENWDT in the startup procedure (see section "Watchdog Timer handling"). Therefore, the bit is cleared in case of an Application Reset or an Internal Application Reset.</i>
DS	1	rh	Timer Enable/Disable Status Flag 0 _B Timer is enabled (default after reset) 1 _B Timer is disabled This bit is cleared when instruction ENWDT was executed and CPUCON1.WDTCTL = 1. This bit is set when instruction DISWDT was executed before EINIT or CPUCON1.WDTCTL = 1. <i>Note: ENWDT and DISWDT instruction will be reflected in this bit.</i>
WWDCLKSEL	4	rw	WWD Clock Select This bit is used to select the clock source of f_{IN} . 0 _B Wake-up Oscillator, f_{WU} 1 _B System Clock, f_{sys} <i>Note: This bit will not be reset to default value during application and internal application reset.</i>

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Field	Bits	Type	Description
WWDDBE	5	rw	Watchdog Window Boundary Enable 0_B Watchdog window boundary feature is disabled. (default) 1_B Watchdog window boundary feature is enabled.
IR	[9:8]	rw	Input Frequency Request Bit 00_B Request to set input frequency to $f_{IN} / 16384$ 01_B Request to set input frequency to $f_{IN} / 256$ 10_B Request to set input frequency to $f_{IN} / 4$ 11_B Request to set input frequency to f_{IN}
0	[3:2], [7:6], [15:10]	r	Reserved Read as 0; should be written with 0.

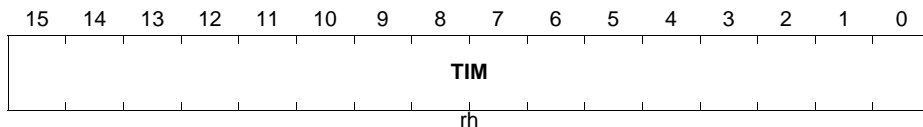
8.11.4.3 WWD Timer Register

WDDTIM

WWD Timer Register

ESFR (F0CA_H/65_H)

Reset Value: FFFC_H



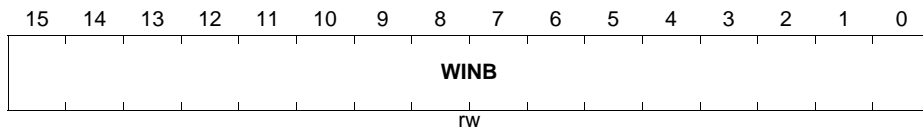
Field	Bits	Type	Description
TIM	[15:0]	rh	Timer Value Reflects the current contents of the Watchdog Timer.

Note: Reading the WDDTIM register while the WWD is running will not reflect the real-time value of the timer due to synchronisation. There is a delay of about 2-7 WWD clock cycles.

8.11.4.4 WWD Window Boundary Count Register

WDTWINB

WWD Window Boundary Count RegisterESFR (F03C_H/1E_H) **Reset Value: 0000_H**



Field	Bits	Type	Description
WINB	[15:0]	rw	Watchdog Window Boundary Count Value This value is programmable. Within this window boundary range from 0000 _H to (WINB), the WWD cannot do a refresh, else it will cause a reset to be asserted.

8.12 SCU Trap Generation

The basic trap structure of the SCU is shown in **Figure 8-36**.

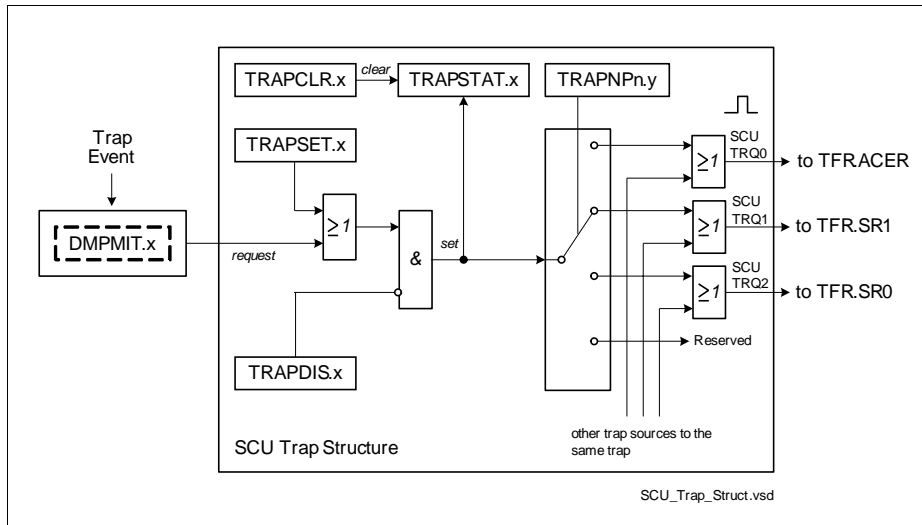


Figure 8-36 SCU Trap Structure

If enabled by the corresponding bit in register **TRAPDIS**, a trap is triggered either by a pulse on the incoming trap line, or by a software set of the respective bit in register **TRAPSET**. The trigger sets the respective flag in register **TRAPSTAT** and is gated to one of the trap nodes, selected by the node pointer registers **TRAPNP**.

The trap flag in register **TRAPSTAT** can be cleared by software by writing to the corresponding bit in register **TRAPCLR**.

If more than one trap source is connected to the same trap (via registers **TRAPNP** and **TRAPNP1**), the requests are combined to one common line.

Trap Node Assignment

The trap sources of the system can be mapped to three trap nodes by programming the trap node pointer registers **TRAPNP** and **TRAPNP1**. The default assignment of the trap sources to the nodes and their corresponding control register is listed in **Table 8-17**.

8.12.1 Trap Support

Some of the trap requests are first fed through a sticky flag register in the **DMP_M** domain. These flags are set with a trigger and if set trigger the trap generation.

The list of trap requests with a sticky flag in register **DMPMIT** is listed in **Table 8-17**.

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Note: When servicing an SCU trap request, make sure that all related request flags are cleared after the identified request has been handled. To clear a trap request that is stored in register DMPMIT, first clear the request source of the source, clear the request within DMP_M via DMPMITCLR, and then clear the request via TRAPCLR.

8.12.2 SCU Trap Sources

The SCU receives the trap lines listed in [Table 8-17](#).

Table 8-17 SCU Trap Request Overview

Source of Trap	Short Name	Sticky Flag in DMPMIT	Default Trap Flag Assignment in Register TFR
Flash Access Trap	FAT	---	TFR.ACER (SCU_TRQ0)
ESR1 Trap	ESR1T	yes	TFR.SR1 (SCU_TRQ1)
ESR2 Trap	ESR2T	yes	TFR.SR1 (SCU_TRQ1)
PLL Trap	OSCWDTT	---	TFR.SR0 (SCU_TRQ2)
Register Access Trap	RAT	yes	TFR.ACER (SCU_TRQ0)
Parity Error Trap	PET	---	TFR.ACER (SCU_TRQ0)
VCO Lock Trap	VCOLCKT	---	TFR.SR0 (SCU_TRQ2)

Field	Bits	Type	Description
OSCWDTT	4	rh	OSCWDT Trap Request Flag TRAPSTAT.OSCWDTT is set when an OSCWDT emergency event occurs and TRAPDIS.OSCWDTT = 0. 0 _B No OSCWDT trap trigger has occurred since this bit was cleared the last time 1 _B An OSCWDT trap trigger has occurred since this bit was cleared the last time
RAT	5	rh	Register Access Trap Request Flag TRAPSTAT.RAT is set when bit DMPMIT.RAT is set and TRAPDIS.RAT = 0. 0 _B No RA trap trigger has occurred since this bit was cleared the last time 1 _B A RA trap trigger has occurred since this bit was cleared the last time
PET	6	rh	Parity Error Trap Request Flag TRAPSTAT.PET is set when a memory parity error occurs and TRAPDIS.PET = 0. 0 _B No PE trap trigger has occurred since this bit was cleared the last time 1 _B A PE trap trigger has occurred since this bit was cleared the last time
VCOLCKT	7	rh	VCOLCK Trap Request Flag TRAPSTAT.VCOLCKT is set when a VCOLCK emergency event occurs and TRAPDIS.VCOLCKT = 0. 0 _B No VCOLCK trap trigger has occurred since this bit was cleared the last time 1 _B A VCOLCK trap trigger has occurred since this bit was cleared the last time
0	1, [15:8]	r	Reserved Read as 0; should be written with 0.

8.12.3.2 Register TRAPCLR

This register contains the software clear control for the trap status flags in register TRAPSTAT. Clearing a bit in this register has no effect, reading a bit always returns zero.

TRAPCLR

Trap Clear Register

SFR (FE8E_H/47_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
								VCOLCK	PET	RAT	OSCWDTT	ESR2T	ESR1T	0	FAT
								T	T	T	T	T	T		T
								w	w	w	w	w	w	r	w

Field	Bits	Type	Description
FAT	0	w	Clear Flash Access Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.FAT is cleared
ESR1T	2	w	Clear ESR1 Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.ESR1T is cleared
ESR2T	3	w	Clear ESR2 Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.ESR2T is cleared
OSCWDTT	4	w	Clear OSCWDTT Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.OSCWDTT is cleared
RAT	5	w	Clear Register Access Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.RAT is cleared
PET	6	w	Clear Parity Error Access Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.PET is cleared
VCOLCKT	7	w	Clear VCOLCK Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.VCOLCKT is cleared
0	1, [15:8]	r	Reserved Read as 0; should be written with 0

Note: These bits are always read as 0.

8.12.3.3 Register TRAPSET

This register contains the software set control for the trap status flags in register TRAPSTAT. Clearing a bit in this register has no effect, reading a bit always returns zero.

TRAPSET

Trap Set Register

SFR (FE8C_H/46_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
								VCO LCK T	PE T	RA T	OSC WDT T	ESR 2 T	ESR 1 T	0	FA T
								w	w	w	w	w	w	r	w

Field	Bits	Type	Description
FAT	0	w	Set Flash Access Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.FAT is set
ESR1T	2	w	Set ESR1 Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.ESR1T is set
ESR2T	3	w	Set ESR2 Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.ESR2T is set
OSCWDTT	4	w	Set OSCWDT Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.OSCWDTT is set
RAT	5	w	Set Register Access Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.RAT is set
PET	6	w	Set Parity Error Access Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.PET is set
VCOLCKT	7	w	Set VCOLCK Trap Request Flag 0 _B No action 1 _B Flag TRAPSTAT.VCOLCKT is set
0	1, [15:8]	r	Reserved Read as 0; should be written with 0

Note: These bits are always read as 0.

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Field	Bits	Type	Description
0	[15:8]	r	Reserved Read as 0; should be written with 0.

8.12.3.5 Register TRAPNP

These register contain the control for the trap node pointers of all SCU trap request trigger sources.

TRAPNP

Trap Node Pointer Register

SFR (FE92_H/49_H)

Reset Value: 8254_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VCOLCK		PE		RA		OSCWDT		ESR2		ESR1		Reserved		FA	
rw		rw		rw		rw		rw		rw		rw		rw	

Field	Bits	Type	Description
FA	[1:0]	rw	Trap Node Pointer for Flash Access Traps TRAPNP.FA selects the trap request output for an enabled FAT trap request. 00 _B Select request output SCU_TRQ0 (TFR.ACER) 01 _B Select request output SCU_TRQ1 (TFR.SR1) 10 _B Select request output SCU_TRQ2 (TFR.SR0) 11 _B Reserved, do not use this combination
Reserved	[3:2]	rw	Reserved Must be written with 01 _B ; same as reset values.
ESR1	[5:4]	rw	Trap Node Pointer for ESR1 Traps TRAPNP.ESR1 selects the trap request output for an enabled ESR1 trap request. 00 _B Select request output SCU_TRQ0 (TFR.ACER) 01 _B Select request output SCU_TRQ1 (TFR.SR1) 10 _B Select request output SCU_TRQ2 (TFR.SR0) 11 _B Reserved, do not use this combination
ESR2	[7:6]	rw	Trap Node Pointer for ESR2 Traps TRAPNP.ESR2 selects the trap request output for an enabled ESR2 trap request. 00 _B Select request output SCU_TRQ0 (TFR.ACER) 01 _B Select request output SCU_TRQ1 (TFR.SR1) 10 _B Select request output SCU_TRQ2 (TFR.SR0) 11 _B Reserved, do not use this combination

System Control Unit (SCU)

Field	Bits	Type	Description
OSCWDT	[9:8]	rw	Trap Node Pointer for OSCWDT Traps TRAPNP.OSCWDT selects the trap request output for an enabled OSCWDT trap request. 00 _B Select request output SCU_TRQ0 (TFR.ACER) 01 _B Select request output SCU_TRQ1 (TFR.SR1) 10 _B Select request output SCU_TRQ2 (TFR.SR0) 11 _B Reserved, do not use this combination
RA	[11:10]	rw	Trap Node Pointer for Register Access Traps TRAPNP.RA selects the trap request output for an enabled RAT trap request. 00 _B Select request output SCU_TRQ0 (TFR.ACER) 01 _B Select request output SCU_TRQ1 (TFR.SR1) 10 _B Select request output SCU_TRQ2 (TFR.SR0) 11 _B Reserved, do not use this combination
PE	[13:12]	rw	Trap Node Pointer for Parity Error Traps TRAPNP.PE selects the trap request output for an enabled PET trap request. 00 _B Select request output SCU_TRQ0 (TFR.ACER) 01 _B Select request output SCU_TRQ1 (TFR.SR1) 10 _B Select request output SCU_TRQ2 (TFR.SR0) 11 _B Reserved, do not use this combination
VCOLCK	[15:14]	rw	Trap Node Pointer for VCOLCK Traps TRAPNP.VCOLCK selects the trap request output for an enabled VCOLCK trap request. 00 _B Select request output SCU_TRQ0 (TFR.ACER) 01 _B Select request output SCU_TRQ1 (TFR.SR1) 10 _B Select request output SCU_TRQ2 (TFR.SR0) 11 _B Reserved, do not use this combination

8.13 Memory Content Protection for RAM Areas

Parity checking is provided for supervising the content of the following on-chip RAM areas (Flash memory is not considered here):

- Program SRAM (PSRAM)
- Data SRAM (DSRAM)
- Dual Port SRAM (DPRAM)
- USICx SRAM (UxRAM)

For each piece of data written to a RAM area the corresponding protection bits are generated and stored along with the user data.

Note: Memory Content Protection with Parity is selected by default.

It must be enabled before the respective RAM area can be used (see [Section 8.13.1](#)).

The subsequent handling of trap requests is described in section [Chapter 8.12](#).

8.13.1 Protection Mode Selection

After a power-on reset, parity protection is selected, but not enabled. The protection must be enabled before the respective RAM area can be used.

Parity Protection Mode

With the parity protection mode being selected, the parity logic generates additional parity bits, which are stored with each piece of data written to the selected RAM area.

Register [PEEN](#) enables the checking of previously stored parity bits.

If enabled, parity errors are detected and indicated in register [PECON](#). Read data are not modified.

Protection Mode Enabling

Before using the RAM, it must be initialized so the correct protection bits are generated and the RAM can be read without error.

CPU memory accesses may produce speculative read operations, in which data is read in advance, in anticipation of its actual use. In some cases, this may result in data accesses outside of the RAM memory regions actually used in the application. Therefore, it is strongly recommended to initialize all content protected RAM before use, to avoid unexpected errors.

Note: The sequence to activate one of these mechanisms is described in section "Preparing to activate Memory Content Protection."

8.13.2 Parity Error Handling

During write operations parity information is generated and stored along with the data. During read operations this parity information is checked and in case of an error a trap request is generated (register PECON), if enabled. The requests from all RAMs can be combined (register PEEN) and trigger a trap via bit PET in register **TRAPSTAT**.

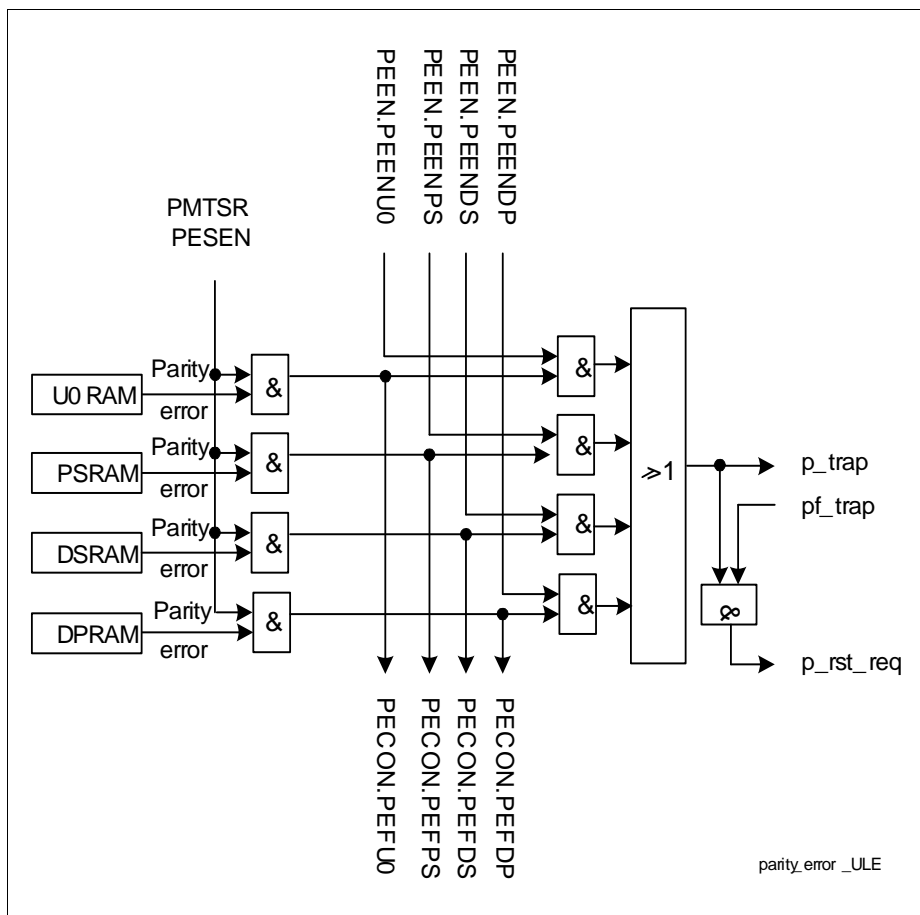


Figure 8-37 Parity Error Control Logic

If a parity error is detected while the trap flag TFR.ACER is set, i.e. during the execution of the associated trap handler routine, a reset request trigger is generated. This is because a second error trap would activate the same handler and, therefore, cannot be handled by the CPU.

Note: The parity trap trigger should activate the Access Error trap (ACER) to support this feature.

8.13.2.1 Parity Software Testing Support

To support testing algorithms for the parity error trap routines a memory parity test logic is implemented for the standard RAM areas (PSRAM, DSRAM, DPRAM).

This logic is controlled by registers PMTPR and PMTSR. If enabled by the respective bit MTENx in register PMTSR, a parity value can be written to any address of the corresponding RAM area through bitfield PWR in register PMTPR. With each read access from that area the parity from the memory parity control is stored in bitfield PRD of register PMTPR.

Table 8-18 lists the valid bits in register PMTPR depending on the memory width.

Table 8-18 Valid Parity Test Bits

Memory	Number of Parity Bits	Valid Bits in PWR/PRD
Dual Port (DP) Memory	2	PWR[1:0]/PRD[9:8]
Data SRAM (DS) Memory	2	PWR[1:0]/PRD[9:8]
Program SRAM (PS) Memory	8	PWR[7:0]/PRD[15:8]

Test software should be located in external memory and should be written in a way that no pre-fetching is performed.

8.13.2.2 Parity Error Registers

Register PEEN enables the functional parity check mechanism for each RAM area separately.

Note: Bit PESEN in register PMTSR globally enables the parity mechanism.

PEEN

Parity Error Enable Register

ESFR (F0C4_H/41_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0								0	0	0	PE EN U0	PE EN PS	PE EN DS	PE EN DP	
rw								rw	rw	rw	rw	rw	rw	rw	

Field	Bits	Type	Description
PEENDP	0	rw	Parity Error Trap Enable for Dual Port Memory 0 _B Disabled 1 _B Trap requested for DPRAM parity errors
PEENDS	1	rw	Parity Error Trap Enable for Data SRAM 0 _B Disabled 1 _B Trap requested for DSRAM parity errors
PEENPS	2	rw	Parity Error Trap Enable for Program SRAM 0 _B Disabled 1 _B Trap requested for PSRAM parity errors
PEENU0	3	rw	Parity Error Trap Enable for USIC0 Memory 0 _B Disabled 1 _B Trap requested for USIC0 memory parity errors
0	[15:4]	rw	Reserved Should be written with 0.

Register PECON controls the functional parity check mechanism.

If enabled the corresponding error flag is set upon the detection of a parity error in the associated RAM area. Otherwise, there is no indication.

Software can clear an error flag by writing 1 to the flag. Writing 0 has no effect.

PECON

Parity Error Control Register **ESFR (F0DA_H/6D_H)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						0		0		0		PEF U0	PEF PS	PEF DS	PEF DP
rwh						rwh		rwh		rwh		rwh	rwh	rwh	rwh

Field	Bits	Type	Description
PEFDP	0	rwh	Parity Error Flag for Dual Port Memory 0 _B No DPRAM error 1 _B A Parity error is indicated and can trigger a trap request trigger, if enabled for DPRAM
PEFDS	1	rwh	Parity Error Flag for Data SRAM 0 _B No DSRAM error 1 _B A Parity error is indicated and can trigger a trap request trigger, if enabled for DSRAM
PEFPS	2	rwh	Parity Error Flag for Program SRAM 0 _B No PSRAM error 1 _B A Parity error is indicated and can trigger a trap request trigger, if enabled for PSRAM
PEFU0	3	rwh	Parity Error Flag for USIC0 Memory 0 _B No USIC0 memory error 1 _B A Parity error is indicated and can trigger a trap request trigger, if enabled for USIC0 memory
0	[15:4]	rwh	Reserved Should be written with 0.

PMTPR

Parity Memory Test Pattern Register **ESFR (F0E4_H/72_H)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRD								PWR							
rh								rw							

Field	Bits	Type	Description
PRD	[15:8]	rh	Parity Read Values for Memory Test For each byte of a memory module the parity bits generated during the most recent read access are indicated here.
PWR	[7:0]	rw	Parity Write Values for Memory Test For each byte of a memory module the parity bits corresponding to the next write access are stored here.

PMTSR

Parity Memory Test Select Register

ESFR (F0E6_H/73_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PES EN			0				0	0		0		MT EN PS	MT EN DS	MT EN DP	
rw			r				rw	rw		rw		rw	rw	rw	

Field	Bits	Type	Description
MTENDP	0	rw	Memory Test Enable Control for Dual Port Memory Controls the test multiplexer for the DPRAM. 0 _B Standard operation 1 _B Test parity bits used (from PMTPR)
MTENDS	1	rw	Memory Test Enable Control for Data SRAM Controls the test multiplexer for the DSRAM. 0 _B Standard operation 1 _B Test parity bits used (from PMTPR)
MTENPS	2	rw	Memory Test Enable Control for Program SRAM Controls the test multiplexer for the PSRAM. 0 _B Standard operation 1 _B Test parity bits used (from PMTPR)
PESEN	15	rw	Parity Error Sensitivity Enable 0 _B Parity errors have no effect 1 _B Parity errors are indicated and can trigger a trap, if enabled
0	[8:3]	rw	Reserved Should be written with 0.
0	[14:9]	r	Reserved Read as 0; should be written with 0.

Note: Only one bit MTENxx should be set at the same time in register PMTSR. Otherwise the result of the parity software test is not reliable.

System Control Unit (SCU)

MCHKCON register is used to support the direct RAM access for USIC module.

MCHKCON

Memory Checking Control Register

ESFR (F0DC_H/6E_H)

Reset Value: 000F_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						0	USIC DRA	0				1	1	1	1
rw						rw	rw	rw				rw	rw	rw	rw

Field	Bits	Type	Description
USICDRA	8	rw	USIC Direct RAM Access 0 _B Direct RAM access for the USIC is not possible 1 _B Direct RAM access for the USIC is possible
1	[3:0]	rw	Reserved Should be written with 1.
0	[7:4], [15:9]	rw	Reserved Should be written with 0.

8.14 Register Control

This block handles the register accesses of the SCU and the register access control for all system register that use one of the following protection modes:

- Unprotected Mode
- Write Protection Mode
- Secured Mode

8.14.1 Register Access Control

There are some dedicated registers that control critical system functions and modes. These registers are protected by a special register security mechanism so these vital system functions cannot be changed inadvertently after the executing of the EINIT instruction. However, as these registers control central system behavior they need to be accessed during operation. The system control software gets this access via a special security state machine.

If an access violation is detected a trap trigger request is generated.

This security mechanism controls the following security levels which can be configured via register SLC:

- **Unprotected Mode**
No protection is active. Registers can be written at any time. This mode is entered after the Application Reset.
- **Write Protected Mode**
Protected registers are locked against any write access. Write accesses have no effect on these registers. This mode is entered automatically after the EINIT instruction is executed.
- **Secured Mode**
Protected registers can be written using a special command.
Access in Secured Mode can be achieved by preceding the intended write access with writing "command 4" to register SLC. After writing "command 4" to register SLC the register protection mechanism remains disabled until the next write to a register on the PD+Bus (SFR, ESFR, XSFR area), i.e. accesses to registers (e.g. CSFR) outside this area do not enable the protection again automatically. Therefore, the lock mechanism after writing "command 4" works differently depending on the register address. Normally one single write access to a protected register is enabled. After this write access the protected registers are locked again automatically. Thereafter, "command 4" has to be written again in order to enable the next write to a protected register. The lock mechanism is not enabled again after a write access to a CSFR register or to a LXBus peripheral register (XLOC area, e.g. USIC, IMB).

Note: In Secured Mode the re-enabling of register protection with respect to the write address after "command 4" can lead to an unexpected, not obvious behaviour of an application:

System Control Unit (SCU)

In case the succeeding write to a protected register is delayed due to an interrupt and the ISR itself uses the “command 4” mechanism. After writing “command 4” inside the ISR the protection is expectedly re-installed instead of released and the following write will lead to an ACER trap within the ISR. An ATOMIC instruction, which couples the unlock with the write to the protected register could be used.

In case the succeeding write is to a register which does not re-enable the protection mechanism again then the write itself will succeed, but in a following “command 4” sequence the write to SLC register re-locks the protection again and the write to a protected register fails.

SCU Registers that are protected by Secured Mode are marked in [Table 8-22](#) as “Sec” protected; protected registers in other modules are summarized in [Table 8-19](#).

Table 8-19 Registers Protected by Secured Mode

Register Name	Module
CPUCON1	CPU
CPUCON2	CPU
MPU_PRD	MPU
MPU_PRA	MPU
MPU_PMx (x = 0 ... 5)	MPU
MCHK_COUNT	MCHK
MCHK_TPRL	MCHK
MCHK_TPRH	MCHK
DBGPRR	OCDS
MEM_KSCCFG	Memory
FL_KSCCFG	Memory
RTC_KSCCFG	RTC
GPT12E_KSCCFG	GPT12
CC2_KSCCFG	CAPCOM2

All registers that are equipped with this protection mechanism have access limitations defined by the selected security level. It is in addition to the normal access parameters (e.g. read only, bit type r or rh). Independently of the security level, all protected registers can also be read.

8.14.1.1 Controlling the Security Level

The two registers Security Level Command register (SLC) and Security Level Status register (SLS) control the security level. The SLC register accepts the commands to

System Control Unit (SCU)

control the state machine modifying the security level, while the SLS register shows the actual password, the actual security level, and the state of the state machine.

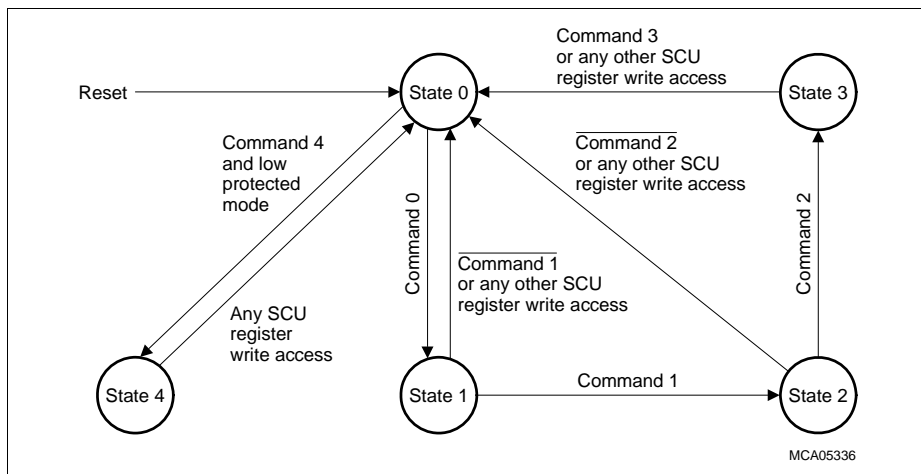


Figure 8-38 State Machine for Security Level Controlling

The following mechanism is used to control the actual security level:

- **Changing the security level**

can be done by executing the following command sequence:

“command 0 - command 1 - command 2 - command 3”.

This sequence establishes a new security level and/or a new password.

Table 8-20 Commands for Security Level Control

Command	Definition	Note
Command 0	AAAA _H	
Command 1	5554 _H	
Command 2	96 _H + ¹⁾ <inverse password>	
Command 3	000 _B + <new level> + 000 _B + <new password>	
Command 4	8E _H + <inverse password>	Secured Mode only

1) '+' denotes a bit field concatenation

Note: It is recommended to lock all command sequences with an atomic sequence.

8.14.2 Register Protection Registers

Register SLC

This register is the interface for the protection commands.

SLC

Security Level Command RegisterESFR (F0C0_H/60_H)

Reset Value: 0000_H



Field	Bits	Type	Description
COMMAND	[15:0]	rw	Security Level Control Command The commands to control the security level must be written to this register (see table)

Register SLS

This register monitors the status of the register protection.

SLS

Security Level Status Register ESFR (F0C2_H/61_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STATE				SL		0		PASSWORD							
rh				rh		r		rh							

Field	Bits	Type	Description
PASSWORD	[7:0]	rh	Current Security Control Password Default after reset = 00 _H
SL	[12:11]	rh	Security Level ¹⁾ 00 _B Unprotected Mode (default) 01 _B Secured Mode 10 _B Reserved, Do not use this combination 11 _B Write Protected Mode
STATE	[15:13]	rh	Current State of Switching State Machine 000 _B Awaiting command 0 or command 4 (default) 001 _B Awaiting command 1 010 _B Awaiting command 2 011 _B Awaiting new security level and password 100 _B Next access granted in Secured Mode 101 _B Reserved, do not use this combination 11X _B Reserved, do not use this combination
0	[10:8]	r	Reserved Read as 0; should be written with 0;

1) While the security level is "unprotected" after reset, it changes to "write protected" after the execution of instruction EINIT.

8.15 Miscellaneous System Registers

This chapter acts as container for various register that are not connected to one specific application topic.

8.15.1 System Registers

8.15.1.1 System Control Register

The following register serve several different system tasks.

SYSCON1

System Control 1 Register

SFR (FF4C_H/A6_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
						0						GLC CST	OCD SEN		0
						r						rw	rw		r

Field	Bits	Type	Description
OCDSSEN	2	rw	OCDS/Cerberus Enable 0 _B OCDS and Cerberus are still in reset state 1 _B ODCS and Cerberus are operable
GLCCST	3	rw	Global CAPCOM Start This bit starts all CAPCOM units synchronously if enabled. 0 _B CAPCOM timer start is controlled locally in each unit 1 _B All CAPCOM timers are started synchronously This bit needs to be cleared via software before setting starts a new CAPCOM start.
0	[1:0], [15:4]	r	Reserved Read as 0; should be written with 0.

8.15.2 Identification Block

For identification of the most important silicon parameters a set of identification registers is defined that provide information on the chip manufacturer, the chip type and its properties.

8.15.2.1 Identification Registers

Register IDMANUF

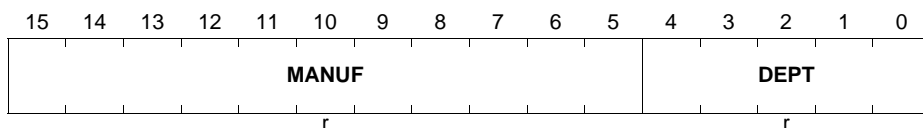
This register contains information about the manufacturer.

IDMANUF

Manufacturer Identification Register

ESFR (F07E_H/3F_H)

Reset Value: 1820_H



Field	Bits	Type	Description
DEPT	[4:0]	r	Department Indicates the department within Infineon. 00 _H AIM MC
MANUF	[15:5]	r	Manufacturer This is the JEDEC normalized manufacturer code. 0C1 _H Infineon Technologies AG

Register IDCHIP

This register contains information about the device.

IDCHIP

Chip Identification Register **ESFR (F07C_H/3E_H)** **Reset Value: XXXX_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CHIPID								Revision							
r								r							

Field	Bits	Type	Description
Revision	[7:0]	r	Device Revision Code Identifies the device step. Please refer to the data sheet for the device specific value.
CHIPID	[15:8]	r	Device Identification Identifies the device name. Please refer to the data sheet for the device specific value.

Register IDMEM

This register contains information about the program memory.

IDMEM

Program Memory Identification Register

ESFR (F07A_H/3D_H)

Reset Value: 3XXX_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TYPE				SIZE											
r				rw											

Field	Bits	Type	Description
SIZE	[11:0]	rw	Size of on-chip Program Memory The size of the implemented program memory in terms of 4 K blocks, i.e. memory size = <SIZE>*4 Kbyte. Please refer to the data sheet for the device specific value.
TYPE	[15:12]	r	Type of on-chip Program Memory Identifies the memory type on this silicon. Please refer to the data sheet for the device specific value.

Register IDPROG

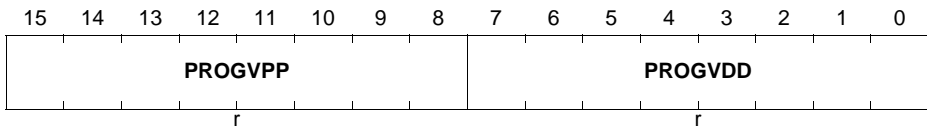
This register is provided for software compatibility reasons only. It contains information about the flash programming voltage. In the XE166U devices, the flash programming voltages are generated internally.

IDPROG

Programming Voltage Id. Register

ESFR (F078_H/3C_H)

Reset Value: 1313_H



Field	Bits	Type	Description
PROGVDD	[7:0]	r	Programming VDD Voltage The voltage of the standard power supply required to program or erase (if applicable) the on-chip program memory. Please refer to the data sheet for the device specific value.
PROGVPP	[15:8]	r	Programming VPP Voltage The voltage of the special programming power supply (if existent) required to program or erase (if applicable) the on-chip program memory. Please refer to the data sheet for the device specific value.

Register IDDMPM

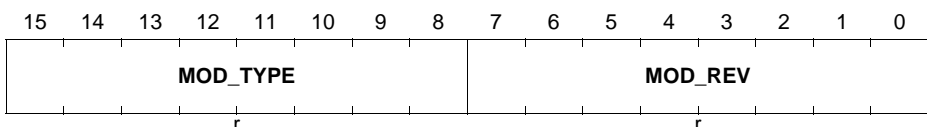
This register contains information about the DMP_M SCU.

IDDMPM

DMP_M Module Identification Register

SFR (FFE2_H)

Reset Value: 60XX_H



Field	Bits	Type	Description
MOD_REV	[7:0]	r	Module Revision Number Defines the revision number. The value of a module revision starts with 01 _H .
MOD_TYPE	[15:8]	r	Module Identification Number Defines the module identification number (SCU_M = 60 _H)

8.15.3 Marker Memory

8.15.3.1 Marker Memory Registers

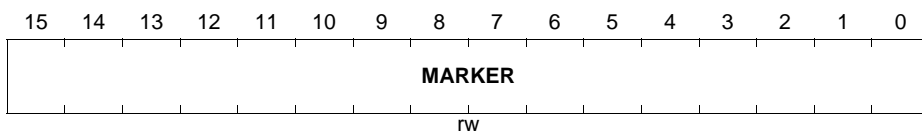
The marker memory consists of following SFRs located in the DMP_M for free usage of the user software.

MKMEM0

Marker Memory 0 Register **SFR (FED0_H/68_H)** **Reset Value: 0000_H**

MKMEM1

Marker Memory 1 Register **SFR (FED2_H/69_H)** **Reset Value: 0000_H**



Field	Bits	Type	Description
MARKER	[15:0]	rw	Marker Content

8.16 SCU Register Addresses

The SCU registers are within the (E)SFR space of the XE166U. Therefore, their specified addresses equal an offset from zero.

Table 8-21 Registers Address Space

Module	Base Address	End Address	Note
SCU	00 0000 _H	00 FFFE _H	

SCU Register Overview

Table 8-22 Register Overview of SCU

Short Name	Register Long Name	Offset Addr.	Protection ¹⁾	Reset ²⁾
WUOSCCON	Wake-up OSC Control Register	F1AE _H	Sec	Power-on Reset
HPOSCCON	High Precision Oscillator Configuration Register	F1B4 _H	Sec	Power-on Reset
PLLOSCCON	PLL Control Register	F1B6 _H	Sec	Power-on Reset
PLLSTAT	PLL Status Register	F0BC _H	-	Power-on Reset
STATCLR1	PLL Status Clear 1 Register	F0E2 _H	Sec	Power-on Reset
PLLCON0	PLL Configuration 0 Register	F1B8 _H	Sec	Power-on Reset
PLLCON1	PLL Configuration 1 Register	F1BA _H	Sec	Power-on Reset
PLLCON2	PLL Configuration 2 Register	F1BC _H	Sec	Power-on Reset
PLLCON3	PLL Configuration 3 Register	F1BE _H	Sec	Power-on Reset
SYSCON0	System Configuration 0 Register	FF4A _H	Sec	Power-on Reset
STATCLR0	Status Clear 0 Register	F0E0 _H	Sec	Power-on Reset
RTCCLKCON	RTC Clock Control Register	FF4E _H	Sec	Power-on Reset

Table 8-22 Register Overview of SCU

Short Name	Register Long Name	Offset Addr.	Protection¹⁾	Reset ²⁾
EXTCON	External Clock Control Register	FF5E _H	Sec	Power-on Reset
STMREL	STM Reload Register	F1A8 _H	Sec	Power-on Reset
STMCON	STM Control Register	F1AA _H	Sec	Power-on Reset
WUTREL	Wake-up Timer Reload Register	F0B0 _H	Sec	Power-on Reset
WUCR	Wake-up Control Register	F1B0 _H	Sec	Power-on Reset
RSTSTAT0	Reset Status 0 Register	F0B2 _H	-	Power-on Reset
RSTSTAT1	Reset Status 1 Register	F0B4 _H	-	Power-on Reset
RSTSTAT2	Reset Status 2 Register	F0B6 _H	-	Power-on Reset
RSTCON0	Reset Configuration 0 Register	F0B8 _H	Sec	Power-on Reset
RSTCON1	Reset Configuration 1 Register	F0BA _H	Sec	Power-on Reset
RSTCNTCON	Reset Counter Configuration Register	F1B2 _H	Sec	Power-on Reset
SWRSTCON	SW Reset Control Register	F0AE _H	Sec	Power-on Reset
ESREXCON1	ESR 1 External Control Register	FF32 _H	Sec	Power-on Reset
ESREXCON2	ESR 2 External Control Register	FF34 _H	Sec	Power-on Reset
ESREXSTAT1	ESR 1 External Status Register	FF36 _H	-	Power-on Reset
ESREXSTAT2	ESR 2 External Status Register	FF38 _H	-	Power-on Reset
CLRESREXSTAT1	Clear ESR 1 External Status Register	FF3A _H	Sec	Power-on Reset

Table 8-22 Register Overview of SCU

Short Name	Register Long Name	Offset Addr.	Protection¹⁾	Reset ²⁾
CLRESREXSTAT2	Clear ESR 2 External Status Register	FF3C _H	Sec	Power-on Reset
ESRCFG1	ESR 1 Configuration Register	F102 _H	Sec	Power-on Reset
ESRCFG2	ESR 2 Configuration Register	F104 _H	Sec	Power-on Reset
SWDCON0	SWD Control 0 Register	F080 _H	Sec	Power-on Reset
SWDCON1	SWD Control 1 Register	F082 _H	Sec	Power-on Reset
PVCMCON0	PVC_M Control for Step 0 Register	F1E4 _H	Sec	Power-on Reset
EVRMCON0	EVR_M Control 0 Register	F084 _H	Sec	Power-on Reset
EVRMCON1	EVR_M Control 1 Register	F086 _H	Sec	Power-on Reset
EVRMSET15VLP	EVR_M Setting for 1.5V HP Register	F096 _H	Sec	Power-on Reset
SEQASTEP1	Sequence Step 1 for Set A Register	FEE6 _H	Sec	Power-on Reset
SEQASTEP2	Sequence Step 2 for Set A Register	FEE8 _H	Sec	Power-on Reset
SEQASTEP3	Sequence Step 3 for Set A Register	FEEA _H	Sec	Power-on Reset
SEQASTEP4	Sequence Step 4 for Set A Register	FEEC _H	Sec	Power-on Reset
SEQASTEP5	Sequence Step 5 for Set A Register	FEED _H	Sec	Power-on Reset
SEQASTEP6	Sequence Step 6 for Set A Register	FEF0 _H	Sec	Power-on Reset
SEQBSTEP1	Sequence Step 1 for Set B Register	FEF4 _H	Sec	Power-on Reset
SEQBSTEP2	Sequence Step 2 for Set B Register	FEF6 _H	Sec	Power-on Reset

Table 8-22 Register Overview of SCU

Short Name	Register Long Name	Offset Addr.	Protection¹⁾	Reset ²⁾
SEQBSTP3	Sequence Step 3 for Set B Register	FEF8 _H	Sec	Power-on Reset
SEQBSTP4	Sequence Step 4 for Set B Register	FEFA _H	Sec	Power-on Reset
SEQBSTP5	Sequence Step 5 for Set B Register	FEFC _H	Sec	Power-on Reset
SEQBSTP6	Sequence Step 6 for Set B Register	FEFE _H	Sec	Power-on Reset
GSCSWREQ	GSC SW Request Register	FF14 _H	Sec	Application Reset
GSCEN	GSC Enable Register	FF16 _H	Sec	Application Reset
GSCSTAT	GSC Status Register	FF18 _H	-	Application Reset
GSCPERSTATEN	GSC Peripheral Status Enable Register	FF04 _H	Sec	Application Reset
GSCPERSTAT	GSC Peripheral Status Register	FF1A _H	-	Application Reset
STSTAT	Start-up Status Register	F1E0 _H	-	Application Reset
EXISEL	External Interrupt Input Select Register	F1A0 _H	Sec	Application Reset
EXICON0	External Interrupt Input Trigger Control 0 Register	F030 _H	Sec	Application Reset
EXICON1	External Interrupt Input Trigger Control 1 Register	F032 _H	Sec	Application Reset
EXICON2	External Interrupt Input Trigger Control 2 Register	F034 _H	Sec	Application Reset
EXICON3	External Interrupt Input Trigger Control 3 Register	F036 _H	Sec	Application Reset
EXOCON0	External Output Trigger Control 0 Register	FE30 _H	Sec	Application Reset
EXOCON1	External Output Trigger Control 1 Register	FE32 _H	Sec	Application Reset

Table 8-22 Register Overview of SCU

Short Name	Register Long Name	Offset Addr.	Protection ¹⁾	Reset ²⁾
EXOCON2	External Output Trigger Control 2 Register	FE34 _H	Sec	Application Reset
EXOCON3	External Output Trigger Control 3 Register	FE36 _H	Sec	Application Reset
INTSTAT	Interrupt Status Register	FF00 _H	-	Application Reset
INTCLR	Interrupt Clear Register	FE82 _H	Sec	Application Reset
INTSET	Interrupt Set Register	FE80 _H	Sec	Application Reset
INTDIS	Interrupt Disable Register	FE84 _H	Sec	Application Reset
INTNP0	Interrupt Node Pointer 0 Register	FE86 _H	Sec	Application Reset
INTNP1	Interrupt Node Pointer 1 Register	FE88 _H	Sec	Application Reset
DMPMIT	DMP_M Interrupt and Trap Trigger Register	FE96 _H	-	Power-on Reset
DMPMITCLR	DMP_M Interrupt and Trap Clear Register	FE98 _H	Sec	Power-on Reset
WDTREL	WDT Reload Register	F0C8 _H	Sec	Application Reset
WDTCS	WDT Control and Status Register	F0C6 _H	Sec	Application Reset
WDTTIM	WDT Timer Register	F0CA _H	Sec	Application Reset
WDTWINB	WDT Window Boundary Count Register	F03C _H	Sec	Application Reset
TRAPSTAT	Trap Status Register	FF02 _H	-	Power-on Reset
TRAPCLR	Trap Clear Register	FE8E _H	Sec	Power-on Reset
TRAPSET	Trap Set Register	FE8C _H	Sec	Application Reset

Table 8-22 Register Overview of SCU

Short Name	Register Long Name	Offset Addr.	Protection¹⁾	Reset ²⁾
TRAPDIS	Trap Disable Register	FE90 _H	Sec	Application Reset
TRAPNP	Trap Node Pointer Register	FE92 _H	Sec	Application Reset
PEEN	Parity Error Enable Register	F0C4 _H	Sec	Power-on Reset
PECON	Parity Error Control Register	F0DA _H	Sec	Power-on Reset
PMTPR	Parity Memory Test Pattern Register	F0E4 _H	Sec	Application Reset
PMTSR	Parity Memory Test Select Register	F0E6 _H	Sec	Application Reset
SLC	Security Level Command Register	F0C0 _H	-	Application Reset
SLS	Security Level Status Register	F0C2 _H	-	Application Reset
SYSCON1	System Control 1 Register	FF4C _H	Sec	Application Reset
IDMANUF	Manufacturer Identification Register	F07E _H	-	Power-on Reset
IDCHIP	Chip Identification Register	F07C _H	-	Power-on Reset
IDMEM	Program Memory Identification Register	F07A _H	-	Power-on Reset
IDPROG	Programming Voltage Identification Register	F078 _H	-	Power-on Reset
IDDMPM	DMP_M Identification Register	FFE2 _H	-	Power-on Reset
MKMEM0	Marker Memory 0 Register	FED0 _H	Sec	Power-on Reset
MKMEM1	Marker Memory 1 Register	FED2 _H	Sec	Power-on Reset

1) Register write protection mechanism: "Sec" = register security mechanism, "-" = always accessible (no protection), otherwise no access is possible.

2) Reset types are defined in [Chapter 8.4.1.2](#).

9 Parallel Ports

The XE166U provides a set of General Purpose Input/Output (GPIO) ports that can be controlled by software and by the on-chip peripheral units:

Table 9-1 Ports of the XE166U in PG-VQFN-48

Group	Width	I/O	Connected Modules
P2	12	I/O	Analog inputs, ADC, CC2, DAP/JTAG, GPT12E, SCU, USIC
P5	6	I	Analog inputs, CCU6, JTAG, GPT12E, CC2
P6	3	I/O	Analog inputs, ADC, JTAG, GPT12E
P10	12	I/O	CCU6, GPT12E, DAP/JTAG, SPD, USIC

*Note: The availability of ports and port pins depends on the selected device type.
This chapter describes the maximum set of ports.*

9.1 General Description

This chapter describes the architecture of the digital control circuit for a single port pin.

9.1.1 Basic Port Operation

There are three types of digital control circuits:

- Digital Input/Output with or without Hardware Override **Figure 9-1**
- Digital Input/Output with Analog Input **Figure 9-2**
- Digital and Analog Input **Figure 9-3**

Port pins marked as Hardware Input (IH) or Hardware Output (OH) in the Pin Definition Table (**Table 9-9**) use the hardware override functionality, Port P6.[1:0] and Port P2.[0:1] are Digital I/O and Analog Input ports and Port 5 contains Digital and Analog Inputs. All others port pins are Standard Digital I/Os.

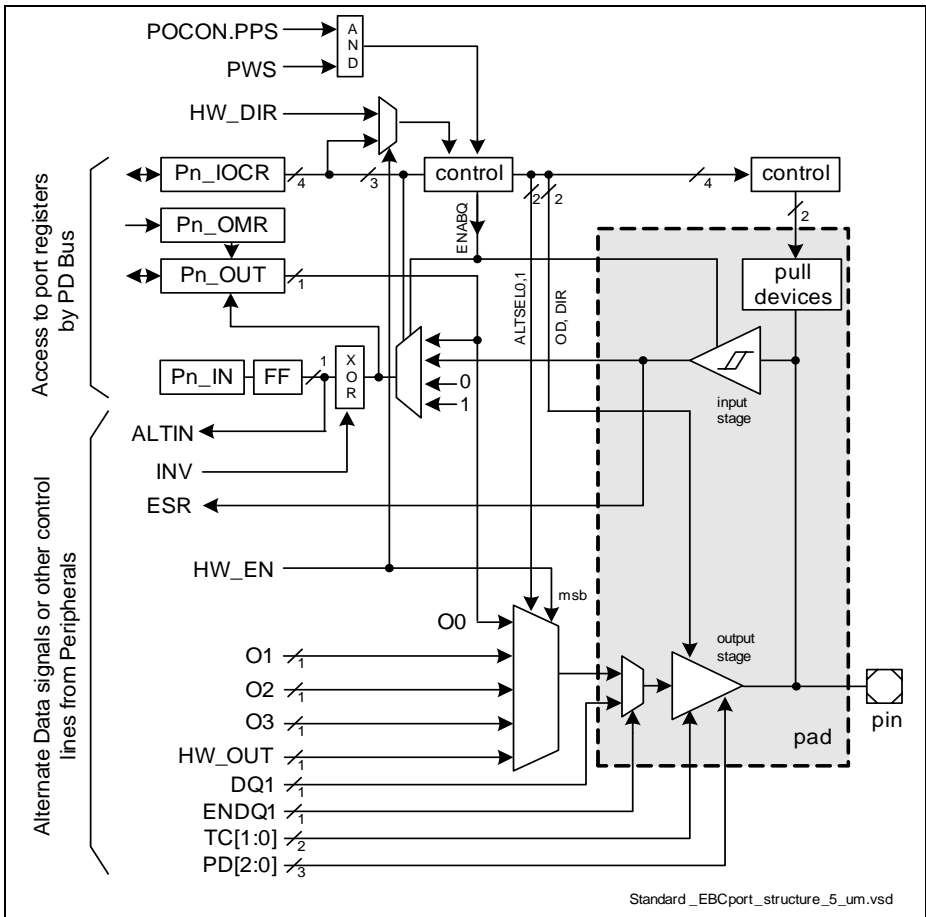


Figure 9-1 Digital Input/Output including Hardware Override Functionality

Note: If HW_EN is activated, INV signal is always zero.

Note: When HW_EN is disabled, the respective ports go to Power Save Mode as all other ports. When HW_EN is active, then the user should set the POCON.PPSx=0.

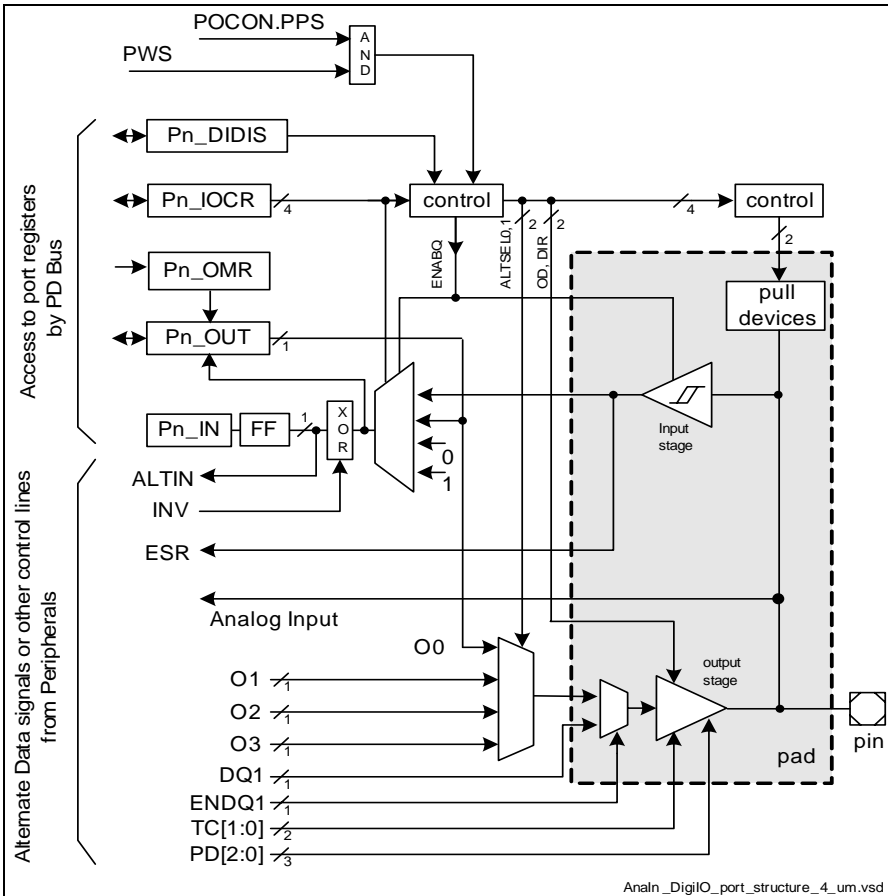


Figure 9-2 Digital Input/Output with Analog Input Functionality

Note: INV signal is derived from Pn_IOC[R].PC[3:2].

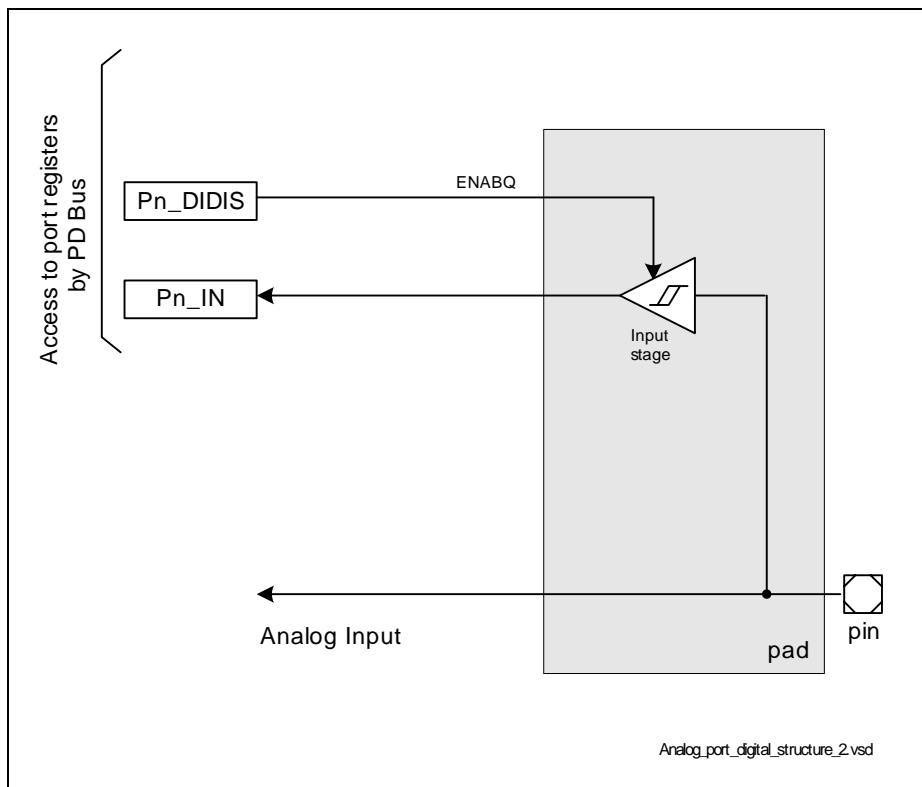


Figure 9-3 Digital and Analog Input Functionality

Note: There is always a standard digital input connected in parallel to each analog input.

9.1.2 Input Stage Control

An input stage consists of a Schmitt trigger, which can be enabled or disabled via software, and an input multiplexer that by default selects the output of the input Schmitt trigger.

A disabled input driver drives high logical level. During and after reset, all input stages are enabled by default.

9.1.3 Output Driver Control

An output stage consists of an output driver, output multiplexer, and register bit fields for their control.

9.1.3.1 Active Mode Behavior

Each output driver can be configured in a push-pull or an open-drain mode, or it can be deactivated (three-stated). An output multiplexer in front of the output driver selects the signal source, choosing either the appropriate bit of the Pn_OUT register, or one of maximum three lines coming from a peripheral unit, see [Figure 9-1](#). The selection is done via the Pn_IOCRR register. Software can set or clear the bit Pn_OUT.Px, which drives the port pin in case it is selected by the output multiplexer.

An output driver with hardware override can select an additional output signal coming from a peripheral. While the hardware override is activated, this signal has higher priority than all other output signals and can not be deselected by the port. In this case, the peripheral controls the direction of the pin.

In active mode the output is also fed back via the input Schmitt trigger and can be evaluated by on-chip components connected to this input.

9.1.3.2 Power Saving Mode Behavior

In Power Saving Mode (core and IO supply voltages available), the behavior of a pin depends on the setting of the POCOnx.PPSx bit. Basically, groups of four pins within a port can be configured to react to Power Save Mode Request or to ignore it. In case a pin group is configured to react to a Power Save Mode Request, each pin within a group reacts according to its own configuration according to the [Table 9-4](#).

9.1.3.3 Reset Behavior

During an Internal Application Reset, all output stages of GPIO pins go to tri-state mode without any pull-up or pull-down devices.

An Application Reset does not change the GPIO configuration but the reset of the internal peripherals can change the data driven on the outputs. Attention must be paid to ensure that no harm is caused to the connected devices by unexpected transitions and output values.

9.1.3.4 Power-fail Behavior

When the core supply fails while the pad supply remains stable, the output stages go into tri-state mode.

9.2 Port Register Description

9.2.1 Pad Driver Control

The pad structure which is used in this device offers the possibility to select the output driver strength and the slew rate. These selections are independent from the output port functionality, such as open-drain, push/pull or input only.

In order to minimize EMI, the driver strength can be adapted to the application requirements by bit fields PDMx. The selection is done in groups of four pins.

The **Port Output Control registers** POCN provide the corresponding control bits. A 4-bit control field configures the driver strength and the edge shape. Word ports consume four control nibbles each, byte ports consume two control nibbles each.

P2_POCN

Port 2 Output Control Register XSFR (E8A4_H) **Reset Value: 0000_H**

P6_POCN

Port 6 Output Control Register XSFR (E8AC_H) **Reset Value: 0000_H**

P10_POCN

Port 10 Output Control Register XSFR (E8B4_H) **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PPS 3	0	PDM3	PPS 2	0	PDM2	PPS 1	0	PDM1	PPS 0	0	PDM0	PPS 3	0	PDM3	PPS 2
rw	r	rw	rw	r	rw	rw	r	rw	rw	r	rw	rw	r	rw	r

Field	Bit	Type	Description
PDM0, PDM1, PDM2, PDM3	[1:0], [5:4], [9:8], [13:12]	rw	Port Driver Mode x Code Driver strength ¹⁾ Edge Shape ²⁾ 00 _B Strong driver Soft edge mode 01 _B Strong driver Slow edge mode 10 _B Medium driver 11 _B Weak driver

Parallel Ports

Field	Bit	Type	Description
PPS0, PPS1, PPS2, PPS3	3, 7, 11, 15	rw	Pin Power Save 0 _B Pin behaves like in the Active Mode. Power Save Management is ignored. 1 _B Behavior in the Power Save Mode described in the Table 9-4 .

- ¹⁾ Defines the current the respective driver can deliver to the external circuitry.
- ²⁾ Defines the switching characteristics to the respective new output level. This also influences the peak currents through the driver when producing an edge, i.e. when changing the output level.

Mapping of the POCON Registers to Pins and Ports

The table below lists the defined POCON registers and the allocation of control bit fields and port pins.

Table 9-2 Port Output Control Register Allocation

Control Register	Controlled Pins (by Px_POCON.[y:z]) ¹⁾				Port Width
	[15:12]	[11:8]	[7:4]	[3:0]	
P2_POCON	---	P2.[10:8] + P2.13 ²⁾	P2.[7:4]	P2.[3:0]	12
P6_POCON	---	---	---	P6.3 + P6.[1:0]	3
P10_POCON	P10.12	P10.[10:8]	P10.[7:4]	P10.[3:0]	12

¹⁾ x denotes the port number, while [y:z] represents the bit field range.

²⁾ The output control of P2.13 deviates from the standard definition, see [Chapter 9.3.1](#).

Note: When assigning functional signals to port pins, please consider the fact that the driver strength is selected for pin groups. Assign functions with similar requirements to pins within the same POCON control group.

9.2.2 Port Output Register

The port output register defines the values of the output pins if the pin is used as general purpose output.

When used as input, the Pn_OUT bits can be used to sample the respective input value continuously and drive the last sampled value while in power saving mode, see [Table 9-4](#).

P2_OUT

Port 2 Output Register

SFR (FFA6_H)

Reset Value: 0000_H

P6_OUT

Port 6 Output Register

SFR (FFAE_H)

Reset Value: 0000_H

P10_OUT

Port 10 Output Register

SFR (FFB6_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
P15	P14	P13	P12	P11	P10	P9	P8	P7	P6	P5	P4	P3	P2	P1	P0
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
Px (x = 0-15)	x	rwh	Port Output Bit x This bit defines the level at the output pin of port Pn, pin x if the output is selected as GPIO output. 0 _B The output level of Pn.x is 0. 1 _B The output level of Pn.x is 1.

9.2.3 Port Output Modification Register

With the port output modification register the port n output register bits get set, cleared, or toggled individually.

P2_OMRH

Port 2 Output Modification Register HighXSFR (E9CA_H) **Reset Value: XXXX_H**

P10_OMRH

Port 10 Output Modification Register HighXSFR (E9EA_H) **Reset Value: XXXX_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PC 15	PC 14	PC 13	PC 12	PC 11	PC 10	PC 9	PC 8	PS 15	PS 14	PS 13	PS 12	PS 11	PS 10	PS 9	PS 8
W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W

Field	Bits	Type	Description
PSx (x = 8-15)	x-8	w	Port Set Bit x Setting this bit sets or toggles the corresponding bit in the port output register Pn_OUT (see Table 9-3). On a read access, this bit returns an undefined value.
PCx (x = 8-15)	x	w	Port Clear Bit x Setting this bit clears or toggles the corresponding bit in the port output register Pn_OUT. (see Table 9-3). On a read access, this bit returns an undefined value.

P2_OMRL

Port 2 Output Modification Register LowXSFR (E9C8_H) **Reset Value: XXXX_H**

P6_OMRL

Port 6 Output Modification Register LowXSFR (E9D8_H) **Reset Value: XXXX_H**

P10_OMRL

Port 10 Output Modification Register LowXSFR (E9E8_H) **Reset Value: XXXX_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PC 7	PC 6	PC 5	PC 4	PC 3	PC 2	PC 1	PC 0	PS 7	PS 6	PS 5	PS 4	PS 3	PS 2	PS 1	PS 0
W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W

Field	Bits	Type	Description
PSx (x = 0-7)	x	w	Port Set Bit x Setting this bit sets or toggles the corresponding bit in the port output register Pn_OUT (see Table 9-3). On a read access, this bit returns an undefined value.
PCx (x = 0-7)	x + 8	w	Port Clear Bit x Setting this bit clears or toggles the corresponding bit in the port output register Pn_OUT. (see Table 9-3). On a read access, this bit returns an undefined value.

Function of the PCx and PSx bit fields

Table 9-3 Function of the Bits PCx and PSx

PCx	PSx	Function
0 or no write access	0 or no write access	Bit Pn_OUT.Px is not changed.
0 or no write access	1	Bit Pn_OUT.Px is set.
1	0 or no write access	Bit Pn_OUT.Px is cleared.
1	1	Bit Pn_OUT.Px is toggled.

Note: If a bit position is not written (one out of two bytes not targeted by a byte write), the corresponding value is considered as 0. Toggling a bit requires one 16-bit write.

9.2.4 Port Input Register

The port input register contains the values currently read at the input pins, also if a port line is assigned as output.

P2_IN

Port n Input Register

SFR (FF84_H)

Reset Value: 0000_H¹⁾

Pn_IN (n=5-6)

Port n Input Register

SFR (FF80_H+2*n)

Reset Value: 0000_H¹⁾

P10_IN

Port 10 Input Register

SFR (FF94_H)

Reset Value: 0000_H¹⁾

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
P15	P14	P13	P12	P11	P10	P9	P8	P7	P6	P5	P4	P3	P2	P1	P0
rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh

¹⁾ Px bits for non implemented I/O lines are always read as 0.

Field	Bits	Type	Description
Px (x = 0-15)	x	rh	Port Input Bit x This bit indicates the level at the input pin of port Pn, pin x. 0 _B The input level of Pn.x is 0. 1 _B The input level of Pn.x is 1.

9.2.5 Port Input/Output Control Registers

The port input/output control registers contain the bit fields to select the digital output and input driver characteristics, such as pull-up/down devices, port direction (input/output), open-drain and alternate output selections. The coding of the options is shown in [Table 9-4](#).

Depending on the port functionality not all of the input/output control registers may be implemented. The structure with one control bit field for each port pin located in different registers offers the possibility to configure port pin functionality of a single pin without accessing some other PCx in the same register by word-oriented writes.

P2_IOCR_x (x=00-10)

Port 2 Input/Output Control Register x XSFR (E840_H+2*x) Reset Value: 0000_H

P2_IOCR13

Port 2 Input/Output Control Register 13 XSFR (E85A_H) Reset Value: 0000_H

P6_IOCR_x (x=00-01)

Port 6 Input/Output Control Register x XSFR (E8C0_H+2*x) Reset Value: 0000_H

P6_IOCR03

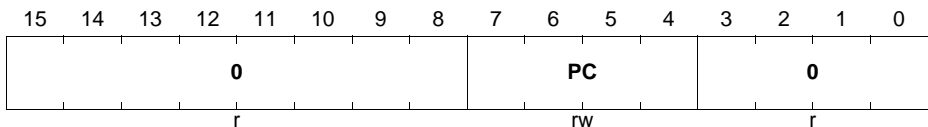
Port 6 Input/Output Control Register 03 XSFR (E8C6_H) Reset Value: 0000_H

P10_IOCR_x (x=00-10)

Port 10 Input/Output Control Register x XSFR (E940_H+2*x) Reset Value: 0000_H

P10_IOCR12

Port 10 Input/Output Control Register 12 XSFR (E958_H) Reset Value: 0000_H



Field	Bits	Type	Description
PC	[7:4]	rw	Port Input/Output Control Bit see Table 9-4
0	[3:0], [15:8]	r	reserved

Coding of the PC bit field

The coding of the GPIO port behavior is done by the bit fields in the port control registers Pn_IOCR_x. There's a control bit field PC for each port pin. The bit fields PC are located in separate control registers in order to allow modifying a port pin (without influencing the others) with simple move operations.

Parallel Ports

Note: When the pin direction is switched to output and the mode is test mode, the output characteristic must be push-pull only.

Table 9-4 PC Coding

PC[3:0]	I/O	Selected Pull-up/down / Selected Output Function	Behavior in Power Saving Mode ¹⁾
0000 _B	Direct Input	No pull device connected	Input value = Pn_OUT; no pull
0001 _B		Pull-down device connected	Input value = 0; pull-down
0010 _B		Pull-up device connected	Input value = 1; pull-up
0011 _B		No pull device connected. In this mode Pn_OUT samples the pad input value continuously.	Input value = Pn_OUT; Pn_OUT always samples input value while not in power save mode = freeze of input value; no pull
0100 _B	Inverted Input	No pull device connected	Input value = $\overline{\text{Pn_OUT}}$; no pull
0101 _B		Pull-down device connected	Input value = 1; pull-down
0110 _B		Pull-up device connected	Input value = 0; pull-up
0111 _B		No pull device connected In this mode Pn_OUT samples the pad input value continuously.	Input value = $\overline{\text{Pn_OUT}}$; Pn_OUT always samples input value while not in power saving mode = freeze of input value; no pull ²⁾
1000 _B	Output (Direct input) Push- pull	General purpose Output O0	Output driver off. Input Schmitt trigger off. Pn_OUT delivered to the internal logic; no pull
1001 _B		Output function O1	
1010 _B		Output function O2	
1011 _B		Output function O3	
1100 _B	Output (Direct input) Open- drain	General purpose Output O0	
1101 _B		Output function O1	
1110 _B		Output function O2	
1111 _B		Output function O3	

¹⁾ In power saving mode, the input Schmitt trigger is always switched off. A defined input value is driven to the internal circuitry instead of the level detected at the input pin.

²⁾ If the IOCR setting is "inverted input", then an inverted signal Pn_OUT is driven internally. The Pn_OUT register itself always contains the real, non-inverted input value of the pin. See Figure 7-1 and Figure 7-2.

9.2.6 Port Digital Input and Output Disable Register

Port 5 has, additionally to the analog input functionality, digital input functionality too. In order to save switching of the internal Schmitt triggers of the digital inputs, they can be disabled by means of the Px_DIDIS Register.

Ports 2 and 6 have, additionally to the analog input functionality, digital input and output functionality too. In order to save switching of the internal Schmitt triggers of the digital inputs, as well as to avoid errors caused by the digital output drivers and the pull devices, they can be disabled by means of the Px_DIDIS Register and setting Px_IOCry.PC to 0XXX_H for pins used as analog inputs.

Note: For ports 2 and 6 pins without analog input functionality, writing to their corresponding bits in Px_DIDIS Register will have no effect.

P2_DIDIS

Port 2 Digital Input Disable RegisterSFR (E9FE_H)

Reset Value: 0000_H

P5_DIDIS

Port 5 Digital Input Disable RegisterSFR (FE8A_H)

Reset Value: 0000_H

P6_DIDIS

Port 6 Digital Input Disable RegisterSFR (FE4E_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
P15	P14	P13	P12	P11	P10	P9	P8	P7	P6	P5	P4	P3	P2	P1	P0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bit	Type	Description
Py (y = 0-15)	y	rw	Bit y Digital Input Control 0 _B Digital input stage (schmitt trigger) is enabled. 1 _B Digital input stage (schmitt trigger) is disabled, necessary if pin is used as analog input.

9.3 Port Description

The pad driver mode registers may be different for each port. As a result, they are described independently for each port in the corresponding chapter.

9.3.1 Port 2

Port 2 is a 12-bit GPIO port. P2[1:0] has additionally analog input functionality. The registers of Port 2 are shown in [Figure 9-4](#).

For this port, all pins can be read as GPIO, from the Port Input Register.

When used as analog input, the digital part of the respective pin can be disabled via P2_DIDIS, see [Section 9.2.6](#).

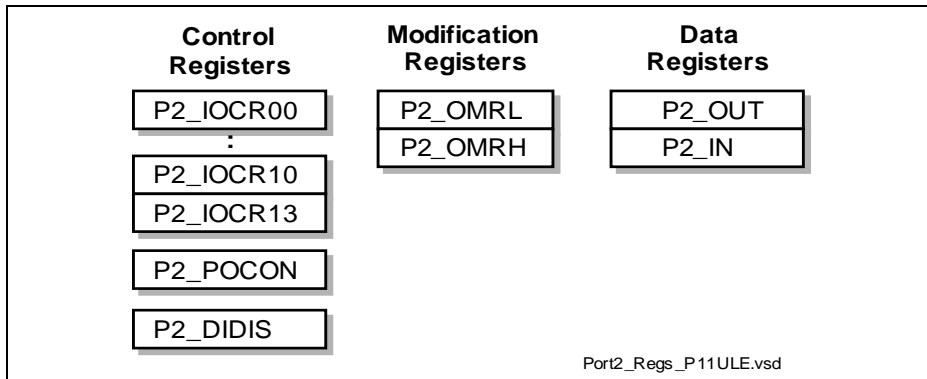


Figure 9-4 Port 2 Register Overview

Table 9-5 Port 2 Registers

Register Short Name	Register Long Name	Address Offset	Reset Value
P2_OUT	Port 2 Output Register	FFA6 _H	0000 _H
P2_IN	Port 2 Input Register	FF84 _H	0000 _H
P2_DIDIS	Port 2 Digital I/O Disable Register	E9FE _H	0000 _H
P2_OMRL	Port 2 Output Modification Register Low	E9C8 _H	XXXX _H
P2_OMRH	Port 2 Output Modification Register High	E9CA _H	XXXX _H
P2_POCON	Port 2 Output Control Register	E8A4 _H	0000 _H
P2_IOCRR00	Port 2 Input/Output Control Register 0	E840 _H	0000 _H
P2_IOCRR01	Port 2 Input/Output Control Register 1	E842 _H	0000 _H
P2_IOCRR02	Port 2 Input/Output Control Register 2	E844 _H	0000 _H
P2_IOCRR03	Port 2 Input/Output Control Register 3	E846 _H	0000 _H
P2_IOCRR04	Port 2 Input/Output Control Register 4	E848 _H	0000 _H
P2_IOCRR05	Port 2 Input/Output Control Register 5	E84A _H	0000 _H

Table 9-5 Port 2 Registers (cont'd)

Register Short Name	Register Long Name	Address Offset	Reset Value
P2_IOCRO6	Port 2 Input/Output Control Register 6	E84C _H	0000 _H
P2_IOCRO7	Port 2 Input/Output Control Register 7	E84E _H	0000 _H
P2_IOCRO8	Port 2 Input/Output Control Register 8	E850 _H	0000 _H
P2_IOCRO9	Port 2 Input/Output Control Register 9	E852 _H	0000 _H
P2_IOCRO10	Port 2 Input/Output Control Register 10	E854 _H	0000 _H
P2_IOCRO13	Port 2 Input/Output Control Register 13	E85A _H	0000 _H

Output Control for Pins P2.[13:12]

The driver mode of pins P2.[13:12] is controlled by the bit field P2_POCON.PDM2, together with pins P2.[11:8].

The power saving behavior of pins P2.[13:12] is controlled by bit P2_POCON.PPS3.

Noise reduction for Analog to Digital Converter

As Port P2.[1:0] pads share the same power supply as the Analog to Digital Converter, caution has to be taken with respect to switching noise caused by their digital outputs. Switching strong output drivers during the sampling phase may severely reduce the precision of the AD Conversion. If switching during the sample phase can't be avoided, it is advised to do this only with weak or medium output drivers.

9.3.2 Port 5

Port 5 is a 6-bit analog or digital input port.

To use the Port 5 as an analog input, the Schmitt trigger in the input stage must be disabled. This is achieved by setting the corresponding bit in the register P5_DIDIS.

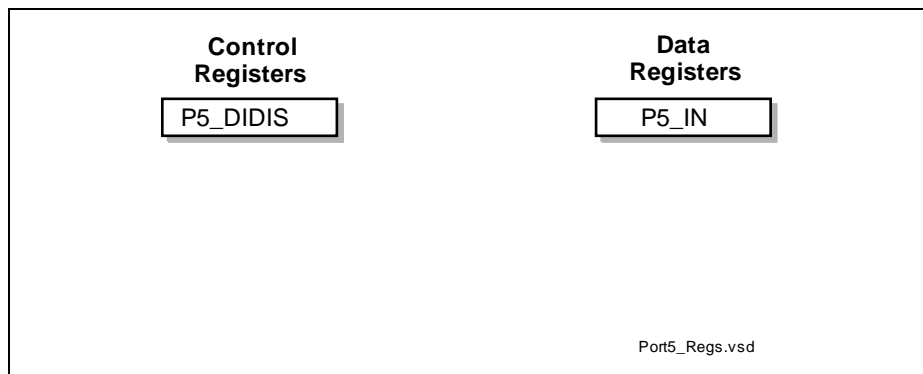


Figure 9-5 Port 5 Register Overview

Table 9-6 Port 5 Registers

Register Short Name	Register Long Name	Address Offset	Reset Value
P5_IN	Port 5 Input Register	FF8A _H	0000 _H
P5_DIDIS	Port 5 Digital Input Disable Register	FE8A _H	0000 _H

9.3.3 Port 6

Port 6 is a 3-bit GPIO and analog input port, except for P6.3, which is GPIO only. The registers of Port 6 are shown in [Figure 9-6](#).

For this port, all pins can be read as GPIO, from the Port Input Register.

When used as analog input, the digital part of the respective pin can be disabled via P6_DIDIS, see [Section 9.2.6](#).

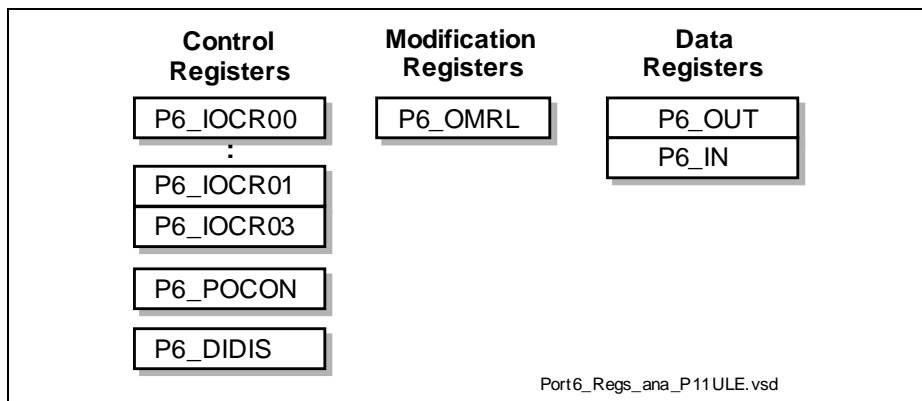


Figure 9-6 Port 6 Register Overview

Table 9-7 Port 6 Registers

Register Short Name	Register Long Name	Address Offset	Reset Value
P6_OUT	Port 6 Output Register	FFAE _H	0000 _H
P6_IN	Port 6 Input Register	FF8C _H	0000 _H
P6_DIDIS	Port 6 Digital I/O Disable Register	FE4E _H	0000 _H
P6_OMRL	Port 6 Output Modification Register Low	E9D8 _H	XXXX _H
P6_POCON	Port 6 Output Control Register	E8AC _H	0000 _H
P6_IOCRO0	Port 6 Input/Output Control Register 0	E8C0 _H	0000 _H
P6_IOCRO1	Port 6 Input/Output Control Register 1	E8C2 _H	0000 _H
P6_IOCRO3	Port 6 Input/Output Control Register 3	E8C6 _H	0000 _H

Noise reduction for Analog to Digital Converter

As Port P6.0 pad(s) share the same power supply as the Analog to Digital Converter, caution has to be taken with respect to switching noise caused by their digital outputs. Switching strong output drivers during the sampling phase may severely reduce the precision of the AD Conversion. If switching during the sample phase can't be avoided, it is advised to do this only with weak or medium output drivers.

If these P6 port pin(s) are used to control the external analog multiplexer of ADC0, the ADC itself controls the switching of the outputs and does so only while the ADC0 is not in the sampling phase.

9.3.4 Port 10

Port 10 is a 12-bit GPIO port. The registers of Port 10 are shown in [Figure 9-7](#).
For this port, all pins can be read as GPIO, from the Port Input Register.

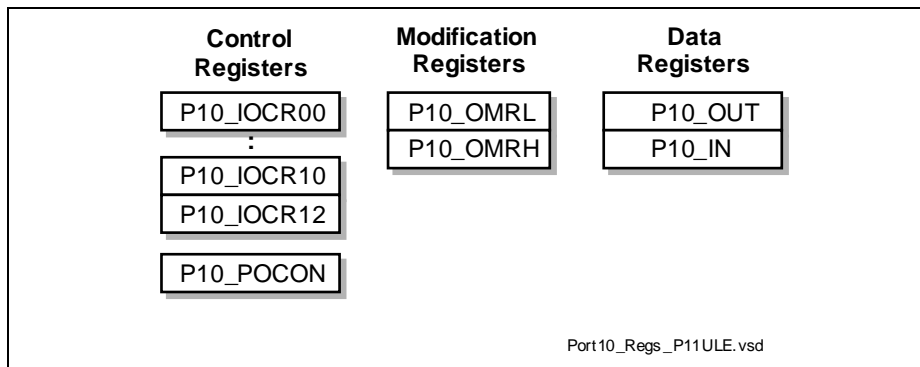


Figure 9-7 Port 10 Register Overview

Table 9-8 Port 10 Registers

Register Short Name	Register Long Name	Address Offset	Reset Value
P10_OUT	Port 10 Output Register	FFB6 _H	0000 _H
P10_IN	Port 10 Input Register	FF94 _H	0000 _H
P10_OMRL	Port 10 Output Modification Register Low	E9E8 _H	XXXX _H
P10_OMRH	Port 10 Output Modification Register High	E9EA _H	XXXX _H
P10_POCON	Port 10 Output Control Register	E8B4 _H	0000 _H
P10_IOCRR0	Port 10 Input/Output Control Register 0	E940 _H	0000 _H
P10_IOCRR1	Port 10 Input/Output Control Register 1	E942 _H	0000 _H
P10_IOCRR2	Port 10 Input/Output Control Register 2	E944 _H	0000 _H
P10_IOCRR3	Port 10 Input/Output Control Register 3	E946 _H	0000 _H
P10_IOCRR4	Port 10 Input/Output Control Register 4	E948 _H	0000 _H
P10_IOCRR5	Port 10 Input/Output Control Register 5	E94A _H	0000 _H
P10_IOCRR6	Port 10 Input/Output Control Register 6	E94C _H	0000 _H
P10_IOCRR7	Port 10 Input/Output Control Register 7	E94E _H	0000 _H
P10_IOCRR8	Port 10 Input/Output Control Register 8	E950 _H	0000 _H
P10_IOCRR9	Port 10 Input/Output Control Register 9	E952 _H	0000 _H

Table 9-8 Port 10 Registers (cont'd)

Register Short Name	Register Long Name	Address Offset	Reset Value
P10_IOC10	Port 10 Input/Output Control Register 10	E954 _H	0000 _H
P10_IOC12	Port 10 Input/Output Control Register 12	E958 _H	0000 _H

9.4 Pin Description

Each port pin of the XE166U can serve several functions of different modules. Also, most functions are available on several port pins. This enables an application to select the optimal connections for its specific circumstances.

A pin can output its own port output signal or one of up to three signals coming from the peripherals. Its input signal is available in its own input register and at several peripherals.

Note: Output signals are selected at the respective port pin, input signals are selected at the respective peripheral.

Table 9-9 summarizes the various functions of each port and pin of the XE166U. The 'Pin' column references to the PG-VQFN-48 package.

Notes to the Pin Definitions table

- **Ctrl.:** The output signal for a port pin is selected via bitfield PC in the associated register Px_IOCry. Output O0 is selected by setting the respective bitfield PC to 1x00_B, output O1 is selected by 1x01_B, etc.
OH output signals and IH input signals are controlled by the hardware override.
- **Type:** Indicates the employed pad type (St=standard pad, Sp=special pad, In=input pad, DA=digital IO and analog input, PS=power supply) and its power supply domain (B, M).
- Functions shaded in grey are new functions added to XE166U derivatives and might not be available to other devices in the family.

Table 9-9 Pin Definitions and Functions

Pin	Symbol	Ctrl.	Type	Function
1	$\overline{\text{TESTM}}$	I	In/B	Testmode Enable Enables factory test modes, must be held HIGH for normal operation (connect to V_{DDPB}). An internal pullup device will hold this pin high when nothing is driving it.
2	$\overline{\text{TRST}}$	I	In/B	Test-System Reset Input For normal system operation, pin $\overline{\text{TRST}}$ should be held low. A high level at this pin at the rising edge of $\overline{\text{PORST}}$ activates the XE166U's debug system. In this case, pin $\overline{\text{TRST}}$ must be driven low once to reset the debug system. An internal pulldown device will hold this pin low when nothing is driving it.

Table 9-9 Pin Definitions and Functions (cont'd)

Pin	Symbol	Ctrl.	Type	Function
3	P6.3	O0 / I	St/B	Bit 3 of Port 6, General Purpose Input/Output
	T3OUT	O2	St/B	GPT12E Timer T3 Toggle Latch Output
	ADC0_REQT RyF	I	St/B	External Request Trigger Input for ADC0
4	P6.1	O0 / I	DA/B	Bit 1 of Port 6, General Purpose Input/Output
	ADC0_CH17	I	DA/B	Analog Input Channel 17 for ADC0
	EMUX1	O1	DA/B	External Analog MUX Control Output 1 (ADC0)
	T3OUT	O2	DA/B	GPT12E Timer T3 Toggle Latch Output
	ADC0_REQT RyE	I	DA/B	External Request Trigger Input for ADC0
	ESR1_6	I	DA/B	ESR1 Trigger Input 6
5	P6.0	O0 / I	DA/B	Bit 0 of Port 6, General Purpose Input/Output
	ADC0_CH16	I	DA/B	Analog Input Channel 16 for ADC0
	EMUX0	O1	DA/B	External Analog MUX Control Output 0 (ADC0)
	BRKOUT	O3	DA/B	OCDS Break Signal Output
	ADC0_REQG TyG	I	DA/B	External Request Gate Input for ADC0
10	P5.0	I	In/B	Bit 0 of Port 5, General Purpose Input
	ADC0_CH0	I	In/B	Analog Input Channel 0 for ADC0
11	P5.2	I	In/B	Bit 2 of Port 5, General Purpose Input
	ADC0_CH2	I	In/B	Analog Input Channel 2 for ADC0
	TDI_A	I	In/B	JTAG Test Data Input
12	P5.3	I	In/B	Bit 3 of Port 5, General Purpose Input
	ADC0_CH3	I	In/B	Analog Input Channel 3 for ADC0
	T3INA	I	In/B	GPT12E Timer T3 Count/Gate Input
13	P5.4	I	In/B	Bit 4 of Port 5, General Purpose Input
	ADC0_CH4	I	In/B	Analog Input Channel 4 for ADC0
	T3EUDA	I	In/B	GPT12E Timer T3 External Up/Down Control Input
	TMS_A	I	In/B	JTAG Test Mode Selection Input

Table 9-9 Pin Definitions and Functions (cont'd)

Pin	Symbol	Ctrl.	Type	Function
14	P5.8	I	In/B	Bit 8 of Port 5, General Purpose Input
	ADC0_CH8	I	In/B	Analog Input Channel 8 for ADC0
	CCU60_T12 HRC	I	In/B	External Run Control Input for T12 of CCU60
	CCU60_T13 HRC	I	In/B	External Run Control Input for T13 of CCU60
15	P5.9	I	In/B	Bit 9 of Port 5, General Purpose Input
	ADC0_CH9	I	In/B	Analog Input Channel 9 for ADC0
	CC2_T7IN	I	In/B	CAPCOM2 Timer T7 Count Input
16	P2.0	O0 / I	DA/B	Bit 0 of Port 2, General Purpose Input/Output
	ADC0_CH19	I	DA/B	Analog Input Channel 19 for ADC0
	T5INB	I	DA/B	GPT12E Timer T5 Count/Gate Input
17	P2.1	O0 / I	DA/B	Bit 1 of Port 2, General Purpose Input/Output
	ADC0_CH20	I	DA/B	Analog Input Channel 20 for ADC0
	T5EUDB	I	DA/B	GPT12E Timer T5 External Up/Down Control Input
	ESR1_5	I	DA/B	ESR1 Trigger Input 5
	ERU_0A0	I	DA/B	External Request Unit Channel 0 Input A0
21	P2.2	O0 / I	St/B	Bit 2 of Port 2, General Purpose Input/Output
	ESR2_5	I	St/B	ESR2 Trigger Input 5
	ERU_1A0	I	St/B	External Request Unit Channel 1 Input A0
22	P2.3	O0 / I	St/B	Bit 3 of Port 2, General Purpose Input/Output
	U0C0_DOUT	O1	St/B	USIC0 Channel 0 Shift Data Output
	CC2_CC16	O3 / I	St/B	CAPCOM2 CC16IO Capture Inp./ Compare Out.
	ESR2_0	I	St/B	ESR2 Trigger Input 0
	U0C0_DX0E	I	St/B	USIC0 Channel 0 Shift Data Input
	U0C1_DX0D	I	St/B	USIC0 Channel 1 Shift Data Input

Table 9-9 Pin Definitions and Functions (cont'd)

Pin	Symbol	Ctrl.	Type	Function
23	P2.4	O0 / I	St/B	Bit 4 of Port 2, General Purpose Input/Output
	U0C1_DOUT	O1	St/B	USIC0 Channel 1 Shift Data Output
	CC2_CC17	O3 / I	St/B	CAPCOM2 CC17IO Capture Inp./ Compare Out.
	ESR1_0	I	St/B	ESR1 Trigger Input 0
	U0C0_DX0F	I	St/B	USIC0 Channel 0 Shift Data Input
24	P2.5	O0 / I	St/B	Bit 5 of Port 2, General Purpose Input/Output
	U0C0_SCLK OUT	O1	St/B	USIC0 Channel 0 Shift Clock Output
	CC2_CC18	O3 / I	St/B	CAPCOM2 CC18IO Capture Inp./ Compare Out.
	U0C0_DX1D	I	St/B	USIC0 Channel 0 Shift Clock Input
	ESR1_10	I	St/B	ESR1 Trigger Input 10
25	P2.6	O0 / I	St/B	Bit 6 of Port 2, General Purpose Input/Output
	U0C0_SELO 0	O1	St/B	USIC0 Channel 0 Select/Control 0 Output
	U0C1_SELO 1	O2	St/B	USIC0 Channel 1 Select/Control 1 Output
	CC2_CC19	O3 / I	St/B	CAPCOM2 CC19IO Capture Inp./ Compare Out.
	CLKIN1 ¹⁾	I	St/B	Clock Signal Input 1
	U0C0_DX2D	I	St/B	USIC0 Channel 0 Shift Control Input
	ESR2_6	I	St/B	ESR2 Trigger Input 6
26	P2.7	O0 / I	St/B	Bit 7 of Port 2, General Purpose Input/Output
	U0C1_SELO 0	O1	St/B	USIC0 Channel 1 Select/Control 0 Output
	U0C0_SELO 1	O2	St/B	USIC0 Channel 0 Select/Control 1 Output
	CC2_CC20	O3 / I	St/B	CAPCOM2 CC20IO Capture Inp./ Compare Out.
	U0C1_DX2C	I	St/B	USIC0 Channel 1 Shift Control Input
	ESR2_7	I	St/B	ESR2 Trigger Input 7

Table 9-9 Pin Definitions and Functions (cont'd)

Pin	Symbol	Ctrl.	Type	Function
27	P2.8	O0 / I	St/B	Bit 8 of Port 2, General Purpose Input/Output
	U0C1_SCLK OUT	O1	St/B	USIC0 Channel 1 Shift Clock Output
	EXTCLK	O2	St/B	Programmable Clock Signal Output
	CC2_CC21	O3 / I	St/B	CAPCOM2 CC21IO Capture Inp./ Compare Out.
	U0C1_DX1D	I	St/B	USIC0 Channel 1 Shift Clock Input
28	P2.9	O0 / I	St/B	Bit 9 of Port 2, General Purpose Input/Output
	U0C1_DOUT	O1	St/B	USIC0 Channel 1 Shift Data Output
	CC2_CC22	O3 / I	St/B	CAPCOM2 CC22IO Capture Inp./ Compare Out.
	C1	I	St/B	Configuration Pin 1
	TCK_A	I	St/B	DAP0/JTAG Clock Input
29	P2.10	O0 / I	St/B	Bit 10 of Port 2, General Purpose Input/Output
	U0C1_DOUT	O1	St/B	USIC0 Channel 1 Shift Data Output
	U0C0_SELO 3	O2	St/B	USIC0 Channel 0 Select/Control 3 Output
	CC2_CC23	O3 / I	St/B	CAPCOM2 CC23IO Capture Inp./ Compare Out.
	U0C1_DX0E	I	St/B	USIC0 Channel 1 Shift Data Input
	CAPINA	I	St/B	GPT12E Register CAPREL Capture Input
30,	P2.13	O0 / I	St/B	Bit 13 of Port 2, General Purpose Input/Output
31	P10.0	O0 / I	St/B	Bit 0 of Port 10, General Purpose Input/Output
	U0C1_DOUT	O1	St/B	USIC0 Channel 1 Shift Data Output
	CCU60_CC6 0	O2	St/B	CCU60 Channel 0 Output
	CCU60_CC6 0INA	I	St/B	CCU60 Channel 0 Input
	ESR1_2	I	St/B	ESR1 Trigger Input 2
	U0C0_DX0A	I	St/B	USIC0 Channel 0 Shift Data Input
	U0C1_DX0A	I	St/B	USIC0 Channel 1 Shift Data Input

Table 9-9 Pin Definitions and Functions (cont'd)

Pin	Symbol	Ctrl.	Type	Function
32	P10.1	O0 / I	St/B	Bit 1 of Port 10, General Purpose Input/Output
	U0C0_DOUT	O1	St/B	USIC0 Channel 0 Shift Data Output
	CCU60_CC6 1	O2	St/B	CCU60 Channel 1 Output
	CCU60_CC6 1INA	I	St/B	CCU60 Channel 1 Input
	U0C0_DX0B	I	St/B	USIC0 Channel 0 Shift Data Input
	U0C0_DX1A	I	St/B	USIC0 Channel 0 Shift Clock Input
33	P10.2	O0 / I	St/B	Bit 2 of Port 10, General Purpose Input/Output
	U0C0_SCLK OUT	O1	St/B	USIC0 Channel 0 Shift Clock Output
	CCU60_CC6 2	O2	St/B	CCU60 Channel 2 Output
	CCU60_CC6 2INA	I	St/B	CCU60 Channel 2 Input
	U0C0_DX1B	I	St/B	USIC0 Channel 0 Shift Clock Input
34	P10.3	O0 / I	St/B	Bit 3 of Port 10, General Purpose Input/Output
	CCU60_COU T60	O2	St/B	CCU60 Channel 0 Output
	U0C0_DX2A	I	St/B	USIC0 Channel 0 Shift Control Input
	U0C1_DX2A	I	St/B	USIC0 Channel 1 Shift Control Input
35	P10.4	O0 / I	St/B	Bit 4 of Port 10, General Purpose Input/Output
	U0C0_SELO 3	O1	St/B	USIC0 Channel 0 Select/Control 3 Output
	CCU60_COU T61	O2	St/B	CCU60 Channel 1 Output
	U0C0_DX2B	I	St/B	USIC0 Channel 0 Shift Control Input
	U0C1_DX2B	I	St/B	USIC0 Channel 1 Shift Control Input
	ESR1_9	I	St/B	ESR1 Trigger Input 9

Table 9-9 Pin Definitions and Functions (cont'd)

Pin	Symbol	Ctrl.	Type	Function
36	P10.5	O0 / I	St/B	Bit 5 of Port 10, General Purpose Input/Output
	U0C1_SCLK OUT	O1	St/B	USIC0 Channel 1 Shift Clock Output
	CCU60_COU T62	O2	St/B	CCU60 Channel 2 Output
	U0C1_DX1B	I	St/B	USIC0 Channel 1 Shift Clock Input
37	P10.6	O0 / I	St/B	Bit 6 of Port 10, General Purpose Input/Output
	U0C0_DOUT	O1	St/B	USIC0 Channel 0 Shift Data Output
	U0C0_DX0C	I	St/B	USIC0 Channel 0 Shift Data Input
	CCU60_CTR APA	I	St/B	CCU60 Emergency Trap Input
38	P10.7	O0 / I	St/B	Bit 7 of Port 10, General Purpose Input/Output
	U0C1_DOUT	O1	St/B	USIC0 Channel 1 Shift Data Output
	CCU60_COU T63	O2	St/B	CCU60 Channel 3 Output
	U0C1_DX0B	I	St/B	USIC0 Channel 1 Shift Data Input
	CCU60_CCP OS0A	I	St/B	CCU60 Position Input 0
	T4INB	I	St/B	GPT12E Timer T4 Count/Gate Input
39	P10.8	O0 / I	St/B	Bit 8 of Port 10, General Purpose Input/Output
	U0C0_MCLK OUT	O1	St/B	USIC0 Channel 0 Master Clock Output
	U0C1_SELO 0	O2	St/B	USIC0 Channel 1 Select/Control 0 Output
	CCU60_CCP OS1A	I	St/B	CCU60 Position Input 1
	U0C0_DX1C	I	St/B	USIC0 Channel 0 Shift Clock Input
	BRKIN_B	I	St/B	OCDS Break Signal Input
	T3EUDB	I	St/B	GPT12E Timer T3 External Up/Down Control Input
	ESR2_11	I	St/B	ESR2 Trigger Input 11

Table 9-9 Pin Definitions and Functions (cont'd)

Pin	Symbol	Ctrl.	Type	Function
40	P10.9	O0 / I	St/B	Bit 9 of Port 10, General Purpose Input/Output
	U0C0_SELO 4	O1	St/B	USIC0 Channel 0 Select/Control 4 Output
	U0C1_MCLK OUT	O2	St/B	USIC0 Channel 1 Master Clock Output
	CCU60_CCP OS2A	I	St/B	CCU60 Position Input 2
	TCK_B	I	St/B	DAP0/JTAG Clock Input
	T3INB	I	St/B	GPT12E Timer T3 Count/Gate Input
44	P10.10	O0 / I	St/B	Bit 10 of Port 10, General Purpose Input/Output
	U0C0_SELO 0	O1	St/B	USIC0 Channel 0 Select/Control 0 Output
	CCU60_COU T63	O2	St/B	CCU60 Channel 3 Output
	U0C0_DX2C	I	St/B	USIC0 Channel 0 Shift Control Input
	TDI_B	I	St/B	JTAG Test Data Input
	U0C1_DX1A	I	St/B	USIC0 Channel 1 Shift Clock Input
45	P10.12	O0 / I	St/B	Bit 12 of Port 10, General Purpose Input/Output
	U0C0_DOUT	O2	St/B	USIC0 Channel 0 Shift Data Output
	TDO_A	OH	St/B	DAP1/JTAG Test Data Output
	SPD_0	I/OH	St/B	SPD Input/Output
	C0	I	St/B	Configuration Pin 0
	U0C0_DX0D	I	St/B	USIC0 Channel 0 Shift Data Input
46	XTAL2	O	Sp/M	Crystal Oscillator Amplifier Output
47	XTAL1	I	Sp/M	Crystal Oscillator Amplifier Input To clock the device from an external source, drive XTAL1, while leaving XTAL2 unconnected. Voltages on XTAL1 must comply to the core supply voltage V_{DDIM} .
	ESR2_9	I	St/B	ESR2 Trigger Input 9

Table 9-9 Pin Definitions and Functions (cont'd)

Pin	Symbol	Ctrl.	Type	Function
48	PORST	I	In/B	Power On Reset Input A low level at this pin resets the XE166U completely. A spike filter suppresses input pulses <10 ns. Input pulses >100 ns safely pass the filter. The minimum duration for a safe recognition should be 120 ns. An internal pullup device will hold this pin high when nothing is driving it.
8	V_{AREF}	-	PS/B	Reference Voltage for A/D Converters ADC0
9	V_{AGND}	-	PS/B	Reference Ground for A/D Converters ADC0
18, 43	V_{DDIM}	-	PS/M	Digital Core Supply Voltage for Domain 1 Decouple with a ceramic capacitor, see Data Sheet for details. All V_{DDIM} pins must be connected to each other.
7, 20, 41	V_{DDPB}	-	PS/B	Digital Pad Supply Voltage for Domain B Connect decoupling capacitors to adjacent V_{DDP}/V_{SS} pin pairs as close as possible to the pins.
6, 19, 42	V_{SS}	-	PS/--	Digital Ground All V_{SS} pins must be connected to the ground-line or ground-plane.

¹⁾ CLKIN1 function is implemented on P2.6 for XE166U derivatives, which might be different from the rest of the family.

10 Dedicated Pins

Most of the input/output or control signals of the XE166U are realized as alternate functions of parallel port pins. There is, however, a number of signals that use separate pins, including the oscillator, special control signals and, of course, the power supply.

Table 10-1 summarizes the dedicated pins of the XE166U.

Table 10-1 XE166U Dedicated Pins

Pin(s)	Function
PORST	Power-On Reset Input
XTAL1, XTAL2	Oscillator Input/Output (main oscillator)
TESTM	Test Mode Enable
TRST	Test-System Reset Input
V_{AREF} , V_{AGND}	Reference voltages for the Analog/Digital Converter
V_{DDIM}	Digital Core Supply for Domain M
V_{DDPB}	Power Supply Input for Domain B
V_{SS}	Digital Ground

The Power-On Reset Input $\overline{\text{PORST}}$ allows to put the XE166U into reset condition either at power-up or upon external events like a hardware failure or manual reset.

The Oscillator Input XTAL1 and Output XTAL2 connect the internal **Main Oscillator** to the external crystal. The oscillator provides an inverter and a feedback element. The standard external oscillator circuitry comprises the crystal, two low end capacitors and series resistor to limit the current through the crystal. The main oscillator is intended for the generation of a high-precision operating clock signal for the XE166U.

An external clock signal may be fed to the input XTAL1, leaving XTAL2 open. The current logic state of input XTAL1 can be read via a status flag, so XTAL1 can be used as digital input if neither the oscillator interface nor the clock input is required.

Note: Pin XTAL1 belongs to the core power domain DMP_M. All input signals, therefore, must be within the core voltage range.

The Test Mode Input $\overline{\text{TESTM}}$ puts the XE166U into test mode, which is used during the production tests of the device. In test mode, the XE166U behaves different from normal operation. Therefore, pin $\overline{\text{TESTM}}$ must be held high (connect to V_{DDPB}) for normal operation in an application system.

The Test Reset Input $\overline{\text{TRST}}$ puts the XE166U's debug system into reset state. During normal operation this input should be held low. For debugging purposes the on-chip debugging system can be enabled by driving pin $\overline{\text{TRST}}$ high at the rising edge of $\overline{\text{PORST}}$.

Dedicated Pins

The Analog Reference Voltage Supply pins V_{AREF} and V_{AGND} provide separate reference voltage for the on-chip Analog/Digital-Converter. This reduces the noise that is coupled to the analog input signals from the digital logic sections and so improves the stability of the conversion results, when V_{AREF} and V_{AGND} are properly decoupled from V_{DD} and V_{SS} . Also, because conversion results are generated in relation to the reference voltages, ratiometric conversions are easily achieved.

Note: Channel 0 of each module can be used as an alternate reference voltage input.

The Digital Core Supply pins V_{DDIM} serve one purpose: While the on-chip EVVRs provide the power for the core logic of the XE166U these pins connect the EVVRs to their external buffer capacitors. The respective V_{DDIM}/V_{SS} pairs should be decoupled as close to the pins as possible. Use ceramic capacitors and observe their values recommended in the respective Data Sheet.

The Power Supply Inputs V_{DDPB} provide the power supply for all the analog and digital logic of the XE166U. The power domain (DMP_B) can be supplied with an arbitrary voltage within the specified voltage range (please refer to the corresponding Data Sheets). These pins supply the output drivers as well as the on-chip EVVRs (V_{DDPB}). The respective V_{DDPB}/V_{SS} pairs should be decoupled as close to the pins as possible.

The Ground Reference pins V_{SS} provide the ground reference voltage for the power supplies as well as the reference voltage for the input signals.

Note: All V_{DDx} pins and all V_{SS} pins must be connected to the power supplies and ground, respectively.

11 Startup Configuration and Bootstrap Loading

After startup, the XE166U executes code out of an on-chip program memory. The initial code source can be selected (refer to the next [Chapter 11.1](#) to find out how) between the following options:

- **Internal Start** Mode: executes code out of the on-chip program Flash.
- **Bootstrap Loading** Modes: execute code out of the on-chip program SRAM (PSRAM). This code is downloaded beforehand via a selectable serial interface.

11.1 Start-up configuration and modes

There are three ways to update (i.e. select new) start-up configuration in XE166U where the first two are existing in all P11 derivatives till now while the third is new one specially introduced for low pin-count devices:

- **Hardware configuration** - according to the values at configuration pins ($\overline{\text{TRST}}$ and configuration pins C1/C0) upon power-on reset
The configuration pin assignment for XE166U is:
 - P10.12 (Pin 12 from Port 10) is C0
- **Software configuration** - according to the value in SCU_SWRSTCON.SWCFG bitfield upon software reset if SCU_SWRSTCON.SWBOOT=1
- **Configuration by Boot Mode Index (BMI)** - according to values taken from dedicated locations in Security Page 0 of Flash Config sector - upon power-on, whereas one only configuration pin is needed to select this option

Next, several specific cases of startup configuration handling must be considered:

- Application or Internal Application reset triggered by hardware request (for example WDT) - the same startup configuration is used as after the previous reset
- Application or Internal Application reset triggered by software while SCU_SWRSTCON.SWBOOT=0- the same startup configuration is used as after the previous reset
- Internal Application reset triggered by hardware request - only $\overline{\text{TRST}}$ pin is evaluated:
 - if $\overline{\text{TRST}}=0$ - Internal Start from Flash is selected, no debugging is possible
 - otherwise - the same startup configuration is used as after the previous reset

After booting, the user software can determine in which mode the device is started by evaluating the SCU_STSTAT.HWCFG-value (plus DBGPRR in case).

Startup Configuration and Bootstrap Loading

11.1.1 Hardware configuration

The start-up mode selection by configuration pins in XE166U is shown in [Table 11-1](#).

Configuration pins are treated by start-up procedure differently depending on additional conditions:

1. If $\overline{\text{TRST}}=0$ - it is purely hardware controlled (so-called “Zero-pin”) configuration - device start from Internal Flash without debug support is executed
2. If $\text{TRST}=1$ - the Boot Mode Index (BMI) is evaluated first and depending on the result - start-up mode and debug configuration are determined either from BMI-value or by configuration pins.

Table 11-1 Start-up Mode Selection in XE166U

TRST	BMI value		CFG-pin	Start-up Mode
			C0 P10.12	
0	not checked		x	Internal Start from Flash, no debug
1	BMI valid	BMI.BLS=disable	x	Start-up and debug mode from BMI
		BMI.BLS=enable	0	Start-up and debug mode from BMI
			1	ASC Bootloader
	BMI invalid/ unconfigured		1	ASC Bootloader
			0	Internal start from Flash, JTAG debug

11.1.2 Software configuration

XE166U supports Software configuration - starting in selected mode upon software reset - in the same way as all the other P11 devices.

The user software must perform following steps:

1. install the value to select a start-up mode according to [Table 11-2](#) into SCU_SWRSTCON.SWCFG bitfield
2. select software boot configuration by installing SCU_SWRSTCON.SWBOOT=1
3. trigger a software reset

Table 11-2 Start-up Modes in XE166U: selection and indication

Start-up Mode	HWCFG ¹⁾ / SWCFG / BMI0 bits							
	7	6	5	4	3	2	1	0
Selection by SWRSTCON.SWCFG or BMI0, indication in HWCFG								
ASC Bootloader, no debug	0	0	x	x	x	x	0	1
Internal Start from Flash, no debug	0	0	x	x	x	x	1	0
Reserved	0	1	x	x	x	x	0	0
ASC Bootloader, debug mode from HWCFG[5:2] ²⁾	0	1	J	C	S	11	0	1
Internal Start from Flash, debug mode from HWCFG[6:2] ²⁾	0	1	J	C	S	11	1	0
Reserved	1	x	x	x	x	x	x	x
Only selection by SWRSTCON.SWCFG, HWCFG indicates then the mode from BMI								
Start-up and debug mode from BMI	0	x	x	x	x	x	1	1

1) The bits marked with x (SWCFG/BMI0) are installed by SSW to 0 in SCU_STSTAT.HWCFG

2) For debug interface configurations refer to [Table 11-3](#) and [Table 11-4](#)

11.1.3 Configuration by Boot Mode Index (BMI)

This new (for P11 family) way of device configuration is introduced especially for low-pin devices like XE166U. It allows to select between all supported start-up modes and debug interface settings with using for this either one only or even no IO pin (refer to [Table 11-1](#)) so allowing maximum flexibility in pin-usage by application.

11.1.3.1 BMI basics

The Boot Mode Index (BMI) consists of two 16-bit words named BMI0 and BMI1, stored one after another in Flash Security Page 0 at offset 020_H...023_H (see also [Chapter 11.1.3.3](#)).

BMI data structure

All the information needed to select start-up mode and debug configuration is stored in the first BMI word - **BMI0** as below defined.

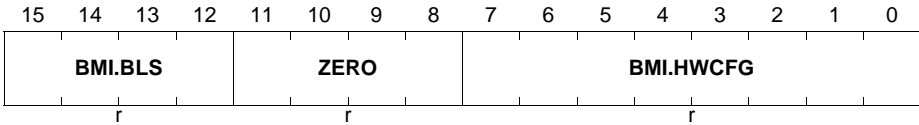
The second word BMI1 is serving as check for data consistence:

- if BMI1 is not inverse to BMI0 (BMI1 <> BMI0) - BMI is considered as invalid
- if BMI1 is inverse to BMI0 (BMI1 = BMI0) - BMI can be valid if all the further conditions (refer to [BMI0](#) definition below and [Chapter 11.1.3.2](#)) are satisfied

Startup Configuration and Bootstrap Loading

BMI0

Boot Mode Index - word 0 Flash Security Page 0 Offset address 20_H



Field	Bits	Typ	Description
BMI.HWCFG	[7:0]	rw	Start-up mode and debug interface configuration - valid value according to Table 11-2, installed by start-up procedure into SCU_STSTAT.HWCFG
ZERO	[11:8]	r	All zero
BMI.BLS	[15:12]	r	UART Bootstrap Loader selection by configuration pin C0 (P10.12): 1010 _B disabled - C0 is not evaluated, mode from BMI is always entered 0101 _B enabled - UART BSL mode is entered if C0=1, mode from BMI otherwise

11.1.3.2 BMI handling by start-up procedure

The BMI-handling by XE166U start-up procedure includes:

1. BMI is copied upon any reset from Flash Config sector into R0/R1 registers (BMI0/BMI1 values respectively) from Local Bank 1 allowing the user to check values programmed
2. BMI is treated as valid if:
 - a) BMI0[7:0] value selects a valid start-up mode according to [Table 11-2](#), AND
 - b) BMI0[11:8] is all zero, AND
 - c) BMI0[15:12]=1010_B or 0101_B, AND
 - d) BMI1=BMI0
3. BMI is evaluated by start-up procedure in two cases:
 - a) always upon power-on when TRST=1
 * if not valid - configuration pins are evaluated to determine the start-up mode
 - b) when SWRSTCON.SWCFG=0xxx xx11_B upon software reset with software configuration (refer to [Table 11-2](#))
 * if not valid - start-up error state is entered
4. if valid in both (3.a and 3.b) cases from above - the condition (BMI.BLS=enable) AND (C0=1) is checked next (refer to [Table 11-1](#)):

Startup Configuration and Bootstrap Loading

- a) if not true - start-up mode and debug interface configuration are selected in accordance to [Table 11-2](#)
- b) otherwise - UART Bootstrap Loader mode without debug is selected

11.1.3.3 Outline of BMI installation

The Boot Mode Index value must be programmed by the user/tool into Block 2 of Security page 0 in Flash Config sector where the words BMI0/BMI1 occupy successive locations at offset 020_H...023_H.

Storing BMI in Config sector has two main aspects which must be taken into account by the user:

- because Config sector is installed in a special way different from User Flash programming, there is very low probability to change/destroy BMI unintentionally or on mistake.
- due to the low Config sector endurance allowing limited number of programming cycles (refer to Data Sheet), also limited number of BMI-changes are possible, more having in mind that the endurance is defined for the Config sector as a whole - i.e. password changes are included into the number of programming cycles (therefore it is recommended to install both BMI and protection with the same programming operation, as in the example flow below described).

BMI installation is intended to be feature of third party tools supporting XE166U.

Generally it is also possible for an advanced user to implement BMI programming and verification procedure on its own. An example flow of such procedure is shown at [Figure 11-1...Figure 11-3](#). The basic knowledge and set-up needed include:

- host UART device is connected to XE166U for sending and receiving data
- XE166U can be started upon power-on in UART bootstrap loader (BSL) mode - for more information on this mode functionality refer to [Chapter 11.5.2](#)
- secondary UART BSL code is available - for example, code produced from the example source at [Figure 11-7](#)
- XE166U software can be written and compiled/assembled to executable code for downloading by secondary UART BSL
- to handle device with protected Flash - the password (64 bit) must be known

The main steps from the example flow are described below.

Note: The proposed handshaking mechanism - sending/receiving markers/flags - is shown on the flow charts but not covered by the text.

1. first part - programming BMI and (optionally) protection data (refer to [Figure 11-1](#) and [Figure 11-2](#)):
 - a) start XE166U with power-on in UART BSL mode
 - b) during primary UART BSL execution, the host sends 32 Bytes of secondary bootloader code to XE166U

Startup Configuration and Bootstrap Loading

- c) after finishing the primary UART BSL, XE166U continues executing the secondary bootloader
- d) UART host sends the code implementing first part - steps f)...k) below - from BMI handling on XE166U
- e) after finishing the secondary UART BSL, XE166U continues executing the code just received - next steps below
- f) XE166U sends dedicated (2 Bytes) marker followed by current BMI0/BMI1 values (4 Bytes) - the host can check and decide either BMI update is needed
- g) if Flash protection is active in the device - the host sends password (4 Bytes) to XE166U and protection is temporary disabled
- h) Security Pages 0 and 1 are erased in Config sector
- i) the host sends protection data (all zeroes if no protection desired) followed by BMI0/BMI1 (2 Bytes) values to be installed
- j) protection and BMI data are programmed into Flash Security Page 0
- k) software reset is triggered to start-up XE166U in UART BSL mode again
- 2. second part - verify BMI and (optionally) confirm protection (refer to [Figure 11-3](#)):
 - a) steps b)...e) from the first part are executed again, where the code downloaded by secondary UART BSL is now different - implementing steps b)...f) below
 - b) XE166U sends dedicated (2 Bytes) marker followed by current (newly programmed) BMI0/BMI1 values (4 Bytes) - the host can check either BMI values are correct
 - c) the host sends 8 Byte password (all zeroes if Flash not protected) and protection is temporary disabled
 - d) the host sends protection lock codes - two words AA55_H if protection is to be activated, any other value if no protection
 - e) if correct locked codes (AA55_H) have been received - Security page 1 is programmed, protection is active and locked
 - f) XE166U enters endless loop - new BMI value and (optionally) the protection are installed

This example flow can be adapted to user needs - let say if no protection handling is needed, respective steps can be not implemented/coded so the sequence will be meaningfully simplified.

Startup Configuration and Bootstrap Loading

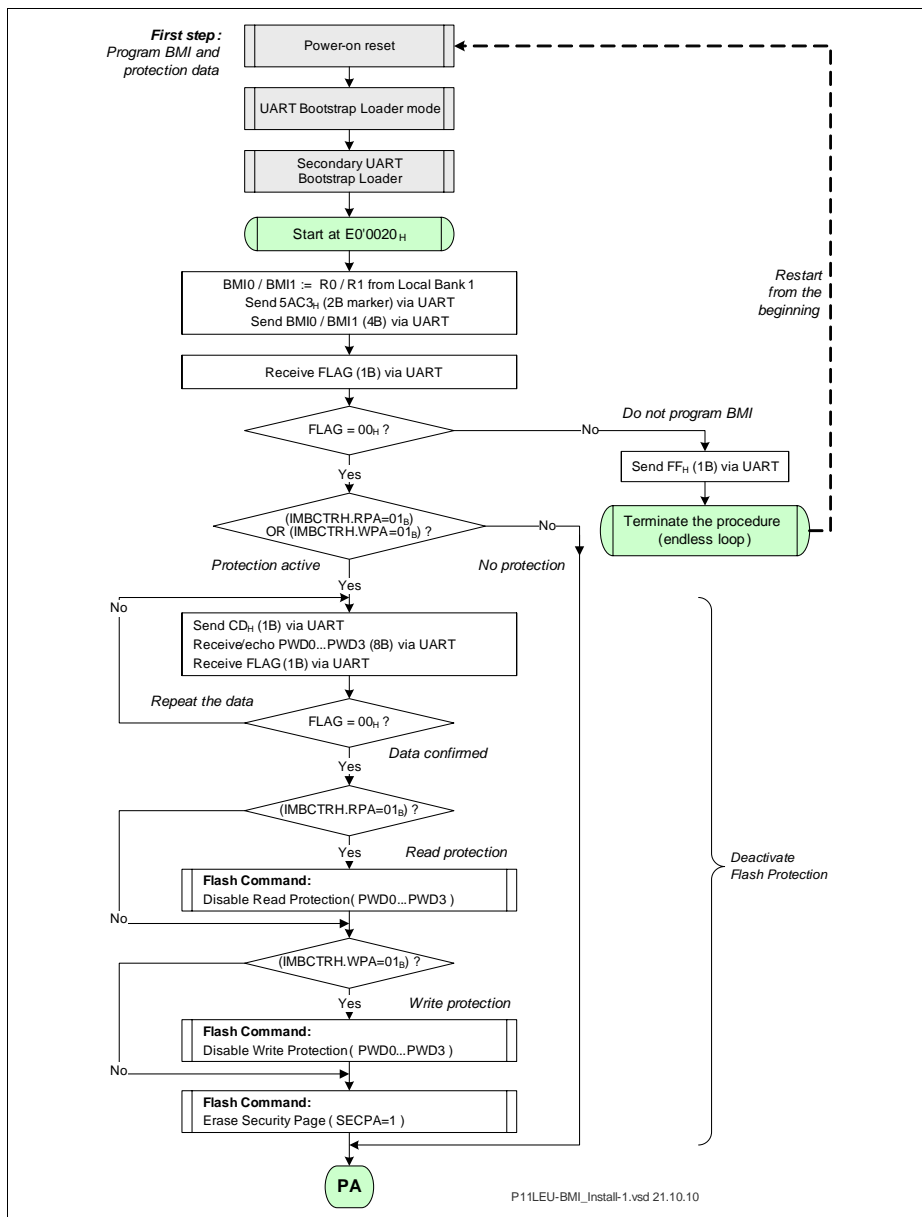


Figure 11-1 Example flow for BMI installation (1/3)

Startup Configuration and Bootstrap Loading

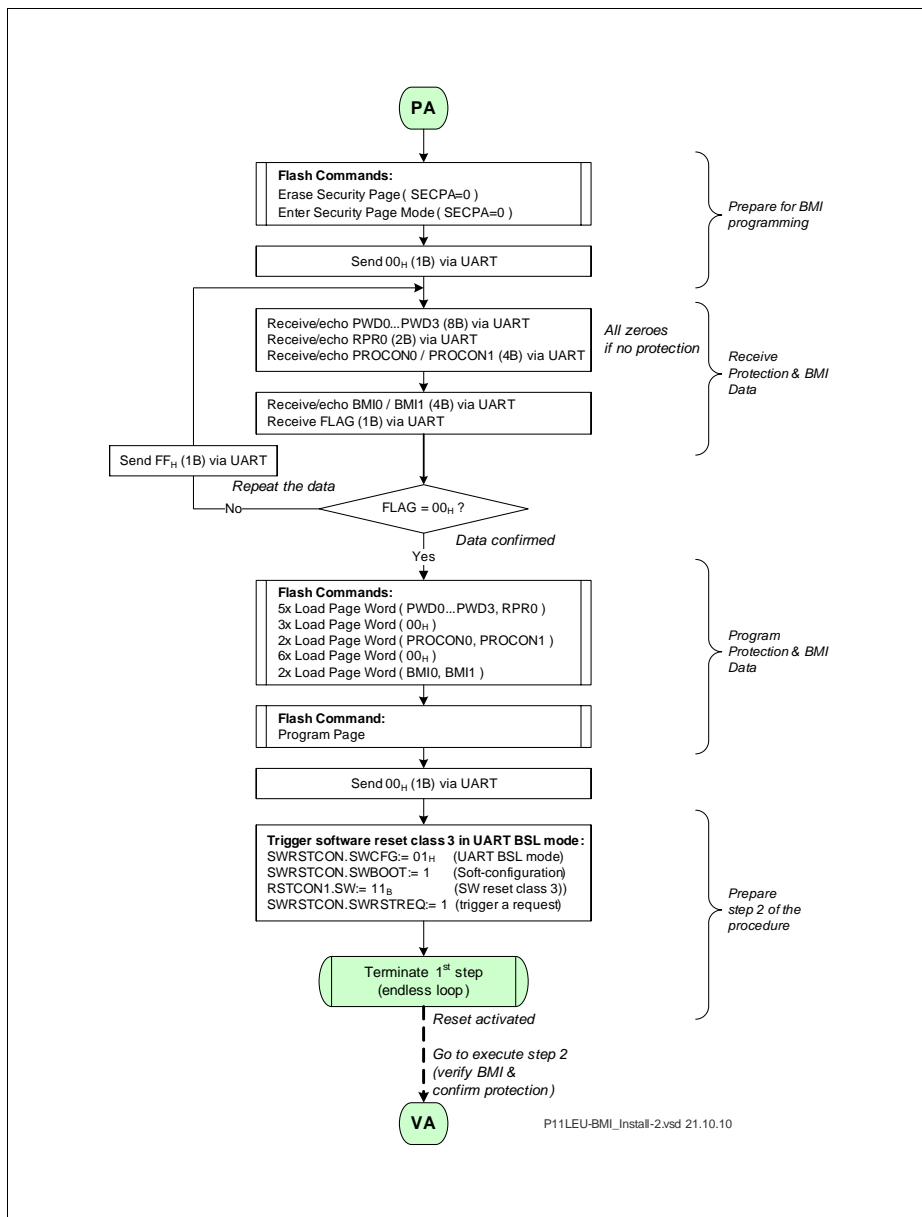


Figure 11-2 Example flow for BMI installation (2/3)

Startup Configuration and Bootstrap Loading

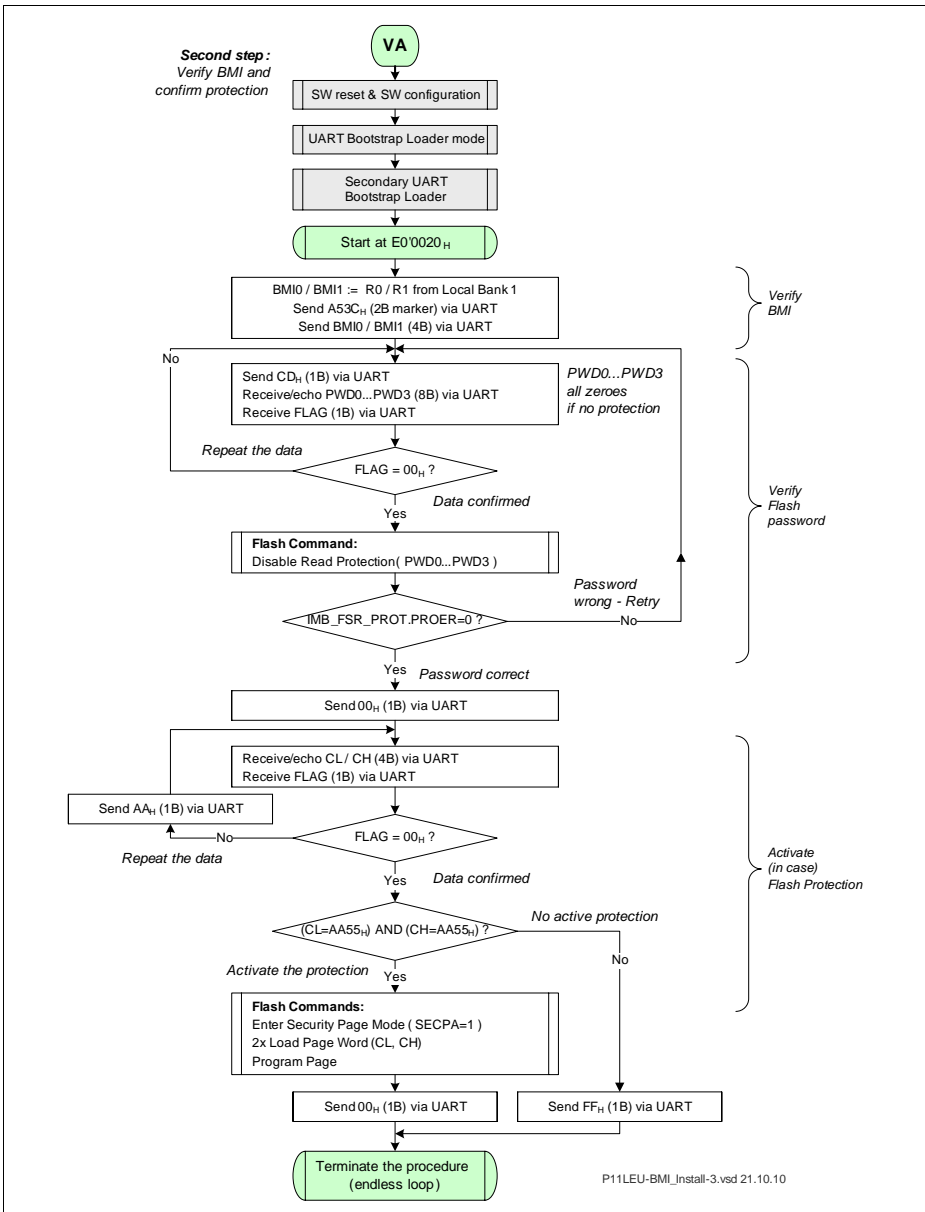


Figure 11-3 Example flow for BMI installation (3/3)

Startup Configuration and Bootstrap Loading

11.1.4 Debug Interface handling

XE166U start-up procedure supports selection of the type (DAP, SPD or JTAG) and pin-location of the debug interface which will be enabled - refer to [Table 11-3](#) and [Table 11-4](#).

Two basic conditions for debug-interface handling must be taken into account:

- debug interface configuration is a part of the complete device startup configuration. Therefore debug interface enabling/disabling/(re)configuration takes place only when the startup configuration (e.g. the startup mode selection) is updated in some of the ways described in [Chapter 11.1](#).
For example, upon an application reset triggered by hardware source (let say WDT) the debug interface will not be touched.
- debug interface will be always disabled, if Internal Start is selected and the on-chip Flash is protected

Table 11-3 Debug Interface configuration by SWRSTCON.SWCFG: DAP

DAP Interface configuration		J	C	S	I1
DAP0 (coded in C)	DAP1 (coded in I1)				
P2.9	P10.12	0	0	x	0
P10.9	P10.12	0	1	x	0
Single pin DAP - SPD at P10.12		0	x	x	1

Table 11-4 Debug Interface configuration by SWRSTCON.SWCFG: JTAG

JTAG Interface configuration				J	C	S	I1
TCK (coded in C)	TMS (coded in S)	TDI (coded in I1)	TDO				
P2.9	P5.4	P5.2	P10.12	1	0	0	0

There are two types of interface signals/pins related to debugging:

Main Debug Interface

These are 2 (in case of DAP), 1 (in case of SPD) or 4 (in case of JTAG) pin(s) as listed in the first 2 columns of [Table 11-3](#) respectively first 4 columns of [Table 11-4](#).

If debugging is enabled, these pins are always assigned to the debug-interface, therefore the application software must never use any of them.

Startup Configuration and Bootstrap Loading

Optional Break Interface

The Break Interface of XE166U Debug System includes two signals: BRKIN and BRKOUT.

The usage of this interface is optional, also selectively either only one out of the two signals or both of them can be utilized.

The Break Interface usage requires additional preparation which will be done - when requested - by the external debugger once the main interface is available.

As long as this preparation and the activation of “Break-In”/“Break-Out” feature has not happened, the respective pin(s) selected to host (potentially) BRKIN/BRKOUT-signal(s) can be still used for other functionality by the application software.

The two Break-signals/pins are handled some differently to each other:

- BRKIN - P5.10 is selected during start-up, the external tool can select (in DBGPRR register) another pin before to activate “Break-In” feature
- BRKOUT - no pin-selection for this signal is done during start-up, the external tool should configure it before to activate “Break-Out” feature

11.2 Device Status after Startup

The main parameters of XE166U-status at the point of time when the first user instruction is executed are summarized below.

11.2.1 Registers modified by the Startup Procedure

Table 11-5 shows the XE166U registers which are initialized during the startup procedure with values different from their reset-content (defined into respective register-descriptions).

There are two groups of registers regarding the way they are affected by startup procedure:

1. registers initialized after any startup
2. registers initialized after power-on

The registers in **Table 11-5** are grouped in accordance to the above differentiation.

Two additional points regarding register-content after startup must be taken into account:

- The register-modifications shown in **Table 11-5** happen independently on the startup mode currently selected, which means also in **Internal Start** mode.
Next to these, in other mode - **Bootstrap Loading (Chapter 11.5)** - more registers are additionally modified during startup, as described into respective Specific Settings chapters for any of the modes.
- The values seen in some bits after startup can be affected not only by the reset procedure itself but also by other events during and even before the last startup - for example an Emergency Event can change the clock-system status.

Startup Configuration and Bootstrap Loading

Therefore occasional exceptions are possible from the above values (as well as from the default register content after reset), mainly for some clock control/status flags. For more information on such special cases and their handling - refer to XE166U Programmer's Guide.

Table 11-5 XE166U Registers installed by the Startup Procedure

Register	Value	Comments
1. After any startup:		
TRAPDIS	009F _H	All SCU-controlled traps disabled except PET and RAT
RSTCON1	UU: 10uu:U _H	Internal Application Reset request generated by WDT
IMBCTRL	556C _H	In Bootstrap Loader mode with protected Flash
	A56C _H	In Internal Start mode or Flash not protected
R8..R15	XXXX	GPRs from Local Bank 1 - used by startup procedure
2. After power-on in DMP_1:		
PLLCON0	0F00 _H	PLL in Normal Mode, N-divider = 16
PLLCON3	0007 _H	K2-divider = 8
SYSCON0	0002 _H	The PLL output (fPLL) used as system clock
WUOSCCON	0000 _H	Wake up Oscillator enabled with fWU approx. 500kHz
HPOSCCON	U:u0uu: UU _H	PLLSTAT.FINDIS bit will not be set in an OSCWDT emergency case
PLLOSCCON	XXXX _H	Device-specific value (chip-to-chip trimming)
EVRMCON0	0100 _H	EVR_M Control 0 register
PVCMCON0	2544 _H	PVC_M Control for Step 0 register

11.2.2 System Frequency after Startup

The system clock which is active when the first user instruction is executed, depends on the currently selected startup mode and the last startup trigger:

- after power-on in all modes - 10MHz (nominal value) from the XE166U internal oscillator (doubled frequency);
- after any functional (not power-on) reset - the clock system configuration is not changed by device startup, respectively the system frequency remains as before the reset.

Startup Configuration and Bootstrap Loading**11.2.3 Watchdog Timer handling**

The Watchdog Timer (WDT) in XE166U is always enabled by the startup procedure and configured to generate Power-on Reset (SCU_RSTCON1.WDT=01_B).

Therefore, the user software must:

- if WDT-usage is foreseen by the code - service it for a first time within approx. 65500 system clock cycles after startup;
- otherwise - disable it within the same time frame as above but before to execute End of Init (EINIT).

The reset requested by WDT serves as response to a device malfunction, due to which malfunction user software can not be anymore executed correctly - respectively the WDT is not regularly served. The power-on reset triggered by WDT and the start-up procedure afterwards put the complete XE166U device into initial state before user software start.

11.2.4 Startup Error state

To prevent possible negative consequences for the device and/or the system, upon unrecoverable error during startup XE166U is put onto a stable, passive and neutral to the external world state - power-save mode where DMP_M is powered with 1V.

This state can be exited with power-on reset only.

11.3 Special Startup Features

XE166U supports some special features, which allow the user software to influence the device startup, providing additional functionality next to the above described.

11.3.1 Supplementary Startup Information from/to the User

The special startup features require/provide additional information from/to the application software, using a dedicated register inside the System Control Unit - STMEM0.

STMEM0 Register

The SCU_STMEM0 register is located in DMP_M power-supply domain and is Security-protected.

The following startup information can be exchanged with application software using this register:

- the user software can influence the next device startup by writing into STMEM0 bits[15:6]
The supported features are described in [Chapter 11.3.2](#).
- if STMEM0[4]=0 after startup - this startup has been triggered by a Functional (i.e. Application or Internal Application) Reset;

Startup Configuration and Bootstrap Loading

In such a case the emergency-status flags indicated in SCU_SYSCON0 bits[15:12] upon device startup can be read by user software from SCU_STMEM0 bits[3:0] as follows:

- bit[0] - OSCWDT Emergency Event Source status
- bit[1] - VCOLCK Emergency Event Source status
- bit[2] - PVC1 Emergency Event Source status
- bit[3] - Clock Select status
- if STMEM0[4]=1 after startup - this startup has been triggered by a Power-On;
 In such a case, additional information is provided by SCU_STMEM0[3] bit:
 - STMEM0[3]=0 - Power-On in DMP_1 domain only
 - STMEM0[3]=1 - Power-On in both DMP_1 and DMP_M domains

STMEM0

Startup Memory 0 Register

ESFR (F0A0_H/50_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USSET	0	RINDP	RINDS	RINPS	0					STSIND					
rw	rw	rw	rw	rw	rw					rw					

Field	Bits	Typ	Description
STSIND	[4:0]	rw	Startup Status Indication to the user: <i>Note: The values not described here are reserved.</i> 0xxxx _B Functional reset - bits[3:0] show status flags (refer to the text description) 11000 _B Power-on reset 1x1xx _B Reserved 1xx1x _B Reserved 1xxx1 _B Reserved
0	[10:5]	rw	Reserved , must be written with reset value 0
RINPS	11	rw	Initialization of the PSRAM: 0 _B not requested 1 _B will be performed upon startup
RINDS	12	rw	Initialization of the DSRAM: 0 _B not requested 1 _B will be performed upon startup
RINDP	13	rw	Initialization of the DPRAM: 0 _B not requested 1 _B will be performed upon startup

Startup Configuration and Bootstrap Loading

Field	Bits	Typ	Description
0	14	rw	Reserved , must be written with reset value 0
USSET	15	rw	RAM Initialization upon startup: 0 _B not requested 1 _B requested in STMEM0 [13:11]

11.3.2 Preparing to activate Memory Content Protection

XE166U supports parity as mechanisms for Memory Content protection, it is disabled by default.

Parity must be only activated by the user after all target RAMs are initialized meaning all location holding correct control bits. This initialization can be done using the sequence shown at [Figure 11-4](#). The processing according to this sequence includes:

- upon power-on of the device (indicated by **STMEM0**[4]=1, **STMEM0**[15] will be 0 in this case) - RAM initialization is needed:
 - optionally - if the application will run with system clock faster than 10MHz (system frequency after power-on) - the clock reconfiguration can be done still here to use increased speed for a faster RAM initialization;
 - install request for RAMs initialization by setting **STMEM0**[15:11]=10111_B;
It is also possible to set selectively only some of the bits[13:11] corresponding to the memories in which the Content Protection will be activated (refer to **STMEM0**-description and [Figure 11-4](#)). This will not bring too much - in sense of a faster startup - because all the memories are initialized in parallel and the time-variation if processing one only or all the RAMs will be not so big.
 - trigger an application reset to cause a new device startup
During this new device startup the RAMs are initialized as requested in **STMEM0**[13:11].
- if **STMEM0**[15]=1 after startup - meaning RAMs have been just initialized:
 - read one location from any initialized memory to assure correct initial state of the read-control logic
 - assure error-flags are reset - clear SCU_PECN by writing one to itself
 - enable parity in SCU_PECN and SCU_PMTSR.PESEN as required by the application
 - enable parity traps in SCU_TRAPDIS register if required by the application

Note: Depending on the application structure this can be done either here or later as part of the further system initialization.

- clear RAM-initialization request - **STMEM0**[15:11]=00000_B;
- continue with further system initialization (if any) and starting the application
- if **STMEM0**[15]=0 after functional reset (not power-on) - RAM initialization is not needed and the request is not active:

Startup Configuration and Bootstrap Loading

- enable parity as required by the application - this is needed because some control registers are reset upon any startup;
- continue with further system initialization (if any) and starting the application.

The read-operations from initialized memories produce no errors, the data delivered is 3000_H.

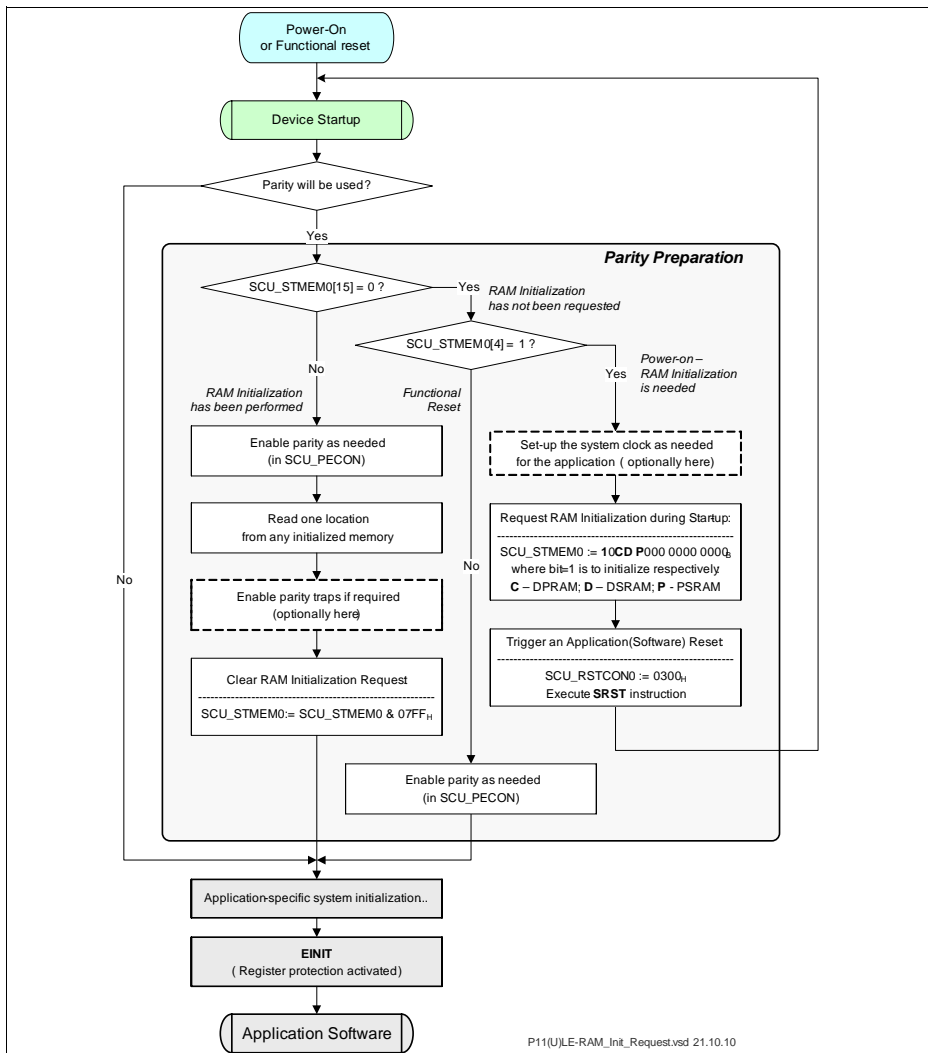


Figure 11-4 Software sequence to prepare parity usage

Startup Configuration and Bootstrap Loading

11.4 Internal Start

When internal start mode is configured, the XE166U immediately begins executing code out of the on-chip Flash memory (first instruction from location C0'0000_H).

Because internal start mode without debug-support is expected to be the configuration used in most cases, this mode can be selected by pulling low the dedicated (e.g. not available for application-purposes) $\overline{\text{TRST}}$ -pin only - so-called 0-pin Configuration.

If debug-support is needed - additional configuration options are available, refer to [Chapter 11.1.4](#).

Note: A read-protected Flash is readable for applications started in Internal mode without disabling the protection.

11.5 Bootstrap Loading

Bootstrap Loading is the technique of transferring code to the XE166U via a certain interface (usually serial) before the regular code execution out of non-volatile program memory commences. Instead, the XE166U executes the previously received code.

This boot-code may be complete (e.g. temporary software for testing or calibration), amend existing code in non-volatile program memory (e.g. with product-specific data or routines), or load additional code (e.g. using higher or more secure protocols). A possible application for bootstrap loading is the programming of virgin Flash memory at the end of a production line, with no external memory or internal Flash required for the initialization code.

The BSL mechanism may be used for standard system startup as well as only for special occasions like system maintenance (firmware update) or end-of-line programming or testing.

The XE166U supports bootstrap loading using following protocol/mode:

- Standard UART protocol, loading 32 bytes (see [Chapter 11.5.2](#))

For a summary of these modes, see also [Table 11-7](#).

11.5.1 General Functionality

Even though each bootstrap loader has its particular functionality, the general handling is the same for all of them.

Entering a Bootstrap Loader

Bootstrap loaders are enabled by selecting a specific startup configuration (see [Chapter 11.1](#)).

The required configuration patterns are summarized in [Table 11-7](#) for the bootstrap loaders.

Startup Configuration and Bootstrap Loading**Loading the Startup Code**

After establishing communication, the BSL enters a loop to receive the respective number of bytes. These bytes are stored sequentially into the on-chip PSRAM, starting at location E0'0000_H. To execute the loaded code the BSL then points register VECSEG to location E0'0000_H, i.e. the first loaded instruction, and then jumps to this instruction.

The loaded code may be the final application code or another, more sophisticated, loader routine that adds a transmission protocol to enhance the integrity of the loaded code or data. It may also contain a code sequence to change the system configuration and enable the bus interface to store the received data into external memory.

This process may go through several iterations or may directly execute the final application.

Exiting Bootstrap Loader Mode

The watchdog timer and the debug system are disabled as long as the Bootstrap loader is active. Watchdog timer and debug system are released automatically when the BSL terminates after having received the last byte from the host.

If 2nd level loaders are used, the loader routine should deactivate the watchdog timer via instruction DISWDT to allow for an extended download period.

The XE166U will start executing out of user memory as externally configured after a non-BSL reset.

Interface to the Host

The bootstrap loader communicates with the external host over a predefined set of interface pins. These interface pins are automatically enabled and controlled by the bootstrap loader. The host must connect to these predefined interface pins.

Table 11-7 indicates the interface pins that are used in each bootstrap loader mode.

11.5.2 UART Bootstrap Loader

The standard UART (Universal Asynchronous Receiver and Transmitter) bootstrap loader transfers program code/data via channel 0 of USIC0 (U0C0) into the PSRAM. The U0C0 receiver is only enabled after the identification byte has been transmitted.

Attention: The UART bootloader in XE166U supports only half-duplex communication where 1 line only (so called K-line) transmits signals in both direction - Pin 12 Port 10 (P10.12) is this common signal.

Data is transferred from the external host to the XE166U using asynchronous eight-bit data frames without parity (1 start bit, 1 stop bit). The number of data bytes to be received in standard UART boot mode is fixed to 32 bytes, which allows up to 16 two-byte instructions.

Startup Configuration and Bootstrap Loading

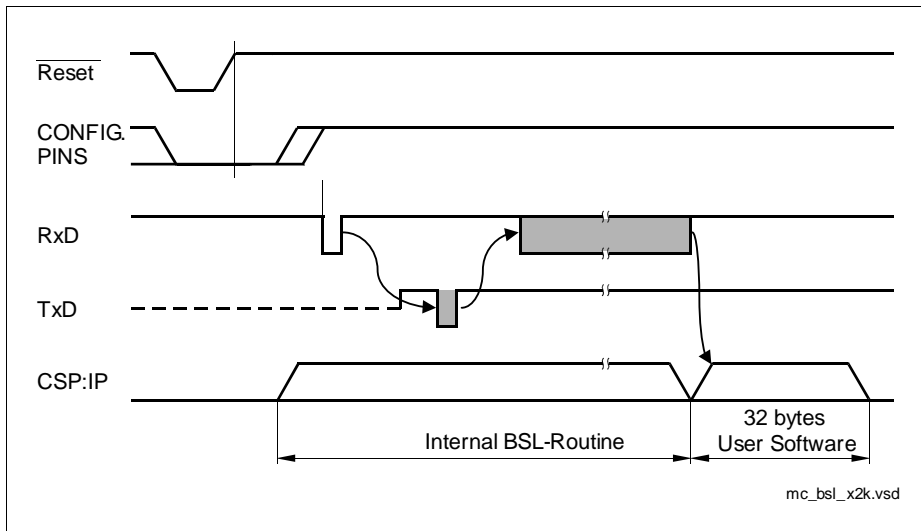


Figure 11-5 Bootstrap Loader Sequence

The XE166U scans the RxD line to receive a zero byte after entering UART BSL mode and the respective initialization. The zero byte is considered as containing one start bit, eight 0 data bits and one stop bit. From the duration of this zero byte it calculates the corresponding baudrate factor with respect to the current CPU clock, initializes the serial interface U0C0 accordingly and switches pin TxD to output. Using this baudrate, an identification byte (D5_H) is returned to the host that provides the loaded data.

Once the identification byte is transmitted, the BSL enters a loop to receive 32 bytes via U0C0. These bytes are stored sequentially into locations E0'0000_H through E0'001F_H of the internal PSRAM and then executed.

Note: For loading more code, a 2nd-level loader must be used - see [Chapter 11.5.2.2](#).

11.5.2.1 Choosing the Baudrate for the BSL

The calculation of the serial baudrate for U0C0 from the length of the first zero byte that is received, allows the operation of the bootstrap loader of the XE166U with a wide range of baudrates. However, the upper and lower limits have to be kept, in order to ensure proper data transfer.

The XE166U uses bitfield PDIV to measure the length of the initial zero byte. The quantization uncertainty of this measurement implies the deviation from the real baudrate.

For a correct data transfer from the host to the XE166U the maximum deviation between the internal initialized baudrate for U0C0 and the real baudrate of the host should be below 2.5%. The deviation (F_B , in percent) between host baudrate and XE166U baudrate can be calculated via [Equation \(11.1\)](#):

$$F_B = \left| \frac{B_{Contr} - B_{Host}}{B_{Contr}} \right| \times 100\% \quad F_B \leq 2.5\% \quad (11.1)$$

Note: Function (F_B) does not consider the tolerances of oscillators and other devices supporting the serial communication.

This baudrate deviation is a nonlinear function depending on the system clock and the baudrate of the host. The maxima of the function (F_B) increase with the host baudrate due to the smaller baudrate prescaler factors and the implied higher quantization error (see [Figure 11-6](#)).

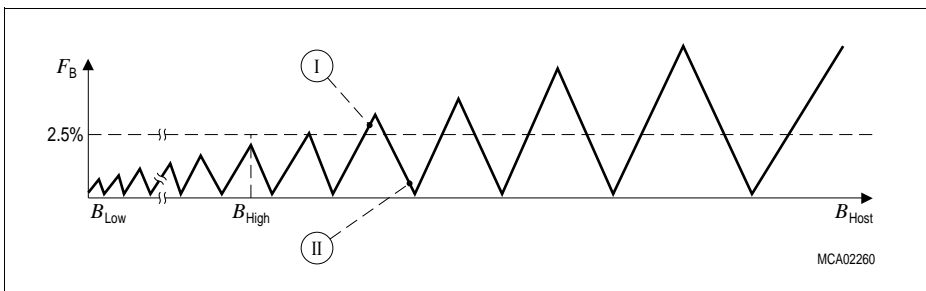


Figure 11-6 Baudrate Deviation between Host and XE166U

The minimum baudrate (B_{Low} in [Figure 11-6](#)) is determined by the maximum count capacity of bitfield PDIV, when measuring the zero byte, i.e. it depends on the system clock. The minimum baudrate is obtained by using the maximum PDIV count 2^{10} in the baudrate formula. Baudrates below B_{Low} would cause PDIV to overflow. In this case U0C0 cannot be initialized properly and the communication with the external host is likely to fail.

Startup Configuration and Bootstrap Loading

The **maximum baudrate** (B_{High} in [Figure 11-6](#)) is the highest baudrate where the deviation still does not exceed the limit, i.e. all baudrates between B_{Low} and B_{High} are below the deviation limit. B_{High} marks the baudrate up to which communication with the external host will work properly without additional tests or investigations.

Higher baudrates, however, may be used as long as the actual deviation does not exceed the indicated limit. A certain baudrate (marked I) in [Figure 11-6](#)) may e.g. violate the deviation limit, while an even higher baudrate (marked II) in [Figure 11-6](#)) stays very well below it. Any baudrate can be used for the bootstrap loader provided that the following three prerequisites are fulfilled:

- the baudrate is within the specified operating range for U0C0
- the external host is able to use this baudrate
- the computed deviation error is below the limit.

Note: When the bootstrap loader mode is entered after a power reset, the bootstrap loader will begin to operate with $f_{\text{SYS}} = f_{\text{IOSC}} \times 2$ (approximately 10 MHz) which will limit the maximum baudrate for U0C0.

Higher levels of the bootstrapping sequence can then switch the clock generation mode in order to achieve higher baudrates for the download.

11.5.2.2 Second Level Bootloader

Most probably the initially loaded routine will load additional code or data, as an average application is likely to require substantially more instructions than could fit into 32 bytes. This second receive loop may directly use the pre-initialized interface U0C0 to receive data and store it to arbitrary user-defined locations.

When UART Bootloader mode is selected and before to jump to the 32 Bytes of code primary loaded, the start-up procedure makes some settings into R0...R3 and DPP1 core registers. The values there are to be used by a secondary UART bootloader for transferring application code via U0C0 to PSRAM. These pre-set registers (see [Table 11-6](#)) and the pre-initialized serial channel make it possible to fit a 2nd-level loader into the available 32 bytes - refer to the example code at [Figure 11-7](#).

The complete processing to download more than 32Bytes via UART-interface is as follows:

- the device is started in UART Bootloader mode
- the secondary bootloader (up to 32 Bytes of code) is sent to the device
- the start-up procedure ends, the downloaded code is started
- the complete application code with length corresponding to the address range defined is sent to device
- the code is started from the address as defined (Code_Start).

Startup Configuration and Bootstrap Loading

```

=====
;
;          ----- pointers/values prepared by the Startup software -----
;
;          DPP0 points to PSRAM base address
;          DPP1 points to USIC base address
;          R0   points to PSR (to check xIF)
;          R1   points to PSCR (to clear xIF)
;          R2   points to RBUF(receive data)
;          R3   contains the mask to clear RIF
;          DPP0:R10 point to E0'0020 (the first free location in PSRAM after ASC BL)
;
=====
;
;          ----- code for a secondary ASC bootstrap loader -----
;
BL0_PSR_RIF_b EQU    14                ; definition of RIF bit-position

; when downloading it , what must be supplied within the respective Byte-positions:

Load_End      lit     '0E001FFh' ; (example value!)      ; end address for loading
Code_Start    lit     '0E00100h' ; (example value!)      ; address where from to start the code

;
;    ATTENTION:
;    With this version, the code downloaded can not cross the page -boundary !
;    For a longer downloads , the enhanced ASC bootloader should be used .
;
;    ----- the code itself is not more than 32 Bytes long -----
;
;    *** optional – if the start address for downloading must be different from E 0'0020 ***
;Load_Beg     lit     '0E00040h' ; (example value!)
;    mov      R10, #(DPP0:Load_Beg)

        diswtd
ld2_mainloop:
    mov      [R1], R3                ; clear RIF

ld2_recloop:
    mov      R4, [R0]                ; check PSR
    jnb      R4,BL0_PSR_RIF_b, ld2_recloop ; wait for RIF

    movb     [R10], [R2]              ; get data from RBUF & store to memory

    cmpi1    R10, #POF (Load_End)    ; check for last address
    jmp      cc_NE, ld2_mainloop

    jmps     SEG Code_Start, SOF Code_Start ; ==> jump to code <==

=====

```

P11_MRplus-SSW-ASC_BL2-v1.0.vsd

Figure 11-7 Secondary UART Bootloader

Startup Configuration and Bootstrap Loading

11.5.2.3 Specific Settings

The following configuration is automatically set when the XE166U has entered Standard UART BSL mode:

Table 11-6 Standard UART BSL-Specific State

Item	Value	Comments
U0C0_CCR	0002 _H	ASC mode selected for USIC0 Channel 0
U0C0_PCRL	0401 _H	1 stop bit, three RxD-samples at point 4
U0C0_SCTRL	0002 _H	Passive data level = 1
U0C0_SCTRH	0707 _H	8 data bits
U0C0_FDRL	43FF _H	Normal divider mode 1:1 selected
U0C0_BRGH	0XXX _H	Measured PDIV value (zero-byte) in bits[9:0]
U0C0_BRGL	1C00 _H	Normal mode, FDIV, 8 clocks/bit
U0C0_DX0CR	0003 _H	Data input selection
DPP1	0081 _H	Points to USIC0 base address ¹⁾
R0	4044 _H	Pointer to U0C0_PSR ¹⁾
R1	4048 _H	Pointer to U0C0_PSCR ¹⁾
R2	405C _H	Pointer to U0C0_RBUIF ¹⁾
R3	4000 _H	Mask to clear RIF ¹⁾
P10_IOC12	00A0 _H	P10.12 assigned to O2-output function (U0C0_DOUT) and direct input (U0C0_DX0D) - K-line, combined Rx/D/TxD

¹⁾ This register setting is provided for a 2nd-level loader routine (see at [Page 11-21](#)).

The identification byte identifies the device to be booted. The following codes are defined:

55_H: 8xC166.

A5_H: Previous versions of the C167 (obsolete).

B5_H: Previous versions of the C165.

C5_H: C167 derivatives.

D5_H: All devices equipped with identification registers (including the XE166U).

Note: The identification byte D5_H does not directly identify a specific derivative. This information can, in this case, be obtained from the identification registers.

Startup Configuration and Bootstrap Loading

11.5.3 Summary of Bootstrap Loader Modes

This table summarizes the external hardware provisions that are required to activate a bootstrap loader in a system.

Table 11-7 Configuration Data for Bootstrap Loader Modes

Bootstrap Loader Mode	Configuration indicated in HWCFG	Receive Line from Host	Transmit Line to Host	Transferred Data	Supported Host Speed
Standard UART	0xxx xx01 _B	RxD = TxD = P10.12		32 bytes	2.4 - 19.2 kbaud

12 On-Chip Debug Support (OCDS)

The XE166U includes an OCDS system, which provides convenient debugging, controlled directly by an external tool via debug interface pins.

OCDS Components

- **Debug Interface**
- **Cerberus**
- **OCDS Module**

On-Chip Debug Support (OCDS)

The OCDS system (**Figure 12-1**) supports a broad range of debug features including breakpoints and the tracing of memory locations. A typical application of the OCDS is to debug user software running on the XE166U in a real time system environment.

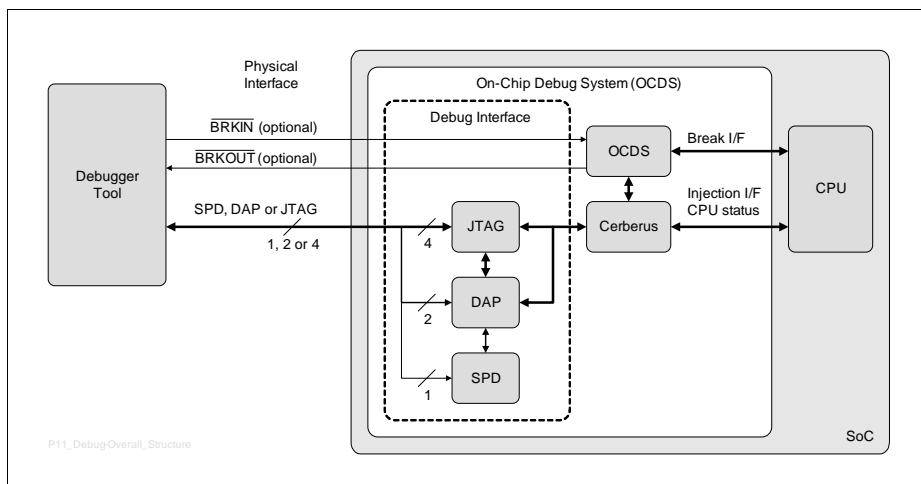


Figure 12-1 OCDS Block Diagram

The OCDS is controlled by an external tool via the **Debug Interface**. The physical interface is SPD, DAP or JTAG plus an optional break interface with one or two pins. The break interface supports very low latency triggers between XE166U and tool and/or system environment if needed. The memory mapped OCDS registers are accessible via the SPD/DAP/JTAG interface using Cerberus. In addition there is a limited set of special Cerberus debug IO instructions. As an alternative the OCDS can be controlled by a debug monitor program, which communicates with the tool over a user interface like CAN. The OCDS system interacts with the CPU through an injection interface to allow execution of Cerberus-generated instructions and through a break port.

OCDS System Features

- Hardware, software and external pin breakpoints
- Trigger action can be CPU-halt, monitor call, data transfer and/or $\overline{\text{BRKOUT}}$ signal
- Read/write access to the whole address space
- Single stepping
- Non intrusive debugging (no debug monitor needed)
- Debug also possible over user interface like CAN (with debug monitor)
- SPD, DAP or JTAG interface and optional break interface
- Injection of arbitrary CPU instructions
- Fast memory tracing through transfer to external bus (if available)

12.1 Debug Interface

The Debug Interface allows to access OCDS resources. Data can be transferred to/from all on- and off-chip memories and memory mapped control registers.

Features and Functions

- Independent interface for OCDS
- Alternative tool access interfaces
 - **JTAG Interface** (IEEE 1149.1 compliant, 4 pins)
 - **DAP (Device Access Port) Interface** (2 pins)
 - **SPD (Single Pin DAP) Interface** (1 pin)
- **OCDS Break-Interface** for external trigger input and signaling of internal triggers
- Generic memory access functionality
- Independent data transfer channel for e.g. programming of flash memory

Attention: The DAP/JTAG clock frequency must be below the current CPU frequency.

JTAG Interface

The JTAG interface is a standardized and dedicated port, primarily provided for boundary scan board tests.

This interface consists of the JTAG IEEE.1149.1-2001 standard signals:

- **TDI** - Serial data input
- **TDO** - Serial data output
- **TCK** - JTAG clock
- **TMS** - State machine control signal

DAP (Device Access Port) Interface

The DAP interface is a device access port standardized for the latest Infineon microcontrollers. It reduces the pin count to two pins and offers high noise immunity and robustness.

This interface consists of the signals:

- **DAP0** - clock
- **DAP1** - Serial data input/output

SPD (Single Pin DAP) Interface

The SPD interface is a device access port standardized for the latest Infineon microcontrollers. It reduces the pin count to the single **SPD** signal and offers high noise immunity and robustness. The SPD performance is similar to a DAP interface with 1.3 MHz clock.

OCDS Break-Interface

Two optional additional signals provide a direct trigger interface between the Debugger and XE166U **OCDS Module**:

- **BRKIN** (BReaK IN request) allows to trigger directly one of the **Debug Actions**.
- **BRKOUT** (BReaK OUT signal) can be activated by OCDS to notify the tool with minimum latency that some predefined debug event has happened.

12.1.1 Routing of Debug Signals

The signals used to connect an external debugger via the JTAG interface and the break interface usually conflict with the requirements to have as many IO pins as possible for the application. In the XE166U, these signals are only provided as alternate functions (no dedicated pins). To minimize the impact caused by the debug interface pins, these signals can be mapped to various positions. Thus, each application can select the variant with the least impact. This is controlled via the Debug Pin Routing Register **DBGPRR**. Pin BRKOUT can be assigned to pins P6.0, P10.11, P1.5, or P9.3 (as far as available for a specific package variant) as an alternate output signal via the respective IOC register.

12.1.1.1 Register DBGPRR

This register controls the pin routing of the SPD/DAP/JTAG pins. The routing options are controlled with the register **DBGPRR**, which is set during start-up as described in **Section 1.3.2**.

The bit field description of **DBGPRR includes all routing options for all derivatives of the family with SPD/DAP/JTAG Interface. For derivatives with lower pin count packages, unavailable positions shall be treated as reserved.**

DBGPRR

Debug Pin Routing Register

ESFR (F06E_H/37_H)

Reset Value: 0001_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRS TL	TRS TS	TRS TGT	DBG EN	JTAG DAP	DPR E	DPR BRKIN	DPR TCK	DPR TMS	DPR TDI	DPR TDO					
rh	rh	rw	rw	rw	r	rw	rw	rw	rw	rw					

Field	Bits	Type	Description
DPRTDO	[1:0]	rw	Pin Routing for DAP1/TDO 00 _B P7.0 01 _B P10.12 10 _B Reserved 11 _B P10.12 is used as SPD pin
DPRTDI	[3:2]	rw	Pin Routing for TDI 00 _B P5.2 01 _B P10.10 10 _B P7.2 11 _B P8.3
DPRTMS	[5:4]	rw	Pin Routing for TMS 00 _B P5.4 01 _B P10.11 10 _B P7.3 11 _B P8.4
DPRTCK	[7:6]	rw	Pin Routing for DAP0/TCK 00 _B P2.9 01 _B P10.9 10 _B P7.4 11 _B P8.5
DPRBRKIN	[9:8]	rw	Pin Routing for BRKIN 00 _B P5.10 01 _B P10.8 10 _B P7.1 11 _B P8.6

Field	Bits	Type	Description
DPRE	10	rw	Port 13 Routing for DAP/JTAG DAP0/TCK P13.6, DAP1/TDO P13.8, TMS P13.3, TDI P13.5. Will overrule all other routing settings for these pins. 0 _B Port 13 is not used. 1 _B Port 13 is used
JTAG_DAP	11	rw	Selection of Debug Interface 0 _B DAP or SPD is used 1 _B JTAG is used
DBGEN	12	rw	Enable for selected Debug Interface 0 _B Interface is disabled 1 _B Interface is enabled
TRSTGT	13	rw	Gating of TRST Pin 0 _B <u>DAP/JTAG</u> reset is internally held active 1 _B TRST pin is routed to DAP/JTAG reset
TRSTS	14	rh	TRST Pin Value Current value of TRST pin
TRSTL	15	rh	Latched TRST Pin Start-up Value Value of TRST pin latched by PORST release

12.2 OCDS Module

The application of the OCDS Module is to debug user software running on the CPU in the customer's system. This is done with an external debugger, which controls the OCDS Module via the independent [Debug Interface](#).

Features

- Hardware, software and external pin breakpoints
- Hardware trigger generation for breakpoints and external pin output
 - Four single address or two address ranges for instruction or data
 - Combination of instruction (range) and data address (range)
 - Combination of data address (range) and data value (range)
 - Task ID, optional in combination with address (range) for instruction or data
 - Masked comparisons for addresses and data
- The OCDS can also be configured by a debug monitor program
- Single stepping with monitor or CPU halt
- Higher priority interrupts can still be served if CPU is halted
- Instruction pointer visible in Halt Mode

Basic Concept

The on chip debug concept is split up into two parts. The first part covers the generation of debug events and the second part defines what actions are taken when a debug event is generated.

- Debug events:
 - **Hardware Breakpoints**
 - **Software Breakpoints**
 - **Break Pin Input** activated
- Debug event actions:
 - **Halt Mode** of the CPU
 - **Call a Monitor**
 - **Triggered Transfer**
 - **Activate External Pin**

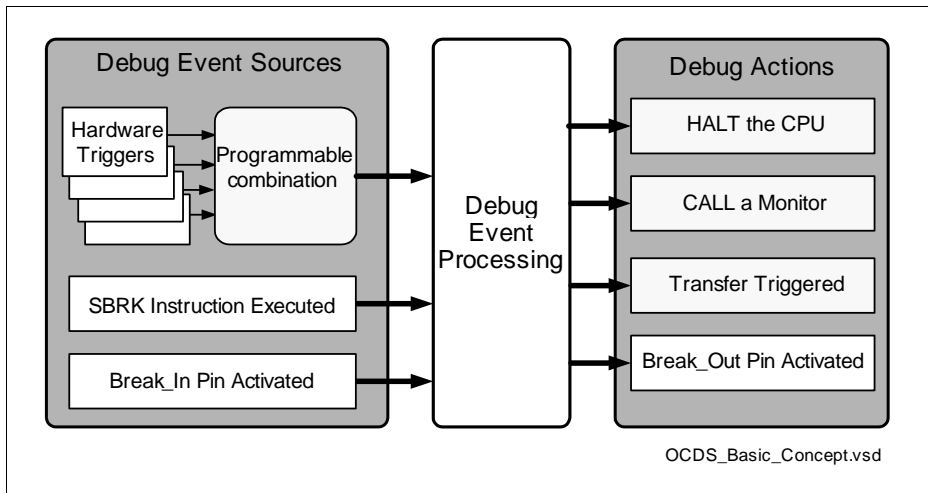


Figure 12-2 OCDS Concept: Block Diagram

12.2.1 Debug Events

The Debug Events can come from a few different sources.

Hardware Breakpoints

The Hardware Breakpoint is a debug-event, raised when a single or a combination of multiple trigger-signals are matching with the programmed conditions. The following hardware trigger sources can be used:

Table 12-1 Hardware Triggers

Trigger Source	Size
Task Identifier	16 bits
Instruction Pointer	24 bits
Data address of reads (two buses monitored)	2 × 24 bits
Data address of writes	24 bits
Data value (reads or writes)	16 bits

Software Breakpoints

A special SBRK (Software BReak) instruction is defined with opcode 0x8C00. It can be used for instance by a debugger to temporarily replace code held in RAM in order to implement Software Breakpoints. When the SBRK instruction has been decoded and it reaches the execute stage, the whole pipeline is canceled including the SBRK instruction. This implies that the next instruction will be fetched from the address the SBRK was found at.

The further behavior is dependent on how OCDS has been programmed:

- if the OCDS is enabled and the software breakpoints are also enabled, then the CPU goes into **Halt Mode**
- if the OCDS is disabled or the software breakpoints are disabled, then the Software Break Trap (SBRKTRAP) is executed - Class A Trap, number 08_H

Break Pin Input

An external debug break pin ($\overline{\text{BRKIN}}$) is provided to allow the debugger to asynchronously interrupt the processor.

12.2.2 Debug Actions

When the OCDS is enabled and a debug event is generated, one of the following actions is taken:

Triggered Transfer

One of the actions that can be specified to occur on a debug event being raised is to trigger the **Cerberus**:

- to execute a Data Transfer. This can be used in critical routines where the system cannot be interrupted to transfer a memory location
- to inject an instruction to the CPU, using this mechanism, an arbitrary instruction can be injected into the XE166U pipeline

Halt Mode

Upon this Action the OCDS Module sends a Break-Request to the CPU.

The CPU accepts this request, if the OCDS Break Level is higher than current CPU priority level. In case a Break-Request is accepted, the system suspends execution with halting the instruction flow.

The Halt Mode can be still interrupted by higher priority user interrupts. It then relies on the external debugger system to interrogate the target purely through reading and updating via the debug interface.

Call a Monitor

One of the possible actions to be taken when a debug event is raised is to call a Monitor Program. This quick entry to a Monitor allows a flexible debug environment to be defined which is capable of satisfying many of the requirements for efficient debugging of a real time system. In the common case the Monitor has the highest priority and can not be interrupted by any other requesting source.

It is also possible to have an Interruptible Monitor Program. In such a case safety critical code can be still served while the Monitor (Debugger) is active, which gives a maximum flexibility to the user.

Activate External Pin

This action activates the external pin $\overline{\text{BRKOUT}}$ of the **OCDS Break-Interface**. It can be used in critical routines where the system cannot be interrupted to signal to the external world that a particular event has happened. Note that the code execution timing is not affected.

12.3 Cerberus

Cerberus is the module which provides and controls all the operations necessary to interact between the external debugger (via the **Debug Interface**), the **OCDS Module** and the internal system of XE166U.

Features

- SPD/DAP/JTAG interface is used as control and data channel
- Generic read/write functionality (RW mode) with access to the whole address space
- Reading and writing of general-purpose registers (GPRs)
- Injection of arbitrary instructions
- External host controls all transactions
- All transactions are available at normal run time and in halt mode
- Priority of transactions can be configured
- Full support for communication between the monitor and debugger
- Optional error protection

On-Chip Debug Support (OCDS)

- Tracing memory locations through transferring values to the external bus
- Analysis register for internal bus locking situations

The target application of Cerberus is to use the SPD/DAP/JTAG interface as an independent port for on-chip debug support. The external debugger can access the OCDS registers and arbitrary memory locations with the injection mechanism.

12.3.1 Functional Overview

Cerberus is operated by an external debugger across the SPD/DAP/JTAG interface. The Debugger uses Cerberus IO Instructions to perform bidirectional data-transfers. Cerberus has two main modes of operation:

Read/Write (RW) Mode

RW Mode is the most common way to operate Cerberus. This mode is used to read and write memory locations or to inject instructions into the CPU pipeline. The injection interface to the CPU is actively used in this mode.

All Cerberus IO Instructions can be used in RW mode. The access to any memory location is performed with injected instructions, as a PEC transfer.

Communication (COM) Mode

In COM mode the debugger communicates with a monitor program running on the CPU. The difference to **Read/Write (RW) Mode** is that the read or write request is not actively executed. It just sets request bits in a CPU accessible status register to signal the monitor, that the debugger wants to send or receive a value. The monitor has to poll this status register, e.g. triggered by a timer interrupt.

COM Mode is the default mode after reset. It can be used to exchange keys with the application software of a locked (RW Mode disabled) device and to unlock RW Mode only in case of matching keys.

12.4 Emulation Device

The XE166U can be emulated using an MCDS (Multi-Core Debug Solution) based Emulation Device with an on-chip trace buffer (**Figure 12-3**). For availability of such an emulator please contact your Infineon tool partner.

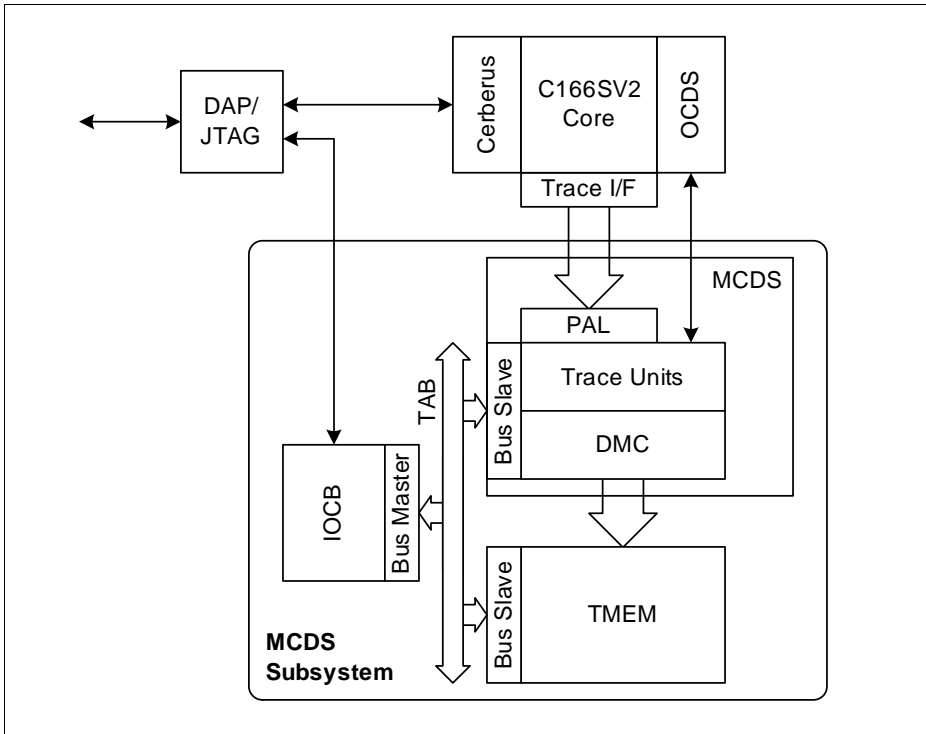


Figure 12-3 Emulation Device Block Diagram

12.4.1 MCDS Use Cases

MCDS allows non intrusive tracing and triggering for debugging, performance analysis and data measurement.

Debugging

- Halt on very complex trigger conditions
- Record trace around bug
- Halt (suspend) system when trace buffer full. Read out and continue
- Highly compressed or cycle accurate trace

Performance Analysis

- Continuous measurement of performance indicators
- Trigger on performance indicators

Data Measurement

- Continuous trace of data writes or reads
- Qualified by address ranges and e.g. software task

12.4.2 MCDS Features

MCDS provides a rich set of features, which allow a very detailed analysis of the software and system behavior on all levels.

CPU Program Trace

- Complete program trace for the 24 bit instruction pointer
- Four independent range comparators

CPU Ownership Trace

- Complete trace of the pipeline “user” (e.g. PEC channel)
- Two independent masked comparators for data transfer qualification

CPU Status Trace

- Complete trace of the execution mode of the CPU
- Non-intrusive access to the current status.

Write Data Trace

- Complete trace of write-back transactions (24 bit address, 8 or 16 bit data)
- Four independent range comparators on the absolute write address
- Four independent signed data comparators on the data value

Read Data Trace

- Complete trace of non CPU memory read transactions (24 bit addr., 8 or 16 bit data)
- Four independent range comparators on the absolute address
- Four independent signed data comparators on the data value

Trace and Trigger Control

- Dedicated programmable trace enables for each Trace Unit
- Trigger output to OCDS
- Eight universal 16 bit counters
- Programmable combinations of triggers as count and clear signals

- Programmable limit comparator in each counter
- Passing a limit is available as unique trigger for each counter
- The counter values can be traced
- Counters can be cascaded to implement state machines
- Pre-scaled reference clock available as trigger
- Four performance indicator signals directly from the CPU

Watch-point Trace

- Messages for eight different watch-points
- Messages containing the current count value of any event/performance Counter

Time Stamping

- Precise time stamps based on the emulation clock (32 bit)
- Precise time stamps based on a reference clock (32 bit)
- Programmable cyclic trigger based on reference clock

12.5 Boundary-Scan

The XE166U eases board-level analysis in the application system by providing Boundary-Scan according to the IEEE standard 1149.1. It supports testing of the interconnections between several devices mounted on a PCB.

Boundary-Scan is accomplished via the JTAG module, using standard JTAG instructions (IEEE1149.1). The Boundary-Scan chain of a device is described in a BSDL file, which is available from your Infineon contact.

Note: Some devices have the same JTAG ID, but require a different BSDL file, due to a different pad to pin bonding in the package.

*Note: For Boundary-Scan to operate properly, the JTAG interface must use the default pins. The reset value of register **DBGPRR** ensures this.*

Initialization of Boundary-Scan

The following sequence is defined to activate Boundary-Scan mode:

- Set $\overline{\text{PORST}} = 1$; $\overline{\text{TRST}} = 1$; $\overline{\text{TESTM}} = 1$
- Negative Pulse on $\overline{\text{PORST}}$
- Wait for Power Domain to startup.
- Negative pulse on $\overline{\text{TRST}}$ to reset the JTAG controller.

Now the test access port for Boundary-Scan is enabled. The Boundary-Scan test can be used for board test with instructions like PRELOAD and EXTEST.

13 Instruction Set Summary

This chapter briefly summarizes the XE166U's instructions ordered by instruction classes. This provides a basic understanding of the XE166U's instruction set, the power and versatility of the instructions and their general usage.

A detailed description of each single instruction, including its operand data type, condition flag settings, addressing modes, length (number of bytes) and object code format is provided in the “**Instruction Set Manual**” for the XE166U Derivatives. This manual also provides tables ordering the instructions according to various criteria, to allow quick references.

Summary of Instruction Classes

Grouping the various instruction into classes aids in identifying similar instructions (e.g. SHR, ROR) and variations of certain instructions (e.g. ADD, ADDB). This provides an easy access to the possibilities and the power of the instructions of the XE166U.

Note: The used mnemonics refer to the detailed description.

Table 13-1 Arithmetic Instructions

Addition of two words or bytes:	ADD	ADDB
Addition with Carry of two words or bytes:	ADDC	ADDCB
Subtraction of two words or bytes:	SUB	SUBB
Subtraction with Carry of two words or bytes:	SUBC	SUBCB
16 × 16 bit signed or unsigned multiplication:	MUL	MULU
16/16 bit signed or unsigned division:	DIV	DIVU
32/16 bit signed or unsigned division:	DIVL	DIVLU
1's complement of a word or byte:	CPL	CPLB
2's complement (negation) of a word or byte:	NEG	NEGB

Table 13-2 Logical Instructions

Bitwise ANDing of two words or bytes:	AND	ANDB
Bitwise ORing of two words or bytes:	OR	ORB
Bitwise XORing of two words or bytes:	XOR	XORB

Table 13-3 Compare and Loop Control Instructions

Comparison of two words or bytes:	CMP	CMPB
Comparison of two words with post-increment by either 1 or 2:	CMP11	CMP12
Comparison of two words with post-decrement by either 1 or 2:	CMPD1	CMPD2

Table 13-4 Boolean Bit Manipulation Instructions

Manipulation of a maskable bit field in either the high or the low byte of a word:	BFLDH	BFLDL
Setting a single bit (to '1'):	BSET	–
Clearing a single bit (to '0'):	BCLR	–
Movement of a single bit:	BMOV	–
Movement of a negated bit:	BMOVN	–
ANDing of two bits:	BAND	–
ORing of two bits:	BOR	–
XORing of two bits:	BXOR	–
Comparison of two bits:	BCMP	–

Table 13-5 Shift and Rotate Instructions

Shifting right of a word:	SHR	–
Shifting left of a word:	SHL	–
Rotating right of a word:	ROR	–
Rotating left of a word:	ROL	–
Arithmetic shifting right of a word (sign bit shifting):	ASHR	–

Table 13-6 Prioritize Instruction

Determination of the number of shift cycles required to normalize a word operand (floating point support):	PRIOR	–
--	-------	---

Table 13-7 Data Movement Instructions

Standard data movement of a word or byte:	MOV	MOVB
Data movement of a byte to a word location with either sign or zero byte extension:	MOVBS	MOVBZ

Note: The data movement instructions can be used with a big number of different addressing modes including indirect addressing and automatic pointer in-/decrementing.

Table 13-8 System Stack Instructions

Pushing of a word onto the system stack:	PUSH	–
Popping of a word from the system stack:	POP	–
Saving of a word on the system stack, and then updating the old word with a new value (provided for register bank switching):	SCXT	–

Table 13-9 Jump Instructions

Conditional jumping to an either absolutely, indirectly, or relatively addressed target instruction within the current code segment:	JMPA	JMPI	JMPR
Unconditional jumping to an absolutely addressed target instruction within any code segment:	JMPS	–	–
Conditional jumping to a relatively addressed target instruction within the current code segment depending on the state of a selectable bit:	JB	JNB	–
Conditional jumping to a relatively addressed target instruction within the current code segment depending on the state of a selectable bit with a post-inversion of the tested bit in case of jump taken (semaphore support):	JBC	JNBS	–

Table 13-10 Call Instructions

Conditional calling of an either absolutely or indirectly addressed subroutine within the current code segment:	CALLA	CALLI
Unconditional calling of a relatively addressed subroutine within the current code segment:	CALLR	–
Unconditional calling of an absolutely addressed subroutine within any code segment:	CALLS	–
Unconditional calling of an absolutely addressed subroutine within the current code segment plus an additional pushing of a selectable register onto the system stack:	PCALL	–
Unconditional branching to the interrupt or trap vector jump table in code segment <VECSEG>:	TRAP	–

Table 13-11 Return Instructions

Returning from a subroutine within the current code segment:	RET	–
Returning from a subroutine within any code segment:	RETS	–
Returning from a subroutine within the current code segment plus an additional popping of a selectable register from the system stack:	RETP	–
Returning from an interrupt service routine:	RETI	–

Table 13-12 System Control Instructions

Resetting the XE166U via software:	SRST	–
Entering the Idle mode:	IDLE	–
No function, do not use ¹⁾ :	PWRDN	–
Servicing the Watchdog Timer:	SRVWDT	–
Disabling the Watchdog Timer:	DISWDT	–
Enabling the Watchdog Timer (can only be executed in WDT enhanced mode):	ENWDT	–
Signifying the end of the initialization routine (switches the register security mechanism to “protected” and disables the effect of any later execution of a DISWDT instruction in WDT compatibility mode):	EINIT	–

¹⁾ Instruction PWRDN is used to enter Power Down mode in previous 16-bit architectures. In the XE166U devices, however, PWRDN has no effect and is executed like a NOP instruction.

Table 13-13 Miscellaneous

Null operation which requires 2 Bytes of storage and the minimum time for execution:	NOP	–
Definition of an unseparable instruction sequence:	ATOMIC	–
Switch ‘reg’, ‘bitoff’ and ‘bitaddr’ addressing modes to the Extended SFR space:	EXTR	–
Override the DPP addressing scheme using a specific data page instead of the DPPs, and optionally switch to ESFR space:	EXTP	EXTPR
Override the DPP addressing scheme using a specific segment instead of the DPPs, and optionally switch to ESFR space:	EXTS	EXTSR

Note: The ATOMIC and EXT instructions provide support for uninterruptable code sequences e.g. for semaphore operations. They also support data addressing beyond the limits of the current DPPs (except ATOMIC), which is advantageous for bigger memory models in high level languages.*

Table 13-14 MAC-Unit Instructions

Multiply (and Accumulate):	CoMUL	CoMAC
Add/Subtract:	CoADD	CoSUB
Shift right/Shift left:	CoSHR	CoSHL
Arithmetic Shift right:	CoASHR	–
Load Accumulator:	CoLOAD	–
Store MAC register:	CoSTORE	–
Compare values:	CoCMP	–
Minimum/Maximum:	CoMIN	CoMAX
Absolute value:	CoABS	–
Rounding:	CoRND	–
Move data:	CoMOV	–
Negate accumulator:	CoNEG	–
Null operation:	CoNOP	–

Protected Instructions

Some instructions of the XE166U which are critical for the functionality of the controller are implemented as so-called Protected Instructions. These protected instructions use the maximum instruction format of 32 bits for decoding, while the regular instructions only use a part of it (e.g. the lower 8 bits) with the other bits providing additional information like involved registers. Decoding all 32 bits of a protected doubleword instruction increases the security in cases of data distortion during instruction fetching. Critical operations like a software reset are therefore only executed if the complete instruction is decoded without an error. This enhances the safety and reliability of a microcontroller system.

14 General Purpose Timer Units (GPT12)

The General Purpose Timer Unit blocks GPT1 and GPT2 have very flexible multifunctional timer structures which may be used for timing, event counting, pulse width measurement, pulse generation, frequency multiplication, and other purposes.

They incorporate five 16-bit timers that are grouped into the two timer blocks GPT1 and GPT2. Each timer in each block may operate independently in a number of different modes such as Gated timer or Counter Mode, or may be concatenated with another timer of the same block.

Each block has alternate input/output functions and specific interrupts associated with it. Input signals can be selected from several sources by register PISEL.

The GPT module is clocked with clock f_{GPT} .

Block GPT1 contains three timers/counters: The core timer T3 and the two auxiliary timers T2 and T4. The maximum resolution is $f_{\text{GPT}}/4$. The auxiliary timers of GPT1 may optionally be configured as reload or capture registers for the core timer. These registers are listed in [Section 14.1.7.1](#).

The following list summarizes the supported features:

- $f_{\text{GPT}}/4$ maximum resolution
- 3 independent timers/counters
- Timers/counters can be concatenated
- 4 operating modes:
 - Timer Mode
 - Gated Timer Mode
 - Counter Mode
 - Incremental Interface Mode
- Reload and Capture functionality
- Separate interrupts

Block GPT2 contains two timers/counters: The core timer T6 and the auxiliary timer T5. The maximum resolution is $f_{\text{GPT}}/2$. An additional Capture/Reload register (CAPREL) supports capture and reload operation with extended functionality. These registers are listed in [Section 14.2.8.1](#).

The core timer T6 may be concatenated with timers of the CAPCOM units (T7 and T8).

The following list summarizes the supported features:

- $f_{\text{GPT}}/2$ maximum resolution
- 2 independent timers/counters
- Timers/counters can be concatenated
- 3 operating modes:
 - Timer Mode
 - Gated Timer Mode
 - Counter Mode

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- Extended capture/reload functions via 16-bit capture/reload register CAPREL
- Separate interrupt

Attention: *.Not every timer can work in Gated Timer Mode or Counter Mode as described in [Chapter 14.1](#) and [Chapter 14.2](#) due to missing input pins. Furthermore, the functionality can be restricted. The not supported timer modes are listed in [Chapter 14.5](#).*

General Purpose Timer Units (GPT12)

14.1 Timer Block GPT1

From a programmer's point of view, the GPT1 block is composed of a set of SFRs as summarized below. Those portions of port and direction registers which are used for alternate functions by the GPT1 block are shaded.

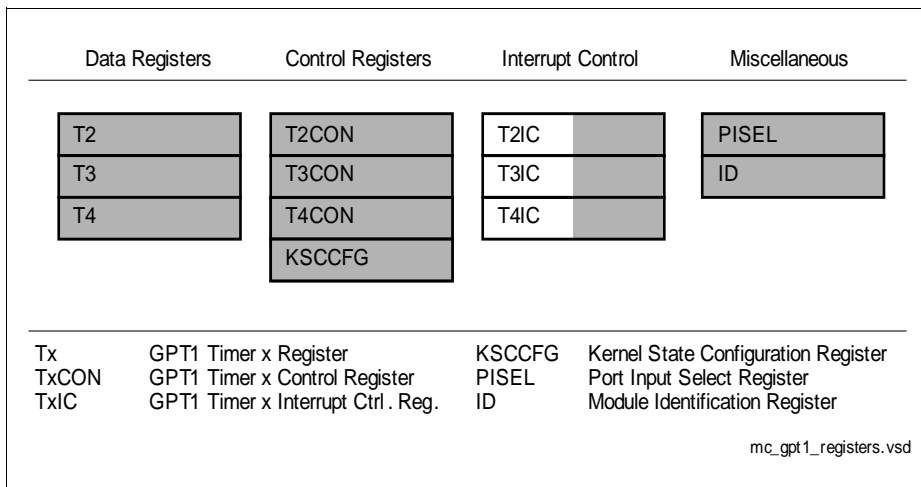


Figure 14-1 SFRs Associated with Timer Block GPT1

All three timers of block GPT1 (T2, T3, T4) can run in one of 4 basic modes: Timer Mode, Gated Timer Mode, Counter Mode, or Incremental Interface Mode. All timers can count up or down. Each timer of GPT1 is controlled by a separate control register TxCON.

Each timer has an input pin TxIN (alternate pin function) associated with it, which serves as the gate control in Gated Timer Mode, or as the count input in Counter Mode. The count direction (up/down) may be programmed via software or may be dynamically altered by a signal at the External Up/Down control input TxEUD (alternate pin function). An overflow/underflow of core timer T3 is indicated by the Output Toggle Latch T3OTL, whose state may be output on the associated pin T3OUT (alternate pin function). The auxiliary timers T2 and T4 may additionally be concatenated with the core timer T3 (through T3OTL) or may be used as capture or reload registers for the core timer T3.

The current contents of each timer can be read or modified by the CPU by accessing the corresponding timer count registers T2, T3, or T4, located in the non-bitaddressable SFR space (see [Section 14.1.7.1](#)). When any of the timer registers is written to by the CPU in the state immediately preceding a timer increment, decrement, reload, or capture operation, the CPU write operation has priority in order to guarantee correct results.

The interrupts of GPT1 are controlled through the Interrupt Control Registers TxIC. These registers are not part of the GPT1 block.

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The input and output lines of GPT1 are connected to pins. The control registers for the port functions are located in the respective port modules.

Note: The timing requirements for external input signals can be found in [Section 14.1.5](#), [Section 14.5.1](#) summarizes the module interface signals, including pins.

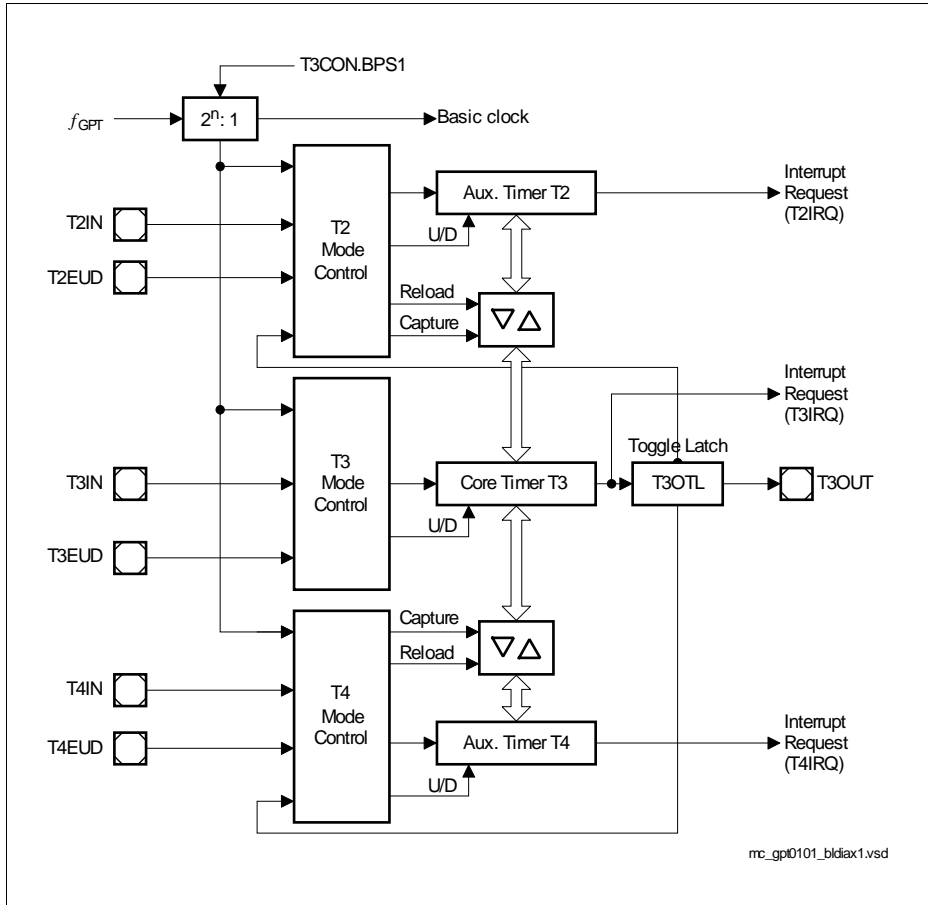


Figure 14-2 GPT1 Block Diagram (n = 2 ... 5)

14.1.1 GPT1 Core Timer T3 Control

The current contents of the core timer T3 are reflected by its count register T3. This register can also be written to by the CPU, for example, to set the initial start value.

The core timer T3 is configured and controlled via its bitaddressable control register T3CON.

Timer T3 Run Control

The core timer T3 can be started or stopped by software through bit T3R (Timer T3 Run Bit). This bit is relevant in all operating modes of T3. Setting bit T3R will start the timer, clearing bit T3R stops the timer.

In Gated Timer Mode, the timer will only run if T3R = 1 and the gate is active (high or low, as programmed).

Note: When bit T2RC or T4RC in timer control register T2CON or T4CON is set, bit T3R will also control (start and stop) the auxiliary timer(s) T2 and/or T4.

Count Direction Control

The count direction of the GPT1 timers (core timer and auxiliary timers) can be controlled either by software or by the external input pin TxEUD (Timer Tx External Up/Down Control Input). These options are selected by bits TxUD and TxUDE in the respective control register TxCON. When the up/down control is provided by software (bit TxUDE = 0), the count direction can be altered by setting or clearing bit TxUD. When bit TxUDE = 1, pin TxEUD is selected to be the controlling source of the count direction. However, bit TxUD can still be used to reverse the actual count direction, as shown in [Table 14-5](#). The count direction can be changed regardless of whether or not the timer is running.

Note: When pin TxEUD is used as external count direction control input, it must be configured as input.

Timer T3 Output Toggle Latch

The overflow/underflow signal of timer T3 is connected to a block named 'Toggle Latch', shown in the Timer Mode diagrams. **Figure 14-3** illustrates the details of this block. An overflow or underflow of T3 will clock two latches: The first latch represents bit T3OTL in control register T3CON. The second latch is an internal latch toggled by T3OTL's output. Both latch outputs are connected to the input control blocks of the auxiliary timers T2 and T4. The output level of the shadow latch will match the output level of T3OTL, but is delayed by one clock cycle. When the T3OTL value changes, this will result in a temporarily different output level from T3OTL and the shadow latch, which can trigger the selected count event in T2 and/or T4.

When software writes to T3OTL, both latches are set or cleared simultaneously. In this case, both signals to the auxiliary timers carry the same level and no edge will be detected. Bit T3OE (overflow/underflow output enable) in register T3CON enables the state of T3OTL to be monitored via an external pin T3OUT. When T3OTL is linked to an external port pin (must be configured as output), T3OUT can be used to control external HW. If T3OE = 1, pin T3OUT outputs the state of T3OTL. If T3OE = 0, pin T3OUT outputs a high level (as long as the T3OUT alternate function is selected for the port pin).

The trigger signals can serve as an input for the counter function or as a trigger source for the reload function of the auxiliary timers T2 and T4.

As can be seen from **Figure 14-3**, when latch T3OTL is modified by software to determine the state of the output line, also the internal shadow latch is set or cleared accordingly. Therefore, no trigger condition is detected by T2/T4 in this case.

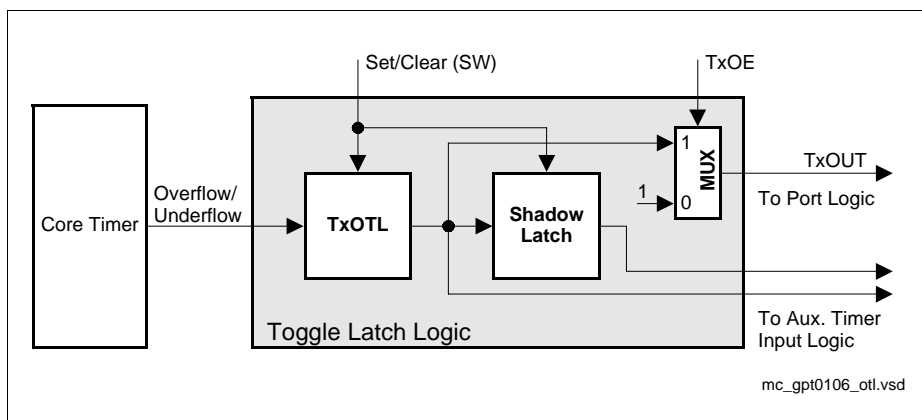


Figure 14-3 Block Diagram of the Toggle Latch Logic of Core Timer T3 (x = 3)

14.1.2 GPT1 Core Timer T3 Operating Modes

Timer T3 can operate in one of several modes.

Timer T3 in Timer Mode

Timer mode for the core timer T3 is selected by setting bitfield T3M in register T3CON to 000_B. In Timer Mode, T3 is clocked with the module's input clock f_{GPT} divided by two programmable prescalers controlled by bitfields BPS1 and T3I in register T3CON. Please see [Section 14.1.5](#) for details on the input clock options.

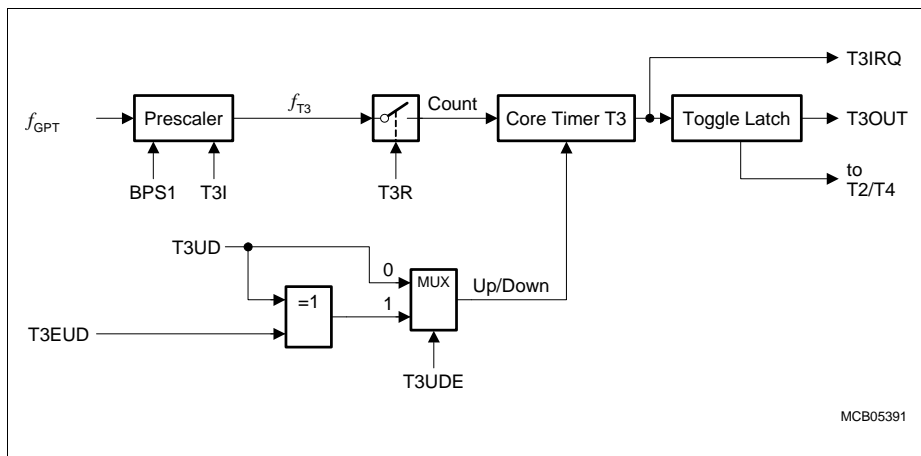


Figure 14-4 Block Diagram of Core Timer T3 in Timer Mode

Timer T3 in Gated Timer Mode

Gated Timer Mode for the core timer T3 is selected by setting bitfield T3M in register T3CON to 010_B or 011_B. Bit T3M.0 (T3CON.3) selects the active level of the gate input. The same options for the input frequency are available in Gated Timer Mode as in Timer Mode (see [Section 14.1.5](#)). However, the input clock to the timer in this mode is gated by the external input pin T3IN (Timer T3 External Input).

To enable this operation, the associated pin T3IN must be configured as input.

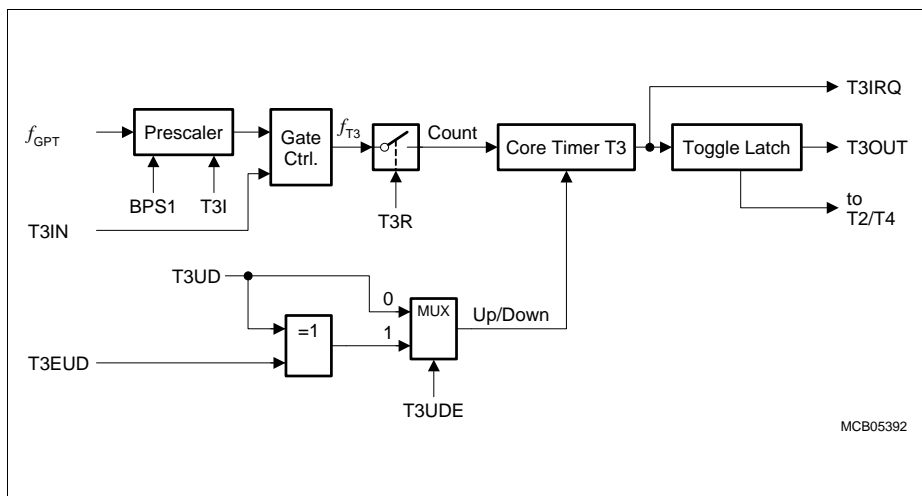


Figure 14-5 Block Diagram of Core Timer T3 in Gated Timer Mode

If T3M = 010_B, the timer is enabled when T3IN shows a low level. A high level at this line stops the timer. If T3M = 011_B, line T3IN must have a high level in order to enable the timer. Additionally, the timer can be turned on or off by software using bit T3R. The timer will only run if T3R is 1 and the gate is active. It will stop if either T3R is 0 or the gate is inactive.

Note: A transition of the gate signal at pin T3IN does not cause an interrupt request.

Timer T3 in Counter Mode

Counter Mode for the core timer T3 is selected by setting bitfield T3M in register T3CON to 001_B. In Counter Mode, timer T3 is clocked by a transition at the external input pin T3IN. The event causing an increment or decrement of the timer can be a positive, a negative, or both a positive and a negative transition at this line. Bitfield T3I in control register T3CON selects the triggering transition (see [Table 14-7](#)).

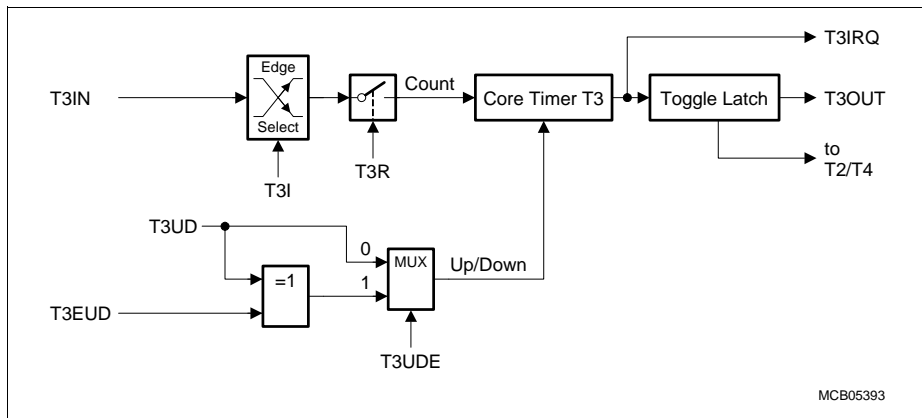


Figure 14-6 Block Diagram of Core Timer T3 in Counter Mode

For Counter Mode operation, pin T3IN must be configured as input. The maximum input frequency allowed in Counter Mode depends on the selected prescaler value. To ensure that a transition of the count input signal applied to T3IN is recognized correctly, its level must be held high or low for a minimum number of module clock cycles before it changes. This information can be found in [Section 14.1.5](#).

Timer T3 in Incremental Interface Mode

Incremental interface mode for the core timer T3 is selected by setting bitfield T3M in register T3CON to 110_B or 111_B. In Incremental Interface Mode, the two inputs associated with core timer T3 (T3IN, T3EUD) are used to interface to an incremental encoder. T3 is clocked by each transition on one or both of the external input pins to provide 2-fold or 4-fold resolution of the encoder input.

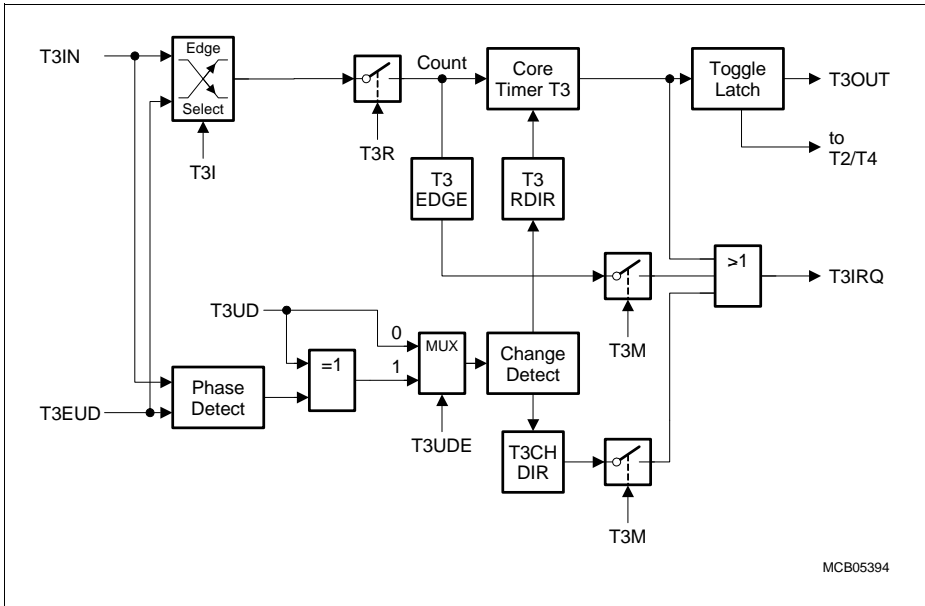


Figure 14-7 Block Diagram of Core Timer T3 in Incremental Interface Mode

Bitfield T3I in control register T3CON selects the triggering transitions (see [Table 14-9](#)). The sequence of the transitions of the two input signals is evaluated and generates count pulses as well as the direction signal. So T3 is modified automatically according to the speed and the direction of the incremental encoder and, therefore, its contents always represent the encoder's current position.

The interrupt request (T3IRQ) generation mode can be selected: In Rotation Detection Mode (T3M = 110_B), an interrupt request is generated each time the count direction of T3 changes. In Edge Detection Mode (T3M = 111_B), an interrupt request is generated each time a count edge for T3 is detected. Count direction, changes in the count direction, and count requests are monitored by status bits T3RDIR, T3CHDIR, and T3EDGE in register T3CON.

The incremental encoder can be connected directly to the XE166U without external interface logic. In a standard system, however, comparators will be employed to convert

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the encoder's differential outputs (such as A, \bar{A}) to digital signals (such as A). This greatly increases noise immunity.

Note: The third encoder output T0, which indicates the mechanical zero position, may be connected to an external interrupt input and trigger a reset of timer T3 (for example via PEC transfer from ZEROS).

If input T4IN is available, T0 can be connected there and clear T3 automatically without requiring an interrupt.

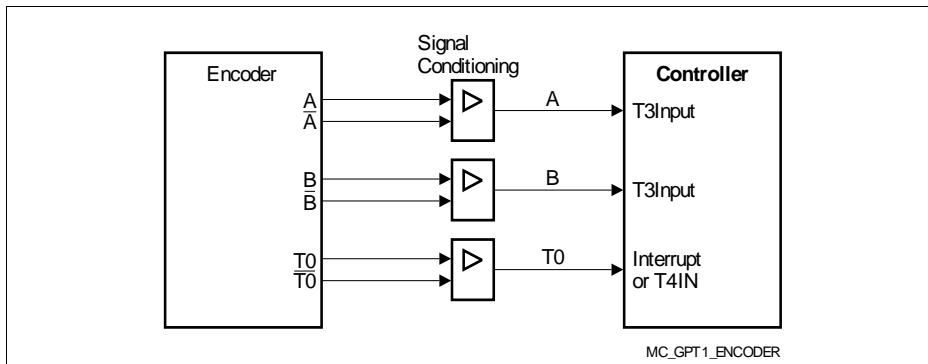


Figure 14-8 Connection of the Encoder to the XE166U

For incremental interface operation, the following conditions must be met:

- Bitfield T3M must be 110_B or 111_B.
- Both pins T3IN and T3EUD must be configured as input.
- Pin T4IN must be configured as input, if used for T0.
- Bit T3UDE must be 1 to enable automatic external direction control.

The maximum count frequency allowed in Incremental Interface Mode depends on the selected prescaler value. To ensure that a transition of any input signal is recognized correctly, its level must be held high or low for a minimum number of module clock cycles before it changes. This information can be found in [Section 14.1.5](#).

As in Incremental Interface Mode two input signals with a 90° phase shift are evaluated, their maximum input frequency can be half the maximum count frequency.

In Incremental Interface Mode, the count direction is automatically derived from the sequence in which the input signals change, which corresponds to the rotation direction of the connected sensor. [Table 14-1](#) summarizes the possible combinations.

Table 14-1 GPT1 Core Timer T3 (Incremental Interface Mode) Count Direction

Level on Respective other Input	T3IN Input		T3EUD Input	
	Rising ↑	Falling ↓	Rising ↑	Falling ↓
High	Down	Up	Up	Down
Low	Up	Down	Down	Up

Figure 14-9 and **Figure 14-10** give examples of T3's operation, visualizing count signal generation and direction control. They also show how input jitter is compensated, which might occur if the sensor rests near to one of its switching points.

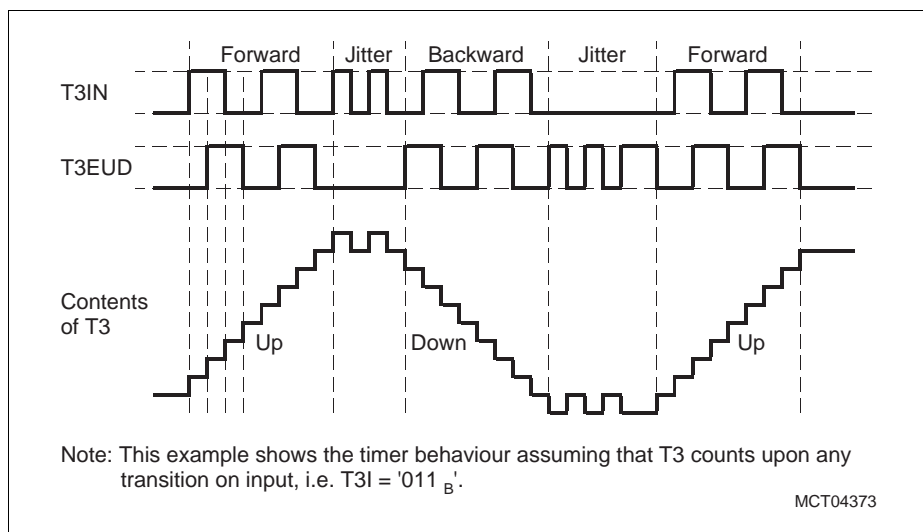


Figure 14-9 Evaluation of Incremental Encoder Signals, 2 Count Inputs

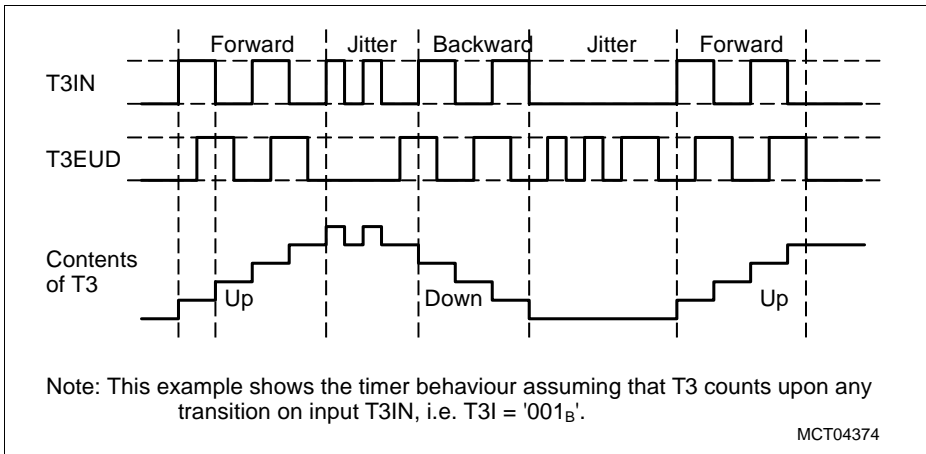


Figure 14-10 Evaluation of Incremental Encoder Signals, 1 Count Input

Note: Timer T3 operating in Incremental Interface Mode automatically provides information on the sensor's current position. Dynamic information (speed, acceleration, deceleration) may be obtained by measuring the incoming signal periods (see [“Combined Capture Modes” on Page 14-58](#)).

14.1.3 GPT1 Auxiliary Timers T2/T4 Control

Auxiliary timers T2 and T4 have exactly the same functionality. They can be configured for Timer Mode, Gated Timer Mode, Counter Mode, or Incremental Interface Mode with the same options for the timer frequencies and the count signal as the core timer T3. In addition to these 4 counting modes, the auxiliary timers can be concatenated with the core timer, or they may be used as reload or capture registers in conjunction with the core timer. The start/stop function of the auxiliary timers can be remotely controlled by the T3 run control bit. Several timers may thus be controlled synchronously.

The current contents of an auxiliary timer are reflected by its count register T2 or T4, respectively. These registers can also be written to by the CPU, for example, to set the initial start value.

The individual configurations for timers T2 and T4 are determined by their bitaddressable control registers T2CON and T4CON, which are organized identically. Note that functions which are present in all 3 timers of block GPT1 are controlled in the same bit positions and in the same manner in each of the specific control registers.

Note: The auxiliary timers have no output toggle latch and no alternate output function.

Timer T2/T4 Run Control

Each of the auxiliary timers T2 and T4 can be started or stopped by software in two different ways:

- Through the associated timer run bit (T2R or T4R). In this case it is required that the respective control bit TxRC = 0.
- Through the core timer's run bit (T3R). In this case the respective remote control bit must be set (TxRC = 1).

The selected run bit is relevant in all operating modes of T2/T4. Setting the bit will start the timer, clearing the bit stops the timer.

In Gated Timer Mode, the timer will only run if the selected run bit is set and the gate is active (high or low, as programmed).

Note: If remote control is selected T3R will start/stop timer T3 and the selected auxiliary timer(s) synchronously.

Count Direction Control

The count direction of the GPT1 timers (core timer and auxiliary timers) is controlled in the same way, either by software or by the external input pin TxEUD. Please refer to the description in [Table 14-5](#).

Note: When pin TxEUD is used as external count direction control input, it must be configured as input.

14.1.4 GPT1 Auxiliary Timers T2/T4 Operating Modes

The operation of the auxiliary timers in the basic operating modes is almost identical with the core timer's operation, with very few exceptions. Additionally, some combined operating modes can be selected.

Timers T2 and T4 in Timer Mode

Timer mode for an auxiliary timer Tx is selected by setting its bitfield TxM in register TxCON to 000_B.

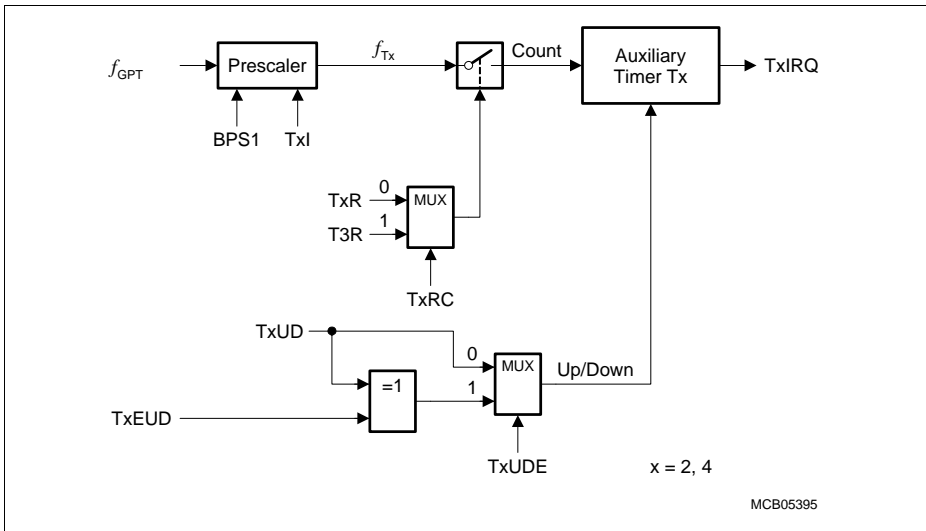


Figure 14-11 Block Diagram of an Auxiliary Timer in Timer Mode

Timers T2 and T4 in Counter Mode

Counter Mode for an auxiliary timer Tx is selected by setting bitfield TxM in register TxCON to 001_B. In Counter Mode, an auxiliary timer can be clocked either by a transition at its external input line TxIN, or by a transition of timer T3's toggle latch T3OTL. The event causing an increment or decrement of a timer can be a positive, a negative, or both a positive and a negative transition at either the respective input pin or at the toggle latch. Bitfield TxI in control register TxCON selects the triggering transition (see [Table 14-8](#)).

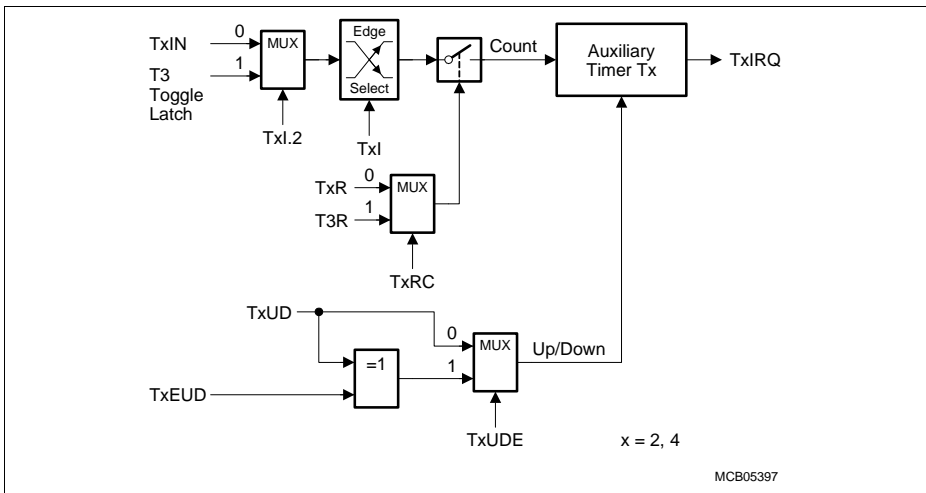


Figure 14-13 Block Diagram of an Auxiliary Timer in Counter Mode

Note: Only state transitions of T3OTL which are caused by the overflows/underflows of T3 will trigger the counter function of T2/T4. Modifications of T3OTL via software will NOT trigger the counter function of T2/T4.

For counter operation, pin TxIN must be configured as input. The maximum input frequency allowed in Counter Mode depends on the selected prescaler value. To ensure that a transition of the count input signal applied to TxIN is recognized correctly, its level must be held high or low for a minimum number of module clock cycles before it changes. This information can be found in [Section 14.1.5](#).

Timers T2 and T4 in Capture Mode

Capture mode for an auxiliary timer Tx is selected by setting bitfield TxM in the respective register TxCON to 101_B. In capture mode, the contents of the core timer T3 are latched into an auxiliary timer register in response to a signal transition at the respective auxiliary timer's external input pin TxIN. The capture trigger signal can be a positive, a negative, or both a positive and a negative transition.

The two least significant bits of bitfield TxI select the active transition (see [Table 14-8](#)). Bit 2 of TxI is irrelevant for capture mode and must be cleared (TxI.2 = 0).

Note: When programmed for capture mode, the respective auxiliary timer (T2 or T4) stops independently of its run flag T2R or T4R.

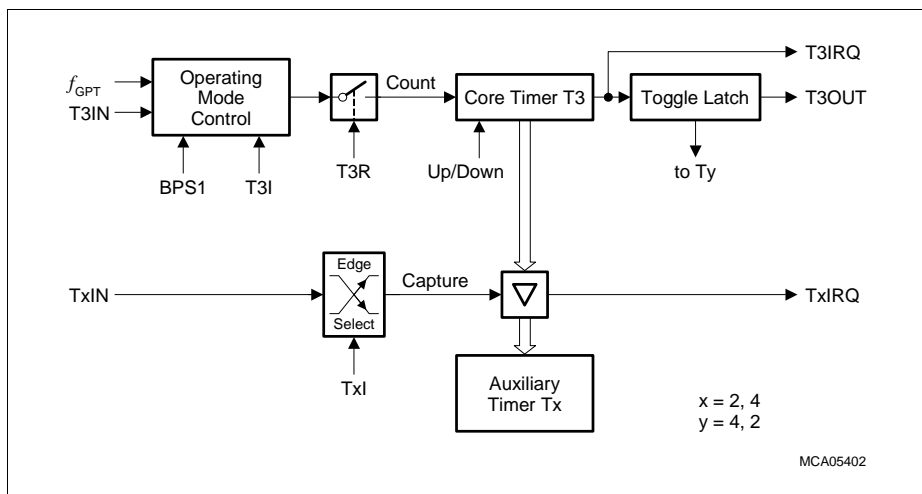


Figure 14-15 GPT1 Auxiliary Timer in Capture Mode

Upon a trigger (selected transition) at the corresponding input pin TxIN the contents of the core timer are loaded into the auxiliary timer register and the associated interrupt request flag TxIR will be set.

For capture mode operation, the respective timer input pin TxIN must be configured as input. To ensure that a transition of the capture input signal applied to TxIN is recognized correctly, its level must be held high or low for a minimum number of module clock cycles, detailed in [Section 14.1.5](#).

Timers T2 and T4 in Incremental Interface Mode

Incremental interface mode for an auxiliary timer Tx is selected by setting bitfield TxM in the respective register TxCON to 110_B or 111_B. In Incremental Interface Mode, the two inputs associated with an auxiliary timer Tx (TxIN, TxEUD) are used to interface to an incremental encoder. Tx is clocked by each transition on one or both of the external input pins to provide 2-fold or 4-fold resolution of the encoder input.

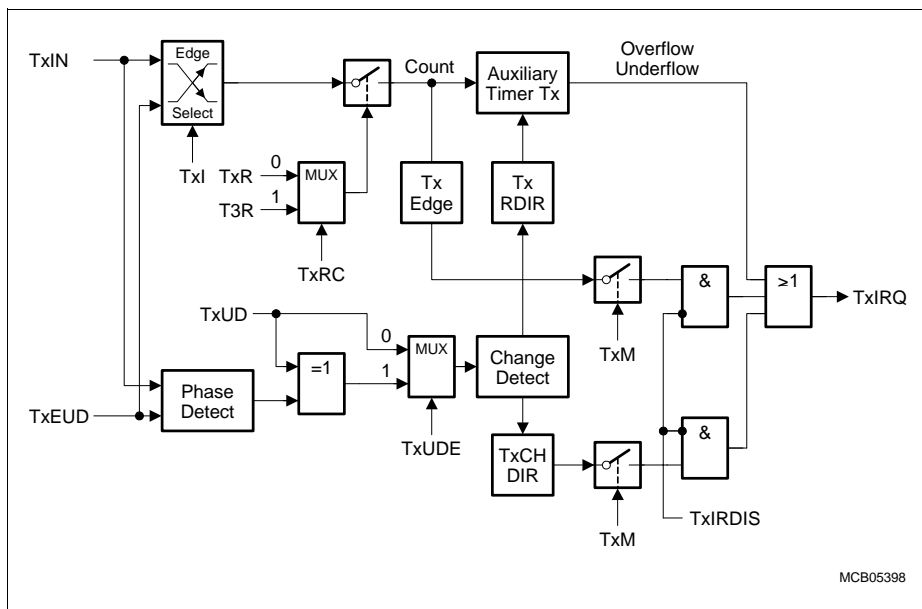


Figure 14-16 Block Diagram of an Auxiliary Timer in Incremental Interface Mode

The operation of the auxiliary timers T2 and T4 in Incremental Interface Mode and the interrupt generation are the same as described for the core timer T3. The descriptions, figures and tables apply accordingly.

*Note: Timers T2 and T4 operating in Incremental Interface Mode automatically provide information on the sensor's current position. For dynamic information (speed, acceleration, deceleration) see **"Combined Capture Modes" on Page 14-58**.*

Timers T2 and T4 in Reload Mode

Reload Mode for an auxiliary timer Tx is selected by setting bitfield TxM in the respective register TxCON to 100_b. In reload mode, the core timer T3 is reloaded with the contents of an auxiliary timer register, triggered by one of two different signals. The trigger signal is selected the same way as the clock source for Counter Mode (see [Table 14-8](#)), i.e. a transition of the auxiliary timer's input TxIN or the toggle latch T3OTL may trigger the reload.

Note: When programmed for reload mode, the respective auxiliary timer (T2 or T4) stops independently of its run flag T2R or T4R.

The timer input pin TxIN must be configured as input if it shall trigger a reload operation.

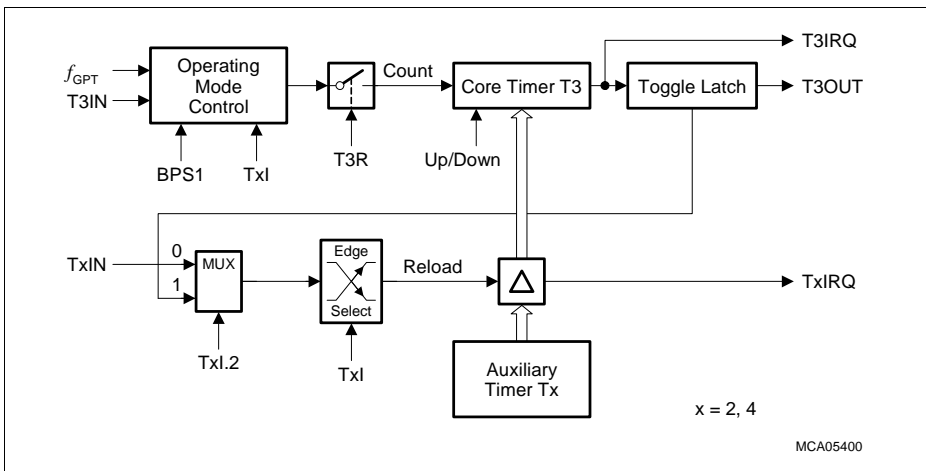


Figure 14-17 GPT1 Auxiliary Timer in Reload Mode

Upon a trigger signal, T3 is loaded with the contents of the respective timer register (T2 or T4) and the respective interrupt request flag (T2IR or T4IR) is set.

Note: When a T3OTL transition is selected for the trigger signal, the interrupt request flag T3IR will also be set upon a trigger, indicating T3's overflow or underflow. Modifications of T3OTL via software will NOT trigger the counter function of T2/T4.

To ensure that a transition of the reload input signal applied to TxIN is recognized correctly, its level must be held high or low for a minimum number of module clock cycles, detailed in [Section 14.1.5](#).

The reload mode triggered by the T3 toggle latch can be used in a number of different configurations. The following functions can be performed, depending on the selected active transition:

General Purpose Timer Units (GPT12)

- If both a positive and a negative transition of T3OTL are selected to trigger a reload, the core timer will be reloaded with the contents of the auxiliary timer each time it overflows or underflows. This is the standard reload mode (reload on overflow/underflow).
- If either a positive or a negative transition of T3OTL is selected to trigger a reload, the core timer will be reloaded with the contents of the auxiliary timer on every second overflow or underflow.
- Using this “single-transition” mode for both auxiliary timers allows to perform very flexible Pulse Width Modulation (PWM). One of the auxiliary timers is programmed to reload the core timer on a positive transition of T3OTL, the other is programmed for a reload on a negative transition of T3OTL. With this combination the core timer is alternately reloaded from the two auxiliary timers.

Figure 14-18 shows an example for the generation of a PWM signal using the “single-transition” reload mechanism. T2 defines the high time of the PWM signal (reloaded on positive transitions) and T4 defines the low time of the PWM signal (reloaded on negative transitions). The PWM signal can be output on pin T3OUT if T3OE = 1. With this method, the high and low time of the PWM signal can be varied in a wide range.

Note: The output toggle latch T3OTL is accessible via software and may be changed, if required, to modify the PWM signal.

However, this will NOT trigger the reloading of T3.

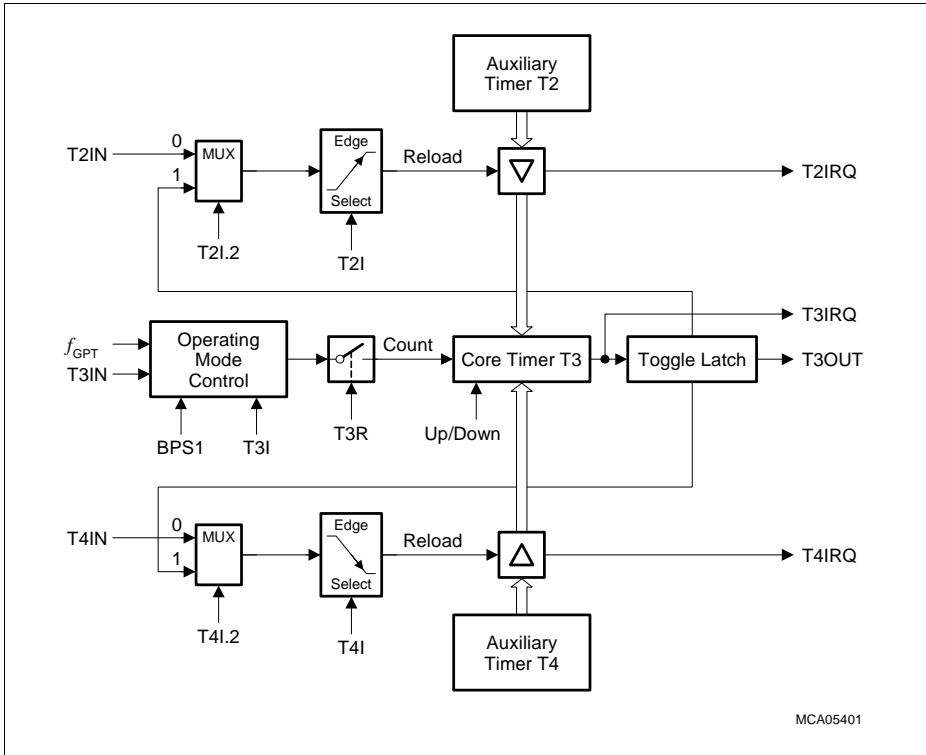


Figure 14-18 GPT1 Timer Reload Configuration for PWM Generation

Note: Although possible, selecting the same reload trigger event for both auxiliary timers should be avoided. In such a case, both reload registers would try to load the core timer at the same time. If this combination is selected, T2 is disregarded and the contents of T4 is reloaded.

General Purpose Timer Units (GPT12)

14.1.5 GPT1 Clock Signal Control

All actions within the timer block GPT1 are triggered by transitions of its basic clock. This basic clock is derived from the system clock by a basic block prescaler, controlled by bitfield BPS1 in register T3CON (see [Figure 14-2](#)). The count clock can be generated in two different ways:

- **Internal count clock**, derived from GPT1's basic clock via a programmable prescaler, is used for (gated) Timer Mode.
- **External count clock**, derived from the timer's input pin(s), is used for Counter Mode.

For both ways, the basic clock determines the maximum count frequency and the timer's resolution:

Table 14-2 Basic Clock Selection for Block GPT1

Block Prescaler ¹⁾	BPS1 = 01 _B	BPS1 = 00 _B ²⁾	BPS1 = 11 _B	BPS1 = 10 _B
Prescaling Factor for GPT1: F(BPS1)	F(BPS1) = 4	F(BPS1) = 8	F(BPS1) = 16	F(BPS1) = 32
Maximum External Count Frequency	$f_{\text{GPT}}/8$	$f_{\text{GPT}}/16$	$f_{\text{GPT}}/32$	$f_{\text{GPT}}/64$
Input Signal Stable Time	$4 \times t_{\text{GPT}}$	$8 \times t_{\text{GPT}}$	$16 \times t_{\text{GPT}}$	$32 \times t_{\text{GPT}}$

1) Please note the non-linear encoding of bitfield BPS1.

2) Default after reset.

Internal Count Clock Generation

In Timer Mode and Gated Timer Mode, the count clock for each GPT1 timer is derived from the GPT1 basic clock by a programmable prescaler, controlled by bitfield TxI in the respective timer's control register TxCON.

The count frequency f_{Tx} for a timer Tx and its resolution r_{Tx} are scaled linearly with lower clock frequencies, as can be seen from the following formula:

$$f_{\text{Tx}} = \frac{f_{\text{GPT}}}{F(\text{BPS1}) \times 2^{<\text{TxI}>}} \quad r_{\text{Tx}}[\mu\text{S}] = \frac{F(\text{BPS1}) \times 2^{<\text{TxI}>}}{f_{\text{GPT}}[\text{MHz}]} \quad (14.1)$$

The effective count frequency depends on the common module clock prescaler factor F(BPS1) as well as on the individual input prescaler factor $2^{<\text{TxI}>}$. [Table 14-6](#) summarizes the resulting overall divider factors for a GPT1 timer that result from these cascaded prescalers.

General Purpose Timer Units (GPT12)

Table 14-3 lists GPT1 timer's parameters (such as count frequency, resolution, and period) resulting from the selected overall prescaler factor and the module clock f_{GPT} . Note that some numbers may be rounded.

Table 14-3 GPT1 Timer Parameters

Module Clock $f_{\text{GPT}} = 10 \text{ MHz}$			Overall Prescaler Factor	Module Clock $f_{\text{GPT}} = 40 \text{ MHz}$		
Frequency	Resolution	Period		Frequency	Resolution	Period
2.5 MHz	400 ns	26.21 ms	4	10.0 MHz	100 ns	6.55 ms
1.25 MHz	800 ns	52.43 ms	8	5.0 MHz	200 ns	13.11 ms
625.0 kHz	1.6 μs	104.9 ms	16	2.5 MHz	400 ns	26.21 ms
312.5 kHz	3.2 μs	209.7 ms	32	1.25 MHz	800 ns	52.43 ms
156.25 kHz	6.4 μs	419.4 ms	64	625.0 kHz	1.6 μs	104.9 ms
78.125 kHz	12.8 μs	838.9 ms	128	312.5 kHz	3.2 μs	209.7 ms
39.06 kHz	25.6 μs	1.678 s	256	156.25 kHz	6.4 μs	419.4 ms
19.53 kHz	51.2 μs	3.355 s	512	78.125 kHz	12.8 μs	838.9 ms
9.77 kHz	102.4 μs	6.711 s	1024	39.06 kHz	25.6 μs	1.678 s
4.88 kHz	204.8 μs	13.42 s	2048	19.53 kHz	51.2 μs	3.355 s
2.44 kHz	409.6 μs	26.84 s	4096	9.77 kHz	102.4 μs	6.711 s

External Count Clock Input

The external input signals of the GPT1 block are sampled with the GPT1 basic clock (see [Figure 14-2](#)). To ensure that a signal is recognized correctly, its current level (high or low) must be held active for at least one complete sampling period, before changing. A signal transition is recognized if two subsequent samples of the input signal represent different levels. Therefore, a minimum of two basic clock periods are required for the sampling of an external input signal. Thus, the maximum frequency of an input signal must not be higher than half the basic clock.

Table 14-4 summarizes the resulting requirements for external GPT1 input signals.

Table 14-4 GPT1 External Input Signal Limits

GPT1 Basic Clock = 10 MHz		Input Frequ. Factor	GPT1 Divider BPS1	Input Phase Duration	GPT1 Basic Clock = 40 MHz	
Max. Input Frequency	Min. Level Hold Time				Max. Input Frequency	Min. Level Hold Time
1.25 MHz	400 ns	$f_{\text{GPT}}/8$	01 _B	$4 \times t_{\text{GPT}}$	5.0 MHz	100 ns
625.0 kHz	800 ns	$f_{\text{GPT}}/16$	00 _B	$8 \times t_{\text{GPT}}$	2.5 MHz	200 ns
312.5 kHz	1.6 μs	$f_{\text{GPT}}/32$	11 _B	$16 \times t_{\text{GPT}}$	1.25 MHz	400 ns
156.25 kHz	3.2 μs	$f_{\text{GPT}}/64$	10 _B	$32 \times t_{\text{GPT}}$	625.0 kHz	800 ns

These limitations are valid for all external input signals to GPT1, including the external count signals in Counter Mode and Incremental Interface Mode, the gate input signals in Gated Timer Mode, and the external direction signals.

14.1.6 Interrupt Control for GPT1 Timers

When a timer overflows from $FFFF_H$ to 0000_H (when counting up), or when it underflows from 0000_H to $FFFF_H$ (when counting down), its interrupt request flag in register GPT12E_T2IC, GPT12E_T3IC, or GPT12E_T4IC will be set. This will cause an interrupt to the respective timer interrupt vector or trigger a PEC service, if the respective interrupt enable bit is set.

There is an interrupt control register for each of the three timers (T2, T3, T4). All interrupt control registers GPT12E_T2IC, GPT12E_T3IC, and GPT12E_T4IC have the same structure described in section Interrupt Control.

In **Reload Mode**, upon a trigger signal, T3 is loaded with the contents of the respective timer (T2 or T4) and the respective interrupt request flag in register GPT12E_T2IC or GPT12E_T4IC is set.

In **Incremental Interface Mode**, the interrupt request generation can be selected as follows:

- In Rotation Detection Mode ($T3M = 110_B$), an interrupt request is generated each time the count direction of T3 changes.
- In Edge Detection Mode ($T3M = 111_B$), an interrupt request is generated each time a count edge for T3 is detected.

In **Capture Mode**, upon a trigger (selected transition) at the corresponding input pin the content of the core timer T3 are loaded into the auxiliary timer register Tx and the associated interrupt request flag in register GPT12E_T2IC or GPT12E_T4IC will be set.

14.1.7 GPT1 Registers

14.1.7.1 GPT1 Timer Registers

GPT12E_T2

Timer T2 Count Register

SFR (FE40_H/20_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T2															
rwh															

Field	Bits	Typ	Description
T2	[15:0]	rwh	Timer T2 Current Value Contains the current value of the timer T2

GPT12E_T3

Timer T3 Count Register

SFR (FE42_H/21_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T3															
rwh															

Field	Bits	Typ	Description
T3	[15:0]	rwh	Timer T3 Current Value Contains the current value of the timer T3

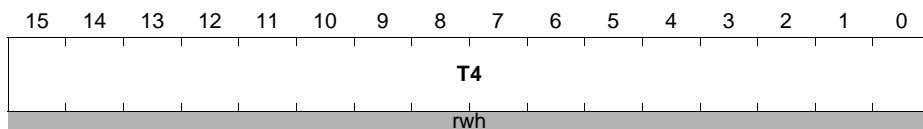
General Purpose Timer Units (GPT12)

GPT12E_T4

Timer T4 Count Register

SFR (FE44_H/22_H)

Reset Value: 0000_H



Field	Bits	Typ	Description
T4	[15:0]	rwh	Timer T4 Current Value Contains the current value of the timer T4

14.1.7.2 GPT1 Timer Control Registers

GPT1 Core Timer T3 Control Register

GPT12E_T3CON

Timer T3 Control Register

SFR (FF42_H/A1_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T3 R DIR	T3 CH DIR	T3 EDG E	BPS1		T3 OTL	T3 OE	T3 UDE	T3 UD	T3 R	T3M			T3I		
rh	rwh	rwh	rw		rwh	rw	rw	rw	rw	rw			rw		

Field	Bits	Type	Description
T3I	[2:0]	rw	Timer T3 Input Parameter Selection Depends on the operating mode, see respective sections for encoding: Table 14-6 for Timer Mode and Gated Timer Mode Table 14-7 for Counter Mode Table 14-9 for Incremental Interface Mode
T3M	[5:3]	rw	Timer T3 Mode Control 000 _B Timer Mode 001 _B Counter Mode 010 _B Gated Timer Mode with gate active low 011 _B Gated Timer Mode with gate active high 100 _B Reserved. Do not use this combination 101 _B Reserved. Do not use this combination 110 _B Incremental Interface Mode (Rotation Detection Mode) 111 _B Incremental Interface Mode (Edge Detection Mode)
T3R	6	rw	Timer T3 Run Bit 0 _B Timer T3 stops 1 _B Timer T3 runs
T3UD	7	rw	Timer T3 Up/Down Control¹⁾ 0 _B Timer T3 counts up 1 _B Timer T3 counts down <i>Note: This bit only controls count direction of T3 if bit T3UDE = 0.</i>

General Purpose Timer Units (GPT12)

Field	Bits	Type	Description
T3UDE	8	rw	Timer T3 External Up/Down Enable¹⁾ 0_B Count direction is controlled by bit T3UD; input T3EUD is disconnected 1_B Count direction is controlled by input T3EUD
T3OE	9	rw	Overflow/Underflow Output Enable 0_B Alternate Output Function Disabled 1_B State of T3 toggle latch is output on pin T3OUT
T3OTL	10	rwh	Timer T3 Overflow Toggle Latch Toggles on each overflow/underflow of T3. Can be set or cleared by software (see separate description)
BPS1	[12:11]	rw	GPT1 Block Prescaler Control Selects the basic clock for block GPT1 (see also Section 14.1.5) 00_B $f_{GPT}/8$ 01_B $f_{GPT}/4$ 10_B $f_{GPT}/32$ 11_B $f_{GPT}/16$
T3EDGE	13	rwh	Timer T3 Edge Detection Flag The bit is set each time a count edge is detected. T3EDGE must be cleared by software. 0_B No count edge was detected 1_B A count edge was detected
T3CHDIR	14	rwh	Timer T3 Count Direction Change Flag This bit is set each time the count direction of timer T3 changes. T3CHDIR must be cleared by software. 0_B No change of count direction was detected 1_B A change of count direction was detected
T3RDIR	15	rh	Timer T3 Rotation Direction Flag 0_B Timer T3 counts up 1_B Timer T3 counts down
0	[31:16]	r	Reserved Read as 0; should be written with 0.

1) See [Table 14-14](#) for encoding of bits T3UD and T3UDE.

General Purpose Timer Units (GPT12)

GPT1 Auxiliary Timers T2/T4 Control Registers

GPT12E_T2CON

Timer T2 Control Register

SFR (FF40_H/A0_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T2 R DIR	T2 CH DIR	T2 EDG E	T2 IR DIS	0		T2 RC	T2 UDE	T2 UD	T2 R	T2M			T2I		
rh	rwh	rwh	rw	r		rw	rw	rw	rw	rw			rw		

Field	Bits	Type	Description
T2I	[2:0]	rw	Timer T2 Input Parameter Selection Depends on the operating mode, see respective sections for encoding: Table 14-6 for Timer Mode and Gated Timer Mode Table 14-8 for Counter Mode Table 14-9 for Incremental Interface Mode
T2M	[5:3]	rw	Timer T2 Mode Control (Basic Operating Mode) 000 _B Timer Mode 001 _B Counter Mode 010 _B Gated Timer Mode with gate active low 011 _B Gated Timer Mode with gate active high 100 _B Reload Mode 101 _B Capture Mode 110 _B Incremental Interface Mode (Rotation Detection Mode) 111 _B Incremental Interface Mode (Edge Detection Mode)
T2R	6	rw	Timer T2 Run Bit 0 _B Timer T2 stops 1 _B Timer T2 runs <i>Note: This bit only controls timer T2 if bit T2RC = 0.</i>
T2UD	7	rw	Timer T2 Up/Down Control¹⁾ 0 _B Timer T2 counts up 1 _B Timer T2 counts down <i>Note: This bit only controls count direction of T2 if bit T2UDE = 0.</i>

General Purpose Timer Units (GPT12)

Field	Bits	Type	Description
T2UDE	8	rw	Timer T2 External Up/Down Enable¹⁾ 0_B Count direction is controlled by bit T2UD; input T2EUD is disconnected 1_B Count direction is controlled by input T2EUD
T2RC	9	rw	Timer T2 Remote Control 0_B Timer T2 is controlled by its own run bit T2R 1_B Timer T2 is controlled by the run bit T3R of core timer T3, not by bit T2R
T2IRDIS	12	rw	Timer T2 Interrupt Disable 0_B Interrupt generation for T2CHDIR and T2EDGE interrupts in Incremental Interface Mode is enabled 1_B Interrupt generation for T2CHDIR and T2EDGE interrupts in Incremental Interface Mode is disabled
T2EDGE	13	rwh	Timer T2 Edge Detection The bit is set each time a count edge is detected. T2EDGE must be cleared by software. 0_B No count edge was detected 1_B A count edge was detected
T2CHDIR	14	rwh	Timer T2 Count Direction Change The bit is set each time the count direction of timer T2 changes. T2CHDIR must be cleared by software. 0_B No change in count direction was detected 1_B A change in count direction was detected
T2RDIR	15	rh	Timer T2 Rotation Direction 0_B Timer T2 counts up 1_B Timer T2 counts down
0	[11:10], [31:16]	r	Reserved Read as 0; should be written with 0.

1) See [Table 14-14](#) for encoding of bits T2UD and T2UDE.

General Purpose Timer Units (GPT12)

GPT12E_T4CON

Timer T4 Control Register

SFR (FF44_H/A2_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T4 R DIR	T4 CH DIR	T4 EDG E	T4 IR DIS	CLR T3 EN	CLR T2 EN	T4 RC	T4 UDE	T4 UD	T4 R	T4M			T4I		
rw	rwh	rwh	rw	rw	rw	rw	rw	rw	rw	rw			rw		

Field	Bits	Type	Description
T4I	[2:0]	rw	Timer T4 Input Parameter Selection Depends on the operating mode, see respective sections for encoding: Table 14-6 for Timer Mode and Gated Timer Mode Table 14-6 for Counter Mode Table 14-9 for Incremental Interface Mode
T4M	[5:3]	rw	Timer T4 Mode Control (Basic Operating Mode) 000 _B Timer Mode 001 _B Counter Mode 010 _B Gated Timer Mode with gate active low 011 _B Gated Timer Mode with gate active high 100 _B Reload Mode 101 _B Capture Mode 110 _B Incremental Interface Mode (Rotation Detection Mode) 111 _B Incremental Interface Mode (Edge Detection Mode)
T4R	6	rw	Timer T4 Run Bit 0 _B Timer T4 stops 1 _B Timer T4 runs <i>Note: This bit only controls timer T4 if bit T4RC = 0.</i>
T4UD	7	rw	Timer T4 Up/Down Control¹⁾ 0 _B Timer T4 counts up 1 _B Timer T4 counts down <i>Note: This bit only controls count direction of T4 if bit T4UDE = 0.</i>

General Purpose Timer Units (GPT12)

Field	Bits	Type	Description
T4UDE	8	rw	Timer T4 External Up/Down Enable¹⁾ 0 _B Count direction is controlled by bit T4UD; input T4EUD is disconnected 1 _B Count direction is controlled by input T4EUD
T4RC	9	rw	Timer T4 Remote Control 0 _B Timer T4 is controlled by its own run bit T4R 1 _B Timer T4 is controlled by the run bit T3R of core timer T3, but not by bit T4R
CLRT2EN	10	rw	Clear Timer T2 Enable Enables the automatic clearing of timer T2 upon a falling edge of the selected T4EUD input. 0 _B No effect of T4EUD on timer T2 1 _B A falling edge on T4EUD clears timer T2
CLRT3EN	11	rw	Clear Timer T3 Enable Enables the automatic clearing of timer T3 upon a falling edge of the selected T4IN input. 0 _B No effect of T4IN on timer T3 1 _B A falling edge on T4IN clears timer T3
T4IRDIS	12	rw	Timer T4 Interrupt Disable 0 _B Interrupt generation for T4CHDIR and T4EDGE interrupts in Incremental Interface Mode is enabled 1 _B Interrupt generation for T4CHDIR and T4EDGE interrupts in Incremental Interface Mode is disabled
T4EDGE	13	rwh	Timer T4 Edge Detection The bit is set each time a count edge is detected. T4EDGE has to be cleared by software. 0 _B No count edge was detected 1 _B A count edge was detected
T4CHDIR	14	rwh	Timer T4 Count Direction Change The bit is set each time the count direction of timer T4 changes. T4CHDIR must be cleared by software. 0 _B No change in count direction was detected 1 _B A change in count direction was detected
T4RDIR	15	rh	Timer T4 Rotation Direction 0 _B Timer T4 counts up 1 _B Timer T4 counts down

General Purpose Timer Units (GPT12)

Field	Bits	Type	Description
0	[31:16]	r	Reserved Read as 0; should be written with 0.

1) See [Table 14-14](#) for encoding of bits T4UD and T4UDE.

General Purpose Timer Units (GPT12)

Encoding of GPT1 Timer Count Direction Control

Table 14-5 GPT1 Timer Count Direction Control

Pin TxEUD	Bit TxUDE	Bit TxUD	Count Direction	Bit TxRDIR
X	0	0	Count Up	0
X	0	1	Count Down	1
0	1	0	Count Up	0
1	1	0	Count Down	1
0	1	1	Count Down	1
1	1	1	Count Up	0

Timer Mode and Gated Timer Mode: Encoding of GPT1 Overall Prescaler Factor

**Table 14-6 GPT1 Overall Prescaler Factors for Internal Count Clock
(Timer Mode and Gated Timer Mode)**

Individual Prescaler for Tx	Common Prescaler for Module Clock ¹⁾			
	BPS1 = 01 _B	BPS1 = 00 _B	BPS1 = 11 _B	BPS1 = 10 _B
Txl = 000 _B	4	8	16	32
Txl = 001 _B	8	16	32	64
Txl = 010 _B	16	32	64	128
Txl = 011 _B	32	64	128	256
Txl = 100 _B	64	128	256	512
Txl = 101 _B	128	256	512	1024
Txl = 110 _B	256	512	1024	2048
Txl = 111 _B	512	1024	2048	4096

1) Please note the non-linear encoding of bitfield BPS1.

Counter Mode: Encoding of GPT1 Input Edge Selection

Table 14-7 GPT1 Core Timer T3 Input Edge Selection (Counter Mode)

T3I	Triggering Edge for Counter Increment/Decrement
000 _B	None. Counter T3 is disabled
001 _B	Positive transition (rising edge) on T3IN
010 _B	Negative transition (falling edge) on T3IN
011 _B	Any transition (rising or falling edge) on T3IN
1XX _B	Reserved. Do not use this combination

Table 14-8 GPT1 Auxiliary Timers T2/T4 Input Edge Selection (Counter Mode)

T2I/T4I	Triggering Edge for Counter Increment/Decrement
X00 _B	None. Counter Tx is disabled
001 _B	Positive transition (rising edge) on TxIN
010 _B	Negative transition (falling edge) on TxIN
011 _B	Any transition (rising or falling edge) on TxIN
101 _B	Positive transition (rising edge) of T3 toggle latch T3OTL
110 _B	Negative transition (falling edge) of T3 toggle latch T3OTL
111 _B	Any transition (rising or falling edge) of T3 toggle latch T3OTL

Incremental Interface Mode: Encoding of Input Edge Selection

**Table 14-9 GPT1 Core Timer T3 Input Edge Selection
(Incremental Interface Mode)**

T3I	Triggering Edge for Counter Increment/Decrement
000 _B	None. Counter T3 stops.
001 _B	Any transition (rising or falling edge) on T3IN.
010 _B	Any transition (rising or falling edge) on T3EUD.
011 _B	Any transition (rising or falling edge) on any T3 input (T3IN or T3EUD).
1XX _B	Reserved. Do not use this combination.

14.1.7.3 GPT1 Timer Interrupt Control Registers

There is an interrupt control register for each of the three timers (T2, T3, T4). All interrupt control registers GPT12E_T2IC, GPT12E_T3IC, and GPT12E_T4IC have the same structure described in section Interrupt Control.

General Purpose Timer Units (GPT12)

14.2 Timer Block GPT2

From a programmer's point of view, the GPT2 block is represented by a set of SFRs as summarized below. Those portions of port and direction registers which are used for alternate functions by the GPT2 block are shaded.

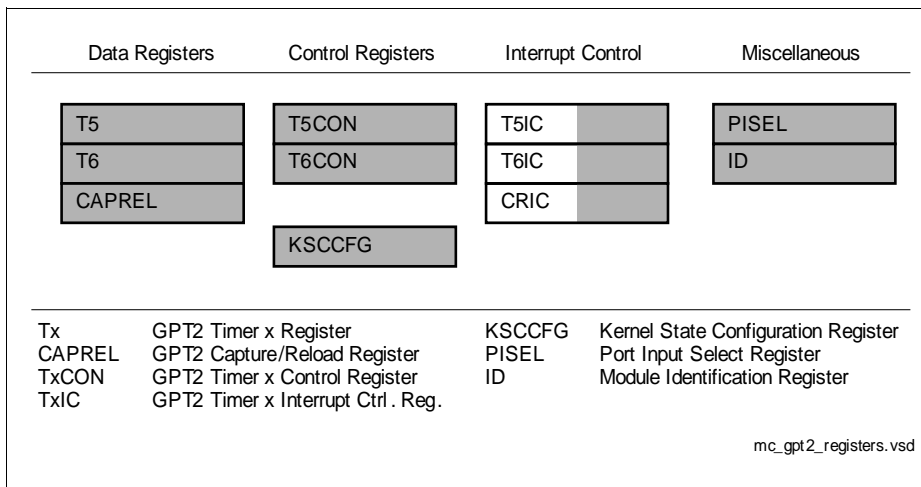


Figure 14-19 SFRs Associated with Timer Block GPT2

Both timers of block GPT2 (T5, T6) can run in one of 3 basic modes: Timer Mode, Gated Timer Mode, or Counter Mode. All timers can count up or down. Each timer of GPT2 is controlled by a separate control register TxCON.

Each timer has an input pin TxIN (alternate pin function) associated with it, which serves as the gate control in Gated Timer Mode, or as the count input in Counter Mode. The count direction (up/down) may be programmed via software or may be dynamically altered by a signal at the External Up/Down control input TxEUD (alternate pin function). An overflow/underflow of core timer T6 is indicated by the Output Toggle Latch T6OTL, whose state may be output on the associated pin T6OUT (alternate pin function). The auxiliary timer T5 may additionally be concatenated with core timer T6 (through T6OTL).

The Capture/Reload register CAPREL can be used to capture the contents of timer T5, or to reload timer T6. A special mode facilitates the use of register CAPREL for both functions at the same time. This mode allows frequency multiplication. The capture function is triggered by the input pin CAPIN, or by GPT1 timer's T3 input lines T3IN and T3EUD. The reload function is triggered by an overflow or underflow of timer T6. Overflows/underflows of timer T6 may also clock the timers of the CAPCOM units.

The current contents of each timer can be read or modified by the CPU by accessing the corresponding timer count registers T5 or T6, located in the non-bitaddressable SFR

General Purpose Timer Units (GPT2)

space (see [Section 14.2.8.1](#)). When any of the timer registers is written to by the CPU in the state immediately preceding a timer increment, decrement, reload, or capture operation, the CPU write operation has priority in order to guarantee correct results.

The interrupts of GPT2 are controlled through the Interrupt Control Registers TxIC. These registers are not part of the GPT2 block.

The input and output lines of GPT2 are connected to pins. The control registers for the port functions are located in the respective port modules.

Note: The timing requirements for external input signals can be found in [Section 14.2.6](#), [Section 14.5.1](#) summarizes the module interface signals, including pins.

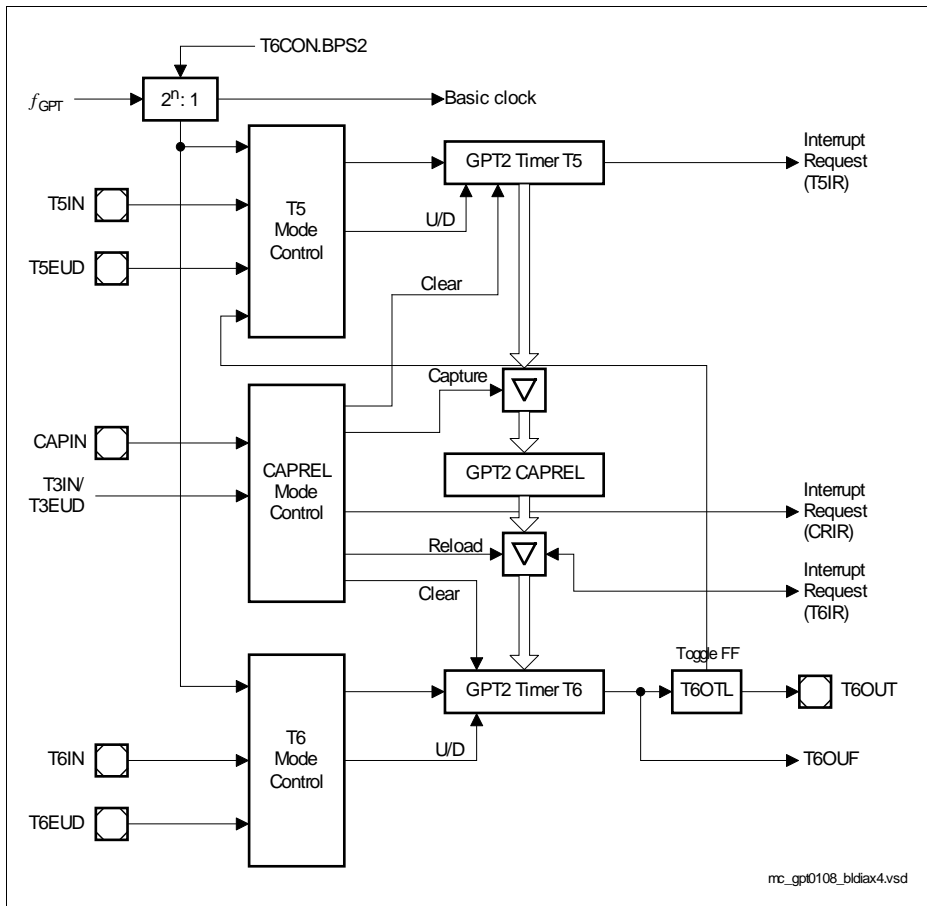


Figure 14-20 GPT2 Block Diagram

14.2.1 GPT2 Core Timer T6 Control

The current contents of the core timer T6 are reflected by its count register T6. This register can also be written to by the CPU, for example, to set the initial start value.

The core timer T6 is configured and controlled via its bitaddressable control register T6CON.

Timer T6 Run Control

The core timer T6 can be started or stopped by software through bit T6R (timer T6 run bit). This bit is relevant in all operating modes of T6. Setting bit T6R will start the timer, clearing bit T6R stops the timer.

In Gated Timer Mode, the timer will only run if T6R = 1 and the gate is active (high or low, as programmed).

Note: When bit T5RC in timer control register T5CON is set, bit T6R will also control (start and stop) the Auxiliary Timer T5.

Count Direction Control

The count direction of the GPT2 timers (core timer and auxiliary timer) can be controlled either by software or by the external input pin TxEUD (Timer Tx External Up/Down Control Input). These options are selected by bits TxUD and TxUDE in the respective control register TxCON. When the up/down control is provided by software (bit TxUDE = 0), the count direction can be altered by setting or clearing bit TxUD. When bit TxUDE = 1, pin TxEUD is selected to be the controlling source of the count direction. However, bit TxUD can still be used to reverse the actual count direction, as shown in [Table 14-14](#). The count direction can be changed regardless of whether or not the timer is running.

Note: When pin TxEUD is used as external count direction control input, it must be configured as input.

Timer T6 Output Toggle Latch

The overflow/underflow signal of timer T6 is connected to a block named 'Toggle Latch', shown in the Timer Mode diagrams. **Figure 14-21** illustrates the details of this block. An overflow or underflow of T6 will clock two latches: The first latch represents bit T6OTL in control register T6CON. The second latch is an internal latch toggled by T6OTL's output. Both latch outputs are connected to the input control block of the auxiliary timer T5. The output level of the shadow latch will match the output level of T6OTL, but is delayed by one clock cycle. When the T6OTL value changes, this will result in a temporarily different output level from T6OTL and the shadow latch, which can trigger the selected count event in T5.

When software writes to T6OTL, both latches are set or cleared simultaneously. In this case, both signals to the auxiliary timers carry the same level and no edge will be detected. Bit T6OE (overflow/underflow output enable) in register T6CON enables the state of T6OTL to be monitored via an external pin T6OUT. When T6OTL is linked to an external port pin (must be configured as output), T6OUT can be used to control external HW. If T6OE = 1, pin T6OUT outputs the state of T6OTL. If T6OE = 0, pin T6OUT outputs a high level (while it selects the timer output signal).

As can be seen from **Figure 14-21**, when latch T6OTL is modified by software to determine the state of the output line, also the internal shadow latch is set or cleared accordingly. Therefore, no trigger condition is detected by T5 in this case.

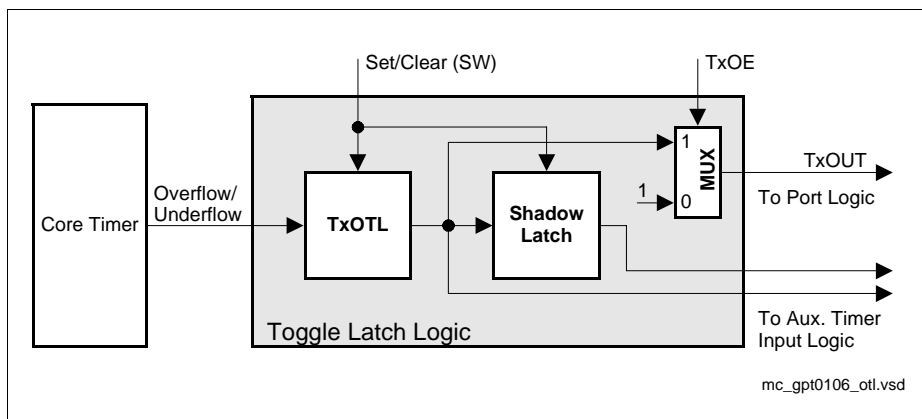


Figure 14-21 Block Diagram of the Toggle Latch Logic of Core Timer T6 (x = 6)

Note: T6 is also used to clock the timers in the CAPCOM units. For this purpose, there is a direct internal connection between the T6 overflow/underflow line and the CAPCOM timers (signal T6OUF).

14.2.2 GPT2 Core Timer T6 Operating Modes

Timer T6 can operate in one of several modes.

Timer T6 in Timer Mode

Timer mode for the core timer T6 is selected by setting bitfield T6M in register T6CON to 000_B. In this mode, T6 is clocked with the module's input clock f_{GPT} divided by two programmable prescalers controlled by bitfields BPS2 and T6I in register T6CON. Please see [Section 14.2.6](#) for details on the input clock options.

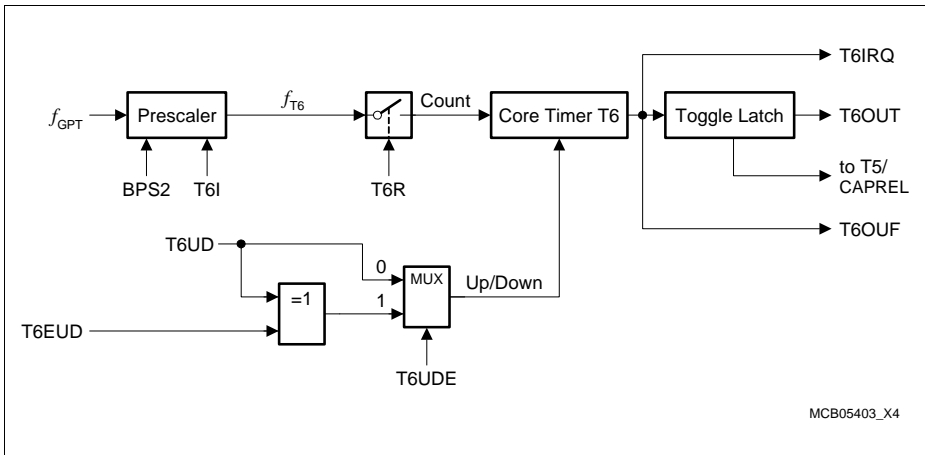


Figure 14-22 Block Diagram of Core Timer T6 in Timer Mode

Timer T6 in Gated Timer Mode

Gated Timer Mode for the core timer T6 is selected by setting bitfield T6M in register T6CON to 010_B or 011_B. Bit T6M.0 (T6CON.3) selects the active level of the gate input. The same options for the input frequency are available in Gated Timer Mode as in Timer Mode (see [Section 14.2.6](#)). However, the input clock to the timer in this mode is gated by the external input pin T6IN (Timer T6 External Input).

To enable this operation, the associated pin T6IN must be configured as input.

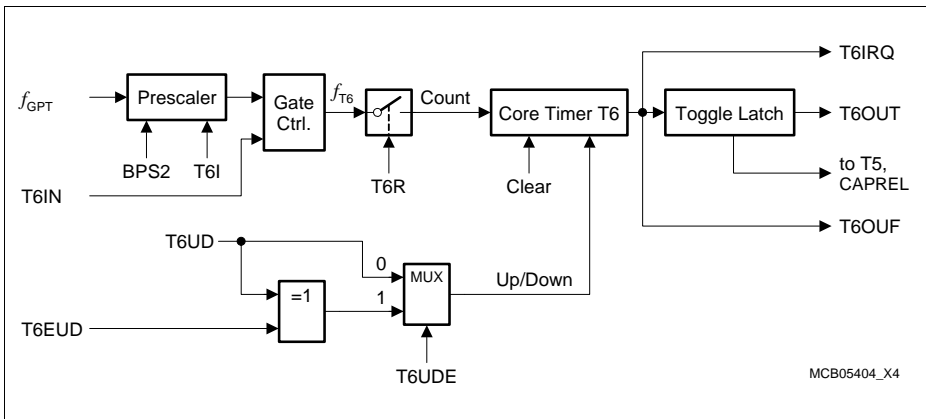


Figure 14-23 Block Diagram of Core Timer T6 in Gated Timer Mode

If T6M = 010_B, the timer is enabled when T6IN shows a low level. A high level at this line stops the timer. If T6M = 011_B, line T6IN must have a high level in order to enable the timer. Additionally, the timer can be turned on or off by software using bit T6R. The timer will only run if T6R is 1 and the gate is active. It will stop if either T6R is 0 or the gate is inactive.

Note: A transition of the gate signal at pin T6IN does not cause an interrupt request.

Timer T6 in Counter Mode

Counter Mode for the core timer T6 is selected by setting bitfield T6M in register T6CON to 001_B. In Counter Mode, timer T6 is clocked by a transition at the external input pin T6IN. The event causing an increment or decrement of the timer can be a positive, a negative, or both a positive and a negative transition at this line. Bitfield T6I in control register T6CON selects the triggering transition (see [Table 14-16](#)).

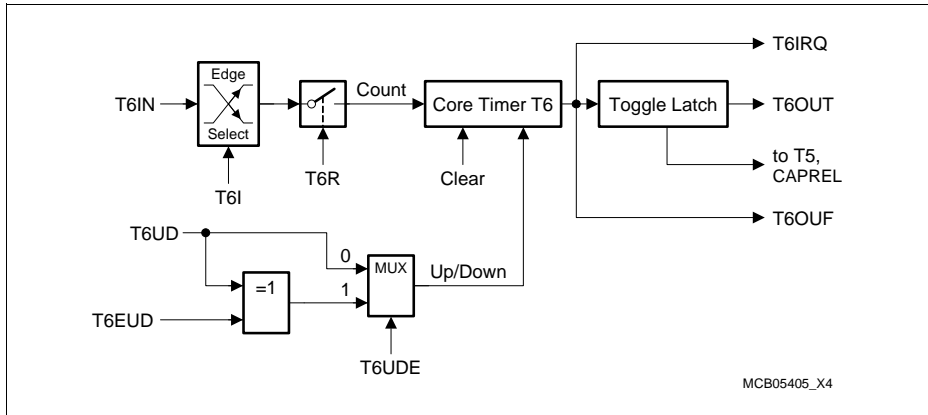


Figure 14-24 Block Diagram of Core Timer T6 in Counter Mode

For Counter Mode operation, pin T6IN must be configured as input. The maximum input frequency allowed in Counter Mode depends on the selected prescaler value. To ensure that a transition of the count input signal applied to T6IN is recognized correctly, its level must be held high or low for a minimum number of module clock cycles before it changes. This information can be found in [Section 14.2.6](#).

14.2.3 GPT2 Auxiliary Timer T5 Control

Auxiliary timer T5 can be configured for Timer Mode, Gated Timer Mode, or Counter Mode with the same options for the timer frequencies and the count signal as the core timer T6. In addition to these 3 counting modes, the auxiliary timer can be concatenated with the core timer. The contents of T5 may be captured to register CAPREL upon an external or an internal trigger. The start/stop function of the auxiliary timers can be remotely controlled by the T6 run control bit. Several timers may thus be controlled synchronously.

The current contents of the auxiliary timer are reflected by its count register T5. This register can also be written to by the CPU, for example, to set the initial start value.

The individual configurations for timer T5 are determined by its bitaddressable control register T5CON. Some bits in this register also control the function of the CAPREL register. Note that functions which are present in all timers of block GPT2 are controlled in the same bit positions and in the same manner in each of the specific control registers.

Note: The auxiliary timer has no output toggle latch and no alternate output function.

Timer T5 Run Control

The auxiliary timer T5 can be started or stopped by software in two different ways:

- Through the associated timer run bit (T5R). In this case it is required that the respective control bit T5RC = 0.
- Through the core timer's run bit (T6R). In this case the respective remote control bit must be set (T5RC = 1).

The selected run bit is relevant in all operating modes of T5. Setting the bit will start the timer, clearing the bit stops the timer.

In Gated Timer Mode, the timer will only run if the selected run bit is set and the gate is active (high or low, as programmed).

Note: If remote control is selected T6R will start/stop timer T6 and the auxiliary timer T5 synchronously.

14.2.4 GPT2 Auxiliary Timer T5 Operating Modes

The operation of the auxiliary timer in the basic operating modes is almost identical with the core timer's operation, with very few exceptions. Additionally, some combined operating modes can be selected.

Timer T5 in Timer Mode

Timer Mode for the auxiliary timer T5 is selected by setting its bitfield T5M in register T5CON to 000_B.

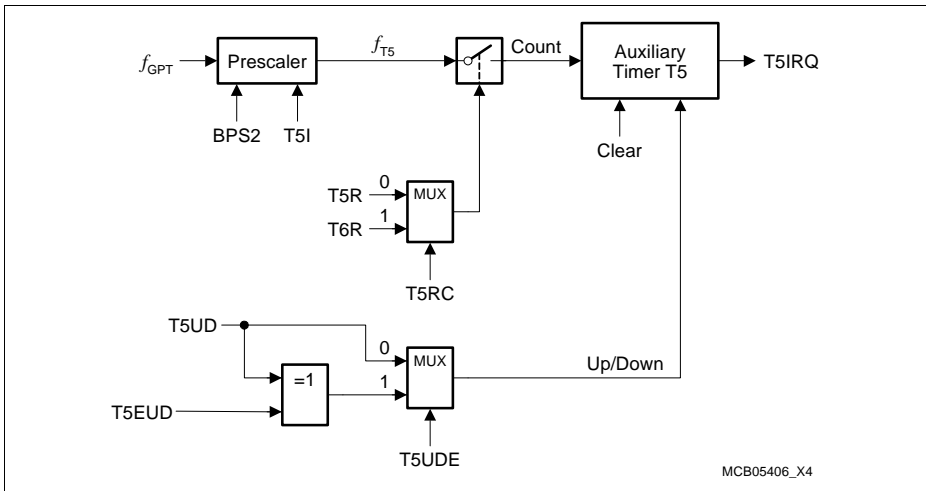


Figure 14-25 Block Diagram of Auxiliary Timer T5 in Timer Mode

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Timer T5 in Gated Timer Mode

Gated Timer Mode for the auxiliary timer T5 is selected by setting bitfield T5M in register T5CON to 010_B or 011_B. Bit T5M.0 (T5CON.3) selects the active level of the gate input.

Note: A transition of the gate signal at line T5IN does not cause an interrupt request.

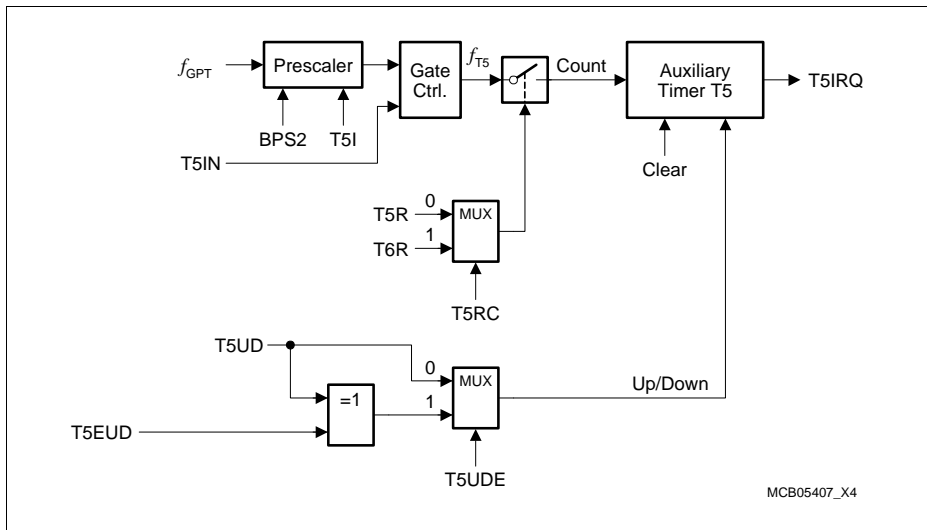


Figure 14-26 Block Diagram of Auxiliary Timer T5 in Gated Timer Mode

Note: There is no output toggle latch for T5.

Start/stop of the auxiliary timer can be controlled locally or remotely.

General Purpose Timer Units (GPT12)

Timer T5 in Counter Mode

Counter Mode for auxiliary timer T5 is selected by setting bitfield T5M in register T5CON to 001_B. In Counter Mode, the auxiliary timer can be clocked either by a transition at its external input line T5IN, or by a transition of timer T6's toggle latch T6OTL. The event causing an increment or decrement of a timer can be a positive, a negative, or both a positive and a negative transition at either the respective input pin or at the toggle latch. Bitfield T5I in control register T5CON selects the triggering transition (see [Table 14-17](#)).

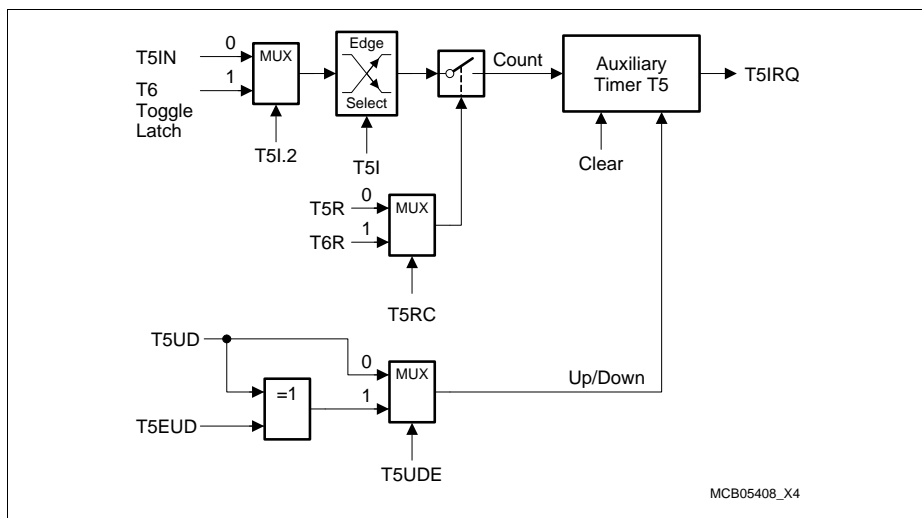


Figure 14-27 Block Diagram of Auxiliary Timer T5 in Counter Mode

Note: Only state transitions of T6OTL which are caused by the overflows/underflows of T6 will trigger the counter function of T5. Modifications of T6OTL via software will NOT trigger the counter function of T5.

For counter operation, pin T5IN must be configured as input. The maximum input frequency allowed in Counter Mode depends on the selected prescaler value. To ensure that a transition of the count input signal applied to T5IN is recognized correctly, its level must be held high or low for a minimum number of module clock cycles before it changes. This information can be found in [Section 14.2.6](#).

Timer Concatenation

Using the toggle bit T6OTL as a clock source for the auxiliary timer in Counter Mode concatenates the core timer T6 with the auxiliary timer T5. This concatenation forms either a 32-bit or a 33-bit timer/counter, depending on which transition of T6OTL is selected to clock the auxiliary timer.

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- **32-bit Timer/Counter:** If both a positive and a negative transition of T6OTL are used to clock the auxiliary timer, this timer is clocked on every overflow/underflow of the core timer T6. Thus, the two timers form a 32-bit timer.
- **33-bit Timer/Counter:** If either a positive or a negative transition of T6OTL is selected to clock the auxiliary timer, this timer is clocked on every second overflow/underflow of the core timer T6. This configuration forms a 33-bit timer (16-bit core timer + T6OTL + 16-bit auxiliary timer).

As long as bit T6OTL is not modified by software, it represents the state of the internal toggle latch, and can be regarded as part of the 33-bit timer.

The count directions of the two concatenated timers are not required to be the same. This offers a wide variety of different configurations.

T6, which represents the low-order part of the concatenated timer, can operate in Timer Mode, Gated Timer Mode or Counter Mode in this case.

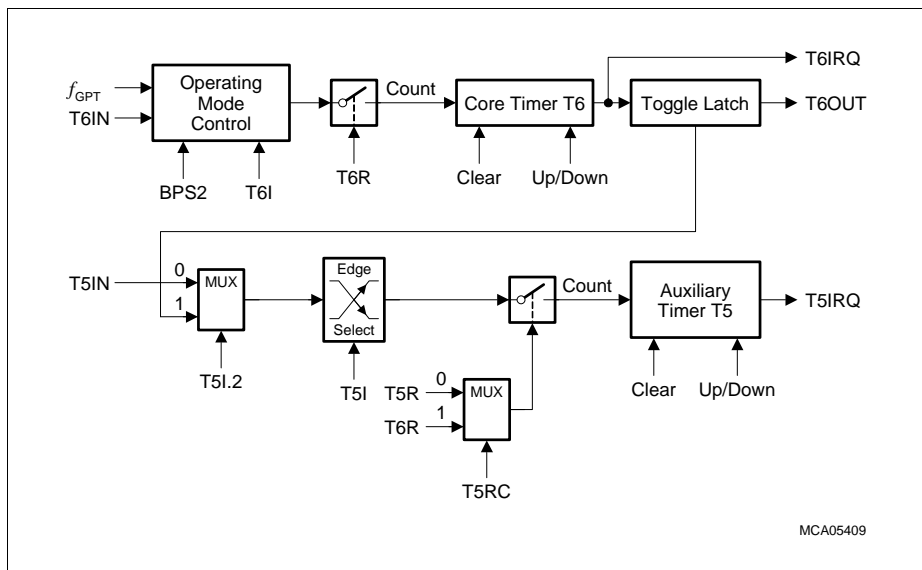


Figure 14-28 Concatenation of Core Timer T6 and Auxiliary Timer T5

14.2.5 GPT2 Register CAPREL Operating Modes

The Capture/Reload register CAPREL can be used to capture the contents of timer T5, or to reload timer T6. A special mode facilitates the use of register CAPREL for both functions at the same time. This mode allows frequency multiplication. The capture function is triggered by CAPIN, by T3IN and T3EUD, or by read GPT1 timers. The reload function is triggered by an overflow or underflow of timer T6.

In addition to the capture function, the capture trigger signal can also be used to clear the contents of timers T5 and T6 individually.

The functions of register CAPREL are controlled via several bit(field)s in the timer control registers T5CON and T6CON.

Capture/Reload Register CAPREL in Capture Mode

Capture mode for register CAPREL is selected by setting bit T5SC in control register T5CON (set bitfield CI in register T5CON to a non-zero value to select a trigger signal). In capture mode, the contents of the auxiliary timer T5 are latched into register CAPREL in response to a signal transition at the selected external input pin(s). Bit CT3 selects the external input line CAPIN or the input lines T3IN and/or T3EUD of GPT1 timer T3 as the source for a capture trigger. Either a positive, a negative, or both a positive and a negative transition at line CAPIN can be selected to trigger the capture function, or transitions on input T3IN or input T3EUD or both inputs, T3IN and T3EUD. The active edge is controlled by bitfield CI in register T5CON. [Table 14-10](#) summarizes these options.

Table 14-10 CAPREL Register Input Edge Selection

CT3	CI	Triggering Signal/Edge for Capture Mode
X	00 _B	None. Capture Mode is disabled.
0	01 _B	Positive transition (rising edge) on CAPIN. ¹⁾
0	10 _B	Negative transition (falling edge) on CAPIN.
0	11 _B	Any transition (rising or falling edge) on CAPIN.
1	01 _B	Any transition (rising or falling edge) on T3IN.
1	10 _B	Any transition (rising or falling edge) on T3EUD.
1	11 _B	Any transition (rising or falling edge) on T3IN or T3EUD.

1) Rising edge must be selected if capturing is triggered by the internal GPT1 read signals (see register PISEL and [“Combined Capture Modes” on Page 14-58](#)).

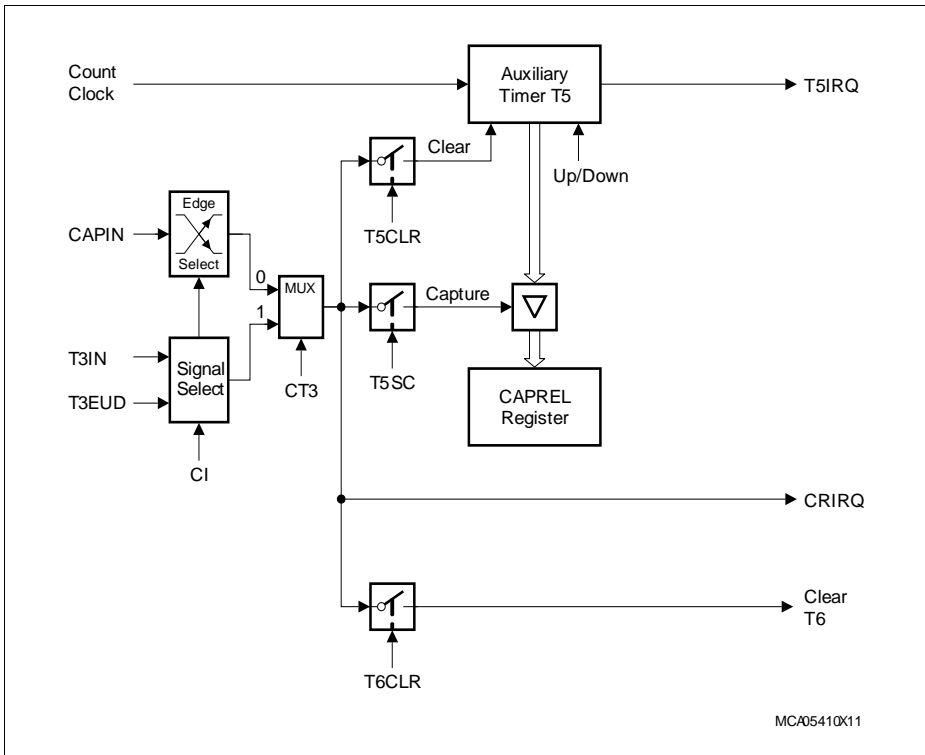


Figure 14-29 Capture/Reload Register CAPREL in Capture Mode

When a selected trigger is detected, the contents of the auxiliary timer T5 are latched into register CAPREL and the interrupt request line CRIRQ is activated. The same event can optionally clear timer T5 and/or timer T6. This option is enabled by bit T5CLR in register T5CON and bit T6CLR in register T6CON, respectively. If TxCLR = 0 the contents of timer Tx is not affected by a capture. If TxCLR = 1 timer Tx is cleared after the current timer T5 value has been latched into register CAPREL.

Note: Bit T5SC only controls whether or not a capture is performed. If T5SC is cleared the external input pin(s) can still be used to clear timer T5 and/or T6, or as external interrupt input(s). This interrupt is controlled by the CAPREL interrupt control register CRIC.

When capture triggers T3IN or T3EUD are enabled (CT3 = 1), register CAPREL captures the contents of T5 upon transitions of the selected input(s). These values can be used to measure T3's input signals. This is useful, for example, when T3 operates in

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Incremental Interface Mode, in order to derive dynamic information (speed, acceleration) from the input signals.

For capture mode operation, the selected pins CAPIN, T3IN, or T3EUD must be configured as input. To ensure that a transition of a trigger input signal applied to one of these inputs is recognized correctly, its level must be held high or low for a minimum number of module clock cycles, detailed in [Section 14.2.6](#).

Capture/Reload Register CAPREL in Reload Mode

Reload mode for register CAPREL is selected by setting bit T6SR in control register T6CON. In reload mode, the core timer T6 is reloaded with the contents of register CAPREL, triggered by an overflow or underflow of T6. This will not activate the interrupt request line CRIRQ associated with the CAPREL register. However, interrupt request line T6IRQ will be activated, indicating the overflow/underflow of T6.

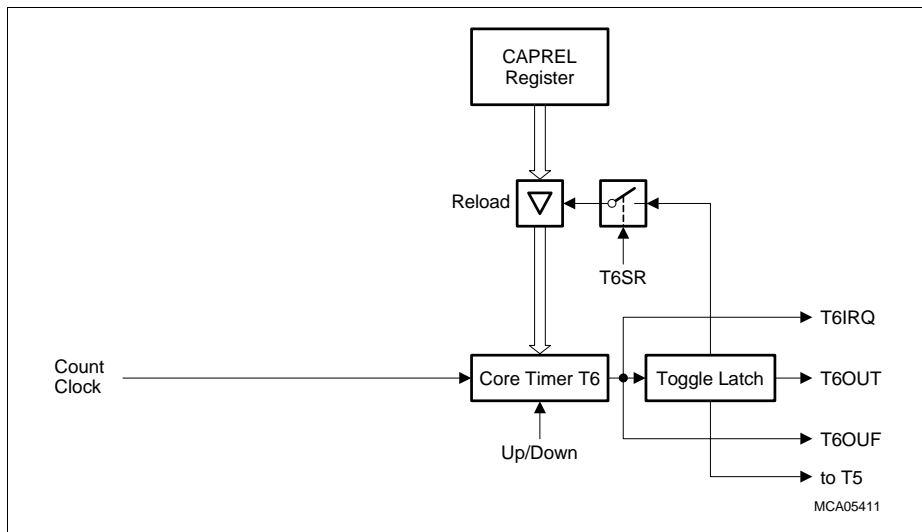


Figure 14-30 Capture/Reload Register CAPREL in Reload Mode

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Capture/Reload Register CAPREL in Capture-And-Reload Mode

Since the reload function and the capture function of register CAPREL can be enabled individually by bits T5SC and T6SR, the two functions can be enabled simultaneously by setting both bits. This feature can be used to generate an output frequency that is a multiple of the input frequency.

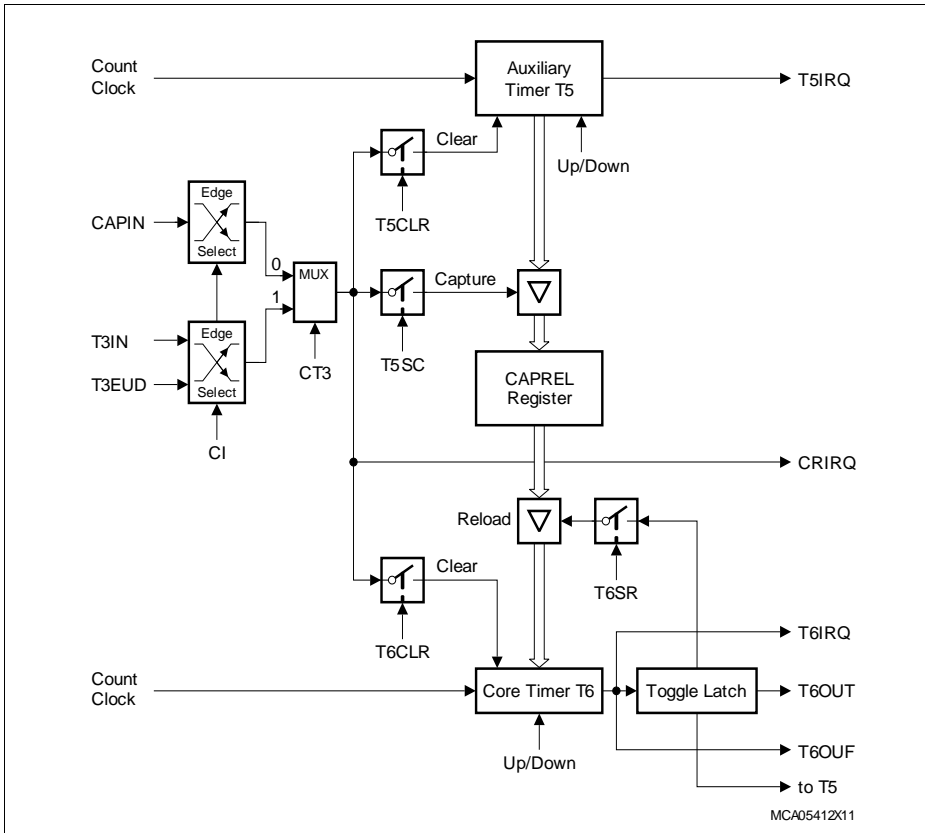


Figure 14-31 Capture/Reload Register CAPREL in Capture-And-Reload Mode

This combined mode can be used to detect consecutive external events which may occur aperiodically, but where a finer resolution, that means, more 'ticks' within the time between two external events is required.

For this purpose, the time between the external events is measured using timer T5 and the CAPREL register. Timer T5 runs in Timer Mode counting up with a frequency of e.g. $f_{GPT}/32$. The external events are applied to pin CAPIN. When an external event occurs,

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the contents of timer T5 are latched into register CAPREL and timer T5 is cleared (T5CLR = 1). Thus, register CAPREL always contains the correct time between two events, measured in timer T5 increments. Timer T6, which runs in Timer Mode counting down with a frequency of e.g. $f_{GPT}/4$, uses the value in register CAPREL to perform a reload on underflow. This means, the value in register CAPREL represents the time between two underflows of timer T6, now measured in timer T6 increments. Since (in this example) timer T6 runs 8 times faster than timer T5, it will underflow 8 times within the time between two external events. Thus, the underflow signal of timer T6 generates 8 'ticks'. Upon each underflow, the interrupt request line T6IRQ will be activated and bit T6OTL will be toggled. The state of T6OTL may be output on pin T6OUT. This signal has 8 times more transitions than the signal which is applied to pin CAPIN.

Note: The underflow signal of Timer T6 can furthermore be used to clock one or more of the timers of the CAPCOM units, which gives the user the possibility to set compare events based on a finer resolution than that of the external events. This connection is accomplished via signal T6OUF.

Capture Correction

A certain deviation of the output frequency is generated by the fact that timer T5 will count actual time units (e.g. T5 running at 1 MHz will count up to the value $64_H/100_D$ for a 10 kHz input signal), while T6OTL will only toggle upon an underflow of T6 (i.e. the transition from 0000_H to $FFFF_H$). In the above mentioned example, T6 would count down from 64_H , so the underflow would occur after 101 timing ticks of T6. The actual output frequency then is 79.2 kHz, instead of the expected 80 kHz.

This deviation can be compensated for by using T6 overflows. In this case, T5 counts down and T6 counts up. Upon a signal transition on pin CAPIN, the count value in T5 is captured into CAPREL and T5 is cleared to 0000_H . In its next clock cycle, T5 underflows to $FFFF_H$, and continues to count down with the following clocks. T6 is reloaded from CAPREL upon an overflow, and continues to count up with its following clock cycles (8 times faster in the above example). In this case, T5 and T6 count the same number of steps with their respective internal count frequency.

In the above example, T5 running at 1 MHz will count down to the value $FF9C_H/-100_D$ for a 10 kHz input signal applied at CAPIN, while T6 counts up from $FF9C_H$ through $FFFF_H$ to 0000_H . So the overflow occurs after 100 timing ticks of T6, and the actual output frequency at T6OUT then is the expected 80 kHz.

However, in this case CAPREL does not directly contain the time between two CAPIN events, but rather its 2's complement. Software will have to convert this value, if it is required for the operation.

Combined Capture Modes

For incremental interface applications in particular, several timer features can be combined to obtain dynamic information such as speed, acceleration, or deceleration. The current position itself can be obtained directly from the timer register (T2, T3, T4).

The time information to determine the dynamic parameters is generated by capturing the contents of the free-running timer T5 into register CAPREL. Two trigger sources for this event can be selected:

- Capture trigger on sensor signal transitions
- Capture trigger on position read operations

Capturing on sensor signal transitions is available for timer T3 inputs. This mode is selected by setting bit CT3 and selecting the intended signal(s) via bitfield CI in register T5CON. CAPREL then indicates the time between two selected transitions (measured in T5 counts).

Capturing on position read operations is available for timers T2, T3, and T4. This mode is selected by clearing bit CT3 and selecting the rising edge via bitfield CI in register T5CON. Bitfield ISCAPIN in register PISEL then selects either a read access from T3 or a read access from any of T2 or T3 or T4. CAPREL then indicates the time between two read accesses.

These operating modes directly support the measurement of position and rotational speed. Acceleration and deceleration can then be determined by evaluating subsequent speed measurements.

14.2.6 GPT2 Clock Signal Control

All actions within the timer block GPT2 are triggered by transitions of its basic clock. This basic clock is derived from the module clock f_{GPT} by a basic block prescaler, controlled by bitfield BPS2 in register T6CON (see [Figure 14-20](#)). The count clock can be generated in two different ways:

- **Internal count clock**, derived from GPT2's basic clock via a programmable prescaler, is used for (gated) Timer Mode.
- **External count clock**, derived from the timer's input pin(s), is used for Counter Mode.

For both ways, the basic clock determines the maximum count frequency and the timer's resolution:

Table 14-11 Basic Clock Selection for Block GPT2

Block Prescaler ¹⁾	BPS2 = 01 _B	BPS2 = 00 _B ²⁾	BPS2 = 11 _B	BPS2 = 10 _B
Prescaling Factor for GPT2: F(BPS2)	F(BPS2) = 2	F(BPS2) = 4	F(BPS2) = 8	F(BPS2) = 16
Maximum External Count Frequency	$f_{GPT}/4$	$f_{GPT}/8$	$f_{GPT}/16$	$f_{GPT}/32$
Input Signal Stable Time	$2 \times t_{GPT}$	$4 \times t_{GPT}$	$8 \times t_{GPT}$	$16 \times t_{GPT}$

1) Please note the non-linear encoding of bitfield BPS2.

2) Default after reset.

Internal Count Clock Generation

In Timer Mode and Gated Timer Mode, the count clock for each GPT2 timer is derived from the GPT2 basic clock by a programmable prescaler, controlled by bitfield TxI in the respective timer's control register TxCON.

The count frequency f_{Tx} for a timer Tx and its resolution r_{Tx} are scaled linearly with lower clock frequencies, as can be seen from the following formula:

$$f_{Tx} = \frac{f_{GPT}}{F(BPS2) \times 2^{<TxI>}} \quad r_{Tx}[\mu S] = \frac{F(BPS2) \times 2^{<TxI>}}{f_{GPT}[\text{MHz}]} \quad (14.2)$$

The effective count frequency depends on the common module clock prescaler factor F(BPS2) as well as on the individual input prescaler factor $2^{<TxI>}$. [Table 14-15](#) summarizes the resulting overall divider factors for a GPT2 timer that result from these cascaded prescalers.

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Table 14-12 lists GPT2 timer's parameters (such as count frequency, resolution, and period) resulting from the selected overall prescaler factor and the module clock f_{GPT} . Note that some numbers may be rounded.

Table 14-12 GPT2 Timer Parameters

System Clock = 10 MHz			Overall Divider Factor	System Clock = 40 MHz		
Frequency	Resolution	Period		Frequency	Resolution	Period
5.0 MHz	200 ns	13.11 ms	2	20.0 MHz	50 ns	3.28 ms
2.5 MHz	400 ns	26.21 ms	4	10.0 MHz	100 ns	6.55 ms
1.25 MHz	800 ns	52.43 ms	8	5.0 MHz	200 ns	13.11 ms
625.0 kHz	1.6 μ s	104.9 ms	16	2.5 MHz	400 ns	26.21 ms
312.5 kHz	3.2 μ s	209.7 ms	32	1.25 MHz	800 ns	52.43 ms
156.25 kHz	6.4 μ s	419.4 ms	64	625.0 kHz	1.6 μ s	104.9 ms
78.125 kHz	12.8 μ s	838.9 ms	128	312.5 kHz	3.2 μ s	209.7 ms
39.06 kHz	25.6 μ s	1.678 s	256	156.25 kHz	6.4 μ s	419.4 ms
19.53 kHz	51.2 μ s	3.355 s	512	78.125 kHz	12.8 μ s	838.9 ms
9.77 kHz	102.4 μ s	6.711 s	1024	39.06 kHz	25.6 μ s	1.678 s
4.88 kHz	204.8 μ s	13.42 s	2048	19.53 kHz	51.2 μ s	3.355 s

External Count Clock Input

The external input signals of the GPT2 block are sampled with the GPT2 basic clock (see [Figure 14-20](#)). To ensure that a signal is recognized correctly, its current level (high or low) must be held active for at least one complete sampling period, before changing. A signal transition is recognized if two subsequent samples of the input signal represent different levels. Therefore, a minimum of two basic clock periods are required for the sampling of an external input signal. Thus, the maximum frequency of an input signal must not be higher than half the basic clock.

Table 14-13 summarizes the resulting requirements for external GPT2 input signals.

Table 14-13 GPT2 External Input Signal Limits

GPT2 Basic Clock = 10 MHz		Input Frequ. Factor	GPT2 Divider BPS2	Input Phase Duration	GPT2 Basic Clock = 40 MHz	
Max. Input Frequency	Min. Level Hold Time				Max. Input Frequency	Min. Level Hold Time
2.5 MHz	200 ns	$f_{\text{GPT}}/4$	01 _B	$2 \times t_{\text{GPT}}$	10.0 MHz	50 ns
1.25 MHz	400 ns	$f_{\text{GPT}}/8$	00 _B	$4 \times t_{\text{GPT}}$	5.0 MHz	100 ns
625.0 kHz	800 ns	$f_{\text{GPT}}/16$	11 _B	$8 \times t_{\text{GPT}}$	2.5 MHz	200 ns
312.5 kHz	1.6 μ s	$f_{\text{GPT}}/32$	10 _B	$16 \times t_{\text{GPT}}$	1.25 MHz	400 ns

These limitations are valid for all external input signals to GPT2, including the external count signals in Counter Mode and the gate input signals in Gated Timer Mode.

14.2.7 Interrupt Control for GPT2 Timers and CAPREL

When a timer overflows from $FFFF_H$ to 0000_H (when counting up), or when it underflows from 0000_H to $FFFF_H$ (when counting down), its interrupt request flag in register GPT12E_T5IC or GPT12E_T6IC will be set. This will cause an interrupt to the respective timer interrupt vector or trigger a PEC service, if the respective interrupt enable bit is set.

Whenever a transition according to the selection in bit field CI is detected at pin CAPIN, interrupt request flag in register GPT12E_CRIC is set. Setting any request flag will cause an interrupt to the respective timer or CAPREL interrupt vector or trigger a PEC service, if the respective interrupt enable bit is set.

There is an interrupt control register for each of the two timers (T5, T6) and for the CAPREL register. All interrupt control registers have the same structure described in section Interrupt Control.

14.2.8 GPT2 Registers

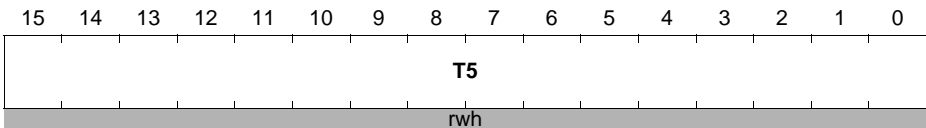
14.2.8.1 GPT2 Timer Registers

GPT12E_T5

Timer 5 Count Register

SFR (FE46_H/23_H)

Reset Value: 0000_H



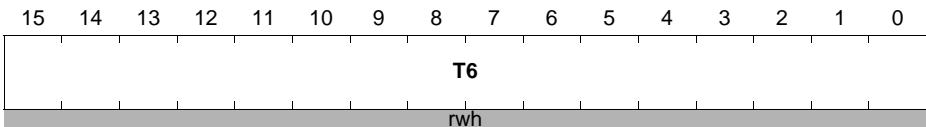
Field	Bits	Typ	Description
T5	[15:0]	rwh	Timer T5 Current Value Contains the current value of the timer T5

GPT12E_T6

Timer T6 Count Register

SFR (FE48_H/24_H)

Reset Value: 0000_H



Field	Bits	Typ	Description
T6	[15:0]	rwh	Timer T6 Current Value Contains the current value of the timer T6

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GPT12E_CAPREL

Capture/Reload Register

SFR (FE4A_H/25_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CAPREL															
rwh															

Field	Bits	Typ	Description
CAPREL	[15:0]	rwh	Current reload value or Captured value Contains the current value of the CAPREL register

14.2.8.2 GPT2 Timer Control Registers

GPT2 Core Timer T6 Control Register

GPT12E_T6CON

Timer T6 Control Register

SFR (FF48_H/A4_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T6 SR	T6 CLR	-	BPS2		T6 OTL	T6 OE	T6 UDE	T6 UD	T6R		T6M			T6I	
rw	rw	-	rw		rwh	rw	rw	rw	rw		rw			rw	

Field	Bits	Type	Description
T6I	[2:0]	rw	Timer T6 Input Parameter Selection Depends on the operating mode, see respective sections for encoding: Table 14-15 for Timer Mode and Gated Timer Mode Table 14-16 for Counter Mode
T6M	[5:3]	rw	Timer T6 Mode Control (Basic Operating Mode) 000 _B Timer Mode 001 _B Counter Mode 010 _B Gated Timer Mode with gate active low 011 _B Gated Timer Mode with gate active high 100 _B Reserved. Do not use this combination. 101 _B Reserved. Do not use this combination. 110 _B Reserved. Do not use this combination. 111 _B Reserved. Do not use this combination.
T6R	6	rw	Timer T6 Run Bit 0 _B Timer T6 stops 1 _B Timer T6 runs
T6UD	7	rw	Timer T6 Up/Down Control¹⁾ 0 _B Timer T6 counts up 1 _B Timer T6 counts down <i>Note: This bit only controls count direction of T6 if bit T6UDE = 0.</i>

General Purpose Timer Units (GPT12)

Field	Bits	Type	Description
T6UDE	8	rw	Timer T6 External Up/Down Enable¹⁾ 0_B Count direction is controlled by bit T6UD; input T6EUD is disconnected 1_B Count direction is controlled by input T6EUD
T6OE	9	rw	Overflow/Underflow Output Enable 0_B Alternate Output Function Disabled 1_B State of timer T6 toggle latch is output on pin T6OUT
T6OTL	10	rwh	Timer T6 Overflow Toggle Latch Toggles on each overflow/underflow of timer T6. Can be set or reset by software (see separate description)
BPS2	[12:11]	rw	GPT2 Block Prescaler Control Selects the basic clock for block GPT2 (see also Section 14.2.6) 00_B $f_{GPT}/4$ 01_B $f_{GPT}/2$ 10_B $f_{GPT}/16$ 11_B $f_{GPT}/8$
T6CLR	14	rw	Timer T6 Clear Enable Bit 0_B Timer T6 is not cleared on a capture event 1_B Timer T6 is cleared on a capture event
T6SR	15	rw	Timer T6 Reload Mode Enable 0_B Reload from register CAPREL disabled 1_B Reload from register CAPREL enabled

1) See [Table 14-14](#) for encoding of bits T6UD and T6UDE.

General Purpose Timer Units (GPT12)

GPT2 Auxiliary Timer T5 Control Registers

GPT12E_T5CON

Timer 5 Control Register

SFR (FF46_H/A3_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T5 SC	T5 CLR	CI	-	CT3	T5 RC	T5 UDE	T5 UD	T5R	T5M			T5I			
rw	rw	rw	-	rw	rw	rw	rw	rw			rw			rw	

Field	Bits	Type	Description
T5I	[2:0]	rw	Timer T5 Input Parameter Selection Depends on the operating mode, see respective sections for encoding: Table 14-15 for Timer Mode and Gated Timer Mode Table 14-17 for Counter Mode
T5M	[5:3]	rw	Timer T5 Mode Control (Basic Operating Mode) 000 _B Timer Mode 001 _B Counter Mode 010 _B Gated Timer Mode with gate active low 011 _B Gated Timer Mode with gate active high 100 _B Reserved. Do not use this combination 101 _B Reserved. Do not use this combination 110 _B Reserved. Do not use this combination 111 _B Reserved. Do not use this combination
T5R	6	rw	Timer T5 Run Bit 0 _B Timer T5 stops 1 _B Timer T5 runs <i>Note: This bit only controls timer T5 if bit T5RC = 0.</i>
T5UD	7	rw	Timer T5 Up/Down Control¹⁾ 0 _B Timer T5 counts up 1 _B Timer T5 counts down <i>Note: This bit only controls count direction of T5 if bit T35DE = 0.</i>
T5UDE	8	rw	Timer T5 External Up/Down Enable¹⁾ 0 _B Count direction is controlled by bit T5UD; input T5EUD is disconnected 1 _B Count direction is controlled by input T5EUD

General Purpose Timer Units (GPT12)

Field	Bits	Type	Description
T5RC	9	rw	Timer T5 Remote Control 0_B Timer T5 is controlled by its own run bit T5R 1_B Timer T5 is controlled by the run bit T6R of core timer T6, not by bit T5R
CT3	10	rw	Timer T3 Capture Trigger Enable 0_B Capture trigger from input line CAPIN 1_B Capture trigger from T3 input lines T3IN and/or T3EUD
CI	[13:12]	rw	Register CAPREL Capture Trigger Selection²⁾ 00_B Capture disabled 01_B Positive transition (rising edge) on CAPIN ³⁾ or any transition on T3IN 10_B Negative transition (falling edge) on CAPIN or any transition on T3EUD 11_B Any transition (rising or falling edge) on CAPIN or any transition on T3IN or T3EUD
T5CLR	14	rw	Timer T5 Clear Enable Bit 0_B Timer T5 is not cleared on a capture event 1_B Timer T5 is cleared on a capture event
T5SC	15	rw	Timer T5 Capture Mode Enable 0_B Capture into register CAPREL disabled 1_B Capture into register CAPREL enabled

1) See [Table 14-14](#) for encoding of bits T5UD and T5UDE.

2) To define the respective trigger source signal, also bit CT3 must be regarded (see [Table 14-10](#)).

3) Rising edge must be selected if capturing is triggered by the internal GPT1 read signals (see register PISEL and [“Combined Capture Modes” on Page 14-58](#)).

Encoding of Timer Count Direction Control

Table 14-14 GPT2 Timer Count Direction Control

Pin TxEUD	Bit TxUDE	Bit TxUD	Count Direction
X	0	0	Count Up
X	0	1	Count Down
0	1	0	Count Up
1	1	0	Count Down
0	1	1	Count Down
1	1	1	Count Up

Timer Mode and Gated Timer Mode: Encoding of Overall Prescaler Factor

**Table 14-15 GPT2 Overall Prescaler Factors for Internal Count Clock
(Timer Mode and Gated Timer Mode)**

Individual Prescaler for Tx	Common Prescaler for Module Clock ¹⁾			
	BPS2 = 01 _B	BPS2 = 00 _B	BPS2 = 11 _B	BPS2 = 10 _B
Txl = 000 _B	2	4	8	16
Txl = 001 _B	4	8	16	32
Txl = 010 _B	8	16	32	64
Txl = 011 _B	16	32	64	128
Txl = 100 _B	32	64	128	256
Txl = 101 _B	64	128	256	512
Txl = 110 _B	128	256	512	1024
Txl = 111 _B	256	512	1024	2048

1) Please note the non-linear encoding of bitfield BPS2.

Counter Mode: Encoding of Input Edge Selection

Table 14-16 GPT2 Core Timer T6 Input Edge Selection (Counter Mode)

T6I	Triggering Edge for Counter Increment/Decrement
000 _B	None. Counter T6 is disabled
001 _B	Positive transition (rising edge) on T6IN
010 _B	Negative transition (falling edge) on T6IN
011 _B	Any transition (rising or falling edge) on T6IN
1XX _B	Reserved. Do not use this combination

Table 14-17 GPT2 Auxiliary Timer T5 Input Edge Selection (Counter Mode)

T5I	Triggering Edge for Counter Increment/Decrement
X00 _B	None. Counter T5 is disabled
001 _B	Positive transition (rising edge) on T5IN
010 _B	Negative transition (falling edge) on T5IN
011 _B	Any transition (rising or falling edge) on T5IN
101 _B	Positive transition (rising edge) of T6 toggle latch T6OTL
110 _B	Negative transition (falling edge) of T6 toggle latch T6OTL
111 _B	Any transition (rising or falling edge) of T6 toggle latch T6OTL

14.2.8.3 GPT2 Timer and CAPREL Interrupt Control Registers

There is an interrupt control register for each of the three timers (T2, T3, T4). All interrupt control registers GPT12E_T5IC, GPT12E_T6IC, and GPT12E_CIC have the same structure described in section Interrupt Control.

General Purpose Timer Units (GPT12)

14.3 Miscellaneous GPT12 Registers

The following registers are not assigned to a specific timer block. They control general functions and/or give general information.

Register GPT12E_PISEL selects timer input signal from several sources under software control.

GPT12E_PISEL

Port Input Select Register

SFR (FE4C_H/26_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ISCAPIN	IST6 EUD	IST6 IN	IST5 EUD	IST5 IN	IST4EUD	IST4IN	IST3EUD	IST3IN	IST2 EUD	IST2 IN					
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Typ	Description
IST2IN	0	rw	Input Select for T2IN 0 _B Signal T2INA is selected 1 _B Signal T2INB is selected
IST2EUD	1	rw	Input Select for T2EUD 0 _B Signal T2EUDA is selected 1 _B Signal T2EUDB is selected
IST3IN	[3:2]	rw	Input Select for T3IN 00 _B Signal T3INA is selected 01 _B Signal T3INB is selected 10 _B Signal T3INC is selected 11 _B Signal T3IND is selected
IST3EUD	[5:4]	rw	Input Select for T3EUD 00 _B Signal T3EUDA is selected 01 _B Signal T3EUDB is selected 10 _B Signal T3EUDC is selected 11 _B Signal T3EUDD is selected
IST4IN	[7:6]	rw	Input Select for T4IN 00 _B Signal T4INA is selected 01 _B Signal T4INB is selected 10 _B Signal T4INC is selected 11 _B Signal T4IND is selected

General Purpose Timer Units (GPT12)

Field	Bits	Typ	Description
IST4EUD	[9:8]	rw	Input Select for T4EUD 00 _B Signal T4EUDA is selected 01 _B Signal T4EADB is selected 10 _B Signal T4EUDC is selected 11 _B Signal T4EUDD is selected
IST5IN	10	rw	Input Select for T5IN 0 _B Signal T5INA is selected 1 _B Signal T5INB is selected
IST5EUD	11	rw	Input Select for T5EUD 0 _B Signal T5EUDA is selected 1 _B Signal T5EADB is selected
IST6IN	12	rw	Input Select for T6IN 0 _B Signal T6INA is selected 1 _B Signal T6INB is selected
IST6EUD	13	rw	Input Select for T6EUD 0 _B Signal T6EUDA is selected 1 _B Signal T6EADB is selected
ISCAPIN	[15:14]	rw	Input Select for CAPIN 00 _B Signal CAPINA is selected 01 _B Signal CAPINB is selected 10 _B Signal CAPINC (Read trigger from T3) is selected 11 _B Signal CAPIND (Read trigger from T2 or T3 or T4) is selected

Note: PISEL's reset value represents the connections available in previous versions.

General Purpose Timer Units (GPT12)

Register GPT12E_KSCCFG controls the overall operation of the GPT12 module.

GPT12E_KSCCFG

Kernel State Configuration Register

SFR(FE1C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BP COM	0	COMCFG	BP SUM	0	SUMCFG	BP NOM	0	NOMCFG	0	BP MOD EN	MOD EN				
w	r	rw	w	r	rw	w	r	rw	r	w	rw				

Field	Bits	Type	Description
MODEN	0	rw	<p>Module Enable</p> <p>This bit enables the module kernel clock and the module functionality.</p> <p>0_B The module is switched off. It does not react on mode control actions and the module clock is switched off immediately (without stop condition). The module does not react on read accesses and ignores write accesses.</p> <p>1_B The module is switched on and can operate. After writing 1 to MODEN, it is recommended to read register KSCCFG to avoid pipeline effects in the control block before accessing other GPT registers.</p> <p><i>Note: This bit is reset by an application reset.</i></p>
BPMODEN	1	w	<p>Bit Protection for MODEN</p> <p>This bit enables the write access to the bit MODEN. It always reads 0. It is only active during the write access cycle.</p> <p>0_B MODEN is not changed.</p> <p>1_B MODEN is updated with the written value.</p> <p><i>Note: This bit is reset by an application reset.</i></p>

General Purpose Timer Units (GPT12)

Field	Bits	Type	Description
NOMCFG	[5:4]	rw	Normal Operation Mode Configuration This bit field defines the kernel mode applied in normal operation mode. $0X_B$ The module is switched on. $1X_B$ The module is switched off. This field is taken into account for CR = 00 or 11. <i>Note: This bit is reset by an application reset.</i>
BPNO	7	w	Bit Protection for NOMCFG This bit enables the write access to the bit field NOMCFG. It always reads 0. It is only active during the write access cycle. 0_B NOMCFG is not changed. 1_B NOMCFG is updated with the written value. <i>Note: This bit is reset by an application reset.</i>
SUMCFG	[9:8]	rw	Suspend Mode Configuration This bit field defines the kernel mode applied in suspend mode. $0X_B$ The module is switched on. $1X_B$ The module is switched off. This field is taken into account for CR = 01. <i>Note: This bit is reset by a debug reset.</i>
BPSUM	11	w	Bit Protection for SUMCFG This bit enables the write access to the bit field SUMCFG. It always reads 0. It is only active during the write access cycle. 0_B SUMCFG is not changed. 1_B SUMCFG is updated with the written value. <i>Note: This bit is reset by a debug reset.</i>
COMCFG	[13:12]	rw	Clock Off Mode Configuration This bit field defines the kernel mode applied in clock off mode. $0X_B$ The module is switched on. $1X_B$ The module is switched off. This field is taken into account for CR = 10. <i>Note: This bit is reset by an application reset.</i>

General Purpose Timer Units (GPT12)

Field	Bits	Type	Description
BPCOM	15	w	Bit Protection for COMCFG This bit enables the write access to the bit field COMCFG. It always reads 0. It is only active during the write access cycle. 0 _B COMCFG is not changed. 1 _B COMCFG is updated with the written value. <i>Note: This bit is reset by an application reset.</i>
0	[3:2], 6, 10, 14	r	Reserved; returns 0 if read; should be written with 0;

General Purpose Timer Units (GPT12)

14.4 Register Table

Table 14-18 shows all registers which are required for programming of the GPT12E module. It summarizes the GPT12E kernel registers and the module external registers and defines their addresses and reset values.

Table 14-18 GPT12E Module Register Summary

Name	Description	Address		Reset Value
		16-Bit	8-Bit	

General Purpose Timer Unit (GPT12E)

GPT12E_ID	GPT12E Module ID Register	FFE6 _H	F3 _H	58XXXX _H
GPT12E_T2CON	GPT12E Timer T2 Control Register	FF40 _H	A0 _H	0000 _H
GPT12E_T3CON	GPT12E Timer T3 Control Register	FF42 _H	A1 _H	0000 _H
GPT12E_T4CON	GPT12E Timer T4 Control Register	FF44 _H	A2 _H	0000 _H
GPT12E_T5CON	GPT12E Timer T5 Control Register	FF46 _H	A3 _H	0000 _H
GPT12E_T6CON	GPT12E Timer T6 Control Register	FF48 _H	A4 _H	0000 _H
GPT12E_CAPREL	GPT12E Capture/Reload Register	FE4A _H	25 _H	0000 _H
GPT12E_T2	GPT12E Timer T2 Register	FE40 _H	20 _H	0000 _H
GPT12E_T3	GPT12E Timer T3 Register	FE42 _H	21 _H	0000 _H
GPT12E_T4	GPT12E Timer T4 Register	FE44 _H	22 _H	0000 _H
GPT12E_T5	GPT12E Timer T5 Register	FE46 _H	23 _H	0000 _H
GPT12E_T6	GPT12E Timer T6 Register	FE48 _H	24 _H	0000 _H
GPT12E_T2IC	GPT12E Timer T2 Interrupt Control Register	FF60 _H	B0 _H	0000 _H
GPT12E_T3IC	GPT12E Timer T3 Interrupt Control Register	FF62 _H	B1 _H	0000 _H
GPT12E_T4IC	GPT12E Timer T4 Interrupt Control Register	FF64 _H	B2 _H	0000 _H
GPT12E_T5IC	GPT12E Timer T5 Interrupt Control Register	FF66 _H	B3 _H	0000 _H
GPT12E_T6IC	GPT12E Timer T6 Interrupt Control Register	FF68 _H	B4 _H	0000 _H
GPT12E_CRIC	GPT12E CAPREL Interrupt Control Register	FF6A _H	B5 _H	0000 _H

14.5 Implementation of the GPT12 Module

This chapter describes the implementation of the GPT12 module in the XE166U device. Not every timer can work in Gated Timer Mode or Counter Mode due to missing input pins described in [Table 14-19](#). Furthermore, some functionality is not available any more.

Following timer modes are not supported:

- Timer T6 in Gated Timer Mode
- Timer T6 in Counter Mode

14.5.1 Module Connections

Besides the described intra-module connections, the timer unit blocks GPT1 and GPT2 are connected to their environment in two basic ways:

- **Internal connections** interface the timers with on-chip resources such as clock generation unit, interrupt controller, or other timers.
The GPT module is clocked with the XE166U system clock, so $f_{\text{GPT}} = f_{\text{SYS}}$.
- **External connections** interface the timers with external resources via port pins.

Note: The GPT12E output signal 'T6OFL' is connected to the CAPCOM2 input 'TOUF' and to the GSC.

The following table shows the digital connections of the GPT12 module with other modules or pins in the XE166U device.

Table 14-19 GPT Digital Connections in XE166U

Signal	from/to Module	I/O to GPT	Can be used to/as
T2INA	0	I	count input signals for timer T2
T2INB	0	I	
T2EUDA	0	I	direction input signals for timer T2
T2EADB	0	I	
T2IRQ	ICU	O	interrupt request from timer T2
T3INA	P5.3	I	count input signals for timer T3
T3INB	P10.9	I	
T3INC	0	I	
T3IND	0	I	

General Purpose Timer Units (GPT12)

Table 14-19 GPT Digital Connections in XE166U (cont'd)

Signal	from/to Module	I/O to GPT	Can be used to/as
T3EUDA	P5.4	I	direction input signals for timer T3
T3EADB	P10.8	I	
T3EUDC	0	I	
T3EUDD	0	I	
T3OUT	P6.1	O	count output signal for timer T3
	P6.3	O	
	ERU_3A2 (SCU)	O	
T3IRQ	ICU	O	interrupt request from timer T3
T4INA	0	I	count input signals for timer T4
T4INB	P10.7	I	
T4INC	0	I	
T4IND	0	I	
T4EUDA	0	I	direction input signals for timer T4
T4EADB	0	I	
T4EUDC	0	I	
T4EUDD	0	I	
T4IRQ	ICU	O	interrupt request from timer T4
T5INA	0	I	count input signals for timer T5
T5INB	P2.0	I	
T5EUDA	0	I	direction input signals for timer T5
T5EADB	P2.1	I	
T5IRQ	ICU	O	interrupt request from timer T5
T6INA	0	I	count input signals for timer T6
T6INB	0	I	
T6EUDA	0	I	direction input signals for timer T6
T6EADB	0	I	
T6OUT	0	O	count output signal for timer T6
T6IRQ	ICU	O	interrupt request from timer T6
T6OFL	CC2_TOUF, SCU (GSC)	O	over/under-flow signal from timer T6

General Purpose Timer Units (GPT12)

Table 14-19 GPT Digital Connections in XE166U (cont'd)

Signal	from/to Module	I/O to GPT	Can be used to/as
CAPINA	P2.10	I	input capture signals
CAPINB	WUT trigger (SCU)	I	Wake-up trigger from WUT
CAPINC	Read trigger from T3	I	
CAPIND	Read trigger from T2 or T3 or T4	I	
CRIRQ	ICU	O	interrupt request from capture control

General Purpose Timer Units (GPT12)

Port Control

Port pins to be used for timer input signals must be switched to input (bitfield PC in the respective port control register must be 0xxx_B) and must be selected via register PISEL.

Port pins to be used for timer output signals must be switched to output and the alternate timer output signal must be selected (bitfield PC in the respective port control register must be 1xxx_B).

For the inputs assigned to Port 5 (uni-directional input ports), the digital input must be enabled by the digital input control registers (PxDIDIS).

Note: The P5 inputs are directly enabled after reset by the default values of registers P5DIDIS.

Note: For a description of the port control registers, please refer to chapter "Parallel Ports".

Interrupts

The GPT12 has six interrupt request lines.

Interrupt nodes to be used for timer interrupt requests must be enabled and programmed to a specific interrupt level.

Debug Details

While the module GPT is disabled, its registers can still be read. While disabled the following registers can be written: PISEL, T5CON.

15 Real Time Clock

The Real Time Clock (RTC) module of the XE166U basically consists of a chain of prescalers and timers. Its count clock is derived from the auxiliary oscillator or from the prescaled main oscillator. The RTC serves various purposes:

- 48-bit timer for long term measurements
- System clock to determine the current time and date
(the RTC's structure supports the direct representation of time and date)
- Cyclic time based interrupt (can be generated by any timer of the chain)

A number of programming options as well as interrupt request signals adjust the operation of the RTC to the application's requirements. The RTC can continue its operation while the XE166U is in certain power-saving modes, such that real time date and time information is provided.

Control Registers		Data Registers		Counter Registers		Interrupt Control	
RTC_CON	E	RTC_T14REL	E	RTC_T14	E	RTC_ISNC	E
RTCCLKCON		RTC_RELH	E	RTC_RTCH	E	RTC_IC	E
RTC_KSCCFG	E	RTC_RELL	E	RTC_RTCL	E		

RTC_CON	Real Time Clock Control Register	RTC_T14	Timer T14 Count Register
RTCCLKCON	RTC Clock Control Register	RTC_T14REL	Timer T14 Reload Register
RTC_ISNC	Interrupt Subnode Control Reg.	RTC_RTCH/L	RTC Count Registers, High/Low
RTC_IC	RTC Interrupt Control Register	RTC_RELH/L	RTC Reload Registers High/Low
RTC_KSCCFG	Kernel State Configuration Reg.		

mc_rtcregx2k.vsd

Figure 15-1 SFRs Associated with the RTC Module

The RTC module consists of a chain of 3 divider blocks:

- a selectable 8:1 divider (on - off)
- the reloadable 16-bit timer T14
- the 32-bit RTC timer block (accessible via RTC_RTCH and RTC_RTCL), made of:
 - the reloadable 10-bit timer CNT0
 - the reloadable 6-bit timer CNT1
 - the reloadable 6-bit timer CNT2
 - the reloadable 10-bit timer CNT3

All timers count upwards. Each of the five timers can generate an interrupt request. All requests are combined to a common node request.

Note: The RTC registers are only affected by a power reset in order to maintain the correct system time even when system or application resets are executed.

15.1 Defining the RTC Time Base

The timer chain of the RTC is clocked with the count clock signal f_{RTC} which is derived from internal sources (oscillators or PLL) or external sources (pins). The currently active clock source is selected by bitfield RTCCLKSEL in register RTCCLKCON. Optionally prescaled by a factor of 32 and/or 8, this is the basic RTC clock. Depending on the operating mode, timer T14 may provide the count increments used by the application and thus determine the input frequency of the RTC timer, that is, the RTC time base (see also [Table 15-2](#)).

The RTC is also supplied with the system clock f_{SYS} of the XE166U. This clock signal is used to control the RTC's logic blocks and its bus interface. To synchronize properly to the count clock, the system clock must run at least four times faster than the count clock, this means $f_{\text{SYS}} \geq 4 \times f_{\text{CNT}}$.

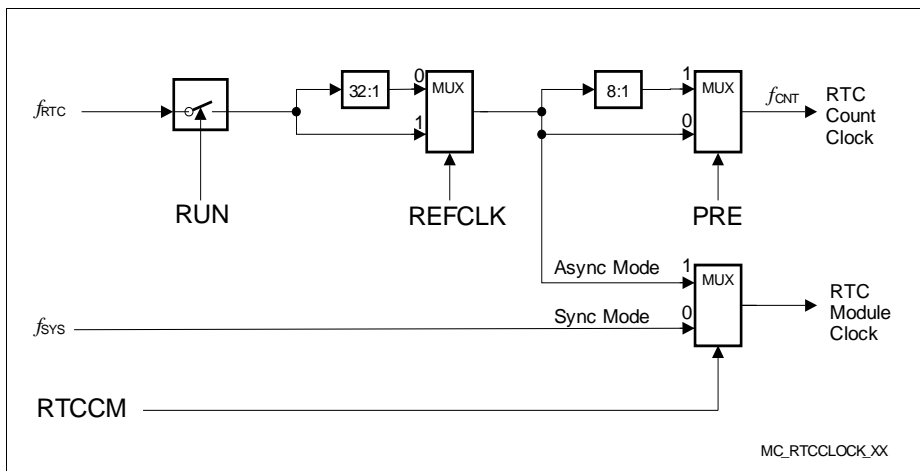


Figure 15-2 RTC Clock Supply Block Diagram

For an example, [Table 15-1](#) lists the interrupt period range and the T14 reload values (for a time base of 1 s and 1 ms):

Table 15-1 RTC Time Base Examples

Oscillator Frequency	T14 Intr. Period		Reload Value A		Reload Value B	
	Min.	Max.	T14REL	Base	T14REL	Base
32.768 kHz	30.52 μ s	16.0 s	8000 _H /F000 _H	1.000 s	FFDF _H /FFFC _H	1.007 ms/ 0.977 ms

Note: Select one value from the reload value pairs, depending if the 8:1 prescaler is disabled/enabled.

Asynchronous Operation

When the system clock frequency becomes lower than $4 \times f_{CNT}$ proper synchronization is not possible and count events may be missed. This can be the case, when the XE166U reduces the system frequency to save power consumption.

In these cases the RTC can be switched to Asynchronous Mode (by clearing bit RTCCM in register RTCCLKCON). In this mode the count registers are directly controlled by the count clock independent of the system clock (hence the name). Asynchronous operation ensures correct time-keeping even during power-save modes.

However, as no synchronization between the count registers and the bus interface can be maintained in asynchronous mode, the RTC registers cannot be written. Read accesses may interfere with count events and, therefore, must be verified (e.g. by reading the same value with three consecutive read accesses).

Note: The access restrictions in asynchronous mode are only meaningful if the system clock is not switched off, of course.

Switching Clocking Modes

The clocking mode of the RTC (synchronous or asynchronous) is selected via bit RTCCM in register RTCCLKCON. After reset, the RTC operates in Synchronous Mode (RTCCM = 1).

The selected clocking mode also affects the access to RTC registers. Bit ACCPOS in register RTC_CON indicates if full register access is possible (ACCPOS = 1, default after reset) or not (ACCPOS = 0). This also indicates the current clocking mode.

Attention: Software should poll bit ACCPOS to determine the proper transition to the intended clocking mode.

After switching to Asynchronous Mode (RTCCM = 0), bit ACCPOS = 0 indicates proper operation in Asynchronous Mode. In this case the system clock can be stopped or reduced.

Note: The clock source for asynchr. mode operation must be selected before switching to asynchr. mode and must only be changed in synchronous mode.

After switching to Synchronous Mode, (RTCCM = 1), bit ACCPOS = 1 indicates proper operation in Synchronous Mode. In this case the RTC registers can again be accessed properly (read and write).

Note: The RTC might lose a counting event (edge of f_{CNT}) when switching from synchronous mode to asynchronous mode while the 8:1 prescaler is disabled. For these applications it is, therefore, recommended to set up the RTC with the 8:1 prescaler enabled.

Increased RTC Accuracy through Software Correction

The accuracy of the XE166U's RTC is determined by the oscillator frequency and by the respective prescaling factor (excluding or including T14 and the 8:1 prescaler). The accuracy limit generated by the prescaler is due to the quantization of a binary counter (where the average is zero), while the accuracy limit generated by the oscillator frequency is due to the difference between the ideal and real frequencies (and therefore accumulates over time). This effect is predictable and can be compensated. The total accuracy of the RTC can be further increased via software for specific applications that demand a high time accuracy.

The key to the improved accuracy is knowledge of the exact oscillator frequency. The relation of this frequency to the expected ideal frequency is a measure of the RTC's deviation. The number of cycles, N, after which this deviation causes an error of ± 1 cycle can be easily computed. So, the only action is to correct the count by ± 1 after each series of N cycles. The correction may be made cyclically, for instance, within an interrupt service routine, or by evaluating a formula when the RTC registers are read (for this the respective "last" RTC value must be available somewhere).

Note: For the majority of applications, however, the standard accuracy provided by the RTC's structure will be more than sufficient.

Adjusting the current RTC value would require reading and then writing the complete 48-bit value. This can only be accomplished by three successive accesses each. To avoid the hassle of reading/writing multi-word values, the RTC incorporates a correction option to simply add or suppress one count pulse.

This is done by setting bit T14INC or T14DEC, respectively, in register RTC_CON. This will add an extra count pulse (T14INC) upon the next count event, or suppress the next count event (T14DEC). The respective bit remains set until its associated action has been performed and is automatically cleared by hardware after this event.

Note: Setting both bits, T14INC and T14DEC, at the same time will have no effect on the count values.

15.2 RTC Run Control

If the RTC shall operate bit RUN in register RTC_CON must be set (default after reset). Bit RUN can be cleared, for example, to exclude certain operation phases from time keeping.

Note: A valid count clock f_{RTC} is required for proper RTC operation, of course.

The RTC is reset by a power reset, a system/application reset does not affect the RTC registers and its operation (RTC_IC will be reset, however). The initialization software must ensure the proper RTC operating mode.

Initialization and Disabling of the RTC

Upon a Power-on Reset, register RTC_CON adopts its reset value of 8003_H, which enables the RTC and both prescalers (factor = $8 \times 32 = 256$).

The RTC's clocking mode (synchronous/asynchronous) is selected bit RTCCM in register RTCCLKCON. Upon a Power-on Reset, register RTCCLKCON adopts its reset value of 0006_H, which selects synchronous operation mode and the WUT as the clock source.

For an application reset that is followed by an initialization of the RTC module, the following steps are recommended:

- select synchronous RTC clocking mode, i.e. set bit RTCCLKCON.RTCCM
- select the intended (running) clock source
- make sure that bit ACCPOS is set, before writing to RTC registers
- initialize the RTC

When the RTC module is not used and shall be disabled after a Power-on Reset, the following steps are recommended:

- stop the RTC by clearing its run bit RTC_CON.RUN
- disable the RTC module by clearing its enable bit RTC_KSCCFG.MODEN.

When the RTC module operates in asynchronous mode and shall stop in a power saving mode, software must make sure that no active clock signal is selected by the RTC clock multiplexer.

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The RTC control register RTC_CON selects the basic operation of the RTC module.

RTC_CON

RTC Control Register

ESFR (F110_H/88_H)

Reset Value: 8003_H

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACC POS	-	-	-	-	-	-	-	-	-	-	-	REF CLK	T14 INC	T14 DEC	PRE	RUN
	rh	-	-	-	-	-	-	-	-	-	-	rw	rwh	rwh	rw	rw

Field	Bits	Type	Description
ACCPOS	15	rh	RTC Register Access Possible 0 _B No write access is possible, only asynchronous reads 1 _B Registers can be read and written
REFCLK	4	rw	RTC Input Source Prescaler (32:1) Disable 0 _B Input Prescaler enabled 1 _B Input Prescaler disabled
T14INC	3	rwh	Increment Timer T14 Value Setting this bit to 1 adds one count pulse upon the next count event, thus incrementing T14. This bit is cleared by hardware after incrementation.
T14DEC	2	rwh	Decrement Timer T14 Value Setting this bit to 1 suppresses the next count event, thus decrementing T14. This bit is cleared by hardware after decrementation.
PRE	1	rw	RTC Input Source Prescaler (8:1) Enable 0 _B Prescaler disabled 1 _B Prescaler enabled
RUN	0	rw	RTC Run Bit 0 _B RTC stopped 1 _B RTC runs

15.3 RTC Operating Modes

The RTC can be configured for several operating modes according to the purpose it is meant to serve. These operating modes are configured by selecting appropriate reload values and interrupt signals.

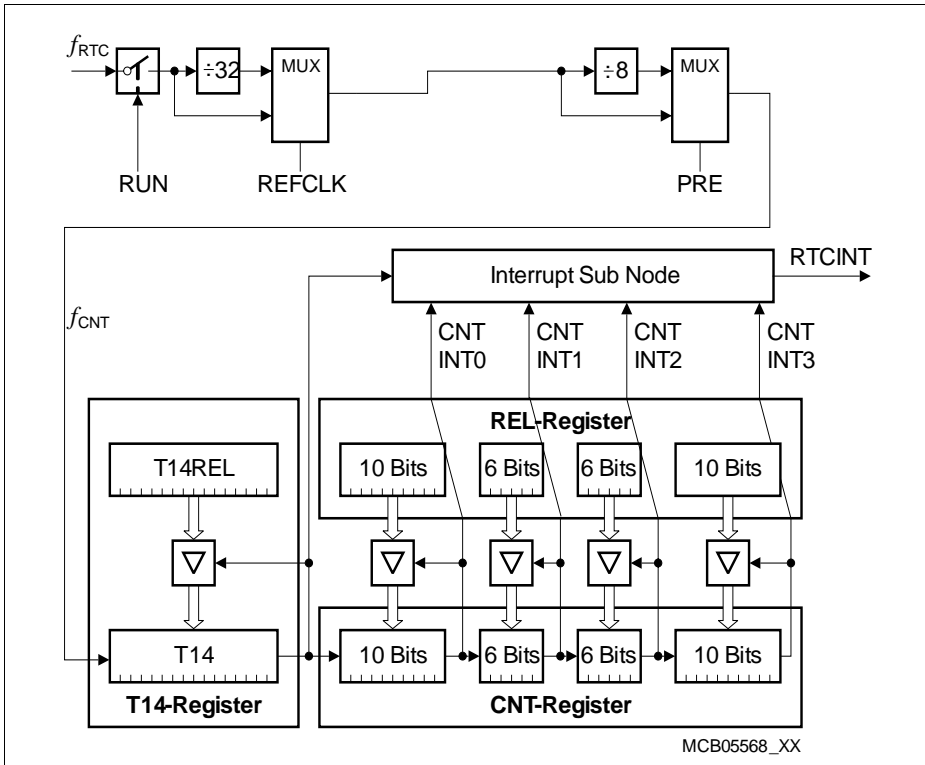


Figure 15-3 RTC Block Diagram

RTC Register Access

The actual value of the RTC is indicated by the three registers T14, RTCL, and RTCH. As these registers are concatenated to build the RTC counter chain, internal overflows occur while the RTC is running. When reading or writing the RTC value, such internal overflows must be taken into account to avoid reading/writing corrupted values.

Care must be taken, when reading the timer(s), as this requires up to three read accesses to the different registers with an inherent time delay between the accesses. An

Real Time Clock

overflow from T14 to RTCL and/or from RTCL to RTCH might occur between the accesses, which needs to be taken into account appropriately.

For example, reading/writing 0000_H from/to RTCH and then accessing RTCL could produce a corrupted value as RTCL may overflow before it can be accessed. In this case, RTCH would be 0001_H. The same precautions must be taken for T14 and T14REL.

Timer T14 and its reload register are accessed via dedicated locations. The four RTC counters CNT3 ... CNT0 are accessed via the two 16-bit RTC timer registers, RTCH and RTCL. The associated four reload values REL3 ... REL0 are accessed via the two 16-bit RTC reload registers, RELH and RELL.

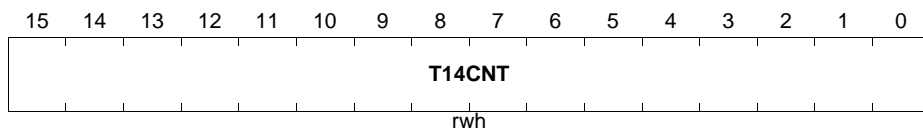
Prescaler T14 and T14 Reload Registers

RTC_T14

T14 Count Register

ESFR(F0D2_H/69_H)

Reset Value: 0000_H



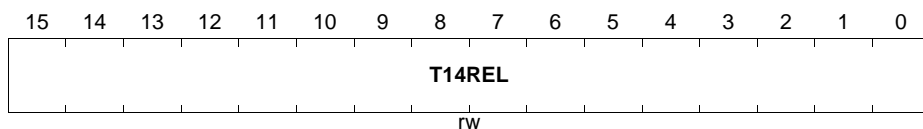
Field	Bits	Typ	Description
T14CNT	[15:0]	rwh	T14 counter

RTC_T14REL

T14 Reload Register

ESFR(F0D0_H/68_H)

Reset Value: 0000_H



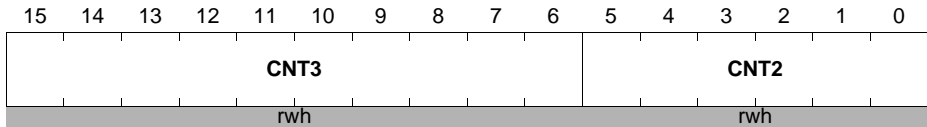
Field	Bits	Typ	Description
T14REL	[15:0]	rw	T14 reload value

RTC_RTCH

RTC Timer High Register

ESFR (F0D6_H/6B_H)

Reset Value: 0000_H



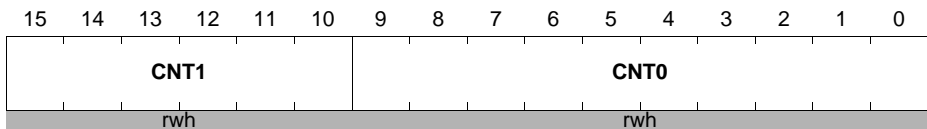
Field	Bits	Type	Description
CNT3	[15:6]	rwh	RTC Timer Count Section CNT3 An overflow of bitfield CNT3 triggers an interrupt request.??
CNT2	[5:0]	rwh	RTC Timer Count Section CNT2 An overflow of bitfield CNT2 triggers a count pulse to count section CNT3 followed by a reload of CNT2 from bitfield REL2. In addition, an interrupt request is triggered.

RTC_RTCL

RTC Timer Low Register

ESFR (F0D4_H/6A_H)

Reset Value: 0000_H



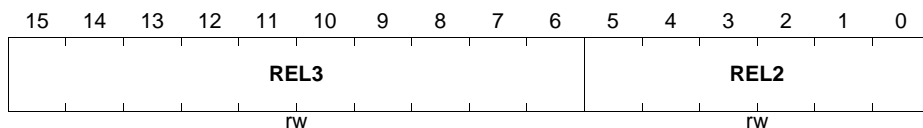
Field	Bits	Type	Description
CNT1	[15:10]	rwh	RTC Timer Count Section CNT1 An overflow of bitfield CNT1 triggers a count pulse to the next count section CNT2 followed by a reload of CNT1 from bitfield REL1. In addition, an interrupt request is triggered.
CNT0	[9:0]	rwh	RTC Timer Count Section CNT0 An overflow of bitfield CNT0 triggers a count pulse to the next count section CNT1 followed by a reload of CNT0 from bitfield REL0. In addition, an interrupt request is triggered.

RTC_RELH

RTC Reload High Register

ESFR (F0CE_H/67_H)

Reset Value: 0000_H



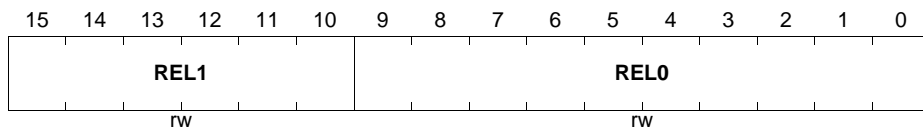
Field	Bits	Type	Description
REL3	[15:6]	rw	RTC Reload Value REL3 This bitfield is copied to bitfield CNT3 upon an overflow of count section CNT3.
REL2	[5:0]	rw	RTC Reload Value REL2 This bitfield is copied to bitfield CNT2 upon an overflow of count section CNT2.

RTC_RELL

RTC Reload Low Register

ESFR (F0CC_H/66_H)

Reset Value: 0000_H



Field	Bits	Type	Description
REL1	[15:10]	rw	RTC Reload Value REL1 This bitfield is copied to bitfield CNT1 upon an overflow of count section CNT1.
REL0	[9:0]	rw	RTC Reload Value REL0 This bitfield is copied to bitfield CNT0 upon an overflow of count section CNT0.

Note: The registers of the RTC receive their reset values only upon a power reset.

15.4 48-bit Timer Operation

The concatenation of timers T14 and COUNT0 ... COUNT3 can be regarded as a 48-bit timer which is clocked with the RTC input frequency, optionally divided by the prescaler. The reload registers T14REL, REL1, and RELH must be cleared to produce a true binary 48-bit timer. However, any other reload value may be used. Reload values other than zero must be used carefully, due to the individual sections of the RTC timer with their own individual overflows and reload values.

The maximum usable timespan is 2^{48} ($\approx 10^{14}$) T14 input clocks. Assuming no prescaler, this would equal more than 200 years at a count frequency of 32 kHz.

15.5 System Clock Operation

A real time system clock can be maintained that keeps on running also during power saving modes (optionally) that maintain a suitable clock signal and supply voltage and indicates the current time and date. This is possible because the RTC module is only reset and cleared by a power reset.

The resolution for this clock information is determined by the input clock of timer T14. By selecting appropriate reload values each cascaded timer can represent directly a part of the current time and/or date. Due to its width, T14 can adjust the RTC to the intended range of operation (time or date). The maximum usable timespan is achieved when T14REL is loaded with 0000_H and so T14 divides by 2^{16} .

System Clock Example

The RTC count clock is 32.768 kHz. By selecting appropriate reload values the RTC timers directly indicate the current time (see [Figure 15-4](#) and [Table 15-2](#)).

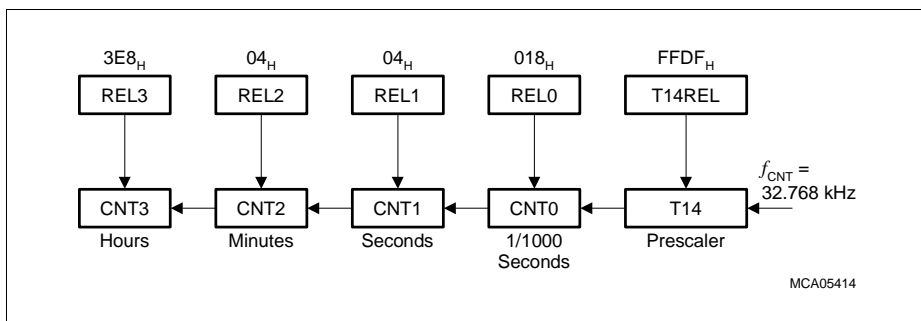


Figure 15-4 RTC Configuration Example

Note: This setup can generate an interrupt request every millisecond, every second, every minute, every hour, or every day.

Each timer in the chain divides the clock by ($2^{\langle \text{timer_width} \rangle} - \langle \text{reload_value} \rangle$) : 1, as the timers count up. **Table 15-2** shows the reload values which must be chosen for a specific scenario (i.e. operating mode of the RTC).

Table 15-2 Reload Value Scenarios

		REL3	REL2	REL1	REL0	T14REL
Time of Day (Figure 15-4)	Formula	$2^{10} - 24$	$2^6 - 60$	$2^6 - 60$	$2^{10} - 1000$	$2^{16} - 33$
	Rel. Value	3E8 _H	04 _H	04 _H	018 _H	FFDF _H
	Function	h	m	s	1/1000 s	Prescaler
	Intr. Period	day	hour	minute	second	millisec. ¹⁾
Day of the Week	Formula	$2^{10} - 7$	$2^6 - 24$	$2^6 - 60$	$2^{10} - 60$	$2^{16} - 32768$
	Rel. Value	3F9 _H	28 _H	04 _H	3C4 _H	8000 _H
	Function	day	h	m	s	Prescaler
	Intr. Period	week	day	hour	minute	second

1) T14 errors in the first example (ms) can be compensated either by choosing an adapted value for REL0, or by using software correction.

15.6 Cyclic Interrupt Generation

The RTC module can generate an interrupt request whenever one of the timers overflows and is reloaded. This interrupt request may be used, for example, to provide a system time tick independent of the CPU frequency without loading the general purpose timers. The interrupt cycle time can be adjusted by choosing appropriate reload values and by enabling the appropriate interrupt request.

In this mode, the other operating modes can be combined. For example, a reload value of T14REL = F9C0_H ($2^{16} - 1600$) generates a T14 interrupt request every 50 ms. Still the subsequent timers can be configured to represent the time or build a binary counter, however with a different time base.

15.7 RTC Interrupt Generation

The overflow signals of each timer of the RTC timer chain can generate an interrupt request. The RTC's interrupt subnode control register ISNC combines these requests to activate the common RTC interrupt request line RTC_IRQ.

Each timer overflow sets its associated request flag in register ISNC. Individual enable bits for each request flag determine whether this request also activates the common interrupt line. The enabled requests are ORed together on this line (see [Figure 15-5](#)). The common interrupt request signal is delayed by 2 system clock cycles due to synchronization.

The interrupt handler can determine the source of an interrupt request via the specific request flags and must clear them after appropriate processing (not cleared by hardware). The common node request bit is automatically cleared when the interrupt handler is vectored to.

Note: If only one source is enabled, no additional software check is required, of course. Both the individual request and the common interrupt node must be enabled.

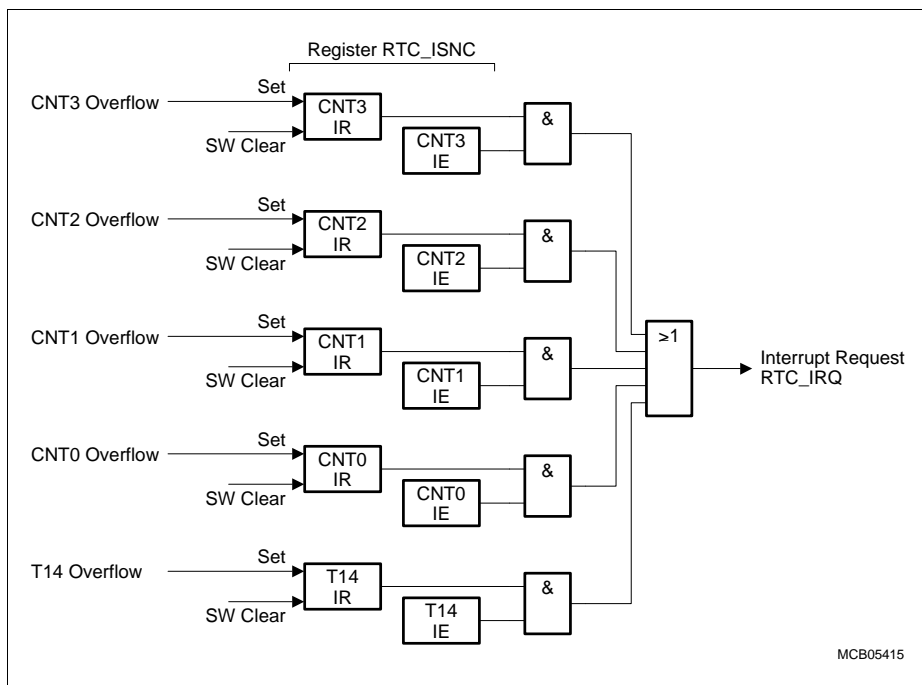


Figure 15-5 Interrupt Block Diagram

RTC_ISNC

RTC Interrupt Subnode Ctrl. Reg.ESFR (F10C_H/86_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
-	-	-	-	-	-	CNT 3IR	CNT 3IE	CNT 2IR	CNT 2IE	CNT 1IR	CNT 1IE	CNT 0IR	CNT 0IE	T14 IR	T14 IE
-	-	-	-	-	-	rwh	rw	rwh	rw	rwh	rw	rwh	rw	rwh	rw

Field	Bits	Type	Description
CNTxIR (x = 0-3)	2*x + 3	rwh	Section CNTx Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
CNTxIE (x = 0-3)	2*x + 2	rw	Section CNTx Interrupt Enable Control Bit 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled
T14IR	1	rwh	T14 Overflow Interrupt Request Flag 0 _B No request pending 1 _B This source has raised an interrupt request
T14IE	0	rw	T14 Overflow Interrupt Enable Control Bit 0 _B Interrupt request is disabled 1 _B Interrupt request is enabled

Note: The interrupt request flags in register ISNC must be cleared by software. They are not cleared automatically when the service routine is entered.

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RTC_IC

RTC Interrupt Ctrl. Reg.

ESFR (F19C_H/CE_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
-	-	-	-	-	-	-	GPX	RTC IR	RTC IE		ILVL			GLVL	
-	-	-	-	-	-	-	rw	rwh	rw		rw			rw	

Field	Bits	Type	Description
GPX	8	rw	Group Priority Extension
RTCIR	7	rwh	RTC Interrupt Request Flag
RTCIE	6	rw	RTC Interrupt Enable Control Bit
ILVL	[5:2]	rw	Interrupt Priority Level
GLVL	[1:0]	rw	Group Priority Extension

Note: Please refer to the general Interrupt Control Register description for an explanation of the control fields.

Register RTC_IC is not part of the RTC module and is reset with any application reset.

15.8 Miscellaneous Registers

RTC_KSCCFG

RTC Kernel State Configuration Register

ESFR(F010_H)

Reset Value: 0001_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BP COM	0	COMCFG	BP SUM	0	SUMCFG	BP NOM	0	NOMCFG	0	BP MOD EN	MOD EN				
w	r	rw	w	r	rw	w	r	rw	r	w	rw				

Field	Bits	Type	Description
MODEN	0	rw	Module Enable This bit enables the module kernel clock and the module functionality. 0 _B The module clock is switched off immediately (without stop condition). The module does not react to mode control actions or read access and ignores write access (except KSCCFG). 1 _B The module is switched on and can operate. To avoid pipeline effects, it is recommended to read register KSCCFG after setting MODEN before accessing other RTC registers.
BPMODEN	1	w	Bit Protection for MODEN 0 _B Bit MODEN is not changed. 1 _B MODEN is updated with the written value.
NOMCFG	[5:4]	rw	Kernel Configuration in Normal Operation Mode 0X _B The module is switched on. 1X _B The module is switched off.
BPNO	7	w	Bit Protection for NOMCFG 0 _B Bitfield NOMCFG is not changed. 1 _B NOMCFG is updated with the written value.
SUMCFG	[9:8]	rw	Kernel Configuration in Suspend Mode Same coding as NOMCFG
BPSUM	11	w	Bit Protection for SUMCFG 0 _B Bitfield SUMCFG is not changed. 1 _B SUMCFG is updated with the written value.
COMCFG	[13:12]	rw	Kernel Configuration in Clock Off Mode Same coding as NOMCFG

Field	Bits	Type	Description
BPCOM	15	w	Bit Protection for COMCFG 0 _B Bitfield COMCFG is not changed. 1 _B COMCFG is updated with the written value.
0	[3:2], 6, 10, 14	r	Reserved; returns 0 if read; should be written with 0;

Note: The protection bits BPxxx enable the write access to their associated bitfields when set. Selected bitfields can be modified by a simple write access without requiring a read-modify-write sequence. They are only active during a write access and are read as 0.

Bitfield SUMCFG is reset by a debug reset, all other bitfields are reset by an application reset.

RTC_ID

RTC Identification Register MEM (FFF8_H/FCH) Reset Value: 5AXX_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOD_TYPE								MOD_REV							
r								r							

Field	Bits	Typ	Description
MOD_REV	[7:0]	r	Module Revision Number MOD_REV defines the revision number. The value of a module revision starts with 01 _H (first revision).
MOD_TYPE	[15:8]	r	Module Type This bit field defines the module identification number (5A _H = RTC).

16 Analog to Digital Converter

The Analog to Digital Converter module (ADC) of the XE166U uses the successive approximation method to convert analog input values (voltages) to discrete digital values.

The input channels can be selected and arbitrated flexibly.

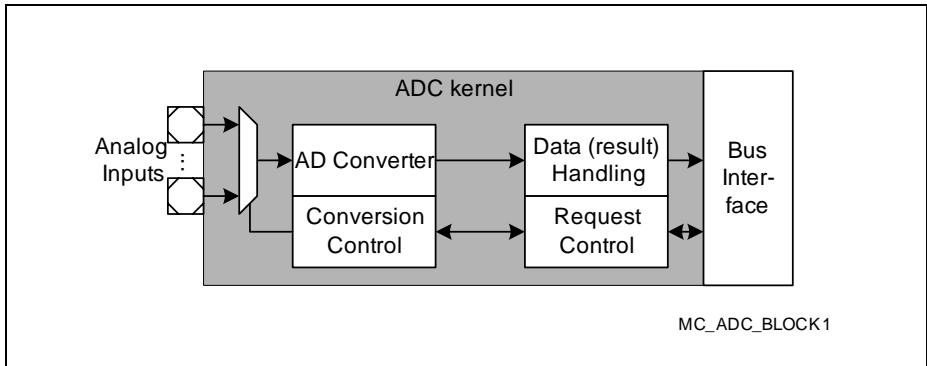


Figure 16-1 ADC Module Block Diagram

You will find the following major sections within this chapter:

- **“Introduction and Basic Structure” on Page 16-4**
- **“Configuration of General Functions” on Page 16-12**
- **“Conversion Request Generation” on Page 16-23**
- **“Request Source Arbitration” on Page 16-49**
- **“Analog Input Channel Configuration” on Page 16-55**
- **“Conversion Result Handling” on Page 16-67**
- **“Synchronization of Conversions” on Page 16-82**
- **“Safety Features” on Page 16-84**
- **“External Multiplexer Control” and “Interrupt Handling” on Page 16-89ff**
- **“Implementation” on Page 16-106** (including a register summary)

The following features describe the functionality of an ADC kernel:

- Input voltage range from 0 V up to analog supply voltage ($V_{DDPA} = 3.0 \text{ V to } 5.5 \text{ V}$)
- Standard (V_{AREF}) and alternate (CH0) reference voltage source selectable for each channel to support ratiometric measurements and different signal scales
- Up to 10 analog input channels
- External analog multiplexer control, including adjusted sample time and scan support
- Conversion speed and sample time adjustable to adapt to sensors and reference
- Conversion time below $1 \mu\text{s}$ (depending on result width and sample time)
- Flexible source selection and arbitration
 - Single-channel conversion (single or repeated)
 - Configurable auto scan conversions (single or repeated)
 - Programmable arbitrary conversion sequence (single or repeated)
 - Conversions triggered by software, timer events, or external events
 - Wait-for-start mode for maximum throughput or
Cancel-inject-restart mode for reduced conversion delay
- Powerful result handling
 - Selectable result width of 8/10/12
 - 8 independent result registers, can be combined to build result FIFOs
 - Configurable limit checking against programmable border values
 - Data rate reduction through adding a selectable number of conversion results
- Flexible interrupt generation (PEC support) based on selectable events
- Built-in safety features
 - Broken wire detection with programmable default levels
 - Multiplexer test mode to verify signal path integrity
- Support of suspend and power saving modes

Table 16-1 Abbreviations used in ADC chapter

Abbreviation	Meaning
ADC	Analog to Digital Converter
DNL	Differential Non-Linearity (error)
FIFO	First-In-First-Out data buffer mechanism
INL	Integral Non-Linearity (error)
LSB _n	Least Significant Bit: finest granularity of the analog value in digital format, represented by one least significant bit of the conversion result with n bits resolution (measurement range divided in 2 ⁿ equally distributed steps)
PEC	Peripheral Event Controller
SCU	System Control Unit of the device
TUE	Total Unadjusted Error

16.1 Introduction and Basic Structure

A set of functional units can be configured according to the requirements of a given application. These units build a path from the input signals to the digital results.

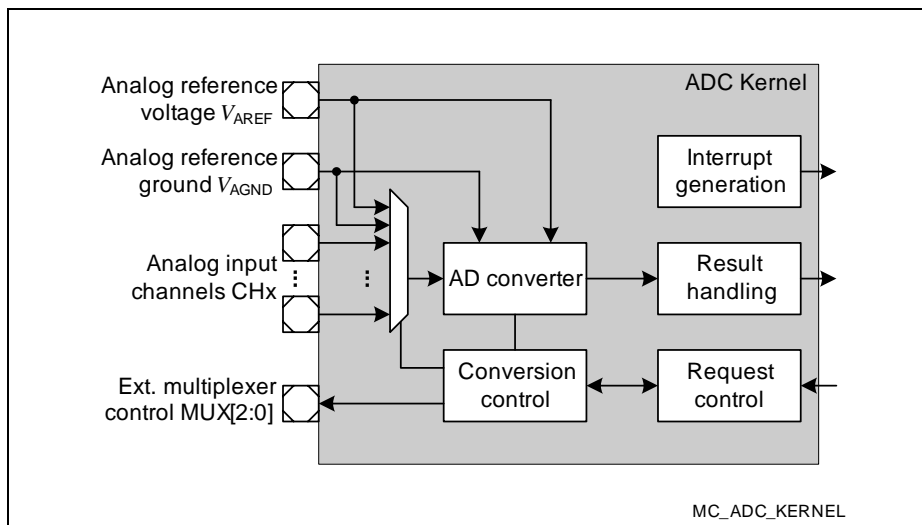


Figure 16-2 ADC Kernel Block Diagram

Conversion Modes and Request Sources

Analog/Digital conversions can be requested by several request sources and can be executed in several conversion modes. The request sources can be enabled concurrently with configurable priorities.

- **Fixed Channel Conversion (single or continuous)**
A specific channel source (request source 0) requests conversions of one selectable channel (once or repeatedly)
- **Auto Scan Conversion (single or continuous)**
A channel scan source (request source 1) requests auto scan conversions of a configurable linear sequence of all available channels (once or repeatedly)
- **Channel Sequence Conversion (single or continuous)**
An arbitrary sequence source (request source 2) requests queued conversions of up to 4 arbitrarily selectable channels (once or repeatedly)

The conversion modes can be used concurrently by the available request sources, i.e. conversions in different modes can be enabled at the same time. Each source can be enabled separately and can be triggered by external events, such as edges of PWM or timer signals, or pin transitions. Read more in [Section 16.5](#)

Request Source Control

Because all request sources can be enabled at the same time, an arbiter resolves concurrent conversion requests from different sources. Each source can be triggered by external signals, by on-chip signals, or by software.

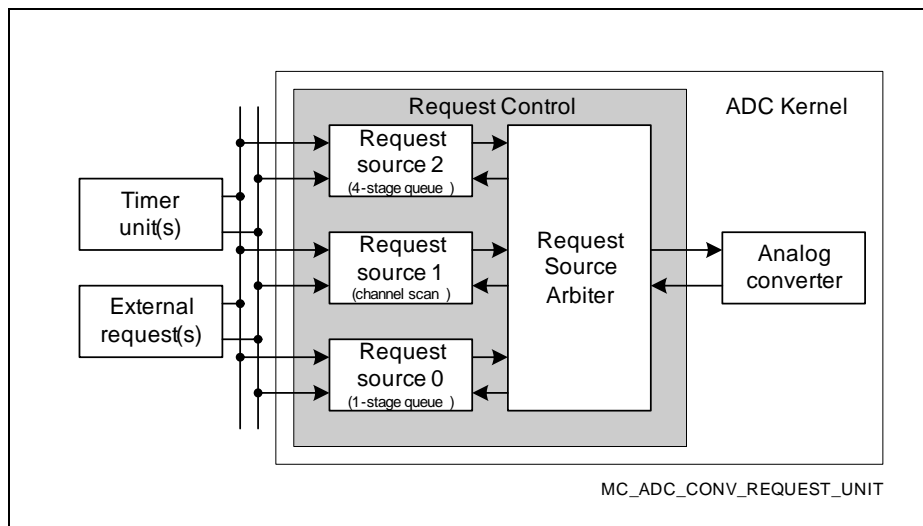


Figure 16-3 Conversion Request Unit

Requests with higher priority can either cancel a running lower-priority conversion (cancel-inject-repeat mode) or be converted immediately after the currently running conversion (wait-for-start mode). If the target result register has not been read, a conversion can be deferred (wait-for-read mode).

Input Channel Selection

The analog input multiplexer selects one of the available analog inputs (CH0 - CHx¹⁾) to be converted. Three sources can select a linear sequence, an arbitrary sequence, or a specific channel. The priorities of these sources can be configured.

Additional external analog multiplexers can be controlled automatically, if more separate input channels are required than are built in.

Note: Not all analog input channels are necessarily available in all packages, due to pin limitations. Please refer to the implementation description in [Section 16.13](#).

¹⁾ The availability of input channels depends on the package of the used product type. A summary can be found in [Section 16.13.3](#).

Conversion Control

Conversion parameters, such as sample phase duration, reference voltage, or result resolution can be configured for 2 input classes. Each channel can be individually assigned to one of these input classes.

The input channels can, thus, be adjusted to the type of sensor (or other analog sources) connected to the ADC.

This unit also controls the built-in multiplexer and external analog multiplexers (via signals EMUX[2:0]) if selected.

Analog/Digital Converter

The selected input channel is converted to a digital value by first sampling the voltage on the selected input and then generating the selected number of result bits.

For 12-bit conversions, post-calibration is executed after converting the channel.

For broken wire detection (see [Section 16.10.1](#)), the converter network can be preloaded before sampling the selected input channel.

Result Handling

The conversion results of each analog input channel can be directed to one of 8 result registers to be stored there. A result register can be used by a group of channels or by a single channel.

The wait-for-read mode avoids data loss due to result overwrite by blocking a conversion until the previous result has been read.

Data reduction (e.g. for digital anti-aliasing filtering) can automatically add up to 4 conversion results before interrupting the CPU.

Alternatively, a low-pass filter can be enabled that preprocesses the conversion results before sending them to the CPU.

Also, result registers can be concatenated to build FIFO structures that store a number of conversion results without overwriting previous data. This increases the allowed CPU latency for retrieving conversion data from the ADC.

An enhanced filter structure can combine a selectable series of conversion results. This supports applications with increased requirements (e.g. knock detection).

Interrupt Generation

Several ADC events can issue interrupt requests to the CPU:

- **Source events** indicate the completion of a conversion sequence in the corresponding request source. This event can be used to trigger the setup of a new sequence.

Analog to Digital Converter

- **Channel events** indicate the completion of a conversion for a certain channel. This can be combined with limit checking, so interrupt are generated only if the result is within a defined range of values.
- **Result events** indicate the availability of new result data in the corresponding result register. If data reduction mode is active, events are generated only after a complete accumulation sequence.

Each interrupt request can be assigned to one of four interrupt nodes. This allows grouping the requests according to the requirements of the application.

Safety Features

Safety-aware applications are supported with two mechanisms that help to ensure the integrity of a signal path.

Broken-wire-detection (BWD) preloads the converter network with a selectable level before sampling the input channel. The result will then reflect the preload value if the input signal is no more connected. If buffer capacitors are used, a certain number of conversions may be required to reach the failure indication level.

Multiplexer test mode (MTM) connects an additional pull-down device to an input channel. A subsequent conversion can then confirm the expected modified signal level. This allows to check the proper connection of a signal source (sensor) to the multiplexer.

16.2 Electrical Models

Each conversion of an analog input voltage to a digital value consists of two consecutive phases:

- During the sample phase, the input voltage is sampled and stored.
The input signal path is a simplified model for this.
- During the conversion phase the stored voltage is converted to a digital result.
The reference voltage path is a simplified model for this.

Input Signal Path

The ADC of the XE166U uses a switched capacitor field represented by C_{AIN} (small parasitic capacitances are present at each input pin). During the sample phase, the capacitor field C_{AIN} is connected to the selected analog input CHx via the input multiplexer (modeled by ideal switches and series resistors R_{AIN}).

The switch to CHx is closed during the sample phase and connects the capacitor field to the input voltage V_{AINx} .

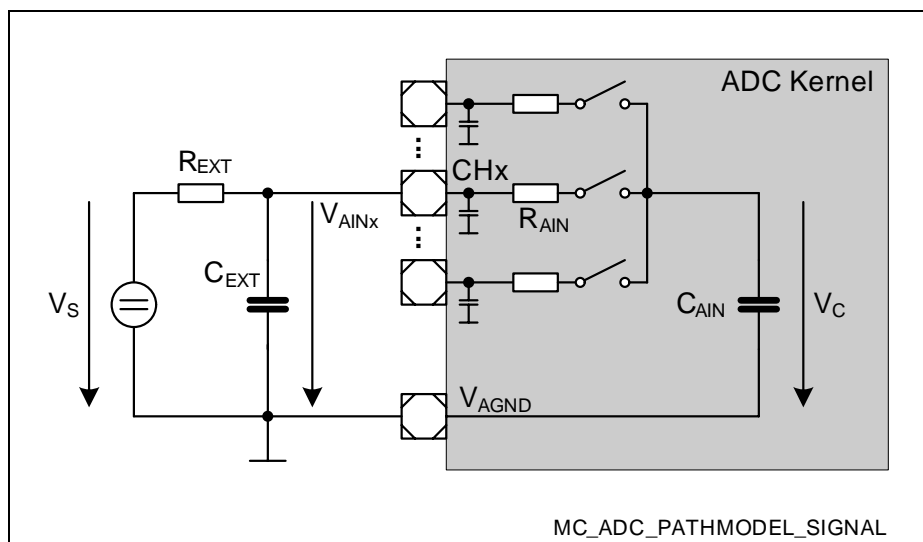


Figure 16-4 Signal Path Model

A simplified model for the analog input signal path is given in [Figure 16-4](#). An analog voltage source (value V_S) with an internal impedance of R_{EXT} delivers the analog input that should be converted.

During the sample phase the corresponding switch is closed and the capacitor field C_{AIN} is charged. Due to the low-pass behavior of the resulting RC combination, the voltage

V_C to be actually converted does not immediately follow V_S . The value R_{EXT} of the analog voltage source and the desired precision of the conversion strongly define the required length of the sample phase.

To reduce the influence of R_{EXT} and to filter input noise, it is recommended to introduce a fast external blocking capacitor C_{EXT} at the analog input pin of the ADC. Like this, mainly C_{EXT} delivers the charge during the sample phase. This structure allows a significantly shorter sample phase than without a blocking capacitor, because the low-pass time constant defining the sample time is mainly given by the values of R_{AIN} and C_{AIN} .

Additionally, the capacitor C_{AIN} is automatically precharged to a voltage of approximately the half of the standard reference voltage V_{AREF} to minimize the average difference between V_{AINx} and V_C at the beginning of a sample phase. Due to varying parameters and parasitic effects, the precharge voltage of C_{AIN} is typically smaller than $V_{AREF} / 2$.

On the other hand, the charge redistribution between C_{EXT} and C_{AIN} leads to a voltage change of V_{AINx} during the sample phase. In order to keep this voltage change lower than 1 LSB_{n1}, it is recommended to use an external blocking capacitor C_{EXT} in the range of at least $2^{n1} \times C_{AIN}$.

The resulting low-pass filter of R_{EXT} and C_{EXT} should be dimensioned in a way to allow V_{AINx} to follow V_S between two sample phases of the same analog input channel.

Please note that, especially at high temperatures, the analog input structure of an ADC can lead to a leakage current and introduces an error due to a voltage drop over R_{EXT} . The ADC input leakage current increases if the input voltage level is close to the analog supply ground V_{SS} or to the analog power supply V_{DDPA} . It is recommended to use an operating range for the input voltage between approximately 3% and 97% of V_{DDPA} to reduce the input leakage current of the respective ADC channel.

Furthermore, the leakage is influenced by an overload condition at adjacent analog inputs. During an overload condition, an input voltage exceeding the supply range is applied at an input and the built-in protection circuit limits the resulting input voltage. This leads to an overload current through the protection circuit that is translated (by a coupling factor) into an additional leakage at adjacent inputs.

Reference Path

During the conversion phase, parts of the capacitor field C_{AIN} are switched to a reference input (V_{AREF} or CH0) or to V_{AGND} . Using CH0 as alternate reference source allows conversions of 5.0 V and 3.3 V based analog input signals with the same ADC kernel. Stable and noise-free reference and analog supply voltages support accurate conversion results. Because noise can also be introduced from other modules (e.g. switching pins), it is strongly recommended to carefully decouple analog from digital signal domains.

The switching of parts of C_{AIN} requires a dynamic current at the selected reference input. The impedance R_{AREF} of the reference voltage source V_R has to be low enough to supply the reference current during the conversion phase. An external blocking capacitor C_{AREF} can supply the peak currents and minimize the current to be delivered by the reference source.

Due to the charge redistribution between C_{AREF} and parts of C_{AIN} , the voltage V_{AREF} decreases during the conversion phase. In order to limit the error introduced by this effect to $1/2 \text{ LSB}_n$, the external blocking capacitor C_{AREF} for the reference input should be at least $2^n \times C_{AIN}$.

The reference current I_{AREF} introduces a voltage drop at R_{AREF} that should not be neglected for the calculation of the overall accuracy. The average reference current during a conversion depends on the reference voltage level and the time t_{CONV} between two conversion starts: $I_{AREF} = C_{AIN} \times V_{AREF} / t_{CONV}$.

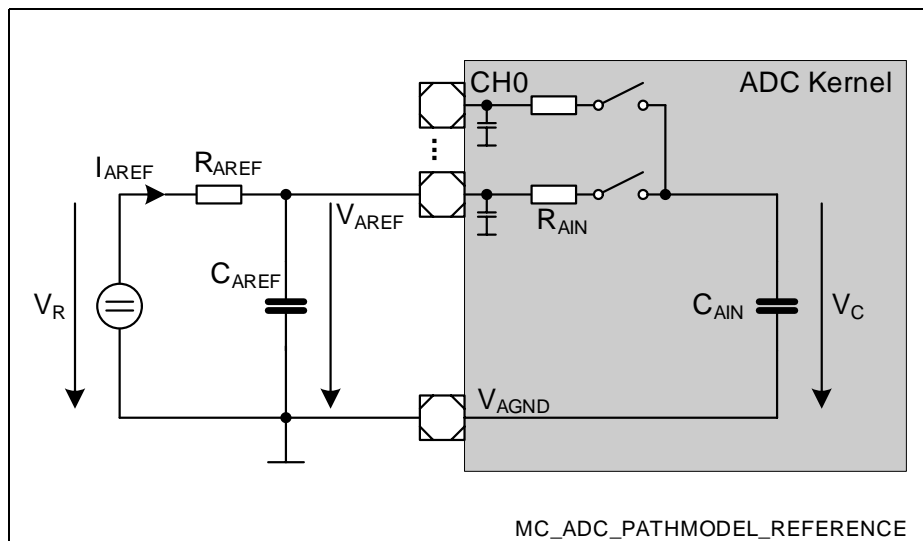


Figure 16-5 Reference Path Model

16.3 Transfer Characteristics and Error Definitions

The transfer characteristic of the ADC describes the association of analog input voltages to the 2^n discrete digital result values (n bits resolution). Each digital result value (in the range of 0 to 2^n-1) represents an input voltage range defined by the reference voltage range divided by 2^n . This range (called quantization step or code width) represents the granularity (called LSB_n) of the ADC. The discrete character of the digital result generates a system-inherent quantization uncertainty of $\pm 0.5 \text{ LSB}_n$ for each conversion result.

The ideal transfer curve has the first digital transition (between 0 and 1) when the analog input reaches 0.5 LSB_n . The quantization steps are equally distributed over the input voltage range.

Analog input voltages below or above the reference voltage limits lead to a saturation of the digital result at 0 or 2^n-1 .

The real transfer curve can exhibit certain deviations from the ideal transfer curve:

- The **offset error** is the deviation of the real transfer line from the ideal transfer line at the lowest code. This refers to best-fit lines through all possible codes, for both cases.
- The **gain error** is the deviation of the slope of the real transfer line from the slope of the ideal transfer line. This refers to best-fit lines through all possible codes, for both cases.
- The **differential non-linearity error** (DNL) is the deviation of the real code width (variation of the analog input voltage between two adjacent digital conversion results) from the ideal code width. A DNL value of -1 LSB_n indicates a missing code.
- The **integral non-linearity error** (INL) is the deviation of the real transfer curve from an adjusted ideal transfer curve (same offset and gain error as the real curve, but equal code widths).
- The **total unadjusted error** (TUE) describes the maximum deviation between a real conversion result and the ideal transfer characteristics over a given measurement range. Since some of these errors noted above can compensate each other, the TUE value generally is much less than the sum of the individual errors.

The TUE also covers production process variations and internal noise effects (if switching noise is generated by the system, this generally leads to an increased TUE value).

16.4 Configuration of General Functions

While many parameters can be selected individually for each channel, source, etc, some adjustments are valid for the whole ADC kernel.

16.4.1 Mode Control

The mode control concept for system control tasks, such as power saving, or suspend request for debugging, allows to program the module behavior under different device operating conditions. The behavior of an ADC kernel can be programmed for each of the device operating modes, that are requested by the global state control part of the SCU. Register [ADC0_KSCFG](#) defines the behavior of the ADC module in the following device operating modes:

- **Normal operation:**
This operating mode is the default operating mode when neither a suspend request nor a clock-off request are pending. The module clock is not switched off, the ADC registers can be read or written. The kernel behavior is defined by KSCFG.NOMCFG.
- **Suspend mode:**
This operating mode is requested when a suspend request (issued by a debugger) is pending in the device. The module clock is not switched off and the ADC registers can be read or written. The kernel behavior is defined by KSCFG.SUMCFG.
- **Clock-off mode:**
This operating mode is requested for power saving purposes. The module clock is switched off automatically when all kernels of the ADC module reached their specified state in a stop mode. In this case, ADC registers can not be accessed. The kernel behavior is defined by KSCFG.COMCFG.

The following internal ADC actions can be influenced by mode control:

- A current conversion of an analog value:
If the request control unit has found a pending conversion request, the conversion can be started. This start has to be enabled by the mode control. If the current kernel mode allows the conversion start (run modes 0 and 1), it will be executed. If the kernel mode does not allow a start (stop modes 0 and 1), the conversion is not started. The start request is not cancelled, but frozen. A “frozen” conversion is started as programmed if the kernel mode is changed to a run mode again.
- An arbiter round:
The start of a new arbiter round has to be enabled by the kernel modes. In stop mode 1, a new arbiter round will not start.

The behavior of an ADC kernel can be programmed for each of the device operating modes (normal operation, suspend mode, clock-off mode). Therefore, an ADC kernel supports four kernel modes, as shown in [Table 16-2](#).

Register KSCFG selects the mode control behavior.

ADC0_KSCFG

Kernel State Configuration Register

XSFR(0C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BP COM	0	COMCFG	BP SUM	0	SUMCFG	BP NOM	0	NOMCFG	0	BP MOD EN	MOD EN				
w	r	rw	w	r	rw	w	r	rw		r	w	rw			

Field	Bits	Type	Description
MODEN	0	rw	Module Enable Generally enables the module kernel clock and the module functionality. 0 _B The module clock is switched off immediately (without stop condition). The module does not react to mode control actions or read access and ignores write access (except KSCFG). 1 _B The module is switched on and can operate. To avoid pipeline effects, it is recommended to read register KSCFG after setting MODEN before accessing other ADC registers.
BPMODEN	1	w	Bit Protection for MODEN 0 _B Bit MODEN is not changed. 1 _B MODEN is updated with the written value.
NOMCFG	[5:4]	rw	Kernel Configuration in Normal Operation Mode 00 _B Run mode 0 is selected. 01 _B Run mode 1 is selected. 10 _B Stop mode 0 is selected. 11 _B Stop mode 1 is selected. The coding is described in Table 16-2 .
BPNOM	7	w	Bit Protection for NOMCFG 0 _B Bitfield NOMCFG is not changed. 1 _B NOMCFG is updated with the written value.
SUMCFG	[9:8]	rw	Kernel Configuration in Suspend Mode Same coding as NOMCFG

Field	Bits	Type	Description
BPSUM	11	w	Bit Protection for SUMCFG 0 _B Bitfield SUMCFG is not changed. 1 _B SUMCFG is updated with the written value.
COMCFG	[13:12]	rw	Kernel Configuration in Clock Off Mode Same coding as NOMCFG
BPCOM	15	w	Bit Protection for COMCFG 0 _B Bitfield COMCFG is not changed. 1 _B COMCFG is updated with the written value.
0	[3:2], 6, 10, 14	r	Reserved; returns 0 if read; should be written with 0;

Note: The protection bits BPxxx enable the write access to their associated bitfields when set. Selected bitfields can be modified by a simple write access without requiring a read-modify-write sequence. They are only active during a write access and are read as 0.

Bitfields SUMCFG and BPSUM are reset by a debug reset, all other bitfields are reset by an application reset.

Table 16-2 ADC Kernel Behavior

Kernel Mode	Kernel Behavior	Code
Run mode 0	Kernel operation as specified, no impact on data transfer (same behavior for run mode 0 and run mode 1)	00 _B
Run mode 1		01 _B
Stop mode 0	A currently running AD conversion is completely finished and the result is treated. Pending conversion request to start a new conversion are not taken into account (but not deleted). They start conversions after entering a run mode as programmed. The arbiter continues as programmed.	10 _B
Stop mode 1	Like stop mode 0, but the arbiter is stopped after it has finished its arbitration round. Additionally, bitfield GLOBSTR.ANON is considered being 00 _B when the kernel has reached the defined stop condition (the bitfield itself is not changed).	11 _B

Generally, bitfield KSCFG.NOMCFG should be configured for run mode 0 as default setting for standard operation. If the ADC kernels should not react to a suspend request (and to continue operation as in normal mode), bitfield KSCFG.SUMCFG has to be configured with the same value as KSCFG.NOMCFG. If the ADC kernels should show a different behavior and stop operation when a specific stop condition is reached, the code for stop mode 0 or stop mode 1 has to be written to KSCFG.SUMCFG.

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A similar mechanism applies for the clock-off mode with the possibility to program the desired behavior by bitfield KSCFG.COMCFG.

Note: The stop mode selection strongly depends on the application needs and it is very unlikely that different stop modes are required in parallel in the same application. As a result, only one stop mode type (either 0 or 1) should be used in the bitfields in register KSCFG. Do not mix stop mode 0 and stop mode 1 and avoid transitions from stop mode 0 to stop mode 1 (or vice versa) for the ADC module.

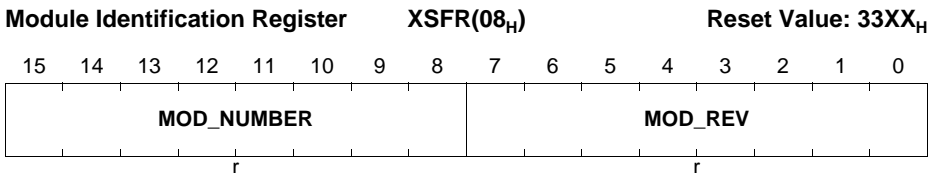
If the module clock is disabled by KSCFG.MODEN = 0 or in clock-off mode when the stop condition is reached (in stop mode 0 or 1), the module can not be accessed by read or write operations (except register KSCFG that can always be accessed). As a consequence, it cannot be configured.

Please note that bit KSCFG.MODEN should only be set by SW while all configuration fields are configured for run mode 0.

16.4.2 Module Identification

The ID register is a read-only register which is used for ADC module identification purposes. It provides 8 bits for module identification and 8 bits for revision numbering.

ID



Field	Bits	Type	Description
MOD_REV	[7:0]	r	Module Revision Number MOD_REV defines the revision number. The value of a module revision starts with 01 _H (first revision).
MOD_NUMBER	[15:8]	r	Module Type Identifies the module itself (33 _H = ADC).

16.4.3 General Clocking Scheme and Control

The different parts of an ADC kernel are driven by clock signals that are based on the clock f_{ADC} of the bus that is used to access the ADC module. The ADC in the XE166U device is connected to the system clock, so $f_{ADC} = f_{SYS}$.

- The analog clock f_{ADCI} is used as internal clock for the converter and defines the conversion length and the sample time (selected by bitfield DIVA).
See [Section 16.7.4](#).
- The digital clock f_{ADCD} is used for the arbiter and defines the duration of an arbiter round (selected by bitfield DIVD)
- All other digital structures (such as interrupts, etc.) are directly driven by the module clock f_{ADC} .

Timing parameters are programmed in register [GLOBCTR](#).

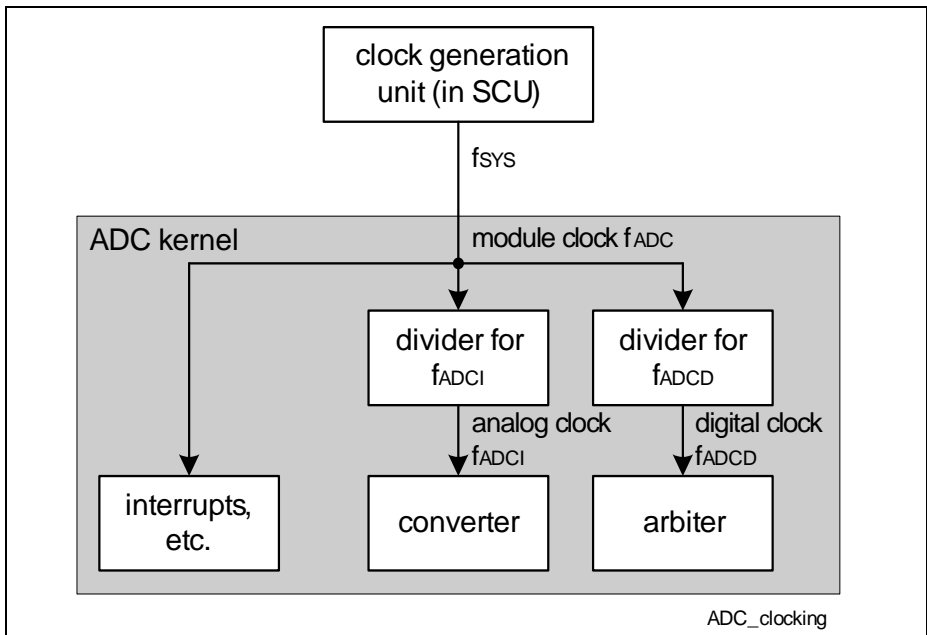


Figure 16-6 Clocking Scheme

Note: If the clock generation for the converter of the ADC falls below a minimum value or is stopped during a running conversion, the conversion result can be corrupted. For correct ADC results, the frequency of f_{ADCI} must not exceed the defined range. Please, refer to the range indicated in the respective Data Sheet.

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The Global Control Register defines the basic timing parameters and the basic operating mode of the converter unit.

GLOBCTR

Global Control Register

XSFR(10_H)

Reset Value: 00FF_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARB M		0		ARBRND		ANON		DIVD				DIVA			
rw		rw		rw		rw		rw				rw			

Field	Bits	Type	Description
DIVA	[5:0]	rw	Divider Factor for the Analog Internal Clock Defines the frequency of the basic converter clock f_{ADCI} (base clock for conversion and sample phase). $00_H \quad f_{ADCI} = f_{ADC} / 2$ $01_H \quad f_{ADCI} = f_{ADC} / 2$ $02_H \quad f_{ADCI} = f_{ADC} / 3$... $3F_H \quad f_{ADCI} = f_{ADC} / 64$
DIVD	[7:6]	rw	Divider Factor for Digital Arbiter Clock Defines the frequency of the arbiter clock f_{ADCD} (each arbitration slot lasts one period). $00_B \quad f_{ADCD} = f_{ADC}$ (recommended for min. arb. time) $01_B \quad f_{ADCD} = f_{ADC} / 2$ $10_B \quad f_{ADCD} = f_{ADC} / 3$ $11_B \quad f_{ADCD} = f_{ADC} / 4$
ANON	[9:8]	rw	Analog Part Switched On Defines the converter operating mode for a stand-alone kernel. The actual mode is selected by bitfield GLOBSTR.ANON . The coding is defined in Section 16.4.4 .
ARBRND	[11:10]	rw	Arbitration Round Length Defines the number of arbitration slots per arb. round (arbitration round length = t_{ARB}). ¹⁾ $00_B \quad 4 \text{ arbitration slots per round } (t_{ARB} = 4 / f_{ADCD})$ $01_B \quad 8 \text{ arbitration slots per round } (t_{ARB} = 8 / f_{ADCD})$ $10_B \quad 16 \text{ arbitration slots per round } (t_{ARB} = 16 / f_{ADCD})$ $11_B \quad 20 \text{ arbitration slots per round } (t_{ARB} = 20 / f_{ADCD})$

Field	Bits	Type	Description
0	[14:12]	rw	Reserved for Future Use Reserved for future use, must be written with 000 _B .
ARBM	15	rw	Arbitration Mode <div> <div>0_B</div> <div>The arbiter runs permanently. This setting is required for equidistant sampling using the signal ARBCNT (see Section 16.9.1).</div> </div> <div> <div>1_B</div> <div>The arbiter only runs if at least one conversion request of an enabled request source is pending. This setting ensures a reproducible latency from an incoming request to the conversion start, if the converter is idle.</div> </div>

- 1) The default setting of 4 arbitration slots is sufficient for correct arbitration. The duration of an arbitration round can be increased if required to synchronize requests.

The Global Configuration Register controls the calibration features (start-up calibration and post-calibration) and the general general multiplexer test mode.

GLOBCFG

Global Configuration Register **XSFR(DE_H)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MTM EN	0				MTMCH			0	DP CAL	SU CAL			0		
rw	r				rw			r	rw	rw			r		

Field	Bits	Type	Description
SUCAL	5	rw	Start-Up Calibration The 0-1 transition of bit SUCAL starts the start-up calibration phase of the analog part (indicated by GLOBSTR.CAL) required for 12-bit conversions. <div> <div>0_B</div> <div>No action</div> </div> <div> <div>1_B</div> <div>Start the start-up calibration phase Start conversions only after the start-up calibration is complete.</div> </div>

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Field	Bits	Type	Description
DPCAL	6	rw	Disable Post-Calibration Controls the automatic post-calibration required for 12-bit conversions. 0_B The automatic post-calibration is enabled 1_B No post-calibration
MTMCH	[12:8]	rw	Multiplexer Test Mode Channel Defines the number of the channel for the multiplexer test mode enabled by bit MTMEN.
MTMEN	15	rw	Multiplexer Test Mode Enable Enables the multiplexer test mode for the channel selected by bitfield MTMCH. 0_B No test mode (standard conversions) 1_B Multiplexer test mode enabled (selected channel is connected to ground via a resistor)
0	[4:0], 7, [14:13]	r	Reserved returns 0 if read; should be written with 0;

Analog to Digital Converter

The Global Status Register indicates the current status of a conversion.

GLOBSTR

Global Status Register

XSFR(12_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		CSRC			0	ANON		CHNR				CAL	SAM PLE	BU SY	
r		rh			r	rh		rh				rh	rh	rh	

Field	Bits	Type	Description
BUSY	0	rh	Analog Part Busy Indicates the converter's activity. 0 _B The converter is idle 1 _B A conversion is currently running
SAMPLE	1	rh	Sample Phase Indication 0 _B The converter is idle or converting 1 _B The input signal is being sampled
CAL	2	rh	Calibration Phase 0 _B Start-up calibration is done, conversions can be started 1 _B Start-up calibration is currently running
CHNR	[7:3]	rh	Channel Number Indicates the current or last converted analog input channel. This bitfield is updated when a conversion is started.
ANON	[9:8]	rh	Analog Part Switched On Defines the operating mode of the converter. This bitfield reflects bitfield GLOBCTR .ANON. The coding is defined in Section 16.4.4 .
CSRC	[13:11]	rh	Currently Converted Request Source Indicates the arbitration slot number of the current (BUSY = 1) or of the last (BUSY = 0) conversion. This bitfield is updated when a conversion is started. 000 _B Current/last conversion for request source 0 001 _B Current/last conversion for request source 1 010 _B Current/last conversion for request source 2 Other combinations are reserved.

Field	Bits	Type	Description
0	[15:14], 10	r	Reserved returns 0 if read; should be written with 0;

16.4.4 Module Activation and Power Saving Modes

The converter of the ADC supports specific power down modes allowing an automatic reduction of the power consumption between two conversions. The following modes are determined by bitfield **GLOBSTR.ANON**:

- **ANON = 11_B: Normal Operation**
The converter is permanently active, conversions are started immediately.
Requires no wakeup time.
- **ANON = 10_B: Fast Standby mode**
The converter enters a power reduction mode after each conversion. It automatically returns to normal operation if a conversion is requested. Fast standby mode reduces the overall power consumption for the ADC supply.
Requires the standard wakeup time (see below).
- **ANON = 01_B: Slow Standby mode**
The converter enters a power save mode after each conversion. It automatically returns to normal operation if a conversion is requested. Slow standby mode enables the lowest overall power consumption for the ADC supply.
Requires the extended wakeup time (see below).
- **ANON = 00_B: Converter switched Off** (default after reset)
The converter is switched off. Furthermore, digital logic blocks are set to their initial state. If the arbiter is currently running, it completes the actual arbitration round and then stops.
To start a conversion, select one of the active modes for ANON.
Requires the extended wakeup time (see below).

Wakeup Time from Analog Powerdown

When the converter is activated, it needs a certain wakeup time to settle before a conversion can be properly executed. This wakeup time must be added to the intended sample time. The required time depends on the operating mode.

In Fast Standby mode the standard wakeup time is approximately 5 μ s, in Slow Standby mode the extended wakeup time is approximately 15 μ s.

Exact numbers can be found in the respective Data Sheets.

Note: The extended wakeup time is also required after initially enabling the converter.

16.5 Conversion Request Generation

The conversion request unit of the ADC kernel autonomously handles the generation of conversion requests. Three request sources can generate requests for the conversion of an analog channel. The arbiter resolves concurrent requests and selects the channel to be converted next.

Upon a trigger event, the request source requests the conversion of a certain analog input channel or a sequence of channels.

- **Software triggers**
directly activate the respective request source.
- **External triggers**
synchronize the request source activation with external events, such as a trigger pulse from a timer generating a PWM signal or from a port pin.

Application software selects the trigger, the channel(s) to be converted, and the request source priority. A request source can also be activated directly by software without requiring an external trigger.

The arbiter regularly scans the request sources for pending conversion requests and selects the conversion request with the highest priority. This conversion request is then forwarded to the converter to start the conversion of the requested channel.

Each request source can operate in single-shot or in continuous mode:

- **In single-shot mode,**
the programmed conversion (sequence) is requested once after being triggered. A subsequent conversion (sequence) must be triggered again.
- **In continuous mode,**
the programmed conversion (sequence) is automatically requested repeatedly after being triggered once.

For each request source, external triggers are generated from one of 8 selectable trigger inputs (REQTRx[H:A]) and from one of 8 selectable gating inputs (REQGTx[H:A]). The available trigger signals for the XE166U are listed in [Section 16.13.4](#).

Note: [Figure 16-3 “Conversion Request Unit” on Page 16-5](#) summarizes the request sources.

Two types of requests sources are available:

- **A channel scan source** can issue conversion requests for a coherent sequence of input channels. This sequence begins with the highest enabled channel number and continues towards lower channel numbers. All available channels¹⁾ can be enabled for the scan sequence. Each channel is converted once per sequence.
A scan source converts a series of input channels permanently or on a regular time

¹⁾ The availability of input channels depends on the package of the used product type. A summary can be found in [Section 16.13.3](#).

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base. For example, if programmed with low priority, some input channels can be scanned in a background task to update information that is not time-critical.

Request source 1 is a channel scan source.

- **A queued source** can issue conversion requests for an arbitrary sequence of input channels. The channel numbers for this sequence can be freely programmed. This supports application-specific conversion sequences that cannot be covered by a channel scan source. Also, multiple conversions of the same channel within a sequence are supported.

A queued source converts a series of input channels permanently or on a regular time base. For example, if programmed with medium priority, some input channels can be converted upon a specified event (e.g. synchronized to a PWM). Conversions of lower priority sources are suspended in the meantime.

- Request source 2 is a 4-stage queued source.
- Request source 0 is a single source, implemented as a 1-stage queued source.

A single source can issue conversion requests for a single input channel. The channel number can be freely programmed.

A single source converts the selected input channel permanently or on a regular time base. For example, if programmed with high priority, a certain channel can be injected into another sequence controlled either by software or by a hardware-triggered.

16.5.1 Channel Scan Request Source Handling

Each analog input channel can be included in or excluded from the scan sequence (see bits in register **CRCR1** and **CRCR1E**). The programmed register value remains unchanged by an ongoing scan sequence. The scan sequence starts with the highest enabled channel number and continues towards lower channel numbers.

Upon a load event, the request pattern is transferred to the pending bits (see register **CRPR1** and **CRPR1E**). The pending conversion requests indicate which input channels are to be converted in an ongoing scan sequence. Each conversion start that was triggered by the scan request source, automatically clears the corresponding pending bit. If the last conversion triggered by the scan source is finished and all pending bits are cleared, the current scan sequence is considered finished and a request source event is generated.

A conversion request is only issued to the request source arbiter if at least one pending bit is set.

If the arbiter aborts a conversion triggered by the scan request source due to higher priority requests, the corresponding pending bit is automatically set. This ensures that an aborted conversion is not lost but takes part in the next arbitration round.

The trigger and gating unit generates load events from the selected external (outside the ADC) trigger and gating signals. For example, a timer unit can issue a request signal to synchronize conversions to PWM events.

Load events start a scan sequence and can be generated either via software or via the selected hardware triggers.

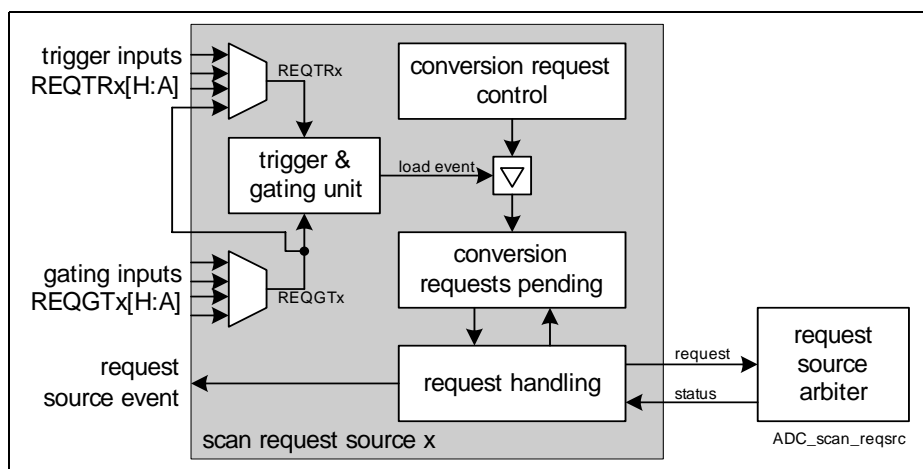


Figure 16-7 Scan Request Source

Scan Source Operation

Configure the scan request source by executing the following actions:

- Select the input channels for the sequence by programming **CRCR1** and **CRCR1E**
- If hardware trigger or gating is desired, select the appropriate trigger¹⁾ and gating inputs and the proper signal transitions by programming **RSIR1**. Enable the trigger and select the gating mode by programming **CRM1**.²⁾
- Define the load event operation (handling of pending bits, autoscan mode) by programming **CRM1**.
 A load event with bit LDM = 0 copies the content of **CRCR1** and **CRCR1E** to **CRPR1** and **CRPR1E** (overwrite mode). This starts a new scan sequence and aborts any pending conversions from a previous scan sequence.
 A load event with bit LDM = 1 OR-combines the content of **CRCR1** and **CRCR1E** to **CRPR1** and **CRPR1E** (combine mode). This starts a scan sequence that includes pending conversions from a previous scan sequence.
- Enable the corresponding arbitration slot (1) to accept conversion requests from the channel scan source (see register **ASENR**).

Start a channel scan sequence by generating a load event:

- If a hardware trigger is selected and enabled, generate the configured transition at the selected input signal, e.g. from a timer or an input pin.
- Generate a software load event by setting **CRM1.LDEV** = 1.
- Generate a load event by writing the scan pattern directly to the pending bits in **CRPR1** and **CRPR1E**. The pattern is copied to **CRCR1** and **CRCR1E** and a load event is generated automatically. Bit ALDM selects if the load event is generated upon writing to CRPR1 or to CRPR1E.
 In this case, a scan sequence can be defined and started with a single data write action, e.g. under PEC control (provided that the pattern fits into one register).

Note: If autoscan is enabled, a load event is generated automatically each time a request source event occurs when the scan sequence has finished. This permanently repeats the defined scan sequence (autoscan).

Stop or abort an ongoing scan sequence by executing the following actions:

- If external gating is enabled, switch the gating signal to the defined inactive level. This does not modify the conversion pending bits, but only prevents issuing conversion requests to the arbiter.
- Disable the corresponding arbitration slot (1) in the arbiter. This does not modify the contents of the conversion pending bits, but only prevents the arbiter from accepting requests from the request handling block.

1) Please refer to "**Hardware Trigger Selection**" on Page 16-47.

2) If PDOU signals from the ERU are used, initialize the ERU accordingly before enabling the gate inputs to avoid un expected signal transitions.

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- Disable the channel scan source by clearing bitfield $ENG\overline{T} = 00_{\text{B}}$. Clear the pending request bits by setting bit **CRM \overline{R} 1**.CLRPND = 1.

Scan Request Source Events and Interrupts

A request source event of a scan source occurs if the last conversion of a scan sequence is finished (all pending bits = 0). A request source event interrupt can be generated based on a request source event according to the structure shown in [Figure 16-8](#). If a request source event is detected, it sets the corresponding indication flag in register [EVINFR](#). These flags can also be set by writing a 1 to the corresponding bit position, whereas writing 0 has no effect. Additionally, a gated event flag [EVINCR.EVINGFx](#) indicates that a request source interrupt has been activated. The indication flags can be cleared by SW by writing a 1 to the corresponding bit position in register [EVINCR](#).¹⁾

The service request output SRx that is selected by the request source event interrupt node pointer bitfields in register [EVINPRO](#) becomes activated each time the related request source event is detected (and enabled by [CRMRx.ENS](#)) or the related bit position in register [EVINFR](#) is written with a 1 (this write action simulates a request source event).

Additionally, a gated event indication flag [EVINCR.EVINGFx](#) (after the gating with the enable bit) becomes set if a service request output becomes activated due to a request source event.

The request source events and the result events share the same registers. The request source event is located at the bit position in register [EVINFR](#):

- Event 1: Request source event of the channel scan source 1 (in arbitration slot 1)

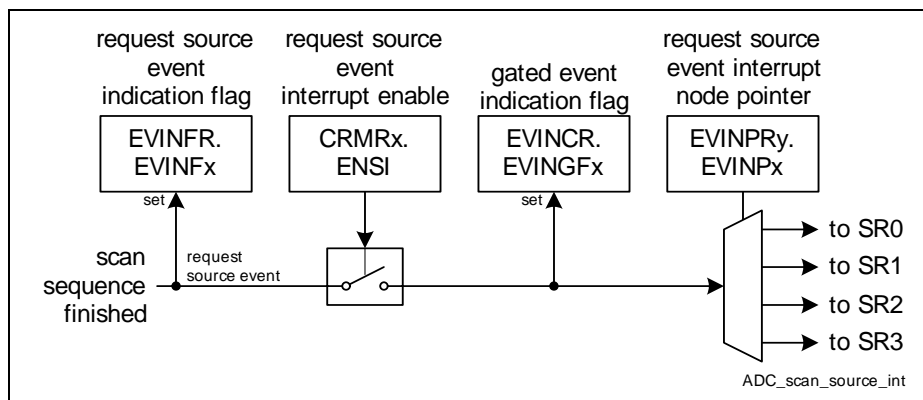


Figure 16-8 Interrupt Generation of a Scan Request Source

1) Please refer to ["Interrupt Request Handling"](#) on [Page 16-94](#).

Analog to Digital Converter

The Conversion Request Mode Register configures the operating mode of the channel scan request source.

CRMR1

Conversion Request 1 Mode Register

XSFR(EC_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						LD EV	CLR PND	REQ GT	ALD M	LD M	SC AN	EN SI	EN TR	ENGT	
r						w	w	rh	rw	rw	rw	rw	rw	rw	

Field	Bits	Type	Description
ENGT	[1:0]	rw	Enable Gate Selects the gating functionality for source 1. 00 _B No conversion requests are issued 01 _B Conversion requests are issued if at least one pending bit is set 10 _B Conversion requests are issued if at least one pending bit is set and REQGTx = 1. 11 _B Conversion requests are issued if at least one pending bit is set and REQGTx = 0. <i>Note: REQGTx is the selected gating signal.</i>
ENTR	2	rw	Enable External Trigger 0 _B External trigger disabled 1 _B The selected edge at the selected trigger input signal REQTR generates the load event
ENSI	3	rw	Enable Source Interrupt 0 _B No request source interrupt 1 _B A request source interrupt is generated upon a request source event (last pending conversion is finished)
SCAN	4	rw	Autoscan Enable 0 _B No autoscan 1 _B Autoscan functionality enabled: a request source event automatically generates a load event

Analog to Digital Converter

Field	Bits	Type	Description
LDM	5	rw	Load Event Mode Defines the transfer mechanism upon a load event. 0 _B Overwrite mode: Upon a load event, the bits of CRCR1 and CRCR1E are copied to CRPR1 and CRPR1E, respectively 1 _B Combine mode: Upon a load event, the bits of CRCR1 and CRCR1E are logical OR combined to the bits of CRPR1 and CRPR1E, respectively
ALDM	6	rw	Automatic Load Event Mode Selects the trigger for a load event generation. 0 _B Writing to CRPR1 generates a load event 1 _B Writing to CRPR1E generates a load event
REQGT	7	rh	Request Gate Level Monitors the level at the selected REQGT input. 0 _B The gate input is low 1 _B The gate input is high
CLRPND	8	w	Clear Pending Bits 0 _B No action 1 _B The bits in register CRPR1 are cleared
LDEV	9	w	Generate Load Event 0 _B No action 1 _B A load event is generated
0	[15:10]	r	Reserved returns 0 if read; should be written with 0;

Analog to Digital Converter

The Conversion Request 1 Control Register selects the lower channels to be converted by request source 1 (channel scan source). Its bits are used to update the pending register CRPR1, when the load event occurs. The upper channels are selected via register CRCR1E.

Note: Writes to register CRPR1 also update CRCR1 and generate a load event.

CRCR1

Conversion Request 1 Control Register

XSFR(E8_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CH 15	CH 14	CH 13	CH 12	CH 11	CH 10	CH 9	CH 8	CH 7	CH 6	CH 5	CH 4	CH 3	CH 2	CH 1	CH 0
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
CHx (x = 0 - 15)	x	rwh	Channel x Request Bit Each bit corresponds to one analog input channel, the channel number CHx is defined by the bit position x in this register. 0 _B No request 1 _B Analog channel CHx will be requested for conversion by this channel scan source

Analog to Digital Converter

The Conversion Request 1 Control Register Extended selects the upper channels to be converted by request source 1 (channel scan source). Its bits are used to update the pending register CRPR1E, when the load event occurs.

Note: Writes to register CRPR1E also update CRCR1E and generate a load event.

CRCR1E

Conversion Request 1 Control Register Extended

XSFR(214_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
				0						CH	CH	CH	CH	CH	CH
										21	20	19	18	17	16
				r						rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
CHx (x = 16 - 21)	x-16	rwh	Channel Bit x Each bit corresponds to one analog input channel, the channel number CHx is defined by the bit position x in this register. 0 _B No request 1 _B The analog channel CHx will be requested for conversion by this channel scan source
0	[15:6]	r	Reserved returns 0 if read; should be written with 0;

Note: Not all channels are available in all products.

Therefore, only the conversion request bits with corresponding channels are valid.

Analog to Digital Converter

The Conversion Request Pending Register indicates which (lower) channels of request source 1 (channel scan source) are requesting a conversion. Its bits are updated from pending register CRCR1, when the load event occurs. The upper channels are indicated in register CRPR1E.

Note: Writes to register CRPR1 also update CRCR1 and generate a load event.

CRPR1

Conversion Request 1 Pending Register

XSFR(EA_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CHP 15	CHP 14	CHP 13	CHP 12	CHP 11	CHP 10	CHP 9	CHP 8	CHP 7	CHP 6	CHP 5	CHP 4	CHP 3	CHP 2	CHP 1	CHP 0
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
CHPx (x = 0 - 15)	x	rwh	Channel Pending Bit x <u>Write view:</u> A write to this address targets the bits in register CRCR1. <u>Read view:</u> Each bit corresponds to one analog channel, the channel number CHx is defined by the bit position in the register. 0 _B No request 1 _B Analog channel CHx is requested for conversion by this channel scan source

Analog to Digital Converter

The Conversion Request Pending Register Extended indicates which upper channels of request source 1 (channel scan source) are requesting a conversion. Its bits are updated from pending register CRCR1E, when the load event occurs.

Note: Writes to register CRPR1E also update CRCR1E and generate a load event.

CRPR1E

Conversion Request 1 Pending Register Extended

XSFR(216_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
										CHP 21	CHP 20	CHP 19	CHP 18	CHP 17	CHP 16
										rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
CHPx (x = 16 - 21)	x-16	rwh	Channel Pending Bit x <u>Write view:</u> A write to this address targets the bits in register CRCR1E. <u>Read view:</u> Each bit corresponds to one analog channel, the channel number CHx is defined by a bit position in the register starting with ch16. 0 _B No request 1 _B Analog channel CHx is requested for conversion by this channel scan source
0	[15:6]	r	Reserved returns 0 if read; should be written with 0;

Note: Not all channels are available in all products.

Therefore, only the request pending bits with corresponding channels are valid.

16.5.2 Queued Request Source Handling

A queued request source supports short conversion sequences of arbitrary channels (contrary to a scan request source with a fixed conversion order for the enabled channels). The programmed sequence is stored in a queue buffer (based on a FIFO mechanism). The requested channel numbers are entered via the queue input, while queue stage 0 defines the channel to be converted next.

A conversion request is only issued to the request source arbiter if a valid entry is stored in queue stage 0.

If the arbiter aborts a conversion triggered by a queued request source due to higher priority requests, the corresponding conversion parameters are automatically saved in the backup stage. This ensures that an aborted conversion is not lost but takes part in the next arbitration round (before stage 0).

The trigger and gating unit generates trigger events from the selected external (outside the ADC) trigger and gating signals. For example, a timer unit can issue a request signal to synchronize conversions to PWM events.

Trigger events start a queued sequence and can be generated either via software or via the selected hardware triggers. The occurrence of a trigger event is indicated by bit QSRx.EV. This flag is cleared when the corresponding conversion is started or by writing to bit QMRx.CEV.

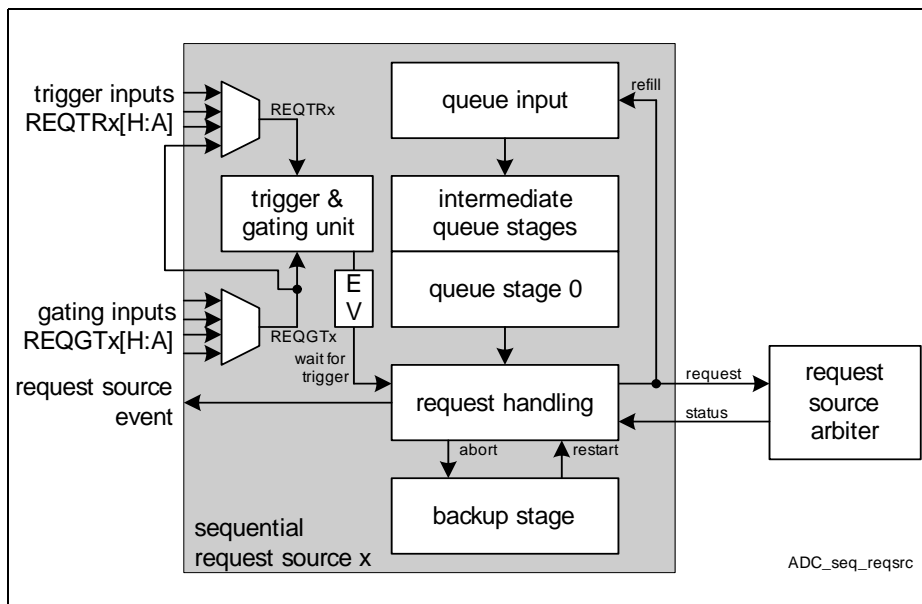


Figure 16-9 Queued Request Source

Analog to Digital Converter

A sequence is defined by entering conversion requests into the queue input register (**QINR0**, **QINR2**). Each entry selects the channel to be converted and can enable an external trigger, generation of an interrupt, and an automatic refill (i.e. keep this entry in the queue after conversion). The entries are stored in the queue buffer stages.

The content of stage 0 (**Q0R0**, **Q0R2**) selects the channel to be converted next. When the requested conversion is started, the contents of this queue stage is invalidated and copied to the backup stage. Then the next queue entry can be handled (if available).

Note: The contents of the queue stages cannot be modified directly, but only by writing to the queue input or by flushing the queue.

If all queue entries have automatic refill selected, the defined conversion sequence can be repeated without re-programming.

Properties of the 2 Queued Request Sources

The ADC of the XE166U provides two queued request sources with different buffer size:

- Queued request source 2 provides 4 buffer stages and can handle sequences of up to 4 input channel entries. It supports short application-specific conversion sequences, especially for timing-critical sequences containing also multiple conversions of the same channel.
- Queued request source 0 provides a single-stage buffer and can handle a single input channel entry. It supports software-controlled conversion requests or hardware-triggered conversions of a single input channel (to “inject” a single conversion into a running sequence).

Queued Source Operation

Configure the queued request source by executing the following actions:

- Define the sequence by writing the entries to the queue input **QINR0** or **QINR2**. Initialize the complete sequence before enabling the request source, because with enabled refill feature, software writes to QINRx are not allowed.
- If hardware trigger or gating is desired, select the appropriate trigger¹⁾ and gating inputs and the proper transitions by programming **RSIR0** or **RSIR2**. Enable the trigger and select the gating mode by programming bitfield ENGTT in register **QMR0** or **QMR2**.²⁾
- Enable the corresponding arbitration slot (0 or 2) to accept conversion requests from the queued source (see register **ASENR**).

Start a queued sequence by generating a trigger event:

- If a hardware trigger is selected and enabled, generate the configured transition at the selected input signal, e.g. from a timer or an input pin.
- Generate a software trigger event by setting QMRx.TREV = 1.
- Write a new entry to the queue input of an empty queue. This leads to a (new) valid queue entry that is forwarded to queue stage 0 and starts a conversion request (if enabled by QMRx.ENGTT and without waiting for an external trigger).

Note: If the refill mechanism is activated, a processed entry is automatically reloaded into the queue. This permanently repeats the respective sequence (autoscan). In this case, do not write to the queue input while the queued source is running. Write operations to a completely filled queue are ignored.

Stop or abort an ongoing queued sequence by executing the following actions:

- If external gating is enabled, switch the gating signal to the defined inactive level. This does not modify the queue entries, but only prevents issuing conversion requests to the arbiter.
- Disable the corresponding arbitration slot (0 or 2) in the arbiter. This does not modify the queue entries, but only prevents the arbiter from accepting requests from the request handling block.
- Disable the queued source by clearing bitfield ENGTT = 00_B.
 - Invalidate the next pending queue entry by setting bit QMRx.CLRV = 1. If the backup stage contains a valid entry, this one is invalidated, otherwise stage 0 is invalidated.
 - Remove all entries from the queue by setting bit QMRx.FLUSH = 1.

1) Please refer to "**Hardware Trigger Selection**" on Page 16-47.

2) If PDOUT signals from the ERU are used, initialize the ERU accordingly before enabling the gate inputs to avoid an unexpected signal transitions.

Queue Request Source Events and Interrupts

A request source event of a queued source occurs when a conversion is finished. A request source event interrupt can be generated based on a request source event according to the structure shown in [Figure 16-10](#). If a request source event is detected, it sets the corresponding indication flag in register [EVINFR](#). These flags can also be set by writing a 1 to the corresponding bit position, whereas writing 0 has no effect. The indication flags can be cleared by SW by writing a 1 to the corresponding bit position in register [EVINCR](#).¹⁾

The interrupt enable bit is taken from stage 0 for a normal sequential conversion, or from the backup stage for a repeated conversion after an abort.

The service request output line SRx that is selected by the request source event interrupt node pointer bitfields in register [EVINPRO](#) becomes activated each time the related request source event is detected (and enabled by Q0Rx.ENSI, or QBURx.ENSI respectively) or the related bit position in register [EVINFR](#) is written with a 1 (this write action simulates a request source event).

Additionally, a gated event indication flag [EVINCR.EVINGFx](#) (after the gating with the enable bit) becomes set if a service request output becomes activated due to a request source event.

The request source events and the result events share the same registers. The request source event is located at the bit position in register [EVINFR](#):

- Event 0: Request source event of queued source 0 (in arbitration slot 0)
- Event 2: Request source event of queued source 2 (in arbitration slot 2)

1) Please refer to "[Interrupt Request Handling](#)" on [Page 16-94](#).

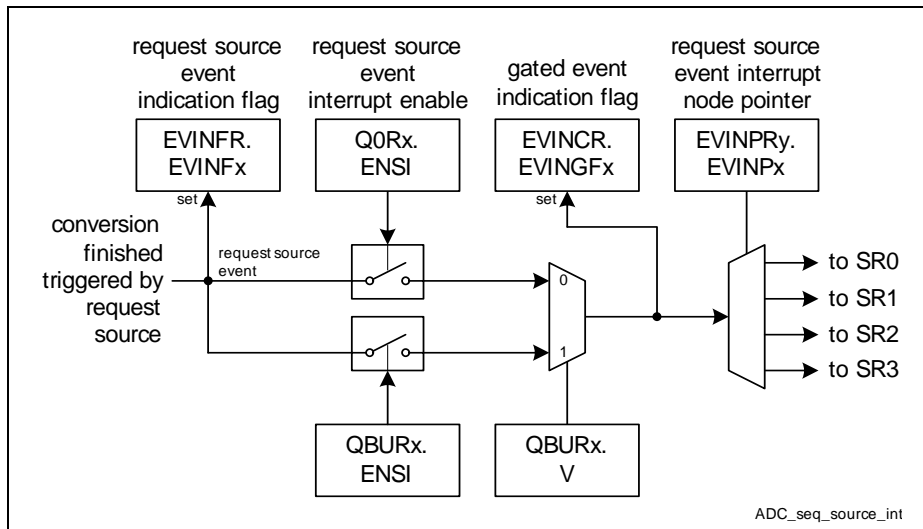


Figure 16-10 Interrupt Generation of a Queued Request Source

Analog to Digital Converter

The Queue Mode Register configures the operating mode of a queued request source.

QMR0

Queue 0 Mode Register

XSFR(E0_H)

Reset Value: 0000_H

QMR2

Queue 2 Mode Register

XSFR(F0_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0				CEV	FLU SH	TR EV	CLR V	0				EN TR	ENGT		
r				w	w	w	w	r				rw	rw		

Field	Bits	Type	Description
ENGT	[1:0]	rw	Enable Gate Selects the gating functionality for source 0/2. 00 _B No conversion requests are issued 01 _B Conversion requests are issued if a valid conversion request is pending in the queue 0 register or in the backup register 10 _B Conversion requests are issued if a valid conversion request is pending in the queue 0 register or in the backup register and REQGTx = 1 11 _B Conversion requests are issued if a valid conversion request is pending in the queue 0 register or in the backup register and REQGTx = 0 <i>Note: REQGTx is the selected gating signal.</i>
ENTR	2	rw	Enable External Trigger 0 _B External trigger disabled 1 _B The selected edge at the selected trigger input signal REQTR generates the trigger event
CLRV	8	w	Clear Valid Bit 0 _B No action 1 _B The next pending valid queue entry in the sequence and the event flag EV are cleared. If there is a valid entry in the queue backup register (QBUR.V = 1), this entry is cleared, otherwise the entry in queue register 0 is cleared.

Analog to Digital Converter

Field	Bits	Type	Description
TREV	9	w	Trigger Event 0 _B No action 1 _B Generate a trigger event by software
FLUSH	10	w	Flush Queue 0 _B No action 1 _B Clear all queue entries (including backup stage) and the event flag EV. The queue contains no more valid entry.
CEV	11	w	Clear Event Flag 0 _B No action 1 _B Clear bit EV
0	[7:3], [15:12]	r	Reserved returns 0 if read; should be written with 0;

*Note: Before SW modifies the queue content by QMR.CLRV or QMR.FLUSH, all HW actions related to this queue have to be finished. Therefore, the arbitration slot has to be disabled and SW has to wait for at least two arbitration rounds (to be sure that this request source can no longer be an arbitration winner). Then, it has to check **GLOBSTR.CRSC** and **GLOBSTR.BUSY** to be sure that a conversion triggered by this request source is no longer running. Then SW can read QBURx and Q0Rx and can start modification of the queue content.*

Analog to Digital Converter

The Queue Status Register indicates the current status of the queued source. The filling level and the empty information refer to the queue intermediate stages (if available) and to the queue register 0. An aborted conversion stored in the backup stage is not indicated by these bits (therefore, see QBURx.V).

QSR0

Queue 0 Status Register

XSFR(E2_H)

Reset Value: 0020_H

QSR2

Queue 2 Status Register

XSFR(F2_H)

Reset Value: 0020_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						EV	REQ GT	0	EMP TY	0			FILL		
r						rh	rh	r	rh	r			rh		

Field	Bits	Type	Description
FILL	[1:0]	rh	Filling Level for Queue 2 Indicates the number of valid queue entries. It is incremented each time a new entry is written to QINRx or by an enabled refill mechanism. It is decremented each time a requested conversion has been started. A new entry is ignored if the filling level has reached its maximum value. 00 _B There is 1 (if EMPTY = 0) or no (if EMPTY = 1) valid entry in the queue 01 _B There are 2 valid entries in the queue 10 _B There are 3 valid entries in the queue 11 _B There are 4 valid entries in the queue <i>Note: In QSR0 (queued source 0), this bitfield is 00_B.</i>
EMPTY	5	rh	Queue Empty 0 _B There are valid entries in the queue (see FILL) 1 _B No valid entries (queue is empty)
REQGT	7	rh	Request Gate Level Monitors the level at the selected REQGT input. 0 _B The gate input is low 1 _B The gate input is high

Field	Bits	Type	Description
EV	8	rh	Event Detected Indicates that an event has been detected while at least one valid entry has been in the queue (queue register 0 or backup stage). Once set, this bit is cleared automatically when the requested conversion is started. 0 _B No trigger event 1 _B A trigger event has been detected
0	[4:2], 6, [15:9]	r	Reserved returns 0 if read; should be written with 0;

Analog to Digital Converter

The Queue Input Register is the entry point for conversion requests of a queued request source.

QINR0

Queue 0 Input Register

XSFR(E6_H)

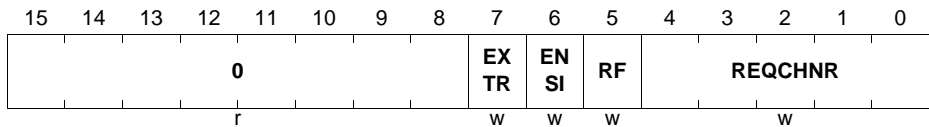
Reset Value: 0000_H

QINR2

Queue 2 Input Register

XSFR(F6_H)

Reset Value: 0000_H



Field	Bits	Type	Description
REQCHNR	[4:0]	w	Request Channel Number Defines the channel number to be converted
RF	5	w	Refill 0 _B No refill: this queue entry is converted once and then invalidated 1 _B Automatic refill: this queue entry is automatically reloaded into QINRx when the related conversion is started
ENSI	6	w	Enable Source Interrupt 0 _B No request source interrupt 1 _B A request source event interrupt is generated upon a request source event (related conversion is finished)
EXTR	7	w	External Trigger Enables the external trigger functionality. 0 _B A valid queue entry immediately leads to a conversion request. 1 _B A valid queue entry waits for a trigger event to occur before issuing a conversion request.
0	[15:8]	r	Reserved returns 0 if read; should be written with 0;

Note: Registers QINRx share addresses with registers QBURx.

Write operations target the control bits in register QINRx. Read operations return the status bits from register QBURx.

Analog to Digital Converter

The queue registers 0 monitor the status of the pending request (queue stage 0).

Q0R0

Queue 0 Register 0

XSFR(E4_H)

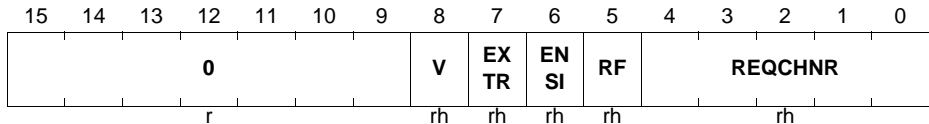
Reset Value: 0000_H

Q0R2

Queue 2 Register 0

XSFR(F4_H)

Reset Value: 0000_H



Field	Bits	Type	Description
REQCHNR	[4:0]	rh	Request Channel Number Stores the channel number to be converted.
RF	5	rh	Refill Selects the handling of handled requests. 0 _B The request is discarded after the conversion start. 1 _B The request is automatically refilled into the queue after the conversion start.
ENSI	6	rh	Enable Source Interrupt 0 _B No request source interrupt 1 _B A request source event interrupt is generated upon a request source event (related conversion is finished)
EXTR	7	rh	External Trigger Enables external trigger events. 0 _B A valid queue entry immediately leads to a conversion request 1 _B The request handler waits for a trigger event
V	8	rh	Request Channel Number Valid Indicates a valid queue entry in queue register 0. 0 _B No valid queue entry 1 _B The queue entry is valid and leads to a conversion request
0	[15:9]	r	Reserved returns 0 if read; should be written with 0;

Analog to Digital Converter

The Queue Backup Registers monitor the status of an aborted queued request.

QBUR0

Queue 0 Backup Register

XSFR(E6_H)

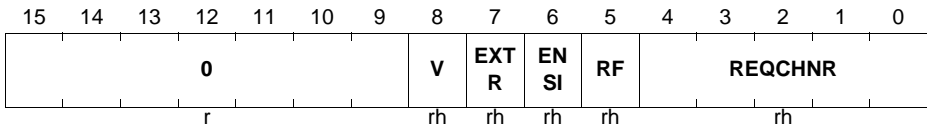
Reset Value: 0000_H

QBUR2

Queue 2 Backup Register

XSFR(F6_H)

Reset Value: 0000_H



Field	Bits	Type	Description
REQCHNR	[4:0]	rh	Request Channel Number The channel number of the aborted conversion that has been requested by this request source
RF	5	rh	Refill The refill control bit of the aborted conversion
ENSI	6	rh	Enable Source Interrupt The enable source interrupt control bit of the aborted conversion
EXTR	7	rh	External Trigger The external trigger control bit of the aborted conversion
V	8	rh	Request Channel Number Valid Indicates if the entry (REQCHNR, RF, TR, ENSI) in the queue backup register is valid. Bit V is set when a running conversion (that has been requested by this request source) is aborted, it is cleared when the aborted conversion is restarted. 0 _B Backup register not valid 1 _B Backup register contains a valid entry. This will be requested before a valid entry in queue register 0 (stage 0) will be requested.
0	[15:9]	r	Reserved returns 0 if read; should be written with 0;

Note: Registers QBURx share addresses with registers QINRx.

Read operations return the status bits from register QBURx. Write operations target the control bits in register QINRx.

16.5.3 Hardware Trigger Selection

Each request source can be activated either by software or by a hardware trigger signal. The hardware triggers can be derived from several module signals or port inputs. Selectable gating signals additionally enable/disable these triggers.

Registers RSIRx select the inputs for the hardware trigger and gating inputs for each request source. For a list of the available input signals, please refer to the implementation chapter, [Section 16.13.4](#).

RSIRO

Request Source 0 Input Register XSFR(00_H) **Reset Value: 0000_H**

RSIR1

Request Source 1 Input Register XSFR(02_H) **Reset Value: 0000_H**

RSIR2

Request Source 2 Input Register XSFR(04_H) **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRI	0	R EN	F EN	0	TRSEL		GTI	0	TM EN	0	GTSEL				
rh	r	rw	rw	r	rw		rh	r	rw	r	rw				

Field	Bits	Type	Description
GTSEL	[2:0]	rw	Gating Input Selection for Source x Selects the input signal used for request gating in request source x. 000 _B Select input signal REQGTxA 001 _B Select input signal REQGTxB ... 111 _B Select input signal REQGTxH
TMEN	4	rw	Timer Mode Enable of Source x Enables the timer mode for equidistant sampling (see Section 16.9.1). 0 _B The timer mode is disabled. The standard gating mechanism can be used. 1 _B The timer mode for equidistant sampling is enabled. The standard gating mechanism has to be enabled permanently (no influence of gating signal).

Field	Bits	Type	Description
GTI	7	rh	Request Gate Level of Source x Monitors the level at the selected REQGTx input. 0 _B The gate input is low 1 _B The gate input is high
TRSEL	[10:8]	rw	Trigger Input Selection for Source x Selects the input signal used for request triggering in request source x. 000 _B Select input signal REQTRxA 001 _B Select input signal REQTRxB ... 111 _B Select input signal REQTRxH
FEN	12	rw	Falling Edge Enable for Trigger of Source x 0 _B No trigger upon a falling edge 1 _B A falling edge on the selected REQTRx input generates a trigger event
REN	13	rw	Rising Edge Enable for Trigger of Source x 0 _B No trigger upon a rising edge 1 _B A rising edge on the selected REQTRx input generates a trigger event
TRI	15	rh	Trigger Input Level of Source x Monitors the level at the selected REQTRx input. 0 _B The trigger input is low 1 _B The trigger input is high
0	3, [6:5], 11, 14	r	Reserved returns 0 if read; should be written with 0.

16.6 Request Source Arbitration

The request source arbiter regularly polls the request sources, one after the other, for pending conversion requests. Each request source is assigned to a certain time slot within an arbitration round, called arbitration slot. The duration of an arbitration slot and the number of slots in an arbitration round are user-configurable via register **GLOBALCTR**.

The priority of each request source is user-configurable via register **RSPRO**, so the arbiter can select the next channel to be converted, in the case of concurrent requests from multiple sources, according to the application requirements.

A disabled or unused arbitration slot is considered empty and does not take part in the arbitration. After reset, all slots are disabled and must be enabled (register **ASENR**) to take part in the arbitration process.

Figure 16-11 summarizes the arbitration sequence. An arbitration round consists of one arbitration slot for each available request source. The synchronization source is always evaluated in the last slot and has a higher priority than all other sources. Additional arbitration slots can be inserted to adjust the timing to other products (not required for the XE166U). At the end of each arbitration round, the arbiter has determined the highest priority conversion request.

If a conversion is started in an arbitration round, this arbitration round does not deliver an arbitration winner. In the XE166U, the following request sources are available:

- Arbitration slot 0: **1-stage queued source**, single input channel
- Arbitration slot 1: **N-channel scan source**, sequences in defined order
- Arbitration slot 2: **4-stage sequential source**, 4-stage sequences in arbitrary order
- Last arbitration slot: **Synchronization source**¹⁾, synchronized conversion requests from another ADC kernel (always handled with the highest priority in a synchronization slave kernel).

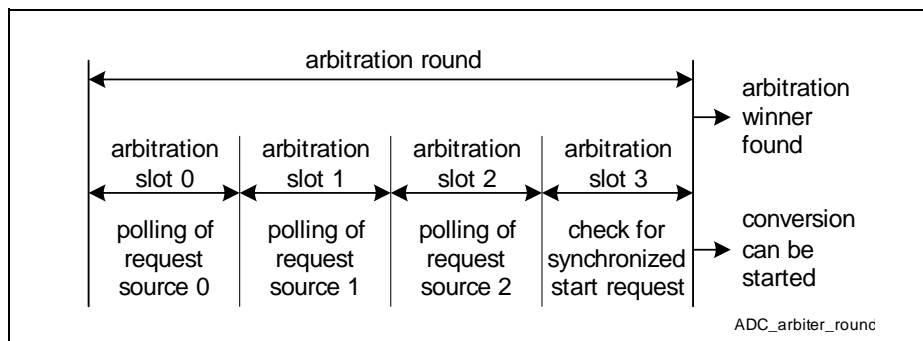


Figure 16-11 Arbitration Round

1) In the XE166U, this last arbitration slot is empty. No other kernels are available.

16.6.1 Arbiter Timing

The timing of the arbiter (i.e. of an arbitration round) is determined by the number of arbitration slots within an arbitration round and by the duration of an arbitration slot.

An arbitration round consist of 4, 8, 16, or 20 arbitration slots (defined by bitfield **GLOBCTR.ARBND**). 4 slots are sufficient for the XE166U, more can be programmed to obtain the same arbiter timing for different products.

The duration of an arbitration slot is configurable $t_{\text{Slot}} = (\text{DIVD}+1) / f_{\text{ADC}}$.

The duration of an arbitration round, therefore, is $t_{\text{ARB}} = N \times t_{\text{Slot}}$ (N = number of slots).

The period of the arbitration round introduces a timing granularity to detect an incoming conversion request signal and the earliest point to start the related conversion. This granularity can introduce a jitter of maximum one arbitration round. The jitter can be reduced by minimizing the period of an arbitration round.

To achieve a reproducible reaction time (constant delay without jitter) between the trigger event of a conversion request (e.g. by a timer unit or due to an external event) and the start of the related conversion, mainly the following two options exist. For both options, the converter has to be idle and other conversion requests must not be pending for at least one arbiter round before the trigger event occurs:

- If bit **GLOBCTR.ARB** = 0, the **arbiter runs permanently**.
The trigger for the conversion triggers has to be generated synchronously to the arbiter timing. Incoming triggers should have exactly n-times the granularity of the arbiter ($n = 1, 2, 3, \dots$). In order to allow some flexibility, the duration of an arbitration slot can be programmed in cycles of f_{ADC} .
- If bit **GLOBCTR.ARB** = 1, the **arbiter stops after an arbitration round** when no conversion request have been found pending any more. The arbiter is started again if at least one enabled request source indicates a pending conversion request. The trigger of a conversion request does need not to be synchronous to the arbiter timing.

Analog to Digital Converter

The Arbitration Slot Enable Register enables/disables the arbitration slots to control whether or not conversion requests are considered.

ASENR

Arbitration Slot Enable Register

XSFR(18_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
													AS EN2	AS EN1	AS EN0
													r	rw	rw

Field	Bits	Type	Description
ASENx (x = 0 - 2)	x	rw	Arbitration Slot x Enable Enables the associated arbitration slot of an arbiter round. The request source bits are not modified by write actions to ASENR. 0 _B The corresponding arbitration slot is disabled and considered as empty. Pending conversion requests from the associated request source are disregarded. 1 _B The corresponding arbitration slot is enabled. Pending conversion requests from the associated request source are arbitrated.
0	[15:3]	r	Reserved returns 0 if read; should be written with 0;

Note: If the arbiter shall not be running continuously (ARBM = 1), no conversion request of the request source for arbitration slot x must be active. Clear conversion requests of the related request source before disabling an arbitration slot.

16.6.2 Request Source Priority and Conversion Start Mode

Each request source has a configurable priority, so the arbiter can resolve concurrent conversion requests from different sources. The request with the highest priority is selected for conversion. These priorities can be adapted to the requirements of a given application (see register [RSPR0](#)).

The **Conversion Start Mode** determines the handling of the conversion request that has won the arbitration.

The Request Source Priority Register defines the request source priority and the conversion start mode for each request source.

Note: Only change priority and conversion start mode settings of a request source while this request source is disabled, and a currently running conversion requested by this source is finished.

RSPR0

Request Source Priority Register 0

XSFR(14 _H)														Reset Value: 0000 _H	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0				CSM 2	0	PRI0 2	CSM 1	0	PRI0 1	CSM 0	0	PRI0 0			
r				rw	r	rw	rw	r	rw	rw	r	rw	rw		

Field	Bits	Type	Description
PRI00, PRI01, PRI02	[1:0], [5:4], [9:8]	rw	Priority of Request Source x Arbitration priority of request source x (in slot x) 00 _B Lowest priority is selected. ... 11 _B Highest priority is selected.
CSM0, CSM1, CSM2	3, 7, 11	rw	Conversion Start Mode of Request Source x 0 _B Wait-for-start mode 1 _B Cancel-inject-repeat mode
0	2, 6, 10, [15:12]	r	Reserved returns 0 if read; should be written with 0;

Conversion Start Mode

When the arbiter has selected the request to be converted next, the handling of this channel depends on the current activity of the converter:

- Converter is currently idle: the conversion of the arbitration winner is started immediately.
- Current conversion has same or higher priority: the current conversion is completed, the conversion of the arbitration winner is started after that.
- Current conversion has lower priority: the action is user-configurable:
 - **Wait-for-start mode:** the current conversion is completed, the conversion of the arbitration winner is started after that. This mode provides maximum throughput, but can produce a jitter for the higher priority conversion.

Example in [Figure 16-12](#):

Conversion A is requested (t1) and started (t2). Conversion B is then requested (t3), but started only after completion of conversion A (t4).

- **Cancel-inject-repeat mode:** the current conversion is aborted, the conversion of the arbitration winner is started after the abortion ($1 \dots 3 f_{\text{ADCI}}$ cycles).

The aborted conversion request is restored in the corresponding request source and takes part again in the next arbitration round. This mode provides minimum jitter for the higher priority conversions, but reduces the overall throughput.

Example in [Figure 16-12](#):

Conversion A is requested (t6) and started (t7). Conversion B is then requested (t8) and started (t9), while conversion A is aborted but requested again. When conversion B is complete (t10), conversion A is restarted.

Exception: If both requests target the same result register with wait-for-read mode active (see [Section 16.8.2](#)), the current conversion cannot be aborted.

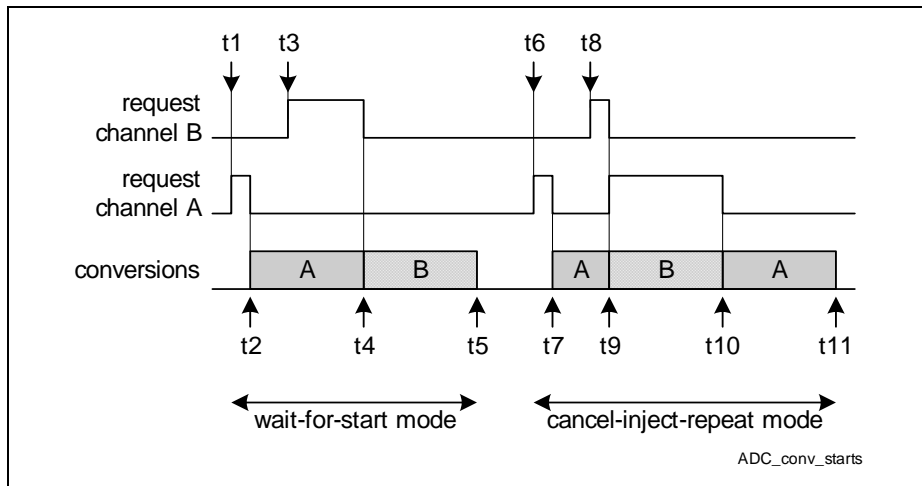


Figure 16-12 Conversion Start Modes

The conversion start mode can be individually programmed for each request source by bits in register **RSPRO** and is applied to all channels requested by the source. In this example, channel A is issued by a request source with a lower priority than the request source requesting the conversion of channel B.

16.7 Analog Input Channel Configuration

For each analog input channel, a number of parameters can be configured that control the conversion of this channel. After a channel has won the arbitration, its parameters are applied to the converter. The channel control registers (CHCTR_x on [Page 16-56](#)) define the following parameters:

- **Conversion parameters:** The input class defines sample time and data width. Each channel is assigned to one of two input classes.
- **Reference selection:** The conversion can use the standard reference (V_{AREF}) or the alternate reference (CH0). The conversion result of an input channel refers to a reference voltage (full scale digital result value if the analog input voltage equals the reference voltage¹⁾). Selecting the alternate reference e.g. allows to connect 3.3 V based sensors to the ADC in a 5.0 V system (the other input channels refers to the standard reference voltage).
Please note that low reference voltages lead to small granularity. As a consequence, the resulting TUE increases due to noise effects.
- **Result target:** The conversion result can be stored in one of 8 result registers.
- **Channel event handling:** Channel events can be restricted to results inside or outside a defined area of values (limit checking). For each channel event an interrupt node can be selected.

In addition to the general channel control, the ADC kernel supports a mechanism (named alias feature, see [Section 16.7.3](#)) to redirect a conversion request to another channel number.

If more analog inputs are required than input pins are available, external analog multiplexers can be added. These external multiplexers can be automatically controlled by the ADC logic. This is described in [Section 16.11](#).

1) Because the compensated ideal transfer curve of the ADC has its first code transition when the input value reaches 0.5 LSB_n , the full scale digital result value is reached when the input value is 1.5 LSB_n below the reference voltage.

16.7.1 Channel Parameters

Each analog input channel is configured by its associated channel control register. The sample time and the result width are selected via an input class.

The Channel Control Registers select the control parameters for each input channel.

CHCTR_x (x = 0 - 15)

Channel x Control Register **XSFR(20_H + x * 2)** **Reset Value: 0000_H**

CHCTR_x (x = 16 - 21)

Channel x Control Register **XSFR(200_H + x * 2)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	RESR SEL		ICL SEL		REF SEL	0		LCC		BND SEL	BND SEL				
r	rw		rw		rw	r		rw		rw	rw				

Field	Bits	Type	Description
BNDASEL	[1:0]	rw	Boundary A Selection Defines the boundary A register for limit checking. 00 _B Use register LCBR0 01 _B Use register LCBR1 10 _B Use register LCBR2 11 _B Use register LCBR3
BNDSEL	[3:2]	rw	Boundary B Selection Defines the boundary B register for limit checking. 00 _B Use register LCBR0 01 _B Use register LCBR1 10 _B Use register LCBR2 11 _B Use register LCBR3
LCC	[6:4]	rw	Limit Check Control Defines the condition under which a channel event is generated (see Section 16.7.2 on Page 16-59). 000 _B Never 001 _B Result outside area I 010 _B Result outside area II 011 _B Result outside area III 100 _B Always (boundaries disregarded) 101 _B Result within area I 110 _B Result within area II 111 _B Result within area III

Field	Bits	Type	Description
REFSEL	[9:8]	rw	Reference Input Selection Defines the reference source for this channel. 00 _B Select the standard reference input V_{AREF} 01 _B Select the alternative reference input CH0 10 _B reserved, do not use 11 _B reserved, do not use
ICLSEL	[11:10]	rw	Input Class Selection Defines the channel-specific parameters. 00 _B Select input class 0 01 _B Select input class 1 10 _B reserved, do not use 11 _B reserved, do not use
RESRSEL	[14:12]	rw	Result Register Selection Selects the target for the conversion result(s). 000 _B Use result register 0 001 _B Use result register 1 ... 111 _B Use result register 7
0	7, 15	r	Reserved returns 0 if read; should be written with 0;

Note: Not all channels are available in all products.

Therefore, only the channel control registers with corresponding channels are valid.

Analog to Digital Converter

An input class defines the length of the sample phase and the resolution of the conversion. Two input classes can be defined and each channel is assigned to one of them. This supports applications with different input circuitries (impedance, RC input filter).

The default settings select the minimum sample phase length of $2f_{\text{ADCI}}$ cycles and a result width of 10 bits.

The Input Class Registers select the sample time and the resolution for each input class.

INPCR_x (x = 0 - 1)

Input Class Register x

XSFR(C0_H + x * 2)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						DW		STC							
r						rw		rw							

Field	Bits	Type	Description
STC	[7:0]	rw	Sample Time Control Number of additional clock cycles to be added to the minimum sample phase of 2 analog clock cycles: $t_{\text{SAMPLE}} = (2 + \text{STC}) / f_{\text{ADCI}}$ For conversions of external channels, this value can be replaced by EMSAMPLE in register EMCTR .
DW	[9:8]	rw	Data Width Defines the number of converted bits for the result. The conversion results are left aligned in the result bitfields. Bit positions that are not converted are 0. 00 _B The result is 10 bits wide (bits 11 ... 2) 01 _B The result is 12 bits wide (bits 11 ... 0) 10 _B The result is 8 bits wide (bits 11 ... 4) Else: reserved, do not use
0	[15:10]	r	Reserved returns 0 if read; should be written with 0;

16.7.2 Limit Checking

The limit checking mechanism automatically compares each conversion result to two boundary values (boundary A and boundary B). For each channel, the user can select these boundaries from a set of 4 programmable values (**LCBR0** to **LCBR3**).

A channel event is then generated depending on the two comparisons. The conditions are selected via bitfield LCC in the respective channel control register.

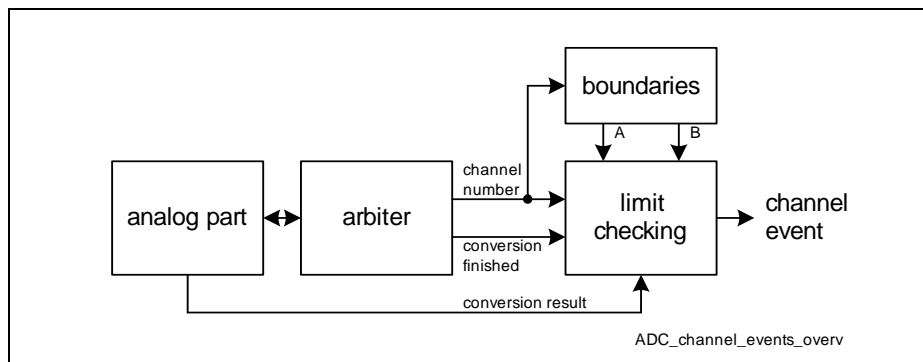


Figure 16-13 Channel Event Generation

The two selectable boundaries split the conversion result range into three areas:

- Area I: Conversion result below or equal to both boundaries.
- Area II: Conversion result above one boundary and below/equal to other boundary.
- Area III: Conversion result above both boundaries.

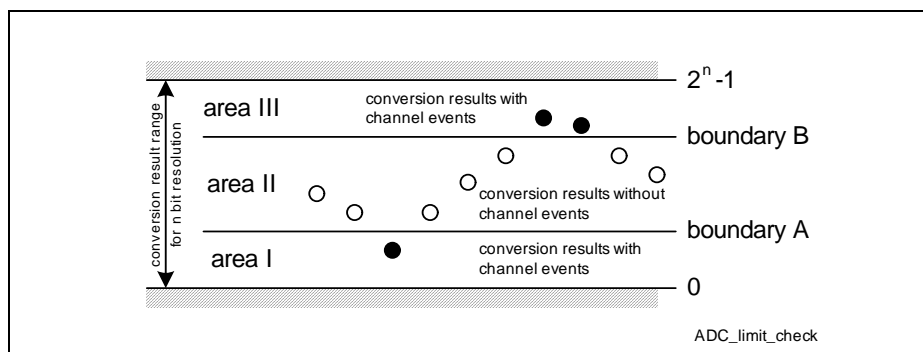


Figure 16-14 Limit Checking

The shown example for limit checking generates channel events only if the conversion results are outside the normal operating range defined by area II (LCC = 010_B).

Analog to Digital Converter

If only two areas are required, use the same boundary register for boundary A and boundary B. In this case, area II is empty and two result ranges are available. Avoid $LCC = x10_B$ in this case.

Typical applications for limit checking are monitoring tasks (temperature, pressure, current, etc.) where the real value of a result is less important than its range. As long as the measured values are within their defined valid range, no CPU action is required. A channel event should be generated only if the conversion result is outside the valid range to indicate a critical condition (over-temperature, loss of pressure, etc.).

The CPU load is minimized if the conversions of the analog input signals to be monitored are part of an auto-scan sequence autonomously triggered on a regular time base. Under normal conditions the CPU load here is zero.

Note: In the case of an over-current protection, the channel event can be used to disable PWM generation to reduce the current (in the XE166U, an interrupt output line of the ADC module is connected to a corresponding input of the CCU6x units to allow fast reactions without CPU intervention).

Boundary Flag Control

The limit checking mechanism can be configured to automatically control the boundary flags. A boundary flag will be set when the conversions result is within area III, and will be cleared when the conversion result is within area I.

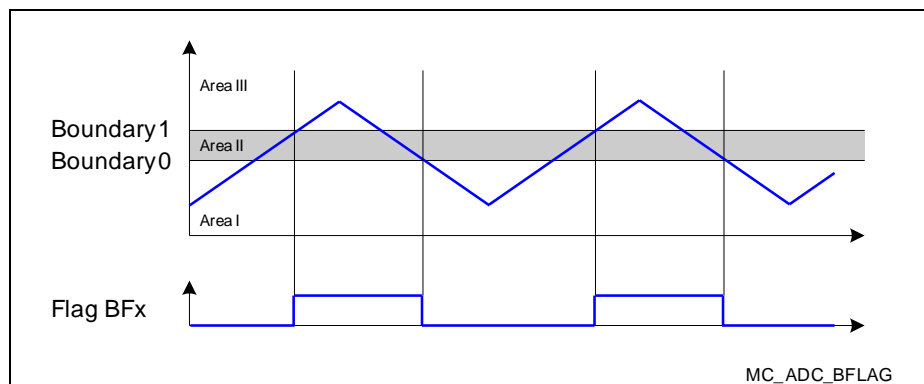


Figure 16-15 Boundary Flag Control

The difference between the two boundary values defines a hysteresis for setting/clearing the boundary flags.

Using this feature on three channels that monitor linear hall elements can produce signals to feed the three hall position inputs of a CCU6x unit.

Analog to Digital Converter

The Limit Check Boundary Registers define compare values (boundaries) for the limit checking unit. The reset values of the boundaries are defined as 10%, 90%, 33% and 66% of the complete result range.

LCBR0

Limit Check Boundary Register 0 XSFR(84_H) **Reset Value: 0198_H**

LCBR1

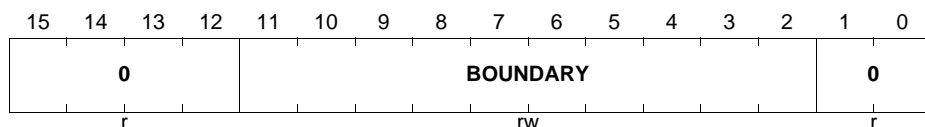
Limit Check Boundary Register 1 XSFR(86_H) **Reset Value: 0E64_H**

LCBR2

Limit Check Boundary Register 2 XSFR(88_H) **Reset Value: 0554_H**

LCBR3

Limit Check Boundary Register 3 XSFR(8A_H) **Reset Value: 0AA8_H**



Field	Bits	Type	Description
BOUNDARY	[11:2]	rw	Boundary for Limit Checking This value is compared to the actual conversion result. ¹⁾
0	[1:0], [15:12]	r	Reserved returns 0 if read; should be written with 0;

- 1) For 8-bit conversion results, bits 2 and 3 of the boundary value are compared with 00_B.
 For 12-bit conversion results, bits 0 and 1 of the result value are compared with 00_B.

Note: The boundary values use the same representation as the result values, i.e. they are left-adjusted on bit 11.

Analog to Digital Converter

The Boundary Flag Control Register holds the boundary flags together with an output enable control bit for each flag.

BFCR

Boundary Flag Control Register XSFR(D4_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BFE	BFE	BFE	BFE	BFE	BFE	BFE	BFE	BFL	BFL	BFL	BFL	BFL	BFL	BFL	BFL
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
rw	rw	rw	rw	rw	rw	rw	rw	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
BFLx (x = 0-7)	x	rwh	Boundary Flag for Channel x 0 _B Result has reached area III but not yet area I 1 _B Result has reached area I but not yet area III
BFE_x (x = 0-7)	x + 8	rw	Enable Bit for Boundary Flag x 0 _B Output 0 on this channel 1 _B Output BFLx on this channel

16.7.3 Alias Feature

The alias feature re-directs conversion requests for channels CH0 or CH1 to other channel numbers. This means that CH0/CH1 are converted with the channel parameters of the referenced channel instead of with their own. The re-direction feature serves several purposes:

- The same signal can be measured twice and the two results (original and re-directed) can be stored in separate result registers. This allows triggering both conversions quickly one after the other while data loss is avoided, independent from the CPU interrupt latency.
 The sensor signal is connected to only one input (instead of two). This can save input pins in low-cost applications and reduces the input leakage to be considered in the error calculation.
- Even if the analog input CH0 is used as alternate reference (see [Figure 16-16](#)), the internal trigger and data handling features for channel CH0 can be used.
- The channel settings for both conversions (of the same signal) can be different in terms of boundary values, interrupts, etc.
- If a queued conversion request source has been set up, a conversion request for channels CH0 or CH1 can be easily re-directed to other input channels without flushing the queue.

Figure 16-16 shows an example where the sensor signal is connected to one input channel (CHx) but two conversions are triggered (for CHx and CH0). The alias feature re-directs the conversion request for CH0 to CHx, but taking into account the settings for CH0. Although the same analog input (CHx) has been measured, the conversion results can be stored and retrieved from result registers RESRx (conversion triggered for CHx) and RESR0 (conversion triggered for CH0). Additionally, different interrupts or limit boundaries can be selected, enabled or disabled.

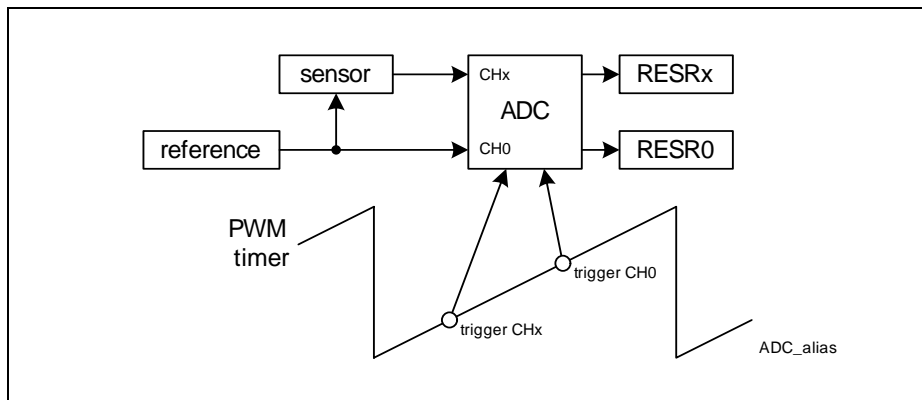


Figure 16-16 Alias Feature

Analog to Digital Converter

In typical low-cost AC-drive applications, only one common current sensor is used to determine the phase currents. Depending on the applied PWM pattern, the measured value has different meanings and the sample points have to be precisely located in the PWM period.

The Alias Register specifies replacement channel numbers for CH0 and CH1, i.e. CH0 and CH1 will use the respective channel numbers when requested.

The programmed alias channel number controls the analog input multiplexer (of the converter). The original channel number controls all other internal actions.

ALR0

Alias Register 0

XSFR(1C_H)

Reset Value: 0100_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			ALIAS1					0			ALIAS0				
r			rw					r			rw				

Field	Bits	Type	Description
ALIAS0	[4:0]	rw	Alias Value for CH0 Conversion Requests Replacement channel number for channel CH0. The conversion is done with the settings defined for CH0.
ALIAS1	[12:8]	rw	Alias Value for CH1 Conversion Requests Replacement channel number for channel CH1. The conversion is done with the settings defined for CH1.
0	[7:5], [15:13]	r	Reserved returns 0 if read; should be written with 0;

16.7.4 Conversion Timing

The total time required for a conversion depends on several user-definable factors:

- The ADC conversion clock frequency, where $f_{\text{ADCI}} = f_{\text{ADC}} / (\text{DIVA}+1)^{1)}$
- The selected sample time, where $t_{\text{S}} = (2 + \text{STC}) \times t_{\text{ADCI}}$
(STC = additional sample time, see also [Section 16.4.3](#))
- The selected result width N (8/10/12 bits)
- The post-calibration time PC, if selected (PC = 2, otherwise 0)
- Synchronization steps done at module clock speed

The conversion time is the sum of sample time, conversion steps, and synchronization. It can be computed with the following formula:

$$t_{\text{CN}} = (2 + \text{STC} + \text{N} + 1 \times \text{PC}) \times t_{\text{ADCI}} + 2 \times t_{\text{ADC}}$$

The frequency at which conversions are triggered also depends on several configurable factors:

- The selected conversion time, according to the input class definitions. For conversions using an external multiplexer, also the extended sample times count.
- Delays induced by cancelled conversions that must be repeated.
- Delays due to equidistant sampling of other channels.
- The configured arbitration cycle time.
- The frequency of external trigger signals, if enabled.

¹⁾ The minimum prescaler factor is 2.

16.7.5 Channel Events and Interrupts

A channel event interrupt can be generated based on a channel event according to the structure shown in **Figure 16-17**. If a channel event is detected, it sets the corresponding indication flag in register **CHINFR**. These flags can also be set by writing a 1 to the corresponding bit position, whereas writing 0 has no effect. The indication flags can be cleared by SW by writing a 1 to the corresponding bit position in register **CHINCR**.

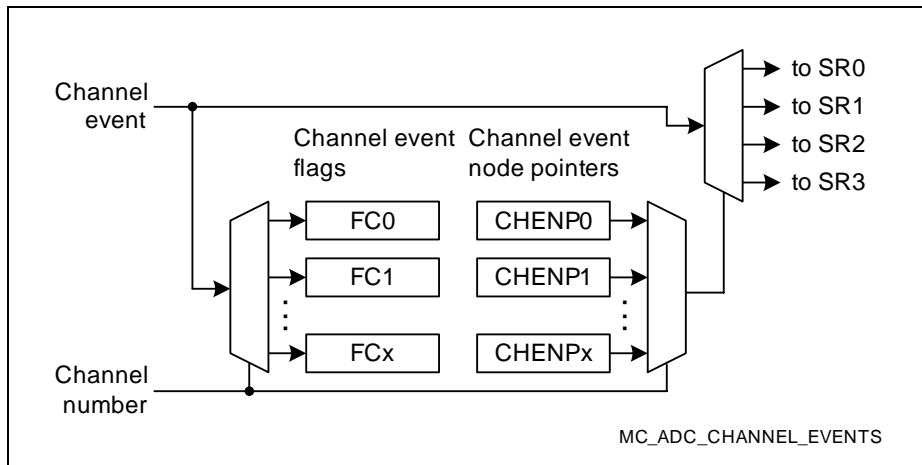


Figure 16-17 Channel Event Interrupt Generation

The service request output line SRx that is selected by the channel node pointer bitfields in registers **CHINPRO** etc., is activated each time the related channel event is detected or the related bit position in register **CHINFR** is written with a 1.

16.8 Conversion Result Handling

The conversion results of each analog input channel can be stored in one of 8 conversion result registers (selected by bitfield RESRSEL in the associated channel control register CHCTR_x). This structure provides different locations for the conversion results of different groups of channels. Depending on the application needs (data reduction, auto-scan, alias feature, result FIFO, etc.), the user can distribute the conversion results to minimize CPU load or to be more tolerant against interrupt latency.

16.8.1 Storage of Conversion Results

Each result register has an individual data valid flag (VF_x) associated with it. This flag indicates when “new” valid data has been stored in the corresponding result register and can be read out.

Depending of the result register read view (see below), the corresponding valid flag is automatically cleared when the result is read or remains set.

- Automatically clearing the valid flag provides an easy handshake between result generation and retrieval. This also supports wait-for-read mode.
- Leaving the valid flag set supports debugging by delivering the result value without disturbing the handshake with the application.

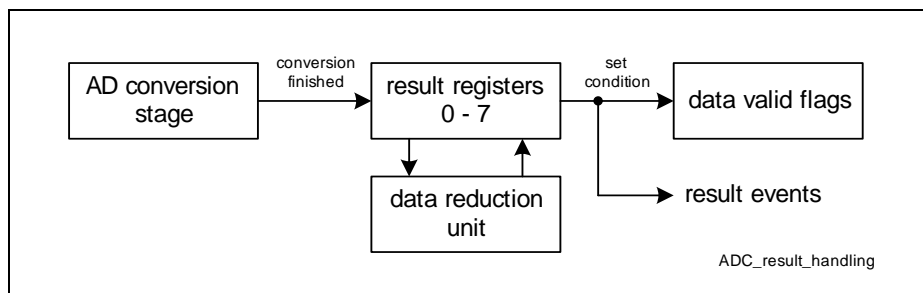


Figure 16-18 Conversion Result Storage

Conversion result handling comprises the following functions:

- Storage of conversion results to user-configurable registers
- Wait-for-read mode to avoid loss of data if several channels share one result register (see [Section 16.8.2](#))
- Result event interrupts (see [Section 16.8.4](#))
- Concatenate result registers to build result FIFO buffers (see [Section 16.8.3](#))
- Data reduction or anti-aliasing filtering (see [Section 16.8.5](#))

Analog to Digital Converter

Up to 4 result values can be added in each result register. This reduces the frequency of interrupts generated by the ADC.

The digital low-pass filter option provides another way of preprocessing the conversion results.

Conversion results are left-aligned on bit 11. Depending on the number of added results, the data width is extended up to bit 13 (or bit 14 if the low-pass filter is enabled).

- Standard application read view **RESRx (x = 0-7)**:
Bits 15-12 indicate the 4 LSBs of the channel number whose conversion triggered the result event.
Bits 11-0 return the result. Reading the result automatically clears the valid flag.
This view is useful only without data reduction.
- Standard debugger read view **RESRVx (x = 0-7)**:
Same as standard application read view, but the corresponding valid bit is not cleared when the result register is read.
- Accumulated application read view **RESRAx (x = 0-7)**:
Returns the accumulated results. No channel number is inserted.
Reading the result automatically clears the valid flag.
- Accumulated debugger read view **RESRAVx (x = 0-7)**:
Same as accumulated standard read view, but the corresponding valid bit is not cleared when the result register is read.

Each result register can be accessed via its 4 different read views, and is associated with a corresponding result control register (**RCRx (x = 0 - 7)**). The valid flags can be read either individually from the corresponding RCRx or altogether from the valid flag register VFR.

The result status shadow register **RSSR** stores the result register number and the channel number of the result value having been read last.

Analog to Digital Converter

The accumulated read views of the result registers deliver the accumulated conversion result generated by the data reduction feature.

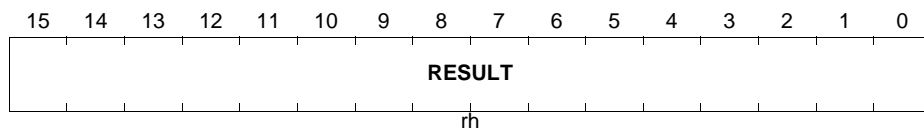
The corresponding valid flag is cleared when register RESRAX is read (application view), whereas it is left unchanged when reading RESRAVx (debugger view).

RESRAx (x = 0-7)

Result Register x, View A **XSFR(50_H + 2 * x)** **Reset Value: 0000_H**

RESRAVx (x = 0-7)

Result Register x, View AV **XSFR(70_H + 2 * x)** **Reset Value: 0000_H**



Field	Bits	Type	Description
RESULT	[15:0]	rh	Conversion Result Sum of accumulated conversion results. The number of valid bits (12/13/14/15) depends on the selected data preprocessing mode.

Analog to Digital Converter

The Result Status Shadow Register is updated when an application view result register is read. It provides result register number and channel number of the most recent read access.

RSSR

Result Status Shadow Register **XSFR(82_H)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		RRNR		0						CHNR					
r		rh		r						rh					

Field	Bits	Type	Description
CHNR	[4:0]	rh	Channel Number Indicates the channel number related to the latest result that has been read out.
RRNR	[14:12]	rh	Result Register Number Indicates the result register for the information stored in CHNR.
0	[11:5], 15	r	Reserved returns 0 if read; should be written with 0;

Note: The accumulated views of the result registers only return the conversion result value. If required, the application can read the channel number from bitfield CHNR after reading RESRAX.

The standard views of the result registers only return the 4 LSBs of the channel number of the last conversion. If required, the complete 5-bit number can be read from bitfield CHNR after reading RESRx.

The Result Control Registers control the behavior of the result registers and monitor their status.

RCRx (x = 0 - 7)

Result Control Register x **XSFR(B0_H + 2 * x)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		VF		0		DRC		0		WFR	FEN	IEN	LPF EN	0	DRCTR
r		rh		r		rh		r	rw	rw	rw	rw	r	rw	

Field	Bits	Type	Description
DRCTR	[1:0]	rw	Data Reduction Control Defines the number of accumulated conversion results for data reduction. The data reduction counter DRC is loaded with this value. 00 _B Accumulate 1 conversion result value (data reduction mode is disabled) 01 _B Accumulate 2 conversion result values 10 _B Accumulate 3 conversion result values 11 _B Accumulate 4 conversion result values
LPFEN	3	rw	Low-Pass Filter Enable 0 _B Standard data reduction, if selected 1 _B Digital low-pass filter operation enabled
IEN	4	rw	Interrupt Enable 0 _B No result event interrupt 1 _B Generate an interrupt upon a result event
FEN	5	rw	FIFO Enable Controls the FIFO functionality for result register x (see Section 16.8.3) 0 _B Standard result register or FIFO input register 1 _B FIFO functionality enabled, i.e. this register builds a part of the FIFO
WFR	6	rw	Wait-for-Read Mode Enables wait-for-read mode for result register x. 0 _B Overwrite mode 1 _B Wait-for-read mode enabled

Field	Bits	Type	Description
DRC	[9:8]	rh	Data Reduction Counter Counts the conversion results still to be accumulated for the final result of the data reduction. The valid flag is set and a result event is generated when this bitfield becomes 0 (by decrementing or by reload). Bitfield DRC can be cleared by writing a 1 to bit position x in register VFR . 00 _B Accumulation complete, the final result is available in the result register 01 _B 1 more result to be added 10 _B 2 more results to be added 11 _B 3 more results to be added
VF	12	rh	Valid Flag Indicates valid contents in result register x. 0 _B No new valid data available 1 _B Result register x contains valid data and has not yet been read This flag can also be read from the general valid flag register VFR-
0	2, 7, [11:10], [15:13]	r	Reserved returns 0 if read; should be written with 0;

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The Valid Flag Register summarizes the flags indicating that the corresponding result register contents are valid. These flags can also be read from the individual result control registers RCRx.

VFR

Valid Flag Register

XSFR(80_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0								VF	VF	VF	VF	VF	VF	VF	VF
								7	6	5	4	3	2	1	0
r								rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
VFx (x = 0 - 7)	x	rwh	Valid Flag for Result Register x Indicates that the contents of result register x is valid, i.e. has been updated but not yet read. Read access: 0 _B No new valid data available 1 _B Result register x contains valid data and has not yet been read Write access: 0 _B No effect 1 _B Clear this valid flag and bitfield DRC in register RCRx (overrides a hardware set action)
0	[15:8]	r	Reserved returns 0 if read; should be written with 0;

16.8.2 Wait-for-Read Mode

The wait-for-read mode is a feature to prevent data loss due to overwriting a result register with a new conversion result before the CPU (or PEC) has read the previous data. For example, auto-scan conversion sequences or other sequences with “relaxed” timing requirements are likely to use the same result register. However, the results come from different input channels, so an overwrite would destroy the result from the previous conversion¹⁾.

Wait-for-read mode automatically suspends the start of a conversion for this channel until the current result has been read. So a conversion or a conversion sequence can be requested by a hardware or software trigger, while each conversion is only started after the previous one has been read. This automatically aligns the conversion sequence with the CPU capability to read the formerly converted result (interrupt latency).

If wait-for-read mode is enabled for a result register (bit WFR = 1 in the corresponding result control register), a request source does not generate a conversion request while the targeted result register contains valid data (indicated by the valid flag VFx = 1) or if a currently running conversion targets the same result register.

If two request sources target the same result register with wait-for-read mode selected, a higher priority source cannot interrupt a lower priority conversion request started before the higher priority source has requested its conversion. Cancel-inject-repeat mode does not work in this case. If the higher priority request targets a different result register, the lower priority conversion can be cancelled and repeated afterwards.

1) Repeated conversions of a single channel that use a separate result register will not destroy other results, but rather update their own previous result value. This way, always the actual signal data is available in the result register.

16.8.3 Result FIFO Buffer

Result registers can either be used as direct target for conversion results (see bitfield RESRSEL in register CHCTR_x) or it can be concatenated with other result registers of the same ADC kernel to form a result FIFO buffer (first-in-first-out buffer mechanism). A result FIFO stores several measurement results that can be read out later with a “relaxed” CPU response timing. It is possible to set up more than one FIFO buffer structure with the available result registers.

Result FIFO structures of two or more registers are built by concatenating result registers to their following “neighbor” result register (see [Figure 16-19](#)) by setting bit RCR_x.FEN = 1.

Conversion results are stored to the register with the highest index of a group. Software reads the values from the register with the lowest index of a group.

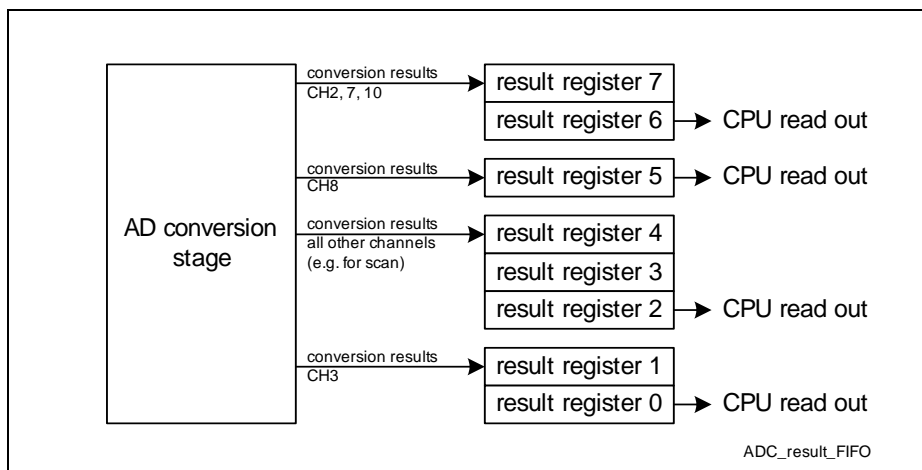


Figure 16-19 Result FIFO Buffers

In the example shown the result registers have been configured in the following way:

- 2-stage buffer consisting of result registers 7-6
- dedicated result register 5
- 3-stage buffer consisting of result registers 4-3-2
- 2-stage buffer consisting of result registers 1-0

Table 16-3 summarizes the required configuration of result registers if they are combined to build result FIFO buffers.

Table 16-3 Properties of Result FIFO Registers

Function	Input Stage	Intermed. Stage	Output Stage
Result target	YES	no	no
Application read	no	no	YES
Data reduction mode	YES	no	no
Wait-for-read mode	YES	no	no
Result event interrupt	no	no	YES
FIFO enable bit (FEN)	0	1	1
Registers in example	7, 4, 1	3	6, 2, 0

Note: If enabled, a result interrupt is generated for each data word in the FIFO.

16.8.4 Result Events and Interrupts

A result event interrupt can be generated based on a result event according to the structure shown in **Figure 16-20**. If a result event is detected, it sets the corresponding indication flag in register **EVINFR**. These flags can also be set by writing a 1 to the corresponding bit position, whereas writing 0 has no effect. The indication flags can be cleared by SW by writing a 1 to the corresponding bit position in register **EVINCR**.

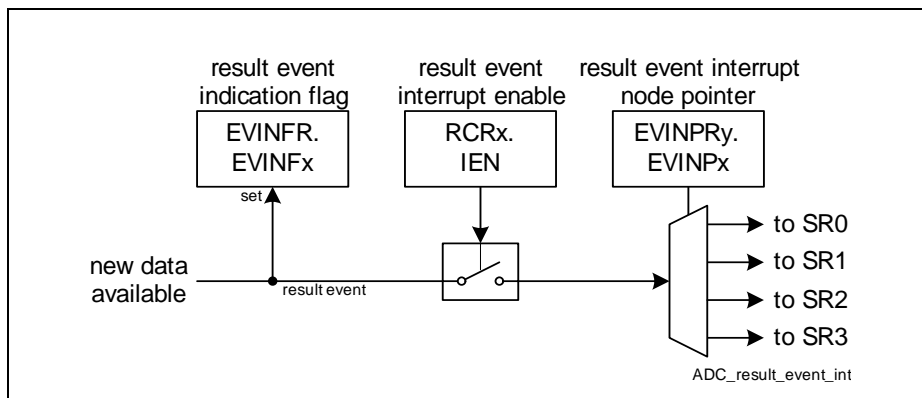


Figure 16-20 Result Event Interrupt Generation

The service request output line SRx that is selected by the result event interrupt node pointer bitfields in registers **EVINPR8** or **EVINPR12** issues an interrupt each time the related result event is detected or the related bit position in register **EVINFR** is written with a 1.

The result events and the request source events share the same registers. The result events are located at the following bit positions in register **EVINFR**:

- Event 8: Result event of result register 0.
- Event 9: Result event of result register 1.
- ...
- Event 15: Result event of result register 7.

16.8.5 Data Reduction and Filtering

Data reduction automatically accumulates a series of conversion results before generating a result interrupt. This can remove some noise from the input signal and reduces the CPU load required to unload the conversion data from the ADC.

The standard data reduction mode accumulates result values within arbitrary result registers.

The enhanced data reduction filter additionally pre-processes the result values by applying filter algorithms (such as moving average).

Standard Data Reduction Mode

The data reduction mode can be used as digital filter for anti-aliasing or decimation purposes. It accumulates a maximum of 4 conversion results to generate a final result.

Each result register can be individually enabled for data reduction, controlled by bitfield DRCTR in registers **RCRx** ($x = 0 - 7$). The data reduction counter DRC indicates the actual status of the accumulation.

Note: Conversions for other result registers can be inserted between conversions to be accumulated.

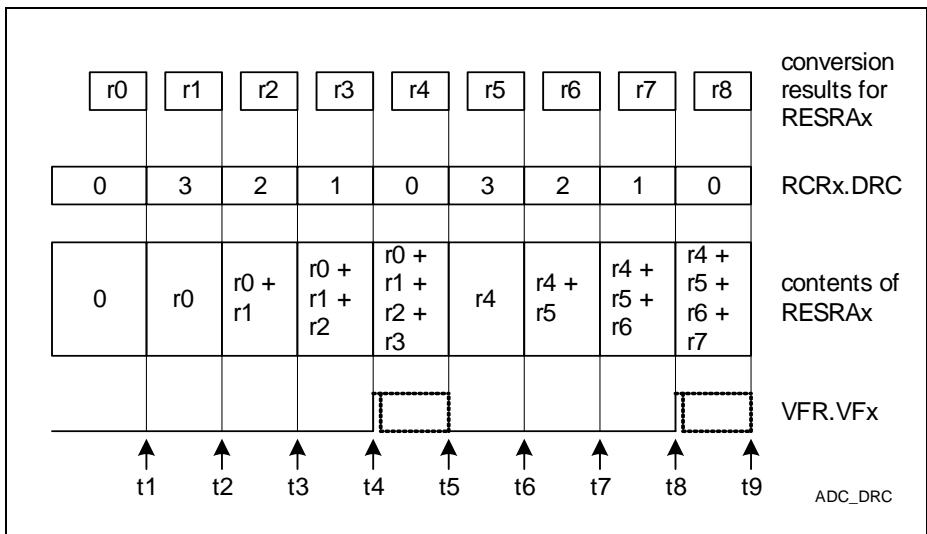


Figure 16-21 Standard Data Reduction Filter

This example shows a data reduction sequence of 4 accumulated conversion results. Eight conversion results (r0 ... r7) are accumulated and produce 2 final results.

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When a conversion is complete and stores data to a result register that has data reduction mode enabled, the data handling is controlled by the data reduction counter DRC:

- If $DRC = 0$ (t_1 , t_5 , t_9 in the example), the conversion result is stored to the register. DRC is loaded with the contents of bitfield RCRx.DRCTR (i.e. the accumulation begins).
- If $DRC > 0$ (t_2 , t_3 , t_4 and t_6 , t_7 , t_8 in the example), the conversion result is added to the value in the result register. DRC is decremented by 1.
- If DRC becomes 0, either decremented from 1 (t_4 and t_8 in the example) or loaded from DRCTR, the valid bit for the respective result register is set and a result register event occurs.

The final result must be read before the next data reduction sequence starts (before t_5 or t_9 in the example). This automatically clears the valid flag.

Note: Software can clear the data reduction counter DRC by clearing the corresponding valid Flag (via [VFR](#)).

The response time to read the final data reduction results can be increased by associating the adjacent result register to build a result FIFO (see [Figure 16-22](#)). In this case, the final result of a data reduction sequence is loaded to the adjacent register. The value can be read from this register until the next data reduction sequence is finished (t_8 in the 2nd example).

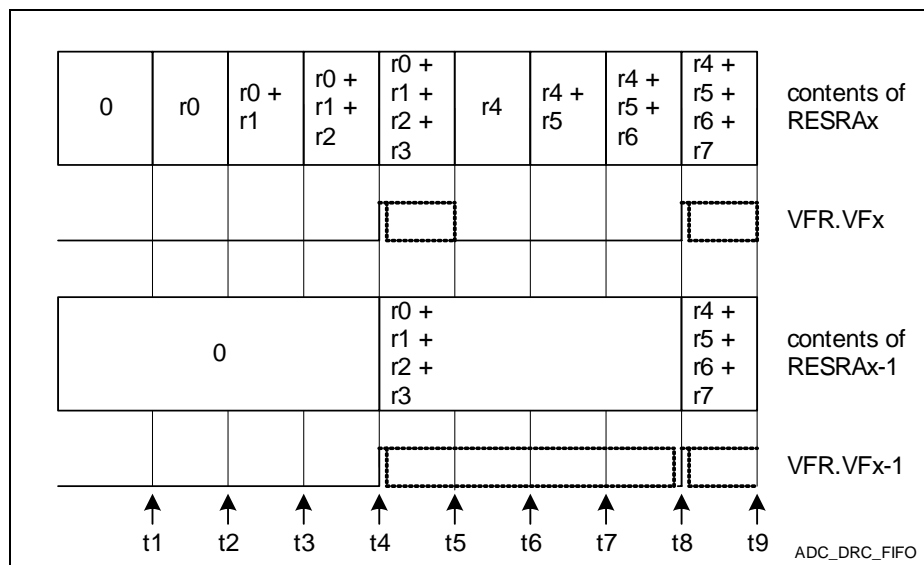


Figure 16-22 Standard Data Reduction Filter with Result FIFO

Digital Low-Pass Filter

Alternatively, the data reduction logic can build a digital low-pass filter by adding the amplified result (factor 4) to the attenuated current value (factor 0.5).

Each result register can be individually enabled for low-pass filtering, controlled by bitfield LPFEN in registers **RCR_x (x = 0 - 7)**. The data reduction counter DRC is not used in this case.

Note: For low-pass filtering, the result data must come from one dedicated channel.

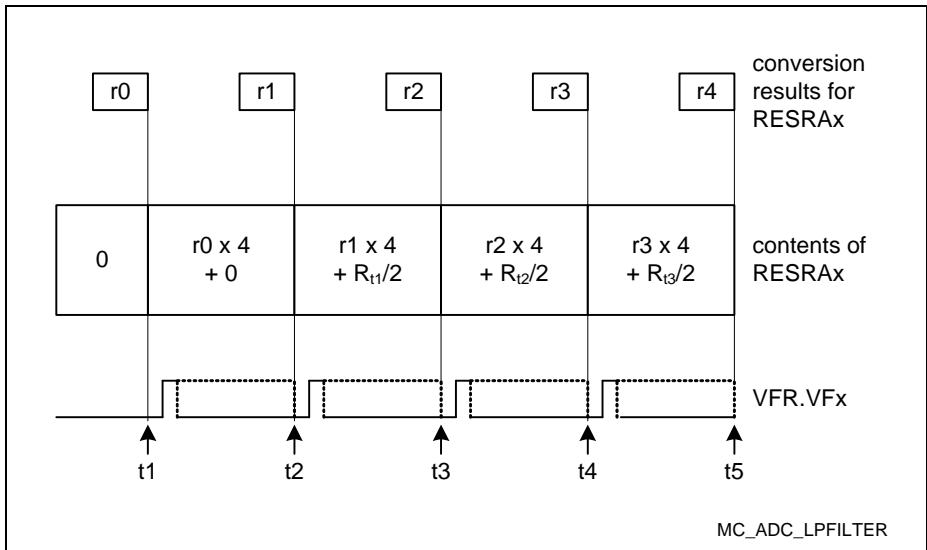


Figure 16-23 Low-Pass Filter Operation

Each result is multiplied by 4 and added to half the previous register value. The valid flag is activated after the addition.

16.9 Synchronization of Conversions

The conversions of an ADC kernel can be scheduled either self-timed according to the kernel's configuration or triggered by external (outside the ADC) signals:

Equidistant sampling supports conversions in a fixed raster with minimum jitter. This optimizes e.g. filter algorithms or audio applications.

16.9.1 Equidistant Sampling

To optimize the input data e.g. for filter or audio applications, conversions can be executed in a fixed timing raster. Conversions for equidistant sampling are triggered by an external signal (e.g. a timer). To generate the trigger signal synchronous to the arbiter, the ADC provides an output signal (ARBCNT) that is activated once per arbitration round and serves as timing base for the trigger timer. In this case, the arbiter must run permanently (GLOBCTR.ARB_M = 0). If the timer has an independent time base, the arbiter can be stopped while no requests are pending. The preface time must be longer than one arbitration round.

Select timer mode (RSIRx.TMEN = 1) for the intended source of equidistant conversions. In timer mode, a request of this source is triggered and arbitrated, but only started when the trigger signal is removed (see [Figure 16-24](#)) and the converter is idle.

To ensure that the converter is idle and the start of conversion can be controlled by the trigger signal, the equidistant conversion requests must receive highest priority. The preface time between request trigger and conversion start must be long enough for a currently active conversion to finish.

The frequency of signal REQTRx defines the sampling rate and its high time defines the preface time interval where the corresponding request source takes part in the arbitration.

Depending on the used request source, equidistant sampling is also supported for a sequence of channels. It is also possible to do equidistant sampling for more than one request source in parallel if the preface times and the equidistant conversions do not overlap.

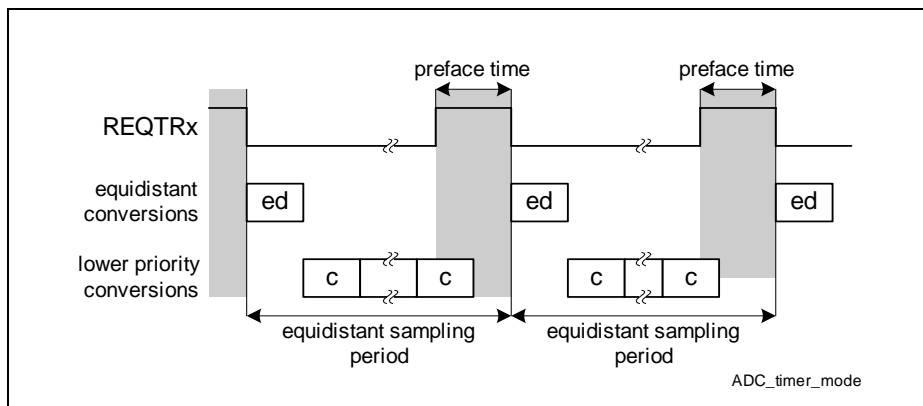


Figure 16-24 Timer Mode for Equidistant Sampling

16.10 Safety Features

Safety-aware applications must ensure that their analog signal inputs are safely connected to the respective signal sources. Two mechanisms are provided to check conversion results for plausibility:

- **Broken Wire Detection** pre-loads the capacitance of the converter to a selectable value. If the signal source is disconnected, the pre-load value will be converted instead of the source signal.
- **Multiplexer Test Mode** intermediately connects a pulldown device to an input channel. Conversions results can then be compared to result without pulldown.

16.10.1 Broken Wire Detection

To support self-test in safety-aware applications, the broken wire detection mechanism helps to check the connection of sensors or other voltage sources to the analog ADC inputs.

Broken wire detection can be individually enabled for each input channel CHx by setting bit ENx = 1 in register **BWDENR** or **BWDENRE**. If enabled, a preparation phase is added before each conversion of an input channel, which pre-loads the capacitor field C_{AIN} to a selectable level before sampling and converting this channel.

For pre-loading an arbitrary channel can be selected (defined by **BWDCFG**.CHP). Broken wire detection preferably uses V_{AGND} and/or V_{AREF} , to use the maximum or the minimum voltage of the measurement range. These reference voltages can be selected via special channel numbers, see **“Analog Connections” on Page 16-110**.

The broken wire detection mechanism applies a voltage outside the expected result value range of the connected sensor. If the actual digital conversion result is located outside the expected measurement range (e.g. by using limit checking) with enabled broken wire detection, a defective connection has been detected. It is recommended to ensure enough margin between the voltage applied during the preparation phase and the sensors output range to minimize the effects of parasitics and leakage.

Note: The length of the complete analog to digital conversion is increased by the length of the preparation phase (same as the sample phase) if the broken wire detection is enabled. This influences the timing of conversion sequences.

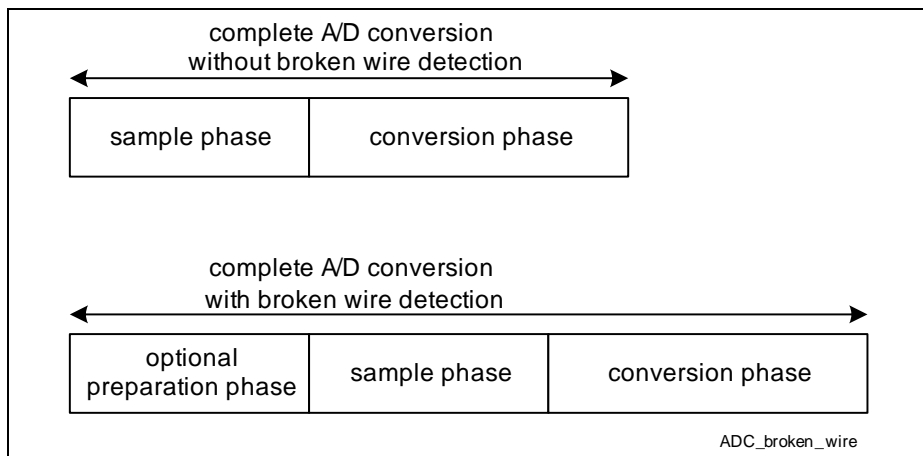


Figure 16-25 Broken Wire Detection

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The Broken Wire Detection Enable Register selects broken wire detection for channels CH15 ... CH0. The channel used for the preparation phase is selected in register **BWDCFGR**.

BWDENR

Broken Wire Detection Enable Reg. XSFR(C8_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN 15	EN 14	EN 13	EN 12	EN 11	EN 10	EN 9	EN 8	EN 7	EN 6	EN 5	EN 4	EN 3	EN 2	EN 1	EN 0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
ENx (x = 0 - 15)	x	rw	Broken Wire Detection Enable for Channel CHx 0 _B Normal operation 1 _B Broken wire detection is enabled (pre-load)

The Broken Wire Detection Enable Register Extended selects broken wire detection for channels CH21 ... CH16. The channel used for the preparation phase is selected in register **BWDCFGR**.

BWDENRE

Broken Wire Detection Enable Register Extended

XSFR(210_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0										EN 21	EN 20	EN 19	EN 18	EN 17	EN 16
r										rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
ENx (x = 16 - 21)	x-16	rw	Broken Wire Detection Enable for Channel CHx 0 _B Normal operation 1 _B Broken wire detection is enabled (pre-load)
0	[15:6]	r	Reserved returns 0 if read; should be written with 0;

Note: Not all channels are available in all products.

Therefore, only the BWD enable bits with corresponding channels are valid.

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The Broken Wire Detection Configuration Register selects a channel for the additional preparation phase.

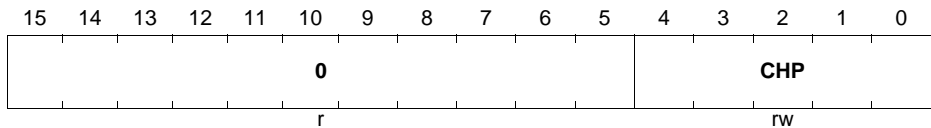
The channels for which broken wire detection is active, are selected via register **BWDENR** and **BWDENRE**.

BWDCFGR

Broken Wire Detection Configuration Register

XSFR(CA_H)

Reset Value: 0000_H



Field	Bits	Type	Description
CHP	[4:0]	rw	Channel Number for Preparation Phase Defines the channel to be used for the preparation phase for the broken wire detection.
0	[15:5]	r	Reserved returns 0 if read; should be written with 0;

16.10.2 Multiplexer Test Mode

Multiplexer test mode is a specific test mode that can be enabled during run time to check the connection to the respective sensor. This is done by connecting a static load R_{MTM} to the selected input channel. The resulting voltage divider reduces the measured voltage by placing an additional load on that channel.

The test result to be expected results from the source impedance and previous result data without pulldown.

Multiplexer test mode for channel 7 is enabled by setting bit MTM7 in register **EMENR**.

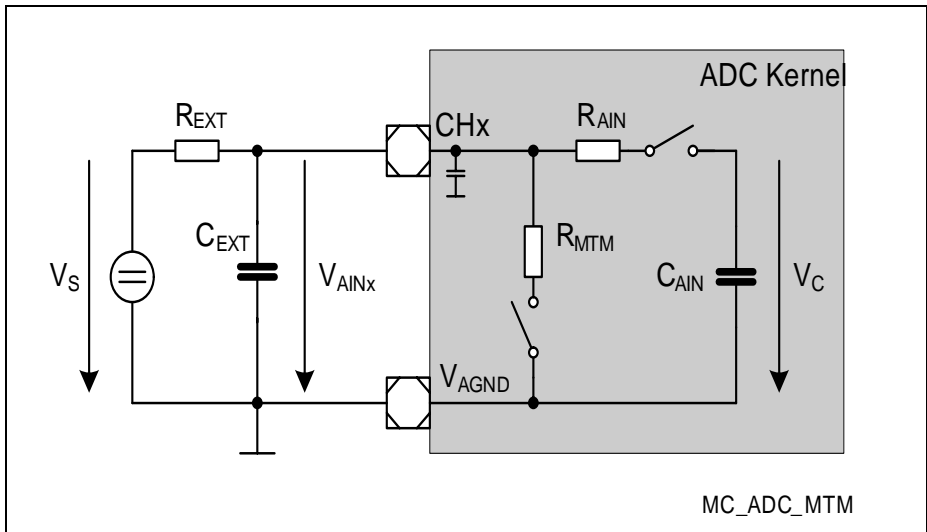


Figure 16-26 Multiplexer Test Mode

16.11 External Multiplexer Control

If an application requires more analog inputs channels than available on the XE166U, external analog multiplexers can be added to extend the number of analog channels. The three output signals EMUX[2:0] can control 1-out-of-8 external multiplexers.

Registers **EMCTR** and **EMENR** configure the control behavior of the external multiplexers. Bitfield EMUX selects the actual external channel. This selection can either be controlled by software (write to bitfield SETEMUX, applied with next conversion start) or automatically by the scan function.

The external multiplexer support can be enabled for each available input channel and supports several modes (selected in register **EMENR**):

- **Software control** without any HW control (EMUXEN = 0):
Automatic control of the external multiplexer is disabled, bitfield EMUX is always updated by write actions to bitfield SETEMUX. Bitfield EMSAMPLE has no effect on the sample time.
- **Hardware control without scan** (EMUXEN = 1, SCANEN = 0):
Bitfield EMUX is updated from bitfield SETEMUX with each conversion start of the channel selected by EMUXCHNR. Bitfield EMSAMPLE controls the sample time for the first conversion with a new EMUX value.
- **Hardware control with scan** (EMUXEN = 1, SCANEN = 1):
Bitfield EMUX is updated after each conversion of the channel selected by EMUXCHNR. If EMUX = 0 it is reloaded from bitfield SETEMUX, otherwise it is decremented by 1. Bitfield EMSAMPLE controls the sample time for each conversion of the selected channel. Two multiplexer control schemes can be selected:
 - **Single-input scan** (TROEN = 0):
An autoscan sequence converting the channel selected by EMUXCHNR leads to one conversion of the multiplexed channel (trigger option disabled). Bitfield EMUX is update for each completed auto scan sequence.
The scan sequence in the example (**Figure 16-27**, assuming SETEMUX = 010_B) is:
4-32-2-1-0--4-31-2-1-0--4-30-2-1-0--4-32-2-1-0--...
 - **Multi-input scan** (TROEN = 1):
When the channel selected by EMUXCHNR is converted, a new conversion request is triggered as long as bitfield EMUX > 0. In a scan request source, this sets the corresponding pending bit. In a queued request source, this sets the valid bit of the backup stage.
All inputs of the external multiplexer are scanned during a single autoscan sequence, beginning with the channel selected by bitfield SETEMUX.
The scan sequence in the example (**Figure 16-27**, assuming SETEMUX = 010_B) is:
4-32-31-30-2-1-0--4-32-31-30-2-1-0--...

Note: It is recommended to write the start value of the first scan sequence to SETEMUX while EMUXEN = 0.

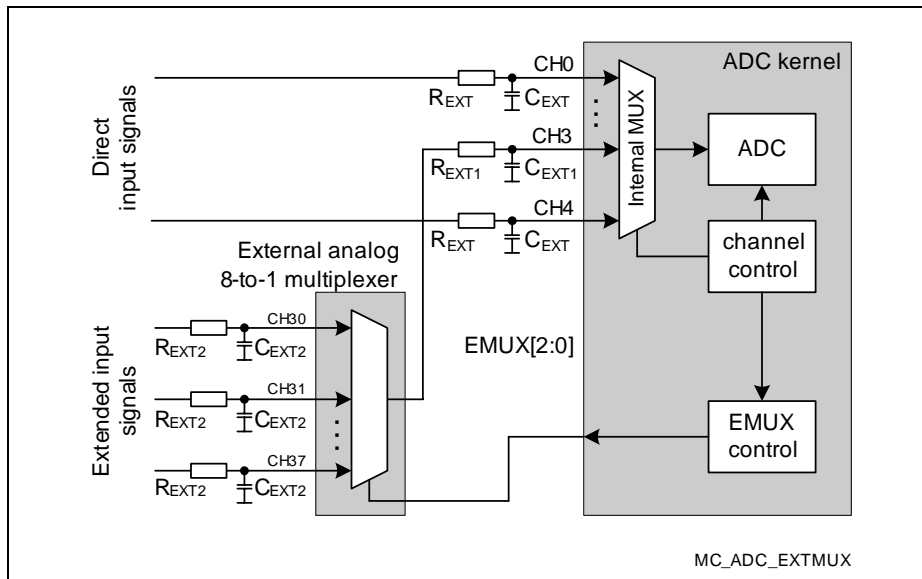


Figure 16-27 External Analog Multiplexer Example

In the shown example, an external multiplexer is connected to channel CH3 (the additional analog inputs are designated CH30 ... CH37).

Many applications will use buffer capacitors or even RC filters on the analog inputs. If an external multiplexer is used, local filters are likely to be placed at its inputs ($R_{EXT2} \cdot C_{EXT2}$ on CH3x in [Figure 16-27](#)). For applications where the external multiplexer is located far from the ADC analog input, it is recommended to add an RC filter directly at the analog input of the ADC ($R_{EXT1} \cdot C_{EXT1}$ on CH3 in [Figure 16-27](#)).

Note: Each RC filter limits the bandwidth of the analog input signal.

The RC filters used with an external multiplexer change the impedance for the corresponding analog input channel, compared to other channels. This can be compensated by using another input class selecting a longer sample phase. The sample phase must be long enough to let the input signal settle.

When the external multiplexer switches (EMUX[2:0] changes), the required sample time to let the input settle is even longer. This is automatically compensated by applying the alternative sample phase length (selected by bitfield [EMCTR.EMSAMPLE](#)) instead of the one given by the input class for the first conversion after EMUX[2:0] has changed. If

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this first conversion is aborted due to a higher priority request, the repeated conversion also uses the value of EMSAMPLE.

The External Multiplexer Enable Register defines which analog input channel is used to control the settings of an external analog multiplexer and defines its operating mode. It also contains bit MTM7 to control the multiplexer test mode for CH7.

EMENR

External Multiplexer Enable Register

XSFR(D6_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MTM7				0				EMUXEN	SCANEN	TROEN			EMUXCHNR		
rw				r				rw	rw	rw			rw		

Field	Bits	Type	Description
EMUXCHNR	[4:0]	rw	Channel Number for External Multiplexer Selects the input channel for which an external multiplexer shall be controlled (if enabled, i.e. EMUXEN = 1). <i>Note: Not all channels are available in all products.</i>
TROEN	5	rw	Trigger Option Enable Selects the scan mode behavior of the external multiplexer (if enabled). 0 _B Single-input scan: convert one external channel per scan sequence 1 _B Multi-input scan: convert a series of external channels per scan sequence
SCANEN	6	rw	Scan Enable Enables the automatic handling of the external multiplexer during scan sequences. 0 _B Hardware control without scan 1 _B Hardware control with scan: bitfield EMUX is automatically modified during scan sequences

Field	Bits	Type	Description
EMUXEN	7	rw	External Multiplexer Control Enable Enables the automatic control of the external multiplexer. 0_B Software control: an external multiplexer is controlled by software only 1_B Hardware control: the external multiplexer is automatically controlled by the ADC's hardware
MTM7	15	rw	Multiplexer Test Mode CH7 Enables the multiplexer test mode for input CH7 0_B No multiplexer test mode 1_B Multiplexer test mode is enabled
0	[14:8]	r	Reserved Read as 0; should be written with 0.

The External Multiplexer Control Register controls an external analog multiplexer and defines the alternative sample phase length for external conversions.

EMCTR

External Multiplexer Control Register

XSFR(D0_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EMSAMPLE								0	EMUX			0	SETEMUX		
rw								r	rh			r	rw		

Field	Bits	Type	Description
SETEMUX	[2:0]	rw	Setting of External Multiplexer Defines the update value for bitfield EMUX. The update options depend on the selected operating mode.
EMUX	[6:4]	rh	Current Setting for External Multiplexer Selects an input on the external multiplexer via outputs EMUX[2:0]. Bitfield EMUX is updated from bitfield SETEMUX. The update options depend on the selected operating mode.

Field	Bits	Type	Description
EMSAMPLE	[15:8]	rw	External Multiplexer Sampling Time Defines the alternative sample phase length for external multiplexer control. This value replaces the standard sample time configuration (STC in register INPCR _x , Page 16-58) for conversions where the external multiplexer setting has changed.
0	3, 7	r	Reserved returns 0 if read; should be written with 0;

16.12 Interrupt Request Handling

Interrupts can be generated by several types of events. The ADC kernel provides 4 independent service request output signals (ADCx_SR[3:0]) connected to interrupt nodes. Three types of events can generate interrupt requests:

- **Request source events:** indicate that a request source completed the requested conversion sequence. For a scan source, the event is generated when the complete defined set of channels has been arbitrated. For a sequential source, the user can define where inside a conversion sequence a request source event is generated. Request source events indicate that a conversion sequence has reached a defined state and software can access the related set of results.
- **Channel events:** indicate that a conversion is finished. Optionally, channel events can be generated only for conversion result within a programmable value range. Channel events preferably indicate analog input values inside or outside a nominal operating range. This offloads the CPU load from background tasks, i.e. an interrupt is only required if the specified conversion result range is met or exceeded.
- **Result events:** indicate a new valid result in a result register. Usually, this triggers a read action by the CPU (or PEC). Optionally, result events can be generated only at a reduced rate if data reduction or enhanced filtering is active. Using a result FIFO increases the tolerable CPU (PEC) interrupt latency for retrieving the result data. For example, a single PEC channel can read the results for a complete auto-scan sequence, if all channels of the sequence target the same result register and the transfers are triggered by result events.

Each ADC event is indicated by a dedicated flag that can be cleared by software. If an interrupt is enabled for a certain event, the interrupt is generated for each event, independent of the status of the corresponding event indication flag. This ensures efficient PEC handling of ADC events (the ADC event can generate an interrupt without the need to clear the indication flag).

Node pointers assign each events to one of the 4 service request output signals SRx. Depending on the relevance of the event for the application, ADC events can be grouped to the service requests. Less important events can share an interrupt node, more important events can be assigned to a dedicated interrupt node.

Note: A conversion can lead to three interrupts, one of each type, if all are enabled.

In this case, the ADC module first triggers the request source event interrupt, then the channel event interrupt, followed by the result event interrupt (all within a few f_{ADC} clock cycles).

Request source events and result events are both handled with a set of event indication registers. Channel events are handled by a separate set of channel event registers.

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The Event Indication Flag Register EVINFR monitors both the detected request source events (flags EVINF0 - EVINF2) and the result events (flags EVINF8 - EVINF15).

EVINFR

Event Indication Flag Register XSFR(A0_H) Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EVIN F15	EVIN F14	EVIN F13	EVIN F12	EVIN F11	EVIN F10	EVIN F9	EVIN F8			0			EVIN F2	EVIN F1	EVIN F0
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh			r			rwh	rwh	rwh

Field	Bits	Type	Description
EVINF_x (x = 0 - 2)	x	rwh	Event Indication Flag for Request Source x Indicates a request source event from source x. 0 _B No source request event 1 _B Source x has generate a request source event
EVINF_x (x = 8 - 15)	x	rwh	Event Indication Flag for Result Register x - 8 Indicates a result event from result register x-8. 0 _B No result event 1 _B Result register x-8 has generated a result event
0	[7:3]	r	Reserved returns 0 if read; should be written with 0;

Note: Writing 1 to a bit of this register sets the corresponding bit and generates the associated interrupt request. Writing a 0 has no effect.

*Bits of register EVINFR can be cleared by writing to the corresponding bits of register **EVINCR**.*

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Writing a 1 to a bit position in the Event Indication Clear Register EVINCR clears the corresponding event indication flag EVIN_{Fx} in register **EVINFR**. If a request source or result event is detected when the corresponding bit position is written with a 1, flag EVIN_{Fx} is cleared.

EVINCR

Event Indication Clear Register **XSFR(A2_H)** **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EVIN C15	EVIN C14	EVIN C13	EVIN C12	EVIN C11	EVIN C10	EVIN C9	EVIN C8			0			EVIN GF2	EVIN GF1	EVIN GF0
w	w	w	w	w	w	w	w			r			rwh	rwh	rwh

Field	Bits	Type	Description
EVINGF_x (x = 0 - 2)	x	rwh	Event Indication Gated Flag for Request Src. x Read access: 0 _B No source event interrupt request 1 _B A service request output has been activated due to an event of request source x. <i>Note: Advantageous to indicate the last conversion of queued sequence.</i> Write access: 0 _B No action 1 _B Bits EVIN _{Fx} and EVINGF _x are cleared
EVINC_x (x = 8 - 15)	x	w	Clear Event Indication Flag for Result Reg. x-8 0 _B No action 1 _B Bit EVIN _{Fx} is cleared
0	[7:3]	r	Reserved returns 0 if read; should be written with 0;

Analog to Digital Converter

The Channel Event Indication Flag Register CHINFR and the Channel Event Indication Flag Register Extended CHINFRE monitors the detected channel events for channels 0 ... 15 and channels 16 ... 21.

CHINFR

Channel Event Indication Flag Register XSFR(90_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CHIN F15	CHIN F14	CHIN F13	CHIN F12	CHIN F11	CHIN F10	CHIN F9	CHIN F8	CHIN F7	CHIN F6	CHIN F5	CHIN F4	CHIN F3	CHIN F2	CHIN F1	CHIN F0
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
CHINFR_x (x = 0 - 15)	x	rwh	Channel x Event Indication Flag Indicates a channel event for channel x. 0 _B No channel event 1 _B Channel x has generated a channel event

CHINFRE

Channel Event Indication Flag Register Extended

XSFR(200_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0										CHIN F21	CHIN F20	CHIN F19	CHIN F18	CHIN F17	CHIN F16
r										rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
CHINFR_x (x = 16 - 21)	x-16	rwh	Channel x Event Indication Flag Indicates a channel event for channel x. 0 _B No channel event 1 _B Channel x has generated a channel event
0	[15:6]	r	Reserved returns 0 if read; should be written with 0;

Note: Writing 1 to a bit of this register sets the corresponding bit and generates the associated interrupt request. Writing a 0 has no effect.

*Bits of register CHINFR or CHINFRE can be cleared by writing to the corresponding bits of register **CHINCR** or **CHINCRE**.*

Analog to Digital Converter

Writing a 1 to a bit position in the channel indication clear register CHINCR or CHINCRE clears the corresponding channel event indication flag CHINFR in register **CHINFR** or **CHINFRE**. If a channel event is detected when the corresponding bit position is written with a 1, flag CHINFRx is cleared.

CHINCR

Channel Event Indication Clear Register

XSFR(92_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CHIN C15	CHIN C14	CHIN C13	CHIN C12	CHIN C11	CHIN C10	CHIN C9	CHIN C8	CHIN C7	CHIN C6	CHIN C5	CHIN C4	CHIN C3	CHIN C2	CHIN C1	CHIN C0
W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W

Field	Bits	Type	Description
CHINCRx (x = 0 - 15)	x	w	Clear Channel Indication Flag 0 _B No action 1 _B Flag CHINFR.x is cleared

CHINCRE

Channel Event Indication Clear Register Extended

XSFR(202_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0										CHIN C21	CHIN C20	CHIN C19	CHIN C18	CHIN C17	CHIN C16
r										W	W	W	W	W	W

Field	Bits	Type	Description
CHINCRx (x = 16 - 21)	x-16	w	Clear Channel Indication Flag 0 _B No action 1 _B Flag CHINFR.x is cleared
0	[15:6]	r	Reserved returns 0 if read; should be written with 0;

Note: Not all channels are available in all products.

Therefore, only the indication flags and clear bits with corresponding channels are valid.

Analog to Digital Converter

Interrupt node pointers assign an event to one of the 4 service requests of an ADC kernel. The grouping of events for a certain service request can, therefore, be configured according to the requirements of a given application.

The Event Interrupt Node Pointer Register 0 assigns the request source events to a service request output SR[3:0].

EVINPR0

Event Interrupt Node Pointer Register 0

XSFR(A8_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						EVINP2		0		EVINP1		0		EVINP0	
r						rw		r		rw		r		rw	

Field	Bits	Type	Description
EVINP0, EVINP1, EVINP2	[1:0], [5:4], [9:8]	rw	Interrupt Node Pointer for Request Source x Selects a service request output for an event of request source x. 00 _B Assign to output SR0 ... 11 _B Assign to output SR3
0	[3:2], [7:6], [15:10]	r	Reserved returns 0 if read; should be written with 0;

Analog to Digital Converter

The Event Interrupt Node Pointer Registers 8 and 12 assign the result events to a service request output SR[3:0].

EVINPR8

Event Interrupt Node Pointer Register 8

XSFR(AC_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	EVINP11	0	EVINP10	0	EVINP9	0	EVINP8								
r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw

Field	Bits	Type	Description
EVINP8, EVINP9, EVINP10, EVINP11	[1:0], [5:4], [9:8], [13:12]	rw	Interrupt Node Pointer for Result Event x-8 Selects a service request output for an event of request register x-8. 00 _B Assign to output SR0 ... 11 _B Assign to output SR3
0	[3:2], [7:6], [11:10], [15:14]	r	Reserved returns 0 if read; should be written with 0;

EVINPR12

Event Interrupt Node Pointer Register 12

XSFR(AE_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	EVINP15	0	EVINP14	0	EVINP13	0	EVINP12								
r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw

Field	Bits	Type	Description
EVINP12, EVINP13, EVINP14, EVINP15	[1:0], [5:4], [9:8], [13:12]	rw	Interrupt Node Pointer for Result Event x-8 Selects a service request output for an event of request register x-8. 00 _B Assign to output SR0 ... 11 _B Assign to output SR3
0	[3:2], [7:6], [11:10], [15:14]	r	Reserved returns 0 if read; should be written with 0;

Analog to Digital Converter

The Channel Interrupt Node Pointer Registers assign each channel event to a service request output SR[3:0].

CHINPR0

Channel Intr. Node Pointer Reg. 0 XSFR(98_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	CHINP3		0	CHINP2		0	CHINP1		0	CHINP0		0	CHINP0		
r	rw		r	rw		r	rw		r	rw		r	rw		

Field	Bits	Type	Description
CHINP0, CHINP1, CHINP2, CHINP3	[1:0], [5:4], [9:8], [13:12]	rw	Interrupt Node Pointer for Channel x Selects a service request output for a channel event from channel x. 00 _B Assign to output SR0 ... 11 _B Assign to output SR3
0	[3:2], [7:6], [11:10], [15:14]	r	Reserved returns 0 if read; should be written with 0;

CHINPR4

Channel Intr. Node Pointer Reg. 4 XSFR(9A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	CHINP7		0	CHINP6		0	CHINP5		0	CHINP4		0	CHINP4		
r	rw		r	rw		r	rw		r	rw		r	rw		

Field	Bits	Type	Description
CHINP4, CHINP5, CHINP6, CHINP7	[1:0], [5:4], [9:8], [13:12]	rw	Interrupt Node Pointer for Channel x Selects a service request output for a channel event from channel x. 00 _B Assign to output SR0 ... 11 _B Assign to output SR3

Field	Bits	Type	Description
0	[3:2], [7:6], [11:10], [15:14]	r	Reserved returns 0 if read; should be written with 0;

CHINPR8

Channel Intr. Node Pointer Reg. 8 XSFR(9C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	CHINP11	0	CHINP10	0	CHINP9	0	CHINP8	0	CHINP7	0	CHINP6	0	CHINP5	0	CHINP4
r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw

Field	Bits	Type	Description
CHINP8, CHINP9, CHINP10, CHINP11	[1:0], [5:4], [9:8], [13:12]	rw	Interrupt Node Pointer for Channel x Selects a service request output for a channel event from channel x. 00 _B Assign to output SR0 ... 11 _B Assign to output SR3
0	[3:2], [7:6], [11:10], [15:14]	r	Reserved returns 0 if read; should be written with 0;

CHINPR12

Channel Interrupt Node Pointer Register 12

XSFR(9E_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	CHINP15	0	CHINP14	0	CHINP13	0	CHINP12	0	CHINP11	0	CHINP10	0	CHINP9	0	CHINP8
r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw

Field	Bits	Type	Description
CHINP12, CHINP13, CHINP14, CHINP15	[1:0], [5:4], [9:8], [13:12]	rw	Interrupt Node Pointer for Channel x Selects a service request output for a channel event from channel x. 00 _B Assign to output SR0 ... 11 _B Assign to output SR3
0	[3:2], [7:6], [11:10], [15:14]	r	Reserved returns 0 if read; should be written with 0;

CHINPR16

Channel Interrupt Node Pointer Register 16

XSFR(208_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	CHINP19	0	CHINP18	0	CHINP17	0	CHINP16	0	CHINP15	0	CHINP14	0	CHINP13	0	CHINP12
r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw	r	rw

Field	Bits	Type	Description
CHINP16, CHINP17, CHINP18, CHINP19	[1:0], [5:4], [9:8], [13:12]	rw	Interrupt Node Pointer for Channel x Selects a service request output for a channel event from channel x. 00 _B Assign to output SR0 ... 11 _B Assign to output SR3
0	[3:2], [7:6], [11:10], [15:14]	r	Reserved returns 0 if read; should be written with 0;

CHINPR20

Channel Interrupt Node Pointer Register 20

XSFR(20A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0										CHINP21		0		CHINP20	
r										rw		r		rw	

Field	Bits	Type	Description
CHINP20, CHINP21	[1:0], [5:4]	rw	Interrupt Node Pointer for Channel x Selects a service request output for a channel event from channel x. 00 _B Assign to output SR0 ... 11 _B Assign to output SR3
0	[3:2], [15:6]	r	Reserved returns 0 if read; should be written with 0;

Note: Not all channels are available in all products.

Therefore, only the node pointers with corresponding channels are valid.

16.13 Implementation

This section describes the implementation of the ADC kernels in the XE166U device.

- [“Address Map” on Page 16-106](#)
- [“Interrupt Control Registers” on Page 16-109](#)
- [“Analog Connections” on Page 16-110](#)
- [“Digital Connections” on Page 16-111](#)

16.13.1 Address Map

The ADC register locations are indicated as offset values in the register descriptions. The exact register address is given by the offset of the register (given in [Table 16-5](#)) plus the kernel base address (given in [Table 16-4](#)) of the module.

Table 16-4 Registers Address Space

Module	Base Address	End Address	Note
ADC0	E000 _H	E2FF _H	E100 _H -E1FF _H unused

Table 16-5 ADC Module Register Summary

Short Name	Description	Offset ¹⁾	See Page
General Registers			
ID	Module Identification Register	08 _H	Page 16-15
KSCFG	Kernel State Configuration Register	0C _H	Page 16-13
GLOBCTR	Global Control Register	10 _H	Page 16-17
GLOBCFG	Global Configuration Register	DE _H	Page 16-18
GLOBSTR	Global Status Register	12 _H	Page 16-20
RSIR0	Request Source 0 Input Select Register	00 _H	Page 16-47
RSIR1	Request Source 1 Input Select Register	02 _H	Page 16-47
RSIR2	Request Source 2 Input Select Register	04 _H	Page 16-47
Arbiter Registers			
ASENR	Arbitration Slot Enable Register	18 _H	Page 16-51
RSPR0	Request Source Priority Register 0	14 _H	Page 16-52
Channel-Related Registers			
CHCTR0-15	Channel Control Register 0-15	20 _H -3E _H	Page 16-56

Table 16-5 ADC Module Register Summary (cont'd)

Short Name	Description	Offset¹⁾	See Page
CHCTR16-21	Channel Control Register 16-21	220 _H -22A _H	Page 16-56
INPCR0	Input Class Register 0	C0 _H	Page 16-58
INPCR1	Input Class Register 1	C2 _H	Page 16-58
LCBR0	Limit Checking Boundary Register 0	84 _H	Page 16-61
LCBR1	Limit Checking Boundary Register 1	86 _H	Page 16-61
LCBR2	Limit Checking Boundary Register 2	88 _H	Page 16-61
LCBR3	Limit Checking Boundary Register 3	8A _H	Page 16-61
BFCR	Boundary Flag Control Register	D4 _H	Page 16-62
CHINFR	Channel Event Indication Flag Register	90 _H	Page 16-97
CHINFRE	Channel Event Indication Flag Register Extended	200 _H	Page 16-97
CHINCR	Channel Event Indication Clear Register	92 _H	Page 16-98
CHINCRE	Channel Event Indication Clear Register Extended	202 _H	Page 16-98
CHINPR0	Channel Interrupt Node Pointer Register 0	98 _H	Page 16-102
CHINPR4	Channel Interrupt Node Pointer Register 4	9A _H	Page 16-102
CHINPR8	Channel Interrupt Node Pointer Register 8	9C _H	Page 16-103
CHINPR12	Channel Interrupt Node Pointer Register 12	9E _H	Page 16-103
CHINPR16	Channel Interrupt Node Pointer Register 16	208 _H	Page 16-104
CHINPR20	Channel Interrupt Node Pointer Register 20	20A _H	Page 16-105
ALR0	Alias Register 0	1C _H	Page 16-64

Result Registers

RESR0-7	Result Register 0-7, normal view	40 _H -4E _H	Page 16-69
RESRA0-7	Result Register 0-7, view A	50 _H -5E _H	Page 16-70
RESRV0-7	Result Register 0-7, view V	60 _H -6E _H	Page 16-69
RESRAV0-7	Result Register 0-7, view AV	70 _H -7E _H	Page 16-70
VFR	Valid Flag Register	80 _H	Page 16-74
RSSR	Result Status Shadow Register	82 _H	Page 16-71
RCR0-7	Result Control Register 0-7	B0 _H -BE _H	Page 16-72
EVINFR	Event Indication Flag Register	A0 _H	Page 16-95

Table 16-5 ADC Module Register Summary (cont'd)

Short Name	Description	Offset¹⁾	See Page
EVINCR	Event Indication Clear Register	A2 _H	Page 16-96
EVINPR0	Event Interrupt Node Pointer Register 0	A8 _H	Page 16-99
EVINPR8	Event Interrupt Node Pointer Register 8	AC _H	Page 16-100
EVINPR12	Event Interrupt Node Pointer Reg. 12	AE _H	Page 16-100

Request Source 0 Registers

QMR0	Queue 0 Mode Register	E0 _H	Page 16-40
QSR0	Queue 0 Status Register	E2 _H	Page 16-42
Q0R0	Queue 0 Register 0	E4 _H	Page 16-45
QBUR0	Queue 0 Backup Register	E6 _H	Page 16-46
QINR0	Queue 0 Input Register	shared	Page 16-44

Request Source 1 Registers

CRCR1	Conversion Request 1 Control Register	E8 _H	Page 16-31
CRCR1E	Conversion Request 1 Control Register Extended	214 _H	Page 16-32
CRPR1	Conversion Request 1 Pending Register	EA _H	Page 16-33
CRPR1E	Conversion Request 1 Pending Register Extended	216 _H	Page 16-34
CRMR1	Conversion Request 1 Mode Register	EC _H	Page 16-29

Request Source 2 Registers

QMR2	Queue 2 Mode Register	F0 _H	Page 16-40
QSR2	Queue 2 Status Register	F2 _H	Page 16-42
Q0R2	Queue 2 Register 0	F4 _H	Page 16-45
QBUR2	Queue 2 Backup Register	F6 _H	Page 16-46
QINR2	Queue 2 Input Register	shared	Page 16-44

Additional Feature Registers

EMENR	External Multiplexer Enable Register	D6 _H	Page 16-91
EMCTR	External Multiplexer Control Register	D0 _H	Page 16-92
BWDENR	Broken Wire Detection Enable Register	C8 _H	Page 16-86

Table 16-5 ADC Module Register Summary (cont'd)

Short Name	Description	Offset ¹⁾	See Page
BWDENRE	Broken Wire Detection Enable Register Extended	210 _H	Page 16-86
BWDCFGR	Broken Wire Detection Configuration Register	CA _H	Page 16-87

1) Short 8-bit addresses are not available for kernel registers of this module.

Note: Register bits marked “w” always deliver 0 when read.

The offsets 06_H, 16_H, C4_H, C6_H, 8C_H, 8E_H, A4_H, A6_H, and AA_H are reserved for future use and must not be accessed.

16.13.2 Interrupt Control Registers

The interrupt control registers are located in the SFR area. They are described in the general interrupt chapter.

Table 16-6 ADC Interrupt Control Registers

Short Name	Description
ADC_0IC	Interrupt Control Register for SR0 of ADC0
ADC_1IC	Interrupt Control Register for SR1 of ADC0
ADC_2IC	Interrupt Control Register for SR2 of ADC0
ADC_3IC	Interrupt Control Register for SR3 of ADC0

Note: Various events can be assigned to one on these interrupt nodes. Please refer to [“Interrupt Request Handling” on Page 16-94](#)

16.13.3 Analog Connections

The analog input multiplexer selects the input channel to be converted from the signals available in this product.

The exact number of analog input channels and the available connection to port pins depend on the employed product type. A summary of channels enclosing all versions of the XE166U can be found in [Table 16-7](#). For the exact number and association, please refer to the corresponding Data Sheet(s).

In addition to real input channels, also the reference voltages can be selected via on-chip connections. This is mainly used for broken wire detection ([Section 16.10.1](#)).

Table 16-7 ADC0 Analog Connections in XE166U

Signal	from/to Module	I/O to ADC0	Can be used to/as, connected to
Power supply and standard reference			
V_{DDPA}	see pinning chapter	I	analog power supply
V_{SS}		I	analog power supply
V_{AREF}		I	positive analog reference
V_{AGND}		I	negative analog reference
Analog input channels			
CH0	P5.0	I	analog input channel 0
CH2	P5.2	I	analog input channel 2
CH3	P5.3	I	analog input channel 3
CH4	P5.4	I	analog input channel 4
CH8	P5.8	I	analog input channel 8
CH9	P5.9	I	analog input channel 9
CH16	P6.0	I	analog input channel 16
CH17	P6.1	I	analog input channel 17
CH19	P2.0	I	analog input channel 19
CH20	P2.1	I	analog input channel 20
CH30	V_{AGND}	I	analog input channel 30 (internal conn. to V_{AGND})
CH31	V_{AREF}	I	analog input channel 31 (internal conn. to V_{AREF})
Other channels	n.c.	I	not available, do not request for conversion

16.13.4 Digital Connections

The following table shows the digital connections of the ADC kernels with other modules or pins in the XE166U device.

The following sections refer to the inter-module connections, whereas the connections of the service request outputs SR[3:0] of each kernel to the interrupt control registers is given in [Section 16.13.2](#).

Note: The functional inputs of the ADC that are marked "I(s)" are additionally synchronized to f_{SYS} before they can affect the module internal logic. The resulting delay of $2/f_{SYS}$ and an uncertainty of $1/f_{SYS}$ have to be taken into account for precise timing calculation. An edge of an input signal can only be correctly detected if the high phase and the low phase of the input signal are both longer than $1/f_{SYS}$.

The functional inputs of the ADC that are marked "I" are already considered as synchronous to f_{SYS} .

Table 16-8 ADC0 Digital Connections in XE166U

Signal	from/to Module	I/O to ADC0	Can be used to/as, connected to
Arbiter Timing			
ARBCNT	CCU60_T12HRE, CCU60_T13HRE,	O	time base for equidistant sampling for CCU60
External multiplexer control			
EMUX[0]	P6.0	O	control of external analog multiplexer(s)
EMUX[1]	P6.1	O	control of external analog multiplexer(s)
EMUX[2]	P6.2	O	control of external analog multiplexer(s)
Request Source 0			
REQGT0A	CCU60_COUT63	I	CCU60
REQGT0B	0	I	
REQGT0C	0	I	
REQGT0D	0	I	
REQGT0E	ERU_PDOUT0	I (s)	ERU
REQGT0F	ERU_PDOUT1	I (s)	ERU
REQGT0G	P6.0	I (s)	external pin
REQGT0H	CCU60_CC60	I (s)	CCU60
REQTR0A	CC2_CC16	I	CC
REQTR0B	ERU_TOUT1	I	ERU

Table 16-8 ADC0 Digital Connections in XE166U (cont'd)

Signal	from/to Module	I/O to ADC0	Can be used to/as, connected to
REQTR0C	0	I	
REQTR0D	0	I	
REQTR0E	P6.1	I (s)	external pin
REQTR0F	P6.3	I (s)	external pin
REQTR0G	ADC0_REQGT0	I (s)	extend input selection for triggering by using gating inputs (with ENGT = 0X)
REQTR0H	ADC0_SR3	I (s)	service request output 3 of ADC0
REQTR0	-	O	selected trigger signal for source 0
REQGT0	ADC0_REQTR0G	O	selected gating signal for source 0

Request Source 1

REQGT1A	CCU60_COUT63	I	CCU60
REQGT1B	0	I	
REQGT1C	0	I	
REQGT1D	0	I	
REQGT1E	ERU_PDOUT0	I (s)	ERU
REQGT1F	ERU_PDOUT1	I (s)	ERU
REQGT1G	P6.0	I (s)	external pin
REQGT1H	CCU60_CC61	I (s)	CCU60
REQTR1A	CC2_CC17	I	CC2
REQTR1B	ERU_TOUT1	I	ERU
REQTR1C	0	I	
REQTR1D	0	I	
REQTR1E	P6.1	I (s)	external pin
REQTR1F	P6.3	I (s)	external pin
REQTR1G	ADC0_REQGT1	I (s)	extend input selection for triggering by using gating inputs (with ENGT = 0X)
REQTR1H	ADC0_SR3	I (s)	service request output 3 of ADC0
REQTR1	-	O	selected trigger signal for source 1
REQGT1	ADC0_REQTR1G	O	selected gating signal for source 1

Request Source 2

Table 16-8 ADC0 Digital Connections in XE166U (cont'd)

Signal	from/to Module	I/O to ADC0	Can be used to/as, connected to
REQGT2A	CCU60_COUT63	I	CCU60
REQGT2B	0	I	
REQGT2C	0	I	
REQGT2D	0	I	
REQGT2E	ERU_PDOUT0	I (s)	ERU
REQGT2F	ERU_PDOUT1	I (s)	ERU
REQGT2G	P6.0	I (s)	external pin
REQGT2H	CCU60_CC62	I (s)	CCU60
REQTR2A	CC2_CC18	I	CC2
REQTR2B	ERU_TOUT1	I	ERU
REQTR2C	0	I	
REQTR2D	0	I	
REQTR2E	P6.1	I (s)	external pin
REQTR2F	P6.3	I (s)	external pin
REQTR2G	ADC0_REQGT2	I (s)	extend input selection for triggering by using gating inputs (with ENG_T = 0X)
REQTR2H	ADC0_SR3	I (s)	service request output 3 of ADC0
REQTR2	-	O	selected trigger signal for source 2
REQGT2	ADC0_REQTR2G	O	selected gating signal for source 2

Service Request Outputs¹⁾

SR3	CCU60_CCPOS2C	O	CCU60 Hall input trigger REQTRxH trigger inputs
SR3_N	CCU60_CTRAPC	O	CCU60 emergency input

Boundary Flag Outputs

BFL0	-	O	
BFL1	-	O	
BFL2	CCU60_CCPOS0B	O	CCU60 Hall input trigger
BFL3	CCU60_CCPOS1B	O	CCU60 Hall input trigger
BFL4	CCU60_CCPOS2B	O	CCU60 Hall input trigger

1) All service request outputs (SR0, SR1, SR2, SR3) are connected to the interrupt controller.
SRx_N is the inverted request signal SRx.

17 Capture/Compare Unit

The XE166U provides a Capture/Compare (CAPCOM2) unit which provides 16 capture/compare channels, which interact with 2 timers. A CAPCOM channel can **capture** the contents of a timer on specific internal or external events, or it can **compare** a timer's contents with given values, and modify output signals in case of a match.

Data Registers	Control Registers	Interrupt Control
CC2_T7/T7REL	CC2_T78CON	CC2_T7IC
CC2_T8/T8REL		CC2_T8IC
CC16-CC19	CC2_M4	CC16IC-CC19IC
CC20-CC23	CC2_M5	CC20IC-CC23IC
CC24-CC27	CC2_M6	CC24IC-CC27IC
CC28-CC31	CC2_M7	CC28IC-CC31IC
	CC2_SEE	
	CC2_SEM	
	CC2_DRM	
	CC2_IOC	
CC2_OUT	CC2_ID	
	CC2_KSCCFG	
CC2_CC16...31	CAPCOM2 Capture/Compare Register 16...31	
CC2_CC16IC...31IC	CAPCOM2 Interrupt Control Register 16...31	
CC2_M4...7	CAPCOM2 Mode Control Register 4...7	
CC2_T78CON	CAPCOM2 Timer Control Register	
CC2_T7, T8	CAPCOM2 Timer Register	
CC2_T7/8REL	CAPCOM2 Timer Reload Register	
CC2_T7IC, T8IC	CAPCOM2 Timer x Interrupt Control Register	
CC2_SEE	CAPCOM2 Single Event Enable Register	
CC2_SEM	CAPCOM2 Single Event Mode Register	
CC2_DRM	CAPCOM2 Double-Register Compare Mode Register	
CC2_OUT	CAPCOM2 Output Register	
CC2_IOC	CAPCOM2 Input/Output Control Register	
CC2_KSCCFG	CAPCOM2 Kernel State Configuration Register	
CC2_ID	CAPCOM2 Module Identification Register	
	cc2_registers.vsd	

Figure 17-1 SFRs Associated with the CAPCOM2 Unit

The two timers of CAPCOM2 are named T7 and T8 and the 16 channels of CAPCOM2 are named CC16...31.

With this mechanism, the CAPCOM2 unit supports generation and control of timing sequences on up to 16 channels with a minimum of software intervention.

From the programmer's point of view, the term 'CAPCOM unit' refers to a set of registers which are associated with this peripheral (see also [Figure 17-1](#)), including the port pins that may be used for alternate input/output functions, and their control bits.

17.1 Functional Overview

The CAPCOM2 unit is typically used to handle high speed IO tasks such as pulse and waveform generation, pulse width modulation, or recording of the time when a specific event occurs. It also supports the implementation of up to 16 software-controlled interrupt events.

The CAPCOM2 Unit consists of two 16-bit timers (T7/T8), each with its own reload register (TxREL), and a bank of sixteen dual-purpose 16-bit capture/compare registers (CCy).

The input clock for the CAPCOM timers is programmable to several prescaled values of the module input clock (f_{CC}), or it can be derived from the overflow/underflow of timer T6. T7 may also operate in counter mode (from an external input), clocked by external events.

Each capture/compare register may be programmed individually for capture or compare operation, and each register may be allocated to either of the two timers. Each capture/compare register has one signal associated with it, which serves as an input signal for the capture operation or as an output signal for the compare operation.

The capture operation causes the current timer contents to be copied into the respective capture/compare register, triggered by an event (transition) on the associated input signal. This event also activates the associated interrupt request line.

The compare operation may cause an output signal transition on the associated output signal, when the allocated timer increments to the value stored in a capture/compare register. The compare match event also activates the associated interrupt request line. In Double-register compare mode a pair of registers controls one common output signal.

The compare output signals are available via a dedicated output register. The output path can be selected.

For the switching of the output signals two timing schemes (see [Section 17.1.10](#)) can be selected:

In **Staggered Mode** the output signals are switched consecutively in 8 steps, which distributes the switching steps over a certain time. In staggered mode, the maximum resolution is $8 t_{CC}$.

In **Non-Staggered Mode** the output signals are switched immediately at the same time. In non-staggered mode, the maximum resolution is $1 t_{CC}$.

[Figure 17-2](#) shows the basic structure of the CAPCOM2 unit.

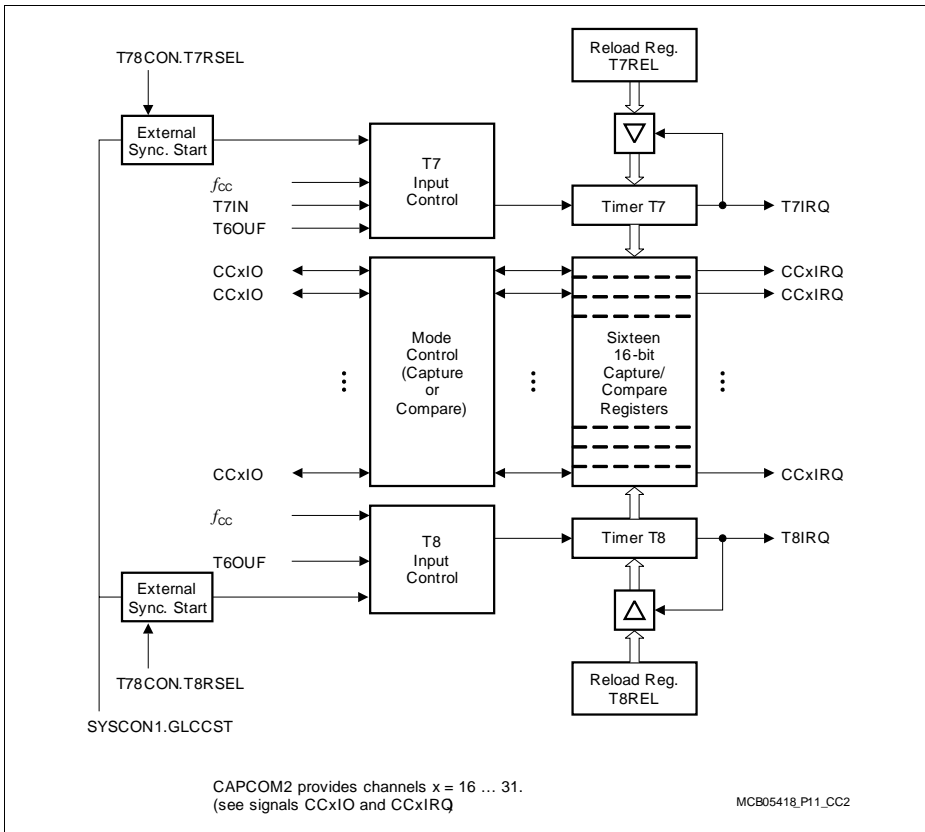


Figure 17-2 CAPCOM2 Unit Block Diagram

There is a possibility to start both timers T7 and T8 synchronously with the CAPCOM6 timers, by setting the bit SYSICON1.GLCCST.

17.1.1 The CAPCOM Timers

The primary use of the timers T7 and T8 is to provide two independent time bases for the capture/compare channels of each unit. The maximum resolution is $8 t_{CC}$ in staggered mode, and $1 t_{CC}$ in non-staggered mode.

The basic structure of the timers, illustrated in [Figure 17-3](#), is identical, except for the input pin (see mark).

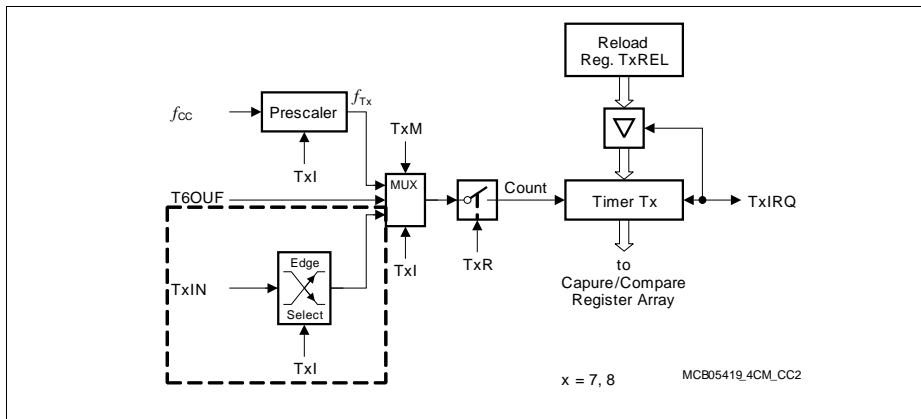


Figure 17-3 Block Diagram of a CAPCOM Timer

The functions of the CAPCOM timers are controlled via the bit-addressable control register **CC2_T78CON**. The high-byte of CC2_T78CON controls T8, the low-byte of CC2_T78CON controls T7. The control options are identical for all timers (except for external input).

In all modes, the timers are always counting upward. The current timer values are accessible for the CPU in the timer registers Tx, which are non bit-addressable registers. When the CPU writes to a register Tx in the state immediately before the respective timer increment or reload is to be performed, the CPU write operation has priority and the increment or reload is disabled to guarantee correct timer operation.

The timer run flags TxR allow the starting and stopping of the timers. The following description of the timer modes and operation always applies to the enabled state of the timers, i.e. the respective run flag is assumed to be set.

Timer Mode

In Timer Mode (TxM = 0), the input clock for a CAPCOM timer is derived from f_{CC} , divided by a programmable prescaler. Each timer has its own individual prescaler, controlled through the individual bitfields TxI in the timer control register CC2_T78CON. The input frequency f_{Tx} for a timer Tx and its resolution r_{Tx} are determined by the following formulas:

Staggered Mode:

$$f_{Tx}[\text{MHz}] = \frac{f_{CC}[\text{MHz}]}{2^{(\langle \text{TxI} \rangle + 3)}} \quad r_{Tx}[\mu\text{s}] = \frac{2^{(\langle \text{TxI} \rangle + 3)}}{f_{CC}[\text{MHz}]} \quad (17.1)$$

Non-Staggered Mode:

$$f_{Tx}[\text{MHz}] = \frac{f_{CC}[\text{MHz}]}{2^{<TxI>}} \quad r_{Tx}[\mu\text{s}] = \frac{2^{<TxI>}}{f_{CC}[\text{MHz}]} \quad (17.2)$$

When a timer overflows from FFFF_H to 0000_H, it is reloaded with the value stored in its respective reload register TxREL. The reload value determines the period P_{Tx} between two consecutive overflows of Tx as follows:

Staggered Mode:

$$P_{Tx}[\mu\text{s}] = \frac{(2^{16} - <TxREL>) \times 2^{(<TxI> + 3)}}{f_{CC}[\text{MHz}]} \quad (17.3)$$

Non-Staggered Mode:

$$P_{Tx}[\mu\text{s}] = \frac{(2^{16} - <TxREL>) \times 2^{<TxI>}}{f_{CC}[\text{MHz}]} \quad (17.4)$$

After a timer has been started by setting its run flag (TxR), the first increment will occur within the time interval which is defined by the selected timer resolution. All further increments occur exactly after the time defined by the timer resolution.

Examples for timer input frequencies, resolution and periods, which result from the selected prescaler option in TxI when using a 40 MHz clock, are listed in [Table 17-1](#) below. The numbers for the timer periods are based on a reload value of 0000_H. Note that some numbers may be rounded.

Table 17-1 Timer Tx Input Clock Selection for Timer Mode, $f_{CC} = 40 \text{ MHz}$

Txl	Prescaler	Input Frequency	Resolution	Period
Staggered Mode				
000 _B	8	5 MHz	200 ns	13.11 ms
001 _B	16	2.5 MHz	400 ns	26.21 ms
010 _B	32	1.25 MHz	800 ns	52.43 ms
011 _B	64	625 kHz	1.6 μs	104.86 ms
100 _B	128	312.5 kHz	3.2 μs	209.72 ms
101 _B	256	156.25 kHz	6.4 μs	419.43 ms
110 _B	512	78.125 kHz	12.8 μs	838.86 ms
111 _B	1024	39.0625 kHz	25.6 μs	1677.72 ms
Non-Staggered Mode				
000 _B	1	40 MHz	25 ns	1.6384 ms
001 _B	2	20 MHz	50 ns	3.2768 ms
010 _B	4	10 MHz	100 ns	6.5536 ms
011 _B	8	5 MHz	200 ns	13.11 ms
100 _B	16	2.5 MHz	400 ns	26.21 ms
101 _B	32	1.25 MHz	800 ns	52.43 ms
110 _B	64	625 kHz	1.6 μs	104.86 ms
111 _B	128	312.5 kHz	3.2 μs	209.72 ms

Counter Mode

In Counter Mode ($\text{TxFM} = 1$), the input clock of a CAPCOM timer is either derived from an associated external input pin, T7IN, or from the over-/underflows of GPT timer T6.

Using an external signal connected to pin TxIN as a counting signal is only possible for timer T7. The only counter option for timer T8 is using the over-/underflows of the GPT timer T6 (selected by $\text{Txl} = 000_{\text{B}}$).

Bitfields T7I are used to select either a positive, a negative, or both a positive and a negative transition of the external signal at pin T7IN to trigger an increment of timer T7. Please note that certain criteria must be met for the external signal and the port pin programming for this mode in order to operate properly. These conditions are detailed in [Chapter 17.1.11](#).

Timer Overflow and Reload

When a CAPCOM timer contains the value $FFFF_H$ at the time a new count trigger occurs, a timer interrupt request is generated, and the timer is loaded with the contents of its associated reload register TxREL. The timer then resumes incrementing with the next count trigger starting from the reloaded value.

The reload registers TxREL are not bit-addressable. After reset, they contain the value 0000_H .

17.1.2 Timer Interrupt

Upon a timer overflow the corresponding timer interrupt request flag TxIR for the respective timer will be set. This flag can be used to generate an interrupt or trigger a PEC service request, when enabled by the respective interrupt enable bit TxIE.

Each timer has its own bit-addressable interrupt control register CC2_TxIC and its own interrupt vector. The organization of the interrupt control registers TxIC is identical with the other interrupt control registers.

17.1.3 Capture/Compare Channels

The 16-bit capture/compare registers **CC2_CCy (y=16-31)** are used as data registers for capture or compare operations with respect to timers T7 and T8. The capture/compare registers are not bit-addressable.

The functions of the 16 capture/compare registers of a unit are controlled by 4 bit-addressable 16-bit mode control registers, named **CC2_M4 ... CC2_M7**, which are all organized identically. Each register contains the bits for mode selection and timer allocation for four capture/compare registers.

Each of the registers CCy may be individually programmed for capture mode or for one of 4 different compare modes, and may be allocated individually to one of the two timers of the CAPCOM unit.

A special **Double-Register Compare Mode** combines two registers to act on one common output signal. When capture or compare operations are disabled for one of the CCy registers, it may be used for general purpose variable storage.

Table 17-2 Selection of Capture Modes and Compare Modes

Mode	MODy	Selected Operating Mode
Disabled	000 _B	Disable Capture and Compare Modes The respective CAPCOM register may be used for general variable storage.
Capture	001 _B	Capture on Positive Transition (Rising Edge) at Pin CCyIO
	010 _B	Capture on Negative Transition (Falling Edge) at Pin CCyIO
	011 _B	Capture on Positive and Negative Transition (Both Edges) at Pin CCyIO
Compare	100 _B	Compare Mode 0: Interrupt Only Several interrupts per timer period. Can enable double-register compare mode for Bank2 registers.
	101 _B	Compare Mode 1: Toggle Output Pin on each Match Several compare events per timer period. Can enable double-register compare mode for Bank1 registers.
	110 _B	Compare Mode 2: Interrupt Only Only one interrupt per timer period.
	111 _B	Compare Mode 3: Set Output Pin on each Match Reset output pin on each timer overflow; only one interrupt per timer period.

Capture/Compare Unit

The detailed discussion of the capture and compare modes is valid for all the capture/compare channels, so registers, bits and pins are only referenced by a placeholder.

17.1.4 Capture Mode

In Capture Mode, the current contents of a CAPCOM timer are copied (captured) into the respective capture/compare register in response to an external event. This is used, for example, to record the time at which an external event has occurred, or to measure the distance between two external events in timer increments.

The event to cause a capture of a timer's contents can be programmed to be either the positive, the negative, or both the positive and the negative transition of the external signal connected to the input pin. This triggering transition is selected by bitfield MODy in the respective mode control register. When the selected external signal transition occurs, the selected timer's contents is copied into the capture/compare register and the respective interrupt request line CCyIRQ is activated. This can cause an interrupt or PEC service request, when enabled.

Note: A capture input can be used as an additional external interrupt input. The capture operation can be disregarded in this case.

Either the contents of timer T7 or T8 can be captured, selected by the timer allocation control bit ACCy in the respective mode control register.

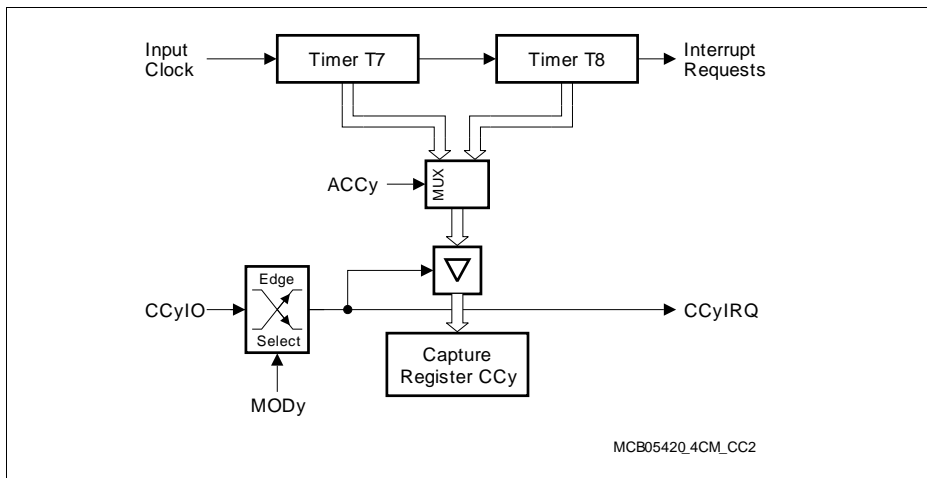


Figure 17-4 Capture Mode Block Diagram

For capture operation, the respective pin must be programmed for input. To ensure that a transition of the input signal is recognized correctly, its level must be held high or low

for a minimum number of module clock cycles before it changes. This information can be found in [Section 17.1.11](#).

17.1.5 Compare Modes

The compare modes allow triggering of events (interrupts and/or output signal transitions) or generation of pulse trains with minimum software overhead. In all compare modes, the 16-bit value stored in a capture/compare register CCy (in the following also referred to as 'compare value') is continuously compared with the contents of the allocated timer (T7 or T8). If the current timer contents match the compare value, the interrupt request line associated with register CCy is activated and, depending on the compare mode, an output signal can be generated at the corresponding output pin CCyIO.

Four different compare modes are available, which can be selected individually for each of the capture/compare registers by bitfield MODy in the respective mode control register. Modes 0 and 2 do not influence the output signals. In the following, each mode is described in detail.

In addition to these 'single-register' modes, a 'double-register' compare mode enables two registers to operate on the same pin. This feature can further reduce software overhead, as two different compare values can be programmed to control a sequence of transitions for a signal. See [Section 17.1.6](#) for details for this operation.

In all Compare Modes, the comparator performs an 'equal to' comparison. This means, a match is only detected when the timer contents are equal to the contents of a compare register. In addition, the comparator is only enabled in the clock cycle directly after the timer was incremented by hardware. This is done to prevent repeated matches if the timer does not operate with the highest possible input clock (either in timer or counter mode). In this case, the timer contents would remain at the same value for several or up to thousands of cycles. This operation has the side-effect, that software modifications of the timer contents will have no effect regarding the comparator. If a timer is set by software to the same value stored in one of the compare registers, no match will be detected. If a compare register is set to a value smaller than the current timer contents, no action will take place.

For the exact operation of the port output function, please see [Section 17.1.8](#).

When two or more compare registers are programmed to the same compare value¹⁾, their corresponding interrupt request flags will be set and the selected output signals will be generated after the allocated timer is incremented to this compare value. Further compare events on the same compare value are disabled²⁾ until the timer is incremented

1) In staggered mode these interrupts and output signals are generated sequentially (see [Section 17.1.10](#)).

2) Even if more compare cycles are executed before the timer increments (lower timer frequency) a given compare value only results in one single compare event.

again or written to by software. After a reset, compare events for register CCy will only become enabled, if the allocated timer has been incremented or written to by software and one of the compare modes described in the following has been selected for this register.

17.1.5.1 Compare Mode 0

This is an interrupt-only mode which can be used for software timing purposes. In this mode, the interrupt request line CCyIRQ is activated each time a match is detected between the contents of the compare register CCy and the allocated timer. A match means, the contents of the timer are equal to ('=') the contents of the compare register. Several of these compare events are possible within a single timer period, if the compare value in register CCy is updated during the timer period. The corresponding port signal CCyIO is not affected by compare events in this mode and can be used as general purpose IO.

Note: If compare mode 0 is programmed for one of the bank2 registers the double-register compare mode may be enabled for this register (see [Chapter 17.1.6](#)).

17.1.5.2 Compare Mode 1

This is a compare mode which influences the associated output signal. Besides this, the basic operation is as in compare mode 0. Each time a match is detected between the contents of the compare register CCy and the allocated timer, the interrupt request line CCyIRQ is activated. In addition, the associated output signal is toggled. Several of these compare events are possible within a single timer period, if the compare value in register CCy is updated during the timer period.

Note: If compare mode 1 is programmed for one of the bank1 registers the double-register compare mode may be enabled for this register (see [Section 17.1.6](#)).

For the exact operation of the port output signal, please see [Section 17.1.8](#).

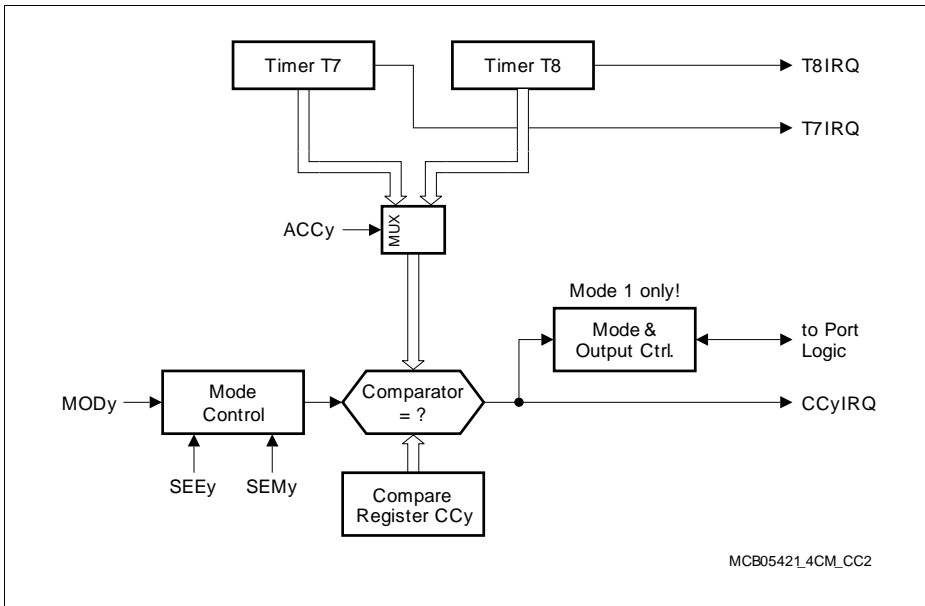


Figure 17-5 Compare Mode 0 and 1 Block Diagram

Note: The signal remains unaffected in compare mode 0.

Figure 17-6 illustrates a few example cases for compare modes 0 and 1.

In all examples, the reload value of the used timer is set to $FFF9_H$. When the timer overflows, it starts counting from this value upwards.

In Case 1, register CCy contains the value $FFFC_H$. When the timer reaches this value, a match is detected, and the interrupt request line CCyIRQ is activated. In compare mode 0, this is all that will happen. In compare mode 1, additionally the associated port output is toggled, causing an inversion of the output signal. If the contents of register CCy are not changed, this operation will take place each time the timer reaches the programmed compare value.

In Case 2, software reloads the compare register CCy with $FFFF_H$ after the first match with $FFFC_H$ has occurred. As the timer continues to count up, it finally reaches this new compare value, and a new match is detected, activating the interrupt request line (both modes) and toggling the output signal (compare mode 1). If then the compare value is left unchanged, the next match will occur when the timer reaches $FFFF_H$ again. This example illustrates, that further compare matches are possible within the current timer period (this is in contrast to compare modes 2 and 3).

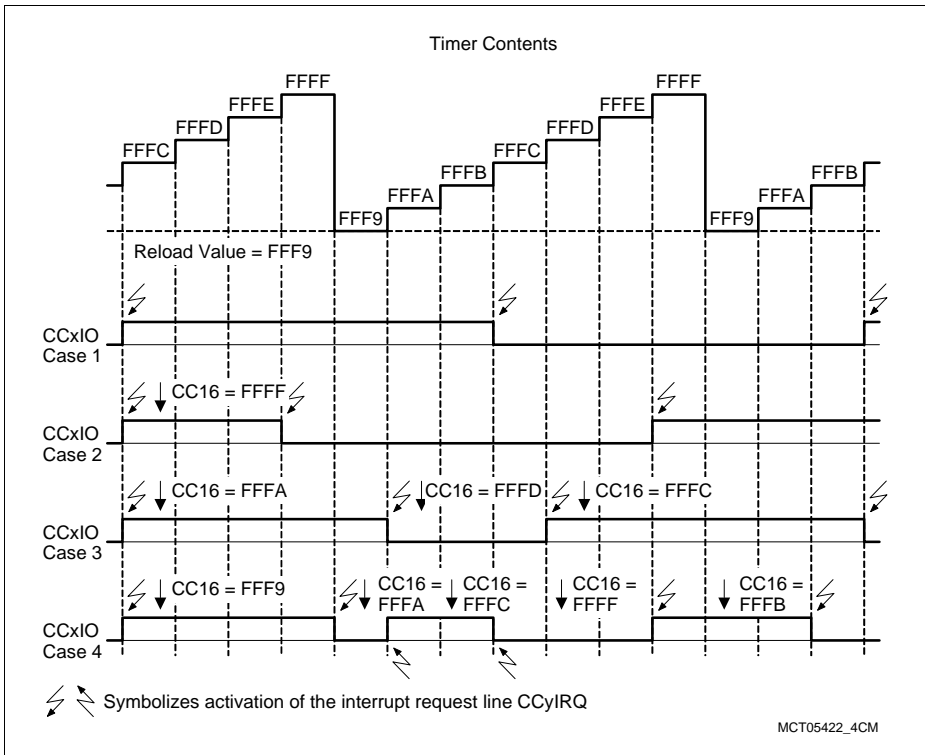


Figure 17-6 Examples for Compare Modes 0 and 1

In Case 3, a new compare value, higher than the current timer contents, causes a new match within the current timer period. The compare register is reloaded with FFFA_H after the first match (at FFFC_H). However, the timer has already passed this value. Thus, it will take until the timer reaches FFFA_H in the following timer period to cause the desired compare match. Reloading register CCy now with a value higher than the current timer contents will cause the next match within this period.

In Case 4, the compare values are equal to the timer reload value or to the maximum count value, FFFF_H.

17.1.5.3 Compare Mode 2

Compare mode 2 is an interrupt-only mode similar to compare mode 0. The main difference is that only one compare match, corresponding to one interrupt request, is possible within a given timer period.

When a match is detected in compare mode 2 for the first time within a count period of the allocated timer, the interrupt request line CCyIRQ is activated. In addition, all further compare matches within the current timer period are disabled, even if a new compare value, higher than the current timer contents, would be written to the register. This blocking is only released when the allocated timer overflows. A new compare value written to the compare register after the first match will only go into effect within the following timer period.

17.1.5.4 Compare Mode 3

Compare mode 3 is based on compare mode 2, but additionally influences the associated port pin. Only one compare event is possible within one timer period.

When a match is detected in compare mode 3 for the first time within a count period of the allocated timer, the interrupt request line CCyIRQ is activated, and the associated output signal is set to 1. In addition, all further compare matches within the current timer period are disabled, even if a new compare value, higher than the current timer contents, would be written to the register. This blocking is only released when the allocated timer overflows. A new compare value written to the compare register after the first match will only go into effect within the following timer period.

The overflow signal is also used to reset the associated output signal to 0.

Special attention has to be paid when the compare value is set equal to the timer reload value. In this case, the compare match signal would try to set the output signal, while the timer overflow tries to reset the output signal. This conflict is avoided such that the state of the output signal is left unchanged in this case.

Note: When the compare value is changed from a value above the current timer contents to a value below the current timer contents, the new value is not recognized before the next timer period.

For the exact operation of the port output signal, please see [Section 17.1.8](#).

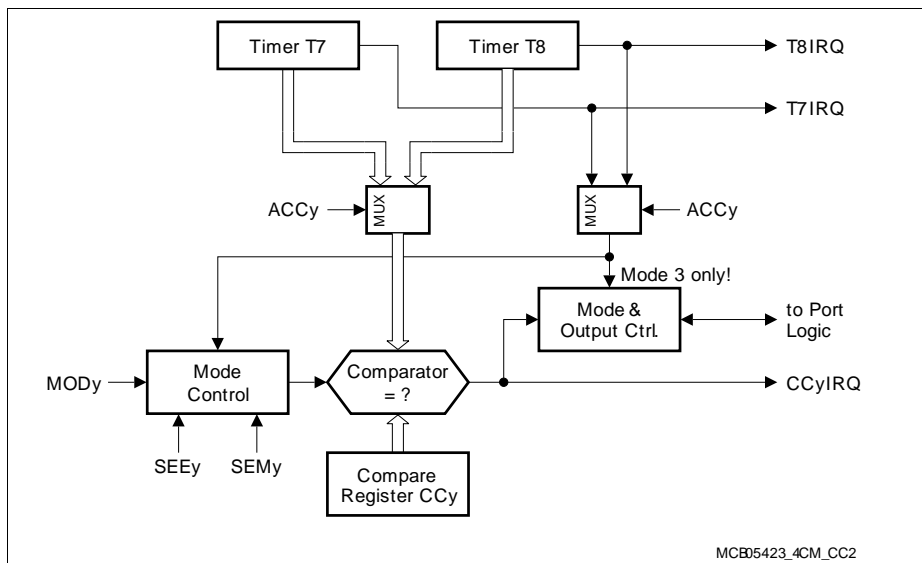


Figure 17-7 Compare Mode 2 and 3 Block Diagram

Note: The port signal remains unaffected in compare mode 2.

Figure 17-8 illustrates a few timing examples for compare modes 2 and 3.

In all examples, the reload value of the used timer is set to $FFF9_H$. When the timer overflows, it starts counting from this value upwards.

In Case 1, register CCy contains the value $FFFC_H$. When the timer reaches this value, a match is detected, and the interrupt request line CCyIRQ is activated. In compare mode 2, this is all that will happen. In compare mode 3, additionally the associated port output is set to 1. The timer continues to count, and finally reaches its overflow. At this point, the port output is reset to 0 again. Note that, although not shown in the diagrams, the overflow signal of the timer also activates the associated interrupt request line TxIRQ. If the contents of register CCy are not changed, the port output will be set again during the following timer period, and reset again when the timer overflows. This operation is ideal for the generation of a pulse width modulated (PWM) signal with a minimum of software overhead. The pulse width is varied by changing the compare value accordingly.

In Case 2, the compare operation is blocked after the first match within a timer period. After the first match at $FFFC_H$, the interrupt request is generated and the port output is set. In addition, further compare matches are disabled. If now a new compare value is written to register CCy, no interrupt request and no port output influence will take place, although the new compare value is higher than the current timer contents. Only after the

overflow of the timer, the compare logic is enabled again, and the next match will be detected at $FFFF_H$. One can see, that this operation is ideal for PWM generation, as software can write a new compare value regardless of whether this value is higher or lower than the current timer contents. It is assured that the new value (usually written to the compare register in the appropriate interrupt service routine) will only go into effect during the following timer period.

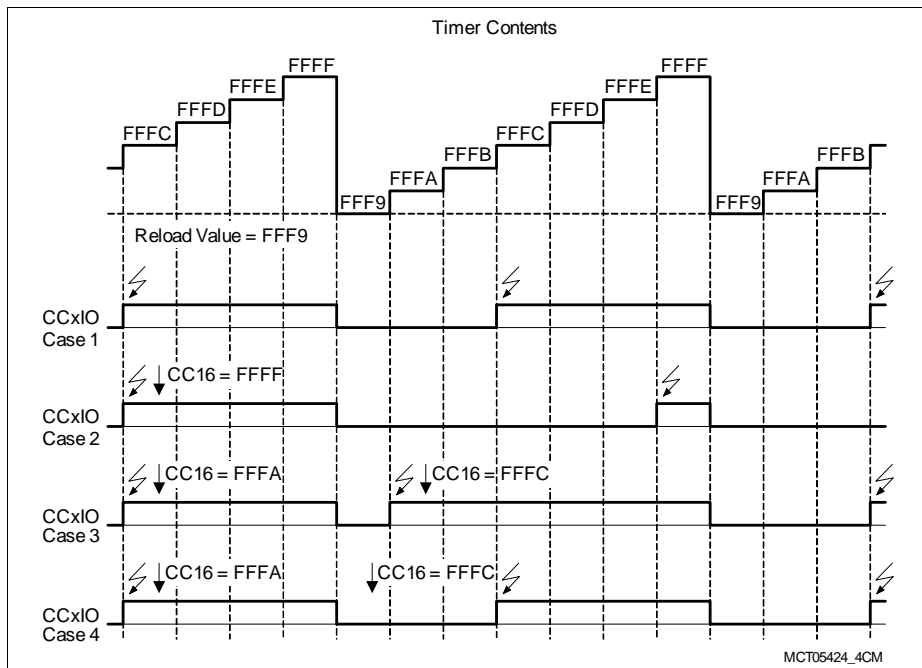


Figure 17-8 Timing Example for Compare Modes 2 and 3

Note: In compare mode 2, only interrupt requests are generated, in mode 3, also the output signals are generated.

In Case 3, further examples for the operation of the compare match blocking are illustrated.

In Case 4, a new compare value is written to a compare register before the first match within the timer period. One can see that, of course, the originally programmed compare match (at $FFFA_H$) will not take place. The first match will be detected at $FFFC_H$. However, it is important to note that the reprogramming of the compare register took place asynchronously - this means, the register was written to without any regard to the current contents of the timer. This is dangerous in the sense that the effect of such an asynchronous reprogramming is not easily predictable. If the timer would have already

reached the originally programmed compare value of $FFFA_H$ by the time the software wrote to the register, a match would have been detected and the reprogramming would go into effect during the next timer period.

The examples in **Figure 17-9** show special cases for compare modes 2 and 3. Case 1 illustrates the effect when the compare value is equal to the reload value of the timer. An interrupt is generated in both modes. In mode 3, the output signal is not affected - it remains at the high level. Setting the compare value equal to the reload value easily enables a 100% duty cycle signal for PWM generation. The important advantage here is that the compare interrupt is still generated and can be used to reload the next compare value. Thus, no special treatment is required for this case (see Case 3).

Cases 2, 4, and 5 show different options for the generation of a 0% duty cycle signal. Case 2 shows an asynchronous reprogramming of the compare value equal to the reload value. At the end of the current timer period, a compare interrupt will be generated, which enables software to set the next compare value. The disadvantage of this method is that at least two timer periods will pass until a new regular compare value can go into effect. The compare match with the reload value $FFF9_H$ will block further compare matches during that timer period. This is additionally illustrated by Case 4.

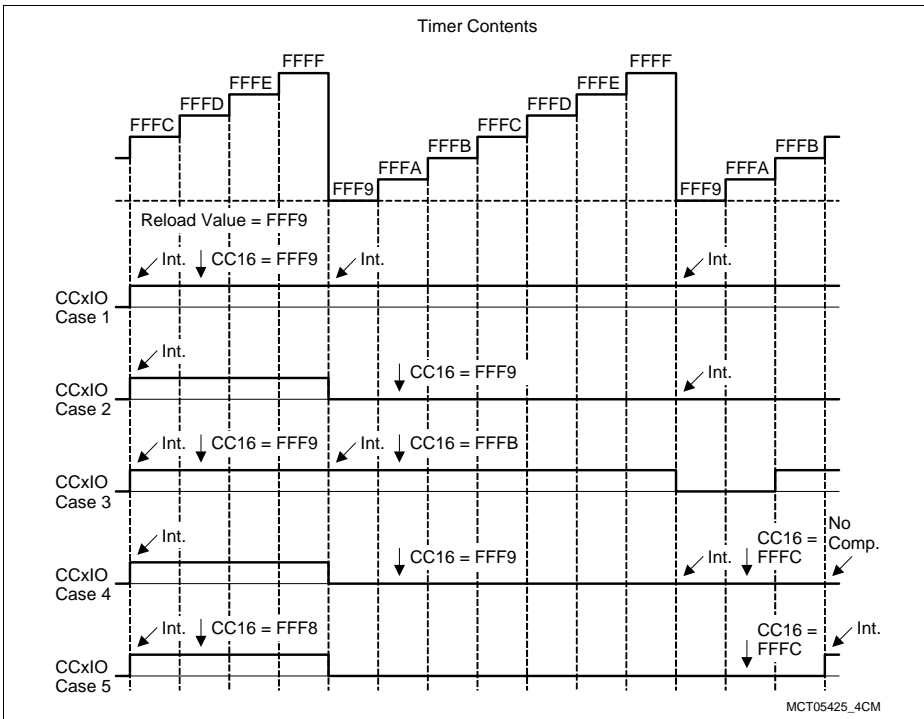


Figure 17-9 Special Cases in Compare Modes 2 and 3

Case 5 shows an option to get around this problem. Here, the compare register is reloaded with $FFF8_H$, a value which is lower than the timer reload value. Thus, the timer will never reach this value, and no compare match will be detected. The output signal will be set to 0 after the first timer overflow. However, after the second overflow, software now reloads the compare register with a regular compare value. As no compare blocking has taken place (since there was no compare match), the newly written compare value will go into effect during the current timer period.

17.1.6 Double-Register Compare Mode

The Double-Register Compare Mode makes it possible to further reduce software overhead for a number of applications. In this mode, two compare registers work together to control one output. This mode is selected via the DRM register, or by a special combination of compare modes for the two registers.

For double-register compare mode, the 16 capture/compare registers of a CAPCOM unit are regarded as two banks of 8 registers each. The lower eight registers form bank1,

while the upper eight registers form bank2. For double-register mode, a bank1 register and a bank2 register form a register pair. Both registers of this register pair operate on the pin associated with the bank1 register.

The relationship between the bank1 and bank2 register of a pair and the effected output pins for double-register compare mode is listed in [Table 17-3](#).

Table 17-3 CAPCOM2 Register Pairs for Double-Register Compare Mode

Register Pair		Used Output Pin	Control Bitfield in CC2_DRM
Bank 1	Bank 2		
CC16	CC24	CC16IO	DR0M
CC17	CC25	CC17IO	DR1M
CC18	CC26	CC18IO	DR2M
CC19	CC27	CC19IO	DR3M
CC20	CC28	CC20IO	DR4M
CC21	CC29	CC21IO	DR5M
CC22	CC30	CC22IO	DR6M
CC23	CC31	CC23IO	DR7M

The double-register compare mode can be programmed individually for each register pair. Double-register compare mode can be selected via a certain combination of compare modes for the two registers of a pair. The bank1 register must be programmed for mode 1 (with port influence), while the bank2 register must be programmed for mode 0 (interrupt-only).

Double-register compare mode can be controlled (this means, enabled or disabled) for each register pair via the associated control bitfield DRxM in register CC2_DRM.

Double-register compare mode can be controlled individually for each of the register pairs.

In the block diagram of the double-register compare mode ([Figure 17-10](#)), a bank2 register will be referred to as CCz, while the corresponding bank1 register will be referred to as CCy.

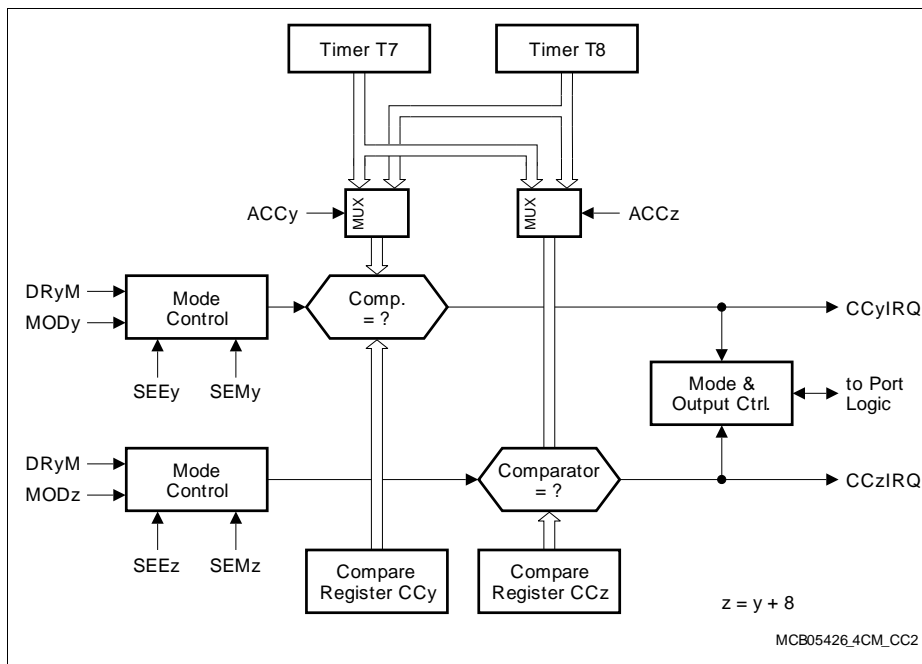


Figure 17-10 Double-Register Compare Mode Block Diagram

When a match is detected for one of the two registers in a register pair (CCy or CCz), the associated interrupt request line (CCyIRQ or CCzIRQ) is activated, and pin CCyIO, corresponding to the bank1 register CCy, is toggled. The generated interrupt always corresponds to the register that caused the match.

Note: If a match occurs simultaneously for both register CCy and register CCz of the register pair, pin CCyIO will be toggled only once, but two separate compare interrupt requests will be generated.

Each of the two registers of a pair can be individually allocated to one of the two timers in the CAPCOM unit. This offers a wide variety of applications, as the two timers can run in different modes with different resolution and frequency. However, this might require sophisticated software algorithms to handle the different timer periods.

Note: The signals CCzIO (which do not serve for double-register compare mode) may be used for general purpose IO.

17.1.7 CAPCOM Interrupts

Upon a capture or compare event, the interrupt request flag CCyIR for the respective capture/compare register CCy is automatically set. This flag can be used to generate an interrupt or trigger a PEC service request when enabled by the interrupt enable bit CCyIE.

Capture interrupts can be regarded as external interrupt requests with the additional feature of recording the time at which the triggering event occurred.

Each of the capture/compare registers (CCy) has its own bitaddressable interrupt control register CC2_CCyIC and its own interrupt vector allocated. These registers are organized in the same way as all other interrupt control registers.

17.1.8 Compare Output Signal Generation

This section discusses the interaction between the CAPCOM Unit and the Port Logic. The block diagram illustrated in [Figure 17-11](#) details the logic of the block “Mode & Output Control”, shown in [Figure 17-5](#), [Figure 17-7](#), and [Figure 17-10](#).

Each output signal is stored in its associated bit of the compare output register CC2_OUT. The individual bits are updated each time an associated compare event occurs. The bits of these registers are connected to the respective port pins as an alternate output function of a port line.

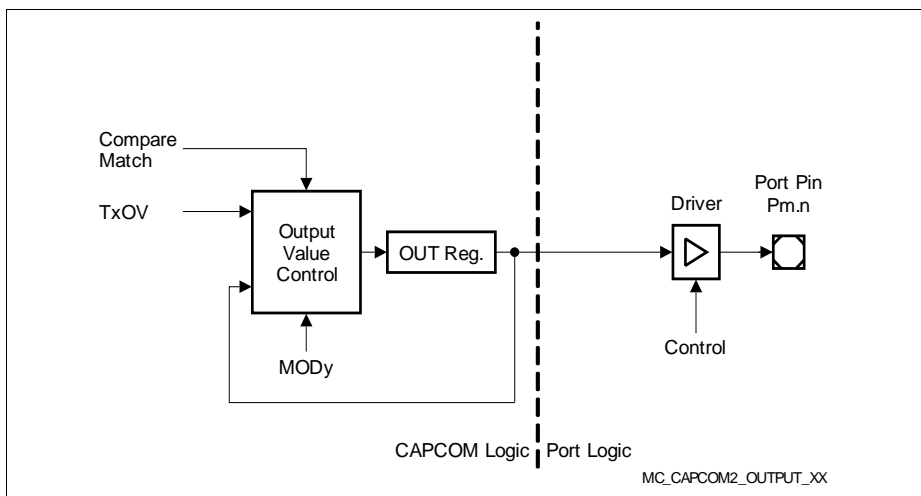


Figure 17-11 Port Output Block Diagram for Compare Modes

Note: A compare output signal is visible at the pin only in compare modes 1 or 3.

The output signal of a compare event can either be a 1, a 0, the complement of the current level, or the previous level. The block 'Output Value Control' determines the correct new level based on the compare event, the timer overflow signal, and the current state of the OUT register bit. For the output toggle function (e.g. in compare mode 1), the state of the OUT register bit is read, inverted, and then written back.

17.1.9 Single Event Mode

If an application requires that one and only one compare event needs to take place (within a certain time frame), single event operation helps to reduce software overhead and to eliminate the need for fast reaction upon events.

In order to achieve a single event operation without this feature, software would have to either disable the compare mode or write a new value, which is outside of the count range of the timer, into the compare register, after the programmed compare match has taken place. Thus, usually an interrupt service routine is required to perform this operation. Interrupt response time may be critical if the timer period is very short - the disable operation needs to be completed before the timer would reach the same value again.

The single event operation eliminates the need for software to react after the first compare match. The complete operation can be set up before the event, and no action is required after the event. The hardware takes care of generating only one event, and then disabling all further compare matches.

This option is programmed via the Single Event Mode register **CC2_SEM** and the Single Event Enable register **CC2_SEE**. Each register provides one bit for each CCy register of a unit.

To setup a single event operation for a CCy register, software first programs the desired compare operation and compare value, and then sets the respective bit in register **CC2_SEM** to enable the single event mode. At last, the respective event enable bit in register **CC2_SEE** is set.

When the programmed compare match occurs, all operations of the selected compare mode take place. In addition, hardware automatically disables all further compare matches and reset the event enable bit in register **CC2_SEE** to 0. As long as this bit is cleared, any compare operation is disabled. To setup a new event, this bit must first be set again.

17.1.10 Staggered and Non-Staggered Operation

The CAPCOM2 unit can run in one of two basic operation modes: Staggered Mode and Non-Staggered Mode. The selection between these modes is performed via register **IOC**.

In staggered mode, a CAPCOM operation cycle consists of 8 module clock cycles, and the outputs of the compare events of the different registers are staggered, that is, the

outputs for compare matches with the same compare value are not switched at the same time, but with a fixed time delay. This operation helps to reduce noise and peak power consumption caused by simultaneous switching outputs.

In non-staggered Mode, a CAPCOM operation cycle is equal to one module clock cycle, and all compare outputs for compare events with the same compare value are switched in the same clock cycle. This mode offers a faster operation and increased resolution of the CAPCOM unit, 8 times higher than in staggered mode.

Staggered Mode

Figure 17-12 illustrates the staggered mode operation for CAPCOM2. In this example, all CCy registers are programmed for compare mode 3.

Registers CC16, CC17, and CC18 are all programmed for a compare value of $FFFE_H$. When the timer increments to $FFFE_H$, the comparator detects a match for all of the three registers. The output CC16IO of register CC16 is switched to 1 one cycle after the comparator match. However, the outputs CC17IO and CC18IO are not switched at the same time, but one, respectively two cycles later. This staggering of the outputs continues for all registers including register CC23. The number of the register indicates the delay of the output signal in clock cycles - the output of register CC23 is switched 7 cycles later than the one of register CC16. In the example, the compare value for register CC13 is set to $FFFD_H$. Thus, the output is switched in the last clock cycle of the CAPCOM cycle in which the timer reached $FFFD_H$.

When the timer overflows, all compare outputs are reset to 0 (compare mode 3). Again, the staggering of the output signals can be seen from **Figure 17-12**.

Looking at registers CC24 through CC31 shows that their outputs are switched in parallel to the respective outputs of registers CC16 through CC23. In fact, the staggering is performed in parallel for the upper and the lower register bank. In this way, it is assured, that both compare signals of a register pair in double-register compare mode operate simultaneously.

Note: This is a general description and only refers to channels connected to pins.

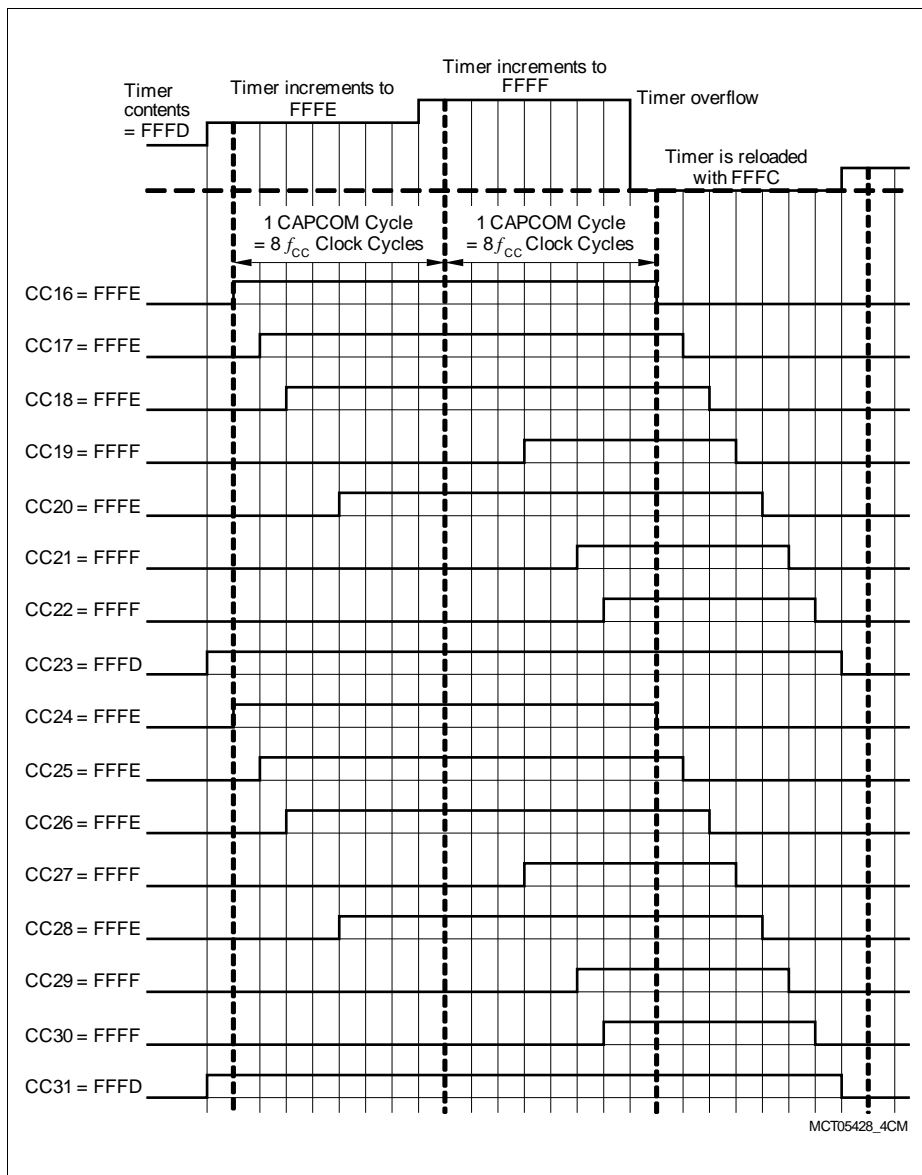


Figure 17-12 Staggered Mode Operation

Non-Staggered Mode

To gain maximum speed and resolution with a CAPCOM unit, it can be switched to non-staggered mode. In this mode, one CAPCOM operation cycle is equal to one module clock cycle. Timer increment and the comparison of its new contents with the contents of the compare register takes place within one clock cycle. The appropriate output signals are switched in the following clock cycle (in parallel to the next possible timer increment and comparison).

Figure 17-13 illustrates the non-staggered mode for CAPCOM2 unit. Note that when the timer overflows, it also takes one additional clock cycle to switch the output signals.

Note: This is a general description and only refers to channels connected to pins.

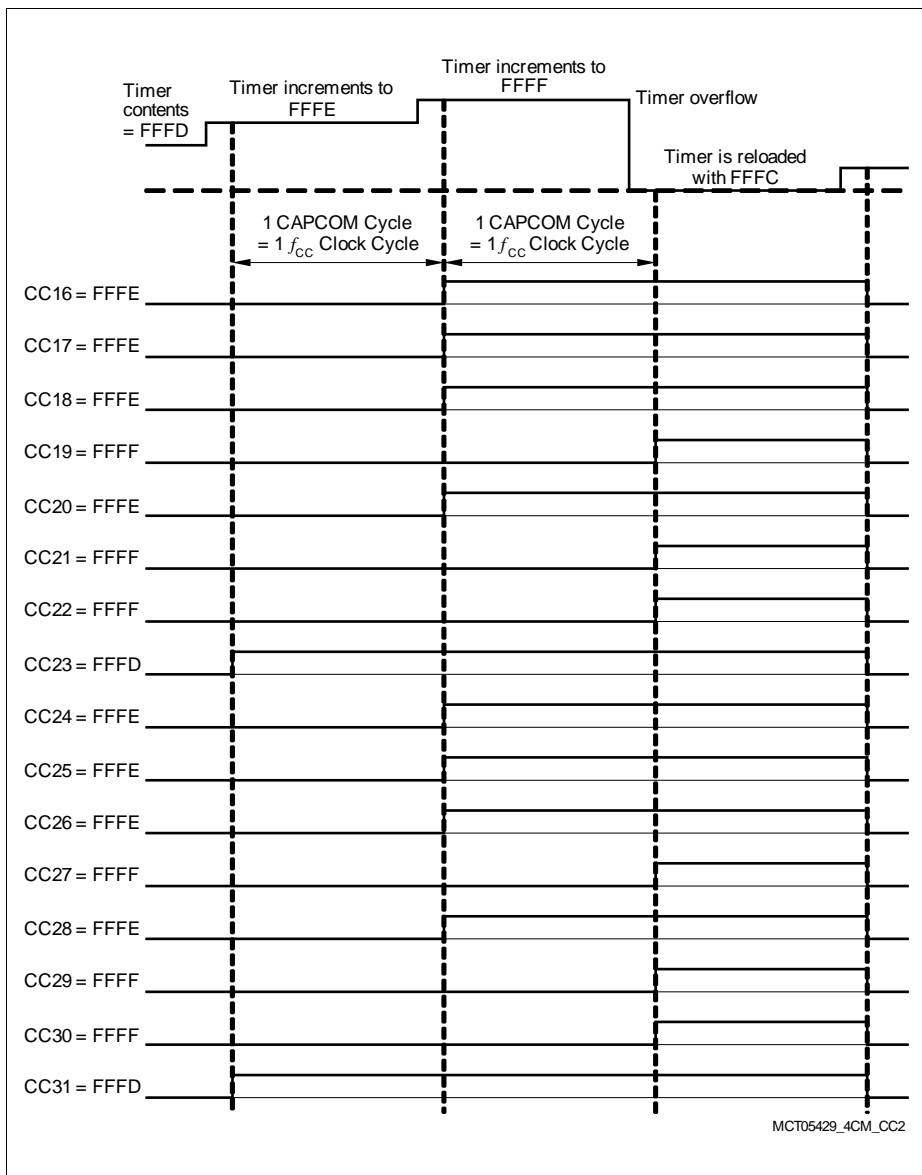


Figure 17-13 Non-Staggered Mode Operation

17.1.11 External Input Signal Requirements

The external input signals of a CAPCOM2 unit are sampled by the CAPCOM2 logic based on the module clock and the basic operation mode (staggered or non-staggered mode). To assure that a signal level is recognized correctly, its high or low level must be held active for at least one complete sampling period.

The duration of a sampling period is one module clock cycle in non-staggered mode, and 8 module clock cycles in staggered mode. To recognize a signal transition, the signal needs to be sampled twice. If the level of the first sampling is different to the level detected during the second sampling, a transition is recognized. Therefore, a minimum of two sampling periods are required for the sampling of an external input signal. Thus, the maximum frequency of an input signal must not be higher than half the module clock frequency in non-staggered mode, and a $1/16^{\text{th}}$ of the module clock frequency in staggered mode.

Table 17-4 summarizes the requirements and limits for external input signals.

Table 17-4 CAPCOM2 External Input Signal Limits

	Non-Staggered Mode	Staggered Mode
Maximum Input Frequency	$f_{\text{CC}} / 2$	$f_{\text{CC}} / 16$
Minimum Input Signal Level Duration	$1 / f_{\text{CC}}$	$8 / f_{\text{CC}}$

In order to use an external signal as a count or capture input, the port pin to which it is connected must be configured as input.

Note: For example for test purposes a pin used as a count or capture input may be configured as output. Software or an other peripheral may control the respective signal and thus trigger count or capture events.

In order to cause a compare output signal to be seen by the external world, the associated port pin must be configured as output. For compare output signals the output of register CC2_OUT is used as an alternate output function of a port.

17.2 CAPCOM2 Registers

The following table presents a summary of the registers provided in the CAPCOM2 module.

Table 17-5 CAPCOM2 Module Register Summary

Name	Description	Address		Reset Value
		16-Bit	8-Bit	

Capture / Compare Unit 2 (CAPCOM2)

CC2_ID	CAPCOM2 Identification Register	FFEE _H	-	50XX _H
CC2_M4	CAPCOM2 Mode Control Register 4	FF22 _H	91 _H	0000 _H
CC2_M5	CAPCOM2 Mode Control Register 5	FF24 _H	92 _H	0000 _H
CC2_M6	CAPCOM2 Mode Control Register 6	FF26 _H	93 _H	0000 _H
CC2_M7	CAPCOM2 Mode Control Register 7	FF28 _H	94 _H	0000 _H
CC2_SEE	CAPCOM2 Single Event Enable Register	FE2A _H	15 _H	0000 _H
CC2_SEM	CAPCOM2 Single Event Mode Register	FE28 _H	14 _H	0000 _H
CC2_DRM	CAPCOM2 Double Register Mode Register	FF2A _H	95 _H	0000 _H
CC2_OUT	CAPCOM2 Output Register	FF2C _H	96 _H	0000 _H
CC2_T7	CAPCOM2 Timer 7 Register	F050 _H	28 _H	0000 _H
CC2_T8	CAPCOM2 Timer 8 Register	F052 _H	29 _H	0000 _H
CC2_T7REL	CAPCOM2 Timer 7 Reload Register	F054 _H	2A _H	0000 _H
CC2_T8REL	CAPCOM2 Timer 8 Reload Register	F056 _H	2B _H	0000 _H
CC2_T78CON	CAPCOM2 Timer 7/8 Control Register	FF20 _H	90 _H	0000 _H
CC2_IOC	CAPCOM2 I/O Control Register	F066 _H	33 _H	0000 _H
CC2_CC16	CAPCOM2 Register 16	FE60 _H	30 _H	0000 _H
CC2_CC17	CAPCOM2 Register 17	FE62 _H	31 _H	0000 _H
CC2_CC18	CAPCOM2 Register 18	FE64 _H	32 _H	0000 _H
CC2_CC19	CAPCOM2 Register 19	FE66 _H	33 _H	0000 _H
CC2_CC20	CAPCOM2 Register 20	FE68 _H	34 _H	0000 _H
CC2_CC21	CAPCOM2 Register 21	FE6A _H	35 _H	0000 _H
CC2_CC22	CAPCOM2 Register 22	FE6C _H	36 _H	0000 _H
CC2_CC23	CAPCOM2 Register 23	FE6E _H	37 _H	0000 _H
CC2_CC24	CAPCOM2 Register 24	FE70 _H	38 _H	0000 _H

Table 17-5 CAPCOM2 Module Register Summary (cont'd)

Name	Description	Address		Reset Value
		16-Bit	8-Bit	
CC2_CC25	CAPCOM2 Register 25	FE72 _H	39 _H	0000 _H
CC2_CC26	CAPCOM2 Register 26	FE74 _H	3A _H	0000 _H
CC2_CC27	CAPCOM2 Register 27	FE76 _H	3B _H	0000 _H
CC2_CC28	CAPCOM2 Register 28	FE78 _H	3C _H	0000 _H
CC2_CC29	CAPCOM2 Register 29	FE7A _H	3D _H	0000 _H
CC2_CC30	CAPCOM2 Register 30	FE7C _H	3E _H	0000 _H
CC2_CC31	CAPCOM2 Register 31	FE7E _H	3F _H	0000 _H
CC2_T7IC	CAPCOM2 Timer 7 Interrupt Control Register	FF6C _H	BD _H	0000 _H
CC2_T8IC	CAPCOM2 Timer 8 Interrupt Control Register	FF6E _H	BE _H	0000 _H
CC2_CC16IC	CAPCOM2 Register 16 Interrupt Control Register Shared Interrupt node, see ISSR register	F1C0 _H	B0 _H	0000 _H
CC2_CC17IC	CAPCOM2 Register 17 Interrupt Control Register Shared Interrupt node, see ISSR register	F1C2 _H	B1 _H	0000 _H
CC2_CC18IC	CAPCOM2 Register 18 Interrupt Control Register Shared Interrupt node, see ISSR register	F1C4 _H	B2 _H	0000 _H
CC2_CC19IC	CAPCOM2 Register 19 Interrupt Control Register Shared Interrupt node, see ISSR register	F1C6 _H	B3 _H	0000 _H
CC2_CC20IC	CAPCOM2 Register 20 Interrupt Control Register Shared Interrupt node, see ISSR register	F1C8 _H	B4 _H	0000 _H
CC2_CC21IC	CAPCOM2 Register 21 Interrupt Control Register Shared Interrupt node, see ISSR register	F1CA _H	B5 _H	0000 _H
CC2_CC22IC	CAPCOM2 Register 22 Interrupt Control Register Shared Interrupt node, see ISSR register	F1CC _H	B6 _H	0000 _H
CC2_CC23IC	CAPCOM2 Register 23 Interrupt Control Register Shared Interrupt node, see ISSR register	F1CE _H	B7 _H	0000 _H

Table 17-5 CAPCOM2 Module Register Summary (cont'd)

Name	Description	Address		Reset Value
		16-Bit	8-Bit	
CC2_CC24IC	CAPCOM2 Register 24 Interrupt Control Register Shared Interrupt node, see ISSR register	F1D0 _H	B8 _H	0000 _H
CC2_CC25IC	CAPCOM2 Register 25 Interrupt Control Register Shared Interrupt node, see ISSR register	F1D2 _H	B9 _H	0000 _H
CC2_CC26IC	CAPCOM2 Register 26 Interrupt Control Register Shared Interrupt node, see ISSR register	F1D4 _H	BA _H	0000 _H
CC2_CC27IC	CAPCOM2 Register 27 Interrupt Control Register Shared Interrupt node, see ISSR register	F1D6 _H	BB _H	0000 _H
CC2_CC28IC	CAPCOM2 Register 28 Interrupt Control Register Shared Interrupt node, see ISSR register	F1D8 _H	BC _H	0000 _H
CC2_CC29IC	CAPCOM2 Register 29 Interrupt Control Register Shared Interrupt node, see ISSR register	F1DA _H	C2 _H	0000 _H
CC2_CC30IC	CAPCOM2 Register 30 Interrupt Control Register Shared Interrupt node, see ISSR register	F1DC _H	C6 _H	0000 _H
CC2_CC31IC	CAPCOM2 Register 31 Interrupt Control Register Shared Interrupt node, see ISSR register	F1DE _H	CA _H	0000 _H

17.2.1 Identification Register

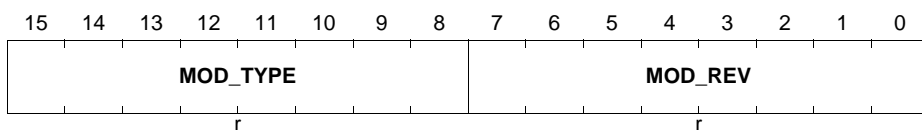
For module type and revision identification the CAPCOM2 unit provides a specific read-only identification register.

CC2_ID

CAPCOM2 Identification Register

MEM (FFEE_H)

Reset Value:50XX_H



Field	Bits	Typ	Description
MOD_REV	[7:0]	r	Module Revision Number Defines the revision number. The value of a module revision starts with 01 _H (first revision).
MOD_TYPE	[15:8]	r	Module Identification Number Defines the module identification number (50 _H = CAPCOM2).

17.2.2 Timer 7/8 Registers

CC2_T7

CAPCOM2 Timer 7 Register

ESFR (F050_H/28_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T7															
rw															

Field	Bits	Typ	Description
T7	[15:0]	rw	Timer 7 Current Value Current value of the Timer 7

CC2_T8

CAPCOM2 Timer 8 Register

ESFR (F052_H/29_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T8															
rw															

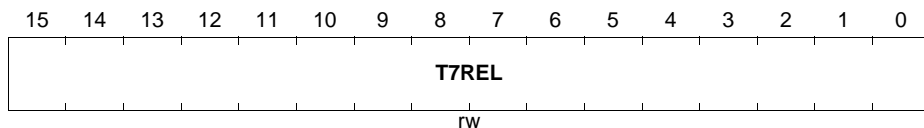
Field	Bits	Typ	Description
T8	[15:0]	rw	Timer 8 Current Value Current value of the Timer 8

CC2_T7REL

CAPCOM2 Timer 7 Reload Register

ESFR (F054_H/2A_H)

Reset Value: 0000_H



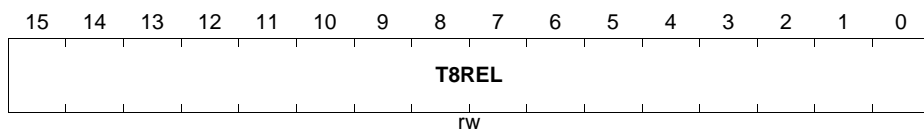
Field	Bits	Typ	Description
T7REL	[15:0]	rw	Timer 7 Reload Value Reload value of the Timer 7

CC2_T8REL

CAPCOM2 Timer 8 Reload Register

ESFR (F056_H/2B_H)

Reset Value: 0000_H



Field	Bits	Typ	Description
T8REL	[15:0]	rw	Timer 8 Reload Value Reload value of the Timer 8

17.2.3 Timer 7/8 Control Register

CC2_T78CON

CAPCOM2 Timer 7/8 Control Register

SFR (FF20_H/90_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
-	T8R	T8RSEL	T8M		T8I		-	T7R	T7RSEL	T7M		T7I			
-	rw	rw	rw		rw		-	rw	rw	rw		rw			

Field	Bits	Typ	Description
T7I, T8I	[2:0], [10:8]	rw	Timer/Counter Tx Input Selection Timer Mode (TxM = 0): Input frequency $f_{Tx} = f_{CC}/2^{(<TxI>+3)}$ or $f_{CC}/2^{(<TxI>)}$, depending on (non-)staggered mode, see Table 17-1 Counter Mode (TxM = 1): 000 _B Overflow/Underflow of GPT Timer T6 001 _B Positive (rising) edge on pin TxIN 010 _B Negative (falling) edge on pin TxIN 011 _B Any edge (rising and falling) on pin TxIN 1XX _B Reserved. Do not use this combination! <i>Note: For timer T8 the only option in counter mode is 000_B. T8 stop in all other cases.</i>
T7M, T8M	3, 11	rw	Timer / Counter x Mode Selection 0 _B Timer Mode 1 _B Counter Mode
T7R, T8R	6, 14	rw	Timer / Counter x Run Control 0 _B Timer/Counter x is disabled. 1 _B Timer/Counter x is enabled.
T7RSEL	[5:4]	rw	Timer T7 External Run Selection Bit field T7RSEL defines the event of signal T7HR that can set the run bit T7R by HW. 00 _B The external setting of T7R is disabled. 01 _B Bit T7R is set if a rising edge of signal T7HR is detected. 10 _B Bit T7R is set if a falling edge of signal T7HR is detected. 11 _B Bit T7R is set if an edge of signal T7HR is detected.

Field	Bits	Typ	Description
T8RSEL	[13:12]	rw	Timer T8 External Run Selection Bit field T8RSEL defines the event of signal T8HR that can set the run bit T8R by HW. 00 _B The external setting of T8R is disabled. 01 _B Bit T8R is set if a rising edge of signal T8HR is detected. 10 _B Bit T8R is set if a falling edge of signal T8HR is detected. 11 _B Bit T8R is set if an edge of signal T8HR is detected.

17.2.4 Capture/Compare Registers

CC2_CCy (y=16-31)

CAPCOM2 Capture/Compare Register y

SFR (FE60_H-32+2*y / 30_H-16+y)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CC															
rwh															

Field	Bits	Typ	Description
CC	[15:0]	rwh	Capture Register Value Current value of the Capture/Compare register y

17.2.5 Capture/Compare Mode Registers

CC2_M4

CAPCOM2 Mode Control Register 4

SFR (FF22_H/91_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACC 19	MOD19		ACC 18	MOD18		ACC 17	MOD17		ACC 16	MOD16					
rw	rw		rw	rw		rw	rw		rw	rw					

Field	Bits	Type	Description
ACCy (y=16-19)	4*y-61	rw	Allocation Bit for CAPCOM Register CCy (y = 16-19) 0 _B CCy allocated to Timer T7 1 _B CCy allocated to Timer T8
MODy (y=16-19)	[4*y-62:4*y-64]	rw	Mode Selection for CAPCOM Register CCy (y = 16-19) See Table 17-2 .

CC2_M5

CAPCOM2 Mode Control Register 5

SFR (FF24_H/92_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACC 23	MOD23		ACC 22	MOD22		ACC 21	MOD21		ACC 20	MOD20					
rw	rw		rw	rw		rw	rw		rw	rw					

Field	Bits	Type	Description
ACCy (y=20-23)	4*y-77	rw	Allocation Bit for CAPCOM Register CCy (y = 20-23) 0 _B CCy allocated to Timer T7 1 _B CCy allocated to Timer T8
MODy (y=20-23)	[4*y-78:4*y-80]	rw	Mode Selection for CAPCOM Register CCy (y = 20-23) See Table 17-2 .

CC2_M6

CAPCOM2 Mode Control Register 6

SFR (FF26_H/93_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACC 27	MOD27			ACC 26	MOD26			ACC 25	MOD25			ACC 24	MOD24		
rw	rw			rw	rw			rw	rw			rw	rw		

Field	Bits	Type	Description
ACC_y (y=24-27)	4*y-93	rw	Allocation Bit for CAPCOM Register CC_y (y = 24-28) 0 _B CC _y allocated to Timer T7 1 _B CC _y allocated to Timer T8
MOD_y (y=24-27)	[4*y-94:4*y-96]	rw	Mode Selection for CAPCOM Register CC_y (y = 24-27) See Table 17-2 .

CC2_M7

CAPCOM2 Mode Control Register 7

SFR (FF28_H/94_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACC 31	MOD31			ACC 30	MOD30			ACC 29	MOD29			ACC 28	MOD28		
rw	rw			rw	rw			rw	rw			rw	rw		

Field	Bits	Type	Description
ACC_y (y=28-31)	4*y-109	rw	Allocation Bit for CAPCOM Register CC_y (y = 28-31) 0 _B CC _y allocated to Timer T7 1 _B CC _y allocated to Timer T8
MOD_y (y=28-31)	[4*y-110:4*y-112]	rw	Mode Selection for CAPCOM Register CC_y (y = 28-31) See Table 17-2 .

17.2.6 Compare Output Register

The CAPCOM2's compare output serves two registers in parallel, the port output register for binary compatibility and a separate one for enhanced functionality. The CAPCOM2 compare output and the port output latch is muxed in the port logic.

Compare output is visible at the pin if compare mode 1 or 3 is programmed in the CAPCOM2.

CC2_OUT

CAPCOM2 Compare Output Register

SFR (FF2C _H /96 _H)														Reset Value: 0000 _H	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IO	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
CCyIO (y=16-31)	y-16	rwh	Compare Output for Channel y Alternative port output for the associated port pin

17.2.7 Double-Register Compare Mode Register

CC2_DRM

CAPCOM2 Double-Register Compare Mode Register

SFR (FF2A_H/95_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DR7M		DR6M		DR5M		DR4M		DR3M		DR2M		DR1M		DR0M	
rw		rw		rw		rw		rw		rw		rw		rw	

Field	Bits	Type	Description
DRxM (x=0-7)	[2*x+1:2*x]	rw	Double Register x Compare Mode Selection 00 _B DRM is controlled via the combination of compare modes 1 and 0 (compatibility mode) 01 _B DRM disabled regardless of compare modes 10 _B DRM enabled regardless of compare modes 11 _B Reserved <i>Note: "x" indicates the register pair index in a bank.</i>

17.2.8 IOC Register

CC2_IOC

CAPCOM2 I/O Control Register ESFR (F066_H/33_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
						-						0	ST AG	0	-
						-						r	rw	rw	-

Field	Bits	Typ	Description
0	1	rw	Reserved read as '0', do not set this bit
STAG	2	rw	Staggered Mode Control 0 _B CAPCOM operates in Staggered Mode 1 _B CAPCOM operates in Non-Staggered Mode
0	3	r	Reserved read as '0', do not set this bit
0	[15:4]	r	Reserved read as '0'

17.2.9 Single Event Mode Register

CC2_SEM

CAPCOM2 Single Event Mode Control Register

SFR (FE28_H/14_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEM	SEM	SEM	SEM	SEM	SEM	SEM	SEM	SEM	SEM	SEM	SEM	SEM	SEM	SEM	SEM
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW

Field	Bits	Type	Description
SEMy (y = 16-31)	y-16	rW	Single Event Mode Control 0 _B Single Event Mode disabled for channel y 1 _B Single Event Mode enabled for channel y

CC2_SEE

CAPCOM2 Single Event Enable Register

SFR (FE2A_H/15_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEE	SEE	SEE	SEE	SEE	SEE	SEE	SEE	SEE	SEE	SEE	SEE	SEE	SEE	SEE	SEE
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW	rW

Field	Bits	Type	Description
SEEy (y = 16-31)	y-16	rW	Single Event Enable Control 0 _B Single Event disabled for channel y 1 _B Single Event enabled for channel y <i>Note: This bit is cleared by hardware after the event has occurred.</i>

17.2.10 KSCCFG Register

CC2_KSCCFG

CAPCOM2 Kernel State Configuration Register

SFR(FE24_H/12_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BP COM	0	COMCFG		BP SUM	0	SUMCFG		BP NOM	0	NOMCFG		0		BP MOD EN	MOD EN
w	r	rw		w	r	rw		w	r	rw		r		w	rw

Field	Bits	Type	Description
MODEN	0	rw	<p>Module Enable</p> <p>This bit enables the module kernel clock and the module functionality.</p> <p>0_B The module is switched off. It does not react on mode control actions and the module clock is switched off immediately (without stop condition). The module does not react on read accesses and ignores write accesses.</p> <p>1_B The module is switched on and can operate. After writing 1 to MODEN, it is recommended to read register KSCCFG to avoid pipeline effects in the control block before accessing other CAPCOM2 registers.</p> <p><i>Note: This bit is reset by an application reset.</i></p>
BPMODEN	1	w	<p>Bit Protection for MODEN</p> <p>This bit enables the write access to the bit MODEN. It always reads 0. It is only active during the write access cycle.</p> <p>0_B MODEN is not changed.</p> <p>1_B MODEN is updated with the written value.</p> <p><i>Note: This bit is reset by an application reset.</i></p>

Field	Bits	Type	Description
NOMCFG	[5:4]	rw	Normal Operation Mode Configuration This bit field defines the kernel mode applied in normal operation mode. 0X _B The module is switched on. 1X _B The module is switched off. This field is taken into account for CR = 00 or 11. <i>Note: This bit is reset by an application reset.</i>
BPNO	7	w	Bit Protection for NOMCFG This bit enables the write access to the bit field NOMCFG. It always reads 0. It is only active during the write access cycle. 0 _B NOMCFG is not changed. 1 _B NOMCFG is updated with the written value. <i>Note: This bit is reset by an application reset.</i>
SUMCFG	[9:8]	rw	Suspend Mode Configuration This bit field defines the kernel mode applied in suspend mode. 0X _B The module is switched on. 1X _B The module is switched off. This field is taken into account for CR = 01. <i>Note: This bit is reset by a debug reset.</i>
BPSUM	11	w	Bit Protection for SUMCFG This bit enables the write access to the bit field SUMCFG. It always reads 0. It is only active during the write access cycle. 0 _B SUMCFG is not changed. 1 _B SUMCFG is updated with the written value. <i>Note: This bit is reset by a debug reset.</i>
COMCFG	[13:12]	rw	Clock Off Mode Configuration This bit field defines the kernel mode applied in clock off mode. 0X _B The module is switched on. 1X _B The module is switched off. This field is taken into account for CR = 10. <i>Note: This bit is reset by an application reset.</i>

Field	Bits	Type	Description
BPCOM	15	w	Bit Protection for COMCFG This bit enables the write access to the bit field COMCFG. It always reads 0. It is only active during the write access cycle. 0 _B COMCFG is not changed. 1 _B COMCFG is updated with the written value. <i>Note: This bit is reset by an application reset.</i>
0	[3:2], 6, 10, 14	r	Reserved; returns 0 if read; should be written with 0;

17.3 Module Implementation

This section describes the connections of the CAPCOM unit to its environment.

17.3.1 Interfaces of the CAPCOM2 Unit

The CAPCOM2 unit is connected to its environment in different ways. These connections are summarized in [Table 17-6](#).

Internal Connections

The overflow/underflow signal T6OFL of GPT2 timer T6 is connected to the CAPCOM2 input T6OUF, providing an optional clock source for the CAPCOM timers.

Synchronous starting is supported by bit SCU_SYSCON1.GLCCST.

Compare output signals can trigger A/D conversions, trigger serial transmissions (USIC), and generate request signals for the external request unit (ERU).

The 18 interrupt request lines of the CAPCOM2 unit are connected to the interrupt control block. The channel interrupt request lines share interrupt nodes with other sources. The selection is done using register SCU_ISSR.

The CAPCOM2 module is clocked with the XE166U system clock, so $f_{CC} = f_{SYS}$.

External Connections

Eight capture/compare signals of the CAPCOM2 unit are connected with input/output ports of the XE166U. Depending on the selected direction, these ports may accept capture trigger signals from the external system or issue compare output signals to external circuitry.

Note: Capture trigger signals may also be derived from output pins. In this case, software can generate the trigger edges, for example.

Timer T7 can be clocked by an external signal.

Table 17-6 CAPCOM2 Connections in XE166U

Signal	from/to Module	I/O to CAPCOM2	Can be used to/as
T7IN	P5.9	I	Timer 7 input from port
T8IN	CCU60_SR2	I	CCU60 interrupt request
T6OUF	T6OFL (GPT12)	I	GPT12 timer T6 overflow
T7HR	GLCCST (SCU)	I	Global CAPCOM start
T8HR	GLCCST (SCU)	I	Global CAPCOM start
CC16IO	P2.3	I	Capture/Compare input
	P2.3 ADC0_REQTR0A	O	Capture/Compare output ADC0 request trigger

Table 17-6 CAPCOM2 Connections in XE166U (cont'd)

Signal	from/to Module	I/O to CAPCOM2	Can be used to/as
CC17IO	P2.4	I	Capture/Compare input
	P2.4 ADC0_REQTR1A	O	Capture/Compare output ADC0 request trigger
CC18IO	P2.5	I	Capture/Compare input
	P2.5 ADC0_REQTR2A	O	Capture/Compare output ADC0 request trigger
CC19IO	P2.6	I	Capture/Compare input
	P2.6	O	Capture/Compare output
CC20IO	P2.7	I	Capture/Compare input
	P2.7	O	Capture/Compare output
CC21IO	P2.8	I	Capture/Compare input
	P2.8	O	Capture/Compare output
CC22IO	P2.9	I	Capture/Compare input
	P2.9	O	Capture/Compare output
CC23IO	P2.10	I	Capture/Compare input
	P2.10 ERU_3A3	O	Capture/Compare output External Request Select input
CC24IO	U0C0_DX2E	O	USIC0 Channel 0 time slot
CC25IO	-	IO	Not connected
CC26IO	-	IO	Not connected
CC27IO	WUT_TRG	I	Wake-up Timer Trigger Event (SCU)
CC28IO	ERU_OGU03	O	Interrupt trigger source
CC29IO	ERU_OGU13	O	Interrupt trigger source
CC30IO	ERU_OGU23	O	Interrupt trigger source
CC31IO	ERU_OGU33	O	Interrupt trigger source

18 Capture/Compare Unit 6 (CCU6)

The CCU6 is a high-resolution 16-bit capture and compare unit with application specific modes, mainly for AC drive control. Special operating modes support the control of Brushless DC-motors using Hall sensors or Back-EMF detection. Furthermore, block commutation and control mechanisms for multi-phase machines are supported. It also supports inputs to start several timers synchronously, an important feature in devices with several CCU6 modules.

This chapter is structured as follows:

- Introduction (see [Section 18.1](#))
including the register overview (see [Section 18.1.3](#))
- Operating T12 (see [Section 18.2](#))
including T12 related registers (see [Section 18.2.8](#))
and capture/compare control registers (see [Section 18.2.9](#))
- Operating T13 (see [Section 18.3](#))
including T13 related registers (see [Section 18.3.6](#))
- Trap handling (see [Section 18.4](#))
- Multi-Channel mode (see [Section 18.5](#))
- Hall sensor mode (see [Section 18.6](#))
- Modulation control registers (see [Section 18.7](#))
- Interrupt handling (see [Section 18.8](#))
including interrupt registers (see [Section 18.8.2](#))
- General module operation (see [Section 18.9](#))
including general registers (see [Section 18.9.3](#))
- Module implementation (see [Section 18.10](#))

18.1 Introduction

The CCU6 unit is made up of a Timer T12 Block with three capture/compare channels and a Timer T13 Block with one compare channel. The T12 channels can independently generate PWM signals or accept capture triggers, or they can jointly generate control signal patterns to drive AC-motors or inverters.

A rich set of status bits, synchronized updating of parameter values via shadow registers, and flexible generation of interrupt request signals provide means for efficient software-control.

*Note: The capture/compare module itself is named CCU6 (capture/compare unit 6).
A capture/compare channel inside this module is named CC6x.*

18.1.1 Feature Set Overview

This section gives an overview over the different building blocks and their main features.

Timer 12 Block Features

- Three capture/compare channels, each channel can be used either as capture or as compare channel
- Generation of a three-phase PWM supported (six outputs, individual signals for high-side and low-side switches)
- 16-bit resolution, maximum count frequency = peripheral clock
- Dead-time control for each channel to avoid short-circuits in the power stage
- Concurrent update of T12 registers
- Center-aligned and edge-aligned PWM can be generated
- Single-shot mode supported
- Start can be controlled by external events
- Capability of counting external events
- Many interrupt request sources
- Hysteresis-like control mode

Timer 13 Block Features

- One independent compare channel with one output
- 16-bit resolution, maximum count frequency = peripheral clock
- Concurrent update of T13 registers
- Can be synchronized to T12
- Interrupt generation at period-match and compare-match
- Single-shot mode supported
- Start can be controlled by external events
- Capability of counting external events

Additional Specific Functions

- Block commutation for Brushless DC-drives implemented
- Position detection via Hall-sensor pattern
- Noise filter supported for position input signals
- Automatic rotational speed measurement and commutation control for block commutation
- Integrated error handling
- Fast emergency stop without CPU load via external signal ($\overline{\text{CTRAP}}$)
- Control modes for multi-channel AC-drives
- Output levels can be selected and adapted to the power stage

18.1.2 Block Diagram

The Timer T12 can operate in capture and/or compare mode for its three channels. The modes can also be combined (e.g. a channel operates in compare mode, whereas another channel operates in capture mode). The Timer T13 can operate in compare mode only. The multi-channel control unit generates output patterns which can be modulated by T12 and/or T13. The modulation sources can be selected and combined for the signal modulation.

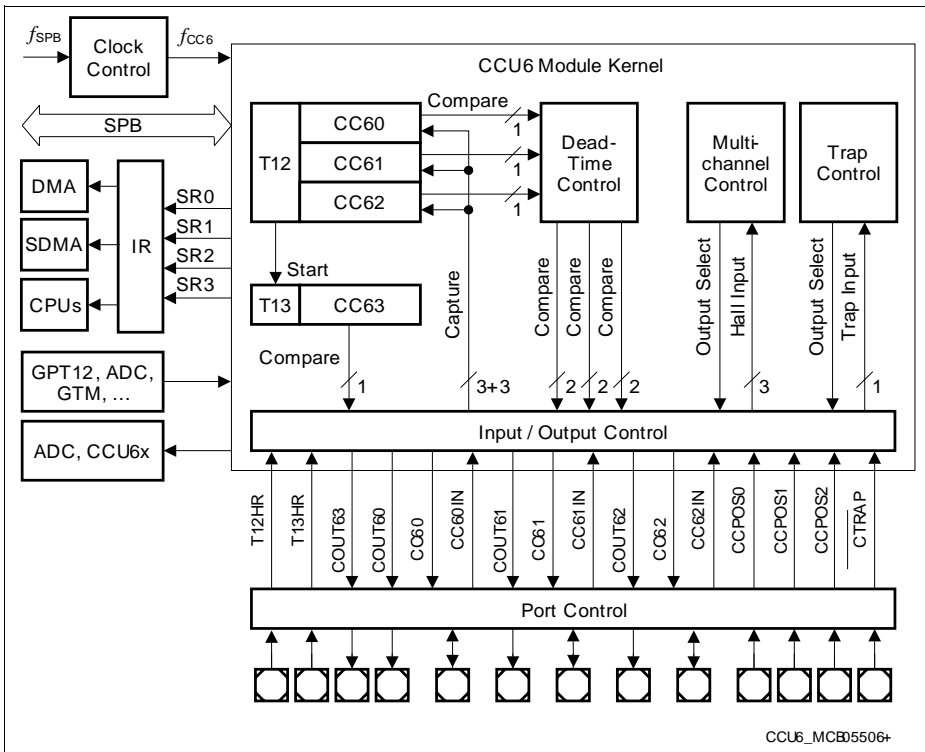


Figure 18-1 CCU6 Block Diagram

18.1.3 Register Overview

For the generation of the overall register table, the prefix “CCU6x_” has to be added to the register names in this table to identify the registers of different CCU6 modules that are implemented. In this naming convention, x indicates the module number.

Table 18-1 shows all registers required for programming of a CCU6 module. It summarizes the CCU6 kernel registers and defines the offset and the reset values. 8-bit short addresses are not available for this module.

T12 related Registers	Cap/Com Control Registers	Interrupt Status/ Control Registers	General Registers
T12	CMPSTAT	IS	KSCFG
T12PR	CMPMODIF	ISS	KSCSR
T12DTC	T12MSEL	ISR	PISELH
CC60R	TCTR0	INP	PISELL
CC60SR	TCTR2	IEN	ID
CC61R	TCTR4	0IC	
CC61SR		1IC	
CC62R		2IC	
CC62SR		3IC	
	Modulation Control Registers		
	MODCTR		
	TRPCTR		
	PSLR		
	MCMCTR		
	MCMOUTS		
	MCMOUT		
T13 related Registers			
T13			
T13PR			
CC63R			
CC63SR			

CCU6_regs2

Figure 18-2 CCU6 Registers

Table 18-1 CCU6 Module Register Summary

Short Name	Description	Offset	Reset Value	See Page
General Registers				
ID	Module Identification Register	08 _H	54XX _H	Page 18-107
PISELL	Module Port Input Select Register	04 _H	0000 _H	Page 18-107
PISELH	Module Port Input Select Register	06 _H	0000 _H	Page 18-109
KSCFG	Kernel State Configuration Register	00 _H	0000 _H	Page 18-112
KSCSR	Kernel State Control Sensitivity Register	0E _H	0000 _H	Page 18-114

Timer T12 related Registers

T12	Timer 12 Counter Register	10 _H	0000 _H	Page 18-32
T12PR	Timer 12 Period Register	12 _H	0000 _H	Page 18-32
T12DTC	Dead-Time Control Register for Timer T12	14 _H	0000 _H	Page 18-35
CC60R	Capture/Compare Register Channel CC60	18 _H	0000 _H	Page 18-33
CC61R	Capture/Compare Register Channel CC61	1A _H	0000 _H	Page 18-33
CC62R	Capture/Compare Register Channel CC62	1C _H	0000 _H	Page 18-33
CC60SR	Capture/Compare Shadow Register Channel CC60	20 _H	0000 _H	Page 18-34
CC61SR	Capture/Compare Shadow Register Channel CC61	22 _H	0000 _H	Page 18-34
CC62SR	Capture/Compare Shadow Register Channel CC62	24 _H	0000 _H	Page 18-34

Capture/Compare Control Registers

CMPSTAT	Compare State Register	28 _H	0000 _H	Page 18-37
CMPMODIF	Compare State Modification Register	2A _H	0000 _H	Page 18-39
T12MSEL	T12 Capture/Compare Mode Select Register	46 _H	0000 _H	Page 18-40
TCTR0	Timer Control Register 0	2C _H	0000 _H	Page 18-41

Table 18-1 CCU6 Module Register Summary (cont'd)

Short Name	Description	Offset	Reset Value	See Page
TCTR2	Timer Control Register 2	2E _H	0000 _H	Page 18-44
TCTR4	Timer Control Register 4	26 _H	0000 _H	Page 18-47

Timer T13 related Registers

T13	Timer 13 Counter Register	30 _H	0000 _H	Page 18-62
T13PR	Timer 13 Period Register	32 _H	0000 _H	Page 18-63
CC63R	Compare Register for Timer 13	34 _H	0000 _H	Page 18-64
CC63SR	Compare Shadow Register for Timer 13	36 _H	0000 _H	Page 18-64

Modulation Control Registers

MODCTR	Modulation Control Register	40 _H	0000 _H	Page 18-78
TRPCTR	Trap Control Register	42 _H	0000 _H	Page 18-80
PSLR	Passive State Level Register	44 _H	0000 _H	Page 18-83
MCMOUTS	Multi-Channel Mode Output Shadow Register	4A _H	0000 _H	Page 18-86
MCMOUT	Multi-Channel Mode Output Register	4C _H	0000 _H	Page 18-87
MCMCTR	Multi-Channel Mode Control Register	4E _H	0000 _H	Page 18-84

Interrupt Status and Node Registers

IS	Interrupt Status Register	50 _H	0000 _H	Page 18-91
ISS	Interrupt Status Set Register	52 _H	0000 _H	Page 18-94
ISR	Interrupt Status Reset Register	54 _H	0000 _H	Page 18-96
INP	Interrupt Node Pointer Register	56 _H	3940 _H	Page 18-101
IEN	Interrupt Node Pointer Register	58 _H	0000 _H	Page 18-98

Note: In the case of a write access to addresses inside the address range (that is covered by the same chip select signal), but that are not the addresses explicitly mentioned for the module, the write access is not taken into account for the module. The same principle is valid for read accesses. In case of a read access to another address, the module does not react.

18.2 Operating Timer T12

The timer T12 block is the main unit to generate the 3-phase PWM signals. A 16-bit counter is connected to 3 channel registers via comparators, that generate a signal when the counter contents match one of the channel register contents. A variety of control functions facilitate the adaptation of the T12 structure to different application needs. Besides the 3-phase PWM generation, the T12 block offers options for individual compare and capture functions, as well as dead-time control and hysteresis-like compare mode.

This section provides information about:

- T12 overview (see [Section 18.2.1](#))
- Counting scheme (see [Section 18.2.2](#))
- Compare modes (see [Section 18.2.3](#))
- Compare mode output path (see [Section 18.2.4](#))
- Capture modes (see [Section 18.2.5](#))
- Shadow transfer (see [Section 18.2.6](#))
- T12 operating mode selection (see [Section 18.2.7](#))
- T12 counter register description (see [Section 18.2.8](#))

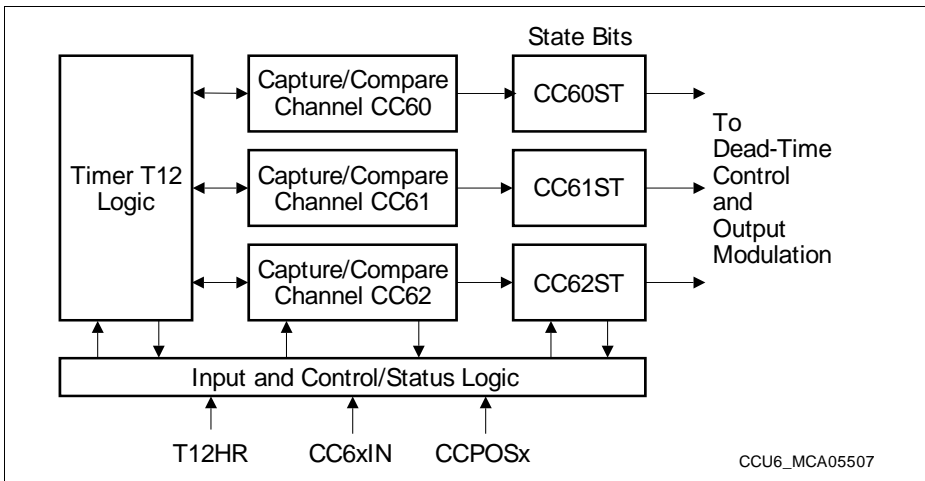


Figure 18-3 Overview Diagram of the Timer T12 Block

18.2.1 T12 Overview

Figure 18-4 shows a detailed block diagram of Timer T12. The functions of the timer T12 block are controlled by bits in registers **TCTR0**, **TCTR2**, **TCTR4**, and **PISELL**.

Timer T12 receives its input clock (f_{T12}) from the module clock f_{CC6} via a programmable prescaler and an optional 1/256 divider or from an input signal T12HR. These options are controlled via bit fields T12CLK and T12PRE (see **Table 18-2**). T12 can count up or down, depending on the selected operation mode. A direction flag, CDIR, indicates the current counting direction.

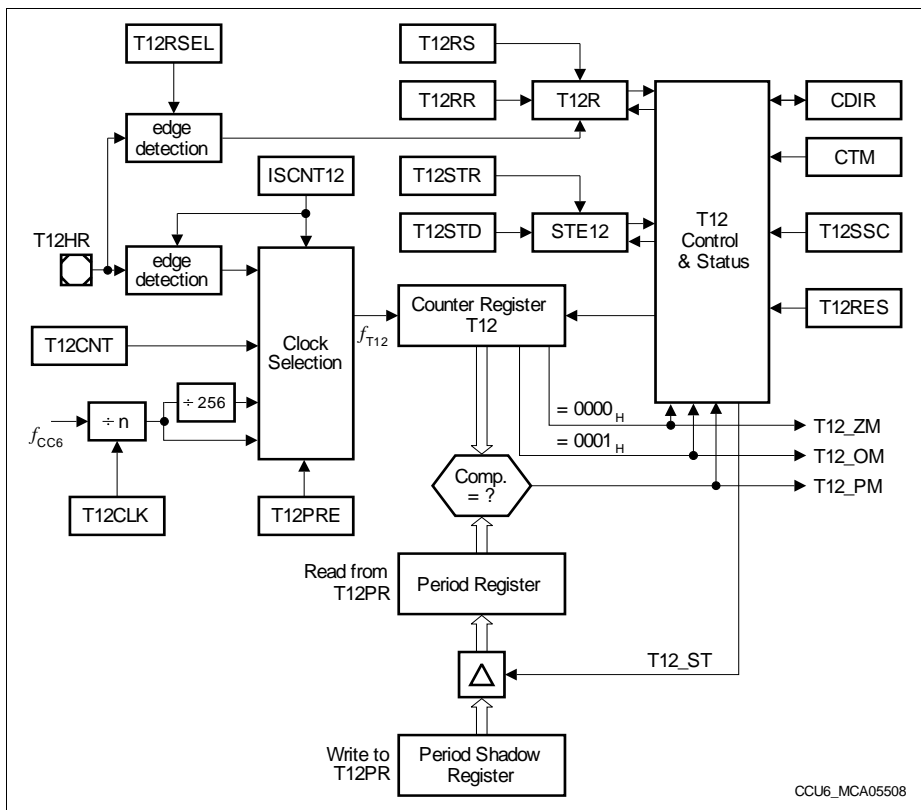


Figure 18-4 Timer T12 Logic and Period Comparators

Via a comparator, the T12 counter register **T12** is connected to a Period Register **T12PR**. This register determines the maximum count value for T12.

In Edge-Aligned mode, T12 is cleared to 0000_H after it has reached the period value defined by T12PR. In Center-Aligned mode, the count direction of T12 is set from 'up' to

Capture/Compare Unit 6 (CCU6)

'down' after it has reached the period value (please note that in this mode, T12 exceeds the period value by one before counting down). In both cases, signal T12_PM (T12 Period Match) is generated. The Period Register receives a new period value from its Shadow Period Register.

A read access to T12PR delivers the current period value at the comparator, whereas a write access targets the Shadow Period Register to prepare another period value. The transfer of a new period value from the Shadow Period Register into the Period Register (see [Section 18.2.6](#)) is controlled via the 'T12 Shadow Transfer' control signal, T12_ST. The generation of this signal depends on the operating mode and on the shadow transfer enable bit STE12. Providing a shadow register for the period value as well as for other values related to the generation of the PWM signal allows a concurrent update by software for all relevant parameters.

Two further signals indicate whether the counter contents are equal to 0000_H (T12_ZM = zero match) or 0001_H (T12_OM = one match). These signals control the counting and switching behavior of T12.

The basic operating mode of T12, either Edge-Aligned mode ([Figure 18-5](#)) or Center-Aligned mode ([Figure 18-6](#)), is selected via bit CTM. A Single-Shot control bit, T12SSC, enables an automatic stop of the timer when the current counting period is finished (see [Figure 18-7](#) and [Figure 18-8](#)).

The start or stop of T12 is controlled by the Run bit T12R that can be modified by bits in register [TCTR4](#). The run bit can be set/cleared by software via the associated set/clear bits T12RS or T12RR, it can be set by a selectable edge of the input signal T12HR ([TCTR2.T12RSEL](#)), or it is cleared by hardware according to preselected conditions.

The timer T12 run bit T12R must not be set while the applied T12 period value is zero. Timer T12 can be cleared via control bit T12RES. Setting this write-only bit does only clear the timer contents, but has no further effects, for example, it does not stop the timer.

The generation of the T12 shadow transfer control signal, T12_ST, is enabled via bit STE12. This bit can be set or reset by software indirectly through its associated set/clear control bits T12STR and T12STD.

While Timer T12 is running, write accesses to the count register T12 are not taken into account. If T12 is stopped and the Dead-Time counters are 0, write actions to register T12 are immediately taken into account.

18.2.2 T12 Counting Scheme

This section describes the clocking and counting capabilities of T12.

18.2.2.1 Clock Selection

In **Timer Mode** (**PISELH.ISCNT12** = 00_B), the input clock f_{T12} of Timer T12 is derived from the internal module clock f_{CC6} through a programmable prescaler and an optional 1/256 divider. The resulting prescaler factors are listed in **Table 18-2**. The prescaler of T12 is cleared while T12 is not running (**TCTR0.T12R** = 0) to ensure reproducible timings and delays.

Table 18-2 Timer T12 Input Frequency Options

T12CLK	Resulting Input Clock f_{T12} Prescaler Off (T12PRE = 0)	Resulting Input Clock f_{T12} Prescaler On (T12PRE = 1)
000 _B	f_{CC6}	$f_{CC6} / 256$
001 _B	$f_{CC6} / 2$	$f_{CC6} / 512$
010 _B	$f_{CC6} / 4$	$f_{CC6} / 1024$
011 _B	$f_{CC6} / 8$	$f_{CC6} / 2048$
100 _B	$f_{CC6} / 16$	$f_{CC6} / 4096$
101 _B	$f_{CC6} / 32$	$f_{CC6} / 8192$
110 _B	$f_{CC6} / 64$	$f_{CC6} / 16384$
111 _B	$f_{CC6} / 128$	$f_{CC6} / 32768$

In **Counter Mode**, timer T12 counts one step:

- If a 1 is written to **TCTR4.T12CNT** and **PISELH.ISCNT12** = 01_B
- If a rising edge of input signal T12HR is detected and **PISELH.ISCNT12** = 10_B
- If a falling edge of input signal T12HR is detected and **PISELH.ISCNT12** = 11_B

18.2.2.2 Edge-Aligned / Center-Aligned Mode

In **Edge-Aligned Mode** (CTM = 0), timer T12 is always counting upwards (CDIR = 0). When reaching the value given by the period register (period-match T12_PM), the value of T12 is cleared with the next counting step (saw tooth shape).

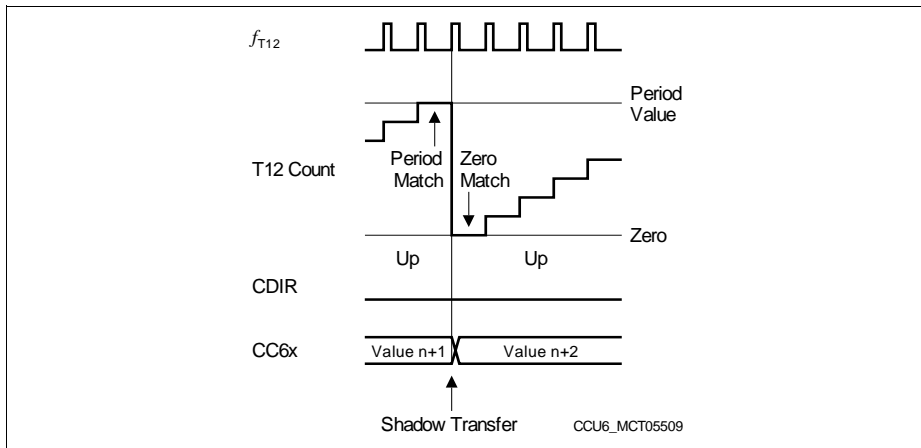


Figure 18-5 T12 Operation in Edge-Aligned Mode

As a result, in Edge-Aligned mode, the timer period is given by:

$$T12_{PER} = \langle \text{Period-Value} \rangle + 1; \text{ in } T12 \text{ clocks } (f_{T12}) \quad (18.1)$$

In **Center-Aligned Mode** (CTM = 1), timer T12 is counting upwards or downwards (triangular shape). When reaching the value given by the period register (period-match T12_PM) while counting upwards (CDIR = 0), the counting direction control bit CDIR is changed to downwards (CDIR = 1) with the next counting step.

When reaching the value 0001_H (one-match T12_OM) while counting downwards, the counting direction control bit CDIR is changed to upwards with the next counting step.

As a result, in Center-Aligned mode, the timer period is given by:

$$T12_{PER} = (\langle \text{Period-Value} \rangle + 1) \times 2; \text{ in } T12 \text{ clocks } (f_{T12}) \quad (18.2)$$

- With the next clock event of f_{T12} the count direction is set to counting up (CDIR = 0) when the counter reaches 0001_H while counting down.
- With the next clock event of f_{T12} the count direction is set to counting down (CDIR = 1) when the Period-Match is detected while counting up.
- With the next clock event of f_{T12} the counter counts up while CDIR = 0 and it counts down while CDIR = 1.

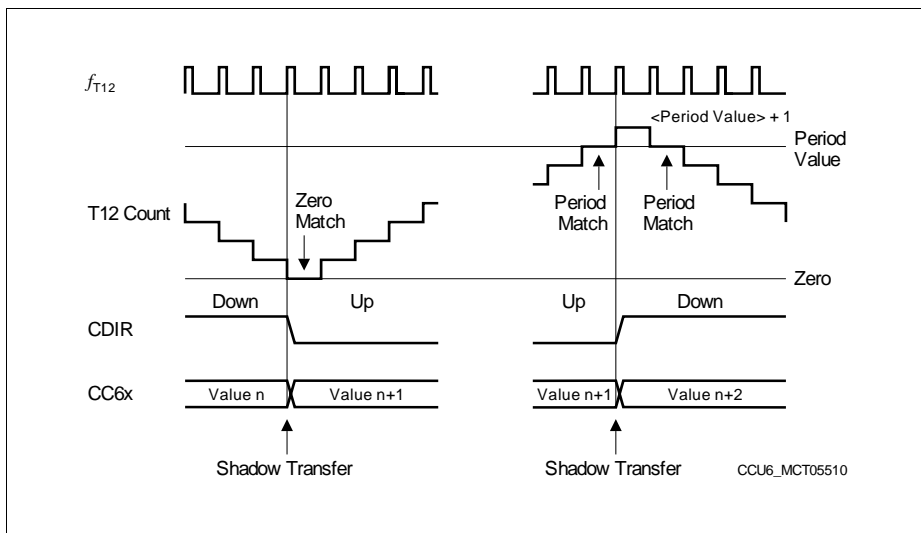


Figure 18-6 T12 Operation in Center-Aligned Mode

Note: Bit CDIR changes with the next timer clock event after the one-match or the period-match. Therefore, the timer continues counting in the previous direction for one cycle before actually changing its direction (see [Figure 18-6](#)).

18.2.2.3 Single-Shot Mode

In Single-Shot Mode, the timer run bit T12R is cleared by hardware. If bit T12SSC = 1, the timer T12 will stop when the current timer period is finished.

In Edge-Aligned mode, T12R is cleared when the timer becomes zero after having reached the period value (see [Figure 18-7](#)).

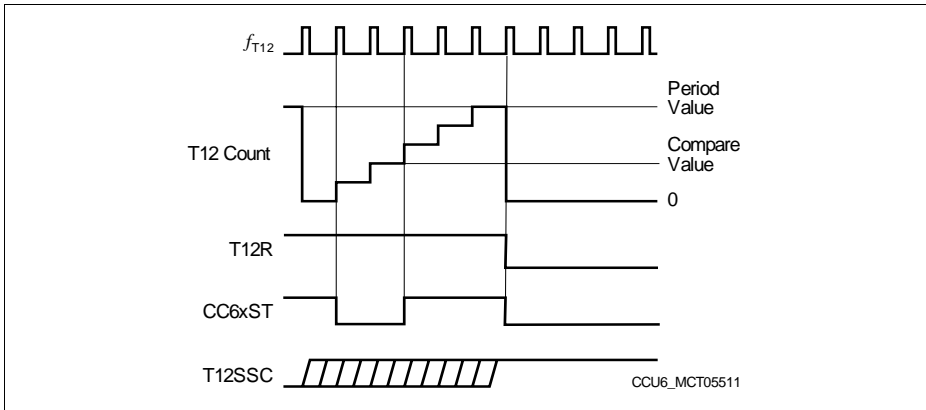


Figure 18-7 Single-Shot Operation in Edge-Aligned Mode

In Center-Aligned mode, the period is finished when the timer has counted down to zero (one clock cycle after the one-match while counting down, see [Figure 18-8](#)).

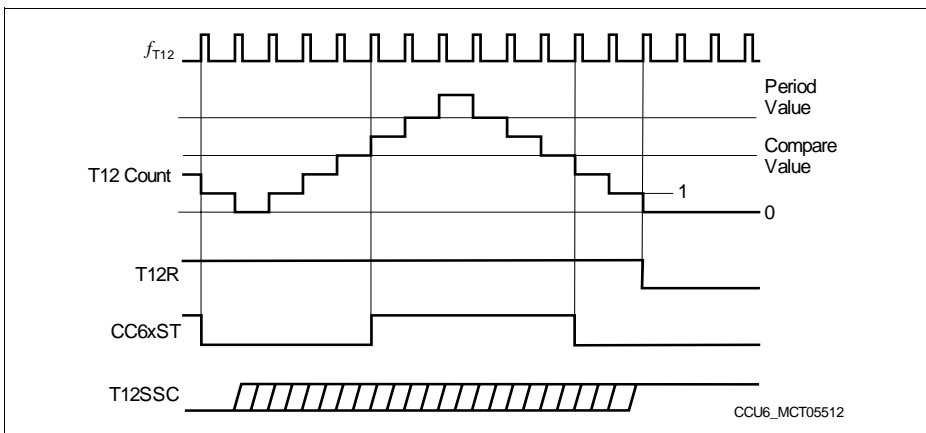


Figure 18-8 Single-Shot Operation in Center-Aligned Mode

18.2.3 T12 Compare Mode

Associated with Timer T12 are three individual capture/compare channels, that can perform compare or capture operations with regard to the contents of the T12 counter. The capture functions are explained in [Section 18.2.5](#).

18.2.3.1 Compare Channels

In Compare Mode (see [Figure 18-9](#)), the three individual compare channels CC60, CC61, and CC62 can generate a three-phase PWM pattern.

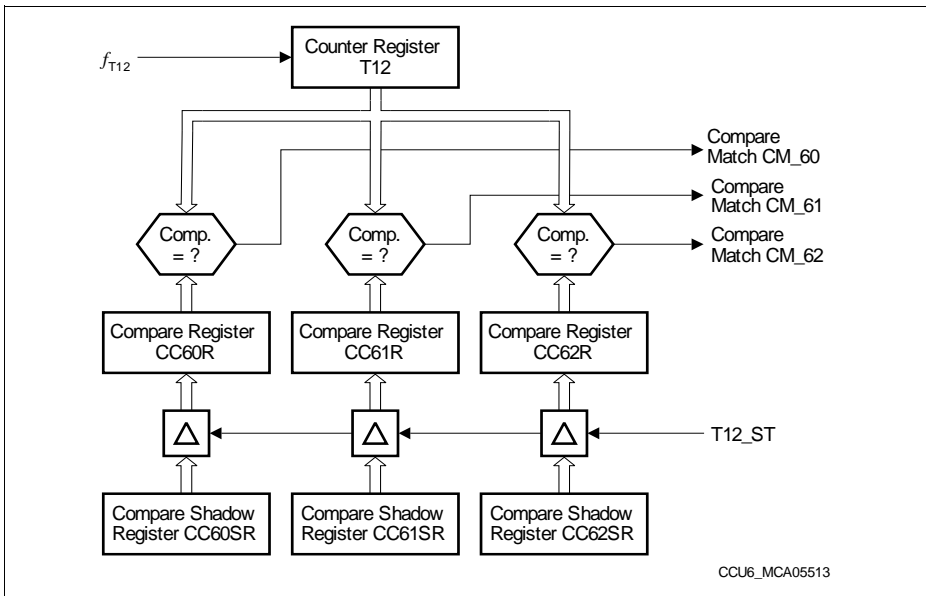


Figure 18-9 T12 Channel Comparators

Each compare channel is connected to the T12 counter register via its individual equal-to comparator, generating a match signal when the contents of the counter matches the contents of the associated compare register. Each channel consists of the comparator and a double register structure - the actual compare register CC6xR, feeding the comparator, and an associated shadow register CC6xSR, that is preloaded by software and transferred into the compare register when signal T12 shadow transfer, T12_ST, gets active. Providing a shadow register for the compare value as well as for other values related to the generation of the PWM signal facilitates a concurrent update by software for all relevant parameters of a three-phase PWM.

18.2.3.2 Channel State Bits

Associated with each (compare) channel is a State Bit, **CMPSTAT.CC6xST**, holding the status of the compare (or capture) operation (see **Figure 18-10**). In compare mode, the State Bits are modified according to a set of switching rules, depending on the current status of timer T12.

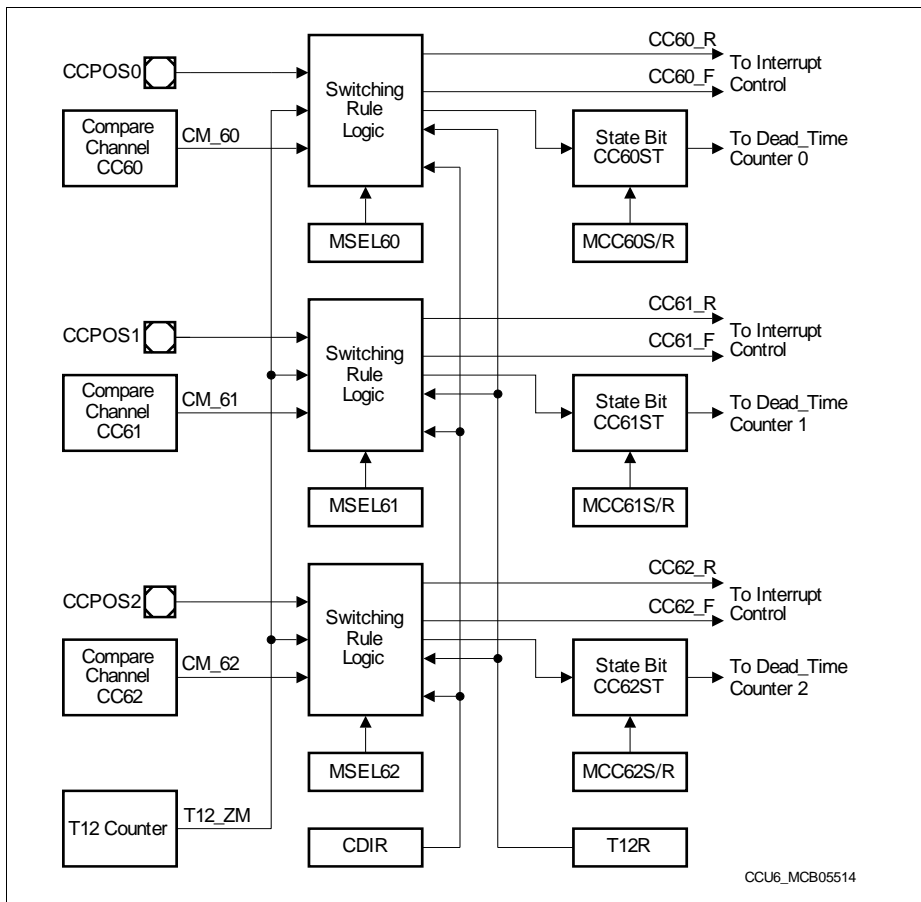


Figure 18-10 Compare State Bits for Compare Mode

The inputs to the switching rule logic for the CC6xST bits are the timer direction (CDIR), the timer run bit (T12R), the timer T12 zero-match signal (T12_ZM), and the actual individual compare-match signals CM_6x as well as the mode control bits, **T12MSEL.MSEL6x**.

Capture/Compare Unit 6 (CCU6)

In addition, each state bit can be set or cleared by software via the appropriate set and reset bits in register **CMPMODIF**, MCC6xS and MCC6xR. The input signals CCPOSx are used in hysteresis-like compare mode, whereas in normal compare mode, these inputs are ignored.

Note: In Hall Sensor, single shot or capture modes, additional/different rules are taken into account (see related sections).

A compare interrupt event CC6x_R is signaled when a compare match is detected while counting upwards, whereas the compare interrupt event CC6x_F is signaled when a compare match is detected while counting down. The actual setting of a State Bit has no influence on the interrupt generation in compare mode.

A modification of a State Bit CC6xST by the switching rule logic due to a compare action is only possible while Timer T12 is running ($T12R = 1$). If this is the case, the following switching rules apply for setting and clearing the State Bits in Compare Mode (illustrated in **Figure 18-11** and **Figure 18-12**):

A State Bit **CC6xST** is set to 1:

- with the next T12 clock (f_{T12}) after a compare-match when T12 is counting up (i.e., when the counter is incremented above the compare value);
- with the next T12 clock (f_{T12}) after a zero-match AND a parallel compare-match when T12 is counting up.

A State Bit **CC6xST** is cleared to 0:

- with the next T12 clock (f_{T12}) after a compare-match when T12 is counting down (i.e., when the counter is decremented below the compare value in center-aligned mode);
- with the next T12 clock (f_{T12}) after a zero-match AND NO parallel compare-match when T12 is counting up.

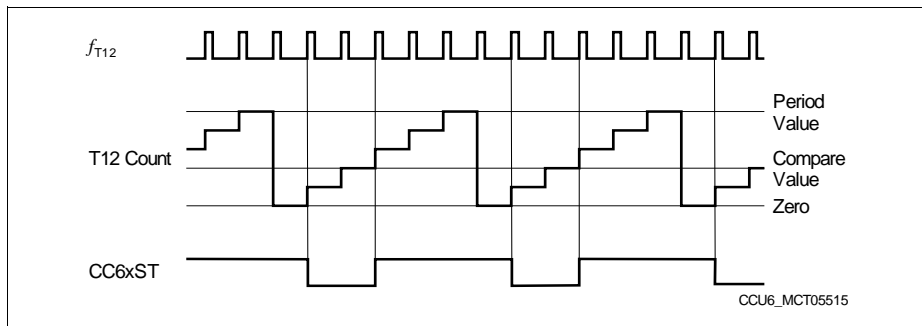


Figure 18-11 Compare Operation, Edge-Aligned Mode

Figure 18-13 illustrates some more examples for compare waveforms. It is important to note that in these examples, it is assumed that some of the compare values are changed

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while the timer is running. This change is performed via a software preload of the Shadow Register, CC6xSR. The value is transferred to the actual Compare Register CC6xR with the T12 Shadow Transfer signal, T12_ST, that is assumed to be enabled.

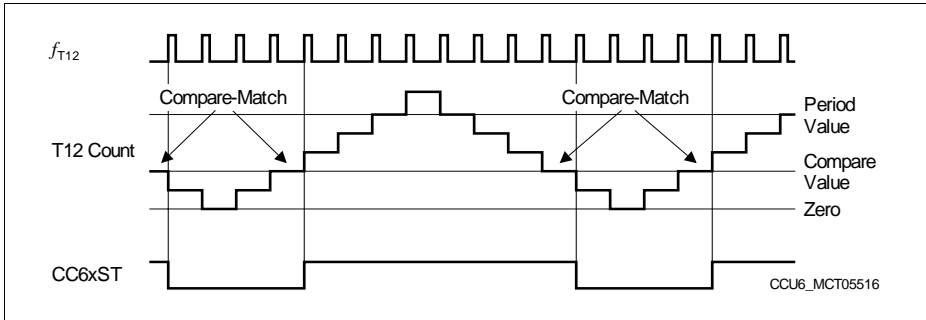


Figure 18-12 Compare Operation, Center-Aligned Mode

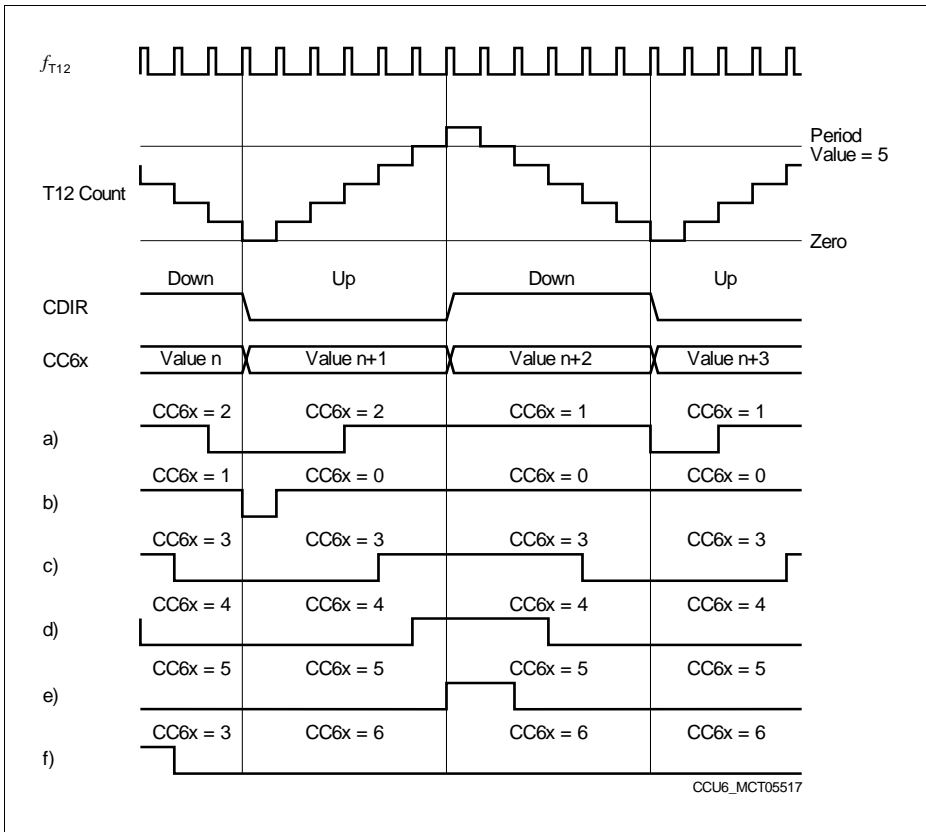


Figure 18-13 Compare Waveform Examples

Example b) illustrates the transition to a duty cycle of 100%. First, a compare value of 0001_H is used, then changed to 0000_H . Please note that a low pulse with the length of one T12 clock is still produced in the cycle where the new value 0000_H is in effect; this pulse originates from the previous value 0001_H . In the following timer cycles, the State Bit CC6xST remains at 1, producing a 100% duty cycle signal. In this case, the compare rule 'zero-match AND compare-match' is in effect.

Example f) shows the transition to a duty cycle of 0%. The new compare value is set to $\langle \text{Period-Value} \rangle + 1$, and the State Bit CC6ST remains cleared.

Figure 18-14 illustrates an example for the waveforms of all three channels. With the appropriate dead-time control and output modulation, a very efficient 3-phase PWM signal can be generated.

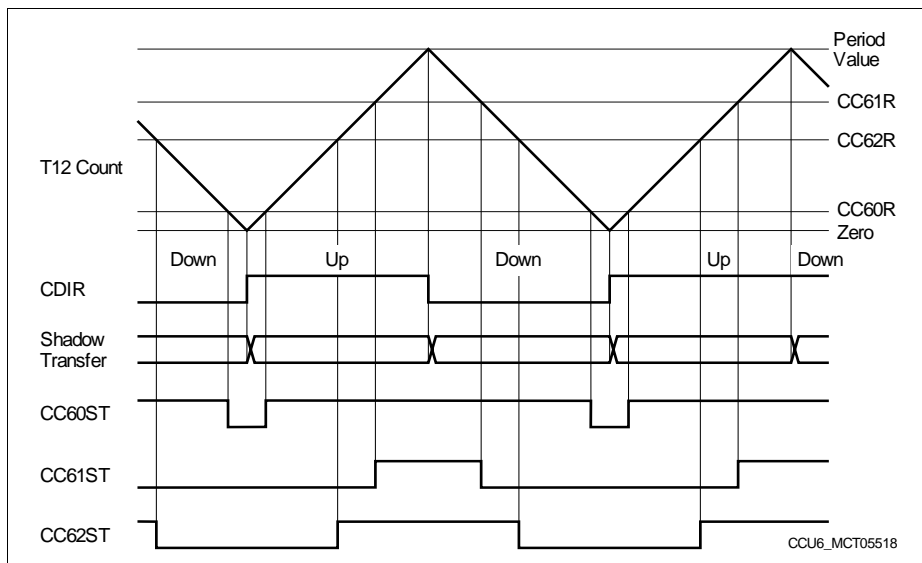


Figure 18-14 Three-Channel Compare Waveforms

18.2.3.3 Hysteresis-Like Control Mode

The hysteresis-like control mode (**T12MSEL**.MSEL6x = 1001_B) offers the possibility to switch off the PWM output if the input CCPOSx becomes 0 by clearing the State Bit CC6xST. This can be used as a simple motor control feature by using a comparator indicating, e.g., overcurrent. While CCPOSx = 0, the PWM outputs of the corresponding channel are driving their passive levels, because the setting of bit CC6xST is only possible while CCPOSx = 1.

As long as input CCPOSx is 0, the corresponding State Bit is held 0. When CCPOSx is at high level, the outputs can be in active state and are determined by bit CC6xST (see **Figure 18-10** for the state bit logic and **Figure 18-15** for the output paths).

The CCPOSx inputs are evaluated with f_{CC6} .

This mode can be used to introduce a timing-related behavior to a hysteresis controller. A standard hysteresis controller detects if a value exceeds a limit and switches its output according to the compare result. Depending on the operating conditions, the switching frequency and the duty cycle are not fixed, but change permanently.

If (outer) time-related control loops based on a hysteresis controller in an inner loop should be implemented, the outer loops show a better behavior if they are synchronized to the inner loops. Therefore, the hysteresis-like mode can be used, that combines timer-related switching with a hysteresis controller behavior. For example, in this mode, an output can be switched on according to a fixed time base, but it is switched off as soon as a falling edge is detected at input CCPOSx.

This mode can also be used for standard PWM with overcurrent protection. As long as there is no low level signal at pin CCPOSx, the output signals are generated in the normal manner as described in the previous sections. Only if input CCPOSx shows a low level, e.g. due to the detection of overcurrent, the outputs are shut off to avoid harmful stress to the system.

18.2.4 Compare Mode Output Path

Figure 18-15 gives an overview on the signal path from a channel State Bit to its output pin in its simplest form. As illustrated, a user has a variety of controls to determine the desired output signal switching behavior in relation to the current state of the State Bit, CC6xST. Please refer to [Section 18.2.4.3](#) for details on the output modulation.

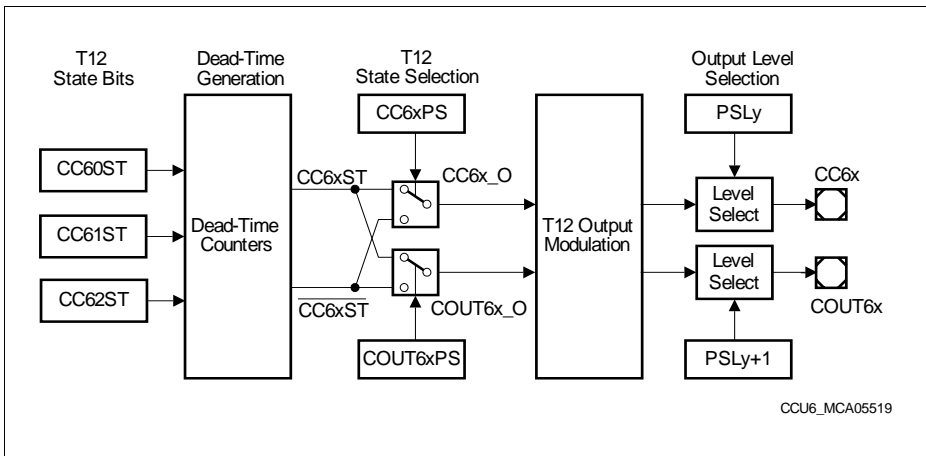


Figure 18-15 Compare Mode Simplified Output Path Diagram

The output path is based on signals that are defined as active or passive. The terms active and passive are not related to output levels, but to internal actions. This mainly applies for the modulation, where T12 and T13 signals are combined with the multi-channel signals and the trap function. The Output level Selection allows the user to define the output level at the output pin for the passive state (inverted level for the active state). It is recommended to configure this block in a way that an external power switch is switched off while the CCU6 delivers an output signal in the passive state.

18.2.4.1 Dead-Time Generation

The generation of (complementary) signals for the high-side and the low-side switches of one power inverter phase is based on the same compare channel. For example, if the high-side switch should be active while the T12 counter value is above the compare value (State Bit = 1), then the low-side switch should be active while the counter value is below the compare value (State Bit = 0).

In most cases, the switching behavior of the connected power switches is not symmetrical concerning the switch-on and switch-off times. A general problem arises if the time for switch-on is smaller than the time for switch-off of the power device. In this case, a short-circuit can occur in the inverter bridge leg, which may damage the complete system. In order to solve this problem by HW, this capture/compare unit

contains a programmable Dead-Time Generation Block, that delays the passive to active edge of the switching signals by a programmable time (the active to passive edge is not delayed).

The Dead-Time Generation Block, illustrated in **Figure 18-16**, is built in a similar way for all three channels of T12. It is controlled by bits in register **T12DTC**. Any change of a CC6xST State Bit activates the corresponding Dead-Time Counter, that is clocked with the same input clock as T12 (f_{T12}). The length of the dead-time can be programmed by bit field DTM. This value is identical for all three channels. Writing **TCTR4.DTRES = 1** sets all dead-times to passive.

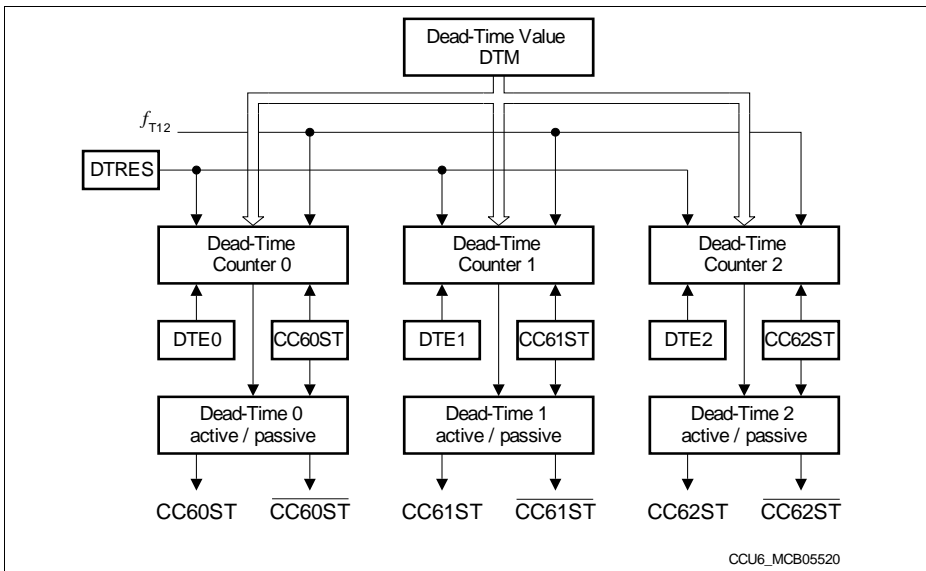


Figure 18-16 Dead-Time Generation Block Diagram

Each of the three dead-time counters has its individual dead-time enable bit, DTE_x. An enabled dead-time counter generates a dead-time delaying the passive-to-active edge of the channel output signal. The change in a State Bit CC6xST is not taken into account while the dead-time generation of this channel is currently in progress (active). This avoids an unintentional additional dead-time if a State Bit CC6xST changes too early. A disabled dead-time counter is always considered as passive and does not delay any edge of CC6xST.

Based on the State Bits CC6xST, the Dead-Time Generation Block outputs a direct signal CC6xST and an inverted signal $\overline{\text{CC6xST}}$ for each compare channel, each masked with the effect of the related Dead-Time Counters (waveforms illustrated in **Figure 18-17**).

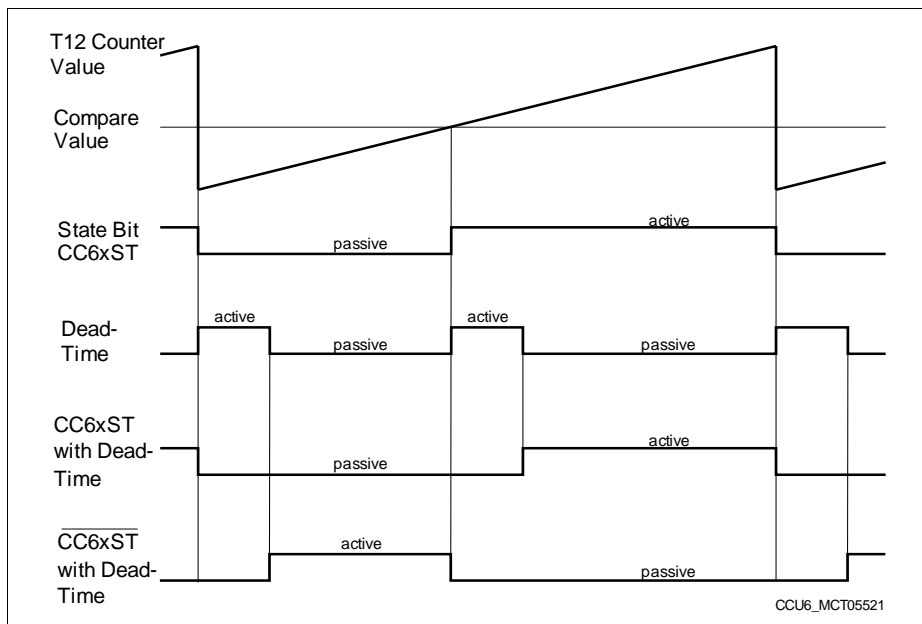


Figure 18-17 Dead-Time Generation Waveforms

18.2.4.2 State Selection

To support a wide range of power switches and drivers, the state selection offers the flexibility to define when a an output can be active and can be modulated, especially useful for **complementary or multi-phase PWM** signals.

The state selection is based on the signals $CC6xST$ and $\overline{CC6xST}$ delivered by the dead-time generator (see [Figure 18-15](#)). Both signals are never active at the same time, but can be passive at the same time. This happens during the dead-time of each compare channel after a change of the corresponding State Bit $CC6xST$.

The user can select independently for each output signal $CC6xO$ and $COUT6xO$ if it should be active before or after the compare value has been reached (see register [CMPSTAT](#)). With this selection, the active (conducting) phases of complementary power switches in a power inverter bridge leg can be positioned with respect to the compare value (e.g. signal $CC6xO$ can be active before, whereas $COUT6xO$ can be active after the compare value is reached). Like this, the output modulation, the trap logic and the output level selection can be programmed independently for each output signal, although two output signals are referring to the same compare channel.

18.2.4.3 Output Modulation and Level Selection

The last block of the data path is the Output Modulation block. Here, all the modulation sources and the trap functionality are combined and control the actual level of the output pins (controlled by the modulation enable bits T1xMODENy and MCMEN in register **MODCTR**). The following signal sources can be combined here **for each T12 output signal** (see **Figure 18-18** for compare channel CC60):

- A **T12 related compare signal** CC6x_O (for outputs CC6x) or COUT6x_O (for outputs COUT6x) delivered by the T12 block (state selection with dead-time) with an individual enable bit T12MODENy per output signal (y = 0, 2, 4 for outputs CC6x and y = 1, 3, 5 for outputs COUT6x)
- The **T13 related compare signal** CC63_O delivered by the T13 state selection with an individual enable bit T13MODENy per output signal (y = 0, 2, 4 for outputs CC6x and y = 1, 3, 5 for outputs COUT6x)
- A **multi-channel output signal** MCMPy (y = 0, 2, 4 for outputs CC6x and y = 1, 3, 5 for outputs COUT6x) with a common enable bit MCMEN
- The **trap state** TRPS with an individual enable bit TRPENy per output signal (y = 0, 2, 4 for outputs CC6x and y = 1, 3, 5 for outputs COUT6x)

If one of the modulation input signals CC6x_O/COUT6x_O, CC63_O, or MCMPy of an output modulation block is enabled and is at passive state, the modulated is also in passive state, regardless of the state of the other signals that are enabled. Only if all enabled signals are in active state the modulated output shows an active state. If no modulation input is enabled, the output is in passive state.

If the Trap State is active (TRPS = 1), then the outputs that are enabled for the trap signal (by TRPENy = 1) are set to the passive state.

The output of each of the modulation control blocks is connected to a level select block that is configured by register **PSLR**. It offers the option to determine the actual output level of a pin, depending on the state of the output line (decoupling of active/passive state and output polarity) as specified by the Passive State Select bit PSLy. If the modulated output signal is in the passive state, the level specified directly by PSLy is output. If it is in the active state, the inverted level of PSLy is output. This allows the user to adapt the polarity of an active output signal to the connected circuitry.

The PSLy bits have shadow registers to allow for updates without undesired pulses on the output lines. The bits related to CC6x and COUT6x (x = 0, 1, 2) are updated with the T12 shadow transfer signal (T12_ST). A read action returns the actually used values, whereas a write action targets the shadow bits. Providing a shadow register for the PSL value as well as for other values related to the generation of the PWM signal facilitates a concurrent update by software for all relevant parameters.

Figure 18-18 shows the output modulation structure for compare channel CC60 (output signals CC60 and COUT60). A similar structure is implemented for the other two compare channels CC61 and CC62.

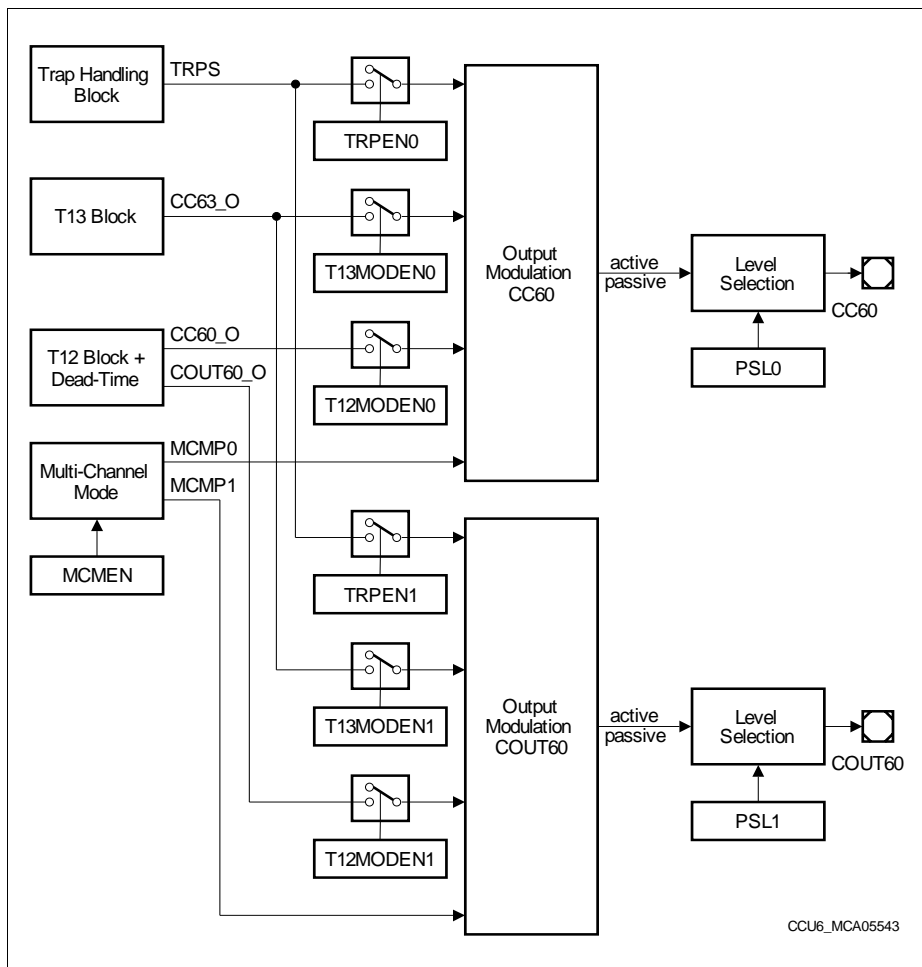


Figure 18-18 Output Modulation for Compare Channel CC60

18.2.5 T12 Capture Modes

Each of the three channels of the T12 Block can also be used to capture T12 time information in response to an external signal CC6xIN.

In capture mode, the interrupt event CC6x_R is detected when a rising edge is detected at the input CC6xIN, whereas the interrupt event CC6x_F is detected when a falling edge is detected.

There are a number of different modes for capture operation. In all modes, both of the registers of a channel are used. The selection of the capture modes is done via the **T12MSEL**. MSEL6x bit fields and can be selected individually for each of the channels.

Table 18-3 Capture Modes Overview

MSEL6x	Mode	Signal	Active Edge	CC6nSR Stored in	T12 Stored in
0100 _B	1	CC6xIN	Rising	–	CC6xR
		CC6xIN	Falling	–	CC6xSR
0101 _B	2	CC6xIN	Rising	CC6xR	CC6xSR
0110 _B	3	CC6xIN	Falling	CC6xR	CC6xSR
0111 _B	4	CC6xIN	Any	CC6xR	CC6xSR

Figure 18-19 illustrates **Capture Mode 1**. When a rising edge (0-to-1 transition) is detected at the corresponding input signal CC6xIN, the current contents of Timer T12 are captured into register CC6xR. When a falling edge (1-to-0 transition) is detected at the input signal CC6xIN, the contents of Timer T12 are captured into register CC6xSR.

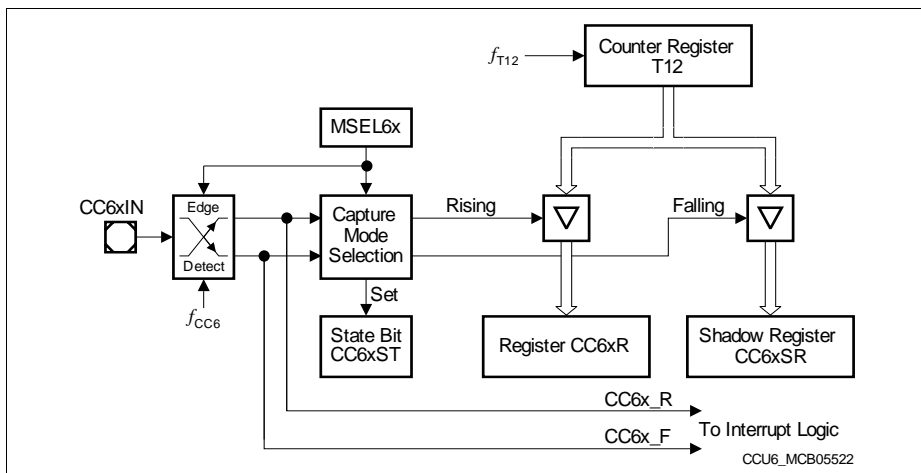


Figure 18-19 Capture Mode 1 Block Diagram

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Capture Modes 2, 3 and 4 are shown in **Figure 18-20**. They differ only in the active edge causing the capture operation. In each of the three modes, when the selected edge is detected at the corresponding input signal CC6xIN, the current contents of the shadow register CC6xSR are transferred into register CC6xR, and the current Timer T12 contents are captured in register CC6xSR (simultaneous transfer). The active edge is a rising edge of CC6xIN for Capture Mode 2, a falling edge for Mode 3, and both, a rising or a falling edge for Capture Mode 4, as shown in **Table 18-3**. These capture modes are very useful in cases where there is little time between two consecutive edges of the input signal.

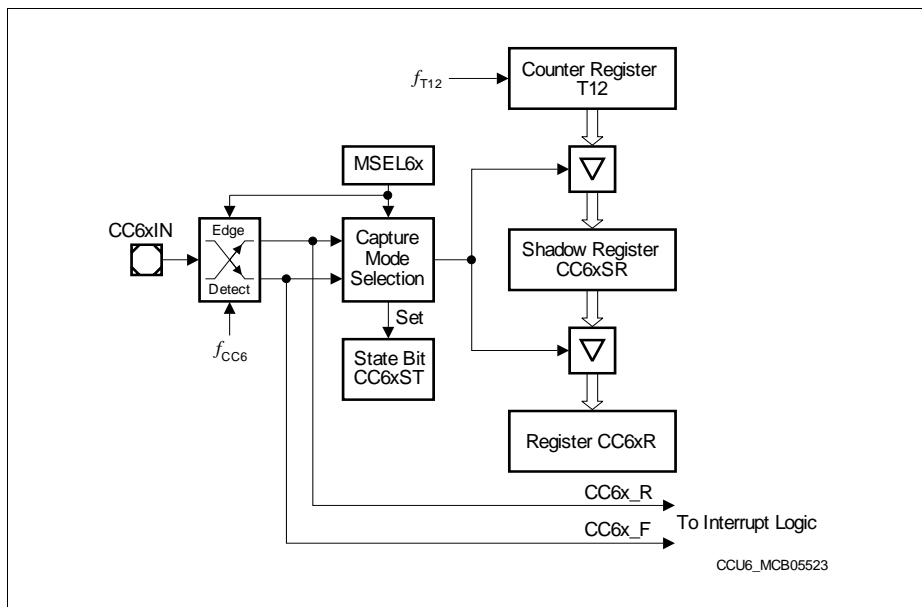


Figure 18-20 Capture Modes 2, 3 and 4 Block Diagram

Capture/Compare Unit 6 (CCU6)

Five further capture modes are called **Multi-Input Capture Modes**, as they use two different external inputs, signal CC6xIN and signal CCPOSx.

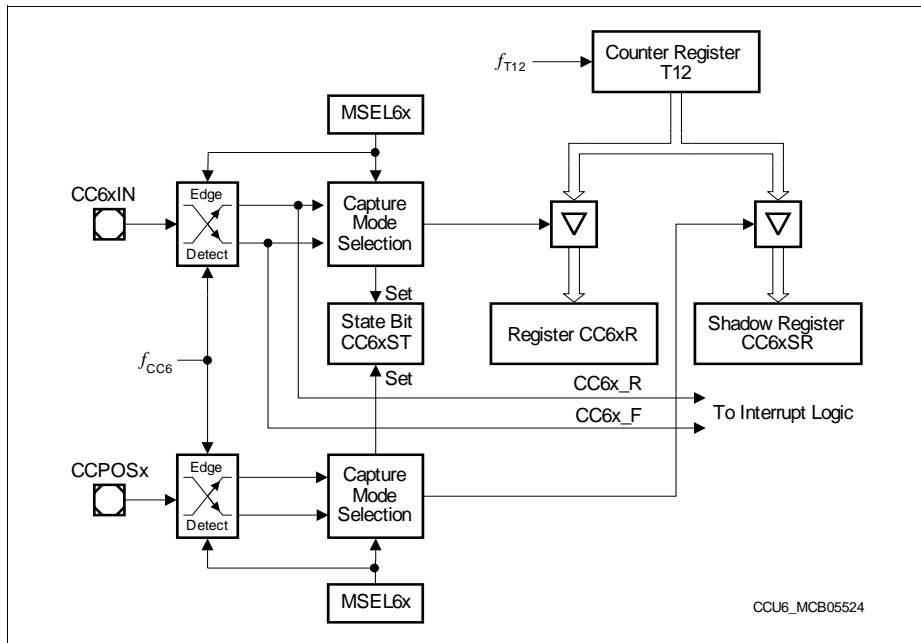


Figure 18-21 Multi-Input Capture Modes Block Diagram

In each of these modes, the current T12 contents are captured in register CC6xR in response to a selected event at signal CC6xIN, and in register CC6xSR in response to a selected event at signal CCPOSx. The possible events can be opposite input transitions, or the same transitions, or any transition at the two inputs. The different options are detailed in [Table 18-4](#).

In each of the various capture modes, the Channel State Bit, CC6xST, is set to 1 when the selected capture trigger event at signal CC6xIN or CCPOSx has occurred. The State Bit is not cleared by hardware, but can be cleared by software.

In addition, appropriate signal lines to the interrupt logic are activated, that can generate an interrupt request to the CPU. Regardless of the selected active edge, all edges detected at signal CC6xIN can lead to the activation of the appropriate interrupt request line (see also [Section 18.8](#)).

Table 18-4 Multi-Input Capture Modes Overview

MSEL6x	Mode	Signal	Active Edge	T12 Stored in
1010 _B	5	CC6xIN	Rising	CC6xR
		CCPOSx	Falling	CC6xSR
1011 _B	6	CC6xIN	Falling	CC6xR
		CCPOSx	Rising	CC6xSR
1100 _B	7	CC6xIN	Rising	CC6xR
		CCPOSx	Rising	CC6xSR
1101 _B	8	CC6xIN	Falling	CC6xR
		CCPOSx	Falling	CC6xSR
1110 _B	9	CC6xIN	Any	CC6xR
		CCPOSx	Any	CC6xSR
1111 _B	—	reserved (no capture or compare action)		

A T12 shadow register transfer takes place (T12_ST active):

- while timer T12 is not running (T12R = 0), or
- STE12 = 1 and a Period-Match is detected while counting up, or
- STE12 = 1 and a One-Match is detected while counting down

When signal T12_ST is active, a shadow register transfer is triggered with the next cycle of the T12 clock. Bit STE12 is automatically cleared with the shadow register transfer.

18.2.7 Timer T12 Operating Mode Selection

The operating mode for the T12 channels are defined by the bit fields **T12MSEL.MSEL6x**.

Table 18-5 T12 Capture/Compare Modes Overview

MSEL6x	Selected Operating Mode
0000 _B , 1111 _B	Capture/Compare modes switched off
0001 _B , 0010 _B , 0011 _B	Compare mode, see Section 18.2.3 same behavior for all three codings
01XX _B	Double-Register Capture modes, see Section 18.2.5
1000 _B	Hall Sensor Mode, see Section 18.6 In order to properly enable this mode, all three MSEL6x fields have to be programmed to Hall Sensor mode.
1001 _B	Hysteresis-like compare mode, see Section 18.2.3.3
1010 _B , 1011 _B , 1100 _B , 1101 _B , 1110 _B	Multi-Input Capture modes, see Section 18.2.5

The clocking and counting scheme of the timers are controlled by the timer control registers **TCTR0** and **TCTR2**. Specific actions are triggered by write operations to register **TCTR4**.

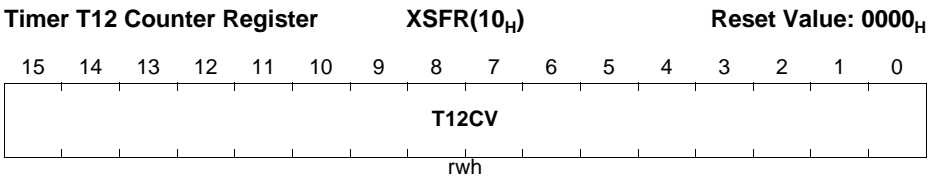
18.2.8 T12 related Registers

18.2.8.1 T12 Counter Register

Register T12 represents the counting value of timer T12. It can only be written while the timer T12 is stopped. Write actions while T12 is running are not taken into account. Register T12 can always be read by SW.

In edge-aligned mode, T12 only counts up, whereas in center-aligned mode, T12 can count up and down.

T12



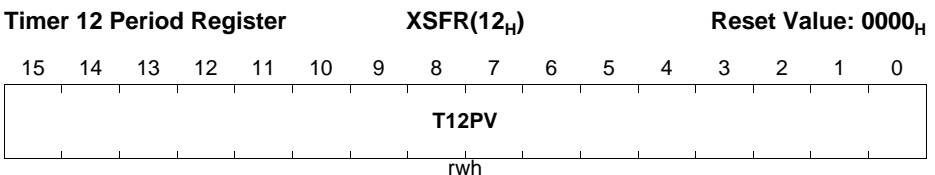
Field	Bits	Type	Description
T12CV	[15:0]	rwh	Timer 12 Counter Value This register represents the 16-bit counter value of Timer12.

Note: While timer T12 is stopped, the internal clock divider is reset in order to ensure reproducible timings and delays.

18.2.8.2 Period Register

Register T12PR contains the period value for timer T12. The period value is compared to the actual counter value of T12 and the resulting counter actions depend on the defined counting rules. This register has a shadow register and the shadow transfer is controlled by bit STE12. A read action by SW delivers the value that is currently used for the compare action, whereas the write action targets a shadow register. The shadow register structure allows a concurrent update of all T12-related values.

T12PR



Field	Bits	Type	Description
T12PV	[15:0]	rwh	T12 Period Value The value T12PV defines the counter value for T12 leading to a period-match. When reaching this value, the timer T12 is set to zero (edge-aligned mode) or changes its count direction to down counting (center-aligned mode).

18.2.8.3 Capture/Compare Registers

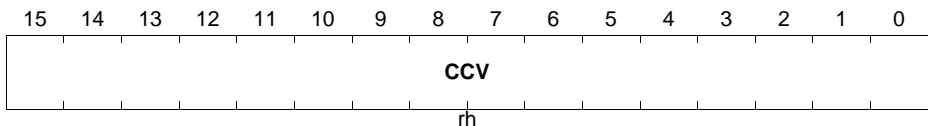
In compare mode, the registers CC6xR (x = 0 - 2) are the actual compare registers for T12. The values stored in CC6xR are compared (all three channels in parallel) to the counter value of T12. In capture mode, the current value of the T12 counter register is captured by registers CC6xR if the corresponding capture event is detected.

CC6xR (x = 0-2)

Capture/Compare Register for Channel CC6x

XSFR(18_H + 2*x)

Reset Value: 0000_H



Field	Bits	Type	Description
CCV	[15:0]	rh	Capture/Compare Value In compare mode, the bit fields CCV contain the values, that are compared to the T12 counter value. In capture mode, the captured value of T12 can be read from these registers.

18.2.8.4 Capture/Compare Shadow Registers

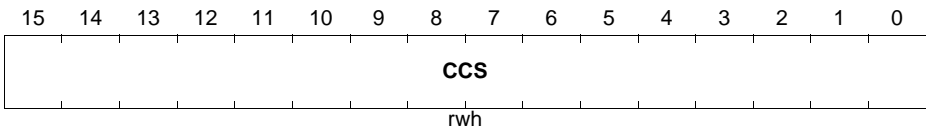
The registers CC6xR can only be read by SW, the modification of the value is done by a shadow register transfer from register CC6xSR. The corresponding shadow registers CC6xSR can be read and written by SW. In capture mode, the value of the T12 counter register can also be captured by registers CC6xSR if the selected capture event is detected (depending on the selected capture mode).

CC6xSR (x=0-2)

Capture/Compare Shadow Reg. for Channel CC6x

XSFR(20_H+2*x)

Reset Value: 0000_H



Field	Bits	Type	Description
CCS	[15:0]	rwh	Shadow Register for Channel x Capture/Compare Value In compare mode, the bit fields contents of CCS are transferred to the bit fields CCV for the corresponding channel during a shadow transfer. In capture mode, the captured value of T12 can be read from these registers.

Note: The shadow registers can also be written by SW in capture mode. In this case, the HW capture event wins over the SW write if both happen in the same cycle (the SW write is discarded).

18.2.8.5 Dead-time Control Register

Register T12DTC controls the dead-time generation for the timer T12 compare channels. Each channel can be independently enabled/disabled for dead-time generation. If enabled, the transition from passive state to active state is delayed by the value defined by bit field DTM.

The dead time counters are clocked with the same frequency as T12.

This structure allows symmetrical dead-time generation in center-aligned and in edge-aligned PWM mode. A duty cycle of 50% leads to CC6x, COUT6x switched on for: 0.5 * period - dead time.

Note: The dead-time counters are not reset by bit T12RES, but by bit DTRES.

T12DTC

Dead-Time Control Register for Timer12

XSFR(14 _H)										Reset Value: 0000 _H					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	DTR 2	DTR 1	DTR 0	0	DTE 2	DTE 1	DTE 0	DTM							
r	rh	rh	rh	r	rw	rw	rw	rw							

Field	Bits	Type	Description
DTM	[7:0]	rw	Dead-Time Bit field DTM determines the programmable delay between switching from the passive state to the active state of the selected outputs. The switching from the active state to the passive state is not delayed.
DTE2, DTE1, DTE0	10, 9, 8	rw	Dead Time Enable Bits Bits DTE0..DTE2 enable and disable the dead time generation for each compare channel (0, 1, 2) of timer T12. <div style="margin-left: 20px;"> 0_B Dead-Time Counter x is disabled. The corresponding outputs switch from the passive state to the active state (according to the actual compare status) without any delay. 1_B Dead-Time Counter x is enabled. The corresponding outputs switch from the passive state to the active state (according to the compare status) with the delay programmed in bit field DTM. </div>

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Field	Bits	Type	Description
DTR2, DTR1, DTR0	14, 13, 12	rh	Dead Time Run Indication Bits Bits DTR0..DTR2 indicate the status of the dead time generation for each compare channel (0, 1, 2) of timer T12. 0 _B Dead-Time Counter x is currently in the passive state. 1 _B Dead-Time Counter x is currently in the active state.
0	15, 11	r	reserved; returns 0 if read; should be written with 0;

18.2.9 Capture/Compare Control Registers

18.2.9.1 Channel State Bits

The Compare State Register CMPSTAT contains status bits monitoring the current capture and compare state and control bits defining the active/passive state of the compare channels.

CMPSTAT

Compare State Register

XSFR(28_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T13	C	C	CC	C	CC	C	CC	0	CC	CC	CC	CC	CC	CC	CC
IM	OUT	OUT	62PS	OUT	61PS	OUT	60PS		63ST	POS	POS	POS	62ST	61ST	60ST
63PS	62PS		61PS	60PS				r	rh	rh	rh	rh	rh	rh	rh

Field	Bits	Type	Description
CC60ST, CC61ST, CC62ST, CC63ST 1)	0, 1, 2, 6	rh	Capture/Compare State Bits Bits CC6xST monitor the state of the capture/compare channels. Bits CC6xST (x = 0, 1, 2) are related to T12, bit CC63ST is related to T13. 0 _B In compare mode, the timer count is less than the compare value. In capture mode, the selected edge has not yet been detected since the bit has been cleared by SW the last time. 1 _B In compare mode, the counter value is greater than or equal to the compare value. In capture mode, the selected edge has been detected.
CCPOS60, CCPOS61, CCPOS62	3, 4, 5	rh	Sampled Hall Pattern Bits Bits CCPOS6x (x = 0, 1, 2) are indicating the value of the input Hall pattern that has been compared to the current and expected value. The value is sampled when the event HCRDY (Hall Compare Ready) occurs. 0 _B The input CCPOS6x has been sampled as 0. 1 _B The input CCPOS6x has been sampled as 1.

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Field	Bits	Type	Description
CC60PS, CC61PS, CC62PS, COOUT60PS, COOUT61PS, COOUT62PS, COOUT63PS 2)	8, 10, 12, 9, 11, 13, 14	rwh	Passive State Select for Compare Outputs Bits CC6xPS, COOUT6xPS select the state of the corresponding compare channel, that is considered to be the passive state. During the passive state, the passive level (defined in register PSLR) is driven by the output pin. Bits CC6xPS, COOUT6xPS (x = 0, 1, 2) are related to T12, bit CC63PS is related to T13. 0_B The corresponding compare signal is in passive state while CC6xST is 0. 1_B The corresponding compare signal is in passive state while CC6xST is 1. In capture mode, these bits are not used.
T13IM ³⁾	15	rwh	T13 Inverted Modulation Bit T13IM inverts the T13 signal for the modulation of the CC6x and COOUT6x (x = 0, 1, 2) signals. 0_B T13 output CC63_O is equal to $\overline{\text{CC63ST}}$. 1_B T13 output CC63_O is equal to CC63ST .
0	7	r	reserved; returns 0 if read; should be written with 0;

1) These bits are set and cleared according to the T12, T13 switching rules

2) These bits have shadow bits and are updated in parallel to the capture/compare registers of T12, T13 respectively. A read action targets the actually used values, whereas a write action targets the shadow bits.

3) This bit has a shadow bit and is updated in parallel to the compare and period registers of T13. A read action targets the actually used values, whereas a write action targets the shadow bit.

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The Compare Status Modification Register CMPMODIF provides software-control (independent set and clear conditions) for the channel state bits CC6xST. This feature enables the user to individually change the status of the output lines by software, for example when the corresponding compare timer is stopped.

CMPMODIF

Compare State Modification Register

XSFR(2A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	MCC 63R		0		MCC 62R	MCC 61R	MCC 60R	0	MCC 63S		0		MCC 62S	MCC 61S	MCC 60S
r	w		r		w	w	w	r	w		r		w	w	w

Field	Bits	Type	Description
MCC60S, MCC61S, MCC62S, MCC63S, MCC60R, MCC61R, MCC62R, MCC63R	0, 1, 2, 6, 8, 9, 10, 14	w	Capture/Compare Status Modification Bits These bits are used to bits to set (MCC6xS) or to clear (MCC6xR) the corresponding bits CC6xST by SW. This feature allows the user to individually change the status of the output lines by SW, e.g. when the corresponding compare timer is stopped. This allows a bit manipulation of CC6xST-bits by a single data write action. The following functionality of a write access to bits concerning the same capture/compare state bit is provided: [MCC6xR, MCC6xS] = 00 _B Bit CC6xST is not changed. 01 _B Bit CC6xST is set. 10 _B Bit CC6xST is cleared. 11 _B reserved
0	[5:3], 7, [13:11], 15	r	reserved; returns 0 if read; should be written with 0;

18.2.9.2 T12 Mode Control Register

Register T12MSEL contains control bits to select the capture/compare functionality of the three channels of Timer T12.

T12MSEL

T12 Mode Select Register

XSFR (46_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
D BYP	HSYNC			MSEL62			MSEL61			MSEL60					
rw	rw			rw			rw			rw					

Field	Bits	Type	Description
MSEL60, MSEL61, MSEL62	[3:0], [7:4], [11:8]	rw	Capture/Compare Mode Selection These bit fields select the operating mode of the three T12 capture/compare channels. Each channel (x = 0, 1, 2) can be programmed individually for one of these modes (except for Hall Sensor Mode). Coding see Table 18-5 .
HSYNC	[14:12]	rw	Hall Synchronization Bit field HSYNC defines the source for the sampling of the Hall input pattern and the comparison to the current and the expected Hall pattern bit fields. Coding see Table 18-11 .
DBYP	15	rw	Delay Bypass DBYP controls whether the source signal for the sampling of the Hall input pattern (selected by HSYNC) is delayed by the Dead-Time Counter 0. 0 _B The bypass is not active. Dead-Time Counter 0 is generating a delay after the source signal becomes active. 1 _B The bypass is active. Dead-Time Counter 0 is not used for a delay.

18.2.9.3 Timer Control Registers

Register TCTR0 controls the basic functionality of both timers, T12 and T13.

Note: A write action to the bit fields T12CLK or T12PRE is only taken into account while the timer T12 is not running (T12R=0). A write action to the bit fields T13CLK or T13PRE is only taken into account while the timer T13 is not running (T13R=0).

TCTR0

Timer Control Register 0

XSFR(2C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		STE 13	T13R	T13 PRE	T13CLK			CTM	CDIR	STE 12	T12R	T12 PRE	T12CLK		
r		rh	rh	rw	rw			rw	rh	rh	rh	rw	rw		

Field	Bits	Type	Description
T12CLK	[2:0]	rw	Timer T12 Input Clock Select Selects the input clock for timer T12 that is derived from the peripheral clock according to the equation $f_{T12} = f_{CC6} / 2^{<T12CLK>}$. 000 _B $f_{T12} = f_{CC6}$ 001 _B $f_{T12} = f_{CC6} / 2$ 010 _B $f_{T12} = f_{CC6} / 4$ 011 _B $f_{T12} = f_{CC6} / 8$ 100 _B $f_{T12} = f_{CC6} / 16$ 101 _B $f_{T12} = f_{CC6} / 32$ 110 _B $f_{T12} = f_{CC6} / 64$ 111 _B $f_{T12} = f_{CC6} / 128$
T12PRE	3	rw	Timer T12 Prescaler Bit In order to support higher clock frequencies, an additional prescaler factor of 1/256 can be enabled for the prescaler for T12. 0 _B The additional prescaler for T12 is disabled. 1 _B The additional prescaler for T12 is enabled.
T12R	4	rh	Timer T12 Run Bit¹⁾ T12R starts and stops timer T12. It is set/cleared by SW by setting bits T12RR or T12RS or it is cleared by HW according to the function defined by bit field T12SSC. 0 _B Timer T12 is stopped. 1 _B Timer T12 is running.

Field	Bits	Type	Description
STE12	5	rh	Timer T12 Shadow Transfer Enable Bit STE12 enables or disables the shadow transfer of the T12 period value, the compare values and passive state select bits and levels from their shadow registers to the actual registers if a T12 shadow transfer event is detected. Bit STE12 is cleared by hardware after the shadow transfer. A T12 shadow transfer event is a period-match while counting up or a one-match while counting down. 0_B The shadow register transfer is disabled. 1_B The shadow register transfer is enabled.
CDIR	6	rh	Count Direction of Timer T12 This bit is set/cleared according to the counting rules of T12. 0_B T12 counts up. 1_B T12 counts down.
CTM	7	rw	T12 Operating Mode 0_B Edge-aligned Mode: T12 always counts up and continues counting from zero after reaching the period value. 1_B Center-aligned Mode: T12 counts down after detecting a period-match and counts up after detecting a one-match.
T13CLK	[10:8]	rw	Timer T13 Input Clock Select Selects the input clock for timer T13 that is derived from the peripheral clock according to the equation $f_{T13} = f_{CC6} / 2^{<T13CLK>}$. 000_B $f_{T13} = f_{CC6}$ 001_B $f_{T13} = f_{CC6} / 2$ 010_B $f_{T13} = f_{CC6} / 4$ 011_B $f_{T13} = f_{CC6} / 8$ 100_B $f_{T13} = f_{CC6} / 16$ 101_B $f_{T13} = f_{CC6} / 32$ 110_B $f_{T13} = f_{CC6} / 64$ 111_B $f_{T13} = f_{CC6} / 128$

Field	Bits	Type	Description
T13PRE	11	rw	Timer T13 Prescaler Bit In order to support higher clock frequencies, an additional prescaler factor of 1/256 can be enabled for the prescaler for T13. 0 _B The additional prescaler for T13 is disabled. 1 _B The additional prescaler for T13 is enabled.
T13R	12	rh	Timer T13 Run Bit²⁾ T13R starts and stops timer T13. It is set/cleared by SW by setting bits T13RR or T13RS or it is set/cleared by HW according to the function defined by bit fields T13SSC, T13TEC and T13TED. 0 _B Timer T13 is stopped. 1 _B Timer T13 is running.
STE13	13	rh	Timer T13 Shadow Transfer Enable Bit STE13 enables or disables the shadow transfer of the T13 period value, the compare value and passive state select bit and level from their shadow registers to the actual registers if a T13 shadow transfer event is detected. Bit STE13 is cleared by hardware after the shadow transfer. A T13 shadow transfer event is a period-match. 0 _B The shadow register transfer is disabled. 1 _B The shadow register transfer is enabled.
0	[15: 14]	r	reserved; returns 0 if read; should be written with 0;

- 1) A concurrent set/clear action on T12R (from T12SSC, T12RR or T12RS) will have no effect. The bit T12R will remain unchanged.
- 2) A concurrent set/cleared action on T13R (from T13SSC, T13TEC, T13RR or T13RS) will have no effect. The bit T12R will remain unchanged.

Capture/Compare Unit 6 (CCU6)

Register TCTR2 controls the single-shot and the synchronization functionality of both timers T12 and T13. Both timers can run in single-shot mode. In this mode they stop their counting sequence automatically after one counting period with a count value of zero. The single-shot mode and the synchronization feature of T13 to T12 allow the generation of events with a programmable delay after well-defined PWM actions of T12.

TCTR2

Timer Control Register 2

XSFR(2E_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0				T13 RSEL		T12 RSEL		0	T13 TED		T13 TEC		T13 SSC	T12 SSC	
r				rw		rw		r	rw		rw		rw	rw	

Field	Bits	Type	Description
T12SSC	0	rw	Timer T12 Single Shot Control This bit controls the single shot-mode of T12. 0 _B The single-shot mode is disabled, no HW action on T12R. 1 _B The single shot mode is enabled, the bit T12R is cleared by HW if - T12 reaches its period value in edge-aligned mode - T12 reaches the value 1 while down counting in center-aligned mode. In parallel to the clear action of bit T12R, the bits CC6xST (x=0, 1, 2) are cleared.
T13SSC	1	rw	Timer T13 Single Shot Control This bit controls the single shot-mode of T13. 0 _B No HW action on T13R 1 _B The single-shot mode is enabled, the bit T13R is cleared by HW if T13 reaches its period value. In parallel to the clear action of bit T13R, the bit CC63ST is cleared.

Field	Bits	Type	Description
T13TEC	[4:2]	rw	T13 Trigger Event Control bit field T13TEC selects the trigger event to start T13 (automatic set of T13R for synchronization to T12 compare signals) according to following combinations: 000 _B no action 001 _B set T13R on a T12 compare event on channel 0 010 _B set T13R on a T12 compare event on channel 1 011 _B set T13R on a T12 compare event on channel 2 100 _B set T13R on any T12 compare event (ch. 0, 1, 2) 101 _B set T13R upon a period-match of T12 110 _B set T13R upon a zero-match of T12 (while counting up) 111 _B set T13R on any edge of inputs CCPOSx
T13TED	[6:5]	rw	Timer T13 Trigger Event Direction¹⁾ Bit field T13TED delivers additional information to control the automatic set of bit T13R in the case that the trigger action defined by T13TEC is detected. 00 _B reserved, no action 01 _B while T12 is counting up 10 _B while T12 is counting down 11 _B independent on the count direction of T12
T12RSEL	[9:8]	rw	Timer T12 External Run Selection Bit field T12RSEL defines the event of signal T12HR that can set the run bit T12R by HW. 00 _B The external setting of T12R is disabled. 01 _B Bit T12R is set if a rising edge of signal T12HR is detected. 10 _B Bit T12R is set if a falling edge of signal T12HR is detected. 11 _B Bit T12R is set if an edge of signal T12HR is detected.

Capture/Compare Unit 6 (CCU6)

Field	Bits	Type	Description
T13RSEL	[11:10]	rw	Timer T13 External Run Selection Bit field T13RSEL defines the event of signal T13HR that can set the run bit T13R by HW. 00 _B The external setting of T13R is disabled. 01 _B Bit T13R is set if a rising edge of signal T13HR is detected. 10 _B Bit T13R is set if a falling edge of signal T13HR is detected. 11 _B Bit T13R is set if an edge of signal T13HR is detected.
0	7, [15: 12]	r	reserved; returns 0 if read; should be written with 0;

1) Example:

If the timer T13 is intended to start at any compare event on T12 (T13TEC=100) the trigger event direction can be programmed to

- counting up >> a T12 channel 0, 1, 2 compare match triggers T13R only while T12 is counting up
- counting down >> a T12 channel 0, 1, 2 compare match triggers T13R only while T12 is counting down
- independent from bit CDIR >> each T12 channel 0, 1, 2 compare match triggers T13R

The timer count direction is taken from the value of bit CDIR. As a result, if T12 is running in edge-aligned mode (counting up only), T13 can only be started automatically if bit field T13TED=01 or 11.

Capture/Compare Unit 6 (CCU6)

Register TCTR4 provides software-control (independent set and clear conditions) for the run bits T12R and T13R. Furthermore, the timers can be reset (while running) and bits STE12 and STE13 can be controlled by software. Reading these bits always returns 0.

TCTR4

Timer Control Register 4

XSFR(26_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T13 STD	T13 STR	T13 CNT	0		T13 RES	T13 RS	T13 RR	T12 STD	T12 STR	T12 CNT	0	DT RES	T12 RES	T12 RS	T12 RR
w	w	w	r		w	w	w	w	w	w	r	w	w	w	w

Field	Bits	Type	Description
T12RR	0	w	Timer T12 Run Reset Setting this bit clears the T12R bit. 0 _B T12R is not influenced. 1 _B T12R is cleared, T12 stops counting.
T12RS	1	w	Timer T12 Run Set Setting this bit sets the T12R bit. 0 _B T12R is not influenced. 1 _B T12R is set, T12 starts counting.
T12RES	2	w	Timer T12 Reset 0 _B No effect on T12. 1 _B The T12 counter register is cleared to zero. The switching of the output signals is according to the switching rules. Setting of T12RES has no impact on bit T12R.
DTRES	3	w	Dead-Time Counter Reset 0 _B No effect on the dead-time counters. 1 _B The three dead-time counter channels are cleared to zero.
T12CNT	5	w	Timer T12 Count Event 0 _B No action 1 _B If enabled (PISELH), timer T12 counts one step.
T12STR	6	w	Timer T12 Shadow Transfer Request 0 _B No action 1 _B STE12 is set, enabling the shadow transfer.

Field	Bits	Type	Description
T12STD	7	w	Timer T12 Shadow Transfer Disable 0 _B No action 1 _B STE12 is cleared without triggering the shadow transfer.
T13RR	8	w	Timer T13 Run Reset Setting this bit clears the T13R bit. 0 _B T13R is not influenced. 1 _B T13R is cleared, T13 stops counting.
T13RS	9	w	Timer T13 Run Set Setting this bit sets the T13R bit. 0 _B T13R is not influenced. 1 _B T13R is set, T13 starts counting.
T13RES	10	w	Timer T13 Reset 0 _B No effect on T13. 1 _B The T13 counter register is cleared to zero. The switching of the output signals is according to the switching rules. Setting of T13RES has no impact on bit T13R.
T13CNT	13	w	Timer T13 Count Event 0 _B No action 1 _B If enabled (PISELH), timer T13 counts one step.
T13STR	14	w	Timer T13 Shadow Transfer Request 0 _B No action 1 _B STE13 is set, enabling the shadow transfer.
T13STD	15	w	Timer T13 Shadow Transfer Disable 0 _B No action 1 _B STE13 is cleared without triggering the shadow transfer.
0	4, [12:11]	r	reserved; returns 0 if read; should be written with 0;

Note: A simultaneous write of a 1 to bits that set and clear the same bit will trigger no action. The corresponding bit will remain unchanged.

18.3 Operating Timer T13

Timer T13 is implemented similarly to Timer T12, but only with one channel in compare mode. A 16-bit up-counter is connected to a channel register via a comparator, that generates a signal when the counter contents match the contents of the channel register. A variety of control functions facilitate the adaptation of the T13 structure to different application needs. In addition, T13 can be started synchronously to timer T12 events.

This section provides information about:

- T13 overview (see [Section 18.3.1](#))
- Counting scheme (see [Section 18.3.2](#))
- Compare mode (see [Section 18.3.3](#))
- Compare output path (see [Section 18.3.4](#))
- Shadow register transfer (see [Section 18.3.5](#))
- T13 counter register description (see [Section 18.3.6](#))

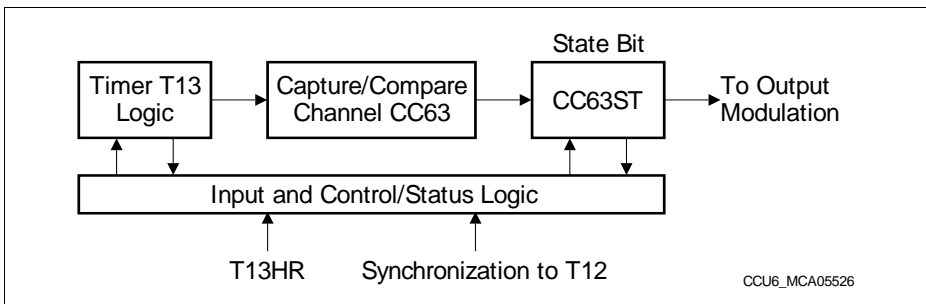


Figure 18-23 Overview Diagram of the Timer T13 Block

18.3.1 T13 Overview

Figure 18-24 shows a detailed block diagram of Timer T13. The functions of the timer T12 block are controlled by bits in registers **TCTR0**, **TCTR2**, **TCTR4**, and **PISELH**. Timer T13 receives its input clock, f_{T13} , from the module clock f_{CC6} via a programmable prescaler and an optional 1/256 divider or from an input signal T13HR. T13 can only count up (similar to the Edge-Aligned mode of T12).

Via a comparator, the timer T13 Counter Register **T13** is connected to the Period Register **T13PR**. This register determines the maximum count value for T13. When T13 reaches the period value, signal T13_PM (T13 Period Match) is generated and T13 is cleared to 0000_H with the next T13 clock edge. The Period Register receives a new period value from its Shadow Period Register, T13PS, that is loaded via software. The transfer of a new period value from the shadow register into T13PR is controlled via the 'T13 Shadow Transfer' control signal, T13_ST. The generation of this signal depends on the associated control bit STE13. Providing a shadow register for the period value as

Capture/Compare Unit 6 (CCU6)

well as for other values related to the generation of the PWM signal facilitates a concurrent update by software for all relevant parameters (refer to [Table 18.3.5](#)).

Another signal indicates whether the counter contents are equal to 0000_H (T13_ZM).

A Single-Shot control bit, T13SSC, enables an automatic stop of the timer when the current counting period is finished (see [Figure 18-26](#)).

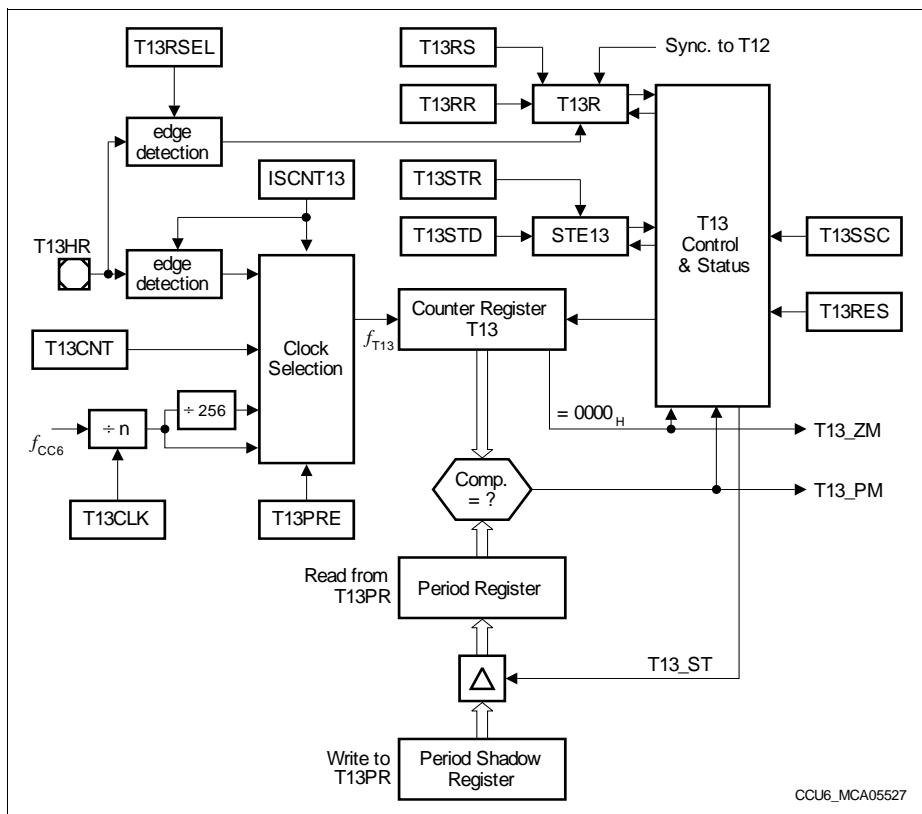


Figure 18-24 T13 Counter Logic and Period Comparators

The start or stop of T13 is controlled by the Run bit, T13R. This control bit can be set by software via the associated set/clear bits T13RS or T13RR in register [TCTR4](#), or it is cleared by hardware according to preselected conditions (single-shot mode).

The timer T13 run bit T13R must not be set while the applied T13 period value is zero. Bit T13R can be set automatically if an event of T12 is detected to synchronize T13 timings to T12 events, e.g. to generate a programmable delay via T13 after an edge of a T12 compare channel before triggering an AD conversion (T13 can trigger ADC

conversions).

Timer T13 can be cleared to 0000_H via control bit T13RES. Setting this write-only bit only clears the timer contents, but has no further effects, e.g., it does not stop the timer.

The generation of the T13 shadow transfer control signal, T13_ST, is enabled via bit STE13. This bit can be set or cleared by software indirectly through its associated set/reset control bits T13STR and T13STD.

Two bit fields, T13TEC and T13TED, control the synchronization of T13 to Timer T12 events. T13TEC selects the trigger event, while T13TED determines for which T12 count direction the trigger should be active.

While Timer T13 is running, write accesses to the count register T13 are not taken into account. If T13 is stopped, write actions to register T13 are immediately taken into account.

Note: The T13 Period Register and its associated shadow register are located at the same physical address. A write access to this address targets the Shadow Register, while a read access reads from the actual period register.

18.3.2 T13 Counting Scheme

This section describes the clocking and the counting capabilities of T13.

18.3.2.1 Clock Selection

In **Timer Mode** (**PISELH**.ISCNT13 = 00_B), the input clock f_{T13} of Timer T13 is derived from the internal module clock f_{CC6} through a programmable prescaler and an optional 1/256 divider. The resulting prescaler factors are listed in **Table 18-6**. The prescaler of T13 is cleared while T13 is not running (**TCTR0**.T13R = 0) to ensure reproducible timings and delays.

Table 18-6 Timer T13 Input Clock Options

T13CLK	Resulting Input Clock f_{T13} Prescaler Off (T13PRE = 0)	Resulting Input Clock f_{T13} Prescaler On (T13PRE = 1)
000 _B	f_{CC6}	$f_{CC6} / 256$
001 _B	$f_{CC6} / 2$	$f_{CC6} / 512$
010 _B	$f_{CC6} / 4$	$f_{CC6} / 1024$
011 _B	$f_{CC6} / 8$	$f_{CC6} / 2048$
100 _B	$f_{CC6} / 16$	$f_{CC6} / 4096$
101 _B	$f_{CC6} / 32$	$f_{CC6} / 8192$
110 _B	$f_{CC6} / 64$	$f_{CC6} / 16384$
111 _B	$f_{CC6} / 128$	$f_{CC6} / 32768$

In **Counter Mode**, timer T13 counts one step:

- If a 1 is written to **TCTR4**.T13CNT and **PISELH**.ISCNT13 = 01_B
- If a rising edge of input signal T13HR is detected and **PISELH**.ISCNT13 = 10_B
- If a falling edge of input signal T13HR is detected and **PISELH**.ISCNT13 = 11_B

18.3.2.2 T13 Counting

The period of the timer is determined by the value in the period Register T13PR according to the following formula:

$$T13_{PER} = \text{<Period-Value>} + 1; \text{ in } T13 \text{ clocks } (f_{T13}) \quad (18.3)$$

Timer T13 can only count up, comparable to the Edge-Aligned mode of T12. This leads to very simple 'counting rule' for the T13 counter:

- The counter is cleared with the next T13 clock edge if a Period-Match is detected. The counting direction is always upwards.

The behavior of T13 is illustrated in **Figure 18-25**.

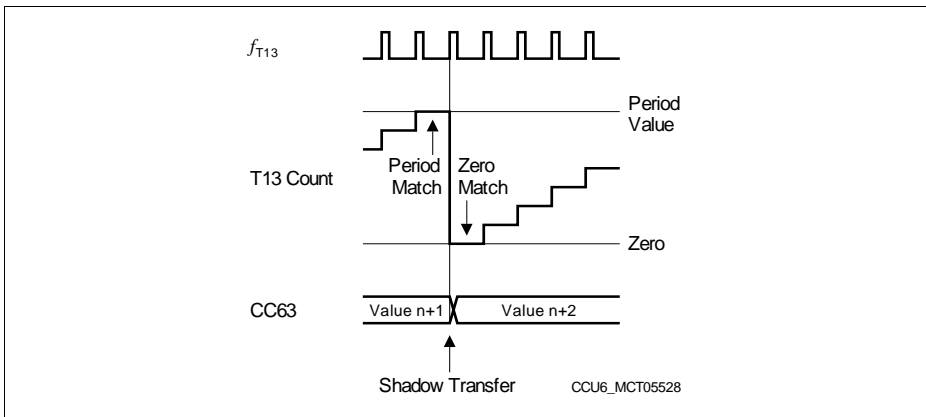


Figure 18-25 T13 Counting Sequence

18.3.2.3 Single-Shot Mode

In Single-Shot Mode, the timer run bit T13R is cleared by hardware. If bit T13SSC = 1, the timer T13 will stop when the current timer period is finished.

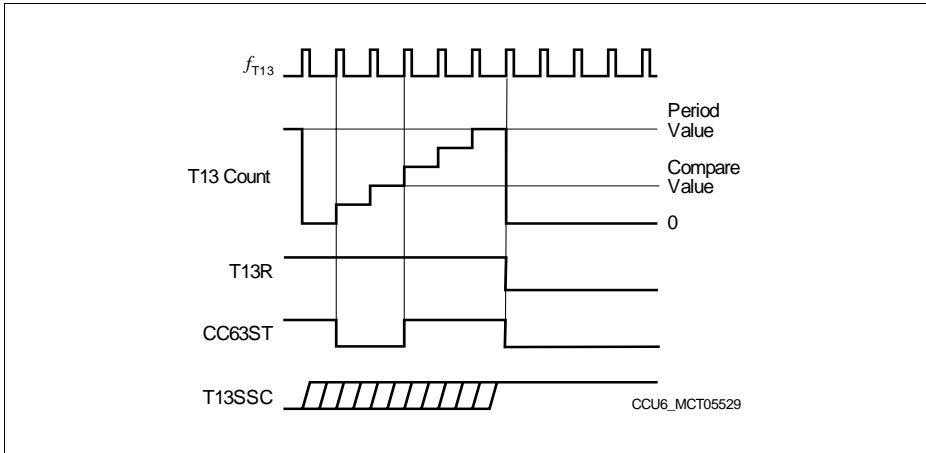


Figure 18-26 Single-Shot Operation of Timer T13

18.3.2.4 Synchronization to T12

Timer T13 can be synchronized to a T12 event. Bit fields T13TEC and T13TED select the event that is used to start Timer T13. The selected event sets bit T13R via HW, and T13 starts counting. Combined with the Single-Shot mode, this feature can be used to generate a programmable delay after a T12 event.

Figure 18-27 shows an example for the synchronization of T13 to a T12 event. Here, the selected event is a compare-match (compare value = 2) while counting up. The clocks of T12 and T13 can be different (other prescaler factor); the figure shows an example in which T13 is clocked with half the frequency of T12.

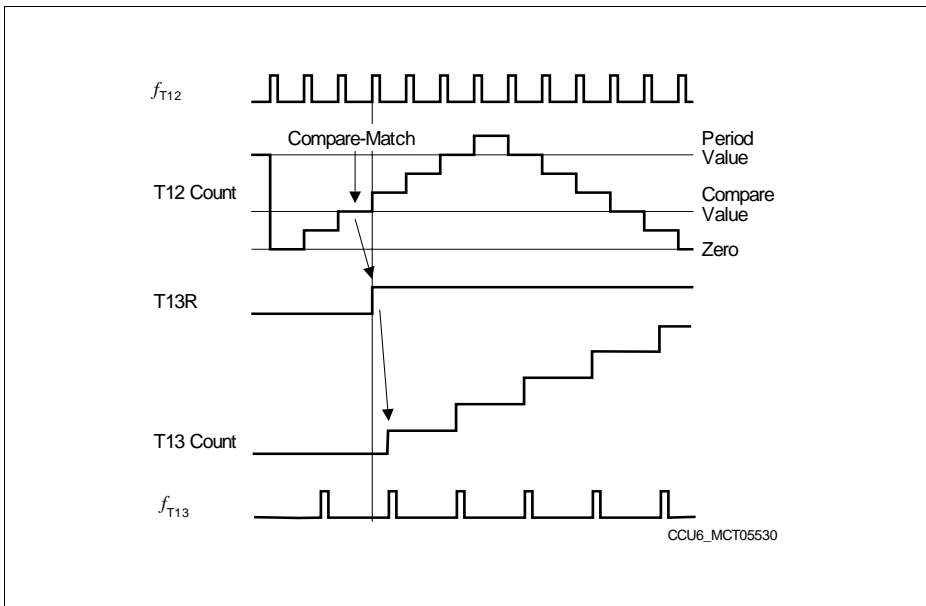


Figure 18-27 Synchronization of T13 to T12 Compare Match

Bit field T13TEC selects the trigger event to start T13 (automatic set of T13R for synchronization to T12 compare signals) according to the combinations shown in [Table 18-7](#). Bit field T13TED additionally specifies for which count direction of T12 the selected trigger event should be regarded (see [Table 18-8](#)).

Table 18-7 T12 Trigger Event Selection

T13TEC	Selected Event
000 _B	None
001 _B	T12 Compare Event on Channel 0 (CM_CC60)
010 _B	T12 Compare Event on Channel 1 (CM_CC61)
011 _B	T12 Compare Event on Channel 2 (CM_CC62)
100 _B	T12 Compare Event on any Channel (0, 1, 2)
101 _B	T12 Period-Match (T12_PM)
110 _B	T12 Zero-Match while counting up (T12_ZM and CDIR = 0)
111 _B	Any Hall State Change

Table 18-8 T12 Trigger Event Additional Specifier

T13TED	Selected Event Specifier
00 _B	Reserved, no action
01 _B	Selected event is active while T12 is counting up (CDIR = 0)
10 _B	Selected event is active while T12 is counting down (CDIR = 1)
11 _B	Selected event is active independently of the count direction of T12

18.3.3 T13 Compare Mode

Associated with Timer T13 is one compare channel, that can perform compare operations with regard to the contents of the T13 counter.

Figure 18-23 gives an overview on the T13 channel in Compare Mode. The channel is connected to the T13 counter register via an equal-to comparator, generating a compare match signal when the contents of the counter matches the contents of the compare register.

The channel consists of the comparator and a double register structure - the actual compare register, **CC63R**, feeding the comparator, and an associated shadow register, **CC63SR**, that is preloaded by software and transferred into the compare register when signal T13 shadow transfer, T13_ST, gets active. Providing a shadow register for the compare value as well as for other values related to the generation of the PWM signal facilitates a concurrent update by software for all relevant parameters.

Associated with the channel is a State Bit, **CMPSTAT.CC63ST**, holding the status of the compare operation. **Figure 18-28** gives an overview on the logic for the State Bit.

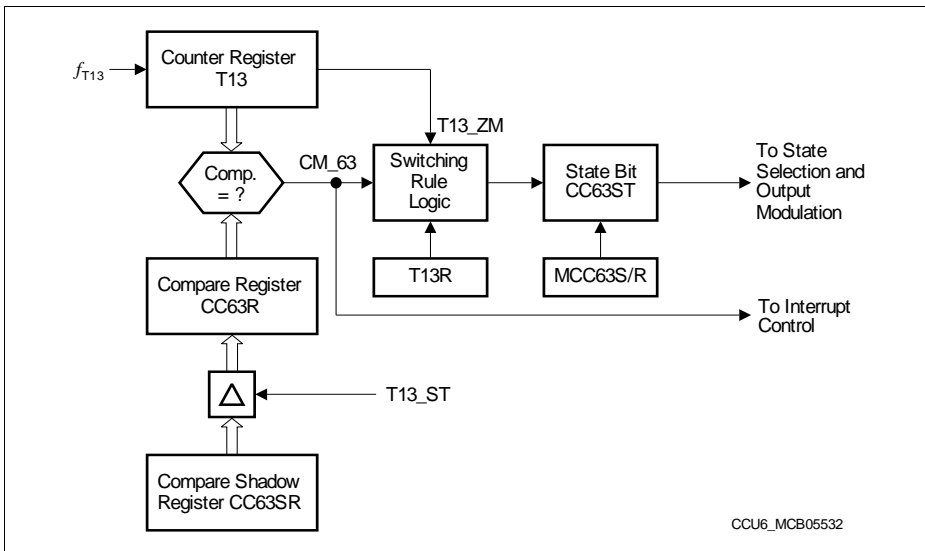


Figure 18-28 T13 State Bit Block Diagram

A compare interrupt event **CM_63** is signaled when a compare match is detected. The actual setting of a State Bit has no influence on the interrupt generation.

The inputs to the switching rule logic for the **CC63ST** bit are the timer run bit (**T13R**), the timer zero-match signal (**T13_ZM**), and the actual individual compare-match signal **CM_63**. In addition, the state bit can be set or cleared by software via bits **MCC63S** and

MCC63R in register **CMPMODIF**.

A modification of the State Bit CC63ST by hardware is only possible while Timer T13 is running ($T13R = 1$). If this is the case, the following switching rules apply for setting and resetting the State Bit in Compare Mode:

State Bit **CC63ST** is **set** to 1

- with the next T13 clock (f_{T13}) after a compare-match (T13 is always counting up) (i.e., when the counter is incremented above the compare value);
- with the next T13 clock (f_{T13}) after a zero-match AND a parallel compare-match.

State Bit **CC63ST** is **cleared** to 0

- with the next T13 clock (f_{T13}) after a zero-match AND NO parallel compare-match.

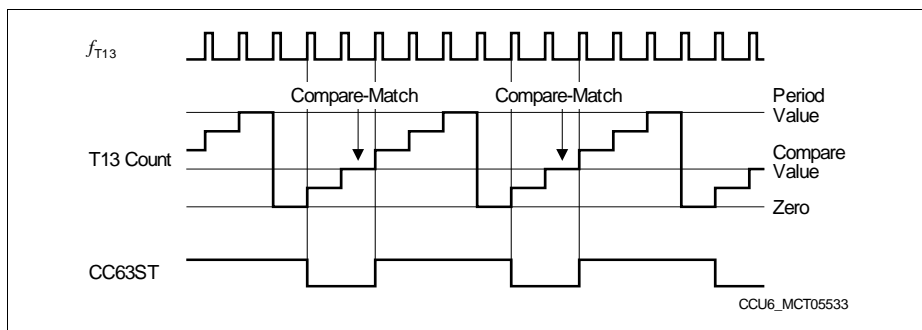


Figure 18-29 T13 Compare Operation

18.3.4 Compare Mode Output Path

Figure 18-30 gives an overview on the signal path from the channel State Bit CC63ST to its output pin COUT63. As illustrated, a user can determine the desired output behavior in relation to the current state of CC63ST. Please refer to [Section 18.2.4.3](#) for detailed information on the output modulation for T12 signals.

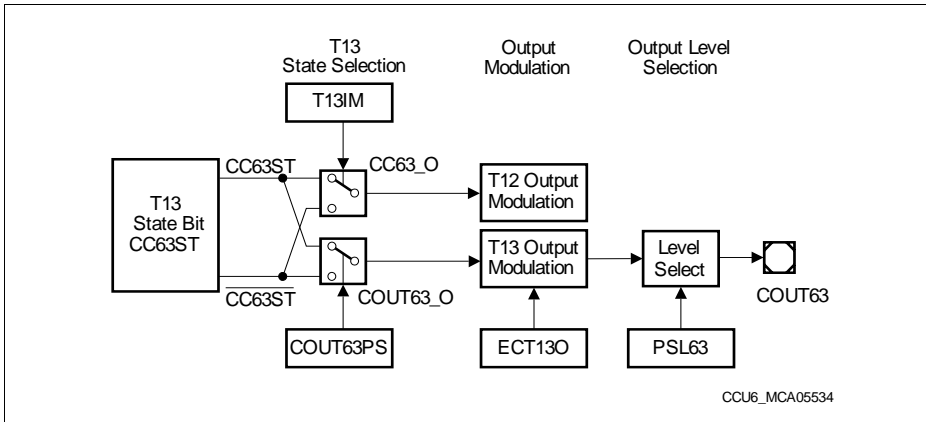


Figure 18-30 Channel 63 Output Path

The output line COUT63_O can generate a T13 PWM at the output pin COUT63. The signal CC63_O can be used to modulate the T12-related output signals with a T13 PWM. In order to decouple COUT63 from the internal modulation, the compare state leading to an active signal can be selected independently by bits T13IM and COUT63PS.

The last block of the data path is the Output Modulation block. Here, the modulation source T13 and the trap functionality are combined and control the actual level of the output pin COUT63 (see [Figure 18-31](#)):

- The **T13 related compare signal** COUT63_O delivered by the T13 state selection with the enable bit **MODCTR.ECT13O**
- The **trap state** TRPS with an individual enable bit **TRPCTR.TRPEN13**

If the modulation input signal COUT63_O is enabled (ECT13O = 1) and is at passive state, the modulated is also in passive state. If the modulation input is not enabled, the output is in passive state.

If the Trap State is active (TRPS = 1), then the output enabled for the trap signal (by TRPEN13 = 1) is set to the passive state.

The output of the modulation control block is connected to a level select block. It offers the option to determine the actual output level of a pin, depending on the state of the output line (decoupling of active/passive state and output polarity) as specified by the Passive State Select bit **PSLR.PSL63**. If the modulated output signal is in the passive

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state, the level specified directly by PSL63 is output. If it is in the active state, the inverted level of PSL63 is output. This allows the user to adapt the polarity of an active output signal to the connected circuitry.

The PSL63 bit has a shadow register to allow for updates with the T13 shadow transfer signal (T13_ST) without undesired pulses on the output lines. A read action returns the actually used value, whereas a write action targets the shadow bit. Providing a shadow register for the PSL value as well as for other values related to the generation of the PWM signal facilitates a concurrent update by software for all relevant parameters.

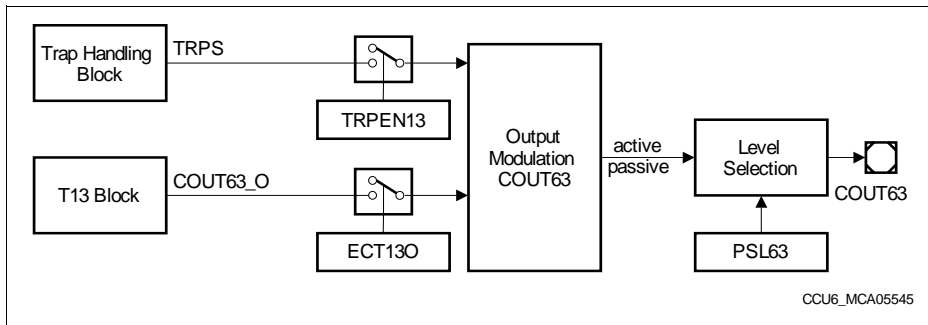


Figure 18-31 T13 Output Modulation

18.3.5 T13 Shadow Register Transfer

A special shadow transfer signal (T13_ST) can be generated to facilitate updating the period and compare values of the compare channel CC63 synchronously to the operation of T13. Providing a shadow register for values defining one PWM period facilitates a concurrent update by software for all relevant parameters. The next PWM period can run with a new set of parameters. The generation of this signal is requested by software via bit **TCTR0.STE13** (set by writing 1 to the write-only bit **TCTR4.T13STR**, cleared by writing 1 to the write-only bit **TCTR4.T13STD**).

When signal T13_ST is active, a shadow register transfer is triggered with the next cycle of the T13 clock. Bit STE13 is automatically cleared with the shadow register transfer.

A T13 shadow register transfer takes place (T13_ST active):

- while timer T13 is not running (T13R = 0), or
- STE13 = 1 and a Period-Match is detected while T13R = 1

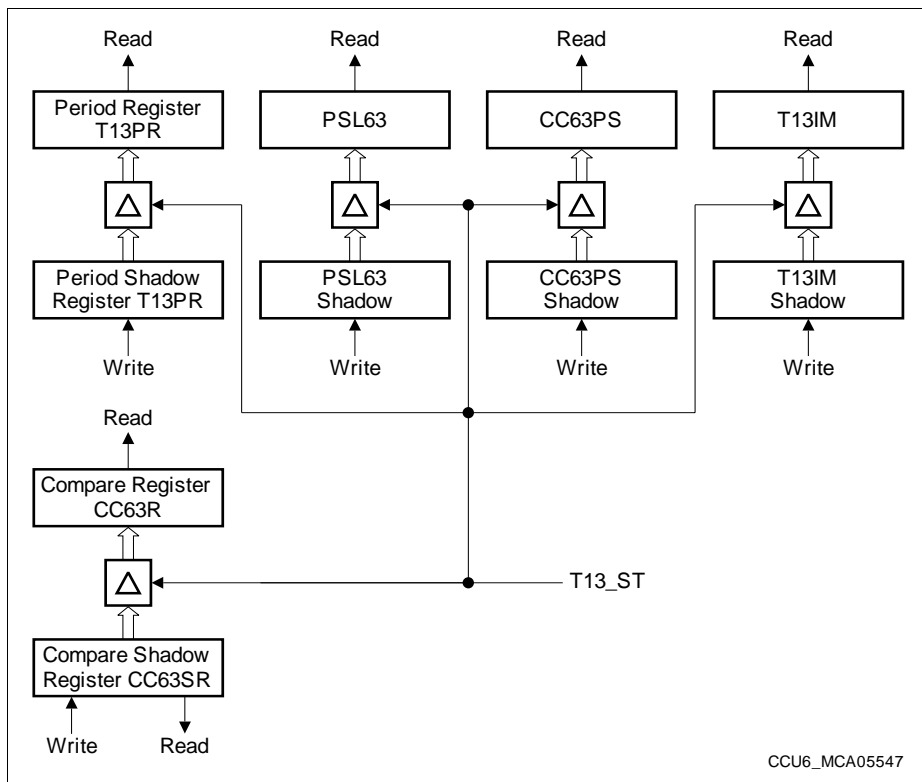


Figure 18-32 T13 Shadow Register Overview

18.3.6 T13 related Registers

18.3.6.1 T13 Counter Register

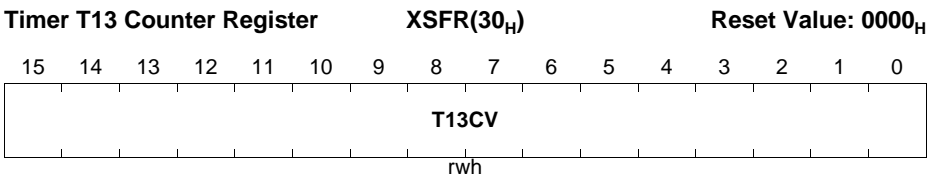
The generation of the patterns for a single channel pulse width modulation (PWM) is based on timer T13. The registers related to timer T13 can be concurrently updated (with well-defined conditions) in order to ensure consistency of the PWM signal. T13 can be synchronized to several timer T12 events.

Timer T13 only supports compare mode on its compare channel CC63.

Register T13 represents the counting value of timer T13. It can only be written while the timer T13 is stopped. Write actions while T13 is running are not taken into account. Register T13 can always be read by SW.

Timer T13 only supports edge-aligned mode (counting up).

T13



Field	Bits	Type	Description
T13CV	[15:0]	rwh	Timer 13 Counter Value This register represents the 16-bit counter value of Timer13.

Note: While timer T13 is stopped, the internal clock divider is reset in order to ensure reproducible timings and delays.

18.3.6.2 Period Register

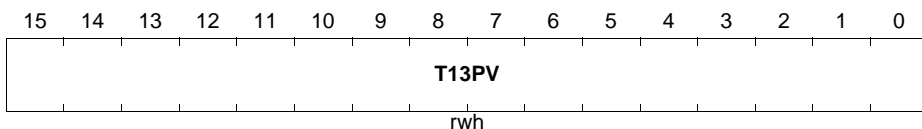
Register T13PR contains the period value for timer T13. The period value is compared to the actual counter value of T13 and the resulting counter actions depend on the defined counting rules. This register has a shadow register and the shadow transfer is controlled by bit STE13. A read action by SW delivers the value currently used for the compare action, whereas the write action targets a shadow register. The shadow register structure allows a concurrent update of all T13-related values.

T13PR

Timer 13 Period Register

XSFR(32_H)

Reset Value: 0000_H



Field	Bits	Type	Description
T13PV	[15:0]	rwh	T13 Period Value The value T13PV defines the counter value for T13 leading to a period-match. When reaching this value, the timer T13 is set to zero.

18.3.6.3 Compare Register

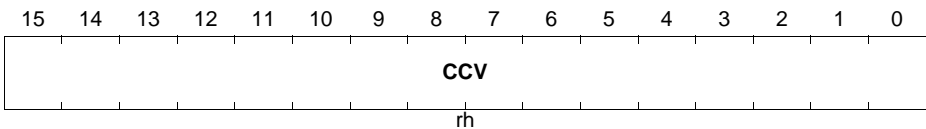
Registers CC63R is the actual compare register for T13. The values stored in CC63R is compared to the counter value of T13. The State Bit CC63ST is located in register **CMPSTAT**.

CC63R

Compare Register for T13

XSFR(34_H)

Reset Value: 0000_H



Field	Bits	Type	Description
CCV	[15:0]	rh	Channel CC63 Compare Value The bit field CCV contains the value, that is compared to the T13 counter value.

18.3.6.4 Compare Shadow Register

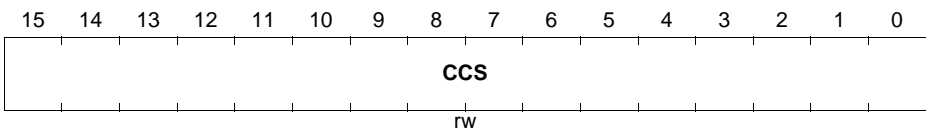
The register CC63R can only be read by SW, the modification of the value is done by a shadow register transfer from register CC63SR. The corresponding shadow register CC63SR can be read and written by SW.

CC63SR

Compare Shadow Register for T13

XSFR(36_H)

Reset Value: 0000_H



Field	Bits	Type	Description
CCS	[15:0]	rw	Shadow Register for Channel CC63 Compare Value The bit field contents of CCS is transferred to the bit field CCV during a shadow transfer.

18.4 Trap Handling

The trap functionality permits the PWM outputs to react on the state of the input signal $\overline{\text{CTRAP}}$. This functionality can be used to switch off the power devices if the trap input becomes active (e.g. to perform an emergency stop). The trap handling and the effect on the output modulation are controlled by the bits in the trap control register **TRPCTR**. The trap flags TRPF and TRPS are located in register **IS** and can be set/cleared by SW by writing to registers **ISS** and **ISR**.

Figure 18-33 gives an overview on the trap function.

The Trap Flag TRPF monitors the trap input and initiates the entry into the Trap State. The Trap State Bit TRPS determines the effect on the outputs and controls the exit of the Trap State.

When a trap condition is detected ($\overline{\text{CTRAP}} = 0$) and the input is enabled ($\text{TRPPEN} = 1$), both, the Trap Flag TRPF and the Trap State Bit TRPS, are set to 1 (trap state active). The output of the Trap State Bit TRPS leads to the Output Modulation Blocks (for T12 and for T13) and can there deactivate the outputs (set them to the passive state). Individual enable control bits for each of the six T12-related outputs and the T13-related output facilitate a flexible adaptation to the application needs.

There are a number of different ways to exit the Trap State. This offers SW the option to select the best operation for the application. Exiting the Trap State can be done either immediately when the trap condition is removed ($\overline{\text{CTRAP}} = 1$ or $\text{TRPPEN} = 0$), or under software control, or synchronously to the PWM generated by either Timer T12 or Timer T13.

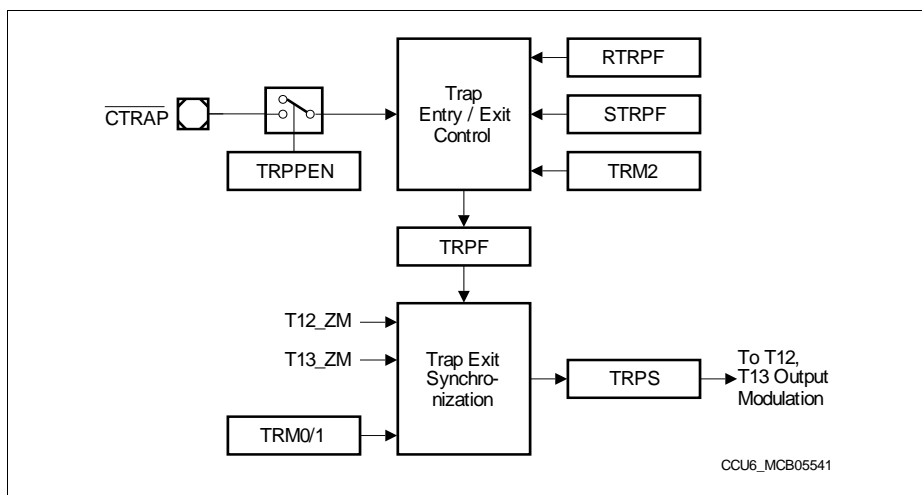


Figure 18-33 Trap Logic Block Diagram

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Clearing of TRPF is controlled by the mode control bit TRPM2. If $TRPM2 = 0$, TRPF is automatically cleared by HW when CTRAP returns to the inactive level ($CTRAP = 1$) or if the trap input is disabled ($TRPPEN = 0$). When $TRPM2 = 1$, TRPF must be reset by SW after CTRAP has become inactive.

Clearing of TRPS is controlled by the mode control bits TRPM1 and TRPM0 (located in the Trap Control Register TRPCTR). A reset of TRPS terminates the Trap State and returns to normal operation. There are three options selected by TRPM1 and TRPM0. One is that the Trap State is left immediately when the Trap Flag TRPF is cleared, without any synchronization to timers T12 or T13. The other two options facilitate the synchronization of the termination of the Trap State to the count periods of either Timer T12 or Timer T13. **Figure 18-34** gives an overview on the associated operation.

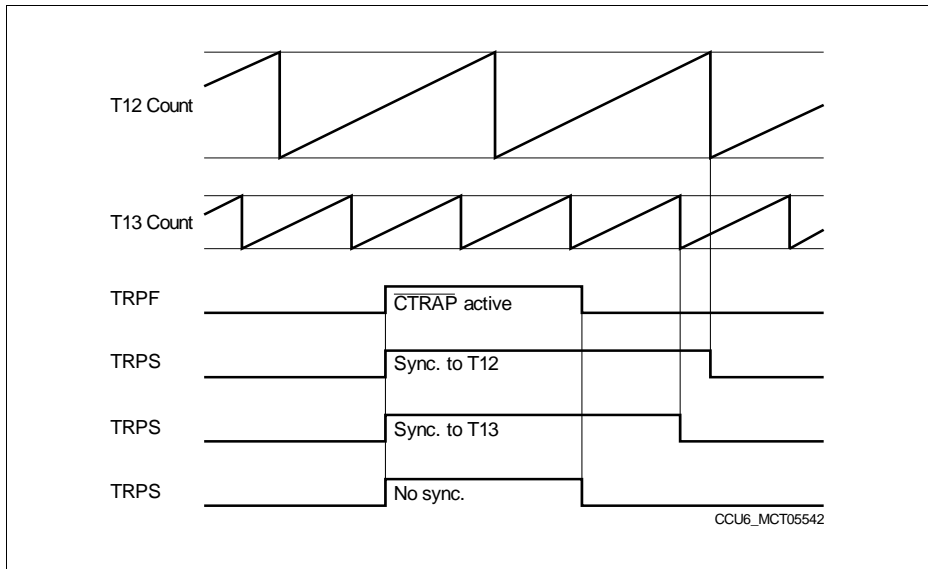


Figure 18-34 Trap State Synchronization (with TRM2 = 0)

18.5 Multi-Channel Mode

The Multi-Channel mode offers the possibility to modulate all six T12-related output signals with one instruction. The bits in bit field **MCMOUT.MCMP** are used to specify the outputs that may become active. If Multi-Channel mode is enabled (bit **MODCTR.MCMEN** = 1), only those outputs may become active, that have a 1 at the corresponding bit position in bit field **MCMP**.

This bit field has its own shadow bit field **MCMOUTS.MCMPS**, that can be written by software. The transfer of the new value in **MCMP** to the bit field **MCMP** can be triggered by, and synchronized to, T12 or T13 events. This structure permits the software to write the new value, that is then taken into account by the hardware at a well-defined moment and synchronized to a PWM signal. This avoids unintended pulses due to unsynchronized modulation sources.

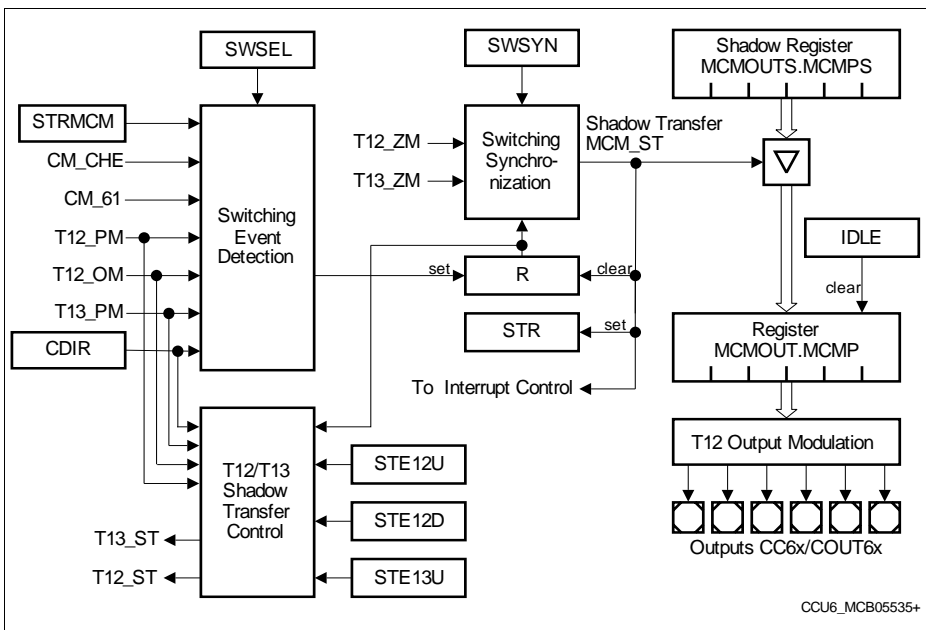


Figure 18-35 Multi-Channel Mode Block Diagram

Figure 18-35 shows the functional blocks for the Multi-Channel operation, controlled by bit fields in register **MCMCTR**. The event that triggers the update of bit field **MCMP** is chosen by **SWSEL**. In order to synchronize the update of **MCMP** to a PWM generated by T12 or T13, bit field **SWSYN** allows the selection of the synchronization event leading to the transfer from **MCMPS** to **MCMP**. Due to this structure, an update takes place with a new PWM period. A reminder flag **R** is set when the selected switching event occurs

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(the event is not necessarily synchronous to the modulating PWM), and is cleared when the transfer takes place. This flag can be monitored by software to check for the status of this logic block. If the shadow transfer from MCMPS to MCMP takes place, bit **IS.STR** becomes set and an interrupt can be generated.

In addition to the Multi-Channel shadow transfer event MCM_ST, the shadow transfers for T12 (T12_ST) and T13 (T13_ST) can be generated to allow concurrent updates of applied duty cycles for T12 and/or T13 modulation and Multi-Channel patterns.

If it is explicitly desired, the update takes place immediately with the occurrence of the selected event when the direct synchronization mode is selected. The update can also be requested by software by writing to bit field MCMPS with the shadow transfer request bit STRMCM = 1. The option to trigger an update by SW is possible for all settings of SWSEL.

By using the direct mode and bit STRMCM = 1, the update takes place completely under software control.

The event selection and synchronization options are summarized in [Table 18-9](#) and [Table 18-10](#).

Table 18-9 Multi-Channel Mode Switching Event Selection

SWSEL	Selected Event (see register MCMCTR)
000 _B	No automatic event detection
001 _B	Correct Hall Event (CM_CHE) detected at input signals CCPOSx without additional delay
010 _B	T13 Period-Match (T13_PM)
011 _B	T12 One-Match while counting down (T12_OM and CDIR = 1)
100 _B	T12 Compare Channel 1 Event while counting up (CM_61 and CDIR = 0) to support the phase delay function by CC61 for block commutation mode.
101 _B	T12 Period-Match while counting up (T12_PM and CDIR = 0)
110 _B , 111 _B	Reserved, no action

Table 18-10 Multi-Channel Mode Switching Synchronization

SWSYN	Synchronization Event (see register MCMCTR)
00 _B	Direct Mode: the trigger event directly causes the shadow transfer
01 _B	T13 Zero-Match (T13_ZM), the MCM shadow transfer is synchronized to a T13 PWM

Table 18-10 Multi-Channel Mode Switching Synchronization (cont'd)

SWSYN	Synchronization Event (see register MCMCTR)
10 _B	T12 Zero-Match (T12_ZM), the MCM shadow transfer is synchronized to a T12 PWM
11 _B	Reserved, no action

18.6 Hall Sensor Mode

For Brushless DC-Motors in block commutation mode, the Multi-Channel Mode has been introduced to provide efficient means for switching pattern generation. These patterns need to be output in relation to the angular position of the motor. For this, usually Hall sensors or Back-EMF sensing are used to determine the angular rotor position. The CCU6 provides three inputs, CCPOS0, CCPOS1, and CCPOS2, that can be used as inputs for the Hall sensors or the Back-EMF detection signals.

There is a strong correlation between the motor position and the output modulation pattern. When a certain position of the motor has been reached, indicated by the sampled Hall sensor inputs (the Hall pattern), the next, pre-determined Multi-Channel Modulation pattern has to be output. Because of different machine types, the modulation pattern for driving the motor can vary. Therefore, it is wishful to have a wide flexibility in defining the correlation between the Hall pattern and the corresponding Modulation pattern. Furthermore, a hardware mechanism significantly reduces the CPU for block-commutation.

The CCU6 offers the flexibility by having a register containing the currently assumed Hall pattern (CURH), the next expected Hall pattern (EXPH) and the corresponding output pattern (MCMP). A new Modulation pattern is output when the sampled Hall inputs match the expected ones (EXPH). To detect the next rotation phase (segment for block commutation), the CCU6 monitors the Hall inputs for changes. When the next expected Hall pattern is detected, the next corresponding Modulation pattern is output.

To increase for noise immunity (to a certain extend), the CCU6 offers the possibility to introduce a sampling delay for the Hall inputs. Some changes of the Hall inputs are not leading to the expected Hall pattern, because they are only short spikes due to noise. The Hall pattern compare logic compares the Hall inputs to the next expected pattern and also to the currently assumed pattern to filter out spikes.

For the Hall and Modulation output patterns, a double-register structure is implemented. While register **MCMOUT** holds the actually used values, its shadow register **MCMOUTS** can be loaded by software from a pre-defined table, holding the appropriate Hall and Modulation patterns for the given motor control.

A transfer from the shadow register into register MCMOUT can take place when a correct Hall pattern change is detected. Software can then load the next values into register MCMOUTS. It is also possible by software to force a transfer from MCMOUTS into MCMOUT.

Note: The Hall input signals CCPOSx and the CURH and EXPH bit fields are arranged in the following order:

CCPOS0 corresponds to CURH.0 (LSB) and EXPH.0 (LSB)

CCPOS1 corresponds to CURH.1 and EXPH.1

CCPOS2 corresponds to CURH.2 (MSB) and EXPH.2 (MSB)

18.6.1 Hall Pattern Evaluation

The Hall sensor inputs CCPOSx can be permanently monitored via an edge detection block (with the module clock f_{CC6}). In order to suppress spikes on the Hall inputs due to noise in rugged inverter environment, two optional noise filtering methods are supported by the Hall logic (both methods can be combined).

- **Noise filtering with delay:**
 For this function, the mode control bit fields MSEL6x for all T12 compare channels must be programmed to 1000_B and DBYP = 0. The selected event triggers Dead-Time Counter 0 to generate a programmable delay (defined by bit field DTM). When the delay has elapsed, the evaluation signal HCRDY becomes activated.
 Output modulation with T12 PWM signals is not possible in this mode.
- **Noise filtering by synchronization to PWM:**
 The Hall inputs are not permanently monitored by the edge detection block, but samples are taken only at defined points in time during a PWM period. This can be used to sample the Hall inputs when the switching noise (due to PWM) does not disturb the Hall input signals.

If neither the delay function of Dead-Time Counter 0 is not used for the Hall pattern evaluation nor the Hall mode for Brushless DC-Drive control is enabled, the timer T12 block is available for PWM generation and output modulation.

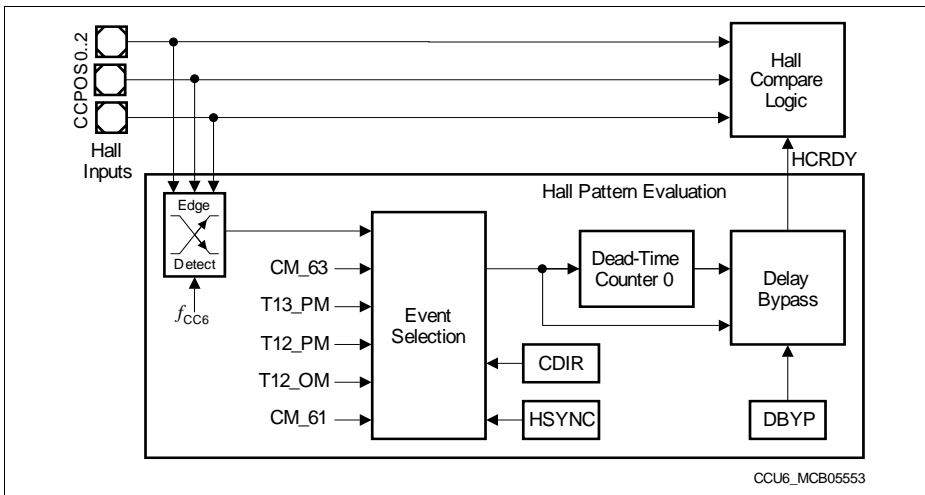


Figure 18-36 Hall Pattern Evaluation

If the evaluation signal HCRDY (Hall Compare Ready, see [Figure 18-37](#)) becomes activated, the Hall inputs are sampled and the Hall compare logic starts the evaluation of the Hall inputs.

Figure 18-36 illustrates the events for Hall pattern evaluation and the noise filter logic, **Table 18-11** summarizes the selectable trigger input signals.

Table 18-11 Hall Sensor Mode Trigger Event Selection

HSYNC	Selected Event (see register T12MSEL)
000 _B	Any edge at any of the inputs CCPOSx, independent from any PWM signal (permanent check).
001 _B	A T13 Compare-Match (CM_63).
010 _B	A T13 Period-Match (T13_PM).
011 _B	Hall sampling triggered by HW sources is switched off.
100 _B	A T12 Period-Match while counting up (T12_PM and CDIR = 0).
101 _B	A T12 One-Match while counting down (T12_OM and CDIR = 1).
110 _B	A T12 Compare-Match of compare channel CC61 while counting up (CM_61 and CDIR = 0).
111 _B	A T12 Compare-Match of compare channel CC61 while counting down (CM_61 and CDIR = 1).

18.6.2 Hall Pattern Compare Logic

Figure 18-37 gives an overview on the double-register structure and the pattern compare logic. Software writes the next modulation pattern (MCMPS) and the corresponding current (CURHS) and expected (EXPHS) Hall patterns into the shadow register MCMOUTS. Register MCMOUT holds the actually used values CURH and EXPH. The modulation pattern MCMP is provided to the T12 Output Modulation block. The current (CURH) and expected (EXPH) Hall patterns are compared to the sampled Hall sensor inputs (visible in register **CMPSTAT**). Sampling of the inputs and the evaluation of the comparator outputs is triggered by the evaluation signal HCRDY (Hall Compare Ready), that is detailed in the next section.

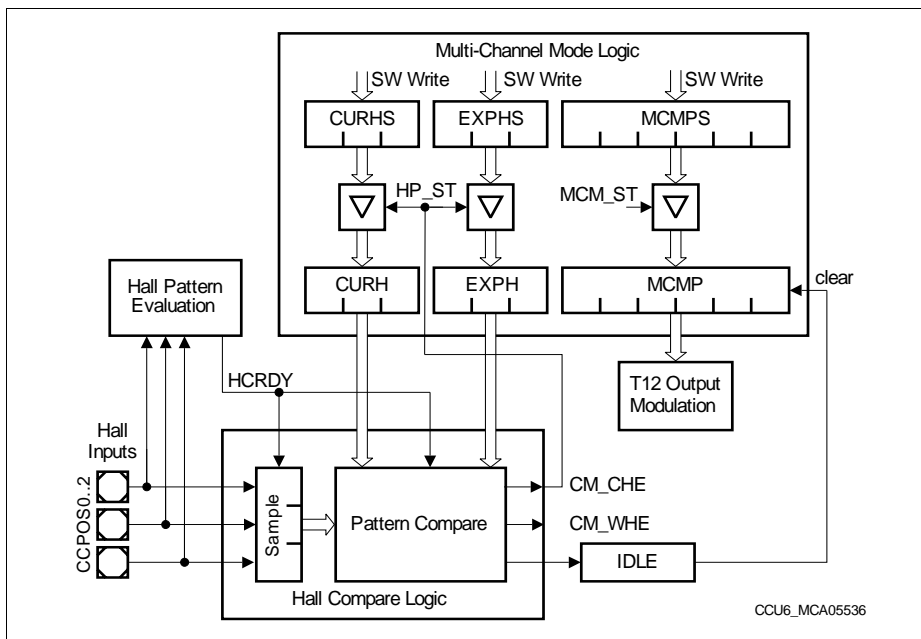


Figure 18-37 Hall Pattern Compare Logic

- If the sampled Hall pattern matches the value programmed in CURH, the detected transition was a spike (no Hall event) and no further actions are necessary.
- If the sampled Hall pattern matches the value programmed in EXPH, the detected transition was the expected event (correct Hall event CM_CHE) and the MCMP value has to change.
- If the sampled Hall pattern matches neither CURH nor EXPH, the transition was due to a major error (wrong Hall event CM_CWE) and can lead to an emergency shut down (IDLE).

At every correct Hall event (CM_CHE), the next Hall patterns are transferred from the shadow register MCMOUTS into MCMOUT (Hall pattern shadow transfer HP_ST), and a new Hall pattern with its corresponding output pattern can be loaded (e.g. from a predefined table in memory) by software into MCMOUTS. For the Modulation patterns, signal MCM_ST is used to trigger the transfer.

Loading this shadow register can also be done by writing MCMOUTS.STRHP = 1 (for EXPH and CURH) or MCMOUTS.STRMCMP = 1 (for MCMP).

18.6.3 Hall Mode Flags

Depending on the Hall pattern compare operation, a number of flags are set in order to indicate the status of the module and to trigger further actions and interrupt requests.

Flag **IS.CHE** (Correct Hall Event) is set by signal CM_CHE when the sampled Hall pattern matches the expected one (EXPH). This flag can also be set by SW by setting bit **ISS.SCHE** = 1. If enabled by bit **IEN.ENCHE** = 1, the set signal for CHE can also generate an interrupt request to the CPU. Bit field **INP.INPCHE** defines which service request output becomes activated in case of an interrupt request. To clear flag CHE, SW needs to write **ISR.RCHE** = 1.

Flag **IS.WHE** indicates a Wrong Hall Event. Its handling for flag setting and resetting as well as interrupt request generation are similar to the mechanism for flag CHE.

The implementation of flag STR is done in the same way as for CHE and WHE. This flag is set by HW by the shadow transfer signal MCM_ST (see also [Figure 18-35](#)).

Please note that for flags CHE, WHE, and STR, the interrupt request generation is triggered by the set signal for the flag. That means, a request can be generated even if the flag is already set. There is no need to clear the flag in order to enable further interrupt requests.

The implementation for the IDLE flag is different. It is set by HW through signal CM_WHE if enabled by bit ENIDLE. Software can also set the flag via bit SIDLE. As long as bit IDLE is set, the modulation pattern field MCMP is cleared to force the outputs to the passive state. Flag IDLE must be cleared by software by writing RIDLE = 1 in order to return to normal operation. To fully restart from IDLE mode, the transfer requests for the bit fields in register MCMOUTS to register MCMOUT have to be initiated by software via bits STRMCM and STRHP in register MCMOUTS. In this way, the release from IDLE mode is under software control, but can be performed synchronously to the PWM signal.

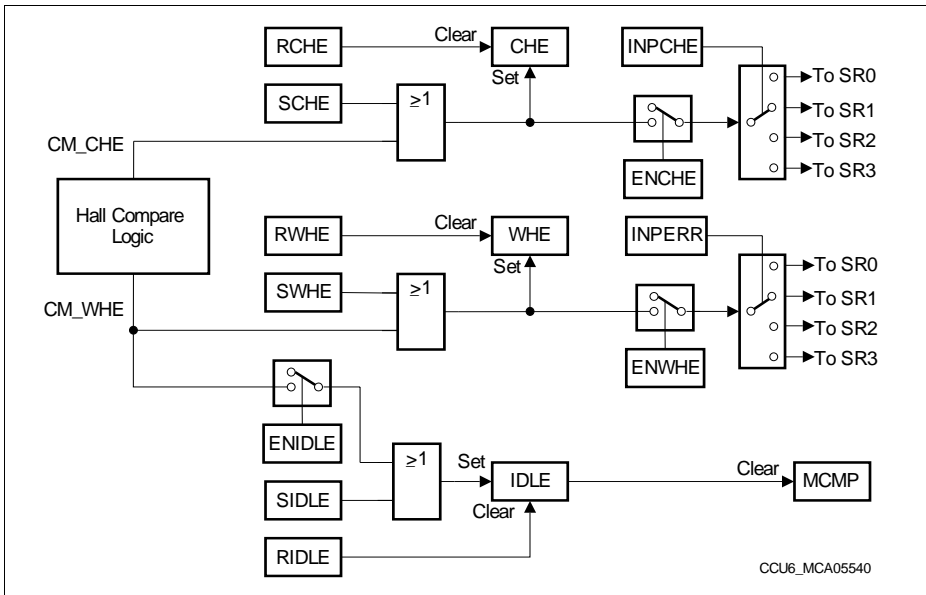


Figure 18-38 Hall Mode Flags

18.6.4 Hall Mode for Brushless DC-Motor Control

The CCU6 provides a mode for the Timer T12 Block especially targeted for convenient control of block commutation patterns for Brushless DC-Motors. This mode is selected by setting all **T12MSEL**.MSEL6x bit fields of the three T12 Channels to 1000_B.

In this mode, illustrated in **Figure 18-39**, channel CC60 is placed in capture mode to measure the time elapsed between the last two correct Hall events, channel CC61 in compare mode to provide a programmable phase delay between the Hall event and the application of a new PWM output pattern, and channel CC62 also in compare mode as first time-out criterion. A second time-out criterion can be built by the T12 period match event.

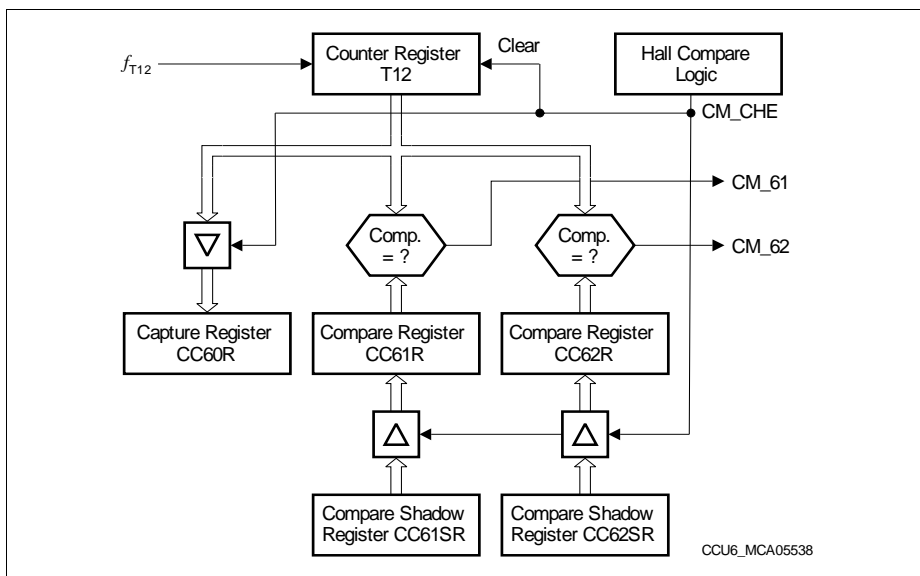


Figure 18-39 T12 Block in Hall Sensor Mode

The signal CM_CHE from the Hall compare logic is used to transfer the new compare values from the shadow registers CC6xSR into the actual compare registers CC6xR, performs the shadow transfer for the T12 period register, to capture the current T12 contents into register CC60R, and to clear T12.

Note: In this mode, the shadow transfer signal T12_ST is not generated. Not all shadow bits, such as the PSLy bits, will be transferred to their main registers. To program the main registers, SW needs to write to these registers while Timer T12 is stopped. In this case, a SW write actualizes both registers.

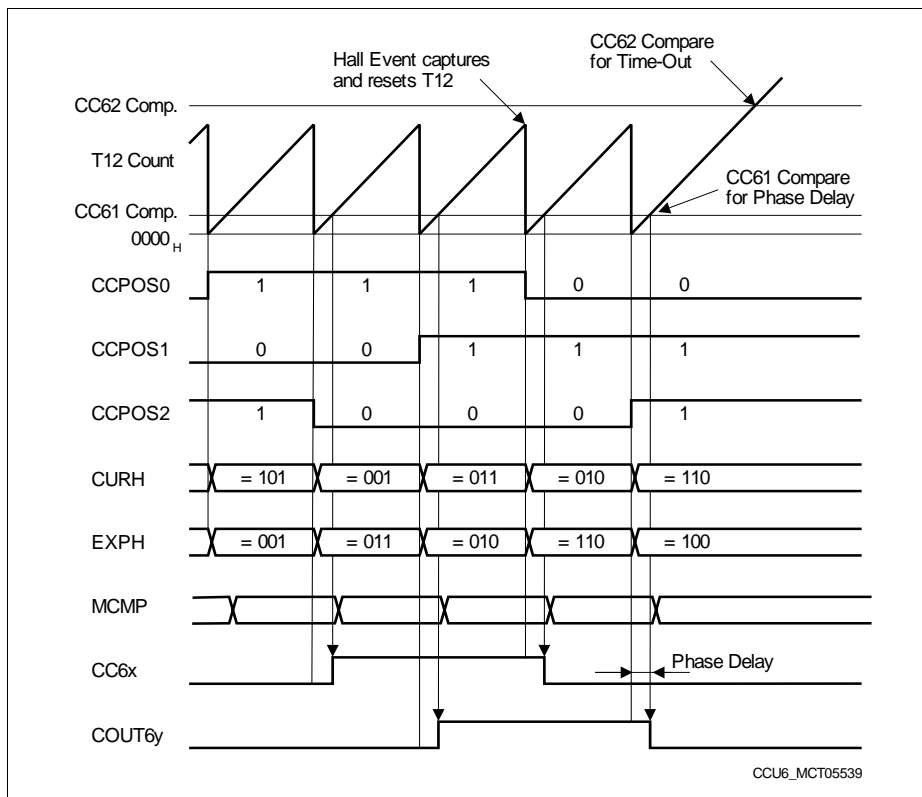


Figure 18-40 Brushless DC-Motor Control Example (all MSEL6x = 1000_B)

After the detection of an expected Hall pattern (CM_CHE active), the T12 count value is captured into channel CC60 (representing the actual rotor speed by measuring the elapsed time between the last two correct Hall events), and T12 is reset. When the timer reaches the compare value in channel CC61, the next multi-channel state is switched by triggering the shadow transfer of bit field MCMP (if enabled in bit field **SWEN**). This trigger event can be combined with the synchronization of the next multi-channel state to the PWM source (to avoid spikes on the output lines, see [Section 18.5](#)). This compare function of channel CC61 can be used as a phase delay from the position sensor input signals to the switching of the output signals, that is necessary if a sensorless back-EMF technique or Hall sensors are used. The compare value in channel CC62 can be used as a time-out trigger (interrupt), indicating that the actual motor speed is far below the desired destination value. An abnormal load change can be detected with this feature and PWM generation can be disabled.

18.7 Modulation Control Registers

18.7.1 Modulation Control

This register contains bits enabling the modulation of the corresponding output signal by PWM pattern generated by the timers T12 and T13. Furthermore, the multi-channel mode can be enabled as additional modulation source for the output signals.

MODCTR

Modulation Control Register

XSFR(40_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ECT 130	0	T13MODEN					MCM EN	0	T12MODEN						
rw	r	rw					rw	r	rw						

Field	Bits	Type	Description
T12MODEN	[5:0]	rw	T12 Modulation Enable These bits enable the modulation of the corresponding output signal by a PWM pattern generated by timer T12. T12MODEN0 = MODCTR.0 for output CC60 T12MODEN1 = MODCTR.1 for output COUT60 T12MODEN2 = MODCTR.2 for output CC61 T12MODEN3 = MODCTR.3 for output COUT61 T12MODEN4 = MODCTR.4 for output CC62 T12MODEN5 = MODCTR.5 for output COUT62 0 _B The modulation of the corresponding output signal by a T12 PWM pattern is disabled. 1 _B The modulation of the corresponding output signal by a T12 PWM pattern is enabled.
MCMEN	7	rw	Multi-Channel Mode Enable 0 _B The modulation of the corresponding output signal by a multi-channel pattern according to bit field MCMOUT is disabled. 1 _B The modulation of the corresponding output signal by a multi-channel pattern according to bit field MCMOUT is enabled.

Field	Bits	Type	Description
T13MODEN	[13:8]	rw	T13 Modulation Enable These bits enable the modulation of the corresponding output signal by the PWM pattern CC63_O generated by timer T13. T13MODEN0 = MODCTR.8 for output CC60 T13MODEN1 = MODCTR.9 for output COUT60 T13MODEN2 = MODCTR.10 for output CC61 T13MODEN3 = MODCTR.11 for output COUT61 T13MODEN4 = MODCTR.12 for output CC62 T13MODEN5 = MODCTR.13 for output COUT62 0 _B The modulation of the corresponding output signal by a T13 PWM pattern is disabled. 1 _B The modulation of the corresponding output signal by a T13 PWM pattern is enabled.
ECT13O	15	rw	Enable Compare Timer T13 Output 0 _B The output COUT63 is in the passive state. 1 _B The output COUT63 is enabled for the PWM signal generated by T13.
0	6, 14	r	reserved; returns 0 if read; should be written with 0;

18.7.2 Trap Control Register

The register TRPCTR controls the trap functionality. It contains independent enable bits for each output signal and control bits to select the behavior in case of a trap condition. The trap condition is a low level on the $\overline{\text{CTRAP}}$ input pin, that is monitored (inverted level) by bit IS.TRPF. While TRPF=1 (trap input active), the trap state bit IS.TRPS is set to 1.

TRPCTR

Trap Control Register

XSFR(42_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRP PEN	TRP EN 13	TRPEN						0				TRP M2	TRP M1	TRP M0	
rw	rw	rw						r				rw	rw	rw	

Field	Bits	Type	Description
TRPM1, TRPM0	1, 0	rw	<p>Trap Mode Control Bits 1, 0</p> <p>These two bits define the behavior of the selected outputs when leaving the trap state after the trap condition has become inactive again.</p> <p>A synchronization to the timer driving the PWM pattern avoids unintended pulses when leaving the trap state.</p> <p>The combination [TRPM1, TRPM0] leads to:</p> <p>00_B The trap state is left (return to normal operation) after TRPF has become 0 again when a zero-match of T12 (while counting up) is detected (synchronization to T12).</p> <p>01_B The trap state is left (return to normal operation) after TRPF has become 0 again when a zero-match of T13 is detected (synchronization to T13).</p> <p>10_B reserved</p> <p>11_B The trap state is left (return to normal operation) immediately after TRPF has become 0 again without any synchronization to T12 or T13.</p>

Field	Bits	Type	Description
TRPM2	2	rw	Trap Mode Control Bit 2 This bit defines how the trap flag TRPF can be cleared after the trap input condition ($\overline{\text{CTRAP}} = 0$ and $\text{TRPPEN} = 1$) is no longer valid (either by $\overline{\text{CTRAP}} = 1$ or by $\text{TRPPEN} = 0$). 0_B Automatic Mode: Bit TRPF is cleared by HW if the trap input condition is no longer valid. 1_B Manual Mode: Bit TRPF stays 0 after the trap input condition is no longer valid. It has to be cleared by SW by writing $\text{ISR.RTRPF} = 1$.
TRPEN	[13:8]	rw	Trap Enable Control Setting a bit enables the trap functionality for the following corresponding output signals: $\text{TRPEN0} = \text{TRPCTR.8}$ for output CC60 $\text{TRPEN1} = \text{TRPCTR.9}$ for output COUT60 $\text{TRPEN2} = \text{TRPCTR.10}$ for output CC61 $\text{TRPEN3} = \text{TRPCTR.11}$ for output COUT61 $\text{TRPEN4} = \text{TRPCTR.12}$ for output CC62 $\text{TRPEN5} = \text{TRPCTR.13}$ for output COUT62 0_B The trap functionality of the corresponding output signal is disabled. The output state is independent from bit IS.TRPS. 1_B The trap functionality of the corresponding output signal is enabled. The output state is set to the passive while $\text{IS.TRPS}=1$.
TRPEN13	14	rw	Trap Enable Control for Timer T13 0_B The trap functionality for output COUT63 is disabled. The output state is independent from bit IS.TRPS. 1_B The trap functionality for output COUT63 is enabled. The output state is set to the passive while $\text{IS.TRPS}=1$.

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Field	Bits	Type	Description
TRPPEN	15	rw	Trap Pin Enable This bit enables the input (pin) function for the trap generation. An interrupt can <u>only be generated</u> if a falling edge is detected at pin CTRAP while TRPPEN = 1. 0 _B The CCU6 trap functionality based on the input CTRAP is disabled. A CCU6 trap can only be generated by SW by setting bit TRPF. 1 _B The CCU6 trap functionality based on the input CTRAP is enabled. A CCU6 trap can be <u>generated</u> by SW by setting bit TRPF or by CTRAP=0.
0	[7:3]	r	reserved; returns 0 if read; should be written with 0;

18.7.3 Passive State Level Register

Register PSLR defines the passive state level of the PWM outputs of the module. The passive state level is the value that is driven during the passive state of the output. During the active state, the corresponding output pin drives the active state level, that is the inverted passive state level. The passive state level permits to adapt the driven output levels to the driver polarity (inverted, not inverted) of the connected power stage. The bits in this register have shadow bit fields to permit a concurrent update of all PWM-related parameters (bit field PSL is updated with T12_ST, whereas PSL63 is updated with T13_ST). The actually used values can be read (attribute "rh"), whereas the shadow bits can only be written (attribute "w").

PSLR

Passive State Level Register

XSFR(44_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0								PSL 63	0	PSL					
r								rwh	r	rwh					

Field	Bits	Type	Description
PSL	[5:0]	rwh	Compare Outputs Passive State Level These bits define the passive level driven by the module outputs during the passive state. PSL0 = PSLR.0 for output CC60 PSL1 = PSLR.1 for output COUT60 PSL2 = PSLR.2 for output CC61 PSL3 = PSLR.3 for output COUT61 PSL4 = PSLR.4 for output CC62 PSL5 = PSLR.5 for output COUT62 0 _B The passive level is 0. 1 _B The passive level is 1.
PSL63	7	rwh	Passive State Level of Output COUT63 This bit defines the passive level driven by the module output COUT63 during the passive state. 0 _B The passive level is 0. 1 _B The passive level is 1.
0	6, [15:8]	r	reserved; returns 0 if read; should be written with 0;

Capture/Compare Unit 6 (CCU6)

Field	Bits	Type	Description
SWSYN	[5:4]	rw	Switching Synchronization Bit field SWSYN defines the synchronization mechanism of the shadow transfer event MCM_ST if it has been requested before (flag R set by an event selected by SWSEL) and if MCMEN = 1. This feature permits the synchronization of the outputs to the PWM source, that is used for modulation (T12 or T13). 00 _B Direct; the trigger event immediately leads to the shadow transfer 01 _B A T13 zero-match triggers the shadow transfer 10 _B A T12 zero-match (while counting up) triggers the shadow transfer 11 _B reserved; no action
STE12U	8	rw	Shadow Transfer Enable for T12 Upcounting This bit enables the shadow transfer T12_ST if flag MCMOUT.R is set or becomes set while a T12 period match is detected while counting up. 0 _B No action 1 _B The T12_ST shadow transfer mechanism is enabled if MCMEN = 1.
STE12D	9	rw	Shadow Transfer Enable for T12 Downcounting This bit enables the shadow transfer T12_ST if flag MCMOUT.R is set or becomes set while a T12 one match is detected while counting down. 0 _B No action 1 _B The T12_ST shadow transfer mechanism is enabled if MCMEN = 1.
STE13U	10	rw	Shadow Transfer Enable for T13 Upcounting This bit enables the shadow transfer T13_ST if flag MCMOUT.R is set or becomes set while a T13 period match is detected. 0 _B No action 1 _B The T13_ST shadow transfer mechanism is enabled if MCMEN = 1.
0	3, [7:6], [15:11]	r	reserved; returns 0 if read; should be written with 0;

Capture/Compare Unit 6 (CCU6)

Register MCMOUTS contains bits used as pattern input for the multi-channel mode and the Hall mode. This register is a shadow register (that can be read and written) for register MCMOUT, indicating the currently active signals.

MCMOUTS

Multi-Channel Mode Output Shadow Register

XSFR(4A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STR HP	0	CURHS			EXPHS			STR MCM	0	MCMPs					
w	r	rw			rw			w	r	rw					

Field	Bits	Type	Description
MCMPs	[5:0]	rw	Multi-Channel PWM Pattern Shadow Bit field MCMPs is the shadow bit field for bit field MCMP. The multi-channel shadow transfer is triggered by MCM_ST according to the transfer conditions defined by register MCMCTR.
STRMCM	7	w	Shadow Transfer Request for MCMPs Writing STRMCM = 1 leads to an immediate activation of MCM_ST to update bit field MCMP by the value of MCMPs. When read, this bit always delivers 0. 0 _B No action. 1 _B Bit field MCMP is updated.
EXPHS	[10:8]	rw	Expected Hall Pattern Shadow Bit field EXPHS is the shadow bit field for bit field EXPH. The shadow transfer takes place when a correct Hall event is detected (CM_CHE).
CURHS	[13:11]	rw	Current Hall Pattern Shadow Bit field CURHS is the shadow bit field for bit field CURH. The shadow transfer takes place when a correct Hall event is detected (CM_CHE).

Field	Bits	Type	Description
STRHP	15	w	Shadow Transfer Request for the Hall Pattern Writing STRHP = 1 leads to an immediate activation of HP_ST to update bit fields EXPH and CURH by EXPHS and CURHS. When read, this bit always delivers 0. 0 _B No action. 1 _B Bit fields EXPH and CURH are updated.
0	6, 14	r	reserved; returns 0 if read; should be written with 0;

MCMOUT

Multi-Channel Mode Output Register

XSFR(4C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		CURH			EXPH			0	R	MCMP					
r		rh			rh			r	rh				rh		

Field	Bits	Type	Description
MCMP	[5:0]	rh	Multi-Channel PWM Pattern Bit field MCMP defines the output pattern for the multi-channel mode. If this mode is enabled by MODCTR.MCMEN = 1, the output state of all T12 related PWM outputs can be modified. This bit field is 0 while IS.IDLE = 1. MCMP0 = MCMOUT.0 for output CC60 MCMP1 = MCMOUT.1 for output COUT60 MCMP2 = MCMOUT.2 for output CC61 MCMP3 = MCMOUT.3 for output COUT61 MCMP4 = MCMOUT.4 for output CC62 MCMP5 = MCMOUT.5 for output COUT62 0 _B The output is set to the passive state. A PWM generated by T12 or T13 are not taken into account. 1 _B The output can be in the active state, depending on the enabled PWM modulation signals generated by T12, T13 and the trap state.

Field	Bits	Type	Description
R	6	rh	Reminder Flag This flag indicates that the shadow transfer from MCMPS to MCMP has been requested by the selected trigger source. It is cleared when the shadow transfer takes place or while MCMEN=0. 0 _B A shadow transfer MCM_ST is not requested. 1 _B A shadow transfer MCM_ST is requested, but has not yet been executed, because the selected synchronization condition has not yet occurred.
EXPH	[10:8]	rh	Expected Hall Pattern Bit field EXPH is updated by a shadow transfer HP_ST from bit field EXPHS. If HCRDY = 1, EXPH is compared to the sampled CCPOSx inputs in order to detect the occurrence of the next desired (=expected) hall pattern or a wrong pattern. If the sampled hall pattern at the hall input pins is equal to bit field EXPH, a correct Hall event has been detected (CM_CHE).
CURH	[13:11]	rh	Current Hall Pattern Bit field CURH is updated by a shadow transfer HP_ST from bit field CURHS. If HCRDY = 1, CURH is compared to the sampled CCPOSx inputs in order to detect a spike. If the sampled Hall pattern at the Hall input pins is equal to bit field CURH, no Hall event has been detected. If the sampled Hall input pattern is neither equal to CURH nor equal to EXPH, the Hall event was not the desired one and may be due to a fatal error (e.g. blocked rotor, etc.). In this case, a wrong Hall event has been detected (CM_WHE).
0	7, [15:14]	r	reserved; returns 0 if read; should be written with 0;

18.8 Interrupt Handling

This section describes the interrupt handling of the CCU6 module.

18.8.1 Interrupt Structure

The HW interrupt event or the SW setting of the corresponding interrupt set bit (in register ISS) sets the event indication flags (in register IS) and can trigger the interrupt generation. The interrupt pulse is generated independently from the interrupt status flag in register IS (it is not necessary to clear the related status bit to be able to generate another interrupt). The interrupt flag can be cleared by SW by writing to the corresponding bit in register ISR.

If enabled by the related interrupt enable bit in register IEN, an interrupt pulse can be generated on one of the four service request outputs (SR0 to SR3) of the module. If more than one interrupt source is connected to the same interrupt node pointer (in register INP), the requests are logically OR-combined to one common service request output (see [Figure 18-41](#)).

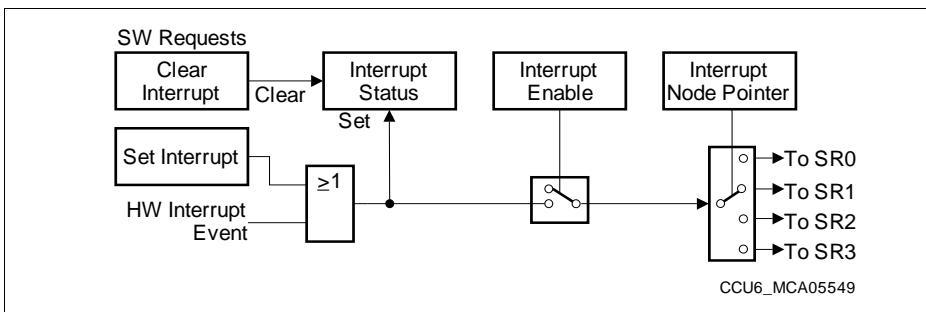


Figure 18-41 General Interrupt Structure

The available interrupt events in the CCU6 are shown in [Figure 18-42](#).

Capture/Compare Unit 6 (CCU6)

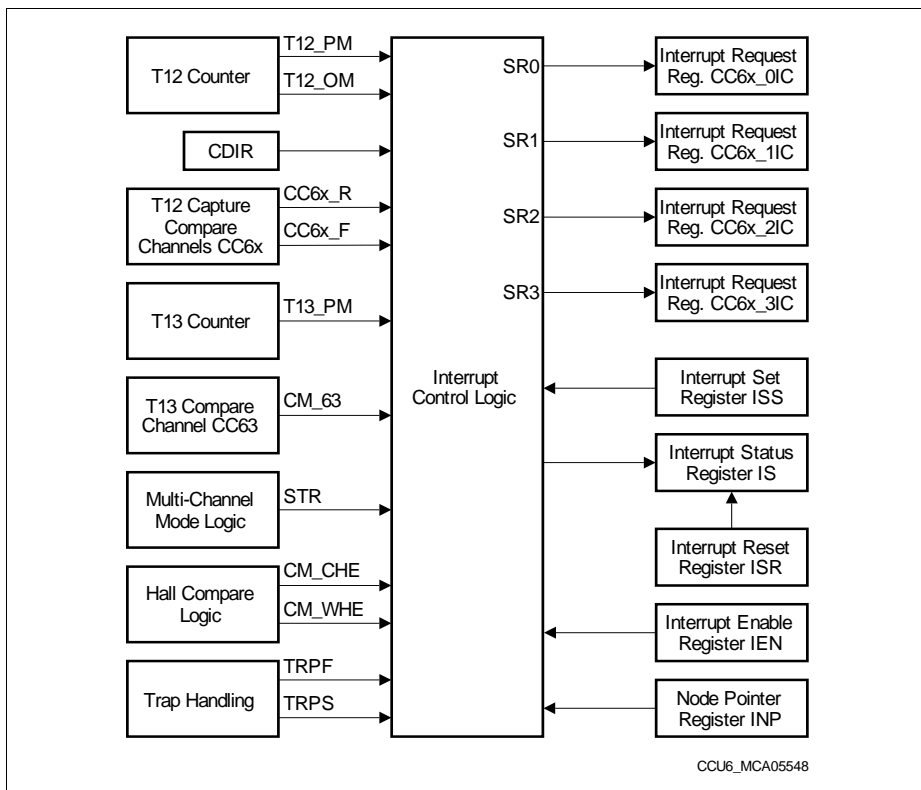


Figure 18-42 Interrupt Sources and Events

18.8.2 Interrupt Registers

18.8.2.1 Interrupt Status Register

Register IS contains the individual interrupt request bits. This register can only be read, write actions have no impact on the contents of this register. The SW can set or clear the bits individually by writing to the registers ISS (to set the bits) or to register ISR (to clear the bits).

The interrupt generation is independent from the value of the bits in register IS, e.g. the interrupt will be generated (if enabled) even if the corresponding bit is already set. The trigger for an interrupt generation is the detection of a set condition (by HW or SW) for the corresponding bit in register IS.

In compare mode (and hall mode), the timer-related interrupts are only generated while the timer is running ($T1xR=1$). In capture mode, the capture interrupts are also generated while the timer T12 is stopped.

Note: Not all bits in register IS can generate an interrupt. Other status bits have been added, that have a similar structure for their set and clear actions. It is recommended that SW checks the interrupt bits bit-wisely (instead of common OR over the bits).

IS

Interrupt Status Register

XSFR(50_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STR	IDLE	WHE	CHE	TRP S	TRP F	T13 PM	T13 CM	T12 PM	T12 OM	ICC 62F	ICC 62R	ICC 61F	ICC 61R	ICC 60F	ICC 60R
rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh	rh

Field	Bits	Type	Description
ICC60R, ICC61R, ICC62R	0, 2, 4	rh	Capture, Compare-Match Rising Edge Flag This bit indicates that event CC6x_R has been detected. This event occurs in compare mode when a compare-match is detected while T12 is counting up (CM_6x and $CDIR = 0$) and in capture mode when a rising edge is detected at the related input CC6xIN. 0 _B The event has not yet been detected. 1 _B The event has been detected.

Capture/Compare Unit 6 (CCU6)

Field	Bits	Type	Description
ICC60F, ICC61F, ICC62F	1, 3, 5	rh	Capture, Compare-Match Falling Edge Flag This bit indicates that event CC6x_F has been detected. This event occurs in compare mode when a compare-match is detected while T12 is counting down (CM_6x and CDIR = 1) and in capture mode when a falling edge is detected at the related input CC6xIN. 0 _B The event has not yet been detected. 1 _B The event has been detected.
T12OM	6	rh	Timer T12 One-Match Flag This bit indicates that a timer T12 one-match while counting down (T12_OM and CDIR = 1) has been detected. 0 _B The event has not yet been detected. 1 _B The event has been detected.
T12PM	7	rh	Timer T12 Period-Match Flag This bit indicates that a timer T12 period-match while counting up (T12_PM and CDIR = 0) has been detected. 0 _B The event has not yet been detected. 1 _B The event has been detected.
T13CM	8	rh	Timer T13 Compare-Match Flag This bit indicates that a timer T13 compare-match (CM_63) has been detected. 0 _B The event has not yet been detected. 1 _B The event has been detected.
T13PM	9	rh	Timer T13 Period-Match Flag This bit indicates that a timer T13 period-match (T13_PM) has been detected. 0 _B The event has not yet been detected. 1 _B The event has been detected.
TRPF	10	rh	Trap Flag This bit indicates if a trap condition (input $\overline{\text{CTRAP}}$ = 0 or by SW) is / has been detected. If $\overline{\text{TRM2}}$ = 0, it becomes cleared automatically if CTRAP = 1 or TRPPEN = 0, whereas if TRM2 = 1, it has to be cleared by writing RTRPF = 1. 0 _B The trap condition has not been detected. 1 _B The trap condition is / has been detected.

Capture/Compare Unit 6 (CCU6)

Field	Bits	Type	Description
TRPS	11	rh	Trap State¹⁾ This bit indicates the actual trap state. It is set if TRPF = 1 and becomes cleared according to the mode selected in register TRPCTR. 0 _B The trap state is not active. 1 _B The trap state is active.
CHE	12	rh	Correct Hall Event This bit indicates that a correct Hall event (CM_CHE) has been detected. 0 _B The event has not yet been detected. 1 _B The event has been detected.
WHE	13	rh	Wrong Hall Event This bit indicates that a wrong Hall event (CM_WHE) has been detected. 0 _B The event has not yet been detected. 1 _B The event has been detected.
IDLE	14	rh	IDLE State If enabled by ENIDLE = 1, this bit is set together with bit WHE and it has to be cleared by SW. 0 _B No action. 1 _B Bit field MCMP is cleared, the selected outputs are set to passive state.
STR	15	rh	Multi-Channel Mode Shadow Transfer Request This bit indicates that a shadow transfer from MCMPS to MCMP (MCM_ST) has taken place. 0 _B The event has not yet been detected. 1 _B The event has been detected.

- 1) During the trap state, the selected outputs are set to the passive state. The logic level driven during the passive state is defined by the corresponding bit in register PSLR. Bits TRPS=1 and TRPF=0 can occur if the trap condition is no longer active but the selected synchronization has not yet taken place.

18.8.2.2 Interrupt Status Set Register

Register ISS contains individual interrupt request set bits to generate a CCU6 interrupt request by software. Writing a 1 sets the bit(s) in register IS at the corresponding bit position(s) and can generate an interrupt event (if available and enabled).

All bit positions read as 0.

ISS

Interrupt Status Set Register

XSFR(52_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
STR	IDLE	WHE	CHE	WHC	TRP	T13	T13	T12	T12	CC	CC	CC	CC	CC	CC
					F	PM	CM	PM	OM	62F	62R	61F	61R	60F	60R
W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W

Field	Bits	Type	Description
SCC60R, SCC61R, SCC62R	0, 2, 4	w	Set Capture, Compare-Match Rising Edge Flag 0 _B No action 1 _B Bit CC6xR will be set.
SCC60F, SCC61F, SCC62F	1, 3, 5	w	Set Capture, Compare-Match Falling Edge Flag 0 _B No action 1 _B Bit CC6xF will be set.
ST12OM	6	w	Set Timer T12 One-Match Flag 0 _B No action 1 _B Bit T12OM will be set.
ST12PM	7	w	Set Timer T12 Period-Match Flag 0 _B No action 1 _B Bit T12PM will be set.
ST13CM	8	w	Set Timer T13 Compare-Match Flag 0 _B No action 1 _B Bit T13CM will be set.
ST13PM	9	w	Set Timer T13 Period-Match Flag 0 _B No action 1 _B Bit T13PM will be set.
STRPF	10	w	Set Trap Flag 0 _B No action 1 _B Bits TRPF and TRPS will be set.

Field	Bits	Type	Description
SWHC	11	w	Software Hall Compare 0 _B No action 1 _B The Hall compare action is triggered.
SCHE	12	w	Set Correct Hall Event Flag 0 _B No action 1 _B Bit CHE will be set.
SWHE	13	w	Set Wrong Hall Event Flag 0 _B No action 1 _B Bit WHE will be set.
SIDLE	14	w	Set IDLE Flag 0 _B No action 1 _B Bit IDLE will be set.
SSTR	15	w	Set STR Flag 0 _B No action 1 _B Bit STR will be set.

18.8.2.3 Status Reset Register

Register ISR contains bits to individually clear the interrupt event flags by software. Writing a 1 clears the bit(s) in register IS at the corresponding bit position(s). All bit positions read as 0.

ISR

Interrupt Status Reset Register

XSFR(54_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
R STR	R IDLE	R WHE	R CHE	0	R TRPF	R T13 PM	R T13 CM	R T12 PM	R T12 OM	R CC 62F	R CC 62R	R CC 61F	R CC 61R	R CC 60F	R CC 60R
w	w	w	w	r	w	w	w	w	w	w	w	w	w	w	w

Field	Bits	Type	Description
RCC60R, RCC61R, RCC62R	0, 2, 4	w	Reset Capture, Compare-Match Rising Edge Flag 0 _B No action 1 _B Bit CC6xR will be cleared.
RCC60F, RCC61F, RCC62F	1, 3, 5	w	Reset Capture, Compare-Match Falling Edge Flag 0 _B No action 1 _B Bit CC6xF will be cleared.
RT12OM	6	w	Reset Timer T12 One-Match Flag 0 _B No action 1 _B Bit T12OM will be cleared.
RT12PM	7	w	Reset Timer T12 Period-Match Flag 0 _B No action 1 _B Bit T12PM IS will be cleared.
RT13CM	8	w	Reset Timer T13 Compare-Match Flag 0 _B No action 1 _B Bit T13CM will be cleared.
RT13PM	9	w	Reset Timer T13 Period-Match Flag 0 _B No action 1 _B Bit T13PM will be cleared.
RTRPF	10	w	Reset Trap Flag 0 _B No action 1 _B Bit TRPF will be cleared (<u>not</u> taken into account while input CTRAP=0 and TRPPEN=1.

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Field	Bits	Type	Description
RCHE	12	w	Reset Correct Hall Event Flag 0 _B No action 1 _B Bit CHE will be cleared.
RWHE	13	w	Reset Wrong Hall Event Flag 1 _B No action 0 _B Bit WHE will be cleared.
RIDLE	14	w	Reset IDLE Flag 0 _B No action 1 _B Bit IDLE will be cleared.
RSTR	15	w	Reset STR Flag 0 _B No action 1 _B Bit STR will be cleared.
0	11	r	reserved; returns 0 if read; should be written with 0;

18.8.2.4 Interrupt Enable Register

Register IEN contains the interrupt enable bits and a control bit to enable the automatic idle function in the case of a wrong hall pattern.

IEN

Interrupt Enable Register

XSFR(58_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN STR	EN IDLE	EN WHE	EN CHE	0	EN TRP F	EN T13 PM	EN T13 CM	EN T12 PM	EN T12 OM	EN CC 62F	EN CC 62R	EN CC 61F	EN CC 61R	EN CC 60F	EN CC 60R
rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
ENCC60R, ENCC61R, ENCC62R	0, 2, 4	rw	Capture, Compare-Match Rising Edge Interrupt Enable for Channel CC6x 0_B No interrupt will be generated if the set condition for bit CC6xR in register IS occurs. 1_B An interrupt will be generated if the set condition for bit CC6xR in register IS occurs. The service request output that will be activated is selected by bit field INPCC6x.
ENCC60F, ENCC61F, ENCC62F	1, 3, 5	rw	Capture, Compare-Match Falling Edge Interrupt Enable for Channel CC6x 0_B No interrupt will be generated if the set condition for bit CC6xF in register IS occurs. 1_B An interrupt will be generated if the set condition for bit CC6xF in register IS occurs. The service request output that will be activated is selected by bit field INPCC6x.
ENT12OM	6	rw	Enable Interrupt for T12 One-Match 0_B No interrupt will be generated if the set condition for bit T12OM in register IS occurs. 1_B An interrupt will be generated if the set condition for bit T12OM in register IS occurs. The service request output that will be activated is selected by bit field INPT12.

Field	Bits	Type	Description
ENT12PM	7	rw	Enable Interrupt for T12 Period-Match 0_B No interrupt will be generated if the set condition for bit T12PM in register IS occurs. 1_B An interrupt will be generated if the set condition for bit T12PM in register IS occurs. The service request output that will be activated is selected by bit field INPT12.
ENT13CM	8	rw	Enable Interrupt for T13 Compare-Match 0_B No interrupt will be generated if the set condition for bit T13CM in register IS occurs. 1_B An interrupt will be generated if the set condition for bit T13CM in register IS occurs. The service request output that will be activated is selected by bit field INPT13.
ENT13PM	9	rw	Enable Interrupt for T13 Period-Match 0_B No interrupt will be generated if the set condition for bit T13PM in register IS occurs. 1_B An interrupt will be generated if the set condition for bit T13PM in register IS occurs. The service request output that will be activated is selected by bit field INPT13.
ENTRPF	10	rw	Enable Interrupt for Trap Flag 0_B No interrupt will be generated if the set condition for bit TRPF in register IS occurs. 1_B An interrupt will be generated if the set condition for bit TRPF in register IS occurs. The service request output that will be activated is selected by bit field INPERR.
ENCHE	12	rw	Enable Interrupt for Correct Hall Event 0_B No interrupt will be generated if the set condition for bit CHE in register IS occurs. 1_B An interrupt will be generated if the set condition for bit CHE in register IS occurs. The service request output that will be activated is selected by bit field INPCHE.

Field	Bits	Type	Description
ENWHE	13	rw	Enable Interrupt for Wrong Hall Event 0_B No interrupt will be generated if the set condition for bit WHE in register IS occurs. 1_B An interrupt will be generated if the set condition for bit WHE in register IS occurs. The service request output that will be activated is selected by bit field INPERR.
ENIDLE	14	rw	Enable Idle This bit enables the automatic entering of the idle state (bit IDLE will be set) after a wrong hall event has been detected (bit WHE is set). During the idle state, the bit field MCMP is automatically cleared. 0_B The bit IDLE is not automatically set when a wrong hall event is detected. 1_B The bit IDLE is automatically set when a wrong hall event is detected.
ENSTR	15	rw	Enable Multi-Channel Mode Shadow Transfer Interrupt 0_B No interrupt will be generated if the set condition for bit STR in register IS occurs. 1_B An interrupt will be generated if the set condition for bit STR in register IS occurs. The service request output that will be activated is selected by bit field INPCHE.
0	11	r	reserved; returns 0 if read; should be written with 0;

18.8.2.5 Interrupt Node Pointer Register

Register INP contains the interrupt node pointers allowing a flexible interrupt handling. These bit fields define which service request output will be activated if the corresponding interrupt event occurs and the interrupt generation for this event is enabled.

INP

Interrupt Node Pointer Register

XSFR(56_H)

Reset Value: 3940_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	INP T13	INP T12	INP ERR	INP CHE	INP CC62	INP CC61	INP CC60								
r	rw	rw	rw	rw	rw	rw	rw								

Field	Bits	Type	Description
INPCC60, INPCC61, INPCC62	[1:0], [3:2], [5:4]	rw	Interrupt Node Pointer for Channel CC6x Interrupts This bit field defines the service request output activated due to a set condition for bit CC6xR (if enabled by bit ENCC6xR) or for bit CC6xF (if enabled by bit ENCC6xF). 00 _B Service request output SR0 is selected. 01 _B Service request output SR1 is selected. 10 _B Service request output SR2 is selected. 11 _B Service request output SR3 is selected.
INPCHE	[7:6]	rw	Interrupt Node Pointer for the CHE Interrupt This bit field defines the service request output activated due to a set condition for bit CHE (if enabled by bit ENCHE) or for bit STR (if enabled by bit ENSTR). Coding see INPCC6x.
INPERR	[9:8]	rw	Interrupt Node Pointer for Error Interrupts This bit field defines the service request output activated due to a set condition for bit TRPF (if enabled by bit ENTRPF) or for bit WHE (if enabled by bit ENWHE). Coding see INPCC6x.

Field	Bits	Type	Description
INPT12	[11:10]	rw	Interrupt Node Pointer for Timer12 Interrupts This bit field defines the service request output activated due to a set condition for bit T12OM (if enabled by bit ENT12OM) or for bit T12PM (if enabled by bit ENT12PM). Coding see INPCC6x.
INPT13	[13:12]	rw	Interrupt Node Pointer for Timer13 Interrupt This bit field defines the service request output activated due to a set condition for bit T13CM (if enabled by bit ENT13CM) or for bit T13PM (if enabled by bit ENT13PM). Coding see INPCC6x.
0	[15:14]	r	reserved; returns 0 if read; should be written with 0;

18.9 General Module Operation

This section provides information about the:

- Configuration of the behavior of the different device operating modes (see mode control description in [Section 18.9.1](#))
- Input selection (see [Section 18.9.2](#))
- General register description (see [Section 18.9.3](#))

18.9.1 Mode Control

The mode control concept for system control tasks, such as power saving, or suspend request for debugging, allows to program the module behavior under different device operating conditions. The behavior of a CCU6 kernel can be programmed for each of the device operating modes, that are requested by the global state control part of the SCU. Therefore, a CCU6 module provides a kernel state configuration register **KSCFG** defining the behavior in the following device operating modes:

- **Normal operation:**
This operating mode is the default operating mode when neither a suspend request nor a clock-off request are pending. The module clock is not switched off and the CCU6 registers can be read or written. The kernel behavior is defined by KSCFG.NOMCFG.
- **Suspend mode:**
This operating mode is requested when a suspend request (issued by a debugger) is pending in the device. The module clock is not switched off and the CCU6 registers can be read or written. The kernel behavior is defined by KSCFG.SUMCFG.
- **Clock-off mode:**
This operating mode is requested for power saving purposes. The module clock is switched off automatically when all kernels of the CCU6 module reached their specified state in a stop mode. In this case, CCU6 registers can not be accessed. The kernel behavior is defined by KSCFG.COMCFG.

The kernel distinguishes four different blocks (T12, T13, Hall logic, and trap logic). These blocks can be individually enabled for the request of stop mode 0 and stop mode 1 by the sensitivity bits **KSCSR.SBx**. If the request sensitivity is disabled, the block continues normal operation. If the request sensitivity is enabled, the block operates as specified for the selected stop mode.

The complete CCU6 acknowledge is given to the GSC when all four blocks have reached their defined end condition.

Table 18-12 CCU6 Functional Blocks

Block	Function	Sensitivity Bit
0	Timer T12: A functional enable is delivered until the specified stop condition is reached. Then, T12 stops counting and the CC6xIN input stages are frozen.	KSCSR.SB0
1	Timer T13: A functional enable is delivered until the specified stop condition is reached. Then, T13 stops counting.	KSCSR.SB1
2	Hall Logic: The hall logic is stopped immediately and the CCPOSx input stages are frozen.	KSCSR.SB2
3	Trap Logic: The trap logic is stopped immediately and the CTRAP input stage is frozen.	KSCSR.SB3

The behavior of the CCU6 kernel can be programmed for each of the device operating modes (normal operation, suspend mode, clock-off mode). Therefore, it supports four kernel modes, as shown in [Table 18-13](#).

Table 18-13 CCU6 Kernel Behavior

Kernel Mode	Kernel Behavior	Code
run mode 0	kernel operation as specified, no impact on CCU6 operation (same behavior for run mode 0 and run mode 1)	00 _B
run mode 1		01 _B

Table 18-13 CCU6 Kernel Behavior (cont'd)

Kernel Mode	Kernel Behavior	Code
stop mode 0	<p>The sensitivity bits are taken into account for:</p> <p>T12 block: Timer T12 continues normal operation (if running) until they reach the end of the PWM period and then it stops (same stop condition as in single shot mode). When the timer stops, the CC6xIN inputs are frozen.</p> <p>T13 block: Timer T13 continues normal operation (if running) until they reach the end of the PWM period and then it stops (same stop condition as in single shot mode).</p> <p>Hall logic block: The CCPOSx input values are frozen.</p> <p>Trap logic block: The CTRAP input value is frozen.</p>	10 _B
stop mode 1	<p>The output lines enabled for the trap condition are set to their passive values (similar to a trap state). The sensitivity bits are taken into account for:</p> <p>T12 block: Timer T12 stops immediately and CC6xIN inputs are frozen.</p> <p>T13 block: Timer T13 stops.</p> <p>Hall logic block: The CCPOSx input values are frozen.</p> <p>Trap logic block: The CTRAP input value is frozen.</p>	11 _B

Generally, bit field KSCFG.NOMCFG should be configured for run mode 0 as default setting for standard operation. If a CCU6 kernel should not react to a suspend request (and to continue operation as in normal mode), bit field KSCFG.SUMCFG has to be configured with the same value as KSCFG.NOMCFG. If a CCU6 kernel should show a different behavior and stop operation when a specific stop condition is reached, the code for stop mode 0 or stop mode 1 has to be written to KSCFG.SUMCFG.

A similar mechanism applies for the clock-off mode with the possibility to program the desired behavior by bit field KSCFG.COMCFG.

Note: The stop mode selection strongly depends on the application needs and it is very unlikely that different stop modes are required in parallel in the same application. As a result, only one stop mode type (either 0 or 1) should be used in the bit fields in register KSCFG. Do not mix stop mode 0 and stop mode 1 and avoid transitions from stop mode 0 to stop mode 1 (or vice versa) for the CCU6 module.

If the module clock is disabled by KSCFG.MODEN = 0 or in clock-off mode when the stop condition is reached (in stop mode 0 or 1), the module can not be accessed by read or write operations (except register KSCFG that can always be accessed). As a consequence, it can not be configured.

Please note that bit KSCFG.MODEN should only be set by SW while all configuration fields are configured for run mode 0.

18.9.2 Input Selection

Each CCU6 input signal can be selected from a vector of four or eight possible inputs by programming the port input select registers **PISELL** and **PISELH**. This permits to adapt the pin functionality of the device to the application requirements.

The output pins for the module output signals are chosen in the ports.

Naming convention:

The input vector CC60IN[D:A] for input signal CC60IN is composed of the signals CC60INA to CC60IND.

Note: All functional inputs of the CCU6 are synchronized to f_{CC6} before they affect the module internal logic. The resulting delay of $2/f_{CC6}$ and for asynchronous signals an additional uncertainty of $1/f_{CC6}$ have to be taken into account for precise timing calculation. An edge of an input signal can only be correctly detected if the high phase and the low phase of the input signal are both longer than $1/f_{CC6}$.

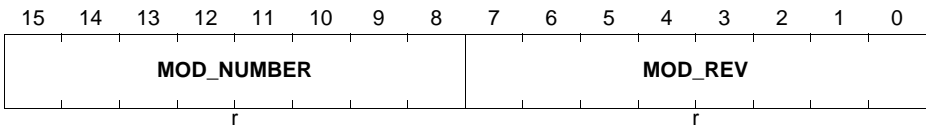
18.9.3 General Registers

18.9.3.1 ID Register

The ID register is a read-only register used for CCU6 module identification purposes. It provides 8 bits for module identification and 8 bits for revision numbering.

ID

Module Identification Register **XSFR(08_H)** **Reset Value: 54XX_H**



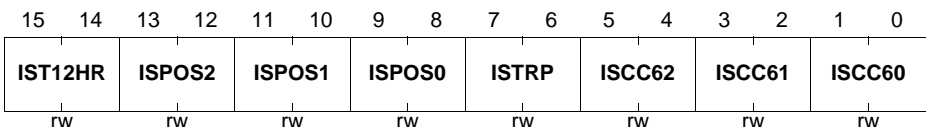
Field	Bits	Type	Description
MOD_REV	[7:0]	r	Module Revision Number Value Bits 7-0 bits are used for module revision numbering. The value of the module revision number starts with 01 _H (first revision), 02 _H , 03 _H , ... up to FF _H .
MOD_NUMBER	[15:8]	r	Module Identification Number Value Bits 15-8 are used for module identification. The CCU6 has the module number 54 _H .

18.9.3.2 Port Input Select Registers

Registers PISELL and PISELH contain bit fields selecting the actual input signal for the module inputs.

PISELL

Port Input Select Register Low **XSFR(04_H)** **Reset Value: 0000_H**



Field	Bits	Type	Description
ISCC60	[1:0]	rw	Input Select for CC60 This bit field defines the input signal used as CC60 capture input. 00 _B The signal CC60INA is selected. 01 _B The signal CC60INB is selected. 10 _B The signal CC60INC is selected. 11 _B The signal CC60IND is selected.
ISCC61	[3:2]	rw	Input Select for CC61 This bit field defines the input signal used as CC61 capture input. 00 _B The signal CC61INA is selected. 01 _B The signal CC61INB is selected. 10 _B The signal CC61INC is selected. 11 _B The signal CC61IND is selected.
ISCC62	[5:4]	rw	Input Select for CC62 This bit field defines the input signal used as CC62 capture input. 00 _B The signal CC62INA is selected. 01 _B The signal CC62INB is selected. 10 _B The signal CC62INC is selected. 11 _B The signal CC62IND is selected.
ISTRP	[7:6]	rw	Input Select for CTRAP This bit field defines the input signal used as CTRAP input. 00 _B The signal CTRAPA is selected. 01 _B The signal CTRAPB is selected. 10 _B The signal CTRAPC is selected. 11 _B The signal CTRAPD is selected.
ISPOS0	[9:8]	rw	Input Select for CCPOS0 This bit field defines the input signal used as CCPOS0 input. 00 _B The signal CCPOS0A is selected. 01 _B The signal CCPOS0B is selected. 10 _B The signal CCPOS0C is selected. 11 _B The signal CCPOS0D is selected.

Field	Bits	Type	Description
ISPOS1	[11:10]	rw	Input Select for CCPOS1 This bit field defines the input signal used as CCPOS1 input. 00 _B The signal CCPOS1A is selected. 01 _B The signal CCPOS1B is selected. 10 _B The signal CCPOS1C is selected. 11 _B The signal CCPOS1D is selected.
ISPOS2	[13:12]	rw	Input Select for CCPOS2 This bit field defines the input signal used as CCPOS2 input. 00 _B The signal CCPOS2A is selected. 01 _B The signal CCPOS2B is selected. 10 _B The signal CCPOS2C is selected. 11 _B The signal CCPOS2D is selected.
IST12HR	[15:14]	rw	Input Select for T12HR This bit field defines the input signal used as T12HR input. 00 _B Either signal T12HRA (if T12EXT = 0) or T12HRE (if T12EXT = 1) is selected. 01 _B Either signal T12HRB (if T12EXT = 0) or T12HRF (if T12EXT = 1) is selected. 10 _B Either signal T12HRC (if T12EXT = 0) or T12HRG (if T12EXT = 1) is selected. 11 _B Either signal T12HRD (if T12EXT = 0) or T12HRH (if T12EXT = 1) is selected.

PISELH

Port Input Select Register High

XSFR(06_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0								T13 EXT	T12 EXT	ISCNT13	ISCNT12	IST13HR			
r								rw	rw	rw	rw	rw			

Field	Bits	Type	Description
IST13HR	[1:0]	rw	<p>Input Select for T13HR</p> <p>This bit field defines the input signal used as T13HR input.</p> <p>00_B Either signal T13HRA (if T13EXT = 0) or T13HRE (if T13EXT = 1) is selected.</p> <p>01_B Either signal T13HRB (if T13EXT = 0) or T13HRF (if T13EXT = 1) is selected.</p> <p>10_B Either signal T13HRC (if T13EXT = 0) or T13HRG (if T13EXT = 1) is selected.</p> <p>11_B Either signal T13HRD (if T13EXT = 0) or T13HRH (if T13EXT = 1) is selected.</p>
ISCNT12	[3:2]	rw	<p>Input Select for T12 Counting Input</p> <p>This bit field defines the input event leading to a counting action of T12.</p> <p>00_B The T12 prescaler generates the counting events. Bit TCTR4.T12CNT is not taken into account.</p> <p>01_B Bit TCTR4.T12CNT written with 1 is a counting event. The T12 prescaler is not taken into account.</p> <p>10_B The timer T12 is counting each rising edge detected in the selected T12HR signal.</p> <p>11_B The timer T12 is counting each falling edge detected in the selected T12HR signal.</p>
ISCNT13	[5:4]	rw	<p>Input Select for T13 Counting Input</p> <p>This bit field defines the input event leading to a counting action of T13.</p> <p>00_B The T13 prescaler generates the counting events. Bit TCTR4.T13CNT is not taken into account.</p> <p>01_B Bit TCTR4.T13CNT written with 1 is a counting event. The T13 prescaler is not taken into account.</p> <p>10_B The timer T13 is counting each rising edge detected in the selected T13HR signal.</p> <p>11_B The timer T13 is counting each falling edge detected in the selected T13HR signal.</p>

Capture/Compare Unit 6 (CCU6)

Field	Bits	Type	Description
T12EXT	6	rw	Extension for T12HR Inputs This bit extends the 2-bit field IST12HR. 0 _B One of the signals T12HR[D:A] is selected. 1 _B One of the signals T12HR[H:E] is selected.
T13EXT	7	rw	Extension for T13HR Inputs This bit extends the 2-bit field IST13HR. 0 _B One of the signals T13HR[D:A] is selected. 1 _B One of the signals T13HR[H:E] is selected.
0	[15:8]	r	reserved; returns 0 if read; should be written with 0;

18.9.3.3 Kernel State Configuration Register

The kernel state configuration register KSCFG allows the selection of the desired kernel modes for the different device operating modes.

Bit fields KSCFG.NOMCFG and KSCFG.COMCFG are reset by an application reset. Bit field KSCFG.SUMCFG is reset by a debug reset.

Note: The coding of the bit fields NOMCFG, SUMCFG and COMCFG is described in [Table 18-13](#).

KSCFG

Kernel State Configuration Register

XSFR(00 _H)														Reset Value: 0000 _H	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BP COM	0	COMCFG	BP SUM	0	SUMCFG	BP NOM	0	NOMCFG	0			0	BP MOD EN	MOD EN	
w	r	rw	w	r	rw	w	r	rw				r	w	rw	

Field	Bits	Type	Description
MODEN	0	rw	Module Enable This bit enables the module kernel clock and the module functionality. 0 _B The module is switched off immediately (without respecting a stop condition). It does not react on mode control actions and the module clock is switched off. The module does not react on read accesses and ignores write accesses (except to KSCFG). 1 _B The module is switched on and can operate. After writing 1 to MODEN, it is recommended to read register KSCFG to avoid pipeline effects in the control block before accessing other CCU6 registers.
BPMODEN	1	w	Bit Protection for MODEN This bit enables the write access to the bit MODEN. It always reads 0. 0 _B MODEN is not changed. 1 _B MODEN is updated with the written value.

Field	Bits	Type	Description
NOMCFG	[5:4]	rw	Normal Operation Mode Configuration This bit field defines the kernel mode applied in normal operation mode. 00 _B Run mode 0 is selected. 01 _B Run mode 1 is selected. 10 _B Stop mode 0 is selected. 11 _B Stop mode 1 is selected.
BPNO	7	w	Bit Protection for NOMCFG This bit enables the write access to the bit field NOMCFG. It always reads 0. 0 _B NOMCFG is not changed. 1 _B NOMCFG is updated with the written value.
SUMCFG	[9:8]	rw	Suspend Mode Configuration This bit field defines the kernel mode applied in suspend mode. Coding like NOMCFG.
BPSUM	11	w	Bit Protection for SUMCFG This bit enables the write access to the bit field SUMCFG. It always reads 0. 0 _B SUMCFG is not changed. 1 _B SUMCFG is updated with the written value.
COMCFG	[13:12]	rw	Clock Off Mode Configuration This bit field defines the kernel mode applied in clock-off mode. Coding like NOMCFG.
BPCOM	15	w	Bit Protection for COMCFG This bit enables the write access to the bit field COMCFG. It always reads 0. 0 _B COMCFG is not changed. 1 _B COMCFG is updated with the written value.
0	[3:2], 6, 10, 14	r	Reserved returns 0 if read; should be written with 0;

Note: The bit protection bits BPxxx allow partly modification of the configuration bits with a single write operation (without the need of a read-modify-write mechanism handled by the CPU).

18.10 Implementation

This section describes the implementation of the CCU6 modules in the XE166U device.

- Address map (see [Section 18.10.1](#))
- Interrupt control registers (see [Section 18.10.2](#))
- Synchronous start (see [Section 18.10.3](#))
- Connections of CCU60 (see [Section 18.10.4.1](#))

18.10.1 Address Map

The CCU6 in the XE166U can be accessed in the following address ranges.

The exact register address is given by the offset of the register (given in [Table 18-1](#)) plus the kernel base address (given in [Table 18-14](#)) of the module.

Table 18-14 Registers Address Space

Module	Base Address	End Address	Note
CCU60	EA00 _H	EA7E _H	

Table 18-15 Registers Overview

Register Short Name	Register Long Name	Offset Address	Page Number
please refer to register table in Section 18.1.3		H	

18.10.2 Interrupt Control Registers

The interrupt control registers are located in the SFR area. They are described in the general interrupt chapter.

Table 18-16 CCU6 Interrupt Control Registers

Short Name	Description
CCU60_0IC	Interrupt Control Register for SR0 of CCU60
CCU60_1IC	Interrupt Control Register for SR1 of CCU60
CCU60_2IC	Interrupt Control Register for SR2 of CCU60
CCU60_3IC	Interrupt Control Register for SR3 of CCU60

18.10.3 Synchronous Start Feature

Synchronous start is supported by connecting bit SYSCON1.GLCCST (global capture/compare start) in the SCU module to the inputs T12HR and T13HR inputs of a CCU6x module.

The same signal can also be connected to other capture/compare units in order to allow a synchronous start of the capture/compare timers.

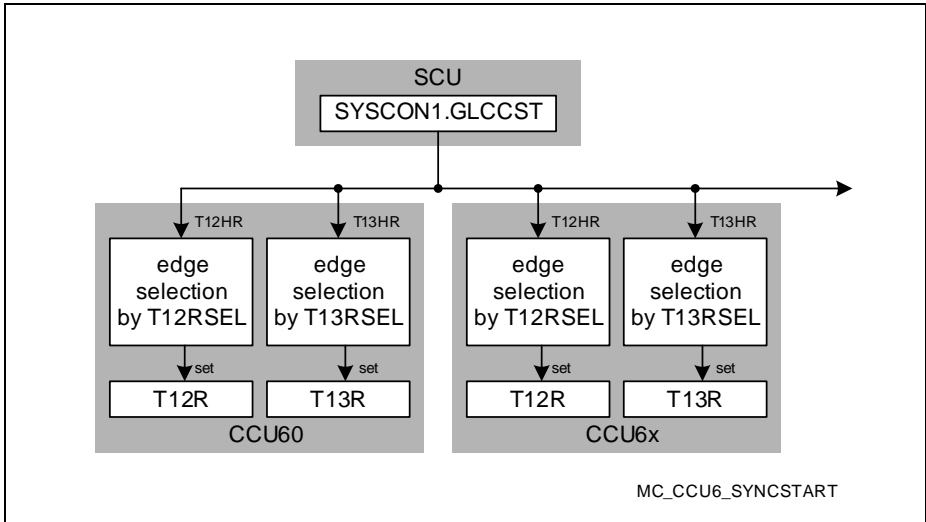


Figure 18-43 Synchronization Concept

18.10.4 Digital Connections

The following tables show the digital connections of the CCU6x module with other modules (on-chip connections) or pins (external connections) of the XE166U.

Each input signal can be selected among 4 or 8 possible input lines, e.g. the input vector for input signal CC60IN is composed of CC60IN[D:A], whereas the input vectors for T12HR and T13HR are composed of T12HR[H:A] and T13HR[H:A].

In addition, the connections of the service request outputs SR[3:0] to the interrupt control registers are summarized in [Section 18.10.2](#).

A CCU6x module is clocked with the XE166U system clock, so $f_{CC6} = f_{SYS}$.

Note: All functional inputs of the CCU6x are synchronized to f_{CC6} before they can affect the module internal logic. For precise timing calculation, please take the resulting delay of $2/f_{CC6}$ and an uncertainty of $1/f_{CC6}$ into account.

To ensure the correct detection of an input signal edge, both the high phase and the low phase of the input signal each must be longer than $1/f_{CC6}$.

18.10.4.1 Connections of CCU60

This table describes the module interconnections of CCU60.

Table 18-17 CCU60 Digital Connections in XE166U

Signal	from/to Module	I/O to CCU60	Can be used to/as
CC60INA	P10.0	I	input signals for capture event on channel CC60
CC60INB	0	I	
CC60INC	0	I	
CC60IND	RTC interrupt	I	
CC61INA	P10.1	I	input signals for capture event on channel CC61
CC61INB	0	I	
CC61INC	0	I	
CC61IND	WUT trigger (SCU)	I	
CC62INA	P10.2	I	input signals for capture event on channel CC62
CC62INB	0	I	
CC62INC	0	I	
CC62IND	0	I	

Table 18-17 CCU60 Digital Connections in XE166U (cont'd)

Signal	from/to Module	I/O to CCU60	Can be used to/as
CTRAPA	P10.6	I	input signals for CTRAP
CTRAPB	0	I	
CTRAPC## #	ADC0_SR3_N	I	
CTRAPD	ERU_PDOUT2	I	
CCPOS0A	P10.7	I	input signals for CCPOS0
CCPOS0B	ADC0_BFL2	I	
CCPOS0C	0	I	
CCPOS0D	0	I	
			edge detection off
CCPOS1A	P10.8	I	input signals for CCPOS1
CCPOS1B	ADC0_BFL3	I	
CCPOS1C	0	I	
CCPOS1D	0	I	
			edge detection off
CCPOS2A	P10.9	I	input signals for CCPOS2
CCPOS2B	ADC0_BFL4	I	
CCPOS2C	ADC0_SR3	I	
CCPOS2D	0	I	
			edge detection off
T12HRA	0	I	input signals for T12HR
T12HRB	0	I	
T12HRC	P5.8	I	
T12HRD	SYSCON1. GLCCST	I	
T12HRE	ADC0_ARBCNT	I	
T12HRF	0	I	
T12HRG	0	I	
T12HRH	0	I	

Table 18-17 CCU60 Digital Connections in XE166U (cont'd)

Signal	from/to Module	I/O to CCU60	Can be used to/as
T13HRA	EXTCLK (SCU)	I	input signals for T13HR
T13HRB	CCU60_T12_ZM	I	
T13HRC	P5.8	I	
T13HRD	SYSCON1. GLCCST	I	
T13HRE	ADC0_ARBCNT	I	
T13HRF	0	I	
T13HRG	U0C0_SR3	I	
T13HRH	0	I	
CC60	P10.0 ADC0_REQGT0H	O	compare outputs of channel CC60
COUT60	P10.3	O	compare outputs of channel CC61
CC61	P10.1 ADC0_REQGT1H	O	
COUT61	P10.4	O	
CC62	P10.2 ADC0_REQGT2H	O	compare outputs of channel CC62
COUT62	P10.5	O	compare output of channel CC63
COUT63	P10.7 P10.10 U0C0_DX2F U0C1_DX2F ADCx_REQGTyA	O	
T12_ZM	CCU60_T13HRB	O	T12 zero match
T13_PM	ERU_OGU02	O	T13 period match
MCM_ST	ERU_OGU01	O	MCM shadow transfer
SR2	CC2_T8IN	O	CC2 timer 8 input

19 Universal Serial Interface Channel

The **Universal Serial Interface Channel** module (USIC) is a flexible interface module covering several serial communication protocols. A USIC module contains two independent communication channels named UxC0 and UxC1, with x being the number of the USIC module (e.g. channel y of USIC module x is referenced as UxCy). The user can program during run-time which protocol will be handled by each communication channel and which pins are used.

This chapter is structured as follows:

- Introduction (see [Page 19-1](#))
- Operating the USIC (see [Page 19-13](#))
- ASC protocol for UART and LIN (see [Page 19-110](#))
- SSC protocol (see [Page 19-131](#))
- IIC protocol (see [Page 19-161](#))
- IIS protocol (see [Page 19-185](#))
- Module implementation in XE166U (see [Page 19-205](#))

19.1 Introduction

This section gives an overview about the feature set of the USIC and introduces the USIC structure. It describes the:

- Feature set overview (see [Page 19-2](#))
- Channel structure (see [Page 19-5](#))
- Input stages (see [Page 19-6](#))
- Output signals (see [Page 19-7](#))
- Baud rate generator (see [Page 19-8](#))
- Channel events and interrupts (see [Page 19-9](#))
- Data shifting and handling (see [Page 19-9](#))

19.1.1 Feature Set Overview

Each USIC channel can be individually configured to match the application needs, e.g. the protocol can be selected or changed during run time without the need for a reset. The following protocols are supported:

- **UART** (ASC, asynchronous serial channel)
 - Module capability: receiver/transmitter with max. baud rate $f_{\text{SYS}} / 4$
 - Wide baud rate range down to single-digit baud rates
 - Number of data bits per data frame: 1 to 63
 - MSB or LSB first
- **LIN** Support by hardware (Local Interconnect Network)
 - Data transfers based on ASC protocol
 - Baud rate detection possible by built-in capture event of baud rate generator
 - Checksum generation under software control for higher flexibility
- **SSC/SPI** (synchronous serial channel with or without slave select lines)
 - Module capability: maximum baud rate $f_{\text{SYS}} / 2$, limited by loop delay
 - Number of data bits per data frame 1 to 63, more with explicit stop condition
 - MSB or LSB first
- **IIC** (Inter-IC Bus)
 - Application baud rate 100 kbit/s to 400 kbit/s
 - 7-bit and 10-bit addressing supported
 - Full master and slave device capability
- **IIS** (infotainment audio bus)
 - Module capability: maximum baud rate $f_{\text{SYS}} / 2$

Note: The real baud rates that can be achieved in a real application depend on the operating frequency of the device, timing parameters as described in the Data Sheet, signal delays on the PCB and timings of the peer device.

In addition to the flexible choice of the communication protocol, the USIC structure has been designed to reduce the system load (CPU load) allowing efficient data handling. The following aspects have been considered:

- **Data buffer capability**
The standard buffer capability includes a double word buffer for receive data and a single word buffer for transmit data. This allows longer CPU reaction times (e.g. interrupt latency).
- **Additional FIFO buffer capability**
In addition to the standard buffer capability, the received data and the data to be transmitted can be buffered in a FIFO buffer structure. The size of the receive and the transmit FIFO buffer can be programmed independently. Depending on the application needs, a total buffer capability of 64 data words can be assigned to the receive and transmit FIFO buffers of a USIC module (the two channels of the USIC module share the 64 data word buffer).

In addition to the FIFO buffer, a bypass mechanism allows the introduction of high-priority data without flushing the FIFO buffer.

- **Transmit control information**

For each data word to be transmitted, a 5-bit transmit control information has been added to automatically control some transmission parameters, such as word length, frame length, or the slave select control for the SPI protocol. The transmit control information is generated automatically by analyzing the address where the user software has written the data word to be transmitted (32 input locations = $2^5 = 5$ bit transmit control information).

This feature allows individual handling of each data word, e.g. the transmit control information associated to the data words stored in a transmit FIFO can automatically modify the slave select outputs to select different communication targets (slave devices) without CPU load. Alternatively, it can be used to control the frame length.

- **Flexible frame length control**

The number of bits to be transferred within a data frame is independent of the data word length and can be handled in two different ways. The first option allows automatic generation of frames up to 63 bits with a known length. The second option supports longer frames (even unlimited length) or frames with a dynamically controlled length.

- **Interrupt capability**

The events of each USIC channel can be individually routed to one of 4 service request outputs SR[3:0], depending on the application needs. Furthermore, specific start and end of frame indications are supported in addition to protocol-specific events.

- **Flexible interface routing**

Each USIC channel offers the choice between several possible input and output pins connections for the communications signals. This allows a flexible assignment of USIC signals to pins that can be changed without resetting the device.

- **Input conditioning**

Each input signal is handled by a programmable input conditioning stage with programmable filtering and synchronization capability.

- **Baud rate generation**

Each USIC channel contains an own baud rate generator. The baud rate generation can be based either on the internal module clock or on an external frequency input. This structure allows data transfers with a frequency that can not be generated internally, e.g. to synchronize several communication partners.

- **Transfer trigger capability**

In master mode, data transfers can be triggered by events generated outside the USIC module, e.g. at an input pin or a timer unit (transmit data validation). This feature allows time base related data transmission.

- **Debugger support**

The USIC offers specific addresses to read out received data without interaction with

the FIFO buffer mechanism. This feature allows debugger accesses without the risk of a corrupted receive data sequence.

To reach a desired baud rate, two criteria have to be respected, the module capability and the application environment. The module capability is defined with respect to the module's input clock frequency, being the base for the module operation. Although the module's capability being much higher (depending on the module clock and the number of module clock cycles needed to represent a data bit), the reachable baud rate is generally limited by the application environment. In most cases, the application environment limits the maximum reachable baud rate due to driver delays, signal propagation times, or due to EMI reasons.

Note: Depending on the selected additional functions (such as digital filters, input synchronization stages, sample point adjustment, data structure, etc.), the maximum reachable baud rate can be limited. Please also take care about additional delays, such as (internal or external) propagation delays and driver delays (e.g. for collision detection in ASC mode, for IIC, etc.).

19.1.2 Channel Structure

The USIC module contains two independent communication channels, with a structure as shown in [Figure 19-1](#).

The data shift unit and the data buffering of each channel support full-duplex data transfers. The protocol-specific actions are handled by the protocol pre-processors (PPP). In order to simplify data handling, an additional FIFO data buffer is optionally available for each USIC module to store transmit and receive data for each channel. This FIFO data buffer is not necessarily available in all devices (please refer to USIC implementation chapter for details).

Due to the independent channel control and baud rate generation, the communication protocol, baud rate and the data format can be independently programmed for each communication channel.

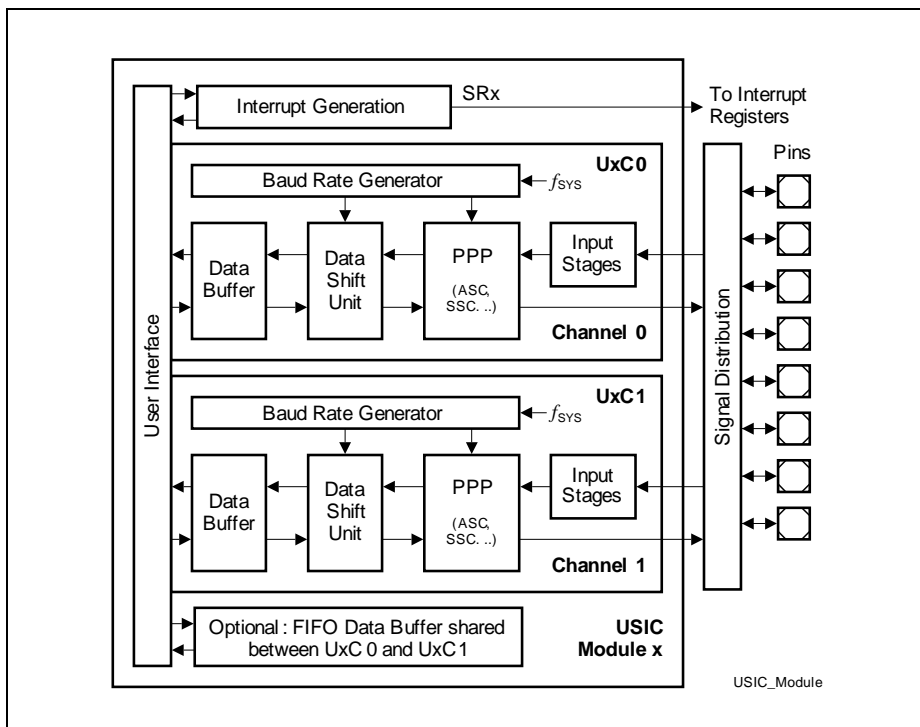


Figure 19-1 USIC Module/Channel Structure

19.1.3 Input Stages

For each protocol up to three input signals are available, the number of actually used inputs depends on the selected protocol. Each input signal is handled by an input stage (called DX0, DX1, DX2) for signal conditioning, such as input selection, polarity control, or a digital input filter. They can be classified according to their meaning for the protocols, see [Table 19-1](#).

The inputs marked as “optional” are not needed for the standard function of a protocol and may be used for enhancements. The descriptions of protocol-specific items are given in the related protocol chapters, for the external frequency input please refer to the baud rate generator, and for the transmit data validation to the data handling section.

Table 19-1 Input Signals for Different Protocols

Selected Protocol	Shift Data Input (handled by DX0)	Shift Clock Input (handled by DX1)	Shift Control Input (handled by DX2)
ASC, LIN	RXD	optional: external frequency input or TXD collision detection	optional: transmit data validation
SSC, SPI (Master)	DIN (MRST, MISO)	optional: external frequency input or delay compensation	optional: transmit data validation or delay compensation
SSC, SPI (Slave)	DIN (MTSR, MOSI)	SCLKIN	SELIN
IIC	SDA	SCL	optional: transmit data validation
IIS (Master)	DIN	optional: external frequency input or delay compensation	optional: transmit data validation or delay compensation
IIS (Slave)	DIN	SCLKIN	WAIN

Note: To allow a certain flexibility in assigning required USIC input functions to port pins of the device, each input stage can select the desired input location among several possibilities.

The available USIC signals and their port locations are listed in the implementation chapter, see [Page 19-210](#).

19.1.4 Output Signals

For each protocol up to eleven protocol-related output signals are available, the number of actually used outputs depends on the selected protocol. They can be classified according to their meaning for the protocols, see [Table 19-2](#).

The outputs marked as “optional” are not needed for the standard function of a protocol and may be used for enhancements. The descriptions of protocol-specific items are given in the related protocol chapters. The MCLKOUT output signal has a stable frequency relation to the shift clock output (the frequency of MCLKOUT can be higher than for SCLKOUT) for synchronization purposes of a slave device to a master device. If the baud rate generator is not needed for a specific protocol (e.g. in SSC slave mode), the SCLKOUT and MCLKOUT signals can be used as clock outputs with 50% duty cycle with a frequency that can be independent from the communication baud rate.

Table 19-2 Output Signals for Different Protocols

Selected Protocol	Shift Data Output DOUT	Shift Clock Output SCLKOUT	Shift Control Outputs SELO[7:0]	Master Clock Output MCLKOUT
ASC, LIN	TXD	not used	not used	optional: master time base
SSC, SPI (master)	DOUT (MTSR, MOSI)	master shift clock	slave select, chip select	optional: master time base
SSC, SPI (slave)	DOUT (MRST, MISO)	optional: independent clock output	not used	optional: independent clock output
IIC	SDA	SCL	not used	optional: master time base
IIS (master)	DOUT	master shift clock	WA	optional: master time base
IIS (slave)	DOUT	optional: independent clock output	not used	optional: independent clock output

Note: To allow a certain flexibility in assigning required USIC output functions to port pins of the device, most output signals are made available on several port pins. The port control itself defines pin-by-pin which signal is used as output signal for a port pin (see port chapter). The available USIC signals and their port locations are listed in the implementation chapter, see [Page 19-210](#).

19.1.5 Baud Rate Generator

Each USIC Channel contains a baud rate generator structured as shown in **Figure 19-2**. It is based on coupled divider stages, providing the frequencies needed for the different protocols. It contains:

- A fractional divider to generate the input frequency $f_{PIN} = f_{FD}$ for baud rate generation based on the internal system frequency f_{SYS} .
- The DX1 input to generate the input frequency $f_{PIN} = f_{DX1}$ for baud rate generation based on an external signal.
- A protocol-related counter to provide the master clock signal MCLK, the shift clock signal SCLK, and other protocol-related signals. It can also be used for time interval measurement, e.g. baud rate detection.
- A time quanta counter associated to the protocol pre-processor defining protocol-specific timings, such shift control signals or bit timings, based on the input frequency f_{CTQIN} .
- The output signals MCLKOUT and SCLKOUT of the protocol-related divider that can be made available on pins. In order to adapt to different applications, some output characteristics of these signals can be configured.

For device-specific details about availability of USIC signals on pins please refer to the implementation section.

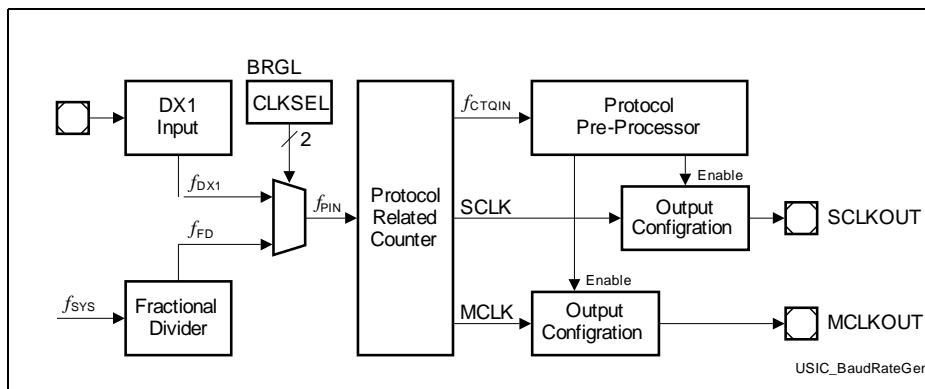


Figure 19-2 Baud Rate Generator

19.1.6 Channel Events and Interrupts

The notification of the user about events occurring during data traffic and data handling is based on:

- Data transfer events related to the transmission or reception of a data word, independent of the selected protocol.
- Protocol-specific events depending on the selected protocol.
- Data buffer events related to data handling by the optional FIFO data buffers.

19.1.7 Data Shifting and Handling

The data handling of the USIC module is based on an independent data shift unit (DSU) and a buffer structure that is similar for the supported protocols. The data shift and buffer registers are 16-bit wide (maximum data word length), but several data words can be concatenated to achieve longer data frames. The DSU inputs are the shift data (handled by input stage DX0), the shift clock (handled by the input stage DX1), and the shift control (handled by the input stage DX2). The signal DOUT represents the shift data output.

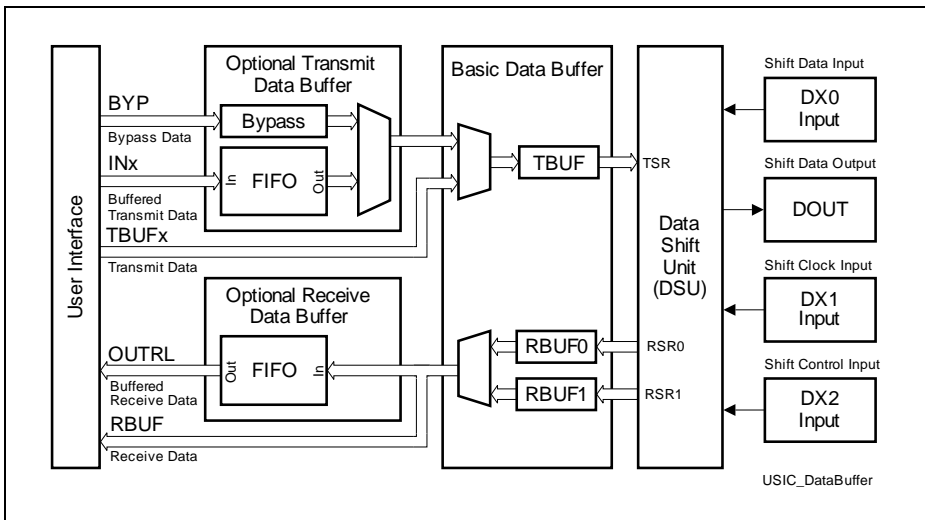


Figure 19-3 Principle of Data Buffering

The principle of data handling comprises:

- A transmitter with a transmit shift register (TSR) in the DSU and a transmit data buffer (TBUF). A data validation scheme allows triggering and gating of data transfers by external events under certain conditions.
- A receiver with two alternating receive shift registers (RSR0 and RSR1) in the DSU and a double receive buffer structure (RBUF0, RBUF1). The alternating receive shift

RBUFD has been introduced. It contains the same value as RBUF, but a read access from RBUFD does not change the status of the data (same data can be read several times). In addition to the received data, some additional status information about each received data word is available in the receiver buffer status registers RBUF01SRL/H (related to data in RBUF0 and RBUF1) and RBUFSR (related to data in RBUF).

Transmit data can be loaded to TBUF by software by writing to the transmit buffer input locations TBUF_x (x = 00-31), consisting of 32 consecutive addresses. The data written to one of these input locations is stored in the transmit buffer TBUF. Additionally, the address of the written location is evaluated and can be used for additional control purposes. This 5-bit wide information (named **Transmit Control Information TCI**) can be used for different purposes in different protocols.

19.1.7.2 FIFO Buffer Structure

To allow easier data setup and handling, an additional data buffering mechanism can be optionally supported. The data buffer is based on the first-in-first-out principle (FIFO) that ensures that the sequence of transferred data words is respected.

If a FIFO buffer structure is used, the data handling scheme (data with associated control information) is similar to the one without FIFO. The additional FIFO buffer can be independently enabled/disabled for transmission and reception (e.g. if data FIFO buffers are available for a specific USIC channel, it is possible to configure the transmit data path without and the receive data path with FIFO buffering).

The transmit FIFO buffer is addressed by using 32 consecutive address locations for IN_x instead of TBUF_x (x=00-31) regardless of the FIFO depth. The 32 addresses are used to store the 5-bit TCI (together with the written data) associated with each FIFO entry.

The receive FIFO can be read out at two independent addresses, OUTR and OUTDRL instead of RBUF and RBUFD. A read from the OUTR location triggers the next data packet to be available for the next read (general FIFO mechanism). In order to allow non-intrusive debugging (without risk of data loss), a second address location (OUTDRL) has been introduced. A read at this location delivers the same value as OUTR, but without modifying the FIFO contents.

The transmit FIFO also has the capability to bypass the data stream and to load bypass data to TBUF. This can be used to generate high-priority messages or to send an emergency message if the transmit FIFO runs empty. The transmission control of the FIFO buffer can also use the transfer trigger and transfer gating scheme of the transmission logic for data validation (e.g. to trigger data transfers by events).

Note: The available size of a FIFO data buffer for a USIC channel depends on the specific device. Please refer to the implementation chapter for details about available FIFO buffer capability.

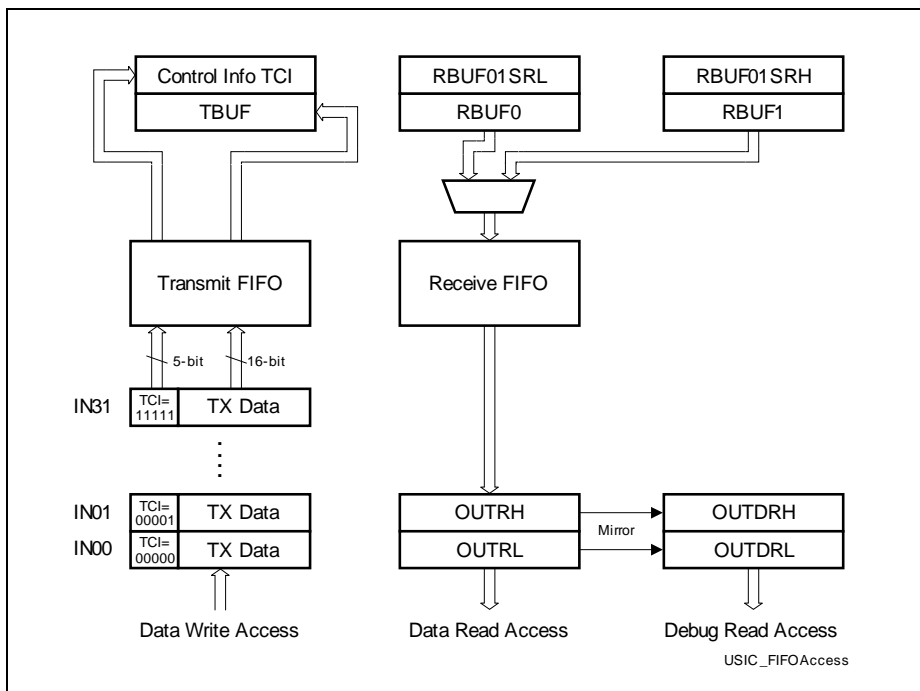


Figure 19-5 Data Access Structure with FIFO

19.2 Operating the USIC

This section describes how to operate the USIC communication channel.

It describes:

- Register Overview (see [Page 19-13](#))
- General channel operation (see [Page 19-18](#))
- Channel control and configuration registers (see [Page 19-25](#))
- Protocol related registers (see [Page 19-33](#))
- Input stages (see [Page 19-36](#))
- Input stage control registers (see [Page 19-38](#))
- Baud rate generation (see [Page 19-41](#))
- Baud rate and shift control registers (see [Page 19-46](#))
- Operating the transmit path (see on [Page 19-51](#))
- Operating the receive path (see [Page 19-55](#))
- Transfer control and status registers (see [Page 19-57](#))
- Data buffer registers (see [Page 19-69](#))
- Operating the FIFO data buffer (see [Page 19-79](#))
- FIFO buffer and bypass registers (see [Page 19-89](#))

19.2.1 Register Overview

The module itself being 32-bit wide, some registers have been split up in two parts for the 16-bit implementation. Both parts keep the same name as the former 32-bit register, with an additional index. The lower part ends with the index L, whereas the upper (higher) part ends with the index H. Former 32-bit registers consisting of only 16 used bits keep their name (without additional index), because only the used bits appear in the register map.

Table 19-3 shows all registers which are required for programming a USIC channel, as well as the FIFO buffer. It summarizes the USIC communication channel registers and defines the relative addresses and the reset values.

Please note that all registers can be accessed with any access width (8-bit, 16-bit), independent of the described width. Short addressing is not supported.

All USIC registers (except bit field KSCFG.SUMCFG) are always reset by a class 3 reset. Bit field KSCFG.SUMCFG is reset by a class 1 reset.

Note: The register bits marked “w” always deliver 0 when read. They are used to modify flip-flops in other registers or to trigger internal actions.

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Figure 19-6 shows the register types of the USIC module registers and channel registers. In a specific microcontroller, module registers of USIC module “x” are marked by the module prefix “USICx_”. Channel registers of USIC module “x” are marked by the channel prefix “UxC0_” and “UxC1_”.

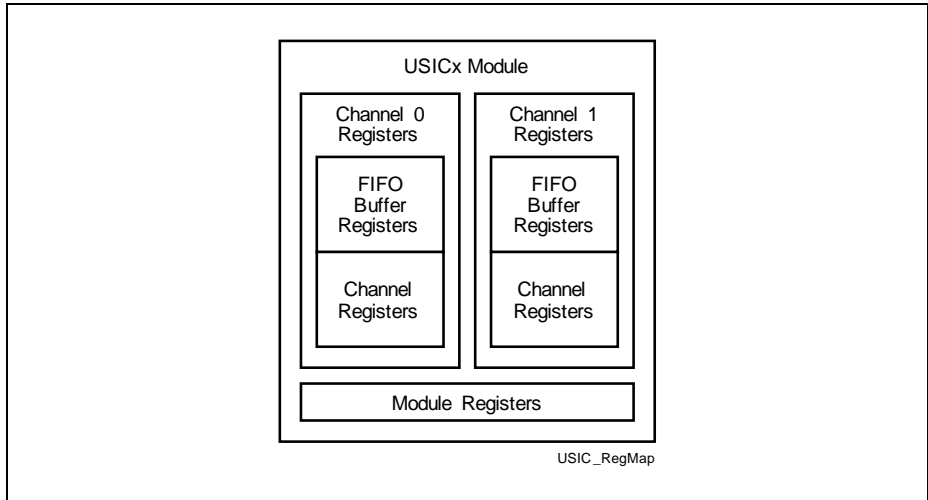


Figure 19-6 USIC Module and Channel Registers

Table 19-3 USIC Kernel-Related and Kernel Registers

Register Short Name	Register Long Name	Offset Addr.	Reset Value	Description see
Module Registers¹⁾				
IDL	Module Identification Register L	008 _H	C0XX _H	
IDH	Module Identification Register H	00A _H	003A _H	
Channel Registers				
FDRL	Fractional Divider Register L	004 _H	0000 _H	Page 19-46
FDRH	Fractional Divider Register H	006 _H	0000 _H	Page 19-47
KSCFG	Kernel State Configuration Register	00C _H	0000 _H	Page 19-29
CCR	Channel Control Register	010 _H	0000 _H	Page 19-25
INPRL	Interrupt Node Pointer Register L	014 _H	0000 _H	Page 19-31
INPRH	Interrupt Node Pointer Register H	016 _H	0000 _H	Page 19-32
CCFG	Channel Configuration Register	018 _H	00CF _H	Page 19-28
BRGL	Baud Rate Generator Register L	01C _H	0000 _H	Page 19-48

Table 19-3 USIC Kernel-Related and Kernel Registers (cont'd)

Register Short Name	Register Long Name	Offset Addr.	Reset Value	Description see
BRGH	Baud Rate Generator Register H	01E _H	0000 _H	Page 19-50
DX0CR	Input Control Register 0	020 _H	0000 _H	Page 19-38
DX1CR	Input Control Register 1	024 _H	0000 _H	
DX2CR	Input Control Register 2	028 _H	0000 _H	
SCTRL	Shift Control Register L	030 _H	0000 _H	Page 19-57
SCTRH	Shift Control Register H	032 _H	0000 _H	Page 19-59
FMRL	Flag Modification Register L	038 _H	0000 _H	Page 19-67
FMRH	Flag Modification Register H	03A _H	0000 _H	Page 19-68
TCSRL	Transmit Control/Status Register L	03C _H	0000 _H	Page 19-60
TCSRH	Transmit Control/Status Register H	03E _H	0000 _H	Page 19-65
PCRL	Protocol Control Register L	040 _H	0000 _H	Page 19-33 ²⁾
				Page 19-123 ³⁾
				Page 19-152 ⁴⁾
				Page 19-179 ⁵⁾
				Page 19-199 ⁶⁾
PCRH	Protocol Control Register H	042 _H	0000 _H	Page 19-33 ²⁾
				Page 19-126 ³⁾
				Page 19-154 ⁴⁾
				Page 19-179 ⁵⁾
				Page 19-201 ⁶⁾

Table 19-3 USIC Kernel-Related and Kernel Registers (cont'd)

Register Short Name	Register Long Name	Offset Addr.	Reset Value	Description see
PSR	Protocol Status Register	044 _H	0000 _H	Page 19-34 ²⁾ Page 19-127 ³⁾ Page 19-156 ⁴⁾ Page 19-182 ⁵⁾ Page 19-202 ⁶⁾
PSCR	Protocol Status Clear Register	048 _H	0000 _H	Page 19-35
RBUFD	Receiver Buffer Register for Debugger	04C _H	0000 _H	Page 19-77
RBUF0	Receiver Buffer Register 0	050 _H	0000 _H	Page 19-70
RBUF1	Receiver Buffer Register 1	054 _H	0000 _H	Page 19-73
RBUFSR	Receiver Buffer Status Register	058 _H	0000 _H	Page 19-78
RBUF	Receiver Buffer Register	05C _H	0000 _H	Page 19-76
RBUF01SRL	Receiver Buffer 01 Status Register L	060 _H	0000 _H	Page 19-70
RBUF01SRH	Receiver Buffer 01 Status Register H	062 _H	0000 _H	Page 19-73
–	Reserved; do not access this location.	06C _H	–	–
–	Reserved; do not access this location.	06E _H	–	–
TBUFx	Transmit Buffer Input Location x (x = 00-31)	080 _H + x*4	0000 _H	Page 19-69

FIFO Buffer Registers

BYP	Bypass Data Register	100 _H	0000 _H	Page 19-89
BYPCLR	Bypass Control Register L	104 _H	0000 _H	Page 19-89
BYPCHR	Bypass Control Register H	106 _H	0000 _H	Page 19-91
TRBPTRL	Transmit/Receive Buffer Pointer Register L	108 _H	0000 _H	Page 19-108
TRBPTRH	Transmit/Receive Buffer Pointer Register H	10A _H	0000 _H	Page 19-109

Table 19-3 USIC Kernel-Related and Kernel Registers (cont'd)

Register Short Name	Register Long Name	Offset Addr.	Reset Value	Description see
TBCTRL	Transmit Buffer Control Register L	110 _H	0000 _H	Page 19-98
TBCTRH	Transmit Buffer Control Register H	112 _H	0000 _H	Page 19-99
RBCTRL	Receive Buffer Control Register L	114 _H	0000 _H	Page 19-101
RBCTRH	Receive Buffer Control Register H	116 _H	0000 _H	Page 19-102
TRBSRL	Transmit/Receive Buffer Status Register L	118 _H	0808 _H	Page 19-92
TRBSRH	Transmit/Receive Buffer Status Register H	11A _H	0000 _H	Page 19-95
TRBSCR	Transmit/Receive Buffer Status Clear Register	11C _H	0000 _H	Page 19-96
OUTRL	Receive Buffer Output Register L	120 _H	0000 _H	Page 19-106
OUTRH	Receive Buffer Output Register H	122 _H	0000 _H	Page 19-106
OUTDRL	Receive Buffer Output Register L for Debugger	124 _H	0000 _H	Page 19-107
OUTDRH	Receive Buffer Output Register H for Debugger	126 _H	0000 _H	Page 19-107
INx	Transmit FIFO Buffer Input Location x (x = 00-31)	180 _H + x*4	0000 _H	Page 19-105

- 1) Details of the module identification registers are described in the implementation section (see [Page 19-207](#)).
- 2) This page shows the general register layout.
- 3) This page shows the register layout in ASC mode.
- 4) This page shows the register layout in SSC mode.
- 5) This page shows the register layout in IIC mode.
- 6) This page shows the register layout in IIS mode.

19.2.2 Operating the USIC Communication Channel

This section describes how to operate a USIC communication channel, including protocol control and status, mode control and interrupt handling. The following aspects have to be taken into account:

- Enable the USIC module for operation and configure the behavior for the different device operation modes (see [Page 19-19](#)).
- Configure the pinning (refer to description in the corresponding protocol section).
- Configure the data structure (shift direction, word length, frame length, polarity, etc.).
- Configure the data buffer structure of the optional FIFO buffer area. A FIFO buffer can only be enabled if the related bit in register CCFG is set.
- Select a protocol by CCR.MODE. A protocol can only be selected if the related bit in register CCFG is set.

19.2.2.1 Protocol Control and Status

The protocol-related control and status information are located in the protocol control registers PCRL and PCRH and in the protocol status register PSR. These registers are shared between the available protocols. As a consequence, the meaning of the bit positions in these registers is different within the protocols.

Use of PCRL/H Bits

The signification of the bits in registers PCRL/PCRH is indicated by the protocol-related alias names for the different protocols.

- PCRL/PRCH for the ASC protocol (see [Page 19-123](#))
- PCRL/PRCH for the SSC protocol (see [Page 19-152](#))
- PCRL/PRCH for the IIC protocol (see [Page 19-179](#))
- PCRL/PRCH for the IIS protocol (see [Page 19-199](#))

Use of PSR Flags

The signification of the flags in register PSR is indicated by the protocol-related alias names for the different protocols.

- PSR flags for the ASC protocol (see [Page 19-127](#))
- PSR flags for the SSC protocol (see [Page 19-156](#))
- PSR flags for the IIC protocol (see [Page 19-182](#))
- PSR flags for the IIS protocol (see [Page 19-202](#))

19.2.2.2 Mode Control

The mode control concept for system control tasks, such as power saving, or suspend request for debugging, allows to program the module behavior under different device operating conditions. The behavior of a communication channel can be programmed for each of the device operating modes, that are requested by the global state control part of the SCU. Therefore, each communication channel has an associated kernel state configuration register KSCFG defining its behavior in the following operating modes:

- Normal operation:
 This operating mode is the default operating mode when neither a suspend request nor a clock-off request are pending. The module clock is not switched off and the USIC registers can be read or written. The channel behavior is defined by KSCFG.NOMCFG.
- Suspend mode:
 This operating mode is requested when a suspend request is pending in the device. The module clock is not switched off and the USIC registers can be read or written. The channel behavior is defined by KSCFG.SUMCFG.
- Clock-off mode:
 This operating mode is requested for power saving purposes. The module clock is switched off automatically when all channels of the USIC module reached their specified state in a stop mode. In this case, USIC registers can not be accessed. The channel behavior is defined by KSCFG.COMCFG.

The behavior of a USIC communication channel can be programmed for each of the device operating modes (normal operation, suspend mode, clock-off mode). Therefore, the USIC communication channel provides four kernel modes, as shown in [Table 19-4](#).

Table 19-4 USIC Communication Channel Behavior

Kernel Mode	Channel Behavior	KSCFG. NOMCFG
Run mode 0	Channel operation as specified, no impact on data transfer	00 _B
Run mode 1		01 _B
Stop mode 0	Explicit stop condition as described in the protocol chapters	10 _B
Stop mode 1		11 _B

Generally, bit field KSCFG.NOMCFG should be configured for run mode 0 as default setting for standard operation. If a communication channel should not react to a suspend request (and to continue its operation as in normal mode), bit field KSCFG.SUMCFG has to be configured with the same value as KSCFG.NOMCFG. If the communication channel should show a different behavior and stop operation when a specific stop condition is reached, the code for stop mode 0 or stop mode 1 have to be written to KSCFG.SUMCFG.

A similar mechanism applies for the clock-off mode with the possibility to program the desired behavior by bit field KSCFG.COMCFG.

The stop conditions are defined for the selected protocol (see mode control description in the protocol section).

Note: The stop mode selection strongly depends on the application needs and it is very unlikely that different stop modes are required in parallel in the same application. As a result, only one stop mode type (either 0 or 1) should be used in the bit fields in register KSCFG. Do not mix stop mode 0 and stop mode 1 and avoid transitions from stop mode 0 to stop mode 1 (or vice versa) for the same communication channel.

If the module clock is disabled by KSCFG.MODEN = 0 or in clock-off mode when the stop condition is reached (in stop mode 0 or 1), the module can not be accessed by read or write operations (except register KSCFG that can always be accessed).

19.2.2.3 General Channel Events and Interrupts

The general event and interrupt structure is shown in [Figure 19-7](#). If a defined condition is met, an event is detected and an event indication flag becomes automatically set. The flag stays set until it is cleared by software. If enabled, an interrupt can be generated if an event is detected. The actual status of the event indication flag has no influence on the interrupt generation. As a consequence, the event indication flag does not need to be cleared to generate further interrupts.

Additionally, the service request output SRx of the USIC channel that becomes activated in case of an event condition can be selected by an interrupt node pointer. This structure allows to assign events to interrupts, e.g. depending on the application, several events can share the same interrupt routine (several events activate the same SRx output) or can be handled individually (only one event activates one SRx output).

The SRx outputs are connected to interrupt control registers to handle the CPU reaction to the service requests. This assignment is described in the implementation section on [Page 19-209](#).

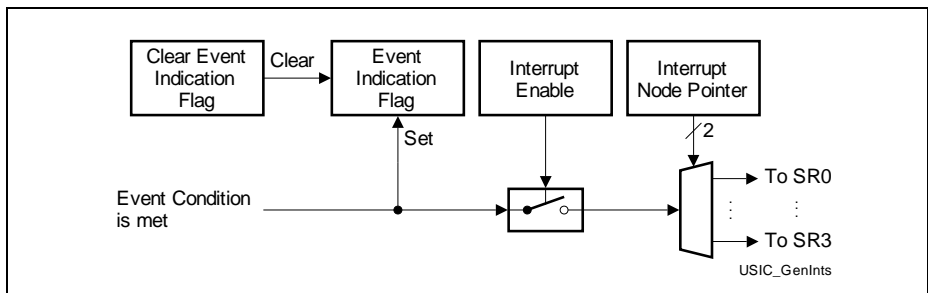


Figure 19-7 General Event and Interrupt Structure

19.2.2.4 Data Transfer Events and Interrupts

The data transfer events are based on the transmission or reception of a data word. The related indication flags are located in register PSR. All events can be individually enabled for interrupt generation.

- **Receive event to indicate that a data word has been received:**
 If a new received word becomes available in the receive buffer RBUF, either a receive event or an alternative receive event occurs.
 The receive event occurs if bit RBUFSR.PERR = 0. It is indicated by flag PSR.RIF and, if enabled, leads to receive interrupt.
- **Receiver start event to indicate that a data word reception has started:**
 When the receive clock edge that shifts in the first bit of a new data word is detected and reception is enabled, a receiver start event occurs. It is indicated by flag PSR.RSIF and, if enabled, leads to transmit buffer interrupt.
 In full duplex mode, this event follows half a shift clock cycle after the transmit buffer event and indicates when the shift control settings are internally “frozen” for the current data word reception and a new setting can be programmed.
 In SSC and IIS mode, the transmit data valid flag TCSRL.TDV is cleared in single shot mode with the receiver start event.
- **Alternative receive event to indicate that a specific data word has been received:**
 If a new received word becomes available in the receive buffer RBUF, either a receive event or an alternative receive event occurs.
 The alternative receive event occurs if bit RBUFSR.PERR = 1. It is indicated by flag PSR.AIF and, if enabled, leads to alternative receive interrupt.
 Depending on the selected protocol, bit RBUFSR.PERR is set to indicate a parity error in ASC mode, the reception of the first byte of a new frame in IIC mode, and the WA information about right/left channel in IIS mode. In SSC mode, it is used as indication if the received word is the first data word, and is set if first and reset if not.
- **Transmit shift event to indicate that a data word has been transmitted:**
 A transmit shift event occurs with the last shift clock edge of a data word. It is indicated by flag PSR.TSIF and, if enabled, leads to transmit shift interrupt.
- **Transmit buffer event to indicate that a data word transmission has been started:**
 When a data word from the transmit buffer TBUF has been loaded to the shift register and a new data word can be written to TBUF, a transmit buffer event occurs. This happens with the transmit clock edge that shifts out the first bit of a new data word and transmission is enabled. It is indicated by flag PSR.TBIF and, if enabled, leads to transmit buffer interrupt.
 This event also indicates when the shift control settings (word length, shift direction, etc.) are internally “frozen” for the current data word transmission.
 In ASC and IIC mode, the transmit data valid flag TCSRL.TDV is cleared in single shot mode with the transmit buffer event.
- **Data lost event to indicate a loss of the oldest received data word:**
 If the data word available in register RBUF (oldest data word from RBUF0 or RBUF1)

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has not been read out before it becomes overwritten with new incoming data, this event occurs. It is indicated by flag PSR.DLIF and, if enabled, leads to a protocol interrupt.

Table 19-5 shows the registers, bits and bit fields indicating the data transfer events and controlling the interrupts of a USIC channel.

Table 19-5 Data Transfer Events and Interrupt Handling

Event	Indication Flag	Indication cleared by	Interrupt enabled by	SRx Output selected by
Standard receive event	PSR.RIF	PSCR.CRIF	CCR.RIEN	INPRL.RINP
Receive start event	PSR.RSIF	PSCR.CRSIF	CCR.RSIEN	INPRL.TBINP
Alternative receive event	PSR.AIF	PSCR.CAIF	CCR.AIEN	INPRL.AINP
Transmit shift event	PSR.TSIF	PSCR.CTSIF	CCR.TSIEN	INPRL.TSINP
Transmit buffer event	PSR.TBIF	PSCR.CTBIF	CCR.TBIEN	INPRL.TBINP
Data lost event	PSR.DLIF	PSCR.CDLIF	CCR.DLIEN	INPRH.PINP

Figure 19-8 shows the two transmit events and interrupts.

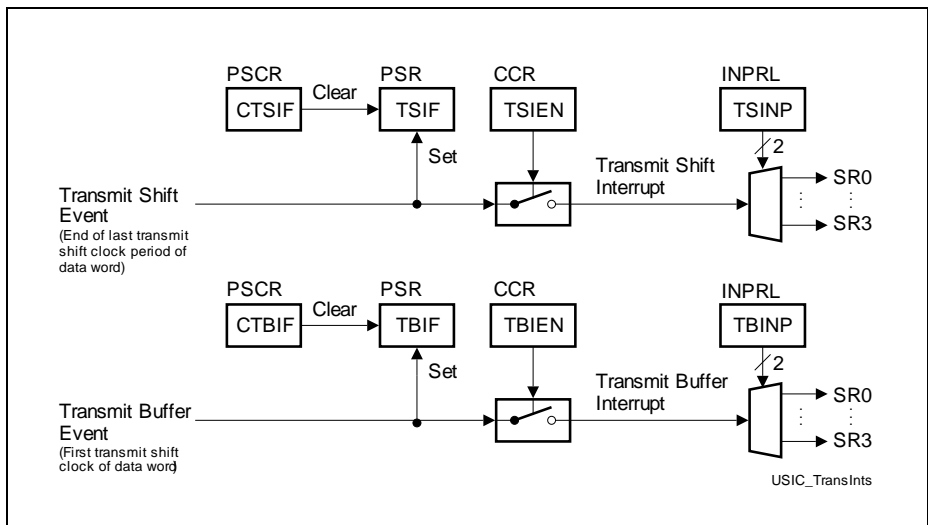


Figure 19-8 Transmit Events and Interrupts

Figure 19-9 shows the receive events and interrupts.

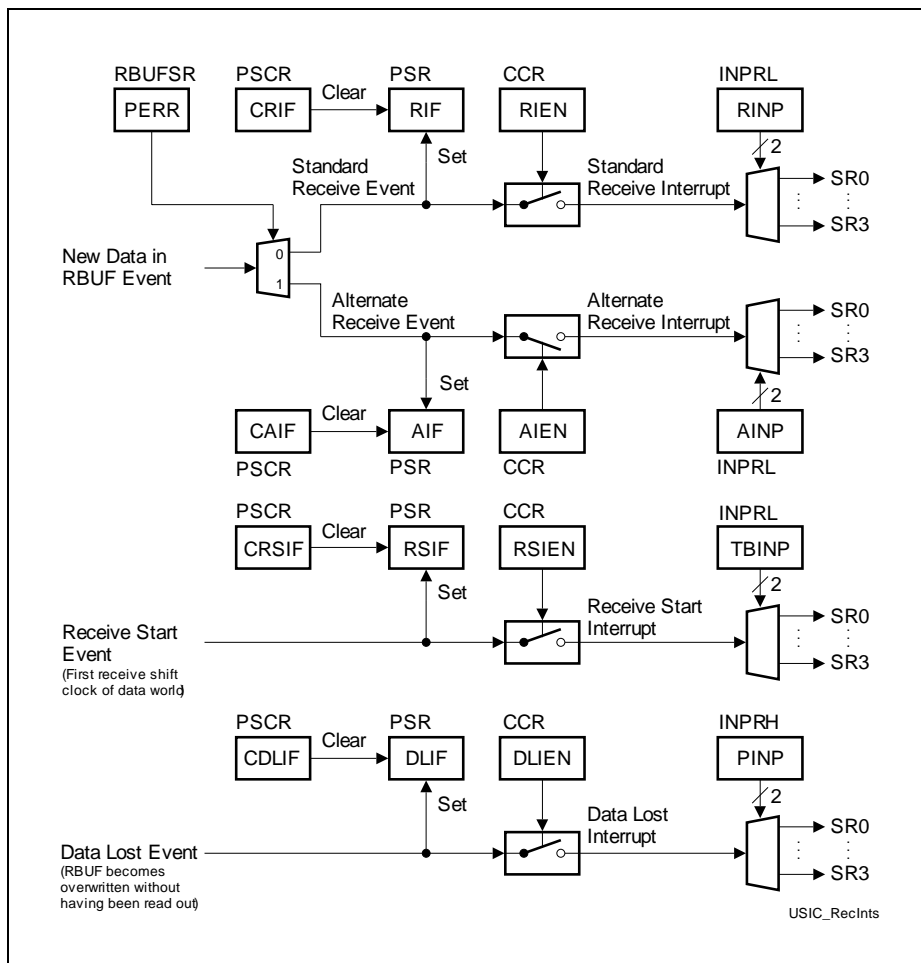


Figure 19-9 Receive Events and Interrupts

19.2.2.5 Protocol-specific Events and Interrupts

These events are related to protocol-specific actions that are described in the corresponding protocol chapters. The related indication flags are located in register PSR. All events can be individually enabled for the generation of the common protocol interrupt.

- Protocol-specific events in ASC mode:
Synchronization break, data collision on the transmit line, receiver noise, format error in stop bits, receiver frame finished, transmitter frame finished
- Protocol-specific events in SSC mode:
MSLS event (start-end of frame in master mode), DX2T event (start/end of frame in slave mode), both based on slave select signals
- Protocol-specific events in IIC mode:
Wrong transmit code (error in frame sequence), start condition received, repeated start condition received, stop condition received, non-acknowledge received, arbitration lost, slave read request, other general errors
- Protocol-specific events in IIS mode:
DX2T event (change on WA line), WA falling edge or rising edge detected, WA generation finished

Table 19-6 Protocol-specific Events and Interrupt Handling

Event	Indication Flag	Indication cleared by	Interrupt enabled by	SRx Output selected by
Protocol-specific events in ASC mode	PSR.ST[8:2]	PSCR.CST[8:2]	PCRL.CTR[7:3]	INPRH.PINP
Protocol-specific events in SSC mode	PSR.ST[3:2]	PSCR.CST[3:2]	PCRL.CTR[15:14]	INPRH.PINP
Protocol-specific events in IIC mode	PSR.ST[8:1]	PSCR.CST[8:1]	PCRH.CTR[24:18]	INPRH.PINP
Protocol-specific events in IIS mode	PSR.ST[6:3]	PSCR.CST[6:3]	PCRL.CTR[6:4], PCRL.CTR[15]	INPRH.PINP

19.2.3 Channel Control and Configuration Registers

19.2.3.1 Channel Control Register

The channel control register contains the enable/disable bits for interrupt generation on channel events, the control of the parity generation and the protocol selection of a USIC channel.

CCR

Channel Control Register

(10_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AI EN	RI EN	TBI EN	TSI EN	DLI EN	RSI EN	PM		0			MODE				
rw	rw	rw	rw	rw	rw	rw		r			rw				

Field	Bits	Type	Description
MODE	[3:0]	rw	Operating Mode This bit field selects the protocol for this USIC channel. Selecting a protocol that is not available (see register CCFG) or a reserved combination disables the USIC channel. When switching between two protocols, the USIC channel has to be disabled before selecting a new protocol. In this case, registers PCRH, PCRL, and PSR have to be cleared or updated by software. 0 _H The USIC channel is disabled. All protocol-related state machines are set to an idle state. 1 _H The SSC (SPI) protocol is selected. 2 _H The ASC (SCI, UART) protocol is selected. 3 _H The IIS protocol is selected. 4 _H The IIC protocol is selected. Other bit combinations are reserved.

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Field	Bits	Type	Description
PM	[9:8]	rw	Parity Mode This bit field defines the parity generation of the sampled input values. 00 _B The parity generation is disabled. 01 _B Reserved 10 _B Even parity is selected (parity bit = 1 on odd number of 1s in data, parity bit = 0 on even number of 1s in data). 11 _B Odd parity is selected (parity bit = 0 on odd number of 1s in data, parity bit = 1 on even number of 1s in data).
RSIEN	10	rw	Receiver Start Interrupt Enable This bit enables the interrupt generation in case of a receiver start event. 0 _B The receiver start interrupt is disabled. 1 _B The receiver start interrupt is enabled. In case of a receiver start event, the service request output SRx indicated by INPRL.TBINP is activated.
DLIEN	11	rw	Data Lost Interrupt Enable This bit enables the interrupt generation in case of a data lost event (data received in RBUFx while RDVx = 1). 0 _B The data lost interrupt is disabled. 1 _B The data lost interrupt is enabled. In case of a data lost event, the service request output SRx indicated by INPRH.PINP is activated.
TSIEN	12	rw	Transmit Shift Interrupt Enable This bit enables the interrupt generation in case of a transmit shift event. 0 _B The transmit shift interrupt is disabled. 1 _B The transmit shift interrupt is enabled. In case of a transmit shift interrupt event, the service request output SRx indicated by INPRL.TSINP is activated.

Field	Bits	Type	Description
TBIEN	13	rw	Transmit Buffer Interrupt Enable This bit enables the interrupt generation in case of a transmit buffer event. 0 _B The transmit buffer interrupt is disabled. 1 _B The transmit buffer interrupt is enabled. In case of a transmit buffer event, the service request output SRx indicated by INPRL.TBINP is activated.
RIEN	14	rw	Receive Interrupt Enable This bit enables the interrupt generation in case of a receive event. 0 _B The receive interrupt is disabled. 1 _B The receive interrupt is enabled. In case of a receive event, the service request output SRx indicated by INPRL.RINP is activated.
AIEN	15	rw	Alternative Receive Interrupt Enable This bit enables the interrupt generation in case of a alternative receive event. 0 _B The alternative receive interrupt is disabled. 1 _B The alternative receive interrupt is enabled. In case of an alternative receive event, the service request output SRx indicated by INPRL.AINP is activated.
0	[7:4]	r	Reserved Read as 0; should be written with 0.

19.2.3.2 Channel Configuration Register

The channel configuration register contains indicates the functionality that is available in the USIC channel.

CCFG

Channel Configuration Register

(18_H)

Reset Value: 00CF_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
			0					TB	RB		0	IIS	IIC	ASC	SSC
			r					r	r		r	r	r	r	r

Field	Bits	Type	Description
SSC	0	r	SSC Protocol Available This bit indicates if the SSC protocol is available. 0 _B The SSC protocol is not available. 1 _B The SSC protocol is available.
ASC	1	r	ASC Protocol Available This bit indicates if the ASC protocol is available. 0 _B The ASC protocol is not available. 1 _B The ASC protocol is available.
IIC	2	r	IIC Protocol Available This bit indicates if the IIC functionality is available. 0 _B The IIC protocol is not available. 1 _B The IIC protocol is available.
IIS	3	r	IIS Protocol Available This bit indicates if the IIS protocol is available. 0 _B The IIS protocol is not available. 1 _B The IIS protocol is available.
RB	6	r	Receive FIFO Buffer Available This bit indicates if an additional receive FIFO buffer is available. 0 _B A receive FIFO buffer is not available. 1 _B A receive FIFO buffer is available.
TB	7	r	Transmit FIFO Buffer Available This bit indicates if an additional transmit FIFO buffer is available. 0 _B A transmit FIFO buffer is not available. 1 _B A transmit FIFO buffer is available.

Field	Bits	Type	Description
0	[5:4], [15:8]	r	Reserved Read as 0; should be written with 0.

19.2.3.3 Kernel State Configuration Register

The kernel state configuration register KSCFG allows the selection of the desired kernel modes for the different device operating modes.

KSCFG

Kernel State Configuration Register (0C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BP COM	0	COMCFG		BP SUM	0	SUMCFG		BP NOM	0	NOMCFG		0	0	BP MOD EN	MOD EN
w	r	rw		w	r	rw		w	r	rw		r	r	w	rw

Field	Bits	Type	Description
MODEN	0	rw	Module Enable This bit enables the module kernel clock and the module functionality. 0 _B The module is switched off immediately (without respecting a stop condition). It does not react on mode control actions and the module clock is switched off. The module does not react on read accesses and ignores write accesses (except to KSCFG). 1 _B The module is switched on and can operate. After writing 1 to MODEN, it is recommended to read register KSCFG to avoid pipeline effects in the control block before accessing other USIC registers.
BPMODEN	1	w	Bit Protection for MODEN This bit enables the write access to the bit MODEN. It always reads 0. 0 _B MODEN is not changed. 1 _B MODEN is updated with the written value.

Field	Bits	Type	Description
NOMCFG	[5:4]	rw	Normal Operation Mode Configuration This bit field defines the kernel mode applied in normal operation mode. 00 _B Run mode 0 is selected. 01 _B Run mode 1 is selected. 10 _B Stop mode 0 is selected. 11 _B Stop mode 1 is selected.
BPNOM	7	w	Bit Protection for NOMCFG This bit enables the write access to the bit field NOMCFG. It always reads 0. 0 _B NOMCFG is not changed. 1 _B NOMCFG is updated with the written value.
SUMCFG	[9:8]	rw	Suspend Mode Configuration This bit field defines the kernel mode applied in suspend mode. Coding like NOMCFG.
BPSUM	11	w	Bit Protection for SUMCFG This bit enables the write access to the bit field SUMCFG. It always reads 0. 0 _B SUMCFG is not changed. 1 _B SUMCFG is updated with the written value.
COMCFG	[13:12]	rw	Clock Off Mode Configuration This bit field defines the kernel mode applied in clock-off mode. Coding like NOMCFG.
BPCOM	15	w	Bit Protection for COMCFG This bit enables the write access to the bit field COMCFG. It always reads 0. 0 _B COMCFG is not changed. 1 _B COMCFG is updated with the written value.
0	[3:2], 6, 10, 14	r	Reserved Read as 0; should be written with 0. Bit 2 can read as 1 after BootROM exit (but can be ignored).

19.2.3.4 Interrupt Node Pointer Registers

The interrupt node pointer registers define the service request output SRx that is activated if the corresponding event occurs and interrupt generation is enabled.

INPRL

Interrupt Node Pointer Register L (14_H) **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	AINP	0	RINP	0	TBINP	0	TSINP								
r	rw	r	rw	r	rw	r	rw					r		rw	

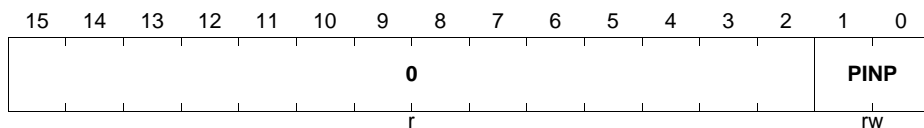
Field	Bits	Type	Description
TSINP	[1:0]	rw	Transmit Shift Interrupt Node Pointer This bit field defines which service request output SRx becomes activated in case of a transmit shift interrupt. 00 _B Output SR0 becomes activated. 01 _B Output SR1 becomes activated. 10 _B Output SR2 becomes activated. 11 _B Output SR3 becomes activated.
TBINP	[5:4]	rw	Transmit Buffer Interrupt Node Pointer This bit field defines which service request output SRx will be activated in case of a transmit buffer interrupt or a receive start interrupt. Coding like TSINP.
RINP	[9:8]	rw	Receive Interrupt Node Pointer This bit field defines which service request output SRx will be activated in case of a receive interrupt. Coding like TSINP.
AINP	[13:12]	rw	Alternative Receive Interrupt Node Pointer This bit field defines which service request output SRx will be activated in case of a alternative receive interrupt. Coding like TSINP.
0	[3:2], [7:6], [11:10], [15:14]	r	Reserved Read as 0; should be written with 0.

INPRH

Interrupt Node Pointer Register H

(16_H)

Reset Value: 0000_H



Field	Bits	Type	Description
PINP	[1:0]	rw	Protocol Interrupt Node Pointer This bit field defines which service request output SRx becomes activated in case of a protocol interrupt. 00 _B Output SR0 becomes activated. 01 _B Output SR1 becomes activated. 10 _B Output SR2 becomes activated. 11 _B Output SR3 becomes activated.
0	[15:2]	r	Reserved Read as 0; should be written with 0.

19.2.4 Protocol Related Registers

19.2.4.1 Protocol Control Registers

The bits in the protocol control registers define protocol-specific functions. They have to be configured by software before enabling a new protocol. Only the bits used for the selected protocol are taken into account, whereas the other bit positions always read as 0. The protocol-specific meaning is described in the related protocol section.

PCRL

Protocol Control Register L

(40_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CTR 15	CTR 14	CTR 13	CTR 12	CTR 11	CTR 10	CTR 9	CTR 8	CTR 7	CTR 6	CTR 5	CTR 4	CTR 3	CTR 2	CTR 1	CTR 0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
CTR _x (x = 0-15)	x	rw	Protocol Control Bit x This bit is a protocol control bit.

PCRH

Protocol Control Register H

(42_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CTR 31	CTR 30	CTR 29	CTR 28	CTR 27	CTR 26	CTR 25	CTR 24	CTR 23	CTR 22	CTR 21	CTR 20	CTR 19	CTR 18	CTR 17	CTR 16
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
CTR _x (x = 16-30)	x - 16	rwh	Protocol Control Bit x This bit is a protocol control bit that can be overwritten by protocol-specific information.
CTR31	15	rwh	Protocol Control Bit 31 In the various protocols, this bit controls the start and the stop of the MCLK signal. 0 _B Signal MCLK is not generated (MCLK = 0). 1 _B Signal MCLK generation is enabled.

19.2.4.2 Protocol Status Register

The flags in the protocol status register can be cleared by writing a 1 to the corresponding bit position in register PSCR. Writing a 1 to a bit position in PSR sets the corresponding flag, but doesn't lead to further actions (no interrupt generation). Writing a 0 has no effect. These flags should be cleared by software before enabling a new protocol. The protocol-specific meaning is described in the related protocol section.

PSR

Protocol Status Register

(44_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AIF	RIF	TBIF	TSIF	DLIF	RSIF	ST9	ST8	ST7	ST6	ST5	ST4	ST3	ST2	ST1	ST0
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
STx (x = 0-9)	x	rwh	Protocol Status Flag x See protocol specific description.
RSIF	10	rwh	Receiver Start Indication Flag 0 _B A receiver start event has not occurred. 1 _B A receiver start event has occurred.
DLIF	11	rwh	Data Lost Indication Flag 0 _B A data lost event has not occurred. 1 _B A data lost event has occurred.
TSIF	12	rwh	Transmit Shift Indication Flag 0 _B A transmit shift event has not occurred. 1 _B A transmit shift event has occurred.
TBIF	13	rwh	Transmit Buffer Indication Flag 0 _B A transmit buffer event has not occurred. 1 _B A transmit buffer event has occurred.
RIF	14	rwh	Receive Indication Flag 0 _B A receive event has not occurred. 1 _B A receive event has occurred.
AIF	15	rwh	Alternative Receive Indication Flag 0 _B An alternative receive event has not occurred. 1 _B An alternative receive event has occurred.

19.2.4.3 Protocol Status Clear Register

Read accesses to this register always deliver 0 at all bit positions.

PSCR

Protocol Status Clear Register

(48_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
AIF	RIF	TBIF	TSIF	DLIF	RSIF	ST9	ST8	ST7	ST6	ST5	ST4	ST3	ST2	ST1	ST0
W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W

Field	Bits	Type	Description
CSTx (x = 0-9)	x	w	Clear Status Flag x in PSR 0 _B No action 1 _B Flag PSR.STx is cleared.
CRSIF	10	w	Clear Receiver Start Indication Flag 0 _B No action 1 _B Flag PSR.RSIF is cleared.
CDLIF	11	w	Clear Data Lost Indication Flag 0 _B No action 1 _B Flag PSR.DLIF is cleared.
CTSIF	12	w	Clear Transmit Shift Indication Flag 0 _B No action 1 _B Flag PSR.TSIF is cleared.
CTBIF	13	w	Clear Transmit Buffer Indication Flag 0 _B No action 1 _B Flag PSR.TBIF is cleared.
CRIF	14	w	Clear Receive Indication Flag 0 _B No action 1 _B Flag PSR.RIF is cleared.
CAIF	15	w	Clear Alternative Receive Indication Flag 0 _B No action 1 _B Flag PSR.AIF is cleared.

19.2.5 Operating the Input Stages

All three input stages offer the same feature set. They are used for all protocols, because the signal conditioning can be adapted in a very flexible way and the digital filters can be switched on and off separately.

19.2.5.1 General Input Structure

All input stages are built in a similar way as shown in **Figure 19-10**. All enable/disable functions and selections are controlled independently for each input stage by bits in the registers DX0CR, DX1CR, and DX2CR.

The desired input signal can be selected among the input lines DXnA to DXnG and a permanent 1-level by programming bit field DSEL. Please refer to the implementation chapter for the device-specific input signal assignment. Bit DPOL allows a polarity inversion of the selected input signal to adapt the input signal polarity to the internal polarity of the data shift unit and the protocol state machine. For some protocols, the input signals can be directly forwarded to the data shift unit for the data transfers (DSEN = 0, INSW = 1) without any further signal conditioning. In this case, the data path does not contain any delay due to synchronization or filtering.

In the case of noise on the input signals, there is the possibility to synchronize the input signal (signal DXnS is synchronized to f_{SYS}) and additionally to enable a digital noise filter in the signal path. The synchronized input signal (and optionally filtered if DFEN = 1) is taken into account by DSEN = 1. Please note that the synchronization leads to a delay in the signal path of 2-3 times the period of f_{SYS} .

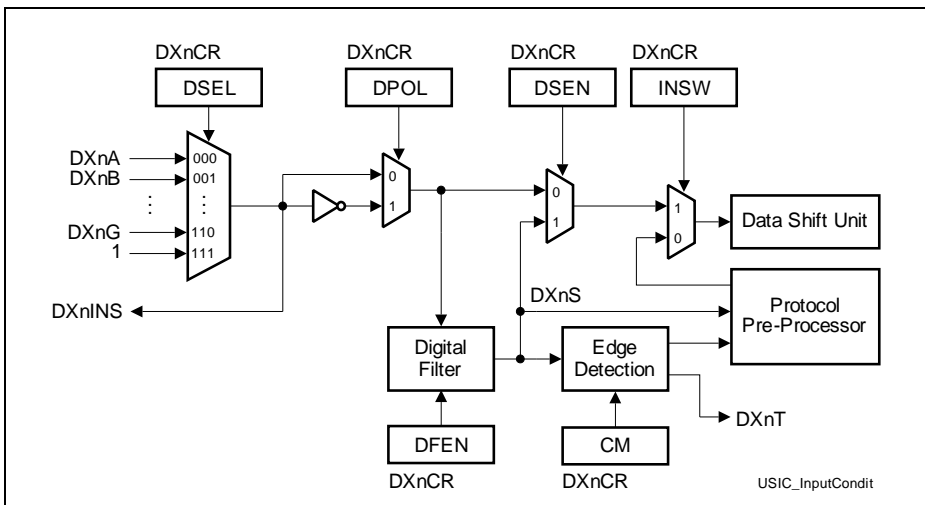


Figure 19-10 Input Conditioning

If the input signals are handled by a protocol pre-processor, the data shift unit is directly connected to the protocol pre-processor by $INSW = 0$. The protocol pre-processor is connected to the synchronized input signal $DXnS$ and, depending on the selected protocol, also evaluates the edges.

19.2.5.2 Digital Filter

The digital filter can be enabled to reduce noise on the input signals. Before being filtered, the input signal becomes synchronized to f_{SYS} . If the filter is disabled, signal $DXnS$ corresponds to the synchronized input signal. If the filter is enabled, pulses shorter than one filter sampling period are suppressed in signal $DXnS$. After an edge of the synchronized input signal, signal $DXnS$ changes to the new value if two consecutive samples of the new value have been detected.

In order to adapt the filter sampling period to different applications, it can be programmed. The first possibility is the system frequency f_{SYS} . Longer pulses can be suppressed if the fractional divider output frequency f_{FD} is selected. This frequency is programmable in a wide range and can also be used to determine the baud rate of the data transfers.

In addition to the synchronization delay of 2-3 periods of f_{SYS} , an enabled filter adds a delay of up to two filter sampling periods between the selected input and signal $DXnS$.

19.2.5.3 Edge Detection

The synchronized (and optionally filtered) signal $DXnS$ can be used as input to the data shift unit and is also an input to the selected protocol pre-processor. If the protocol pre-processor does not use the $DXnS$ signal for protocol-specific handling, $DXnS$ can be used for other tasks, e.g. to control data transmissions in master mode (a data word can be tagged valid for transmission, see chapter about data buffering).

A programmable edge detection indicates that the desired event has occurred by activating the trigger signal $DXnT$ (introducing a delay of one period of f_{SYS} before a reaction to this event can take place).

19.2.5.4 Selected Input Monitoring

The selected input signal of each input stage has been made available with the signals $DX0INS$, $DX1INS$, and $DX2INS$. These signals can be used in the system to trigger other actions, e.g. to generate interrupts.

19.2.5.5 Loop Back Mode

The USIC transmitter output signals can be connected to the corresponding receiver inputs of the same communication channel in loop back mode. Therefore, the input "G" of the input stages that are needed for the selected protocol have to be selected. In this

case, drivers for ASC, SSC, and IIS can be evaluated on-chip without the connections to port pins. Data transferred by the transmitter can be received by the receiver as if it would have been sent by another communication partner.

19.2.6 Input Stage Register

19.2.6.1 Input Control Registers

The input control registers contain the bits to define the characteristics of the input stages (input stage DX0 is controlled by register DX0CR, etc.).

DX0CR

Input Control Register 0 (20_H) **Reset Value: 0000_H**

DX1CR

Input Control Register 1 (24_H) **Reset Value: 0000_H**

DX2CR

Input Control Register 2 (28_H) **Reset Value: 0000_H**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DXS		0			CM	SF SEL	D POL	0	DS EN	DF EN	IN SW	0		DSEL	
rw		r			rw	rw	rw	r	rw	rw	rw	r		rw	

Field	Bits	Type	Description
DSEL	[2:0]	rw	Data Selection for Input Signal This bit field defines the input data signal for the corresponding input line for protocol pre-processor. The selection can be made from the input vector DXn[G:A]. 000 _B The data input DXnA is selected. 001 _B The data input DXnB is selected. 010 _B The data input DXnC is selected. 011 _B The data input DXnD is selected. 100 _B The data input DXnE is selected. 101 _B The data input DXnF is selected. 110 _B The data input DXnG is selected. 111 _B The data input is always 1.

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Field	Bits	Type	Description
INSW	4	rw	Input Switch This bit defines if the data shift unit input is derived from the input data path DXn or from the selected protocol pre-processors. 0_B The input of the data shift unit is controlled by the protocol pre-processor. 1_B The input of the data shift unit is connected to the selected data input line. This setting is used if the signals are directly derived from an input pin without treatment by the protocol pre-processor.
DFEN	5	rw	Digital Filter Enable This bit enables/disables the digital filter for signal DXnS. 0_B The input signal is not digitally filtered. 1_B The input signal is digitally filtered.
DSEN	6	rw	Data Synchronization Enable This bit selects if the asynchronous input signal or the synchronized (and optionally filtered) signal DXnS can be used as input for the data shift unit. 0_B The un-synchronized signal can be taken as input for the data shift unit. 1_B The synchronized signal can be taken as input for the data shift unit.
DPOL	8	rw	Data Polarity for DXn This bit defines the signal polarity of the input signal. 0_B The input signal is not inverted. 1_B The input signal is inverted.
SFSEL	9	rw	Sampling Frequency Selection This bit defines the sampling frequency of the digital filter for the synchronized signal DXnS. 0_B The sampling frequency is f_{SYS} . 1_B The sampling frequency is f_{FD} .

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Field	Bits	Type	Description
CM	[11:10]	rw	Combination Mode This bit field selects which edge of the synchronized (and optionally filtered) signal DXnS activates the trigger output DXnT of the input stage. 00 _B The trigger activation is disabled. 01 _B A rising edge activates DXnT. 10 _B A falling edge activates DXnT. 11 _B Both edges activate DXnT.
DXS	15	rh	Synchronized Data Value This bit indicates the value of the synchronized (and optionally filtered) input signal. 0 _B The current value of DXnS is 0. 1 _B The current value of DXnS is 1.
0	3, 7, [14:12]	r	Reserved Read as 0; should be written with 0.

19.2.7 Operating the Baud Rate Generator

The following blocks can be configured to operate the baud rate generator, see also [Figure 19-2](#) on [Page 19-8](#).

19.2.7.1 Fractional Divider

The fractional divider generates its output frequency f_{FD} by dividing the input frequency f_{SYS} either by an integer factor n or by multiplication by $n/1024$. It has two operating modes:

- Normal divider mode (FDRL.DM = 01_B):
In this mode, the output frequency f_{FD} is derived from the input clock f_{SYS} by an integer division by a value between 1 and 1024. The division is based on a counter FDRH.RESULT that is incremented by 1 with f_{SYS} . After reaching the value 3FF_H, the counter is loaded with FDRL.STEP and then continues counting. In order to achieve $f_{FD} = f_{SYS}$, the value of STEP has to be programmed with 3FF_H.
The output frequency in normal divider mode is defined by the equation:

$$f_{FD} = f_{SYS} \times \frac{1}{n} \quad \text{with } n = 1024 - \text{STEP} \quad (19.1)$$

- Fractional divider mode (FDRL.DM = 10_B):
In this mode, the output frequency f_{FD} is derived from the input clock f_{SYS} by a fractional multiplication by $n/1024$ for a value of n between 0 and 1023. In general, the fractional divider mode allows to program the average output clock frequency with a finer granularity than in normal divider mode. Please note that in fractional divider mode f_{FD} can have a maximum period jitter of one f_{SYS} period. This jitter is not accumulated over several cycles.
The frequency f_{FD} is generated by an addition of FDRL.STEP to FDRH.RESULT with f_{SYS} . The frequency f_{FD} is based on the overflow of the addition result over 3FF_H.
The output frequency in fractional divider mode is defined by the equation:

$$f_{FD} = f_{SYS} \times \frac{n}{1024} \quad \text{with } n = \text{STEP} \quad (19.2)$$

The output frequency f_{FD} of the fractional divider is selected for baud rate generation by BRGL.CLKSEL = 00_B.

19.2.7.2 External Frequency Input

The baud rate can be generated referring to an external frequency input (instead of to f_{SYS}) if in the selected protocol the input stage DX1 is not needed (DX1CTR.INSW = 0). In this case, an external frequency input signal at the DX1 input stage can be synchronized and sampled with the system frequency f_{SYS} . It can be optionally filtered

by the digital filter in the input stage. This feature allows data transfers with frequencies that can not be generated by the device itself, e.g. for specific audio frequencies.

If $BRGL.CLKSEL = 10_B$, the trigger signal $DX1T$ determines f_{DX1} . In this mode, either the rising edge, the falling edge, or both edges of the input signal can be used for baud rate generation, depending on the configuration of the $DX1T$ trigger event by bit field $DX1CTR.CM$. The signal $MCLK$ toggles with each trigger event of $DX1T$.

If $BRGL.CLKSEL = 11_B$, the rising edges of the input signal can be used for baud rate generation. The signal $MCLK$ represents the synchronized input signal $DX1S$.

Both, the high time and the low time of external input signal must each have a length of minimum 2 periods of f_{SYS} to be used for baud rate generation.

19.2.7.3 Protocol-Related Counter in Divider Mode

In divider mode, the protocol-related counter is used for an integer division delivering the output frequency f_{PDIV} . Additionally, two divider stages with a fixed division by 2 provide the output signals $MCLK$ and $SCLK$ with 50% duty cycle. If the fractional divider mode is used, the maximum fractional jitter of 1 period of f_{SYS} can also appear in these signals. The outputs frequencies of this divider is controlled by registers $BRGL$ and $BRGH$.

In order to define a frequency ratio between the master clock $MCLK$ and the shift clock $SCLK$, the divider stage for $MCLK$ is located in front of the divider by $PDIV+1$, whereas the divider stage for $SCLK$ is located at the output of this divider.

$$f_{MCLK} = \frac{f_{PIN}}{2} \quad (19.3)$$

$$f_{SCLK} = \frac{f_{PDIV}}{2} \quad (19.4)$$

In the case that the master clock is used as reference for external devices (e.g. for IIS components) and a fixed phase relation to $SCLK$ and other timing signals is required, it is recommended to use the $MCLK$ signal as input for the $PDIV$ divider. If the $MCLK$ signal is not used or a fixed phase relation is not necessary, the faster frequency f_{PIN} can be selected as input frequency.

$$\begin{aligned} f_{PDIV} &= f_{PIN} \times \frac{1}{PDIV + 1} & \text{if } PPPEN = 0 \\ f_{PDIV} &= f_{MCLK} \times \frac{1}{PDIV + 1} & \text{if } PPPEN = 1 \end{aligned} \quad (19.5)$$

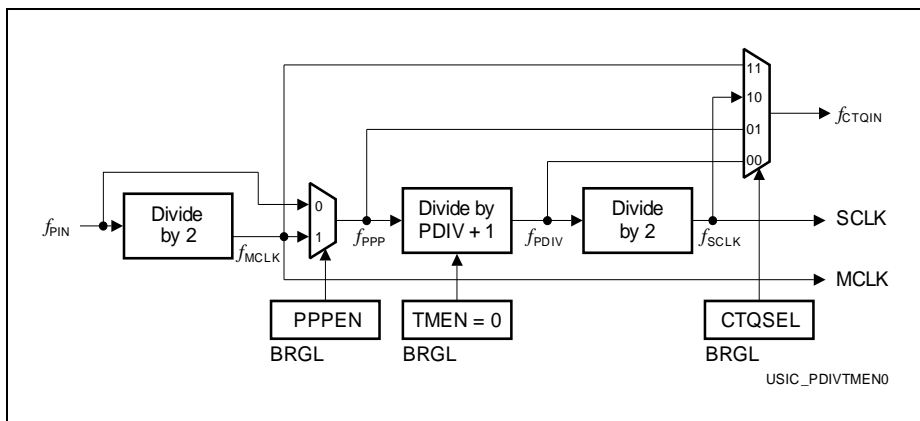


Figure 19-11 Protocol-Related Counter (Divider Mode)

19.2.7.4 Protocol-Related Counter in Capture Mode

In capture mode, the protocol-related counter stage can be used for time interval measurement (BRGL.TMEN = 1). In this case, the frequency division is disabled (reception and transmission are not possible) and the counter is working as capture timer by counting f_{PPP} periods. When reaching its maximum value, the counter stops counting. If an event is indicated by DX0T or DX1T, the actual counter value is captured into bit field BRGH.PDIV and the counter restarts from 0. Additionally, a transmit shift interrupt event is generated (bit PSRL.TSIF becomes set).

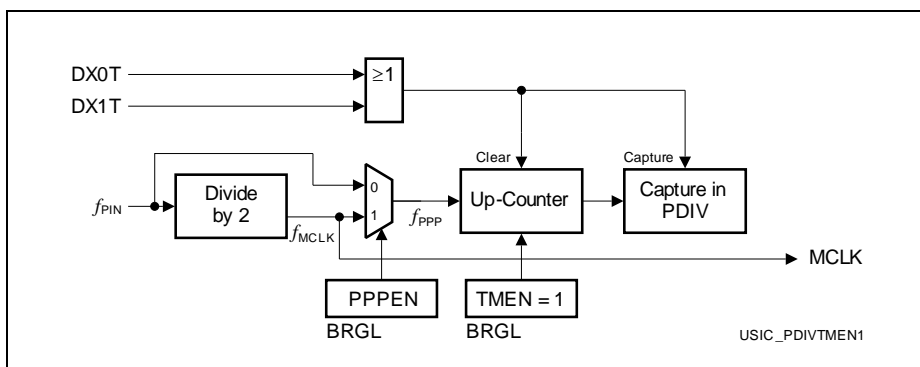


Figure 19-12 Protocol-Related Counter (Capture Mode)

The capture mode can be used to measure the baud rate in slave mode before starting data transfers, e.g. to measure the time between two edges of a data signal (by DX0T)

or of a shift clock signal (by DX1T). The conditions to activate the DXnT trigger signals can be configured in each input stage.

19.2.7.5 Time Quanta Counter

The time quanta counter CTQ associated to the protocol pre-processor allows to generate time intervals for protocol-specific purposes. The length of a time quantum t_q is given by the selected input frequency f_{CTQIN} and the programmed pre-divider value. The meaning of the time quanta depend on the selected protocol, please refer to the corresponding chapters for more protocol-specific information.

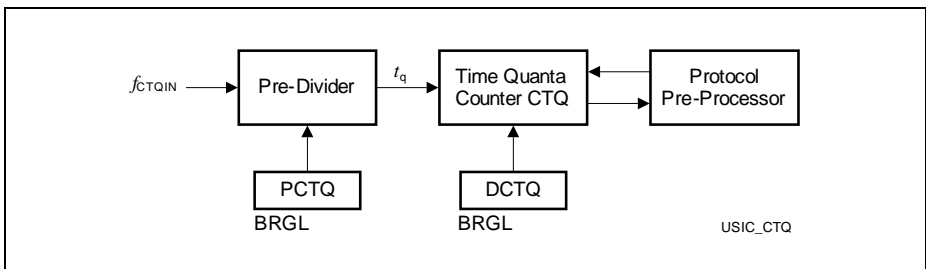


Figure 19-13 Time Quanta Counter

19.2.7.6 Shift Clock Output Configuration

The master clock output signal MCLKOUT available at the corresponding output pin can be configured in polarity. The MCLK signal can be generated for each protocol in order to provide a kind of higher frequency time base compared to the shift clock.

The configuration mechanism of the master clock output signal MCLKOUT ensures that no shortened pulses can occur. Each MCLK period consists of two phases, an active phase, followed by a passive phase. The polarity of the MCLKOUT signal during the active phase is defined by the inverted level of bit BRGH.MCLKCFG, evaluated at the start of the active phase. The polarity of the MCLKOUT signal during the passive phase is defined by bit BRGH.MCLKCFG, evaluated at the start of the passive phase. If bit BRGH.MCLKOUT is programmed with another value, the change is taken into account with the next change between the phases. This mechanism ensures that no shorter pulses than the length of a phase occur at the MCLKOUT output. In the example shown in [Figure 19-14](#), the value of BRGH.MCLKCFG is changed from 0 to 1 during the passive phase of MCLK period 2.

The generation of the MCLKOUT signal is enabled/disabled by the protocol pre-processor, based on bit PCRH.MCLK. After this bit has become set, signal MCLKOUT is generated with the next active phase of the MCLK period. If PCRH.MCLK = 0 (MCLKOUT generation disabled), the level for the passive phase is also applied for active phase.

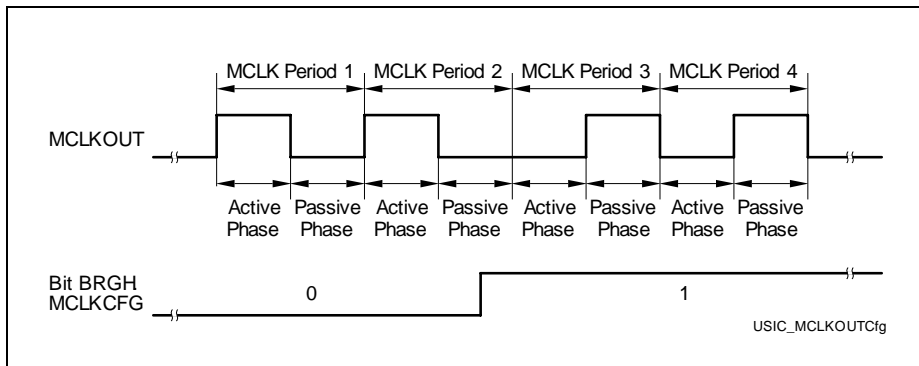


Figure 19-14 Master Clock Output Configuration

The shift clock output signal SCLKOUT available at the corresponding output pin can be configured in polarity and additionally, a delay of one period of f_{PDIV} (= half SCLK period) can be introduced. The delay allows to adapt the order of the shift clock edges to the application requirements. If the delay is used, it has to be taken into account for the calculation of the signal propagation times and loop delays.

The mechanism for the polarity control of the SCLKOUT signal is similar to the one for MCLKOUT, but based on bit field BRGH.SCLKCFG. The generation of the SCLKOUT signal is enabled/disabled by the protocol pre-processor. Depending on the selected protocol, the protocol pre-processor can control the generation of the SCLKOUT signal independently of the divider chain, e.g. for protocols without the need of a shift clock available at a pin, the SCLKOUT generation is disabled.

19.2.8 Baud Rate Generator Registers

19.2.8.1 Fractional Divider Registers

The fractional divider registers FDRL and FDRH allow the generation of the internal frequency f_{FD} , that is derived from the system clock f_{SYS} .

FDRL

Fractional Divider Register L

(04_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DM		0				STEP									
rw		r				rw									

Field	Bits	Type	Description
STEP	[9:0]	rw	Step Value In normal divider mode STEP contains the reload value for RESULT after RESULT has reached 3FF _H . In fractional divider mode STEP defines the value added to RESULT with each input clock cycle.
DM	[15:14]	rw	Divider Mode This bit fields defines the functionality of the fractional divider block. 00 _B The divider is switched off, $f_{FD} = 0$. 01 _B Normal divider mode selected. 10 _B Fractional divider mode selected. 11 _B The divider is switched off, $f_{FD} = 0$.
0	[13:10]	r	Reserved Read as 0; should be written with 0.

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FDRH

Fractional Divider Register H

(06_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		0				RESULT									
rw		r				rh									

Field	Bits	Type	Description
RESULT	[9:0]	rh	Result Value In normal divider mode this bit field is updated with f_{SYS} according to: $RESULT = RESULT + 1$ In fractional divider mode this bit field is updated with f_{SYS} according to: $RESULT = RESULT + STEP$ If bit field DM is written with 01 _B or 10 _B , RESULT is loaded with a start value of 3FF _H .
0	[15:14]	rw	Reserved for Future Use Must be written with 0 to allow correct fractional divider operation.
0	[13:10]	r	Reserved Read as 0; should be written with 0.

19.2.8.2 Baud Rate Generator Registers

The protocol-related divider for baud rate generation is controlled by the registers BRGL and BRGH.

BRGL

Baud Rate Generator Register L

(1C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	DCTQ					PCTQ	CTQSEL		0	PPP EN	TM EN	0	CLKSEL		
r	rw					rw	rw		r	rw	rw	r	rw		

Field	Bits	Type	Description
CLKSEL	[1:0]	rw	Clock Selection This bit field defines the input frequency f_{PIN} 00 _B The fractional divider frequency f_{FD} is selected. 01 _B Reserved, no action 10 _B The trigger signal DX1T defines f_{PIN} . Signal MCLK toggles with f_{PIN} . 11 _B Signal MCLK corresponds to the DX1S signal and the frequency f_{PIN} is derived from the rising edges of DX1S.
TMEN	3	rw	Timing Measurement Enable This bit defines the functionality of the protocol-related divider. 0 _B Divider mode: $f_{PDIV} = f_{PPP} / (PDIV + 1)$ Data transfers are possible and the trigger signals DX0T and DX1T are ignored. 1 _B Capture mode: The 10-bit counter is incremented by 1 with f_{PPP} and stops counting when reaching its maximum value. If one of the trigger signals DX0T or DX1T become active, the counter value is captured into bit field PDIV, the counter is cleared and a transmit shift event is generated. Data transfers are not possible.

Field	Bits	Type	Description
PPPEN	4	rw	Enable 2:1 Divider for f_{PPP} This bit defines the input frequency f_{PPP} . 0_B The 2:1 divider for f_{PPP} is disabled. $f_{PPP} = f_{PIN}$ 1_B The 2:1 divider for f_{PPP} is enabled. $f_{PPP} = f_{MCLK} = f_{PIN} / 2$.
CTQSEL	[7:6]	rw	Input Selection for CTQ This bit defines the length of a time quantum for the protocol pre-processor. 00_B $f_{CTQIN} = f_{PDIV}$ 01_B $f_{CTQIN} = f_{PPP}$ 10_B $f_{CTQIN} = f_{SCLK}$ 11_B $f_{CTQIN} = f_{MCLK}$
PCTQ	[9:8]	rw	Pre-Divider for Time Quanta Counter This bit field defines length of a time quantum t_q for the time quanta counter in the protocol pre-processor. $t_Q = (PCTQ + 1) / f_{CTQIN}$
DCTQ	[14:10]	rw	Denominator for Time Quanta Counter This bit field defines the number of time quanta t_q taken into account by the time quanta counter in the protocol pre-processor.
0	2, 5, 15	r	Reserved Read as 0; should be written with 0.

BRGH

Baud Rate Generator Register H

(1E_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SCLKCFG		M CLK CFG	0			PDIV									
rw		rw	r			rwh									

Field	Bits	Type	Description
PDIV	[9:0]	rwh	<p>Divider Mode: Divider Factor to Generate f_{PDIV} This bit field defines the ratio between the input frequency f_{PP} and the divider frequency f_{PDIV}.</p> <p>Capture Mode: Captured Time Interval The value of the counter is captured into this bit field if one of the trigger signals DX0T or DX1T are activated by the corresponding input stage.</p>
MCLKCFG	13	rw	<p>Master Clock Configuration This bit field defines the level of the passive phase of the MCLKOUT signal.</p> <p>0_B The passive level is 0. 1_B The passive level is 1.</p>
SCLKCFG	[15:14]	rw	<p>Shift Clock Output Configuration This bit field defines the level of the passive phase of the SCLKOUT signal and enables/disables a delay of half of a SCLK period.</p> <p>00_B The passive level is 0 and the delay is disabled. 01_B The passive level is 1 and the delay is disabled. 10_B The passive level is 0 and the delay is enabled. 11_B The passive level is 1 and the delay is enabled.</p>
0	[12:10]	r	<p>Reserved Read as 0; should be written with 0.</p>

19.2.9 Operating the Transmit Data Path

The transmit data path is based on a 16-bit wide transmit shift register TSR and a transmit buffer TBUF. The data transfer parameters like data word length, data frame length, or the shift direction are controlled commonly for transmission and reception by the shift control registers. Register TCSRL mainly controls the transmit data handling, whereas register TCSRH monitors the transmit status.

A change of the value of the data shift output signal DOUT only happens at the corresponding edge of the shift clock input signal. The level of the last data bit of a data word/frame is held constant at DOUT until the next data word begins with the next corresponding edge of the shift clock.

19.2.9.1 Transmit Buffering

The transmit shift register TSR can not be directly accessed by software, because it is automatically updated with the value stored in the transmit buffer TBUF if a currently transmitted data word is finished and new data is valid for transmission. Data words can be loaded directly into TBUF by writing to one of the transmit buffer input locations TBUFx (see [Page 19-52](#)) or, optionally, by a FIFO buffer stage (see [Page 19-79](#)).

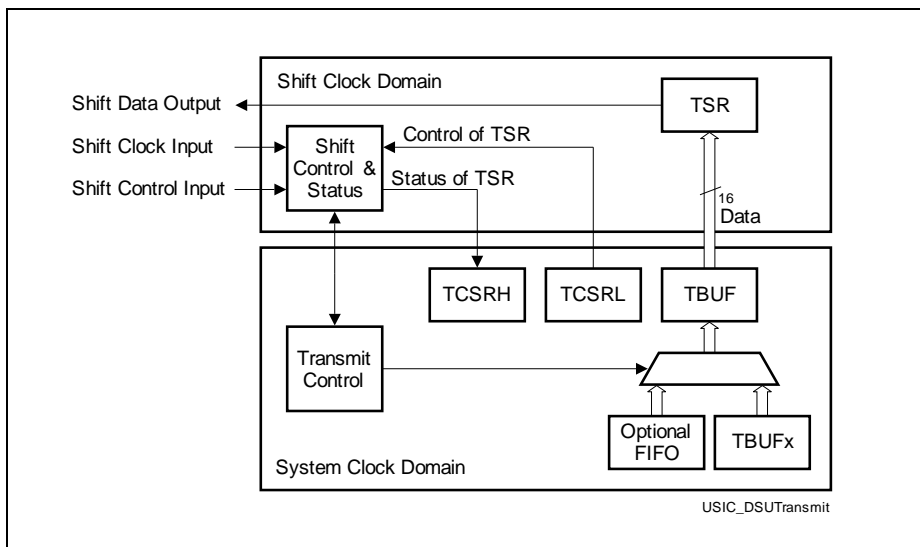


Figure 19-15 Transmit Data Path

19.2.9.2 Transmit Control Information

The transmit control information TCI can be used as additional control parameter for data transfers. The TCI is derived from the address x of the written TBUF x transmit buffer input location.

It can be used to dynamically change the data word length, the data frame length, or other protocol-specific functions (for more details about this topic, please refer to the corresponding protocol chapters). The way how the TCI is used in different applications can be programmed by bits WLEMD, FLEMD, SELMD, and WAMD in register TCSRL. Please note that not all possible settings lead to useful system behavior.

- **Word length control:**
If TCSRL.WLEMD = 1, bit field SCTRH.WLE is updated with TCI[3:0] if a transmit buffer input location TBUF x is written. This function can be used in all protocols to dynamically change the data word length between 1 and 16 data bits per data word. Additionally, bit TCSRL.EOF is updated with TCI[4]. This function can be used in SSC master mode to control the slave select generation to finish data frames. It is recommended to program TCSRL.FLEMD = TCSRL.SELMD = 0.
- **Frame length control:**
If TCSRL.FLEMD = 1, bit field SCTRH.FLE[4:0] is updated with TCI[4:0] and SCTRH.FLE[5] becomes 0 if a transmit buffer input location TBUF x is written. This function can be used in all protocols to dynamically change the data frame length between 1 and 32 data bits per data frame. It is recommended to program TCSRL.SELMD = TCSRL.WLEMD = TCSRL.WAMD = 0.
- **Select output control:**
If TCSRL.SELMD = 1, bit field PCR.CTR[20:16] is updated with TCI[4:0] and PCR.CTR[23:21] becomes 0 if a transmit buffer input location TBUF x is written. This function can be used in SSC master mode to define the targeted slave device(s). It is recommended to program TCSRL.WLEMD = TCSRL.FLEMD = TCSRL.WAMD = 0.
- **Word address control:**
If TCSRL.WAMD = 1, bit TCSRL.WA is updated with TCI[4] if a transmit buffer input location TBUF x is written. This function can be used in IIS mode to define if the data word is transmitted on the right or the left channel. It is recommended to program TCSRL.SELMD = TCSRL.FLEMD = 0.

19.2.9.3 Transmit Data Validation

The data word in the transmit buffer TBUF can be tagged valid or invalid for transmission by bit TCSRL.TDV (transmit data valid). A combination of data flow related and event related criteria define whether the data word is considered valid for transmission. A data validation logic checks the start conditions for each data word. Depending on the result of the check, the transmit shift register is loaded with different values, according to the following rules:

- If a USIC channel is the communication master (it defines the start of each data word transfer), a data word transfer can only be started with valid data in the transmit buffer TBUF. In this case, the transmit shift register is loaded with the content of TBUF, that is not changed due to this action.
- If a USIC channel is a communication slave (it can not define the start itself, but has to react), a data word transfer requested by the communication master has to be started independently of the status of the data word in TBUF. If a data word transfer is requested and started by the master, the transmit shift register is loaded at the first corresponding shift clock edge either with the data word in TBUF (if it is valid for transmission) or with the level defined by bit SCTRL.PDL (if the content of TBUF has not been valid at the transmission start). In both cases, the content of TBUF is not changed.

The control and status bits for the data validation are located in registers TCSRL or TCSRH. The data validation is based on the logic blocks shown in **Figure 19-16**.

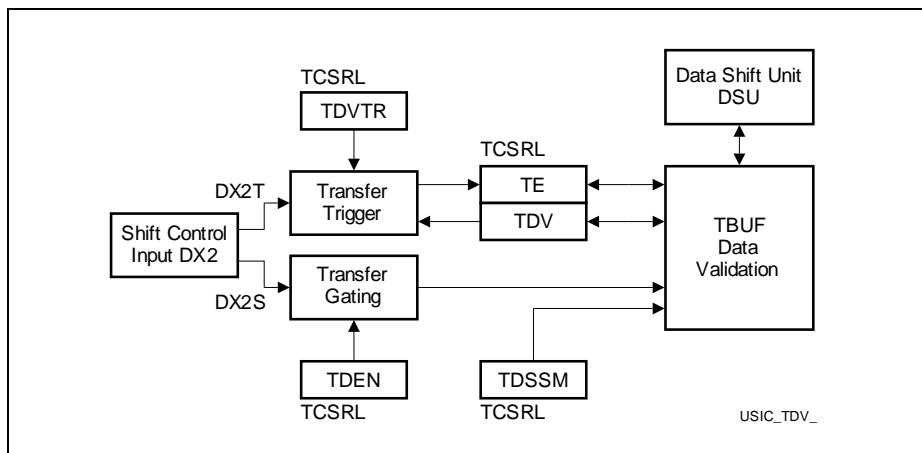


Figure 19-16 Transmit Data Validation

- A transfer gating logic enables or disables the data word transfer from TBUF under software or under hardware control. If the input stage DX2 is not needed for data

shifting, signal DX2S can be used for gating purposes. The transfer gating logic is controlled by bit field TCSRL.TDEN.

- A transfer trigger logic supports data word transfers related to events, e.g. timer based or related to an input pin. If the input stage DX2 is not needed for data shifting, signal DX2T can be used for trigger purposes. The transfer trigger logic is controlled by bit TCSRL.TDVTR and the occurrence of a trigger event is indicated by bit TCSRH.TE.
- A data validation logic combining the inputs from the gating logic, the triggering logic and DSU signals. A transmission of the data word located in TBUF can only be started if the gating enables the start, bit TCSRL.TDV = 1, and bit TCSRH.TE = 1. The content of the transmit buffer TBUF should not be overwritten with new data while it is valid for transmission and a new transmission can start. If the content of TBUF has to be changed, it is recommended to clear bit TCSRL.TDV by writing FMRL.MTDV = 10_B before updating the data. Bit TCSRL.TDV becomes automatically set when TBUF is updated with new data. Another possibility are the interrupts TBI (for ASC and IIC) or RSI (for SSC and IIS) indicating that a transmission has started. While a transmission is in progress, TBUF can be loaded with new data. In this case the user has to take care that an update of the TBUF content takes place before a new transmission starts.

With this structure, the following data transfer functionality can be achieved:

- If bit TCSRL.TDSSM = 0, the content of the transmit buffer TBUF is always considered as valid for transmission. The transfer trigger mechanism can be used to start the transfer of the same data word based on the selected event (e.g. on a timer base or an edge at a pin) to realize a kind of life-sign mechanism. Furthermore, in slave mode, it is ensured that always a correct data word is transmitted instead of the passive data level.
- Bit TCSRL.TDSSM = 1 has to be programmed to allow word-by-word data transmission with a kind of single-shot mechanism. After each transmission start, a new data word has to be loaded into the transmit buffer TBUF, either by software write actions to one of the transmit buffer input locations TBUFx or by an optional data buffer (e.g. FIFO buffer). To avoid that data words are sent out several times or to allow data handling with an additional data buffer (e.g. FIFO), bit TCSRL.TDSSM has to be 1.
- Bit TCSRL.TDV becoming automatically set when a new data word is loaded into the transmit buffer TBUF, a transmission start can be requested by a write action of the data to be transmitted to at least the low byte of one of the transmit buffer input locations TBUFx. The additional information TCI can be used to control the data word length or other parameters independently for each data word by a single write access.
- Bit field FMRL.MTDV allows software driven modification (set or clear) of bit TCSRL.TDV. Together with the gating control bit field TCSRL.TDEN, the user can set up the transmit data word without starting the transmission. A possible program

sequence could be: clear TCSRL.TDEN = 00_B, write data to TBUFx, clear TCSRL.TDV by writing FMRL.MTDV = 10_B, re-enable the gating with TCSRL.TDEN = 01_B and then set TCSRL.TDV under software control by writing FMRL.MTDV = 01_B.

19.2.10 Operating the Receive Data Path

The receive data path is based on two 16-bit wide receive shift registers RSR0 and RSR1 and a receive buffer for each of them (RBUF0 and RBUF1). The data transfer parameters like data word length, data frame length, or the shift direction are controlled commonly for transmission and reception by the shift control registers.

Register RBUF01SRL monitors the status of RBUF0 and register RBUF01SRH of RBUF1.

19.2.10.1 Receive Buffering

The receive shift registers cannot be directly accessed by software, but their contents are automatically loaded into the receive buffer registers RBUF0 (or RBUF1 respectively) if a complete data word has been received or the frame is finished. The received data words in RBUF0 or RBUF1 can be read out in the correct order directly from register RBUF or, optionally, from a FIFO buffer stage (see [Page 19-79](#)).

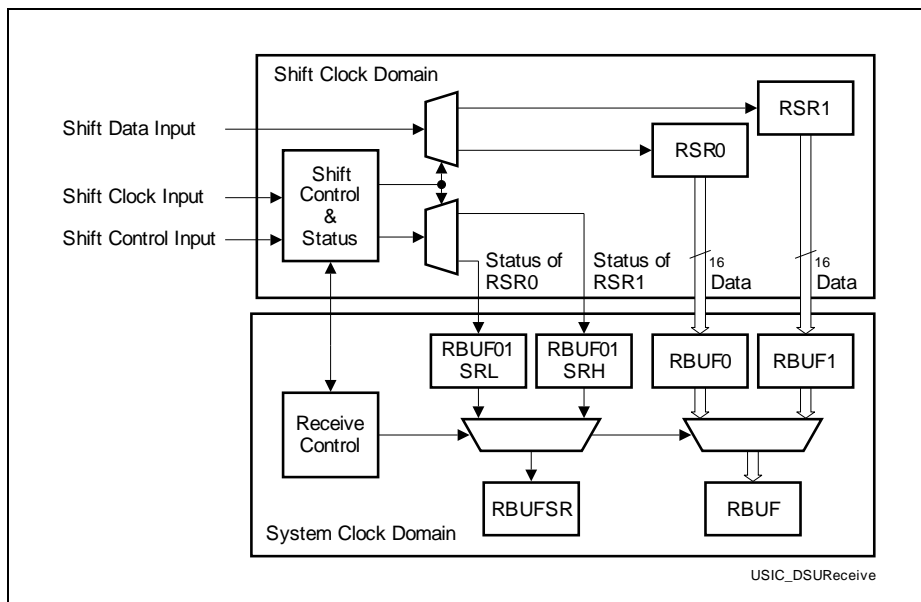


Figure 19-17 Receive Data Path

19.2.10.2 Baud Rate Constraints

The following baud rate constraints have to be respected to ensure correct data reception and buffering. The user has to take care about these restrictions when selecting the baud rate and the data word length with respect to the module clock frequency f_{SYS} .

- A received data word in a receiver shift register RSRx must be held constant for at least 4 periods of f_{SYS} in order to ensure correct loading of the related receiver buffer register RBUFx.
- The shift control signal has to be constant inactive for at least 5 periods of f_{SYS} between two consecutive frames in order to correctly detect the end of a frame.
- The shift control signal has to be constant active for at least 1 period of f_{SYS} in order to correctly detect a frame (shortest frame).
- A minimum setup and hold time of the shift control signal with respect to the shift clock signal has to be ensured.

19.2.11 Transfer Control and Status Registers

19.2.11.1 Shift Control Registers

The data shift unit is controlled by the registers defined in this section. The values in these registers are applied for data transmission and reception.

Please note that the shift control settings SDIR, WLE, and FLE are shared between transmitter and receiver. They are internally “frozen” for a each data word transfer in the transmitter with the first transmit shift clock edge and with the first receive shift clock edge in the receiver. The software has to take care that updates of these bit fields by software are done coherently (e.g. refer to the receiver start event indication PSR.RSIF).

SCTRL

Shift Control Register L

(30_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
0						TRM		DOCFG		0				PDL		S DIR
r						rw		rw		r				rw		rw

Field	Bits	Type	Description
SDIR	0	rw	Shift Direction This bit defines the shift direction of the data words for transmission and reception. 0 _B Shift LSB first. The first data bit of a data word is located at bit position 0. 1 _B Shift MSB first. The first data bit of a data word is located at the bit position given by bit field SCTR.H.WLE.
PDL	1	rw	Passive Data Level This bit defines the output level at the shift data output signal when no data is available for transmission. The PDL level is output with the first relevant transmit shift clock edge of a data word. 0 _B The passive data level is 0. 1 _B The passive data level is 1.
DOCFG	[7:6]	rw	Data Output Configuration This bit defines the relation between the internal shift data value and the data output signal DOUT. X0 _B DOUT = shift data value X1 _B DOUT = inverted shift data value

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Field	Bits	Type	Description
TRM	[9:8]	rw	Transmission Mode This bit field describes how the shift control signal is interpreted by the DSU. Data transfers are only possible while the shift control signal is active. 00 _B The shift control signal is considered as inactive and data frame transfers are not possible. 01 _B The shift control signal is considered active if it is at 1-level. This is the setting to be programmed to allow data transfers. 10 _B The shift control signal is considered active if it is at 0-level. It is recommended to avoid this setting and to use the inversion in the DX2 stage in case of a low-active signal. 11 _B The shift control signal is considered active without referring to the actual signal level. Data frame transfer is possible after each edge of the signal.
0	[5:2], [15:10]	r	Reserved Read as 0; should be written with 0.

SCTRH

Shift Control Register H

(32_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0				WLE				0		FLE					
r				rwh				r		rwh					

Field	Bits	Type	Description
FLE	[5:0]	rwh	Frame Length This bit field defines how many bits are transferred within a data frame. A data frame can consist of several concatenated data words. If TCSRL.FLEMD = 1, the value can be updated automatically by the data handler.
WLE	[11:8]	rwh	Word Length This bit field defines the data word length (amount of bits that are transferred in each data word) for reception and transmission. The data word is always right-aligned in the data buffer at the bit positions [WLE down to 0]. If TCSRL.WLEMD = 1, the value can be updated automatically by the data handler. 0 _H The data word contains 1 data bit located at bit position 0. 1 _H The data word contains 2 data bits located at bit positions [1:0]. ... E _H The data word contains 15 data bits located at bit positions [14:0]. F _H The data word contains 16 data bits located at bit positions [15:0].
0	[7:6], [15:12]	r	Reserved Read as 0; should be written with 0.

19.2.11.2 Transmission Control and Status Registers

The data transmission is controlled by register TCSRL.

TCSRL

Transmit Control/Status Register L (3C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	WA	TD VTR	TDEN	0	TD SSM	TDV	EOF	SOE	0	WA MD	FLE MD	SEL MD	WLE MD		
r	rwh	rw	rw	r	rw	rh	rwh	rwh	r	rw	rw	rw	rw		

Field	Bits	Type	Description
WLEMD	0	rw	WLE Mode This bit enables the data handler to automatically update the bit field SCTRH.WLE by the transmit control information TCI[3:0] and bit TCSR.EOF by TCI[4] (see Page 19-52). If enabled, an automatic update takes place when new data is loaded to register TBUF, either by writing to one of the transmit buffer input locations TBUFx or by an optional data buffer. 0 _B The automatic update of SCTRH.WLE and TCSR.EOF is disabled. 1 _B The automatic update of SCTRH.WLE and TCSR.EOF is enabled.
SELMD	1	rw	Select Mode This bit can be used mainly for the SSC protocol. It enables the data handler to automatically update bit field PCRH.CTR[20:16] by the transmit control information TCI[4:0] and clear bit field PCRH.CTR[23:21] (see Page 19-52). If enabled, an automatic update takes place when new data is loaded to register TBUF, either by writing to one of the transmit buffer input locations TBUFx or by an optional data buffer. 0 _B The automatic update of PCRH.CTR[23:16] is disabled. 1 _B The automatic update of PCRH.CTR[23:16] is enabled.

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Field	Bits	Type	Description
FLEMD	2	rw	FLE Mode This bit enables the data handler to automatically update bits SCTR.H.FLE[4:0] by the transmit control information TCI[4:0] and to clear bit SCTR.H.FLE[5] (see Page 19-52). If enabled, an automatic update takes place when new data is loaded to register TBUF, either by writing to one of the transmit buffer input locations TBUFx or by an optional data buffer. 0 _B The automatic update of FLE is disabled. 1 _B The automatic update of FLE is enabled.
WAMD	3	rw	WA Mode This bit can be used mainly for the IIS protocol. It enables the data handler to automatically update bit TCSRL.WA by the transmit control information TCI[4] (see Page 19-52). If enabled, an automatic update takes place when new data is loaded to register TBUF, either by writing to one of the transmit buffer input locations TBUFx or by an optional data buffer. 0 _B The automatic update of bit WA is disabled. 1 _B The automatic update of bit WA is enabled.
SOF	5	rw	Start Of Frame This bit is only taken into account for the SSC protocol, otherwise it is ignored. It indicates that the data word in TBUF is considered as the first word of a new SSC frame if it is valid for transmission (TCSRL.TDV = 1). This bit becomes cleared when the TBUF data word is transferred to the transmit shift register. 0 _B The data word in TBUF is not considered as first word of a frame. 1 _B The data word in TBUF is considered as first word of a frame. A currently running frame is finished and MSLS becomes deactivated (respecting the programmed delays).

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Field	Bits	Type	Description
EOF	6	rwh	<p>End Of Frame</p> <p>This bit is only taken into account for the SSC protocol, otherwise it is ignored. It can be modified automatically by the data handler if bit WLEMD = 1. It indicates that the data word in TBUF is considered as the last word of an SSC frame. If it is the last word, the MSLS signal becomes inactive after the transfer, respecting the programmed delays. This bit becomes cleared when the TBUF data word is transferred to the transmit shift register.</p> <p>0_B The data word in TBUF is not considered as last word of an SSC frame.</p> <p>1_B The data word in TBUF is considered as last word of an SSC frame.</p>
TDV	7	rh	<p>Transmit Data Valid</p> <p>This bit indicates that the data word in the transmit buffer TBUF can be considered as valid for transmission. The TBUF data word can only be sent out if TDV = 1. It is automatically set when data is moved to TBUF (by writing to one of the transmit buffer input locations TBUFx, or optionally, by the bypass or FIFO mechanism).</p> <p>0_B The data word in TBUF is not valid for transmission.</p> <p>1_B The data word in TBUF is valid for transmission and a transmission start is possible. New data should not be written to a TBUFx input location while TDV = 1.</p>

Field	Bits	Type	Description
TDSSM	8	rw	<p>TBUF Data Single Shot Mode</p> <p>This bit defines if the data word TBUF data is considered as permanently valid or if the data should only be transferred once.</p> <p>0_B The data word in TBUF is not considered as invalid after it has been loaded into the transmit shift register. The loading of the TBUF data into the shift register does not clear TDV.</p> <p>1_B The data word in TBUF is considered as invalid after it has been loaded into the shift register. In ASC and IIC mode, TDV is cleared with the TBI event, whereas in SSC and IIS mode, it is cleared with the RSI event.</p> <p>TDSSM = 1 has to be programmed if an optional data buffer is used.</p>
TDEN	[11:10]	rw	<p>TBUF Data Enable</p> <p>This bit field controls the gating of the transmission start of the data word in the transmit buffer TBUF.</p> <p>00_B A transmission start of the data word in TBUF is disabled. If a transmission is started, the passive data level is sent out.</p> <p>01_B A transmission of the data word in TBUF can be started if TDV = 1.</p> <p>10_B A transmission of the data word in TBUF can be started if TDV = 1 while DX2S = 0.</p> <p>11_B A transmission of the data word in TBUF can be started if TDV = 1 while DX2S = 1.</p>
TDVTR	12	rw	<p>TBUF Data Valid Trigger</p> <p>This bit enables the transfer trigger unit to set bit TCSRH.TE if the trigger signal DX2T becomes active for event driven transfer starts, e.g. timer-based or depending on an event at an input pin. Bit TDVTR has to be 0 for protocols where the input stage DX2 is used for data shifting.</p> <p>0_B Bit TCSRH.TE is permanently set.</p> <p>1_B Bit TCSRH.TE is set if DX2T becomes active while TDV = 1.</p>

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Field	Bits	Type	Description
WA	13	rwh	<p>Word Address</p> <p>This bit is only taken into account for the IIS protocol, otherwise it is ignored. It can be modified automatically by the data handler if bit WAMD = 1. Bit WA defines for which channel the data stored in TBUF will be transmitted.</p> <p>0_B The data word in TBUF will be transmitted after a falling edge of WA has been detected (referring to PSR.WA).</p> <p>1_B The data word in TBUF will be transmitted after a rising edge of WA has been detected (referring to PSR.WA).</p>
0	4, 9, [15:14]	r	<p>Reserved</p> <p>Read as 0; should be written with 0.</p>

The data transmission status is monitored by register TCSRH.

TCSRH

Transmit Control/Status Register H (3E_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		TE		TVC	TV	0		T SOF	0						
r		rh		rh	rh	r		rh	r						

Field	Bits	Type	Description
TSOF	8	rh	Transmitted Start Of Frame This bit indicates if the latest start of a data word transmission has taken place for the first data word of a new data frame. This bit is updated with the transmission start of each data word. 0 _B The latest data word transmission has not been started for the first word of a data frame. 1 _B The latest data word transmission has been started for the first word of a data frame.
TV	10	rh	Transmission Valid This bit represents the transmit buffer underflow and indicates if the latest start of a data word transmission has taken place with a valid data word from the transmit buffer TBUF. This bit is updated with the transmission start of each data word. 0 _B The latest start of a data word transmission has taken place while no valid data was available. As a result, the transmission of a data words with passive level (SCTRL.PDL) has been started. 1 _B The latest start of a data word transmission has taken place with valid data from TBUF.
TVC	11	rh	Transmission Valid Cumulated This bit cumulates the transmit buffer underflow indication TV. It is cleared automatically together with bit TV and has to be set by writing FMRL.ATVC = 1. 0 _B Since TVC has been set, at least one data buffer underflow condition has occurred. 1 _B Since TVC has been set, no data buffer underflow condition has occurred.

Field	Bits	Type	Description
TE	12	rh	<p>Trigger Event</p> <p>If the transfer trigger mechanism is enabled, this bit indicates that a trigger event has been detected ($DX2T = 1$) while $TCSRL.TDV = 1$. If the event trigger mechanism is disabled, the bit TE is permanently set. It is cleared by writing $FMRL.MTDV = 10_B$ or when the data word located in TBUF is loaded into the shift register.</p> <p>0_B The trigger event has not yet been detected. A transmission of the data word in TBUF can not be started.</p> <p>1_B The trigger event has been detected (or the trigger mechanism is switched off) and a transmission of the data word in TBUF can not be started.</p>
0	[7:0], 9, [15:13]	r	<p>Reserved</p> <p>Read as 0; should be written with 0.</p>

19.2.11.3 Flag Modification Registers

The flag modification registers FMRL, FMRH allow the modification of control and status flags related to data handling by using only write accesses. Read accesses to FMRL, FMRH always deliver 0 at all bit positions.

Additionally, the service request outputs of this USIC channel can be activated by software (the activation is triggered by the write access and is deactivated automatically).

FMRL

Flag Modification Register L

(38_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
C RDV 1	C RDV 0					0					A TVC	0		MTDV	
w	w					r					w	r		w	

Field	Bits	Type	Description
MTDV	[1:0]	w	Modify Transmit Data Valid Writing to this bit field can modify bits TCSR.L.TDV and TCSR.H.TE to control the start of a data word transmission by software. 00 _B No action. 01 _B Bit TDV is set, TE is unchanged. 10 _B Bits TDV and TE are cleared. 11 _B Reserved
ATVC	4	w	Activate Bit TVC Writing to this bit can set bit TCSR.H.TVC to start a new cumulation of the transmit buffer underflow condition. 0 _B No action. 1 _B Bit TCSR.H.TVC is set.
CRDV0	14	w	Clear Bits RDV for RBUF0 Writing 1 to this bit clears bits RBUF0.SRL.RDV00 and RBUF0.SRH.RDV10 to declare the received data in RBUF0 as no longer valid (to emulate a read action). 0 _B No action. 1 _B Bits RBUF0.SRL.RDV00 and RBUF0.SRH.RDV10 are cleared.

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Field	Bits	Type	Description
CRDV1	15	w	Clear Bit RDV for RBUF1 Writing 1 to this bit clears bits RBUF01SRL.RDV01 and RBUF01SRH.RDV11 to declare the received data in RBUF1 as no longer valid (to emulate a read action). 0 _B No action. 1 _B Bits RBUF01SRL.RDV01 and RBUF01SRH.RDV11 are cleared.
0	[3:2], [13:5]	r	Reserved Read as 0; should be written with 0.

FMRH

Flag Modification Register H

(3A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0												SI O3	SI O2	SI O1	SI O0
r												w	w	w	w

Field	Bits	Type	Description
SIO0, SIO1, SIO2, SIO3	0, 1, 2, 3	w	Set Interrupt Output SRx Writing a 1 to this bit field activates the service request output SRx of this USIC channel. It has no impact on service request outputs of other USIC channels. 0 _B No action. 1 _B The service request output SRx is activated.
0	[15:4]	r	Reserved Read as 0; should be written with 0.

19.2.12 Data Buffer Registers

19.2.12.1 Transmit Buffer Locations

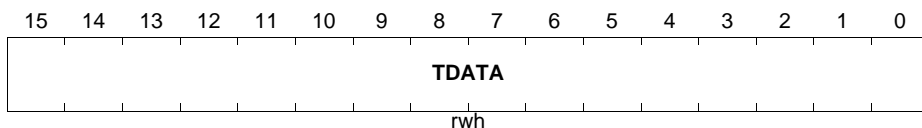
The 32 independent data input locations TBUF00 to TBUF31 are address locations that can be used as data entry locations for the transmit buffer. Data written to one of these locations will appear in a common register TBUF. Additionally, the 5 bit coding of the number [31:0] of the addressed data input location represents the transmit control information TCI (please refer to the protocol sections for more details).

The internal transmit buffer register TBUF contains the data that will be loaded to the transmit shift register for the next transmission of a data word. It can be read out at all TBUF00 to TBUF31 addresses.

TBUF_x (x = 00-31)

Transmit Buffer Input Location x $(80_H + x \cdot 4)$

Reset Value: 0000_H



Field	Bits	Type	Description
TDATA	[15:0]	rwh	Transmit Data This bit field contains the data to be transmitted (read view). A data write action to at least the low byte of TDATA sets TCSRL.TDV.

19.2.12.2 Receive Buffer Registers RBUF0, RBUF1

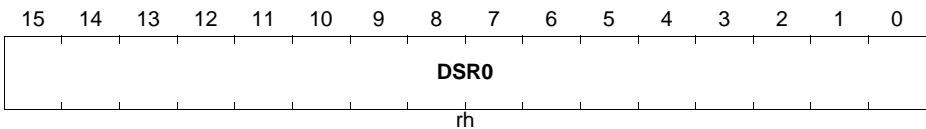
The receive buffer register RBUF0 contains the data received from RSR0. A read action does not change the status of the receive data from “not yet read = valid” to “already read = not valid”.

RBUF0

Receiver Buffer Register 0

(50_H)

Reset Value: 0000_H



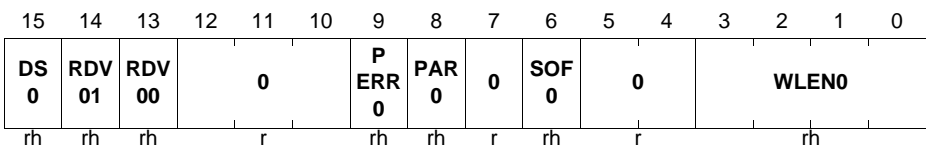
Field	Bits	Type	Description
DSR0	[15:0]	rh	Data of Shift Register 0

The receive buffer status register RBUF01SRL provides the status of the data in receive buffer RBUF0.

RBUF01SRL

Receiver Buffer 01 Status Register L (60_H)

Reset Value: 0000_H



Field	Bits	Type	Description
WLEN0	[3:0]	rh	Received Data Word Length in RBUF0 This bit field indicates how many bits have been received within the last data word stored in RBUF0. This number indicates how many data bits have to be considered as receive data, whereas the other bits in RBUF0 have been cleared automatically. The received bits are always right-aligned. 0 _H One bit has been received. ... F _H Sixteen bits have been received.

Field	Bits	Type	Description
SOF0	6	rh	Start of Frame in RBUF0 This bit indicates whether the data word in RBUF0 has been the first data word of a data frame. 0_B The data in RBUF0 has not been the first data word of a data frame. 1_B The data in RBUF0 has been the first data word of a data frame.
PAR0	8	rh	Protocol-Related Argument in RBUF0 This bit indicates the value of the protocol-related argument. This value is elaborated depending on the selected protocol and adds additional information to the data word in RBUF0. The meaning of this bit is described in the corresponding protocol chapter.
PERR0	9	rh	Protocol-related Error in RBUF0 This bit indicates if the value of the protocol-related argument meets an expected value. This value is elaborated depending on the selected protocol and adds additional information to the data word in RBUF0. The meaning of this bit is described in the corresponding protocol chapter. 0_B The received protocol-related argument PAR matches the expected value. The reception of the data word sets bit PSR.RIF and can generate a receive interrupt. 1_B The received protocol-related argument PAR does not match the expected value. The reception of the data word sets bit PSR.AIF and can generate an alternative receive interrupt.

Field	Bits	Type	Description
RDV00	13	rh	<p>Receive Data Valid in RBUF0</p> <p>This bit indicates the status of the data content of register RBUF0. This bit is identical to bit RBUF01SRH.RDV10 and allows consisting reading of information for the receive buffer registers. It is set when a new data word is stored in RBUF0 and automatically cleared if it is read out via RBUF.</p> <p>0_B Register RBUF0 does not contain data that has not yet been read out.</p> <p>1_B Register RBUF0 contains data that has not yet been read out.</p>
RDV01	14	rh	<p>Receive Data Valid in RBUF1</p> <p>This bit indicates the status of the data content of register RBUF1. This bit is identical to bit RBUF01SRH.RDV11 and allows consisting reading of information for the receive buffer registers. It is set when a new data word is stored in RBUF1 and automatically cleared if it is read out via RBUF.</p> <p>0_B Register RBUF1 does not contain data that has not yet been read out.</p> <p>1_B Register RBUF1 contains data that has not yet been read out.</p>
DS0	15	rh	<p>Data Source</p> <p>This bit indicates which receive buffer register (RBUF0 or RBUF1) is currently visible in registers RBUF(D) and in RBUFSR for the associated status information. It indicates which buffer contains the oldest data (the data that has been received first). This bit is identical to bit RBUF01SRH.DS1 and allows consisting reading of information for the receive buffer registers.</p> <p>0_B The register RBUF contains the data of RBUF0 (same for associated status information).</p> <p>1_B The register RBUF contains the data of RBUF1 (same for associated status information).</p>
0	[5:4], 7, [12:10]	r	<p>Reserved</p> <p>Read as 0; should be written with 0.</p>

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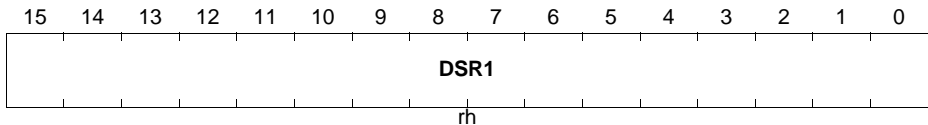
The receive buffer register RBUF1 contains the data received from RSR1. A read action does not change the status of the receive data from "not yet read = valid" to "already read = not valid".

RBUF1

Receiver Buffer Register 1

(54_H)

Reset Value: 0000_H



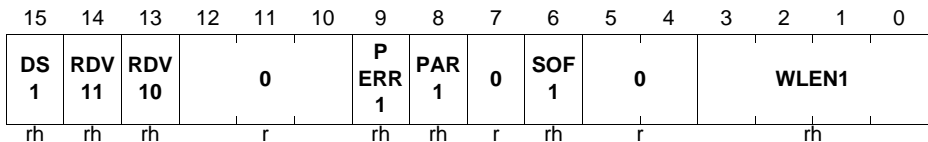
Field	Bits	Type	Description
DSR1	[15:0]	rh	Data of Shift Register 1

The receive buffer status register RBUF01SRH provides the status of the data in receive buffer RBUF1.

RBUF01SRH

Receiver Buffer 01 Status Register H (62_H)

Reset Value: 0000_H



Field	Bits	Type	Description
WLEN1	[3:0]	rh	Received Data Word Length in RBUF1 This bit field indicates how many bits have been received within the last data word stored in RBUF1. This number indicates how many data bits have to be considered as receive data, whereas the other bits in RBUF1 have been cleared automatically. The received bits are always right-aligned. 0 _H One bit has been received. ... F _H Sixteen bits have been received.

Field	Bits	Type	Description
SOF1	6	rh	Start of Frame in RBUF1 This bit indicates whether the data word in RBUF1 has been the first data word of a data frame. 0 _B The data in RBUF1 has not been the first data word of a data frame. 1 _B The data in RBUF1 has been the first data word of a data frame.
PAR1	8	rh	Protocol-Related Argument in RBUF1 This bit indicates the value of the protocol-related argument. This value is elaborated depending on the selected protocol and adds additional information to the data word in RBUF1. The meaning of this bit is described in the corresponding protocol chapter.
PERR1	9	rh	Protocol-related Error in RBUF1 This bit indicates if the value of the protocol-related argument meets an expected value. This value is elaborated depending on the selected protocol and adds additional information to the data word in RBUF1. The meaning of this bit is described in the corresponding protocol chapter. 0 _B The received protocol-related argument PAR matches the expected value. The reception of the data word sets bit PSR.RIF and can generate a receive interrupt. 1 _B The received protocol-related argument PAR does not match the expected value. The reception of the data word sets bit PSR.AIF and can generate an alternative receive interrupt.
RDV10	13	rh	Receive Data Valid in RBUF0 This bit indicates the status of the data content of register RBUF0. This bit is identical to bit RBUF01SRL.RDV00 and allows consistent reading of information for the receive buffer registers. 0 _B Register RBUF0 does not contain data that has not yet been read out. 1 _B Register RBUF0 contains data that has not yet been read out.

Field	Bits	Type	Description
RDV11	14	rh	Receive Data Valid in RBUF1 This bit indicates the status of the data content of register RBUF1. This bit is identical to bit RBUF01SRL.RDV01 and allows consisting reading of information for the receive buffer registers. 0 _B Register RBUF1 does not contain data that has not yet been read out. 1 _B Register RBUF1 contains data that has not yet been read out.
DS1	15	rh	Data Source This bit indicates which receive buffer register (RBUF0 or RBUF1) is currently visible in registers RBUF(D) and in RBUFSR for the associated status information. It indicates which buffer contains the oldest data (the data that has been received first). This bit is identical to bit RBUF01SRL.DS0 and allows consisting reading of information for the receive buffer registers. 0 _B The register RBUF contains the data of RBUF0 (same for associated status information). 1 _B The register RBUF contains the data of RBUF1 (same for associated status information).
0	[5:4], 7, [12:10]	r	Reserved Read as 0; should be written with 0.

19.2.12.3 Receive Buffer Registers RBUF, RBUFD, RBUFSR

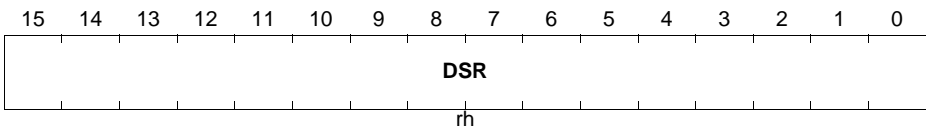
The receiver buffer register RBUF shows the content of the either RBUF0 or RBUF1, depending on the order of reception. Always the oldest data (the data word that has been received first) from both receive buffers can be read from RBUF. It is recommended to read out the received data from RBUF instead of RBUF0/1. With a read access of at least the low byte of RBUF, the status of the receive data is automatically changed from “not yet read = valid” to “already read = not valid”, the content of RBUF becomes updated, and the next received data word becomes visible in RBUF.

RBUF

Receiver Buffer Register

(5C_H)

Reset Value: 0000_H



Field	Bits	Type	Description
DSR	[15:0]	rh	Received Data This bit field monitors the content of either RBUF0 or RBUF1, depending on the reception sequence.

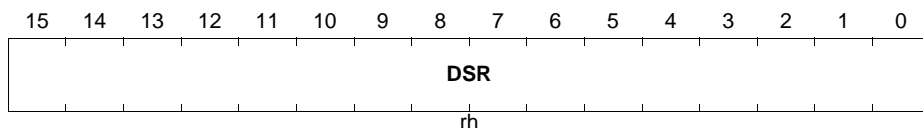
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If a debugger should be used to monitor the received data, the automatic update mechanism has to be de-activated to guaranty data consistency. Therefore, the receiver buffer register for debugging RBUFD is available. It is similar to RBUF, but without the automatic update mechanism by a read action. So a debugger (or other monitoring function) can read RBUFD without disturbing the receive sequence.

RBUFD

Receiver Buffer Register for Debugger (4C_H)

Reset Value: 0000_H



Field	Bits	Type	Description
DSR	[15:0]	rh	Data from Shift Register Same as RBUF.DSR, but without releasing the buffer after a read action.

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The receive buffer status register RBUFSR provides the status of the data in receive buffers RBUF and RBUFD. If bits RBUF01SRL.DS0 (or RBUF01SRH.DS1) are 0, the content of RBUF01SRL is monitored in RBUFSR, otherwise the content of RBUF01SRH is shown.

RBUFSR

Receiver Buffer Status Register

(58_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DS	RDV 1	RDV 0	0			P ERR	PAR	0	SOF	0	WLEN				
rh	rh	rh	r			rh	rh	r	rh	r	rh				

Field	Bits	Type	Description
WLEN	[3:0]	rh	Received Data Word Length in RBUF or RBUFD Description see RBUF01SRL.WLEN0 or RBUF01SRH.WLEN1.
SOF	6	rh	Start of Frame in RBUF or RBUFD Description see RBUF01SRL.SOF0 or RBUF01SRH.SOF1.
PAR	8	rh	Protocol-Related Argument in RBUF or RBUFD Description see RBUF01SRL.PAR0 or RBUF01SRH.PAR1.
PERR	9	rh	Protocol-related Error in RBUF or RBUFD Description see RBUF01SRL.PERR0 or RBUF01SRH.PERR1.
RDV0	13	rh	Receive Data Valid in RBUF or RBUFD Description see RBUF01SRL.RDV00 or RBUF01SRH.RDV10.
RDV1	14	rh	Receive Data Valid in RBUF or RBUFD Description see RBUF01SRL.RDV01 or RBUF01SRH.RDV11.
DS	15	rh	Data Source of RBUF or RBUFD Description see RBUF01SRL.DS0 or RBUF01SRH.DS1.
0	[5:4], 7, [12:10]	r	Reserved Read as 0; should be written with 0.

19.2.13 Operating the FIFO Data Buffer

The FIFO data buffers of a USIC module are built in a similar way, with transmit buffer and receive buffer capability for each channel. Depending on the device, the amount of available FIFO buffer area can vary. In the XE166U, totally 64 buffer entries can be distributed among the transmit or receive FIFO buffers of both channels of the USIC module.

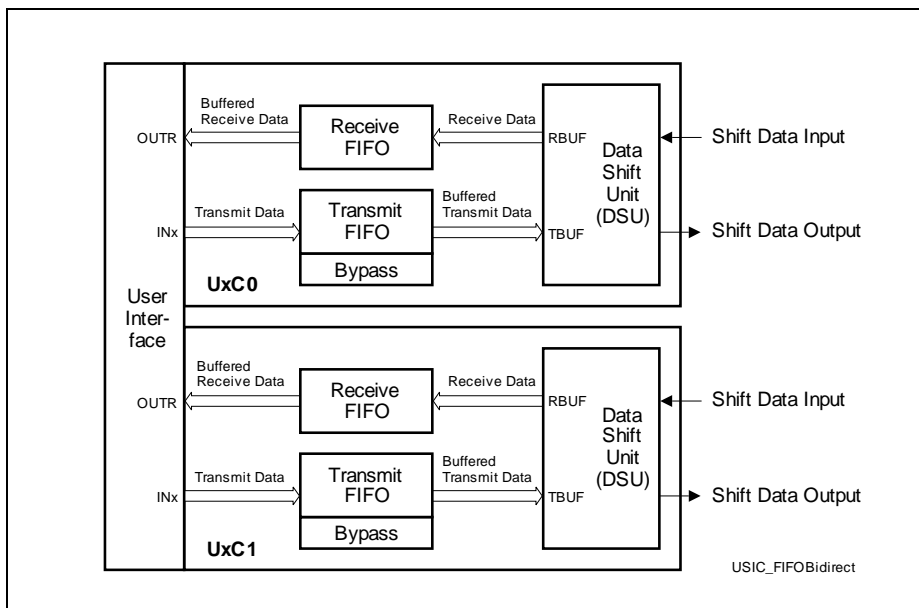


Figure 19-18 FIFO Buffer Overview

In order to operate the FIFO data buffers, the following issues have to be considered:

- **FIFO buffer available and selected:**
 The transmit FIFO buffer and the bypass structure are only available if $CCFG.TB = 1$, whereas the receive FIFO buffer is only available if $CCFG.RB = 1$.
 It is recommended to configure all buffer parameters while there is no data traffic for this USIC channel and the FIFO mechanism is disabled by $TBCTRL.SIZE = 0$ (for transmit buffer) or $RBCTRL.SIZE = 0$ (for receive buffer). The allocation of a buffer area by writing $TBCTRL$ or $RBCTRL$ has to be done while the corresponding FIFO buffer is disabled. The FIFO buffer interrupt control bits can be modified independently of data traffic.
- **FIFO buffer setup:**
 The total amount of available FIFO buffer entries limits the length of the transmit and receive buffers for each USIC channel.

- Bypass setup:
In addition to the transmit FIFO buffer, a bypass can be configured as described on [Page 19-86](#).

19.2.13.1 FIFO Buffer Partitioning

If available, the FIFO buffer area consists of a defined number of FIFO buffer entries, each containing a data part and the associated control information (RCI for receive data, TCI for transmit data). One FIFO buffer entry represents the finest granularity that can be allocated to a receive FIFO buffer or a transmit FIFO buffer. All available FIFO buffer entries of a USIC module are located one after the other in the FIFO buffer area. The overall counting starts with FIFO entry 0, followed by 1, 2, etc.

For each USIC module, a certain number of FIFO entries is available, that can be allocated to the channels of the same USIC module. It is not possible to assign FIFO buffer area to USIC channels that are not located within the same USIC module.

For each USIC channel, the size of the transmit and the receive FIFO buffer can be chosen independently. For example, it is possible to allocate the full amount of available FIFO entries as transmit buffer for one USIC channel. Some possible scenarios of FIFO buffer partitioning are shown in [Figure 19-19](#).

Each FIFO buffer consists of a set of consecutive FIFO entries. The size of a FIFO data buffer can only be programmed as a power of 2, starting with 2 entries, then 4 entries, then 8 entries, etc. A FIFO data buffer can only start at a FIFO entry aligned to its size. For example, a FIFO buffer containing n entries can only start with FIFO entry 0, n , $2 \times n$, $3 \times n$, etc. and consists of the FIFO entries $[x \times n, (x+1) \times n - 1]$, with x being an integer number (incl. 0). It is not possible to have "holes" with unused FIFO entries within a FIFO buffer, whereas there can be unused FIFO entries between two FIFO buffers.

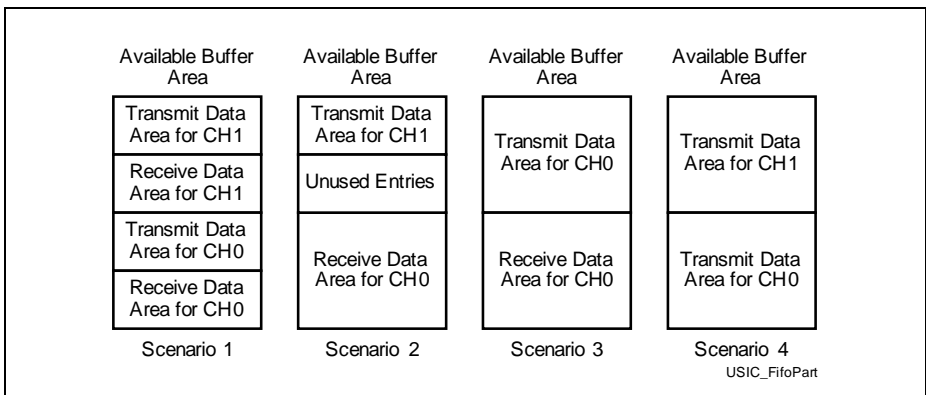


Figure 19-19 FIFO Buffer Partitioning

The data storage inside the FIFO buffers is based on pointers, that are internally updated whenever the data contents of the FIFO buffers have been modified. This happens automatically when new data is put into a FIFO buffer or the oldest data is taken from a FIFO buffer. As a consequence, the user program does not need to modify the pointers for data handling. Only during the initialization phase, the start entry of a FIFO buffer has to be defined by writing the number of the first FIFO buffer entry in the FIFO buffer to the corresponding bit field DPTR in register RBCTRL (for a receive FIFO buffer) or TBCTRL (for a transmit FIFO buffer) while the related bit field RBCTRH.SIZE=0 (or TBCTRH.SIZE = 0, respectively). The assignment of buffer entries to a FIFO buffer (regarding to size and pointers) must not be changed by software while the related USIC channel is taking part in data traffic.

19.2.13.2 Data Buffer Events and Interrupts

The transmit FIFO buffer mechanism detects the following events, that can lead to interrupts (if enabled).

- **Standard transmit buffer event:**
The filling level of the transmit buffer (given by TRBSRH.TBFLVL) exceeds (TBCTRH.LOF = 1) or falls below (TBCTRH.LOF = 0) a programmed limit (TBCTRL.LIMIT). The trigger of this event is the transition from equal to below or bigger, not the fact of being below or above.
If the standard transmit buffer event is used to indicate that new data has to be written to one of the INx locations, TBCTRH.LOF = 0 should be programmed.
- **Transmit buffer error event:**
The software has written to a full buffer. The written value is ignored.

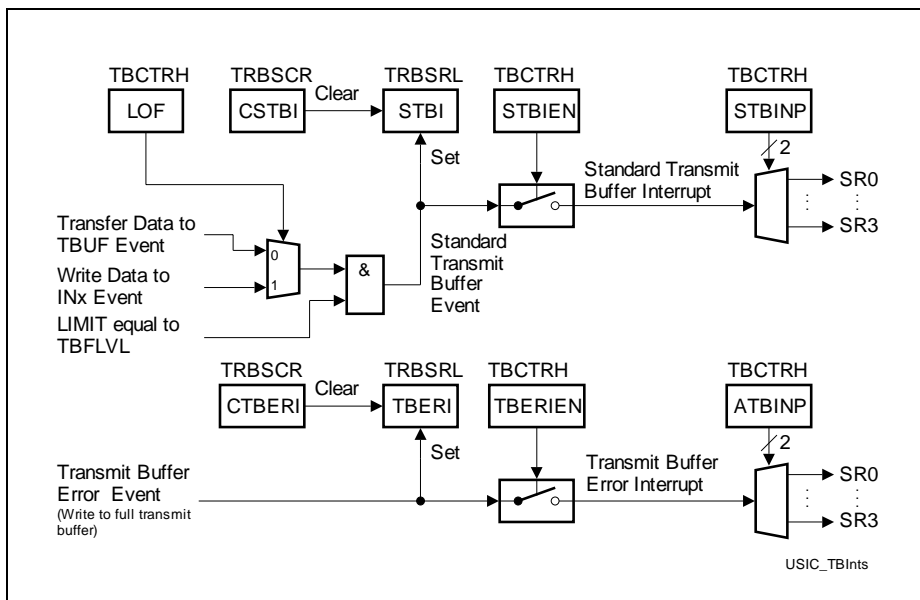


Figure 19-20 Transmit Buffer Events

The receive FIFO buffer mechanism detects the following events, that can lead to an interrupt (if enabled). The standard receive buffer event and the alternative receive buffer event can be programmed to two different modes, one referring to the filling level of the receive buffer, the other one related to a bit position in the receive control information RCI of the data word that becomes available in OUTRL.

If the interrupt generation refers to the filling level of the receive FIFO buffer, only the standard receive buffer event is used, whereas the alternative receive buffer event is not used. This mode can be selected to indicate that a certain amount of data has been received, without regarding the content of the associated RCI.

If the interrupt generation refers to RCI, the filling level is not taken into account. Each time a new data word becomes available in OUTRL, an event is detected. If bit RCI[4] = 0, a standard receive buffer event is signaled, otherwise an alternative receive buffer device (RCI[4] = 1). Depending on the selected protocol and the setting of RBCTRH.RCIM, the value of RCI[4] can hold different information that can be used for protocol-specific interrupt handling (see protocol sections for more details).

- Standard receive buffer event in filling level mode (RBCTRH.RNM = 0):
 The filling level of the receive buffer (given by TRBSRH.RBFLVL) exceeds (RBCTRH.LOF = 1) or falls below (RBCTRH.LOF = 0) a programmed limit (RBCTRL.LIMIT). The trigger of this event is the transition from equal to below or

greater, not the fact of being below or above.

If the standard receive buffer event is used to indicate that new data has to be read from OUTRL, RBCTRH.LOF = 1 should be programmed.

- Standard receive buffer event in RCI mode (RBCTRH.RNM = 1):
If the OUTR stage is updated with a new data value with RCI[4] = 0.
- Alternative receive buffer event in filling level mode (RBCTRH.RNM = 0): not used
- Alternative receive buffer event in RCI mode (RBCTRH.RNM = 1):
If the OUTR stage is updated with a new value with RCI[4] = 1.
- Receive buffer error event:
The software reads from an empty buffer. The read data is invalid.

Figure 19-21 shows the receiver buffer events and interrupts in filling level mode.

Note: A buffer event in filling level mode occurs only when the filling level transitions away from the threshold value. Transitions starting with a filling level other than the threshold level generate no trigger event.

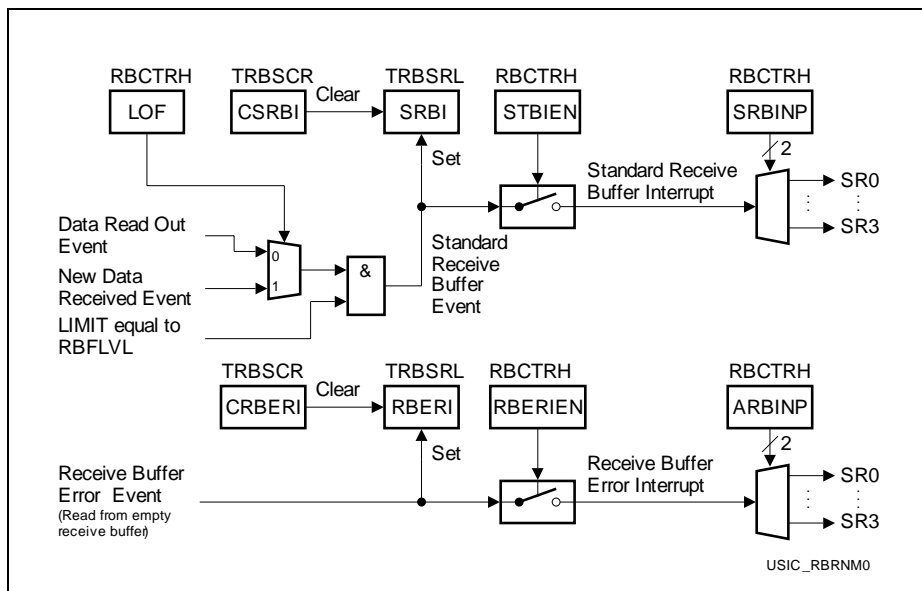


Figure 19-21 Receiver Buffer Events in Filling Level Mode

Figure 19-22 shows the receiver buffer events and interrupts in RCI mode.

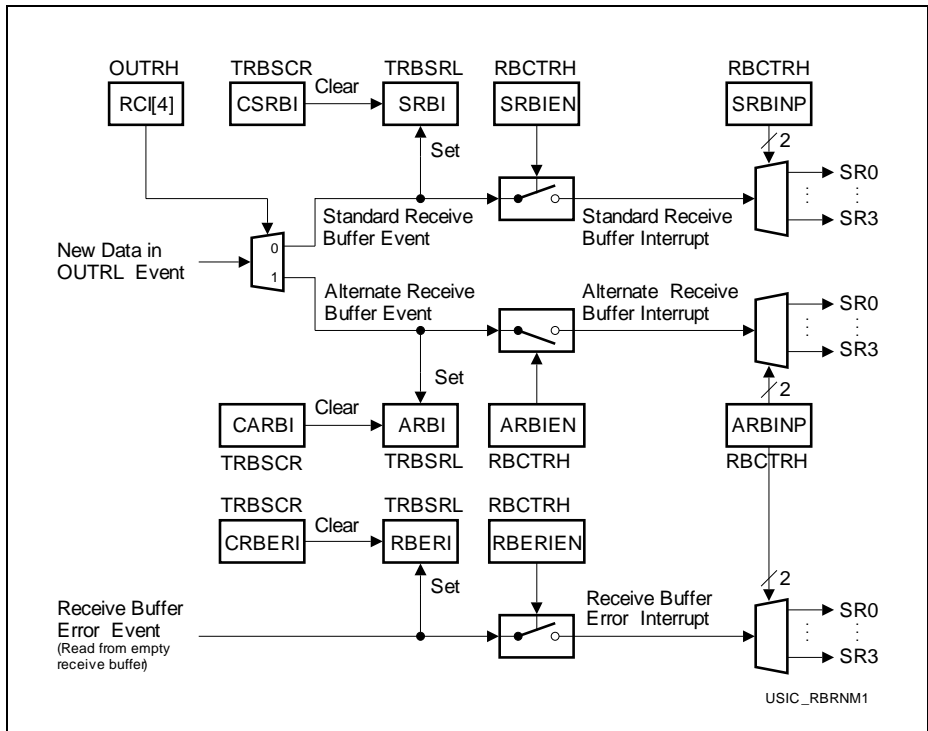


Figure 19-22 Receiver Buffer Events in RCI Mode

Table 19-7 shows the registers, bits and bit fields to indicate the buffer events and to control the interrupts related to the FIFO buffers (transmit and the receive) of a USIC channel.

Table 19-7 Buffer Events and Interrupt Handling

Event	Indication Flag	Indication cleared b	Interrupt enabled by	SRx Output selected by
Standard transmit buffer event	TRBSRL. STBI	TRBSCR. CSTBI	TBCTRH. STBIEN	TBCTRH. STBINP
Transmit buffer error event	TRBSRL. TBERI	TRBSCR. CTBERI	TBCTRH. TBERIEN	TBCTRH. ATBINP
Standard receive buffer event	TRBSRL. SRBI	TRBSCR. CSRBI	RBCTRH. SRBIEN	RBCTRH. SRBINP

Table 19-7 Buffer Events and Interrupt Handling (cont'd)

Event	Indication Flag	Indication cleared b	Interrupt enabled by	SRx Output selected by
Alternative receive buffer event	TRBSRL. ARBI	TRBSCR. CARBI	RBCTRH. ARBIEN	RBCTRH. ARBINP
Receive buffer error event	TRBSRL. RBERI	TRBSCR. CRBERI	RBCTRH. RBERIEN	RBCTRH. ARBINTXDP

19.2.13.3 FIFO Buffer Bypass

The data bypass mechanism is part of the transmit FIFO control block. It allows to introduce a data word in the data stream without modifying the transmit FIFO buffer contents, e.g. to send a high-priority message. The bypass structure consists of a bypass data word of maximum 16 bits in register BYP and some associated control information in registers BYPCRL and BYPCRH. For example, these bits define the word length of the bypass data word and configure a transfer trigger and gating mechanism similar to the one for the transmit buffer TBUF.

The bypass data word can be tagged valid or invalid for transmission by bit BYRCRL.BDV (bypass data valid). A combination of data flow related and event related criteria define whether the bypass data word is considered valid for transmission. A data validation logic checks the start conditions for this data word. Depending on the result of the check, the transmit buffer register TBUF is loaded with different values, according to the following rules:

- Data from the transmit FIFO buffer or the bypass data can only be transferred to TBUF if TCSRL.TDV = 0 (TBUF is empty).
- Bypass data can only be transferred to TBUF if the bypass is enabled by BYPCRL.BDEN or the selecting gating condition is met.
- If the bypass data is valid for transmission and has either a higher transmit priority than the FIFO data or if the transmit FIFO is empty, the bypass data is transferred to TBUF.
- If the bypass data is valid for transmission and has a lower transmit priority than the FIFO buffer that contains valid data, the oldest transmit FIFO data is transferred to TBUF.
- If the bypass data is not valid for transmission and the FIFO buffer contains valid data, the oldest FIFO data is transferred to TBUF.
- If neither the bypass data is valid for transmission nor the transmit FIFO buffer contains valid data, TBUF is unchanged.

The bypass data validation is based on the logic blocks shown in [Figure 19-23](#).

- A transfer gating logic enables or disables the bypass data word transfer to TBUF under software or under hardware control. If the input stage DX2 is not needed for data shifting, signal DX2S can be used for gating purposes. The transfer gating logic is controlled by bit field BYPCRL.BDEN.
- A transfer trigger logic supports data word transfers related to events, e.g. timer based or related to an input pin. If the input stage DX2 is not needed for data shifting, signal DX2T can be used for trigger purposes. The transfer trigger logic is controlled by bit BYPCRL.BDVTR.
- A bypass data validation logic combining the inputs from the gating logic, the triggering logic and TCSRL.TDV.

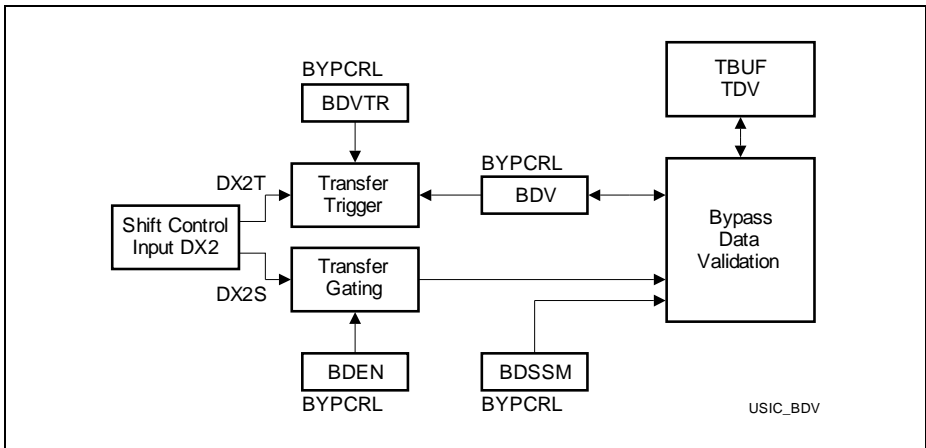


Figure 19-23 Bypass Data Validation

With this structure, the following bypass data transfer functionality can be achieved:

- Bit `BYPCLR.BDSSM = 1` has to be programmed for a single-shot mechanism. After each transfer of the bypass data word to TBUF, the bypass data word has to be tagged valid again. This can be achieved either by writing a new bypass data word to BYP or by DX2T if `BDVTR = 1` (e.g. trigger on a timer base or an edge at a pin).
- Bit `BYPCLR.BDSSM = 0` has to be programmed if the bypass data is permanently valid for transmission (e.g. as alternative data if the data FIFO runs empty).

19.2.13.4 FIFO Access Constraints

The data in the shared FIFO buffer area is accessed by the hardware mechanisms for data transfer of each communication channel (for transmission and reception) and by software to read out received data or to write data to be transmitted. As a consequence, the data delivery rate can be limited by the FIFO mechanism. Each access by hardware to the FIFO buffer area has priority over a software access, that is delayed in case of an access collision.

In order to avoid data loss and stalling of the CPU due to delayed software accesses, the baud rate, the word length and the software access mechanism have to be taken into account. Each access to the FIFO data buffer area by software or by hardware takes one period of f_{SYS} . Especially a continuous flow of very short, consecutive data words can lead to an access limitation.

19.2.13.5 Handling of FIFO Transmit Control Information

In addition to the transmit data, the transmit control information TCI can be transferred from the transmit FIFO or bypass structure to the USIC channel. Depending on the selected protocol and the enabled update mechanism, some settings of the USIC channel parameters can be modified. The modifications are based on the TCI of the FIFO data word loaded to TBUF or by the bypass control information if the bypass data is loaded into TBUF.

- TCSRL.SELMD = 1: update of PCRH.CTR[20:16] by FIFO TCI or BYPCRH.BSELO with additional clear of PCRH.CTR[23:21]
- TCSRL.WLEMD = 1: update of SCTR.H.WLE and TCSRL.EOF by FIFO TCI or BYPCR.H.BWLE (if the WLE information is overwritten by TCI or BWLE, the user has to take care that FLE is set accordingly)
- TCSRL.FLEMD = 1: update of SCTR.H.FLE[4:0] by FIFO TCI or BYPCR.H.BWLE with additional clear of SCTR.H.FLE[5]
- TCSRL.WAMD = 1: update of TCSRL.WA by FIFO TCI[4]

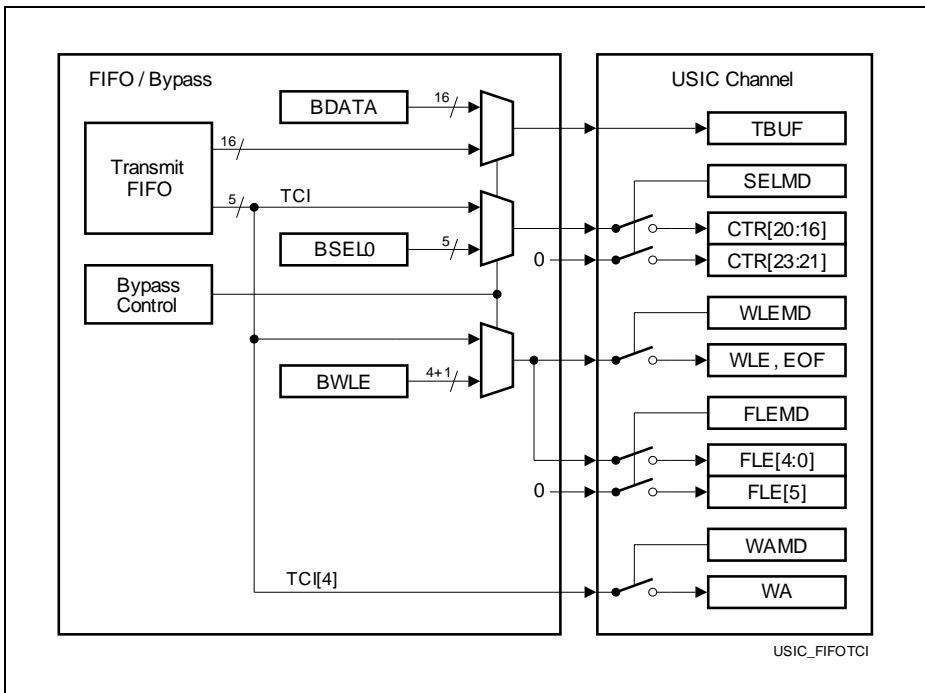


Figure 19-24 TCI Handling with FIFO / Bypass

19.2.14 FIFO Buffer and Bypass Registers

19.2.14.1 Bypass Registers

A write action to at least the low byte of the bypass data register sets BYPCRL.BDV = 1 (bypass data tagged valid).

BYP

Bypass Data Register (100 _H)															Reset Value: 0000 _H
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BDATA															
rw															

Bit (Field)	Width	Type	Description
BDATA	[15:0]	rw	Bypass Data This bit field contains the bypass data.

BYPCRL

Bypass Control Register L (104 _H)															Reset Value: 0000 _H
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BDV	0	B PRIO	BD VTR	BDEN	0	BD SSM	0					BWLE			
rh	r	rw	rw	rw	r	rw	r					rw			

Field	Bits	Type	Description
BWLE	[3:0]	rw	Bypass Word Length This bit field defines the word length of the bypass data. The word length is given by BWLE + 1 with the data word being right-aligned in the data buffer at the bit positions [BWLE down to 0]. The bypass data word is always considered as an own frame with the length of BWLE. Same coding as SCTRH.WLE.

Field	Bits	Type	Description
BDSSM	8	rw	Bypass Data Single Shot Mode This bit defines if the bypass data is considered as permanently valid or if the bypass data is only transferred once (single shot mode). 0 _B The bypass data is still considered as valid after it has been loaded into TBUF. The loading of the data into TBUF does not clear BDV. 1 _B The bypass data is considered as invalid after it has been loaded into TBUF. The loading of the data into TBUF clears BDV.
BDEN	[11:10]	rw	Bypass Data Enable This bit field defines if and how the transfer of bypass data to TBUF is enabled. 00 _B The transfer of bypass data is disabled. 01 _B The transfer of bypass data to TBUF is possible. Bypass data will be transferred to TBUF according to its priority if BDV = 1. 10 _B Gated bypass data transfer is enabled. Bypass data will be transferred to TBUF according to its priority if BDV = 1 and while DX2S = 0. 11 _B Gated bypass data transfer is enabled. Bypass data will be transferred to TBUF according to its priority if BDV = 1 and while DX2S = 1.
BDVTR	12	rw	Bypass Data Valid Trigger This bit enables the bypass data for being tagged valid when DX2T is active (for time framing or time-out purposes). 0 _B Bit BDV is not influenced by DX2T. 1 _B Bit BDV is set if DX2T is active.
BPRIO	13	rw	Bypass Priority This bit defines the priority between the bypass data and the transmit FIFO data. 0 _B The transmit FIFO data has a higher priority than the bypass data. 1 _B The bypass data has a higher priority than the transmit FIFO data.

Universal Serial Interface Channel

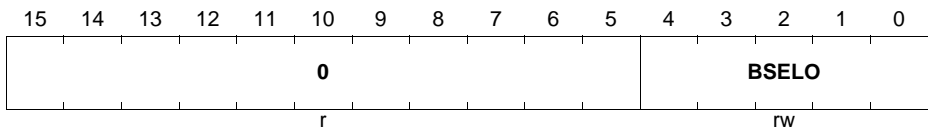
Field	Bits	Type	Description
BDV	15	rh	Bypass Data Valid This bit defines if the bypass data is valid for a transfer to TBUF. This bit is set automatically by a write access to at least the low-byte of register BYP. It can be cleared by software by writing TRBSCR.CBDV. 0 _B The bypass data is not valid. 1 _B The bypass data is valid.
0	[7:4], 9, 14	r	Reserved Read as 0; should be written with 0.

BYPCRH

Bypass Control Register H

(106_H)

Reset Value: 0000_H



Field	Bits	Type	Description
BSELO	[4:0]	rw	Bypass Select Outputs This bit field contains the value that is written to PCRH.CTR[20:16] if bypass data is transferred to TBUF. In the SSC protocol, this bit field can be used to define which SELOx output line will be activated when bypass data is transmitted.
0	[15:5]	r	Reserved Read as 0; should be written with 0.

19.2.14.2 General FIFO Buffer Control Registers

The transmit and receive FIFO status information of UxCy is given in registers UxCy_TRBSRL/H.

The bits related to the transmitter buffer in this register can only be written if the transmit buffer functionality is enabled by CCFG.TB = 1, otherwise write accesses are ignored. A similar behavior applies for the bits related to the receive buffer referring to CCFG.RB = 1.

The interrupt flags (event flags) in the transmit and receive FIFO status register TRBSRL can be cleared by writing a 1 to the corresponding bit position in register TRBSCR, whereas writing a 0 has no effect on these bits. Writing a 1 by software to SRBI, RBERI, ARBI, STBI, or TBERI sets the corresponding bit to simulate the detection of a transmit/receive buffer event, but without activating any service request output (therefore, see FMR.SIOx).

Bits TBUS and RBUS have been implemented for testing purposes. They can be ignored by data handling software. Please note that a read action can deliver either a 0 or a 1 for these bits. It is recommended to treat them as "don't care".

TRBSRL

Transmit/Receive Buffer Status Register L

(118_H)

Reset Value: 0808_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	T BUS	T FUL L	T EMP TY	0	TB ERI	ST BI	0	R BUS	R FUL L	R EMP TY	AR BI	RB ERI	SR BI		
r	rh	rh	rh	r	rwh	rwh	r	rh	rh	rh	rwh	rwh	rwh		

Field	Bits	Type	Description
SRBI	0	rwh	Standard Receive Buffer Event This bit indicates that a standard receive buffer event has been detected. It is cleared by writing TRBSCR.CSRBI = 1. If enabled by RBCTRH.SRBIEN, the service request output SRx selected by RBCTRH.SRBINP becomes activated if a standard receive buffer event is detected. 0 _B A standard receive buffer event has not been detected. 1 _B A standard receive buffer event has been detected.

Field	Bits	Type	Description
RBERI	1	rwh	<p>Receive Buffer Error Event</p> <p>This bit indicates that a receive buffer error event has been detected. It is cleared by writing $TRBSCR.CRBERI = 1$.</p> <p>If enabled by $RBCTRH.RBERIEN$, the service request output SRx selected by $RBCTRH.ARBINP$ becomes activated if a receive buffer error event is detected.</p> <p>0_B A receive buffer error event has not been detected.</p> <p>1_B A receive buffer error event has been detected.</p>
ARBI	2	rwh	<p>Alternative Receive Buffer Event</p> <p>This bit indicates that an alternative receive buffer event has been detected. It is cleared by writing $TRBSCR.CARBI = 1$.</p> <p>If enabled by $RBCTRH.ARBIEN$, the service request output SRx selected by $RBCTRH.ARBINP$ becomes activated if an alternative receive buffer event is detected.</p> <p>0_B An alternative receive buffer event has not been detected.</p> <p>1_B An alternative receive buffer event has been detected.</p>
REMPY	3	rh	<p>Receive Buffer Empty</p> <p>This bit indicates whether the receive buffer is empty.</p> <p>0_B The receive buffer is not empty.</p> <p>1_B The receive buffer is empty.</p>
RFULL	4	rh	<p>Receive Buffer Full</p> <p>This bit indicates whether the receive buffer is full.</p> <p>0_B The receive buffer is not full.</p> <p>1_B The receive buffer is full.</p>

Universal Serial Interface Channel

Field	Bits	Type	Description
RBUS	5	rh	Receive Buffer Busy This bit indicates whether the receive buffer is currently updated by the FIFO handler. 0_B The receive buffer information has been completely updated. 1_B The OUTRL/H update from the FIFO memory is ongoing. A read from OUTRL/H will be delayed. FIFO pointers from the previous read are not yet updated.
STBI	8	rwh	Standard Transmit Buffer Event This bit indicates that a standard transmit buffer event has been detected. It is cleared by writing <code>TRBSCR.CSTBI = 1</code> . If enabled by <code>TBCTRH.STBIEN</code> , the service request output <code>SRx</code> selected by <code>TBCTRH.STBINP</code> becomes activated if a standard transmit buffer event is detected. 0_B A standard transmit buffer event has not been detected. 1_B A standard transmit buffer event has been detected.
TBERI	9	rwh	Transmit Buffer Error Event This bit indicates that a transmit buffer error event has been detected. It is cleared by writing <code>TRBSCR.CTBERI = 1</code> . If enabled by <code>TBCTRH.TBERIEN</code> , the service request output <code>SRx</code> selected by <code>TBCTRH.ATBINP</code> becomes activated if a transmit buffer error event is detected. 0_B A transmit buffer error event has not been detected. 1_B A transmit buffer error event has been detected.
TEMPY	11	rh	Transmit Buffer Empty This bit indicates whether the transmit buffer is empty. 0_B The transmit buffer is not empty. 1_B The transmit buffer is empty.

Universal Serial Interface Channel

Field	Bits	Type	Description
TFULL	12	rh	Transmit Buffer Full This bit indicates whether the transmit buffer is full. 0_B The transmit buffer is not full. 1_B The transmit buffer is full.
TBUS	13	rh	Transmit Buffer Busy This bit indicates whether the transmit buffer is currently updated by the FIFO handler. 0_B The transmit buffer information has been completely updated. 1_B The FIFO memory update after write to INx is ongoing. A write to INx will be delayed. FIFO pointers from the previous INx write are not yet updated.
0	[7:6], 10, [15:14]	r	Reserved Read as 0; should be written with 0.

TRBSRH

Transmit/Receive Buffer Status Register H

(11A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0								0							
r					rh			r				rh			

Field	Bits	Type	Description
RBFLVL	[6:0]	rh	Receive Buffer Filling Level This bit field indicates the filling level of the receive buffer, starting with 0 for an empty buffer.
TBFLVL	[14:8]	rh	Transmit Buffer Filling Level This bit field indicates the filling level of the transmit buffer, starting with 0 for an empty buffer.
0	7, 15	r	Reserved Read as 0; should be written with 0.

Universal Serial Interface Channel

The bits in register TRBSCR are used to clear the notification bits in register TRBSRL or to clear the FIFO mechanism for the transmit or receive buffer. A read action always delivers 0.

TRBSCR

Transmit/Receive Buffer Status Clear Register

(11C_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLU SH TB	FLU SH RB	0			C BDV	C TB ERI	C ST BI	0					C AR BI	C RB ERI	C SR BI
w	w	r			w	w	w	r					w	w	w

Field	Bits	Type	Description
CSRBI	0	w	Clear Standard Receive Buffer Event 0 _B No effect. 1 _B Clear TRBSRL.SRBI.
CRBERI	1	w	Clear Receive Buffer Error Event 0 _B No effect. 1 _B Clear TRBSRL.RBERI.
CARBI	2	w	Clear Alternative Receive Buffer Event 0 _B No effect. 1 _B Clear TRBSRL.ARBI.
CSTBI	8	w	Clear Standard Transmit Buffer Event 0 _B No effect. 1 _B Clear TRBSRL.STBI.
CTBERI	9	w	Clear Transmit Buffer Error Event 0 _B No effect. 1 _B Clear TRBSRL.TBERI.
CBDV	10	w	Clear Bypass Data Valid 0 _B No effect. 1 _B Clear BYPCRL.BDV.
FLUSHRB	14	w	Flush Receive Buffer 0 _B No effect. 1 _B The receive FIFO buffer is cleared (filling level is cleared and output pointer is set to input pointer value). Should only be used while the FIFO buffer is not taking part in data traffic.

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Field	Bits	Type	Description
FLUSHTB	15	w	Flush Transmit Buffer 0_B No effect. 1_B The transmit FIFO buffer is cleared (filling level is cleared and output pointer is set to input pointer value). Should only be used while the FIFO buffer is not taking part in data traffic.
0	[7:3], [13:11]	r	Reserved Read as 0; should be written with 0.

19.2.14.3 Transmit FIFO Buffer Control Registers

The transmit FIFO buffer is controlled by registers TBCTRL and TBCTRH. These registers can only be written if the transmit buffer functionality is enabled by CCFG.TB = 1, otherwise write accesses are ignored.

TBCTRL

Transmitter Buffer Control Register L (110_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0								0							
r								r							

Field	Bits	Type	Description
DPTR	[5:0]	w	Data Pointer This bit field defines the start value for the transmit buffer pointers when assigning the FIFO entries to the transmit FIFO buffer. A read always delivers 0. When writing DPTR while SIZE = 0, both transmitter pointers TDIPTR and RTDOPTR in register TRBPTRL are updated with the written value and the buffer is considered as empty. A write access to DPTR while SIZE > 0 is ignored and does not modify the pointers.
LIMIT	[13:8]	rw	Limit For Interrupt Generation This bit field defines the target filling level of the transmit FIFO buffer that is used for the standard transmit buffer event detection.
0	[7:6], [15:14]	r	Reserved Read as 0; should be written with 0.

TBCTR_H

Transmitter Buffer Control Register H (112_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TB ERI EN	ST BI EN	0	LOF	0	SIZE			0			ATBINP	0	STBINP		
rw	rw	r	rw	r	rw			r			rw	r	rw		

Field	Bits	Type	Description
STBINP	[1:0]	rw	Standard Transmit Buffer Interrupt Node Pointer This bit field defines which service request output SR _x becomes activated in case of a standard transmit buffer event. 00 _B Output SR0 becomes activated. 01 _B Output SR1 becomes activated. 10 _B Output SR2 becomes activated. 11 _B Output SR3 becomes activated.
ATBINP	[4:3]	rw	Alternative Transmit Buffer Interrupt Node Pointer This bit field define which service request output SR _x will be activated in case of a transmit buffer error event. 00 _B Output SR0 becomes activated. 01 _B Output SR1 becomes activated. 10 _B Output SR2 becomes activated. 11 _B Output SR3 becomes activated.
SIZE	[10:8]	rw	Buffer Size This bit field defines the number of FIFO entries assigned to the transmit FIFO buffer. 000 _B The FIFO mechanism is disabled. The buffer does not accept any request for data. 001 _B The FIFO buffer contains 2 entries. 010 _B The FIFO buffer contains 4 entries. 011 _B The FIFO buffer contains 8 entries. 100 _B The FIFO buffer contains 16 entries. 101 _B The FIFO buffer contains 32 entries. 110 _B The FIFO buffer contains 64 entries. 111 _B Reserved

Universal Serial Interface Channel

Field	Bits	Type	Description
LOF	12	rw	Buffer Event on Limit Overflow This bit defines which relation between filling level and programmed limit leads to a standard transmit buffer event. 0_B A standard transmit buffer event occurs when the filling level equals the limit value and gets lower due to transmission of a data word. 1_B A standard transmit buffer interrupt event occurs when the filling level equals the limit value and gets bigger due to a write access to a data input location INx.
STBIEN	14	rw	Standard Transmit Buffer Interrupt Enable This bit enables/disables the generation of a standard transmit buffer interrupt in case of a standard transmit buffer event. 0_B The standard transmit buffer interrupt generation is disabled. 1_B The standard transmit buffer interrupt generation is enabled.
TBERIEN	15	rw	Transmit Buffer Error Interrupt Enable This bit enables/disables the generation of a transmit buffer error interrupt in case of a transmit buffer error event (software writes to a full transmit buffer). 0_B The transmit buffer error interrupt generation is disabled. 1_B The transmit buffer error interrupt generation is enabled.
0	2, [7:5], 11, 13	r	Reserved Read as 0; should be written with 0.

19.2.14.4 Receive FIFO Buffer Control Registers

The receive FIFO buffer is controlled by registers RBCTRL and RBCTRH. These registers can only be written if the receive buffer functionality is enabled by CCFG.RB = 1, otherwise write accesses are ignored.

RBCTRL

Receiver Buffer Control Register L (114_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0								0							
r								r							

Field	Bits	Type	Description
DPTR	[5:0]	w	Data Pointer This bit field defines the start value for the receive buffer pointers when assigning the FIFO entries to the receive FIFO buffer. A read always delivers 0. When writing DPTR while SIZE = 0, both receiver pointers RDIPTR and RDOPTR in register TRBPTRH are updated with the written value and the buffer is considered as empty. A write access to DPTR while SIZE > 0 is ignored and does not modify the pointers.
LIMIT	[13:8]	rw	Limit For Interrupt Generation This bit field defines the target filling level of the receive FIFO buffer that is used for the standard receive buffer event detection.
0	[7:6], [15:14]	r	Reserved Read as 0; should be written with 0.

RBCTRH

Receiver Buffer Control Register H (116_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RB ERI EN	SR BI EN	AR BI EN	LOF	RNM	SIZE			RCIM		0	ARBINP		0	SRBINP	
rw	rw	rw	rw	rw	rw			rw		r	rw		r	rw	

Field	Bits	Type	Description
SRBINP	[1:0]	rw	Standard Receive Buffer Interrupt Node Pointer This bit field defines which service request output SRx becomes activated in case of a standard receive buffer event. 00 _B Output SR0 becomes activated. 01 _B Output SR1 becomes activated. 10 _B Output SR2 becomes activated. 11 _B Output SR3 becomes activated.
ARBINP	[4:3]	rw	Alternative Receive Buffer Interrupt Node Pointer This bit field defines which service request output SRx becomes activated in case of an alternative receive buffer event or a receive buffer error event. 00 _B The output SR0 becomes activated. 01 _B The output SR1 becomes activated. 10 _B The output SR2 becomes activated. 11 _B The output SR3 becomes activated.
RCIM	[7:6]	rw	Receiver Control Information Mode This bit field defines which information from the receiver status register RBUFSR is propagated as 5 bit receiver control information RCI[4:0] to the receive FIFO buffer and can be read out in registers OUT(D)RH. 00 _B RCI[4] = PERR, RCI[3:0] = WLEN 01 _B RCI[4] = SOF, RCI[3:0] = WLEN 10 _B RCI[4] = 0, RCI[3:0] = WLEN 11 _B RCI[4] = PERR, RCI[3] = PAR, RCI[2:1] = 00 _B , RCI[0] = SOF

Universal Serial Interface Channel

Field	Bits	Type	Description
SIZE	[10:8]	rw	Buffer Size This bit field defines the number of FIFO entries assigned to the receive FIFO buffer. 000 _B The FIFO mechanism is disabled. The buffer does not accept any request for data. 001 _B The FIFO buffer contains 2 entries. 010 _B The FIFO buffer contains 4 entries. 011 _B The FIFO buffer contains 8 entries. 100 _B The FIFO buffer contains 16 entries. 101 _B The FIFO buffer contains 32 entries. 110 _B The FIFO buffer contains 64 entries. 111 _B Reserved
RNM	11	rw	Receiver Notification Mode This bit defines the receive buffer event mode. The receive buffer error event is not affected by RNM. 0 _B Filling level mode: A standard receive buffer event occurs when the filling level equals the limit value and changes, either due to a read access from OUTRL (LOF = 0) or due to a new received data word (LOF = 1). 1 _B RCI mode: A standard receive buffer event occurs when register OUTRL is updated with a new value if the corresponding value in OUTRH.RCI[4] = 0. If OUTRH.RCI[4] = 1, an alternative receive buffer event occurs instead of the standard receive buffer event.
LOF	12	rw	Buffer Event on Limit Overflow This bit defines which relation between filling level and programmed limit leads to a standard receive buffer event in filling level mode (RNM = 0). In RCI mode (RNM = 1), bit fields LIMIT and LOF are ignored. 0 _B A standard receive buffer event occurs when the filling level equals the limit value and gets lower due to a read access from OUTRL. 1 _B A standard receive buffer event occurs when the filling level equals the limit value and gets bigger due to the reception of a new data word.

Universal Serial Interface Channel

Field	Bits	Type	Description
ARBIEN	13	rw	Alternative Receive Buffer Interrupt Enable This bit enables/disables the generation of an alternative receive buffer interrupt in case of an alternative receive buffer event. 0_B The alternative receive buffer interrupt generation is disabled. 1_B The alternative receive buffer interrupt generation is enabled.
SRBIEN	14	rw	Standard Receive Buffer Interrupt Enable This bit enables/disables the generation of a standard receive buffer interrupt in case of a standard receive buffer event. 0_B The standard receive buffer interrupt generation is disabled. 1_B The standard receive buffer interrupt generation is enabled.
RBERIEN	15	rw	Receive Buffer Error Interrupt Enable This bit enables/disables the generation of a receive buffer error interrupt in case of a receive buffer error event (the software reads from an empty receive buffer). 0_B The receive buffer error interrupt generation is disabled. 1_B The receive buffer error interrupt generation is enabled.
0	2, 5	r	Reserved Read as 0; should be written with 0.

19.2.14.5 FIFO Buffer Data Registers

The 32 independent data input locations IN00 to IN31 are addresses that can be used as data entry locations for the transmit FIFO buffer. Data written to one of these locations will be stored in the transmit buffer FIFO. Additionally, the 5-bit coding of the number [31:0] of the addressed data input location represents the transmit control information TCI.

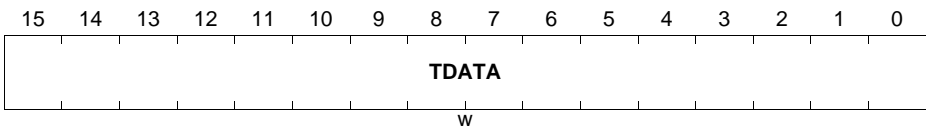
If the FIFO is already full and new data is written to it, the write access is ignored and a transmit buffer error event is signaled.

INx (x = 00-31)

Transmit FIFO Buffer Input Location x

(180_H + x * 4)

Reset Value: 0000_H



Field	Bits	Type	Description
TDATA	[15:0]	w	Transmit Data This bit field contains the data to be transmitted (write view), read actions deliver 0. A write action to at least the low byte of TDATA triggers the data storage in the FIFO.

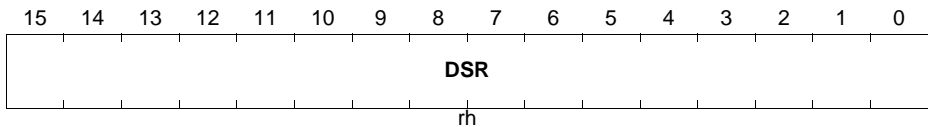
Universal Serial Interface Channel

The receiver FIFO buffer output register OUTRL shows the oldest received data word in the FIFO buffer. A read action from this address location delivers the received data. With a read access of at least the low byte, the data is declared to be read and the next entry becomes visible. Register OUTRH contains the receiver control information RCI containing the information selected by RBCTRH.RCIM. Write accesses to OUTRL/H are ignored.

OUTRL

Receiver Buffer Output Register L (120_H)

Reset Value: 0000_H

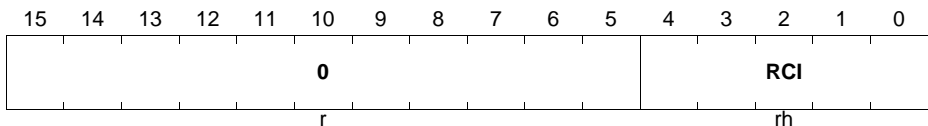


Field	Bits	Type	Description
DSR	[15:0]	rh	Received Data This bit field monitors the content of the oldest data word in the receive FIFO. Reading at least the low byte releases the buffer entry currently shown in DSR.

OUTRH

Receiver Buffer Output Register H (122_H)

Reset Value: 0000_H



Field	Bits	Type	Description
RCI	[4:0]	rh	Receiver Control Information This bit field monitors the receiver control information associated to DSR. The bit structure of RCI depends on bit field RBCTRH.RCIM.
0	[15:5]	r	Reserved Read as 0; should be written with 0.

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If a debugger should be used to monitor the received data in the FIFO buffer, the FIFO mechanism must not be activated in order to guaranty data consistency. Therefore, a second address set is available, named OUTDRL/H (D like debugger), having the same bit fields like the original buffer output register OUTRL/H, but without the FIFO mechanism. A debugger can read here (in order to monitor the receive data flow) without the risk of data corruption. Write accesses to OUTDRL/H are ignored.

OUTDRL

Receiver Buffer Output Register L for Debugger

(124_H)

Reset Value: 0000_H



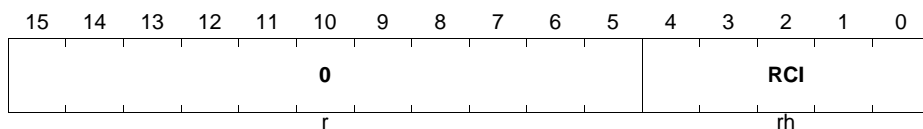
Field	Bits	Type	Description
DSR	[15:0]	rh	Data from Shift Register Same as OUTRL.DSR, but without releasing the buffer after a read action.

OUTDRH

Receiver Buffer Output Register H for Debugger

(126_H)

Reset Value: 0000_H



Field	Bits	Type	Description
RCI	[4:0]	rh	Receive Control Information from Shift Register Same as OUTRH.RCI.
0	[15:5]	r	Reserved Read as 0; should be written with 0.

19.2.14.6 FIFO Buffer Pointer Registers

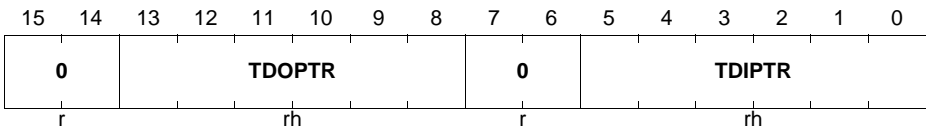
The pointers for FIFO handling of the transmit and receive FIFO buffers are located in registers TRBPTRL (for the transmit buffer) and TRBPTRH (for the receive buffer). The pointers are automatically handled by the FIFO buffer mechanism and do not need to be modified by software. As a consequence, these registers can only be read by software (e.g. for verification purposes), whereas write accesses are ignored.

TRBPTRL

Transmit/Receive Buffer Pointer Register L

(108_H)

Reset Value: 0000_H



Field	Bits	Type	Description
TDIPTR	[5:0]	rh	Transmitter Data Input Pointer This bit field indicates the buffer entry that will be used for the next transmit data coming from the INx addresses.
TDOPTR	[13:8]	rh	Transmitter Data Output Pointer This bit field indicates the buffer entry that will be used for the next transmit data to be output to TBUF.
0	[7:6], [15:14]	r	Reserved Read as 0; should be written with 0.

TRBPTRH

Transmit/Receive Buffer Pointer Register H
(10A_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0								0							
r								r							

Field	Bits	Type	Description
RDIPTTR	[5:0]	rh	Receiver Data Input Pointer This bit field indicates the buffer entry that will be used for the next receive data coming from RBUF.
RDOPTTR	[13:8]	rh	Receiver Data Output Pointer This bit field indicates the buffer entry that will be used for the next receive data to be output at the OUT(D)RL addresses.
0	[7:6], [15:14]	r	Reserved Read as 0; should be written with 0.

19.3 Asynchronous Serial Channel (ASC = UART)

The asynchronous serial channel ASC covers the reception and the transmission of asynchronous data frames and provides a hardware LIN support. The receiver and transmitter being independent, frames can start at different points in time for transmission and reception. The ASC mode is selected by $CCR.MODE = 0010_B$ with $CCFG.ASC = 1$ (ASC mode available).

This chapter contains the following sections:

- Signal description (see [Page 19-110](#))
- Frame format (see [Page 19-111](#))
- Bit timing (see [Page 19-115](#))
- Operating the ASC (see [Page 19-114](#))
- Protocol registers (see [Page 19-123](#))
- Hardware LIN support (see [Page 19-129](#))

19.3.1 Signal Description

An ASC connection is characterized by the use of a single connection line between a transmitter and a receiver. The receiver input RXD signal is handled by the input stage DX0.

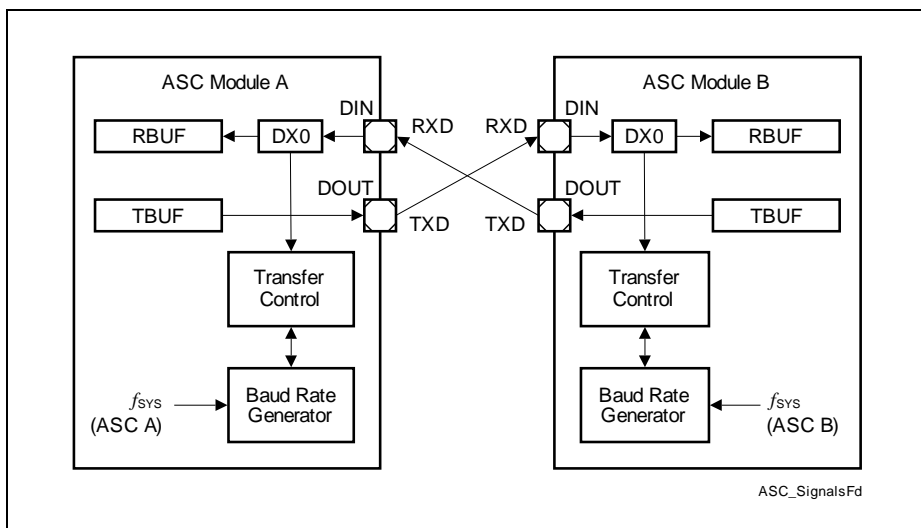


Figure 19-25 ASC Signal Connections for Full-Duplex Communication

For full-duplex communication, an independent communication line is needed for each transfer direction. [Figure 19-25](#) shows an example with a point-to-point full-duplex connection between two communication partners ASC A and ASC B.

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For half-duplex or multi-transmitter communication, a single communication line is shared between the communication partners. **Figure 19-26** shows an example with a point-to-point half-duplex connection between ASC A and ASC B. In this case, the user has to take care that only one transmitter is active at a time. In order to support transmitter collision detection, the input stage DX1 can be used to monitor the level of the transmit line and to check if the line is in the idle state or if a collision occurred.

There are two possibilities to connect the receiver input DIN to the transmitter output DOUT. Communication partner ASC A uses an internal connection with only the transmit pin TXD, that is delivering its input value as RXD to the DX0 input stage for reception and to DX1 to check for transmitter collisions. Communication partner ASC B uses an external connection between the two pins TXD and RXD.

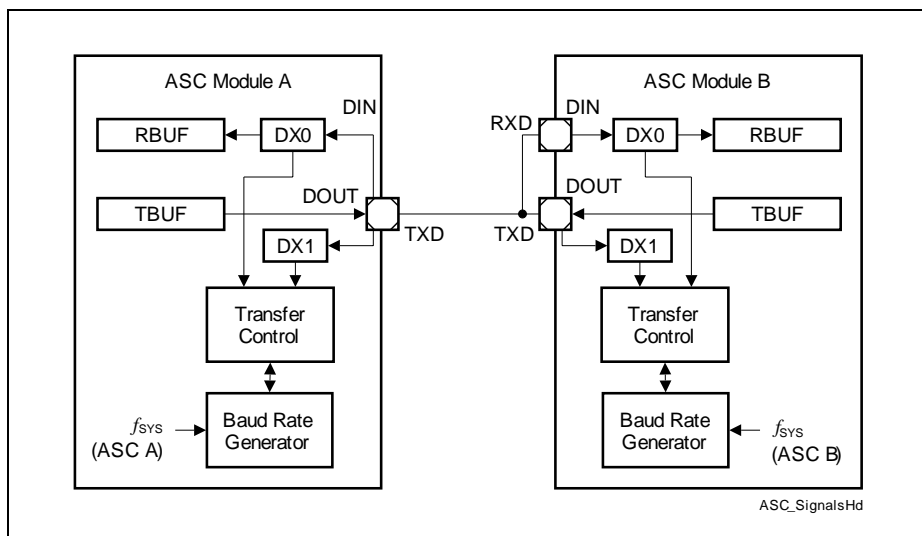


Figure 19-26 ASC Signal Connections for Half-Duplex Communication

19.3.2 Frame Format

A standard ASC frame is shown in **Figure 19-27**. It consists of:

- An idle time with the signal level 1.
- One start of frame bit (SOF) with the signal level 0.
- A data field containing a programmable number of data bits (1-63).
- A parity bit (P), programmable for either even or odd parity. It is optionally possible to handle frames without parity bit.
- One or two stop bits with the signal level 1.

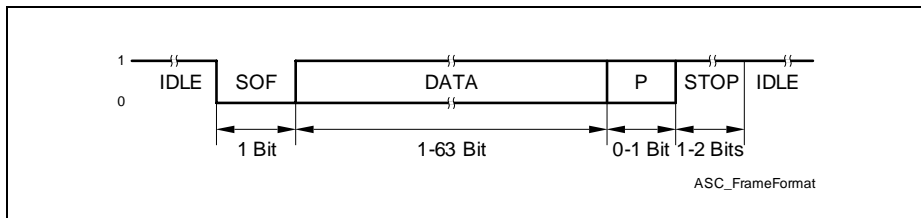


Figure 19-27 Standard ASC Frame Format

The protocol specific bits (SOF, P, STOP) are automatically handled by the ASC protocol state machine and do not appear in the data flow via the receive and transmit buffers.

19.3.2.1 Idle Time

The receiver and the transmitter independently check the respective data input lines (DX0, DX1) for being idle. The idle detection ensures that an SOF bit of a recently enabled ASC module does not collide with an already running frame of another ASC module.

In order to start the idle detection, the user software has to clear bits PSR.RXIDLE and/or PSR.TXIDLE, e.g. before selecting the ASC mode or during operation. If a bit is cleared by software while a data transfer is in progress, the currently running frame transfer is finished normally before starting the idle detection again. Frame reception is only possible if PSR.RXIDLE = 1 and frame transmission is only possible if PSR.TXIDLE = 1. The duration of the idle detection depends on the setting of bit PCRL.IDM. In the case that a collision is not possible, the duration can be shortened and the bus can be declared as being idle by setting PCRL.IDM = 0.

In the case that the complete idle detection is enabled by PCRL.IDM = 1, the data input of DX0 is considered as idle (PSR.RXIDLE becomes set) if a certain number of consecutive passive bit times has been detected. The same scheme applies for the transmitter's data input of DX1. Here, bit PSR.TXIDLE becomes set if the idle condition of this input signal has been detected.

The duration of the complete idle detection is given by the number of programmed data bits per frame plus 2 (in the case without parity) or plus 3 (in the case with parity). The counting of consecutive bit times with 1 level restarts from the beginning each time an edge is found, after leaving a stop mode or if ASC mode becomes enabled.

If the idle detection bits PSR.RXIDLE and/or TXIDLE are cleared by software, the counting scheme is not stopped (no re-start from the beginning). As a result, the cleared bit(s) can become set immediately again if the respective input line still meets the idle criterion.

Please note that the idle time check is based on bit times, so the maximum time can be up to 1 bit time more than programmed value (but not less).

19.3.2.2 Start Bit Detection

The receiver input signal DIN (selected signal of input stage DX0) is checked for a falling edge. An SOF bit is detected when a falling edge occurs while the receiver is idle or after the sampling point of the last stop bit. To increase noise immunity, the SOF bit timing starts with the first falling edge that is detected. If the sampled bit value of the SOF is 1, the previous falling edge is considered to be due to noise and the receiver is considered to be idle again.

19.3.2.3 Data Field

The length of the data field (number of data bits) can be programmed by bit field SCTRH.FLE. It can vary between 1 and 63 data bits, corresponding to values of SCTRH.FLE = 0 to 62 (the value of 63 is reserved and must not be programmed in ASC mode).

The data field can consist of several data words, e.g. a transfer of 12 data bits can be composed of two 8-bit words, with the 12 bits being split into 8-bits of the first word and 4 bits of the second word. The user software has to take care that the transmit data is available in-time, once a frame has been started. If the transmit buffer runs empty during a running data frame, the passive data level (SCTRL.PDL) is sent out.

The shift direction can be programmed by SCTRL.SDIR. The standard setting for ASC frames with LSB first is achieved with the default setting SDIR = 0.

19.3.2.4 Parity Bit

The ASC allows parity generation for transmission and parity check for reception on frame base. The type of parity can be selected by bit field CCR.PM, common for transmission and reception (no parity, even or odd parity). If the parity handling is disabled, the ASC frame does not contain any parity bit. For consistency reasons, all communication partners have to be programmed to the same parity mode.

After the last data bit of the data field, the transmitter automatically sends out its calculated parity bit if parity generation has been enabled. The receiver interprets this bit as received parity and compares it to its internally calculated one. The received parity bit value and the result of the parity check are monitored in the receiver buffer status registers as receiver buffer status information. These registers contain bits to monitor a protocol-related argument (PAR) and protocol-related error indication (PERR).

19.3.2.5 Stop Bit(s)

Each ASC frame is completed by 1 or 2 of stop bits with the signal level 1 (same level as the idle level). The number of stop bits is programmable by bit PSR.STPB. A new start bit can be transferred directly after the last stop bit.

19.3.3 Operating the ASC

In order to operate the ASC protocol, the following issues have to be considered:

- **Select ASC mode:**
It is recommended to configure all parameters of the ASC that do not change during run time while $CCR.MODE = 0000_B$. Bit field $SCTRL.TRM = 01_B$ has to be programmed. The configuration of the input stages has to be done while $CCR.MODE = 0000_B$ to avoid unintended edges of the input signals and the ASC mode can be enabled by $CCR.MODE = 0010_B$ afterwards.
- **Pin connections:**
Establish a connection of input stage DX0 with the selected receive data input pin (signal DIN) with $DX0CR.INSW = 0$ and configure a transmit data output pin (signal DOUT). For collision or idle detection of the transmitter, the input stage DX1 has to be connected to the selected transmit output pin, also with $DX1CR.INSW = 0$. Additionally, program $DX2CR.INSW = 0$.
Due to the handling of the input data stream by the synchronous protocol handler, the propagation delay of the synchronization in the input stage has to be considered.
- **Bit timing configuration:**
The desired baud rate setting has to be selected, comprising the fractional divider, the baud rate generator and the bit timing. Please note that not all feature combinations can be supported by the application at the same time, e.g. due to propagation delays. For example, the length of a frame is limited by the frequency difference of the transmitter and the receiver device. Furthermore, in order to use the average of samples ($SMD = 1$), the sampling point has to be chosen to respect the signal settling and data propagation times.
- **Data format configuration:**
The word length, the frame length, and the shift direction have to be set up according to the application requirements by programming the registers $SCTRL$ and $SCTRH$. If required by the application, the data input and output signals can be inverted. Additionally, the parity mode has to be configured ($CCR.PM$).

19.3.3.1 Bit Timing

In ASC mode, each bit (incl. protocol bits) is divided into time quanta in order to provide granularity in the sub-bit range to adjust the sample point to the application requirements. The number of time quanta per bit is defined by bit fields BRGL.DCTQ and the length of a time quantum is given by BRGL.PCTQ.

In the example given in [Figure 19-28](#), one bit time is composed of 16 time quanta (BRGL.DCTQ = 15). It is not recommended to program less than 4 time quanta per bit time.

Bit field PCRL.SP determines the position of the sampling point for the bit value. The value of PCRL.SP must not be set to a value greater than BRGL.DCTQ. It is possible to sample the bit value only once per bit time or to take the average of samples. Depending on bit PCRL.SMD, either the current input value is directly sampled as bit value, or a majority decision over the input values sampled at the latest three time quanta is taken into account. The standard ASC bit timing consists of 16 time quanta with sampling after 8 or 9 time quanta with majority decision.

The bit timing setup (number of time quanta and the sampling point definition) is common for the transmitter and the receiver. Due to independent bit timing blocks, the receiver and the transmitter can be in different time quanta or bit positions inside their frames. The transmission of a frame is aligned to the time quanta generation.

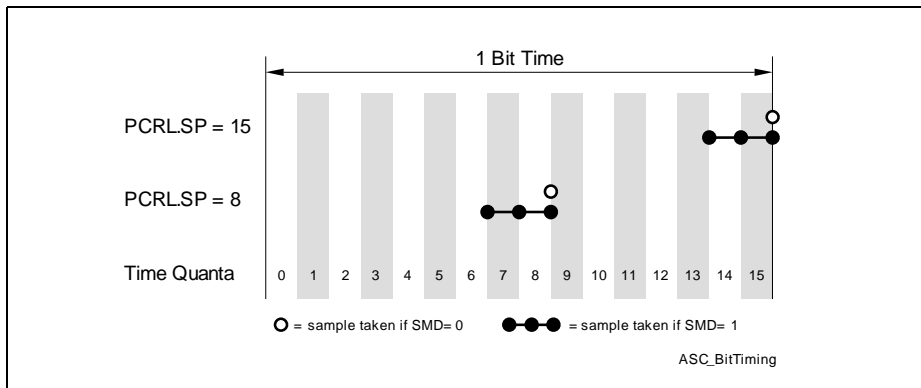


Figure 19-28 ASC Bit Timing

The sample point setting has to be adjusted carefully if collision or idle detection is enabled (via DX1 input signal), because the driver delay and some external delays have to be taken into account. The sample point for the transmit line has to be set to a value where the bit level is stable enough to be evaluated.

If the sample point is located late in the bit time, the signal itself has more time to become stable, but the robustness against differences in the clock frequency of transmitter and receiver decreases.

19.3.3.2 Baud Rate Generation

The baud rate f_{ASC} in ASC mode depends on the number of time quanta per bit time and their timing. The baud rate setting should only be changed while the transmitter and the receiver are idle. The bits in register BRGL define the baud rate setting:

- BRGL.CTQSEL
to define the input frequency f_{CTQIN} for the time quanta generation
- BRGL.PCTQ
to define the length of a time quantum (division of f_{CTQIN} by 1, 2, 3, or 4)
- BRGL.DCTQ
to define the number of time quanta per bit time

The standard setting is given by CTQSEL = 00_B ($f_{CTQIN} = f_{PDIV}$) and PPPEN = 0 ($f_{PPP} = f_{PIN}$). Under these conditions, the baud rate is given by:

$$f_{ASC} = f_{PIN} \times \frac{1}{PDIV + 1} \times \frac{1}{PCTQ + 1} \times \frac{1}{DCTQ + 1} \quad (19.6)$$

In order to generate slower frequencies, two additional divide-by-2 stages can be selected by CTQSEL = 10_B ($f_{CTQIN} = f_{SCLK}$) and PPPEN = 1 ($f_{PPP} = f_{MCLK}$), leading to:

$$f_{ASC} = \frac{f_{PIN}}{2 \times 2} \times \frac{1}{PDIV + 1} \times \frac{1}{PCTQ + 1} \times \frac{1}{DCTQ + 1} \quad (19.7)$$

19.3.3.3 Noise Detection

The ASC receiver permanently checks the data input line of the DX0 stage for noise (the check is independent from the setting of bit PCRL.SMD). Bit PSR.RNS (receiver noise) becomes set if the three input samples of the majority decision are not identical at the sample point for the bit value. The information about receiver noise gets accumulated over several bits in bit PSR.RNS (it has to be cleared by software) and can trigger a protocol interrupt each time noise is detected if enabled by PCRL.RNIEN.

19.3.3.4 Collision Detection

In some applications, such as data transfer over a single data line shared by several sending devices (see [Figure 19-26](#)), several transmitters have the possibility to send on the same data output line TXD. In order to avoid collisions of transmitters being active at the same time or to allow a kind of arbitration, a collision detection has been implemented.

The data value read at the TXD input at the DX1 stage and the transmitted data bit value are compared after the sampling of each bit value. If enabled by PCRL.CDEN = 1 and a bit sent is not equal to the bit read back, a collision is detected and bit PSR.COL is set. If enabled, bit PSR.COL = 1 disables the transmitter (the data output lines become 1)

and generates a protocol interrupt. The content of the transmit shift register is considered as invalid, so the transmit buffer has to be programmed again.

19.3.3.5 Pulse Shaping

For some applications, the 0 level of transmitted bits with the bit value 0 is not applied at the transmit output during the complete bit time. Instead of driving the original 0 level, only a 0 pulse is generated and the remaining time quanta of the bit time are driven with 1 level. The length of a bit time is not changed by the pulse shaping, only the signalling is changed.

In the standard ASC signalling scheme, the 0 level is signalled during the complete bit time with bit value 0 (ensured by programming PCRH.PL = 000_B). In the case PCRH.PL > 000_B, the transmit output signal becomes 0 for the number of time quanta defined by PCRH.PL. In order to support correct reception with pulse shaping by the transmitter, the sample point has to be adjusted in the receiver according to the applied pulse length.

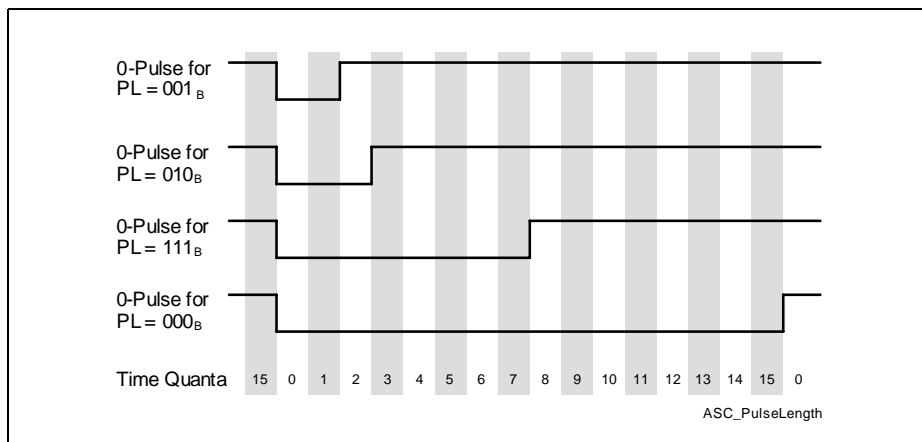


Figure 19-29 Transmitter Pulse Length Control

Figure 19-30 shows an example for the transmission of an 8-bit data word with LSB first and one stop bit (e.g. like for IrDA). The polarity of the transmit output signal has been inverted by SCTRL.DOCFG = 01_B.

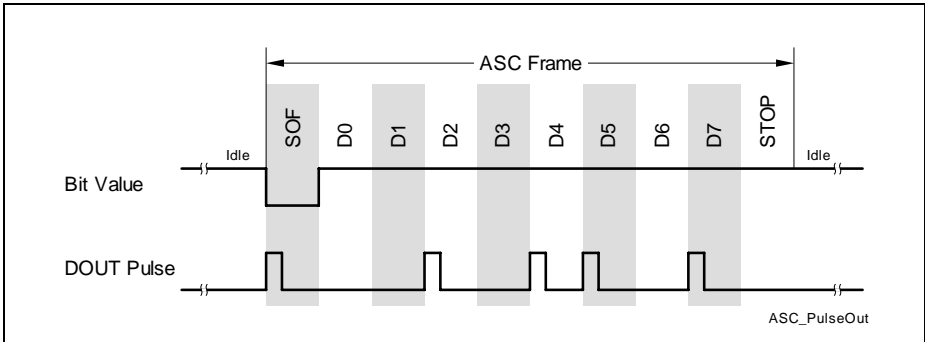


Figure 19-30 Pulse Output Example

19.3.3.6 Automatic Shadow Mechanism

The contents of the protocol control registers PCRL and PCRH, as well as bit field SCTR.H.FLE are internally kept constant while a data frame is transferred by an automatic shadow mechanism (shadowing takes place with each frame start). The registers can be programmed all the time with new settings that are taken into account for the next data frame. During a data frame, the applied (shadowed) setting is not changed, although new values have been written after the start of the data frame.

Bit fields SCTR.H.WLE and SCTR.L.SDIR are shadowed automatically with the start of each data word. As a result, a data frame can consist of data words with a different length. It is recommended to change SCTR.L.SDIR only when no data frame is running to avoid interference between hardware and software.

Please note that the starting point of a data word can be different for a transmitter and a receiver. In order to ensure correct handling, it is recommended to modify SCTR.H.WLE only while transmitter and receiver are both idle. If the transmitter and the receiver are referring to the same data signal (e.g. in a LIN bus system), SCTR.H.WLE can be modified while a data transfer is in progress after the RSI event has been detected.

19.3.3.7 End of Frame Control

The number of bits per ASC frame is defined by bit field SCTR.H.FLE. In order to support different frame length settings for consecutively transmitted frames, this bit field can be modified by hardware. The automatic update mechanism is enabled by TCSRL.FLEMD = 1 (in this case, bits TCSRL.WLEMD, SELMD, and WAMD have to be cleared).

If enabled, the transmit control information TCI automatically overwrites the bit field TCSRL.FLEMD when the ASC frame is started (leading to frames with 1 to 32 data bits). The TCI value represents the written address location of TBUFxx (without additional data

buffer) or INxx (with additional data buffer). With this mechanism, an ASC with 8 data bits is generated by writing a data word to TBUF07 (IN07, respectively).

19.3.3.8 Mode Control Behavior

In ASC mode, the following kernel modes are supported:

- Run Mode 0/1:
Behavior as programmed, no impact on data transfers.
- Stop Mode 0:
Bit PSR.TXIDLE is cleared. A new transmission is not started. A current transmission is finished normally. Bit PSR.RXIDLE is not modified. Reception is still possible. When leaving stop mode 0, bit TXIDLE is set according to PCR.IDM.
- Stop Mode 1:
Bit PSR.TXIDLE is cleared. A new transmission is not started. A current transmission is finished normally. Bit PSR.RXIDLE is cleared. A new reception is not possible. A current reception is finished normally. When leaving stop mode 1, bits TXIDLE and RXIDLE are set according to PCR.IDM.

19.3.3.9 Disabling ASC Mode

In order to switch off ASC mode without any data corruption, the receiver and the transmitter have to be both idle. This is ensured by requesting Stop Mode 1 in register KSCFG. After waiting for the end of the frame, the ASC mode can be disabled.

19.3.3.10 Protocol Interrupt Events

The following protocol-related events are generated in ASC mode and can lead to a protocol interrupt. The collision detection and the transmitter frame finished events are related to the transmitter, whereas the receiver events are given by the synchronization break detection, the receiver noise detection, the format error checks and the end of the received frame.

Please note that the bits in register PSR are not automatically cleared by hardware and have to be cleared by software in order to monitor new incoming events.

- Collision detection:
This interrupt indicates that the transmitted value (DOUT) does not match with the input value of the DX1 input stage at the sample point of a bit. For more details refer to [Page 19-116](#).
- Transmitter frame finished:
This interrupt indicates that the transmitter has completely finished a frame. Bit PSR.TFF becomes set at the end of the last stop bit. The DOUT signal assignment to port pins can be changed while no transmission is in progress.
- Receiver frame finished:
This interrupt indicates that the receiver has completely finished a frame. Bit

PSR.RFF becomes set at the end of the last stop bit. The DIN signal assignment to port pins can be changed while no reception is in progress.

- Synchronization break detection:
This interrupt can be used in LIN networks to indicate the reception of the synchronization break symbol (at the beginning of a LIN frame).
- Receiver noise detection:
This interrupt indicates that the input value at the sample point of a bit and at the two time quanta before are not identical.
- Format error:
The bit value of the stop bit(s) is defined as 1 level for the ASC protocol. A format error is signalled if the sampled bit value of a stop bit is 0.

19.3.3.11 Data Transfer Interrupt Handling

The data transfer interrupts indicate events related to ASC frame handling.

- Transmit buffer interrupt TBI:
Bit PSR.TBIF is set after the start of first data bit of a data word. This is the earliest point in time when a new data word can be written to TBUF.
With this event, bit TCSR.LTDV is cleared and new data can be loaded to the transmit buffer.
- Transmit shift interrupt TSI:
Bit PSR.TSIF is set after the start of the last data bit of a data word.
- Receiver start interrupt RSI:
Bit PSR.RSIF is set after the sample point of the first data bit of a data word.
- Receiver interrupt RI and alternative interrupt AI:
Bit PSR.RIF is set after the sampling point of the last data bit of a data word if this data word is not directly followed by a parity bit (parity generation disabled or not the last word of a data frame).
If the data word is directly followed by a parity bit (last data word of a data frame and parity generation enabled), bit PSR.RIF is set after the sampling point of the parity bit if no parity error has been detected. If a parity error has been detected, bit PSR.AIF is set instead of bit PSR.RIF.
The first data word of a data frame is indicated by RBUFSR.SOF = 1 for the received word.
Bit PSR.RIF is set for a receiver interrupt RI with WA = 0. Bit PSR.AIF is set for a alternative interrupt AI with WA = 1.

19.3.3.12 Protocol-Related Argument and Error

The protocol-related argument (RBUFSR.PAR) and the protocol-related error (RBUFSR.PERR) are two flags that are assigned to each received data word in the corresponding receiver buffer status registers.

In ASC mode, the received parity bit is monitored by the protocol-related argument and the result of the parity check by the protocol-related error indication (0 = received parity bit equal to calculated parity value). This information being elaborated only for the last received data word of each data frame, both bit positions are 0 for data words that are not the last data word of a data frame or if the parity generation is disabled.

19.3.3.13 Receive Buffer Handling

If a receive FIFO buffer is available (CCFG.RB = 1) and enabled for data handling (RBCTRH.SIZE > 0), it is recommended to set RBCTRH.RCIM = 11_B in ASC mode. This leads to an indication that the data word has been the first data word of a new data frame if bit OUTRH.RCI[0] = 1, a parity error is indicated by OUTRH.RCI[4] = 1, and the received parity bit value is given by OUTRH.RCI[3].

The standard receive buffer event and the alternative receive buffer event can be used for the following operations in RCI mode (RBCTRH.RNM = 1):

- A standard receive buffer event indicates that a data word can be read from OUTRL that has been received without parity error.
- An alternative receive buffer event indicates that a data word can be read from OUTRL that has been received with parity error.

19.3.3.14 Sync-Break Detection

The receiver permanently checks the DIN signal for a certain number of consecutive bit times with 0 level. The number is given by the number of programmed bits per frame (SCTRH.FLE) plus 2 (in the case without parity) or plus 3 (in the case with parity). If a 0 level is detected at a sample point of a bit after this event has been found, bit PSR.SBD is set and additionally, a protocol interrupt can be generated (if enabled by PCRL.SBD = 1). The counting restarts from 0 each time a falling edge is found at input DIN. This feature can be used for the detection of a synchronization break for slave devices in a LIN bus system (the master doesn't check for sync break).

For example, in a configuration for 8 data bits without parity generation, bit PCRL.SBD is set after at the next sample point at 0 level after 10 complete bit times have elapsed (representing the sample point of the 11th bit time since the first falling edge).

19.3.3.15 Transfer Status Indication

The receiver status can be monitored by flag PSR[9] = BUSY if bit PCRH.CTR[16] (receiver status enable RSTEN) is set. In this case, bit BUSY is set during a complete frame reception from the beginning of the start of frame bit to the end of the last stop bit.

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The transmitter status can be monitored by flag PSR[9] = BUSY if bit PCRH.CTR[17] (transmitter status enable TSTEN) is set. In this case, bit BUSY is set during a complete frame reception from the beginning of the start of frame bit to the end of the last stop bit. If both bits RSTEN and TSTEN are set, flag BUSY indicates the logical OR-combination of the receiver and the transmitter status. If both bits are cleared, flag BUSY is not modified depending on the transfer status (status changes are ignored).

19.3.4 ASC Protocol Registers

In ASC mode, the registers PCRH, PCRL and PSR handle ASC related information.

19.3.4.1 ASC Protocol Control Registers

In ASC mode, the PCRL/PCRH register bits or bit fields are defined as described in this section.

PCRL

Protocol Control Register L [ASC Mode]

(40_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PL			SP					FFI EN	FEI EN	RNI EN	CD EN	SBI EN	IDM	STP B	SMD
rw			rw					rw	rw	rw	rw	rw	rw	rw	rw

Field	Bits	Type	Description
SMD	0	rw	Sample Mode This bit field defines the sample mode of the ASC receiver. The selected data input signal can be sampled only once per bit time or three times (in consecutive time quanta). When sampling three times, the bit value shifted in the receiver shift register is given by a majority decision among the three sampled values. 0 _B Only one sample is taken per bit time. The current input value is sampled. 1 _B Three samples are taken per bit time and a majority decision is made.
STPB	1	rw	Stop Bits This bit defines the number of stop bits in an ASC frame. 0 _B The number of stop bits is 1. 1 _B The number of stop bits is 2.

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Field	Bits	Type	Description
IDM	2	rw	Idle Detection Mode This bit defines if the idle detection is switched off or based on the frame length. 0 _B The bus idle detection is switched off and bits PSR.TXIDLE and PSR.RXIDLE are set automatically to enable data transfers without checking the inputs before. 1 _B The bus is considered as idle after a number of consecutive passive bit times defined by SCTRH.FLE plus 2 (in the case without parity bit) or plus 3 (in the case with parity bit).
SBIEN	3	rw	Synchronization Break Interrupt Enable This bit enables the generation of a protocol interrupt if a synchronization break is detected. The automatic detection is always active, so bit SBD can be set independently of SBIEN. 0 _B The interrupt generation is disabled. 1 _B The interrupt generation is enabled.
CDEN	4	rw	Collision Detection Enable This bit enables the reaction of a transmitter to the collision detection. 0 _B The collision detection is disabled. 1 _B If a collision is detected, the transmitter stops its data transmission, outputs a 1, sets bit PSR.COL and generates a protocol interrupt. In order to allow data transmission again, PSR.COL has to be cleared by software.
RNIEN	5	rw	Receiver Noise Detection Interrupt Enable This bit enables the generation of a protocol interrupt if receiver noise is detected. The automatic detection is always active, so bit PSR.RNS can be set independently of PCRL.RNIEN. 0 _B The interrupt generation is disabled. 1 _B The interrupt generation is enabled.

Field	Bits	Type	Description
FEIEN	6	rw	Format Error Interrupt Enable This bit enables the generation of a protocol interrupt if a format error is detected. The automatic detection is always active, so bits PSR.FER0/FER1 can be set independently of PCRL.FEIEN. 0 _B The interrupt generation is disabled. 1 _B The interrupt generation is enabled.
FFIEN	7	rw	Frame Finished Interrupt Enable This bit enables the generation of a protocol interrupt if the receiver or the transmitter reach the end of a frame. The automatic detection is always active, so bits PSR.RFF or PSR.TFF can be set independently of PCRL.FFIEN. 0 _B The interrupt generation is disabled. 1 _B The interrupt generation is enabled.
SP	[12:8]	rw	Sample Point This bit field defines the sample point of the bit value. The sample point must not be located outside the programmed bit timing ($PCRL.SP \leq BRGL.DCTQ$).
PL	[15:13]	rw	Pulse Length This bit field defines the length of a 0 data bit, counted in time quanta, starting with the time quantum 0 of each bit time. Each bit value that is a 0 can lead to a 0 pulse that is shorter than a bit time, e.g. for IrDA applications. The length of a bit time is not changed by PL, only the length of the 0 at the output signal. The pulse length must not be longer than the programmed bit timing ($PCRH.PL \leq BRGL.DCTQ$). This bit field is only taken into account by the transmitter and is ignored by the receiver. 000 _B The pulse length is equal to the bit length (no shortened 0). 001 _B The pulse length of a 0 bit is 2 time quanta. 010 _B The pulse length of a 0 bit is 3 time quanta. ... 111 _B The pulse length of a 0 bit is 8 time quanta.

PCRH

Protocol Control Register H [ASC Mode]

(42_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
M							0							TST	RST
CLK														EN	EN
rw							r							rw	rw

Field	Bits	Type	Description
RSTEN	0	rw	Receiver Status Enable This bit enables the modification of flag PSR[9] = BUSY according to the receiver status. 0 _B Flag PSR[9] is not modified depending on the receiver status. 1 _B Flag PSR[9] is set during the complete reception of a frame.
TSTEN	1	rw	Transmitter Status Enable This bit enables the modification of flag PSR[9] = BUSY according to the transmitter status. 0 _B Flag PSR[9] is not modified depending on the transmitter status. 1 _B Flag PSR[9] is set during the complete transmission of a frame.
0	[14:2]	r	Reserved Returns 0 if read; not modified in ASC mode.
MCLK	15	rw	Master Clock Enable This bit enables the generation of the master clock MCLK. 0 _B The MCLK generation is disabled and the MCLK signal is 0. 1 _B The MCLK generation is enabled.

19.3.4.2 ASC Protocol Status Register

In ASC mode, the PSR register bits or bit fields are defined as described in this section. The bits and bit fields in register PSR are not cleared by hardware.

The flags in the PSR register can be cleared by writing a 1 to the corresponding bit position in register PSCR. Writing a 1 to a bit position in PSR sets the corresponding flag, but doesn't lead to further actions (no interrupt generation). Writing a 0 has no effect. The PSR flags should be cleared by software before enabling a new protocol.

PSR

Protocol Status Register [ASC Mode] (44_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AIF	RIF	TBIF	TSIF	DLIF	RSIF	BU SY	TFF	RFF	FER 1	FER 0	RNS	COL	SBD	RX IDLE	TX IDLE
rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
TXIDLE	0	rwh	Transmission Idle This bit shows if the transmit line (DX1) has been idle. A frame transmission can only be started if TXIDLE is set. 0 _B The transmitter line has not yet been idle. 1 _B The transmitter line has been idle and frame transmission is possible.
RXIDLE	1	rwh	Reception Idle This bit shows if the receive line (DX0) has been idle. A frame reception can only be started if RXIDLE is set. 0 _B The receiver line has not yet been idle. 1 _B The receiver line has been idle and frame reception is possible.
SBD	2	rwh	Synchronization Break Detected¹⁾ This bit is set if a programmed number of consecutive bit values with level 0 has been detected (called synchronization break, e.g. in a LIN bus system). 0 _B A synchronization break has not yet been detected. 1 _B A synchronization break has been detected.

Field	Bits	Type	Description
COL	3	rwh	Collision Detected¹⁾ This bit is set if a collision has been detected (with PCRL.CDEN = 1). 0 _B A collision has not yet been detected and frame transmission is possible. 1 _B A collision has been detected and frame transmission is not possible.
RNS	4	rwh	Receiver Noise Detected¹⁾ This bit is set if receiver noise has been detected. 0 _B Receiver noise has not been detected. 1 _B Receiver noise has been detected.
FER0	5	rwh	Format Error in Stop Bit 0¹⁾ This bit is set if a 0 has been sampled in the stop bit 0 (called format error 0). 0 _B A format error 0 has not been detected. 1 _B A format error 0 has been detected.
FER1	6	rwh	Format Error in Stop Bit 1¹⁾ This bit is set if a 0 has been sampled in the stop bit 1 (called format error 1). 0 _B A format error 1 has not been detected. 1 _B A format error 1 has been detected.
RFF	7	rwh	Receive Frame Finished¹⁾ This bit is set if the receiver has finished the last stop bit. 0 _B The received frame is not yet finished. 1 _B The received frame is finished.
TFF	8	rwh	Transmitter Frame Finished¹⁾ This bit is set if the transmitter has finished the last stop bit. 0 _B The transmitter frame is not yet finished. 1 _B The transmitter frame is finished.
BUSY	9	r	Transfer Status BUSY This bit indicates the receiver status (if PCRH.RSTEN = 1) or the transmitter status (if PCRH.TSTEN = 1) or the logical OR combination of both (if PCRH.RSTEN = PCRH.TSTEN = 1). 0 _B A data transfer does not take place. 1 _B A data transfer currently takes place.
RSIF	10	rwh	Receiver Start Indication Flag 0 _B A receiver start event has not occurred. 1 _B A receiver start event has occurred.

Field	Bits	Type	Description
DLIF	11	rwh	Data Lost Indication Flag 0 _B A data lost event has not occurred. 1 _B A data lost event has occurred.
TSIF	12	rwh	Transmit Shift Indication Flag 0 _B A transmit shift event has not occurred. 1 _B A transmit shift event has occurred.
TBIF	13	rwh	Transmit Buffer Indication Flag 0 _B A transmit buffer event has not occurred. 1 _B A transmit buffer event has occurred.
RIF	14	rwh	Receive Indication Flag 0 _B A receive event has not occurred. 1 _B A receive event has occurred.
AIF	15	rwh	Alternative Receive Indication Flag 0 _B An alternative receive event has not occurred. 1 _B An alternative receive event has occurred.

1) This status bit can generate a protocol interrupt (see [Page 19-24](#)). The general interrupt status flags are described in the general interrupt chapter.

19.3.5 Hardware LIN Support

In order to support the LIN protocol, bit TCSRL.FLEMD = 1 should be set for the master. For slave devices, it can be cleared and the fixed number of 8 data bits has to be set (SCTRH.FLE = 7_H). For both, master and slave devices, the parity generation has to be switched off (CCR.PM = 00_B) and transfers take place with LSB first (SCTRL.SDIR = 0) and 1 stop bit (PCRL.STPB = 0).

The Local Interconnect Network (LIN) data exchange protocol contains several symbols that can all be handled in ASC mode. Each single LIN symbol represents a complete ASC frame. The LIN bus is a master-slave bus system with a single master and multiple slaves (for the exact definition please refer to the official LIN specification).

A complete LIN frame contains the following symbols:

- Synchronization break:

The master sends a synchronization break to signal the beginning of a new frame. It contains at least 13 consecutive bit times at 0 level, followed by at least one bit time at 1 level (corresponding to 1 stop bit). Therefore, TBUF11 (or IN11) has to be written with 0 (leading to a frame with SOF followed by 12 data bits at 0 level).

A slave device shall detect 11 consecutive bit times at 0 level, which done by the synchronization break detection. Bit PSR.SBD is set if such an event is detected and a protocol interrupt can be generated. Additionally, the received data value of 0 appears in the receive buffer and a format error is signaled.

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If the baud rate of the slave has to be adapted to the master, the baud rate measurement has to be enabled for falling edges by setting $BRGL.TMEN = 1$, $DX0CR.CM = 10_H$ and $DX1CR.CM = 00_H$ before the next symbol starts.

- Synchronization byte:

The master sends this symbol after writing the data value 55_H to TBUF07 (or IN07). A slave device can either receive this symbol without any further action (and can discard it) or it can use the falling edges for baud rate measurement. Bit $PSR.TSIF = 1$ (with optionally the corresponding interrupt) indicates the detection of a falling edge and the capturing of the elapsed time since the last falling edge in $BRGH.PDIV$. Valid captured values can be read out after the second, third, fourth and fifth activation of $TSIF$. After the fifth activation of $TSIF$ within this symbol, the baud rate detection has to be disabled ($BRGL.TMEN = 0$) and $BRGH.PDIV$ can be programmed with the formerly captured value divided by twice the number of time quanta per bit (assuming $BRGL.PCTQ = 00_B$).

In order to avoid a $PDIV$ overflow during baud rate measurement, the prescaler settings of the fractional divider must be set in a way that leads to a target value of $PDIV$ well below $1024 / (2 \times \text{number of time quanta per bit time})$. As this procedure leads to low $PDIV$ target values, the baud rate measurement accuracy becomes limited. Therefore, the following procedure is recommended:

- Slowing down the fractional divider for baud rate measurement by $2 \times \text{number of time quanta per bit time}$.
- Writing the current value of $FDRL.DM$ again to restart the fraction divider.
- Switching-on the baud rate measurement by writing $BRGL.TMEN = 1$ (note that the synchronization break detection is not possible when baud rate measurement is enabled).
- Restoring the fractional divider to its original settings.
- Switching-off the baud rate measurement by writing $BRGL.TMEN = 0$.
- The measurement result in $BRGH.PDIV$ can now be directly used as baud rate setting.

- Other symbols:

The other symbols of a LIN frame can be handled with ASC data frames without specific actions.

If LIN frames should be sent out on a frame base by the LIN master, the input $DX2$ can be connected to external timers to trigger the transmit actions (e.g. the synchronization break symbol has been prepared but is started if a trigger occurs). Please note that during the baud rate measurement of the ASC receiver, no transmission can take place by the ASC transmitter of the same USIC channel.

19.4 Synchronous Serial Channel (SSC)

The synchronous serial channel SSC covers the data transfer function of an SPI-like module. It can handle reception and transmission of synchronous data frames between a device operating in master mode and at least one device in slave mode. The SSC mode is selected by $CCR.MODE = 0001_B$ with $CCFG.SSC = 1$ (SSC mode is available).

This chapter contains the following sections:

- Signal description (see [Page 19-131](#))
- General SSC issues (see [Page 19-139](#))
- Master mode operation (see [Page 19-143](#))
- Slave mode operation (see [Page 19-150](#))
- Protocol registers (see [Page 19-152](#))
- Timing considerations (see [Page 19-158](#))

19.4.1 Signal Description

A synchronous SSC data transfer is characterized by a simultaneous transfer of a shift clock signal together with the transmit and/or receive data signal(s) to determine when the data is valid (definition of transmit and sample point).

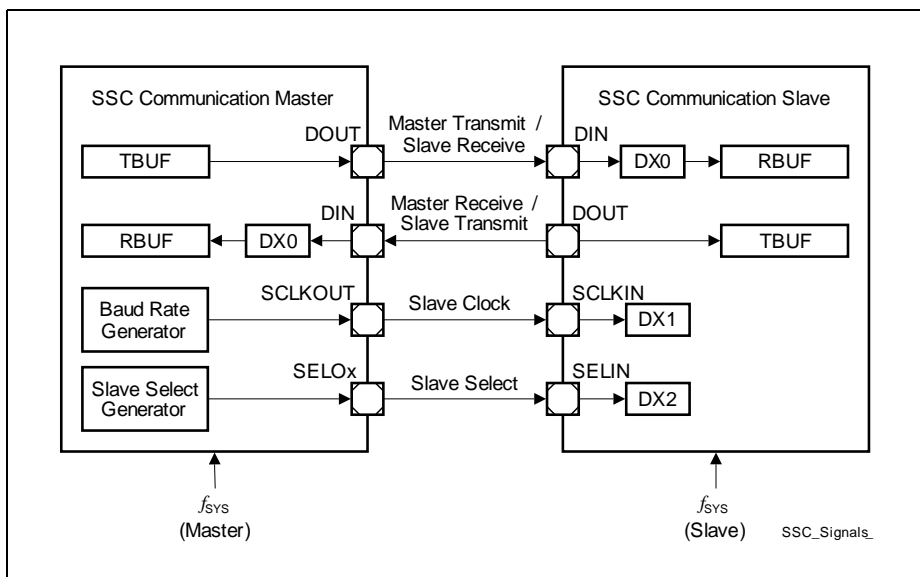


Figure 19-31 SSC Signals for Full-Duplex Communication

In order to explicitly indicate the start and the end of a data transfer and to address more than one slave devices individually, the SSC module supports the handling of slave

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select signals. They are optional and are not necessarily needed for SSC data transfers. The SSC module supports up to 8 different slave select output signals for master mode operation (named SELO_x, with $x = 0-7$) and 1 slave select input SELIN for slave mode. In most applications, the slave select signals are active low.

A device operating in master mode controls the start and end of a data frame, as well as the generation of the shift clock and slave select signals. This comprises the baud rate setting for the shift clock and the delays between the shift clock and the slave select output signals. If several SSC modules are connected together, there can be only one SSC master at a time, but several slaves. Slave devices receive the shift clock and optionally a slave select signal(s). For the programming of the input stages DX0, DX1, and DX2 please refer to [Page 19-36](#).

Table 19-8 SSC Communication Signals

SSC Mode	Receive Data	Transmit Data	Shift Clock	Slave Select(s)
Master	MRST ¹⁾ , input DIN, handled by DX0	MTSR ²⁾ , Output DOUT	Output SCLKOUT	Output(s) SELO _x
Slave	MTSR, input DIN, handled by DX0	MRST, Output DOUT	Input SCLKIN, handled by DX1	input SELIN, handled by DX2

1) MRST = master receive slave transmit, also known as MISO = master in slave out

2) MTSR = master transmit slave receive, also known as MOSI = master out slave in

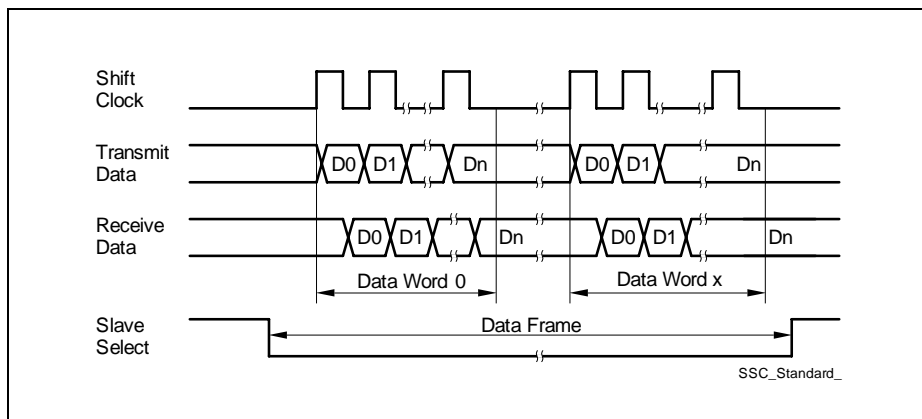


Figure 19-32 4-Wire SSC Standard Communication Signals

19.4.1.1 Transmit and Receive Data Signals

In half-duplex mode, a single data line is used, either for data transfer from the master to a slave or from a slave to the master. In this case, MRST and MTSR are connected together, one signal as input, the other one as output, depending on the data direction. The user software has to take care about the data direction to avoid data collision (e.g. by preparing dummy data of all 1s for transmission in case of a wired AND connection with open-drain drivers or by enabling/disabling push/pull output drivers). In full-duplex mode, data transfers take place in parallel between the master device and a slave device via two independent data signals MTSR and MRST, as shown in **Figure 19-31**.

The receive data input signal DIN is handled by the input stage DX0. In master mode (referring to MRST) as well as in slave mode (referring to MTSR), the data input signal DIN is taken from an input pin. The signal polarity of DOUT (data output) with respect to the data bit value can be configured in block DOCFG (data output configuration) by bit field SCTRL.DOCFG.

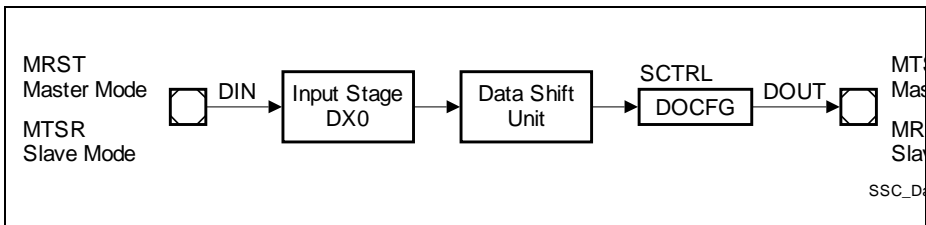


Figure 19-33 SSC Data Signals

19.4.1.2 Shift Clock Signals

The shift clock signal is handled by the input stage DX1. In slave mode, the signal SCLKIN is received from an external master, so the DX1 stage has to be connected to an input pin. The input stage can invert the received input signal to adapt to the polarity of SCLKIN to the function of the data shift unit (data transmission on rising edges, data reception on falling edges).

In master mode, the shift clock is generated by the internal baud rate generator. The output signal SCLK of the baud rate generator is taken as shift clock input for the data shift unit. The internal signal SCLK is made available for external slave devices by signal SCLKOUT.

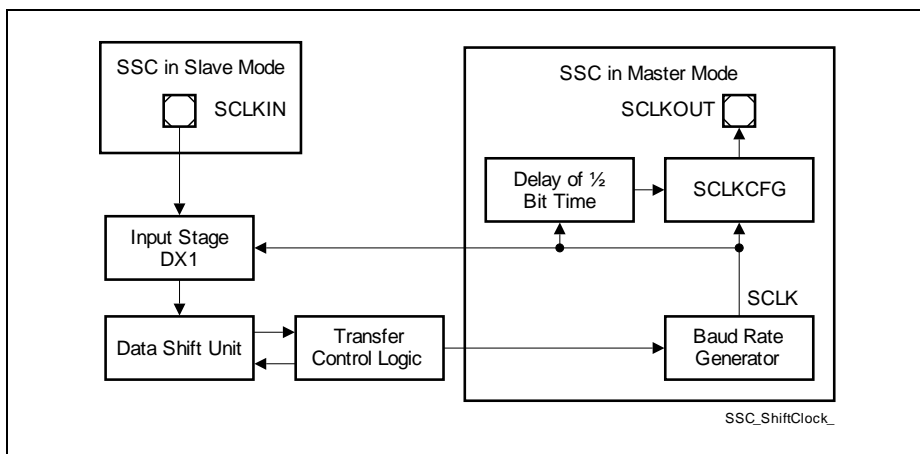


Figure 19-34 SSC Shift Clock Signals

Due to the multitude of different SSC applications, in master mode, there are different ways to configure the shift clock output signal SCLKOUT with respect to SCLK. This is done in the block SCLKCFG (shift clock configuration) by bit field BRGH.SCLKCFG, allowing 4 possible settings, as shown in [Figure 19-35](#).

- No delay, no polarity inversion (SCLKCFG = 00_B, SCLKOUT equals SCLK):
 The inactive level of SCLKOUT is 0, while no data frame is transferred. The first data bit of a new data frame is transmitted with the first rising edge of SCLKOUT and the first data bit is received in with the first falling edge of SCLKOUT. The last data bit of a data frame is transmitted with the last rising clock edge of SCLKOUT and the last data bit is received in with the last falling edge of SCLKOUT. This setting can be used in master and in slave mode. It corresponds to the behavior of the internal data shift unit.
- No delay, polarity inversion (SCLKCFG = 01_B):
 The inactive level of SCLKOUT is 1, while no data frame is transferred. The first data

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bit of a new data frame is transmitted with the first falling clock edge of SCLKOUT and the first data bit is received with the first rising edge of SCLKOUT. The last data bit of a data frame is transmitted with the last falling edge of SCLKOUT and the last data bit is received with the last rising edge of SCLKOUT. This setting can be used in master and in slave mode.

- SCLKOUT is delayed by 1/2 shift clock period, no polarity inversion (SCLKCFG = 10_B):

The inactive level of SCLKOUT is 0, while no data frame is transferred.

The first data bit of a new data frame is transmitted 1/2 shift clock period before the first rising clock edge of SCLKOUT. Due to the delay, the next data bits seem to be transmitted with the falling edges of SCLKOUT. The last data bit of a data frame is transmitted 1/2 period of SCLKOUT before the last rising clock edge of SCLKOUT. The first data bit is received 1/2 shift clock period before the first falling edge of SCLKOUT. Due to the delay, the next data bits seem to be received with the rising edges of SCLKOUT. The last data bit is received 1/2 period of SCLKOUT before the last falling clock edge of SCLKOUT.

This setting can be used only in master mode and not in slave mode (the connected slave has to provide the first data bit before the first SCLKOUT edge, e.g. as soon as it is addressed by its slave select).

- SCLKOUT is delayed by 1/2 shift clock period, polarity inversion (SCLKCFG = 11_B):

The inactive level of SCLKOUT is 1, while no data frame is transferred.

The first data bit of a new data frame is transmitted 1/2 shift clock period before the first falling clock edge of SCLKOUT. Due to the delay, the next data bits seem to be transmitted with the rising edges of SCLKOUT. The last data bit of a data frame is transmitted 1/2 period of SCLKOUT before the last falling clock edge of SCLKOUT. The first data bit is received 1/2 shift clock period before the first rising edge of SCLKOUT. Due to the delay, the next data bits seem to be received with the falling edges of SCLKOUT. The last data bit is received 1/2 period of SCLKOUT before the last rising clock edge of SCLKOUT.

This setting can be used only in master mode and not in slave mode (the connected slave has to provide the first data bit before the first SCLKOUT edge, e.g. as soon as it is addressed by its slave select).

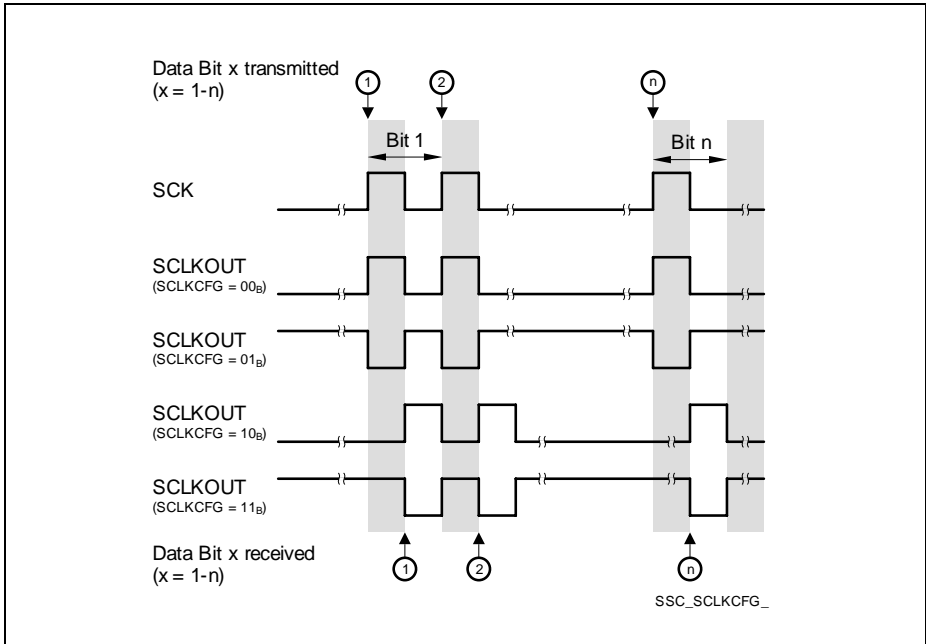


Figure 19-35 SCLKOUT Configuration in SSC Master Mode

Note: If a configuration with delay is selected and a slave select line is used, the slave select delays have to be set up accordingly.

19.4.1.3 Slave Select Signals

The slave select signal is handled by the input stage DX2. In slave mode, the input signal SELIN is received from an external master via an input pin. The input stage can invert the received input signal to adapt the polarity of signal SELIN to the function of the data shift unit (the module internal signals are considered as high active, so a data transfer is only possible while the slave select input of the data shift unit is at 1-level, otherwise, shift clock pulses are ignored and do not lead to data transfers). If an input signal SELIN is low active, it should be inverted in the DX2 input stage.

In master mode, a master slave select signal MSLS is generated by the internal slave select generator. In order to address different external slave devices independently, the internal MSLS signal is made available externally via up to 8 SELOx output signals that can be configured by the block SELCFG (select configuration).

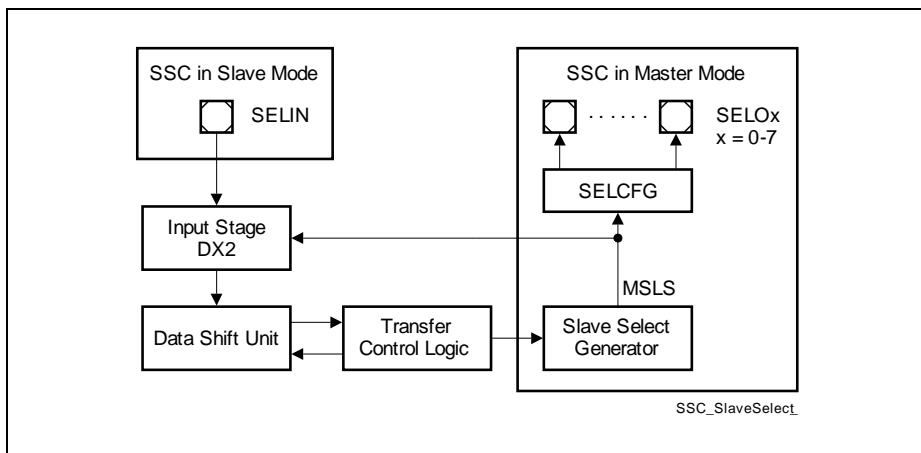


Figure 19-36 SSC Slave Select Signals

The control of the SELCFG block is based on protocol specific bits and bit fields in the protocol control register parts PCRL and PCRH. For the generation of the MSLS signal please refer to [Section 19.4.3.2](#).

- PCRL.SELCTR to chose between direct and coded select mode
- PCRL.SELINV to invert the SELOx outputs
- PCRH.SELO[7:0] as individual value for each SELOx line

The SELCFG block supports the following configurations of the SELOx output signals:

- Direct Select Mode (SELCTR = 1):
 Each SELOx line (with x = 0-7) can be directly connected to an external slave device. If bit x in bit field SELO is 0, the SELOx output is permanently inactive. A SELOx output becomes active while the internal signal MSLS is active (see

Section 19.4.3.2) and bit x in bit field SELO is 1. Several external slave devices can be addressed in parallel if more than one bit in bit field SELO are set during a data frame. The number of external slave devices that can be addressed individually is limited to the number of available SELOx outputs.

- Coded Select Mode (SELCTR = 0):
The SELOx lines (with x = 1-7) can be used as addresses for an external address decoder to increase the number of external slave devices. These lines only change with the start of a new data frame and have no other relation to MSLS. Signal SELO0 can be used as enable signal for the external address decoder. It is active while MSLS is active (during a data frame) and bit 0 in bit field SELO is 1. Furthermore, in coded select mode, this output line is delayed by one cycle of f_{SYS} compared to MSLS to allow the other SELOx lines to stabilize before enabling the address decoder.

19.4.2 Operating the SSC

This chapter contains SSC issues, that are of general interest and not directly linked to either master mode or slave mode.

19.4.2.1 Automatic Shadow Mechanism

The contents of the baud rate control registers BRGL and BRGH, bit field SCTRH.FLE as well as the protocol control registers PCRL and PCRH are internally kept constant while a data frame is transferred (= while MSLS is active) by an automatic shadow mechanism. The registers can be programmed all the time with new settings that are taken into account for the next data frame. During a data frame, the applied (shadowed) setting is not changed, although new values have been written after the start of the data frame.

Bit fields SCTRH.WLE and SCTRL.SDIR are shadowed automatically with the start of each data word. As a result, a data frame can consist of data words with a different length. It is recommended to change SCTRL.SDIR only when no data frame is running to avoid interference between hardware and software.

Please note that the starting point of a data word are different for a transmitter (first bit transmitted) and a receiver (first bit received). In order to ensure correct handling, it is recommended to refer to the receive start interrupt RSI before modifying SCTRL.WLE. If TCSRL.WLEMD = 1, it is recommended to update TCSRL and TBUFxx after the receiver start interrupt has been generated.

19.4.2.2 Mode Control Behavior

In SSC mode, the following kernel modes are supported:

- Run Mode 0/1:
Behavior as programmed, no impact on data transfers.
- Stop Mode 0/1:
The content of the transmit buffer is considered as not valid for transmission. Although being considered as 0, bit TCSRL.TDV it is not modified by the stop mode condition.
In master mode, a currently running word transfer is finished normally, but no new data word is started (the stop condition is not considered as end-of-frame condition). In slave mode, a currently running word transfer is finished normally. Passive data will be sent out instead of a valid data word if a data word transfer is started by the external master while the slave device is in stop mode. In order to avoid passive slave transmit data, it is recommended not to program stop mode for an SSC slave device if the master device does not respect the slave device's stop mode.

19.4.2.3 Disabling SSC Mode

In order to disable SSC mode without any data corruption, the receiver and the transmitter have to be both idle. This is ensured by requesting Stop Mode 1 in register KSCFG. After Stop Mode 1 has been acknowledged by KSCFG.2 = 1, the SSC mode can be disabled.

19.4.2.4 Data Frame Control

An SSC data frame can consist of several consecutive data words that may be separated by an inter-word delay. Without inter-word delay, the data words seem to form a longer data word, being equivalent to a data frame. The length of the data words are most commonly identical within a data frame, but may also differ from one word to another. The data word length information (defined by SCTR.H.WLE) is evaluated for each new data word, whereas the frame length information (defined by SCTR.H.FLE) is evaluated at the beginning at each start of a new frame.

The length of an SSC data frame can be defined in two different ways:

- By the number of bits per frame:
If the number of bits per data frame is defined (frame length FLE), a slave select signal is not necessarily required to indicate the start and the end of a data frame.
If the programmed number of bits per frame is reached within a data word, the frame is considered as finished and remaining data bits in the last data word are ignored and are not transferred.
This method can be applied for data frames with up to 63 data bits.
- By the slave select signal:
If the number of bits per data frame is not known, the start/end information of a data frame is given by a slave select signal. If a deactivation of the slave select signal is detected within a data word, the frame is considered as finished and remaining data bits in the last data word are ignored and are not transferred.
This method has to be applied for frames with more than 63 data bits (programming limit of FLE). The advantage of slave select signals is the clearly defined start and end condition of data frames in a data stream. Furthermore, slave select signals allow to address slave devices individually.

19.4.2.5 Parity Mode

Parity generation is not supported in SSC mode and bit field CCR.PM = 00_B has to be programmed.

19.4.2.6 Transfer Mode

In SSC mode, bit field SCTRL.TRM = 01_B has to be programmed to allow data transfers. Setting SCTRL.TRM = 00_B disables and stops the data transfer immediately.

19.4.2.7 Data Transfer Interrupt Handling

The data transfer interrupts indicate events related to SSC frame handling.

- Transmit buffer interrupt TBI:
Bit PSR.TBIF is set after the start of first data bit of a data word.
- Transmit shift interrupt TSI:
Bit PSR.TSIF is set after the start of the last data bit of a data word.
- Receiver start interrupt RSI:
Bit PSR.RSIF is set after the reception of the first data bit of a data word.
With this event, bit TCSRL.TDV is cleared and new data can be loaded to the transmit buffer.
- Receiver interrupt RI:
The reception of the second, third, and all subsequent words in a multi-word frame is always indicated by RBUFSSR.SOF = 0. Bit PSR.RIF is set after the reception of the last data bit of a data word if RBUFSSR.SOF = 0.
Bit RBUFSSR.SOF indicates whether the received data word has been the first data word of a multi-word frame or some subsequent word. In SSC mode, it decides if alternative interrupt or receive interrupt is generated.
- Alternative interrupt AI:
The reception of the first word in a frame is always indicated by RBUFSSR.SOF = 1. This is true both in case of reception of multi-word frames and single-word frames. In SSC mode, this results in setting PSR.AIF.

19.4.2.8 Protocol-Related Argument and Error

The protocol-related argument (RBUFSSR.PAR) and the protocol-related error (RBUFSSR.PERR) are two flags that are assigned to each received data word in the corresponding receiver buffer status registers.

In SSC mode, these flags are always 0 (parity handling must be disabled). The received start of frame indication is monitored by the protocol-related error indication (0 = received word is not the first word of a frame, 1 = received word is the first word of a new frame).

19.4.2.9 Receive Buffer Handling

If a receive FIFO buffer is available (CCFG.RB = 1) and enabled for data handling (RBCTRH.SIZE > 0), it is recommended to set RBCTRH.RCIM = 01_B in SSC mode. This leads to an indication that the data word has been the first data word of a new data frame if bit OUTRH.RCI[4] = 1, and the word length of the received data is given by OUTRH.RCI[3:0].

The standard receive buffer event and the alternative receive buffer event can be used for the following operation in RCI mode (RBCTRH.RNM = 1):

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- A standard receive buffer event indicates that a data word can be read from OUTRL that has not been the first word of a data frame.
- An alternative receive buffer event indicates that the first data word of a new data frame can be read from OUTRL.

19.4.3 Operating the SSC in Master Mode

In order to operate the SSC in master mode, the following issues have to be considered:

- **Select SSC mode:**
It is recommended to configure all parameters of the SSC that do not change during run time while $CCR.MODE = 0000_B$. Bit field $SCTRL.TRM = 01_B$ has to be programmed. The configuration of the input stages has to be done while $CCR.MODE = 0000_B$ to avoid unintended edges of the input signals and the SSC mode can be enabled by $CCR.MODE = 0001_B$ afterwards.
- **Pin connections:**
Establish a connection of input stage DX0 with the selected receive data input pin (DIN) with $DX0CR.INSW = 1$ and configure a transmit data output pin (DOUT).
- **Baud rate generation:**
The desired baud rate setting has to be selected, comprising the fractional divider and the baud rate generator. Bit $DX1CR.INSW = 0$ has to be programmed to use the baud rate generator output SCLK directly as input for the data shift unit. Configure a shift clock output pin (signal SCLKOUT).
- **Slave select generation:**
The slave select delay generation has to be enabled by setting $PCRL.MSLSEN = 1$ and the programming of the time quanta counter setting. Bit $DX2CR.INSW = 0$ has to be programmed to use the slave select generator output MSLS as input for the data shift unit. Configure slave select output pins (signals SELOx) if needed.
- **Data format configuration:**
The word length, the frame length, and the shift direction have to be set up according to the application requirements by programming the registers SCTRL and SCTRH.

Note: The USIC can only receive in master mode if it is transmitting, because the master frame handling refers to bit TDV of the transmitter part.

19.4.3.1 Baud Rate Generation

The baud rate (determining the length of one data bit) of the SSC is defined by the frequency of the SCLK signal (one period of f_{SCLK} represents one data bit). The SSC baud rate generation does not imply any time quanta counter.

In a standard SSC application, the phase relation between the optional MCLK output signal and SCLK is not relevant and can be disabled ($BRGL.PPPEN = 0$). In this case, the SCLK signal directly derives from the protocol input frequency f_{PIN} . In the exceptional case that a fixed phase relation between the MCLK signal and SCLK is required (e.g. when using MCLK as clock reference for external devices), the additional divider by 2 stage has to be taken into account ($BRGL.PPPEN = 1$).

The adjustable divider factor is defined by bit field BRGH.PDIV.

$$f_{\text{SCLK}} = \frac{f_{\text{PIN}}}{2} \times \frac{1}{\text{PDIV} + 1} \quad \text{if } \text{PPPEN} = 0$$

$$f_{\text{SCLK}} = \frac{f_{\text{PIN}}}{2 \times 2} \times \frac{1}{\text{PDIV} + 1} \quad \text{if } \text{PPPEN} = 1$$
(19.8)

19.4.3.2 MSLS Generation

The slave select signals indicate the start and the end of a data frame and are also used by the communication master to individually select the desired slave device. A slave select output of the communication master becomes active a programmable time before a data part of the frame is started (leading delay T_{ld}), necessary to prepare the slave device for the following communication. After the transfer of a data part of the frame, it becomes inactive again a programmable time after the end of the last bit (trailing delay T_{td}) to respect the slave hold time requirements. If data frames are transferred back-to-back one after the other, the minimum time between the deactivation of the slave select and the next activation of a slave select is programmable (next-frame delay T_{nf}). If a data frame consists of more than one data word, an optional delay between the data words can also be programmed (inter-word delay T_{iw}).

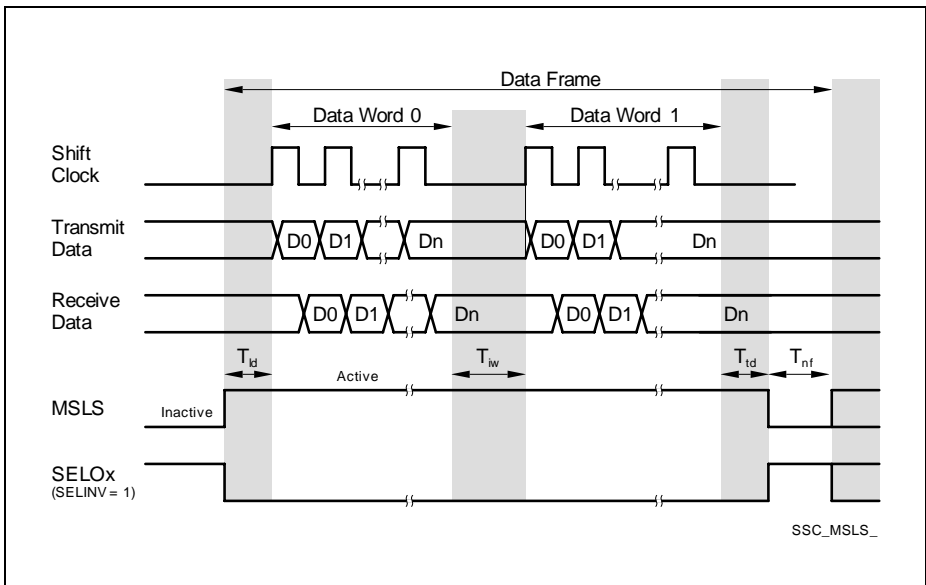


Figure 19-37 MSLS Generation in SSC Master Mode

In SSC master mode, the slave select delays are defined as follows:

- **Leading delay T_{ld} :**
The leading delay starts if valid data is available for transmission. The internal signal MSLS becomes active with the start of the leading delay. The first shift clock edge (rising edge) of SCLK is generated by the baud rate generator after the leading delay has elapsed.
- **Trailing delay T_{td}**
The trailing delay starts at the end of the last SCLK cycle of a data frame. The internal signal MSLS becomes inactive with the end of the trailing delay.
- **Inter-word delay T_{iw} :**
This delay is optional and can be enabled/disabled by PCRH.TIWEN. If the inter-word delay is disabled (TIWEN = 0), the last data bit of a data word is directly followed by the first data bit of the next data word of the same data frame. If enabled (TIWEN = 1), the inter-word delay starts at the end of the last SCLK cycle of a data word. The first SCLK cycle of the following data word of the same data frame is started when the inter-word delay has elapsed. During this time, no shift clock pulses are generated and signal MSLS stays active. The communication partner has time to “digest” the previous data word or to prepare for the next one.
- **Next-frame delay T_{nf} :**
The next-frame delay starts at the end of the trailing delay. During this time, no shift clock pulses are generated and signal MSLS stays inactive. A frame is considered as finished after the next-frame delay has elapsed.

19.4.3.3 Automatic Slave Select Update

If the number of bits per SSC frame and the word length are defined by bit fields SCTRH.FLE and SCTRH.WLE, the transmit control information TCI can be used to update the slave select setting PCRH.CTR[23:16] to control the SELOx select outputs. The automatic update mechanism is enabled by TCSRL.SELMD = 1 (bits TCSRL.WLEMD, FLEMD, and WAMD have to be cleared). In this case, the TCI of the first data word of a frame defines the slave select setting of the complete frame due to the automatic shadow mechanism (see [Page 19-118](#)).

19.4.3.4 Slave Select Delay Generation

The slave select delay generation is based on time quanta. The length of a time quantum (defined by the period of the f_{CTQIN}) and the number of time quanta per delay can be programmed.

In standard SSC applications, the leading delay T_{ld} and the trailing delay T_{td} are mainly used to ensure stability on the input and output lines as well as to respect setup and hold times of the input stages. These two delays have the same length (in most cases shorter than a bit time) and can be programmed with the same set of bit fields.

- **BRGL.CTQSEL**
to define the input frequency f_{CTQIN} for the time quanta generation for T_{ld} and T_{td}
- **BRGL.PCTQ**
to define the length of a time quantum (division of f_{CTQIN} by 1, 2, 3, or 4) for T_{ld} and T_{td}
- **BRGL.DCTQ**
to define the number of time quanta for the delay generation for T_{ld} and T_{td}

The inter-word delay T_{iw} and the next-frame delay T_{nf} are used to handle received data or to prepare data for the next word or frame. These two delays have the same length (in most cases in the bit time range) and can be programmed with a second, independent set of bit fields.

- **PCRL.CTQSEL1**
to define the input frequency f_{CTQIN} for the time quanta generation for T_{nf} and T_{iw}
- **PCRL.PCTQ1**
to define the length of a time quantum (division of f_{CTQIN} by 1, 2, 3, or 4) for T_{nf} and T_{iw}
- **PCRL.DCTQ1**
to define the number of time quanta for the delay generation for T_{nf} and T_{iw}
- **PCRH.TIWEN**
to enable/disable the inter-word delay T_{iw}

Each delay depends on the length of a time quantum and the programmed number of time quanta given by the bit fields CTQSEL/CTQSEL1, PCTQ/DCTQ and PCTQ1/DCTQ1 (the coding of CTQSEL1 is similar to CTQSEL, etc.). To provide a high flexibility in programming the delay length, the input frequencies can be selected between several possibilities (e.g. based on bit times or on the faster inputs of the protocol-related divider). The delay times are defined as follows:

$$T_{ld} = T_{td} = \frac{(PCTQ + 1) \times (DCTQ + 1)}{f_{CTQIN}} \quad (19.9)$$

$$T_{iw} = T_{nf} = \frac{(PCTQ1 + 1) \times (DCTQ1 + 1)}{f_{CTQIN}}$$

19.4.3.5 Protocol Interrupt Events

The following protocol-related events generated in SSC mode and can lead to a protocol interrupt. They are related to the start and the end of a data frame. After the start of a data frame a new setting could be programmed for the next data frame and after the end of a data frame the SSC connections to pins can be changed.

Please note that the bits in register PSR are not all automatically cleared by hardware and have to be cleared by software in order to monitor new incoming events.

- **MSLS Interrupt:**
This interrupt indicates in master mode (MSLS generation enabled) that a data frame has started (activation of MSLS) and has been finished (deactivation of MSLS). Any change of the internal MSLS signal sets bit PSR.MSLSEV and additionally, a protocol interrupt can be generated if PCRL.MSLSIEN = 1. The actual state of the internal MSLS signal can be read out at PSR.MSLS to take appropriate actions when this interrupt has been detected.
- **DX2T Interrupt:**
This interrupt monitors edges of the input signal of the DX2 stage (although this signal is not used as slave select input for data transfers).
A programmable edge detection for the DX2 input signal sets bit PSR.DX2TEV and additionally, a protocol interrupt can be generated if PCRL.DX2TIEN = 1. The actual state of the selected input signal can be read out at PSR.DX2S to take appropriate actions when this interrupt has been detected.

19.4.3.6 End-of-Frame Control

The information about the frame length is required for the MSLS generator of the master device. In addition to the mechanism based on the number of bits per frame (selected with $SCTRH.FLE < 63$), the following alternative mechanisms for end of frame handling are supported. It is recommended to set $SCTRH.FLE = 63$ (if several end of frame mechanisms are activated in parallel, the first end condition being found finishes the frame).

- **Software-based start of frame indication TCSRL.SOF:**
 This mechanism can be used if software handles the TBUF data without data FIFO. If bit SOF is set, a valid content of TBUF is considered as first word of a new frame. Bit SOF has to be set before the content of TBUF is transferred to the transmit shift register, so it is recommended to write it before writing data to TBUF. A current data word transfer is finished completely and the slave select delays T_{td} and T_{nf} are applied before starting a new data frame with T_{td} and the content of TBUF. For software-handling of bit SOF, bit $TCSRL.WLEMD = 0$ has to be programmed. In this case, all $TBUF[31:0]$ address locations show an identical behavior (TCI not taken into account for data handling).
- **Software-based end of frame indication TCSRL.EOF:**
 This mechanism can be used if software handles the TBUF data without data FIFO. If bit EOF is set, a valid content of TBUF is considered as last word of a new frame. Bit EOF has to be set before the content of TBUF is transferred to the transmit shift register, so it is recommended to write it before writing data to TBUF. The data word in TBUF is sent out completely and the slave select delays T_{td} and T_{nf} are applied. A new data frame can start with T_{td} with the next valid TBUF value. For software-handling of bit EOF, bit $TCSRL.WLEMD = 0$ has to be programmed. In this case, all $TBUF[31:0]$ address locations show an identical behavior (TCI not taken into account for data handling).
- **Software-based address related end of frame handling:**
 This mechanism can be used if software handles the TBUF data without data FIFO. If bit $TCSRL.WLEMD = 1$, the address of the written $TBUF[31:0]$ is used as transmit control information $TCI[4:0]$ to update $SCTRH.WLE (= TCI[3:0])$ and $TCSRL.EOF (= TCI[4])$ for each data word. The written $TBUF[31:0]$ address location defines the word length and the end of a frame (locations $TBUF[31:16]$ lead to a frame end). For example, writing transmit data to $TBUF[07]$ results in a data word of 8-bit length without finishing the frame, whereas writing transmit data to $TBUF[31]$ leads to a data word length of 16 bits, followed by T_{td} , the deactivation of MSLS and T_{nf} . If $TCSRL.WLEMD = 1$, bits $TCSRL.EOF$ and SOF , as well as $SCTRH.WLE$ must not be written by software after writing data to a TBUF location. Furthermore, it is recommended to clear bits $TCSRL.SELMD$, $FLEMD$ and $WAMD$.
- **FIFO-based address related end of frame handling:**
 This mechanism can be used if a data FIFO is used to store the transmit data. The general behavior is similar to the software-based address related end of frame

handling, except that transmit data is not written to the locations TBUF[31:0], but to the FIFO input locations IN[31:0] instead. In this case, software must not write to any of the TBUF locations.

- TBUF related end of frame handling:
If bit PCRL.FEM = 0, an end of frame is assumed if the transmit buffer TBUF does not contain valid transmit data at the end of a data word transmission (TCSR.LTDV = 0 or in Stop Mode). In this case, the software has to take care that TBUF does not run empty during a data frame in Run Mode. If bit PCRL.FEM = 1, signal MSLS stays active while the transmit buffer is waiting for new data (TCSR.LTDV = 1 again) or until Stop Mode is left.
- Explicit end of frame by software:
The software can explicitly stop a frame by clearing bit PSR.MSLS by writing a 1 to the related bit position in register PSCR. This write action immediately clears bit PSR.MSLS, whereas the internal MSLS signal becomes inactive after finishing a currently running word transfer and respecting the slave select delays T_{td} and T_{rf} .

19.4.4 Operating the SSC in Slave Mode

In order to operate the SSC in slave mode, the following issues have to be considered:

- **Select SSC mode:**
It is recommended to configure all parameters of the SSC that do not change during run time while $CCR.MODE = 0000_B$. Bit field $SCTRL.TRM = 01_B$ has to be programmed. The configuration of the input stages has to be done while $CCR.MODE = 0000_B$ to avoid unintended edges of the input signals and the SSC mode can be enabled afterwards by $CCR.MODE = 0001_B$.
- **Pin connections:**
Establish a connection of input stage DX0 with the selected receive data input pin (signal DIN) with $DX0CR.INSW = 1$ and configure a transmit data output pin (signal DOUT).
Establish a connection of input stage DX1 with the selected shift clock input pin (signal SCLKIN) with $DX1CR.INSW = 1$.
Establish a connection of input stage DX2 with the selected slave select input pin (signal SELIN) with $DX2CR.INSW = 1$. If no slave select input signal is used, the DX2 stage has to deliver a 1-level to the data shift unit to allow data reception and transmission. If a slave device is not selected (DX2 stage delivers a 0 to the data shift unit) and a shift clock pulse are received, the incoming data is not received and the DOUT signal outputs the passive data level defined by $SCTRL.PDL$.
- **Baud rate generation:**
The baud rate generator is not needed and can be switched off by the fractional divider.
- **Slave select generation:**
The slave select delay generation is not needed and can be switched off. The bits and bit fields $MSLSEN$, $SELCTR$, $SELINV$, $CTQSEL1$, $PCTQ1$, $DCTQ1$, $MSLSIEN$, $SELO[7:0]$, and $TIWEN$ in registers $PCRL/PCRH$ are not necessary and can be programmed to 0.

19.4.4.1 Protocol Interrupts

The following protocol-related events generated in SSC mode and can lead to a protocol interrupt. They are related to the start and the end of a data frame. After the start of a data frame a new setting could be programmed for the next data frame and after the end of a data frame the SSC connections to pins can be changed.

Please note that the bits in register PSR are not all automatically cleared by hardware and have to be cleared by software in order to monitor new incoming events.

- **MSLS event:**
The MSLS generation being switched off, this event is not available.
- **DX2T event:**
The slave select input signal $SELIN$ is handled by the DX2 stage and the edges of the selected signal can generate a protocol interrupt. This interrupt allows to indicate

that a data frame has started and/or that a data frame has been completely finished. A programmable edge detection for the DX2 input signal activates DX2T, sets bit PSR.DX2TEV and additionally, a protocol interrupt can be generated if PCRL.DX2TIEN = 1. The actual state of the selected input signal can be read out at PSR.DX2S to take appropriate actions when this interrupt has been detected.

19.4.4.2 End-of-Frame Control

In slave mode, the following possibilities exist to determine the frame length. The slave device either has to refer to an external slave select signal, or to the number of received data bits.

- **Frame length known in advance by the slave device, no slave select:**
In this case bit field SCTR.H.FLE can be programmed to the known value (if it does not exceed 63 bits). A currently running data word transfer is considered as finished if the programmed frame length is reached.
- **Frame length not known by the slave, no slave select:**
In this case, the slave device's software has to decide on data word base if a frame is finished. Bit field SCTR.H.FLE can be either programmed to the word length SCTR.H.WLE, or to its maximum value to disable the slave internal frame length evaluation by counting received bits.
- **Slave device addressed via slave select signal SELIN:**
If the slave device is addressed by a slave select signal delivered by the communication master, the frame start and end information are given by this signal. In this case, bit field SCTR.H.FLE should be programmed to its maximum value to disable the slave internal frame length evaluation.

19.4.5 SSC Protocol Registers

In SSC mode, the registers PCRL, PCRH and PSR handle SSC related information.

19.4.5.1 SSC Protocol Control Registers

In SSC mode, the PCRL/PCRH register bits or bit fields are defined as described in this section.

PCRL

Protocol Control Register L [SSC Mode]

(40_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DX2 TIEN	MSL SIEN	0	DCTQ1				PCTQ1		CTQSEL1		FEM	SE INV	SEL CTR	MSL SEN	
rw		rw			rw			rw		rw		rw	rw	rw	rw

Field	Bits	Type	Description
MSLSEN	0	rw	MSLS Enable This bit enables/disables the generation of the master slave select signal MSLS. If the SSC is a transfer slave, the SLS information is read from a pin and the internal generation is not needed. If the SSC is a transfer master, it has to provide the MSLS signal. 0 _B The MSLS generation is disabled (MSLS = 0). This is the setting for SSC slave mode. 1 _B The MSLS generation is enabled. This is the setting for SSC master mode.
SELCTR	1	rw	Select Control This bit selects the operating mode for the SELO[7:0] outputs. 0 _B The coded select mode is enabled. 1 _B The direct select mode is enabled.
SELINV	2	rw	Select Inversion This bit defines if the polarity of the SELO[7:0] outputs in relation to the master slave select signal MSLS. 0 _B The SELO outputs have the same polarity as the MSLS signal (active high). 1 _B The SELO outputs have the inverted polarity to the MSLS signal (active low).

Field	Bits	Type	Description
FEM	3	rw	Frame End Mode This bit defines if a transmit buffer content that is not valid for transmission is considered as an end of frame condition for the slave select generation. 0 _B The current data frame is considered as finished when the last bit of a data word has been sent out and the transmit buffer TBUF does not contain new data (TDV = 0). 1 _B The MSLS signal is kept active also while no new data is available and no other end of frame condition is reached. In this case, the software can accept delays in delivering the data without automatic deactivation of MSLS in multi-word data frames.
CTQSEL1	[5:4]	rw	Input Frequency Selection This bit field defines the input frequency f_{CTQIN} for the generation of the slave select delays T_{iw} and T_{nf} . 00 _B $f_{CTQIN} = f_{PDIV}$ 01 _B $f_{CTQIN} = f_{PPP}$ 10 _B $f_{CTQIN} = f_{SCLK}$ 11 _B $f_{CTQIN} = f_{MCLK}$
PCTQ1	[7:6]	rw	Divider Factor PCTQ1 for T_{iw} and T_{nf} This bit field represents the divider factor PCTQ1 (range = 0 - 3) for the generation of the inter-word delay and the next-frame delay. $T_{iw} = T_{nf} = 1/f_{CTQIN} \times (PCTQ1 + 1) \times (DCTQ1 + 1)$
DCTQ1	[12:8]	rw	Divider Factor DCTQ1 for T_{iw} and T_{nf} This bit field represents the divider factor DCTQ1 (range = 0 - 31) for the generation of the inter-word delay and the next-frame delay. $T_{iw} = T_{nf} = 1/f_{CTQIN} \times (PCTQ1 + 1) \times (DCTQ1 + 1)$
MSLSIEN	14	rw	MSLS Interrupt Enable This bit enables/disables the generation of a protocol interrupt if the state of the MSLS signal changes (indicated by PSR.MSLSEV = 1). 0 _B A protocol interrupt is not generated if a change of signal MSLS is detected. 1 _B A protocol interrupt is generated if a change of signal MSLS is detected.

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Field	Bits	Type	Description
DX2TIEN	15	rw	DX2T Interrupt Enable This bit enables/disables the generation of a protocol interrupt if the DX2T signal becomes activated (indicated by PSR.DX2TEV = 1). 0_B A protocol interrupt is not generated if DX2T is activated. 1_B A protocol interrupt is generated if DX2T is activated.
0	13	rw	Reserved Returns 0 if read; should be written with 0.

PCRH

Protocol Control Register H [SSC Mode]

(42_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
M CLK				0			TIW EN					SELO			
rw				rw			rw					rw			

Field	Bits	Type	Description
SELO	[7:0]	rw	Select Output This bit field defines the setting of the SELO[7:0] output lines. 0_B The corresponding SELOx line cannot be activated. 1_B The corresponding SELOx line can be activated (according to the mode selected by SELCTR).
TIWEN	8	rw	Enable Inter-Word Delay T_{iw} This bit enables/disables the inter-word delay T_{iw} after the transmission of a data word. 0_B No delay between data words of the same frame. 1_B The inter-word delay T_{iw} is enabled and introduced between data words of the same frame.

Universal Serial Interface Channel

Field	Bits	Type	Description
MCLK	15	rw	Master Clock Enable This bit enables/disables the generation of the master clock output signal MCLK, independent from master or slave mode. 0 _B The MCLK generation is disabled and output MCLK = 0. 1 _B The MCLK generation is enabled.
0	[14:9]	rw	Reserved Returns 0 if read; not modified in SSC mode.

19.4.5.2 SSC Protocol Status Register

In SSC mode, the PSR register bits or bit fields are defined as described in this section. The bits and bit fields in register PSR are not cleared by hardware.

The flags in the PSR register can be cleared by writing a 1 to the corresponding bit position in register PSCR. Writing a 1 to a bit position in PSR sets the corresponding flag, but doesn't lead to further actions (no interrupt generation). Writing a 0 has no effect. The PSR flags should be cleared by software before enabling a new protocol.

PSR

Protocol Status Register [SSC Mode] (44_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AIF	RIF	TBIF	TSIF	DLIF	RSIF				0			DX2 TEV	MSL SEV	DX2 S	MSL S
rwh	rwh	rwh	rwh	rwh	rwh				r			rwh	rwh	rwh	rwh

Field	Bits	Type	Description
MSLS	0	rwh	MSLS Status This bit indicates the current status of the MSLS signal. It must be cleared by software to stop a running frame. 0 _B The internal signal MSLS is inactive (0). 1 _B The internal signal MSLS is active (1).
DX2S	1	rwh	DX2S Status This bit indicates the current status of the DX2S signal that can be used as slave select input SELIN. 0 _B DX2S is 0. 1 _B DX2S is 1.
MSLSEV	2	rwh	MSLS Event Detected¹⁾ This bit indicates that the MSLS signal has changed its state since MSLSEV has been cleared. Together with the MSLS status bit, the activation/deactivation of the MSLS signal can be monitored. 0 _B The MSLS signal has not changed its state. 1 _B The MSLS signal has changed its state.
DX2TEV	3	rwh	DX2T Event Detected¹⁾ This bit indicates that the DX2T trigger signal has been activated since DX2TEV has been cleared. 0 _B The DX2T signal has not been activated. 1 _B The DX2T signal has been activated.

Universal Serial Interface Channel

Field	Bits	Type	Description
0	[9:4]	r	Reserved Returns 0 if read; not modified in SSC mode.
RSIF	10	rwh	Receiver Start Indication Flag 0 _B A receiver start event has not occurred. 1 _B A receiver start event has occurred.
DLIF	11	rwh	Data Lost Indication Flag 0 _B A data lost event has not occurred. 1 _B A data lost event has occurred.
TSIF	12	rwh	Transmit Shift Indication Flag 0 _B A transmit shift event has not occurred. 1 _B A transmit shift event has occurred.
TBIF	13	rwh	Transmit Buffer Indication Flag 0 _B A transmit buffer event has not occurred. 1 _B A transmit buffer event has occurred.
RIF	14	rwh	Receive Indication Flag 0 _B A receive event has not occurred. 1 _B A receive event has occurred.
AIF	15	rwh	Alternative Receive Indication Flag 0 _B An alternative receive event has not occurred. 1 _B An alternative receive event has occurred.

1) This status bit can generate a protocol interrupt in SSC mode (see [Page 19-24](#)). The general interrupt status flags are described in the general interrupt chapter.

19.4.6 SSC Timing Considerations

The input and output signals have to respect certain timings in order to ensure correct data reception and transmission. In addition to module internal timings (due to input filters, reaction times on events, etc.), also the timings from the input pin via the input stage (T_{in}) to the module and from the module via the output driver stage to the pin (T_{out}), as well as the signal propagation on the wires (T_{prop}) have to be taken into account.

Please note that there might be additional delays in the DXn input stages, because the digital filter and the synchronization stages lead to systematic delays, that have to be considered if these functions are used.

19.4.6.1 Closed-loop Delay

A system-inherent limiting factor for the baud rate of an SSC connection is the closed-loop delay. In a typical application setup, a communication master device is connected to a slave device in full-duplex mode with independent lines for transmit and receive data. In a general case, all transmitters refer to one shift clock edge for transmission and all receivers refer to the other shift clock edge for reception. The master device's SSC module sends out the transmit data, the shift clock and optionally the slave select signal. Therefore, the baud rate generation (BRG) and slave select generation (SSG) are part of the master device. The frame control is similar for SSC modules in master and slave mode, the main difference is the fact which module generates the shift clock and optionally, the slave select signals.

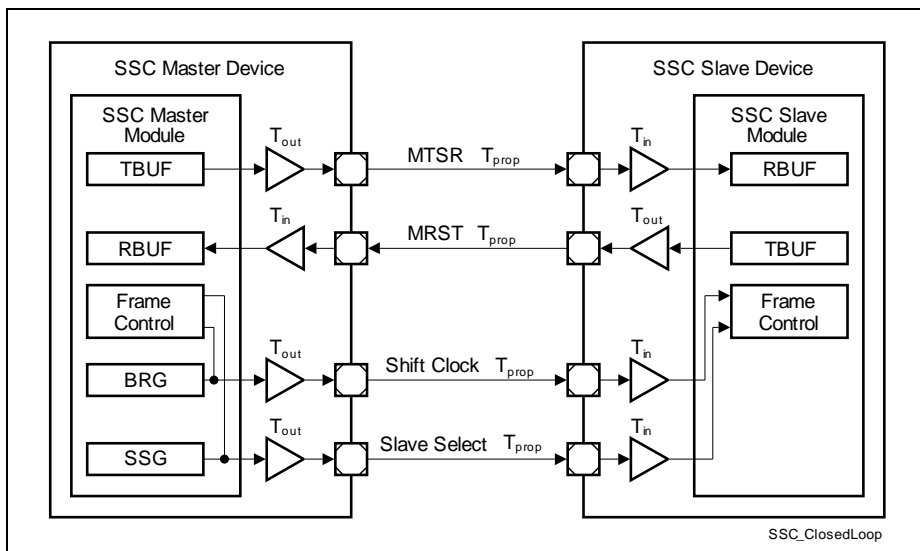


Figure 19-38 SSC Closed-loop Delay

The signal path between the SSC modules of the master and the slave device includes the master's output driver, the wiring to the slave device and the slave device's input stage. With the received shift clock edges, the slave device receives the master's transmit data and transmits its own data back to the master device, passing by a similar signal path in the other direction. The master module receives the slave's transmit data related to its internal shift clock edges. In order to ensure correct data reception in the master device, the slave's transmit data has to be stable (respecting setup and hold times) as master receive data with the next shift clock edge of the master (generally 1/2 shift clock period). To avoid data corruption, the accumulated delays of the input and output stages, the signal propagation on the wiring and the reaction times of the transmitter/receiver have to be carefully considered, especially at high baud rates.

In the given example, the time between the generation of the shift clock signal and the evaluation of the receive data by the master SSC module is given by the sum of $T_{out_master} + 2 \times T_{prop} + T_{in_slave} + T_{out_slave} + T_{in_master}$ + module reaction times + input setup times. The input path is characterized by an input delay depending mainly on the input stage characteristics of the pads. The output path delay is determined by the output driver delay and its slew rate, the external load and current capability of the driver. The device specific values for the input/output driver are given in the Data Sheet.

19.4.6.2 Delay Compensation in Master Mode

A higher baud rate can be reached by delay compensation in master mode. This compensation is possible if (at least) the shift clock pin is bidirectional.

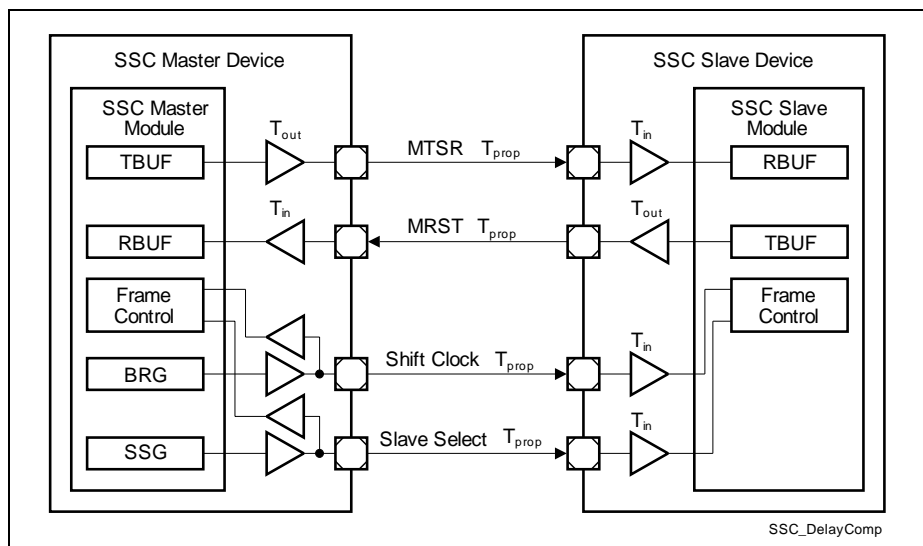


Figure 19-39 SSC Master Mode with Delay Compensation

Universal Serial Interface Channel

If the shift clock signal in master mode is directly taken from the input function in parallel to the output signal, the output delay of the master device's shift clock output is compensated and only the difference between the input delays of the master and the slave devices have to be taken into account instead of the complete master's output delay and the slave's input delay of the shift clock path.

In the given example, the time between the evaluation of the shift clock signal and the receive data by the master SSC module is reduced by $T_{in_master} + T_{out_master}$.

Although being a master mode, the shift clock input and optionally the slave select signal are not directly connected internally to the data shift unit, but are taken as external signals from input pins ($DXnCR.INSW = 1$). The delay compensation does not lead to additional pins for the SSC communication if the shift clock output pin (slave select output pin, respectively) is/are bidirectional. In this case, the input signal is decoupled from other internal signals, because it is related to the signal level at the pin itself.

19.5 Inter-IC Bus Protocol (IIC)

The IIC protocol of the USIC refers to the IIC bus specification version 2.1, january 2000 from Philips Semiconductors. Contrary to that specification, the USIC device assumes rise/fall times of the bus signals of max. 300 ns in all modes. Please refer to the pad characteristics in the AC/DC chapter for the driver capability. CBUS mode and HS mode are not supported.

The IIC mode is selected by $CCR.MODE = 0100_B$ with $CCFG.IIC = 1$ (IIC mode available).

This chapter contains the following sections:

- Introduction (see [Page 19-161](#))
- Operating the IIC protocol (see [Page 19-165](#))
- Symbol timing and programming (see [Page 19-171](#))
- Data flow handling (see [Page 19-174](#))
- IIC protocol registers (see [Page 19-179](#))

19.5.1 Introduction

USIC IIC Features:

- Two-wire interface, with one line for shift clock transfer and synchronization (shift clock SCL), the other one for the data transfer (shift data SDA)
- Communication in standard mode (100 kBit/s) or in fast mode (up to 400 kBit/s)
- Support of 7-bit addressing, as well as 10-bit addressing
- Master mode operation,
where the IIC controls the bus transactions and provides the clock signal.
- Slave mode operation,
where an external master controls the bus transactions and provides the clock signal.
- Multi-master mode operation,
where several masters can be connected to the bus and bus arbitration can take place, i.e. the IIC module can be master or slave. The master/slave operation of an IIC bus participant can change from frame to frame.
- Efficient frame handling (low software effort), also allowing PEC transfers
- Powerful interrupt handling due to multitude of indication flags
- Compensation support for input delays

19.5.1.1 Signal Description

An IIC connection is characterized by two wires (SDA and SCL). The output drivers for these signals must have open-drain characteristics to allow the wired-AND connection of all SDA lines together and all SCL lines together to form the IIC bus system. Due to this structure, a high level driven by an output stage does not necessarily lead immediately to a high level at the corresponding input. Therefore, each SDA or SCL connection has to be input and output at the same time, because the input function always monitors the level of the signal, also while sending.

- Shift data SDA: input handled by DX0 stage, output signal DOUT
- Shift clock SCL: input handled by DX1 stage, output signal SCLKOUT

Figure 19-25 shows a connection of two IIC bus participants (modules IIC A and IIC B) using the USIC. In this example, the pin assignment of module IIC A shows separate pins for the input and output signals for SDA and SCL. This assignment can be used if the application does not provide pins having DOUT and a DX0 stage input for the same pin (similar for SCLKOUT and DX1). The pin assignment of module IIC B shows the connection of DOUT and a DX0 input at the same pin, also for SCLKOUT and a DX1 input.

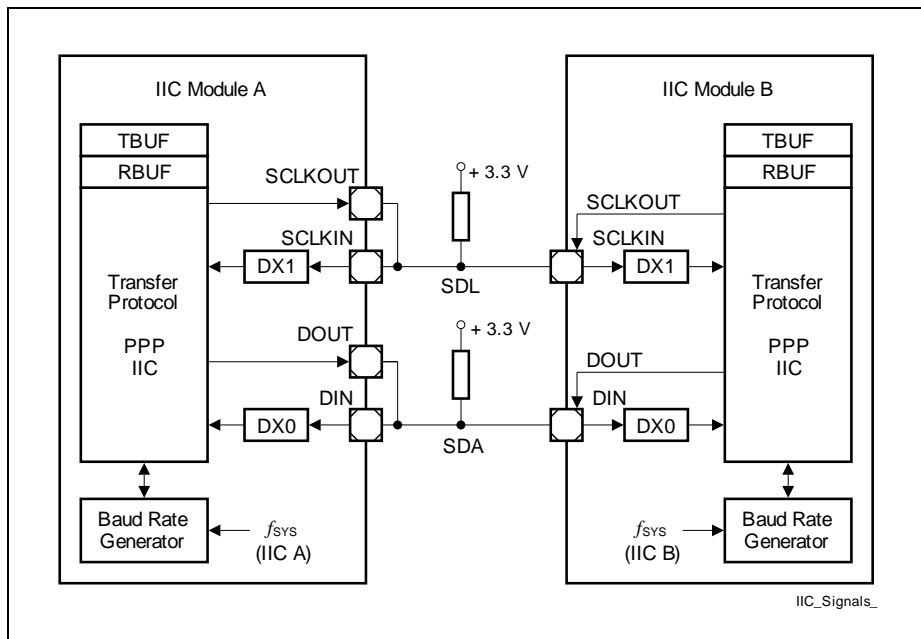


Figure 19-40 IIC Signal Connections

19.5.1.2 Symbols

A symbol is a sequence of edges on the lines SDA and SCL. Symbols contain 10 or 25 time quanta t_q , depending on the selected baud rate. The baud rate generator determines the length of the time quanta t_q , the sequence of edges in a symbol is handled by the IIC protocol pre-processor, and the sequence of symbols can be programmed by the user according to the application needs.

The following symbols are defined:

- Bus idle:
SDA and SCL are high. No data transfer takes place currently.
- Data bit symbol:
SDA stable during the high phase of SCL. SDA then represents the transferred bit value. There is one clock pulse on SCL for each transferred bit of data. During data transfers SDA may only change while SCL is low.
- Start symbol:
Signal SDA being high followed by a falling edge of SDA while SCL is high indicates a start condition. This start condition initiates a data transfer over the IIC bus after the bus has been idle.
- Repeated start symbol:
This start condition initiates a data transfer over the bus after a data symbol when the bus has not been idle. Therefore, SDA is set high and SCL low, followed by a start symbol.
- Stop symbol:
A rising edge on SDA while SCL is high indicates a stop condition. This stop condition terminates a data transfer to release the bus to idle state. Between a start condition and a stop condition an arbitrary number of bytes may be transferred.

19.5.1.3 Frame Format

Data is transferred by the 2-line IIC bus (SDA, SCL) using a protocol that ensures reliable and efficient transfers. The sender of a (data) byte receives and checks the value of the following acknowledge field. The IIC being a wired-AND bus system, a 0 of at least one device leads to a 0 on the bus, which is received by all devices.

A data word consists of 8 data bit symbols for the data value, followed by another data bit symbol for the acknowledge bit. The data word can be interpreted as address information (after a start symbol) or as transferred data (after the address).

In order to be able to receive an acknowledge signal, the sender of the data bits has to release the SDA line by sending a 1 as acknowledge value. Depending on the internal state of the receiver, the acknowledge bit is either sent active or passive.

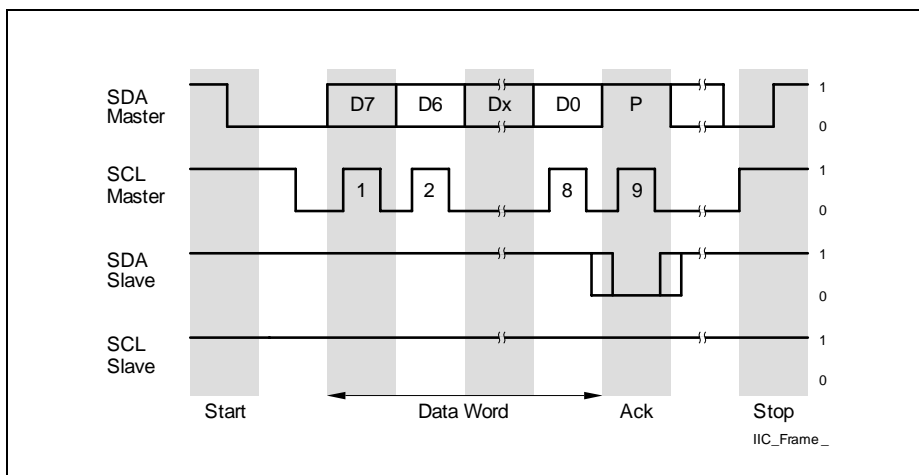


Figure 19-41 IIC Frame Example (simplified)

19.5.2 Operating the IIC

In order to operate the IIC protocol, the following issues have to be considered:

- **Select IIC mode:**
 It is recommended to configure all parameters of the IIC that do not change during run time while $CCR.MODE = 0000_B$. Bit field $SCTRL.TRM = 11_B$ should to be programmed. The configuration of the input stages has to be done while $CCR.MODE = 0000_B$ to avoid unintended edges of the input signals and the IIC mode can be enabled by $CCR.MODE = 0100_B$ afterwards.
- **Pin connections:**
 Establish a connection of input stage DX0 (with $DX0CR.DPOL = 0$) to the selected shift data pin SDA (signal DIN) with $DX0CR.INSW = 0$ and configure the transmit data output signal DOUT (with $SCTRL.DOCFG = 00_B$) to the same pin. If available, this can be the same pin for input and output, or connect the selected input pin and the output pin to form the SDA line.
 The same mechanism applies for the shift clock line SCL. Here, signal $SCLKOUT$ (with $BRGH.SCLKCFG = 00_B$) and an input of the DX1 stage have to be connected (with $DX1CR.DPOL = 0$).
 The input stage DX2 is not used for the IIC protocol.
 If the digital input filters are enabled in the DX0/1 stages, their delays have to be taken into account for correct calculation of the signal timings.
 The pins used for SDA and SCL have to be set to open-drain mode to support the wired-AND structure of the IIC bus lines.
 Note that the basic I/O port configuration for the IIC I/O pins must also setup correctly before the IIC mode becomes enabled by $CCR.MODE = 0100_B$.
- **Bit timing configuration:**
 In standard mode (100 kBit/s) a minimum module frequency of 2 MHz is necessary, whereas in fast mode (400 kBit/s) a minimum of 10 MHz is required. Additionally, if the digital filter stage should be used to eliminate spikes up to 50 ns, a filter frequency of 20 MHz is necessary.
 There could be an uncertainty in the SCL high phase timing of maximum $1/f_{PPP}$ if another IIC participant lengthens the SCL low phase on the bus.
 More details are given in [Section 19.5.3](#).
- **Data format configuration:**
 The data format has to be configured for 8 data bits ($SCTRH.WLE = 7$), unlimited data flow ($SCTRH.FLE = 3FF_H$), and MSB shifted first ($SCTRL.SDIR = 1$). The parity generation has to be disabled ($CCR.PM = 00_B$).
- **General hints:**
 The IIC slave module becomes active (for reception or transmission) if it is selected by the address sent by the master. In the case that the slave sends data to the master, it uses the transmit path. So a master must not request to read data from the slave address defined for its own channel in order to avoid collisions.
 The built-in error detection mechanisms are only activated while the IIC module is

taking part in IIC bus traffic.

If the slave can not deal with too high frequencies, it can lengthen the low phase of the SCL signal.

For data transfers according to the IIC specification, the shift data line SDA shall only change while $SCL = 0$ (defined by IIC bus specification).

19.5.2.1 Transmission Chain

The IIC bus protocol requiring a kind of in-bit-response during the arbitration phase and while a slave is transmitting, the resulting loop delay of the transmission chain can limit the reachable maximal baud rate, strongly depending on the bus characteristics (bus load, module frequency, etc.).

Figure 19-25 shows the general signal path and the delays in the case of a slave transmission. The shift clock SCL is generated by the master device, output on the wire, then it passes through the input stage and the input filter. Now, the edges can be detected and the SDA data signal can be generated accordingly. The SDA signal passes through the output stage and the wire to the master receiver part. There, it passes through the input stage and the input filter before it is sampled.

This complete loop has to be finished (including all settling times to obtain stable signal levels) before the SCL signal changes again. The delays in this path have to be taken into account for the calculation of the baud rate as a function of f_{SYS} and f_{PPP} .

19.5.2.2 Byte Stretching

If a device is selected as transceiver and should transmit a data byte but the transmit buffer TBUF does not contain valid data to be transmitted, the device ties down $SCL = 0$ at the end of the previous acknowledge bit. The waiting period is finished if new valid data has been detected in TBUF.

19.5.2.3 Baud Rate Update

The baud rate setting can be changed from frame to frame. The BRGL/H register setting and PCR.STIM are sampled (shadowed) while the IIC bus is idle. A new setting of these bits can be programmed while a frame is running. The new setting will be taken into account with the start of the next frame. In order to minimize the risk of inconsistencies when changing baud rate setting (several registers have to be updated), it is recommended to avoid baud rate changes while the IIC protocol is enabled, especially for slave devices.

19.5.2.4 Master Arbitration

During the address and data transmission, the master transmitter checks at the rising edge of SCL for each data bit if the value it is sending is equal to the value read on the SDA line. If yes, the next data bit values can be 0. If this is not the case (transmitted

value = 1, value read = 0), the master has lost the transmit arbitration. This is indicated by status flag PSR.ARL and can generate a protocol interrupt if enabled by PCRH.ARLIEN.

When the transmit arbitration has been lost, the software has to initialize the complete frame again, starting with the first address byte together with the start condition for a new master transmit attempt. Arbitration also takes place for the ACK bit.

19.5.2.5 Release of TBUF

In case of a non-acknowledge or an error, the content of TBUF becomes invalid. In both cases, the software has to flush the transmit buffer and to set it up again with appropriate values to react on the previous event.

19.5.2.6 Mode Control Behavior

In multi-master mode, only run mode 0 and stop mode 0 are supported, the other modes must not be programmed.

- **Run Mode 0:**
Behavior as programmed. If TCSRL.TDV = 0 (no new valid TBUF entry found) when a new TBUF entry needs to be processed, the IIC module waits for TDV becoming set to continue operation.
- **Run Mode 1:**
Behavior as programmed. If in master mode, TCSRL.TDV = 0 (no new valid TBUF entry found) when a new TBUF entry needs to be processed, the IIC module sends a stop condition to finish the frame. In slave mode, no difference to run mode 0.
- **Stop Mode 0:**
Bit TCSRL.TDV is internally considered as 0 (the bit itself is not modified by the stop mode). A currently running word is finished normally, but no new word is started in case of master mode (wait for TDV active).
Bit TDV being considered as 0 for master and slave, the slave will force a wait state on the bus if read by an external master, too.
Additionally, it is not possible to force the generation of a STOP condition out of the wait state. The reason is, that a master read transfer must be finished with a not-acknowledged followed by a STOP condition to allow the slave to release his SDA line. Otherwise the slave may force the SDA line to 0 (first data bit of next byte) making it impossible to generate the STOP condition (rising edge on SDA).
To continue operation, the mode must be switched to run mode 0
- **Stop Mode 1:**
Same as stop mode 0, but additionally, a master sends a STOP condition to finish the frame.
If stop mode 1 is requested for a master device after the first byte of a 10 bit address, a stop condition will be sent out. In this case, a slave device will issue an error interrupt.

19.5.2.7 IIC Protocol Interrupt Events

The following protocol-related events are generated in IIC mode and can lead to a protocol interrupt.

Please note that the bits in register PSR are not all automatically cleared by hardware and have to be cleared by software in order to monitor new incoming events.

- **Transmit buffer event:**
The transmit buffer event indication flag PSR.TBIF is set when the content of the transmit buffer TBUF has been loaded to the transmit shift register, indicating that the action requested by the TBUF entry has started.
With this event, bit TCSRL.TDV is cleared. This interrupt can be used to write the next TBUF entry while the last one is in progress (handled by the transmitter part).
- **Receive event:**
This receive event indication flag PSR.RIF indicates that a new data byte has been written to the receive buffer RBUF0/1 (except for the first data word of a new data frame, that is indicated by an alternative receive interrupt). The flag becomes set when the data byte is received (after the falling edge of SCL). This interrupt can be used to read out the received data while a new data byte can be in progress (handled by the receiver part).
- **Alternate receive event:**
The alternative receive event indication flag AIF is based on bit RBUFSR[9] (same as RBUF[9]), indicating that the received data word has been the first data word of a new data frame.
- **Protocol interrupt events:**
The IIC protocol related interrupt events are either indicating the reception of symbols or the detection of frame errors (common indication PSR.ERR) or unexpected/wrong TDF codes (common indication PSR.WTDF).
 - start condition received at a correct position in a frame (PSR.SCR)
 - repeated start condition received at a correct position in a frame (PSR.RSCR)
 - stop condition transferred at a correct position in a frame (PSR.PCR)
 - master arbitration lost (PSR.ARL)
 - slave read requested (PSR.SRR)
 - non-acknowledge received (PSR.NACK)
 - start condition not at the expected position in a frame (PSR.ERR)
 - stop condition not at the expected position in a frame (PSR.ERR)
 - as slave, 10-bit address interrupted by a stop condition after the first address byte (PSR.ERR)
 - TDF slave code in master mode (PSR.WTDF)
 - TDF master code in slave mode (PSR.WTDF)
 - Reserved TDF code found (PSR.WTDF)
 - Start condition code during a running frame in master mode (PSR.WTDF)
 - Data byte transmission code after transfer direction has been changed to reception (master read) in master mode (PSR.WTDF)

If a wrong TDF code is found in TBUF, the error event is active until the TDF value is either corrected or invalidated. If the related interrupt is enabled, the interrupt handler should check PSR.WDTF first and correct or invalidate TBUF, before dealing with the other possible interrupt events.

19.5.2.8 Receiver Address Acknowledge

After a (repeated) start condition, the master sends a slave address to identify the target device of the communication. The start address can comprise one or two address bytes (for 7 bit or for 10 bit addressing schemes). After an address byte, a slave sensitive to the transmitted address has to acknowledge the reception.

Therefore, the slave's address can be programmed in the device, where it is compared to the received address. In case of a match, the slave answers with an acknowledge (SDA = 0). Slaves that are not targeted answer with a non-acknowledge (SDA = 1).

In addition to the match of the programmed address, an other address byte value has to be answered with an acknowledge if the slave is capable to handle the corresponding requests. The address byte 00_H indicates a general call address, that can be acknowledged. The value 01_H stands for a start byte generation, that is not acknowledged

In order to allow selective acknowledges for the different values of the address byte(s), the following control mechanism is implemented:

- The address byte 00_H is acknowledged if bit PCRH.ACK00 is set.
- The address byte 01_H is not acknowledged.
- The first 7 bits of a received first address byte are compared to the programmed slave address (PCR.SLAD[15:9]). If these bits match, the slave sends an acknowledge. In addition to this, if the slave address is programmed to 1111 0XX_B, the slave device waits for a second address byte and compares it also to PCR.SLAD[7:0] and sends an acknowledge accordingly to cover the 10 bit addressing mode. The user has to take care about reserved addresses (refer to IIC specification for more detailed description). Only the address 1111 0XX_B is supported.

Under each of these conditions, bit PSR.SLSEL will be set when the addressing delivered a match. This bit is cleared automatically by a (repeated) start condition.

19.5.2.9 Receiver Handling

A selected slave receiver always acknowledges a received data byte. If the receive buffers RBUF0/1 are already full and can not accept more data, the respective register is overwritten (PSR.DLI becomes set in this case and a protocol interrupt can be generated).

An address reception also uses the registers RBUF0/1 to store the address before checking if the device is selected. The received addresses do not set RDV0/1, so the addresses are not handled like received data.

19.5.2.10 Receiver Status Information

In addition to the received data byte, some IIC protocol related information is stored in the 16-bit data word of the receive buffer. The received data byte is available at the bit positions RBUF[7:0], whereas the additional information is monitored at the bit positions RBUF[12:8]. This structure allows to identify the meaning of each received data byte without reading additional registers, also when using a FIFO data buffer.

- **RBUF[8]:**
Value of the received acknowledge bit. This information is also available in RBUFSR[8] as protocol argument.
- **RBUF[9]:**
A 1 at this bit position indicates that after a (repeated) start condition followed by the address reception the first data byte of a new frame has been received. A 0 at this bit position indicates further data bytes. This information is also available in RBUFSR[9], allowing different interrupt routines for the address and data handling.
- **RBUF[10]:**
A 0 at this bit position indicates that the data byte has been received when the device has been in slave mode, whereas a 1 indicates a reception in master mode.
- **RBUF[11]:**
A 1 at this bit position indicates an incomplete/erroneous data byte in the receive buffer caused by a wrong position of a START or STOP condition in the frame. The bit is not identical to the frame error status bit in PSR, because the bit in the PSR has to be cleared by software ("sticky" bit), whereas RBUF[11] is evaluated data byte by data byte. If RBUF[11] = 0, the received data byte has been correct, independent of former errors.
- **RBUF[12]:**
A 0 at this bit position indicates that the programmed address has been received. A 1 indicates a general call address.

19.5.3 Symbol Timing

The symbol timing of the IIC is determined by the master stimulating the shift clock line SCL. It is different for standard and fast IIC mode.

- 100 kBaud standard mode (PCR.H.STIM = 0):
The symbol timing is based on 10 time quanta t_q per symbol. A minimum module clock frequency $f_{SYS} = 2$ MHz is required.
- 400 kBaud standard mode (PCR.H.STIM = 1):
The symbol timing is based on 25 time quanta t_q per symbol. A minimum module clock frequency $f_{SYS} = 10$ MHz is required.

The baud rate setting should only be changed while the transmitter and the receiver are idle or CCR.MODE = 0. The bits in register BRGL define the length of a time quantum t_q that is given by one period of f_{PCTQ} .

- BRGL.CTQSEL
to define the input frequency f_{CTQIN} for the time quanta generation
- BRGL.PCTQ
to define the length of a time quantum (division of f_{CTQIN} by 1, 2, 3, or 4)
- BRGL.DCTQ
to define the number of time quanta per symbol (number of $t_q = DCTQ + 1$)

The standard setting is given by CTQSEL = 00_B ($f_{CTQIN} = f_{PDIV}$) and PPEN = 0 ($f_{PPP} = f_{IN}$). Under these conditions, the frequency f_{PCTQ} is given by:

$$f_{PCTQ} = f_{PIN} \times \frac{1}{PDIV + 1} \times \frac{1}{PCTQ + 1} \quad (19.10)$$

To respect the specified SDA hold time of 300 ns after a falling edge of signal SCL, a hold delay t_{HDEL} has been introduced. It also prevents an erroneous detection of a start or a stop condition. The length of this delay can be programmed by bit field PCR.H.HDEL. Taking into account the input sampling and output update, bit field HDEL can be programmed according to:

$$\begin{aligned} HDEL &\geq 300 \text{ ns} \times f_{PPP} - \left(3 \times \frac{f_{PPP}}{f_{SYS}} \right) + 1 && \text{with digital filter and } HDEL_{\min} = 2 \\ & && (19.11) \\ HDEL &\geq 300 \text{ ns} \times f_{PPP} - \left(3 \times \frac{f_{PPP}}{f_{SYS}} \right) + 2 && \text{without digital filter and } HDEL_{\min} = 1 \end{aligned}$$

If the digital input filter is used, HDEL compensates the filter delay of 2 filter periods (f_{PPP} should be used) in case of a spike on the input signal. This ensures that a data bit on the SDA line changing just before the rising edge or behind the falling edge of SCL won't be treated as a start or stop condition.

19.5.3.1 Start Symbol

Figure 19-42 shows the general start symbol timing.

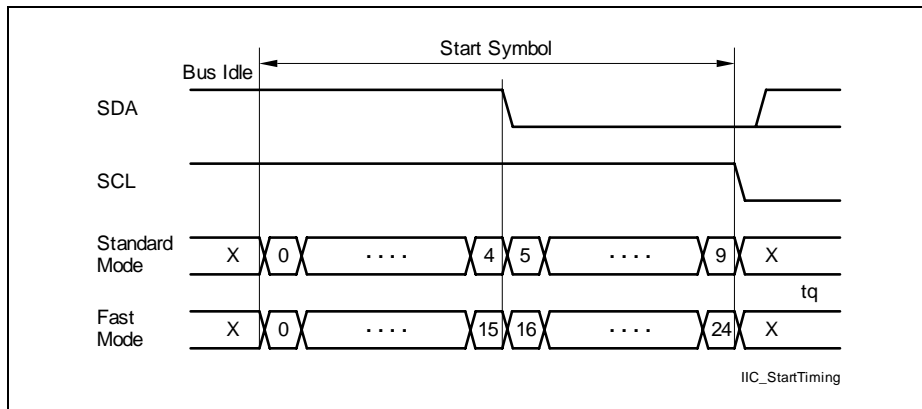


Figure 19-42 Start Symbol Timing

19.5.3.2 Repeated Start Symbol

During the first part of a repeated start symbol, an SCL low value is driven for the specified number of time quanta. Then a high value is output. After the detection of a rising edge at the SCL input, a normal start symbol is generated, as shown in **Figure 19-43**.

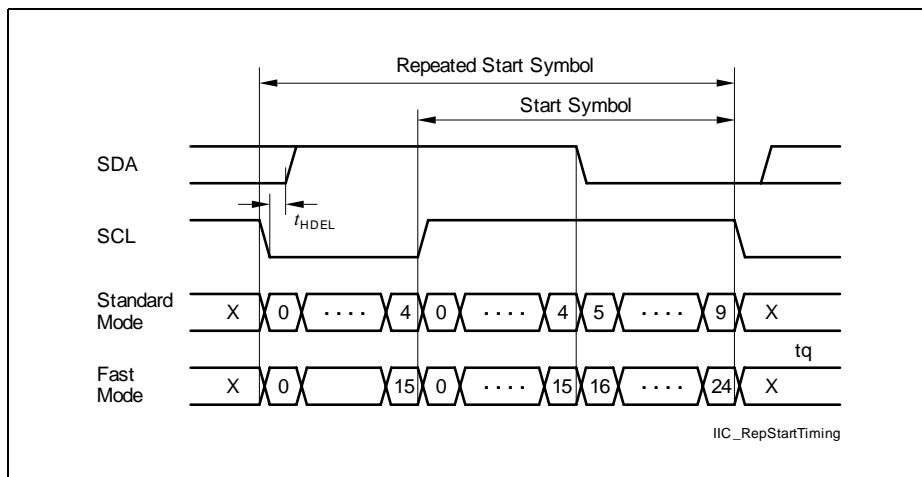


Figure 19-43 Repeated Start Symbol Timing

19.5.3.3 Stop Symbol

Figure 19-44 shows the stop symbol timing.

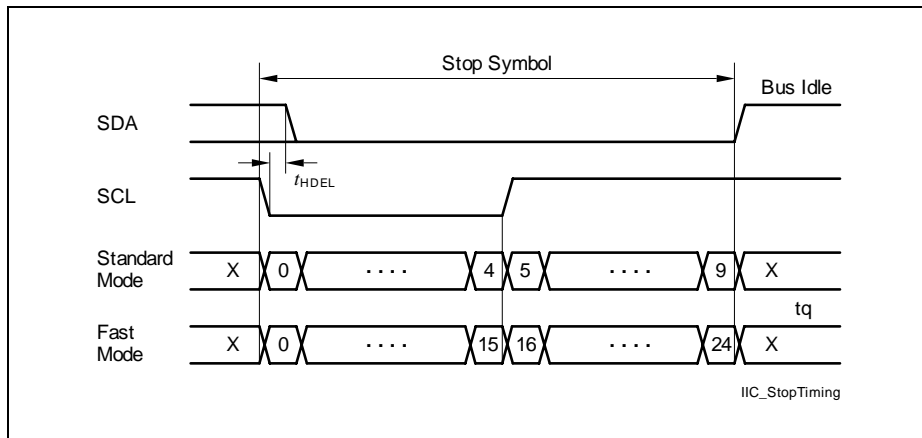


Figure 19-44 Stop Symbol Timing

19.5.3.4 Data Bit Symbol

Figure 19-45 shows the general data bit symbol timing.

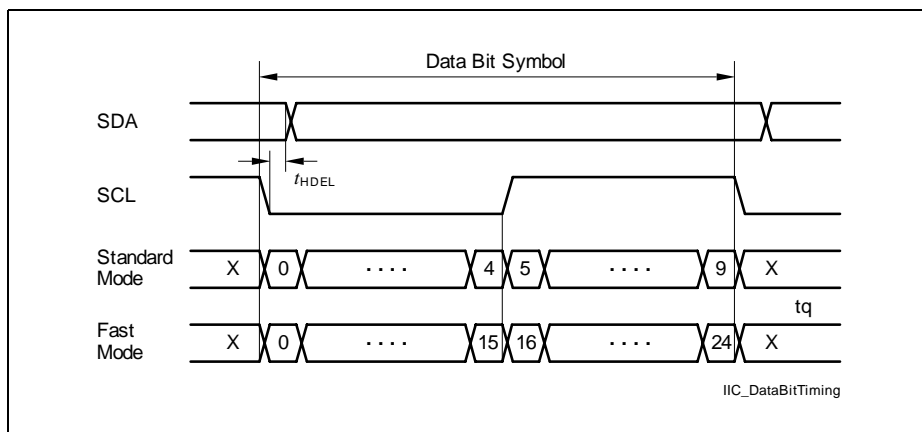


Figure 19-45 Data Bit Symbol

Output SDA changes after the time t_{HDEL} defined by PCRH.HDEL has elapsed if a falling edge is detected at the SCL input to respect the SDA hold time. The value of

PCR.HDEL allows compensation of the delay of the SCL input path (sampling, filtering).

In the case of an acknowledge transmission, the USIC IIC waits for the receiver indicating that a complete byte has been received. This adds an additional delay of 3 periods of f_{SYS} to the path. The minimum module input frequency has to be selected properly to ensure the SDA setup time to SCL rising edge.

19.5.4 Data Flow Handling

The handling of the data flow and the sequence of the symbols in an IIC frame is controlled by the IIC transmitter part of the USIC communication channel. The IIC bus protocol is byte-oriented, whereas a USIC data buffer word can contain up to 16 data bits. In addition to the data byte to be transmitted (located at TBUF[7:0]), bit field TDF (transmit data format) to control the IIC sequence is located at the bit positions TBUF[10:8]. The TDF code defines for each data byte how it should be transmitted (IIC master or IIC slave), and controls the transmission of (repeated) start and stop symbols. This structure allows the definition of a complete IIC frame for an IIC master device only by writing to TBUFx or by using a FIFO data buffer mechanism, because no other control registers have to be accessed.

If a wrong or unexpected TDF code is encountered (e.g. due to a software error during setup of the transmit buffer), a stop condition will be sent out by the master. This leads to an abort of the currently running frame. A slave module waits for a valid TDF code and sets SCL = 0. The software then has to invalidate the unexpected TDF code and write a valid one.

Please note that during an arbitration phase in multi-master bus systems an unpredictable bus behavior may occur due to an unexpected stop condition.

19.5.4.1 Transmit Data Formats

The following transmit data formats are available in master mode:

- Send data byte as master (TDF = 000_B):
This format is used to transmit a data byte from the master to a slave. The transmitter sends its data byte (TBUF[7:0]), receives and checks the acknowledge bit sent by the slave.
- Receive data byte and send acknowledge 0 (TDF = 010_B):
This format is used by the master to read a data byte from a slave. The master acknowledges the transfer with a 0-level to continue the transfer. The content of TBUF[7:0] is ignored.
- Receive data byte and send acknowledge 1 (TDF = 011_B):
This format is used by the master to read a data byte from a slave. The master does not acknowledge the transfer with a 1-level to finish the transfer. The content of TBUF[7:0] is ignored.

- Send start condition (TDF = 100_B):
If TBUF contains this entry while the bus is idle, a start condition will be generated. The content of TBUF[7:0] is taken as first address byte for the transmission (bits TBUF[7:1] are the address, the LSB is the read/write control).
 - Send repeated start condition (TDF = 101_B):
If TBUF contains this entry and SCL = 0 and a byte transfer is not in progress, a repeated start condition will be sent out if the device is the current master. The current master is defined as the device that has set the start condition (and also won the master arbitration) for the current message. The content of TBUF[7:0] is taken as first address byte for the transmission (bits TBUF[7:1] are the address, the LSB is the read/write control).
 - Send stop condition (TDF = 110_B):
If the current master has finished its last byte transfer (including acknowledge), it sends a stop condition if this format is in TBUF. The content of TBUF[7:0] is ignored.
 - TDF = 111_B :
Reserved and must not be programmed. No additional action except releasing the TBUF entry and setting the error bit in PSR (that can lead to a protocol interrupt).
- The following transmit data format is available in slave mode (the symbols in a frame are controlled by the master and the slave only has to send data if it has been “asked” by the master):
- Send data byte as slave (TDF = 001_B):
This format is used to transmit a data byte from a slave to the master. The transmitter sends its data byte (TBUF[7:0]) plus the acknowledge bit as a 1.

19.5.4.2 Valid Master Transmit Data Formats

Due to the IIC frame format definitions, only some specific sequences of TDF codes are possible and valid. If the USIC IIC module detects a wrong TDF code in a running frame, the transfer is aborted and flag PCR.WTDF is set. Additionally, an interrupt can be generated if enabled by the user. In case of a wrong TDF code, the frame will be aborted immediately with a STOP condition if the USIC IIC master still owns the SDA line. But if the accessed slave owns the SDA line (read transfer), the master must perform a dummy read with a non-acknowledge so that the slave releases the SDA line before a STOP condition can be sent. The received data byte of the dummy read will be stored in RBUF0/1, but RDV0/1 won't be set. Therefore the dummy read won't generate a receive interrupt and the data byte won't be stored into the receive FIFO.

If the transfer direction has changed in the current frame (master read access), the transmit data request (TDF = 000_B) is not possible and won't be accepted (leading to a wrong TDF Code indication).

Table 19-9 Valid TDF Codes Overview

Frame Position	Valid TDF Codes
First TDF code (master idle)	Start (100 _B)
Read transfer: second TDF code (after start or repeated start)	Receive with acknowledge (010 _B) or receive with not-acknowledge (011 _B)
Write transfer: second TDF code (after start or repeated start)	Transmit (000 _B), repeated start (101 _B), or stop (110 _B)
Read transfer: third and subsequent TDF code after acknowledge	Receive with acknowledge (010 _B) or receive with not-acknowledge (011 _B)
Read transfer: third and subsequent TDF code after not-acknowledge	Repeated start (101 _B) or stop (110 _B)
Write transfer: third and subsequent TDF code	Transmit (000 _B), repeated start (101 _B), or stop (110 _B)

- First TDF code:
A master transfer starts with the TDF start code (100_B). All other codes are ignored, but no WTDF error will be indicated.
- TDF code after a start (100_B) or repeated start code (101_B) in case of a read access:
If a master-read transfer is started (determined by the LSB of the address byte = 1), the transfer direction of SDA changes and the slave will actively drive the data line. In this case, only the codes 010_B and 011_B are valid. To abort the transfer in case of a wrong code, a dummy read must be performed by the master before the STOP condition can be generated.

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- TDF code after a start (100_B) or repeated start code (101_B) in case of a write access:
If a master-write transfer is started (determined by the LSB of the address byte = 0), the master still owns the SDA line. In this case, the transmit (000_B), repeated start (101_B) and stop (110_B) codes are valid. The other codes are considered as wrong. To abort the transfer in case of a wrong code, the STOP condition is generated immediately.
- TDF code of the third and subsequent command in case of a read access with acknowledged previous data byte:
If a master-read transfer is started (determined by the LSB of the address byte), the transfer direction of SDA changes and the slave will actively drive the data line. To force the slave to release the SDA line, the master has to not-acknowledge a byte transfer. In this case, only the receive codes 010_B and 011_B are valid. To abort the transfer in case of a wrong code, a dummy read must be performed by the master before the STOP condition can be generated.
- TDF code of the third and subsequent command in case of a read access with a not-acknowledged previous data byte:
If a master-read transfer is started (determined by the LSB of the address byte), the transfer direction of SDA changes and the slave will actively drive the data line. To force the slave to release the SDA line, the master has to not-acknowledge a byte transfer. In this case, only the restart (101_B) and stop code (110_B) are valid. To abort the transfer in case of a wrong code, the STOP condition is generated immediately.
- TDF code of the third and subsequent command in case of a write access:
If a master-write transfer is started (determined by the LSB of the address byte), the master still owns the SDA line. In this case, the transmit (000_B), repeated start (101_B) and stop (110_B) codes are valid. The other codes are considered as wrong. To abort the transfer in case of a wrong code, the STOP condition is generated immediately.
- After a master device has received a non-acknowledge from a slave device, a stop condition will be sent out automatically, except if the following TDF code requests a repeated start condition. In this case, the TDF code is taken into account, whereas all other TDF codes are ignored.

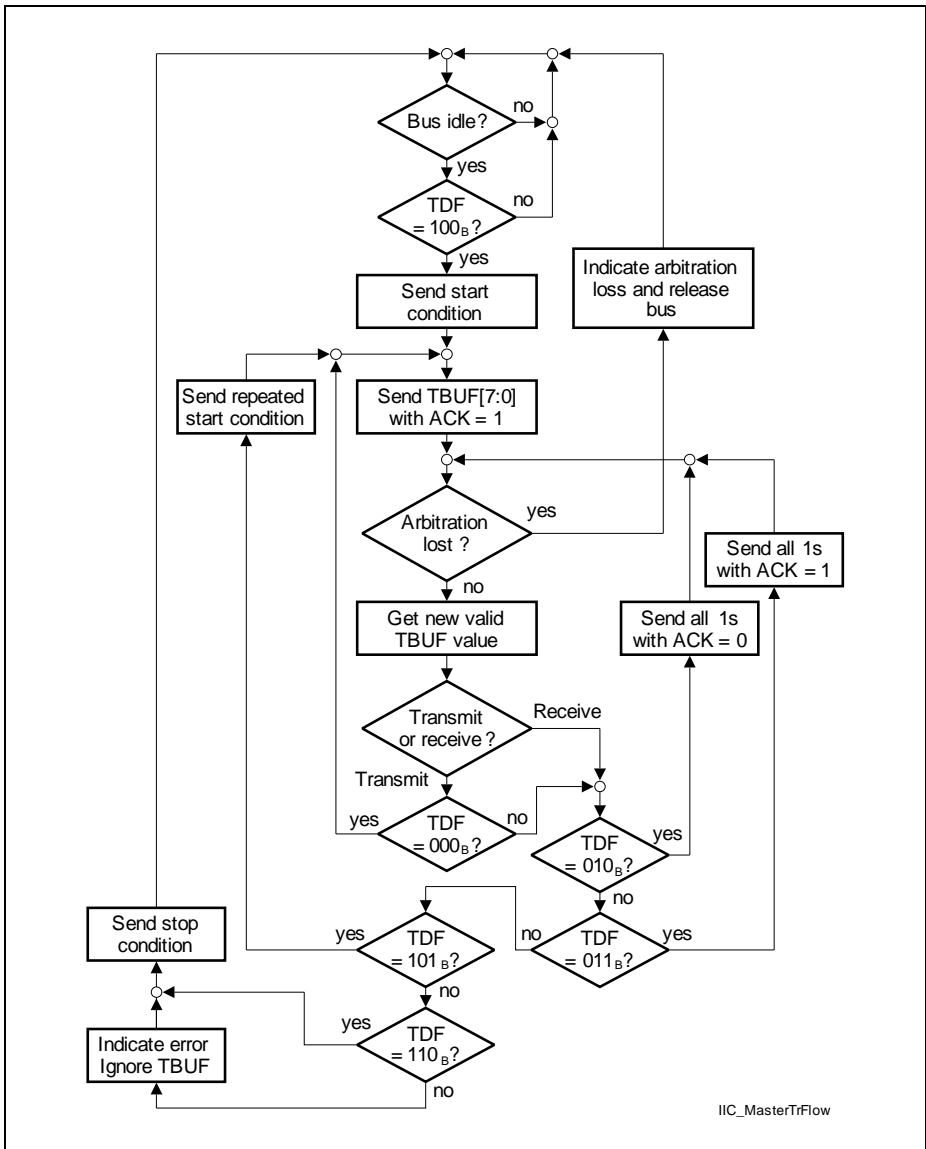


Figure 19-46 IIC Master Transmission

19.5.5 IIC Protocol Registers

In IIC mode, the registers PCRH, PCRL and PSR handle IIC related information.

19.5.5.1 IIC Protocol Control Registers

In IIC mode, the PCRL/PCRH register bits or bit fields are defined as described in this section.

PCRL

Protocol Control Register L [IIC Mode] (40_H)

Reset Value: 0000_H

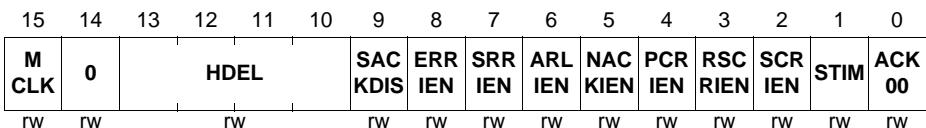


Field	Bits	Type	Description
SLAD	[15:0]	rw	Slave Address This bit field contains the programmed slave address. The corresponding bits in the first received address byte are compared to the bits SLAD[15:9] to check for address match. If SLAD[15:11] = 11110 _B , then the second address byte is also compared to SLAD[7:0].

PCRH

Protocol Control Register H [IIC Mode] (42_H)

Reset Value: 0000_H



Field	Bits	Type	Description
ACK00	0	rw	Acknowledge 00_H This bit defines if a slave device should be sensitive to the slave address 00 _H . 0 _B The slave device is not sensitive to this address. 1 _B The slave device is sensitive to this address.

Field	Bits	Type	Description
STIM	1	rw	Symbol Timing This bit defines how many time quanta are used in a symbol. 0 _B A symbol contains 10 time quanta. The timing is adapted for standard mode (100 kBaud). 1 _B A symbol contains 25 time quanta. The timing is adapted for fast mode (400 kBaud).
SCRIEN	2	rw	Start Condition Received Interrupt Enable This bit enables the generation of a protocol interrupt if a start condition is detected. 0 _B The start condition interrupt is disabled. 1 _B The start condition interrupt is enabled.
RSCRIEN	3	rw	Repeated Start Condition Received Interrupt Enable This bit enables the generation of a protocol interrupt if a repeated start condition is detected. 0 _B The repeated start condition interrupt is disabled. 1 _B The repeated start condition interrupt is enabled.
PCRIEN	4	rw	Stop Condition Received Interrupt Enable This bit enables the generation of a protocol interrupt if a stop condition is detected. 0 _B The stop condition interrupt is disabled. 1 _B The stop condition interrupt is enabled.
NACKIEN	5	rw	Non-Acknowledge Interrupt Enable This bit enables the generation of a protocol interrupt if a non-acknowledge is detected by a master. 0 _B The non-acknowledge interrupt is disabled. 1 _B The non-acknowledge interrupt is enabled.
ARLIEN	6	rw	Arbitration Lost Interrupt Enable This bit enables the generation of a protocol interrupt if an arbitration lost event is detected. 0 _B The arbitration lost interrupt is disabled. 1 _B The arbitration lost interrupt is enabled.
SRRIEN	7	rw	Slave Read Request Interrupt Enable This bit enables the generation of a protocol interrupt if a slave read request is detected. 0 _B The slave read request interrupt is disabled. 1 _B The slave read request interrupt is enabled.

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Field	Bits	Type	Description
ERRIEN	8	rw	Error Interrupt Enable This bit enables the generation of a protocol interrupt if an IIC error condition is detected (indicated by PSR.ERR or PSR.WTDF). 0 _B The error interrupt is disabled. 1 _B The error interrupt is enabled.
SACKDIS	9	rw	Slave Acknowledge Disable This bit disables the generation of an active acknowledge signal for a slave device (active acknowledge = 0 level). Once set by software, it is automatically cleared with each (repeated) start condition. If this bit is set after a byte has been received (indicated by an interrupt) but before the next acknowledge bit has started, the next acknowledge bit will be sent with passive level. This would indicate that the receiver does not accept more bytes. As a result, a minimum of 2 bytes will be received if the first receive interrupt is used to set this bit. 0 _B The generation of an active slave acknowledge is enabled (slave acknowledge with 0 level = more bytes can be received). 1 _B The generation of an active slave acknowledge is disabled (slave acknowledge with 1 level = reception stopped).
HDEL	[13:10]	rw	Hardware Delay This bit field defines the delay used to compensate the internal treatment of the SCL signal (see Page 19-171) in order to respect the SDA hold time specified for the IIC protocol.
0	14	rw	Reserved Returns 0 if read; should be written with 0.
MCLK	15	rw	Master Clock Enable This bit enables generation of the master clock MCLK (not directly used for IIC protocol, can be used as general frequency output). 0 _B The MCLK generation is disabled and MCLK is 0. 1 _B The MCLK generation is enabled.

19.5.5.2 IIC Protocol Status Register

The following PSR status bits or bit fields are available in IIC mode. Please note that the bits in register PSR are not cleared by hardware.

The flags in the PSR register can be cleared by writing a 1 to the corresponding bit position in register PSCR. Writing a 1 to a bit position in PSR sets the corresponding flag, but doesn't lead to further actions (no interrupt generation). Writing a 0 has no effect. These flags should be cleared by software before enabling a new protocol.

PSR

Protocol Status Register [IIC Mode] (44_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AIF	RIF	TBIF	TSIF	DLIF	RSIF	0	ERR	SRR	ARL	N ACK	PCR	R SCR	SCR	W TDF	SL SEL
rwh	rwh	rwh	rwh	rwh	rwh	r	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh	rwh

Field	Bits	Type	Description
SLSEL	0	rwh	Slave Select This bit indicates that this device has been selected as slave. 0 _B The device is not selected as slave. 1 _B The device is selected as slave.
WTDF	1	rwh	Wrong TDF Code Found¹⁾ This bit indicates that an unexpected/wrong TDF code has been found. A protocol interrupt can be generated if PCRH.ERRIEN = 1. 0 _B A wrong TDF code has not been found. 1 _B A wrong TDF code has been found.
SCR	2	rwh	Start Condition Received¹⁾ This bit indicates that a start condition has been detected on the IIC bus lines. A protocol interrupt can be generated if PCRH.SCRIEN = 1. 0 _B A start condition has not yet been detected. 1 _B A start condition has been detected.

Field	Bits	Type	Description
RSCR	3	rwh	Repeated Start Condition Received¹⁾ This bit indicates that a repeated start condition has been detected on the IIC bus lines. A protocol interrupt can be generated if PCRH.RSCRIEN = 1. 0 _B A repeated start condition has not yet been detected. 1 _B A repeated start condition has been detected.
PCR	4	rwh	Stop Condition Received¹⁾ This bit indicates that a stop condition has been detected on the IIC bus lines. A protocol interrupt can be generated if PCRH.PCRIEN = 1. 0 _B A stop condition has not yet been detected. 1 _B A stop condition has been detected.
NACK	5	rwh	Non-Acknowledge Received¹⁾ This bit indicates that a non-acknowledge has been received in master mode. This bit is not set in slave mode. A protocol interrupt can be generated if PCRH.NACKIEN = 1. 0 _B A non-acknowledge has not been received. 1 _B A non-acknowledge has been received.
ARL	6	rwh	Arbitration Lost¹⁾ This bit indicates that an arbitration has been lost. A protocol interrupt can be generated if PCRH.ARLIEN = 1. 0 _B An arbitration has not been lost. 1 _B An arbitration has been lost.
SRR	7	rwh	Slave Read Request¹⁾ This bit indicates that a slave read request has been detected. It becomes active to request the first data byte to be made available in the transmit buffer. For further consecutive data bytes, the transmit buffer issues more interrupts. For the end of the transfer, the master transmitter sends a stop condition. A protocol interrupt can be generated if PCRH.SRRIEN = 1. 0 _B A slave read request has not been detected. 1 _B A slave read request has been detected.

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Field	Bits	Type	Description
ERR	8	rwh	Error¹⁾ This bit indicates that an IIC error (frame format or TDF code) has been detected. A protocol interrupt can be generated if PCRH.ERRIEN = 1. 0 _B An IIC error has not been detected. 1 _B An IIC error has been detected.
0	9	r	Reserved Returns 0 if read; not modified in IIC mode.
RSIF	10	rwh	Receiver Start Indication Flag 0 _B A receiver start event has not occurred. 1 _B A receiver start event has occurred.
DLIF	11	rwh	Data Lost Indication Flag 0 _B A data lost event has not occurred. 1 _B A data lost event has occurred.
TSIF	12	rwh	Transmit Shift Indication Flag 0 _B A transmit shift event has not occurred. 1 _B A transmit shift event has occurred.
TBIF	13	rwh	Transmit Buffer Indication Flag 0 _B A transmit buffer event has not occurred. 1 _B A transmit buffer event has occurred.
RIF	14	rwh	Receive Indication Flag 0 _B A receive event has not occurred. 1 _B A receive event has occurred.
AIF	15	rwh	Alternative Receive Indication Flag 0 _B An alternative receive event has not occurred. 1 _B An alternative receive event has occurred.

1) This status bit can generate a protocol interrupt (see [Page 19-24](#)). The general interrupt status flags are described in the general interrupt chapter.

19.6 IIS Protocol

This chapter describes how the USIC module handles the IIS protocol. This serial protocol can handle reception and transmission of synchronous data frames between a device operating in master mode and a device in slave mode. An IIS connection based on a USIC communication channel supports half-duplex and full-duplex data transfers. The IIS mode is selected by $\text{CCR.MODE} = 0011_{\text{B}}$ with $\text{CCFG.IIS} = 1$ (IIS mode is available).

This chapter contains the following sections:

- Introduction (see [Page 19-185](#))
- General IIS issues (see [Page 19-189](#))
- Master mode operation (see [Page 19-194](#))
- Slave mode operation (see [Page 19-198](#))
- Protocol registers (see [Page 19-199](#))

19.6.1 Introduction

The IIS protocol is a synchronous serial communication protocol mainly for audio and infotainment applications and refers to the Philips specification, 1986, revised June 5, 1996.

19.6.1.1 Signal Description

A connection between an IIS master and an IIS slave is based on the following signals:

- A shift clock signal SCK, generated by the transfer master. It is permanently generated while an IIS connection is established, also while no valid data bits are transferred.
- A word address signal WA (also named WS), generated by the transfer master. It indicates the beginning of a new data word and the targeted audio channel (e.g. left/right). The word address output signal WA is available on all SELOx outputs if the WA generation is enabled (by $\text{PCR.WAGEN} = 1$ for the transfer master). The WA signal changes synchronously to the falling edges of the shift clock.
- If the transmitter is the IIS master device, it generates a master transmit slave receive data signal. The data changes synchronously to the falling edges of the shift clock.
- If the transmitter is the IIS slave device, it generates a master receive slave transmit data signal. The data changes synchronously to the falling edges of the shift clock.

The transmitter part and the receiver part of the USIC communication channel can be used together to establish a full-duplex data connection between an IIS master and a slave device.

Table 19-10 IIS IO Signals

IIS Mode	Receive Data	Transmit Data	Shift Clock	Word Address
Master	Input DIN, handled by DX0	Output DOUT	Output SCLKOUT	Output(s) SELOx
Slave	Input DIN, handled by DX0	Output DOUT	Input SCLKIN, handled by DX1	Input SELIN, handled by DX2

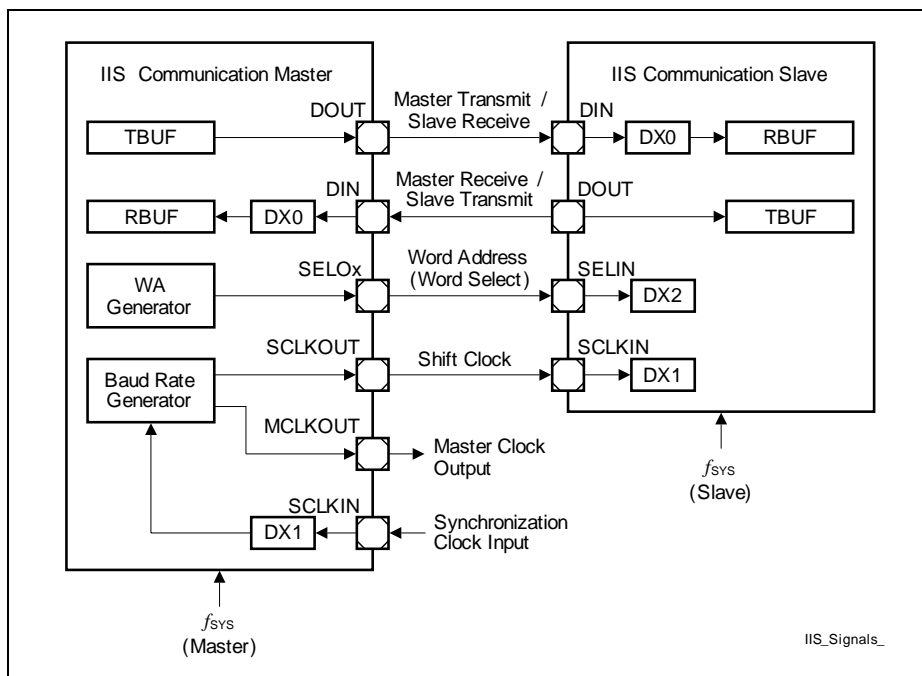


Figure 19-47 IIS Signals

Two additional signals are available for the USIC IIS communication master:

- A master clock output signal MCLKOUT with a fixed phase relation to the shift clock to support oversampling for audio components. It can also be used as master clock output of a communication network with synchronized IIS connections.
- A synchronization clock input SCLKIN for synchronization of the shift clock generation to an external frequency to support audio frequencies that can not be directly derived from the system clock f_{sys} of the communication master. It can be used as master clock input of a communication network with synchronized IIS connections.

19.6.1.2 Protocol Overview

An IIS connection supports transfers for two different data frames via the same data line, e.g. a data frames for the left audio channel and a data frame for the right audio channel. The word address signal WA is used to distinguish between the different data frames. Each data frame can consist of several data words.

In a USIC communication channel, data words are tagged for being transmitted for the left or for the right channel. Also the received data words contain a tag identifying the WA state when the data has been received.

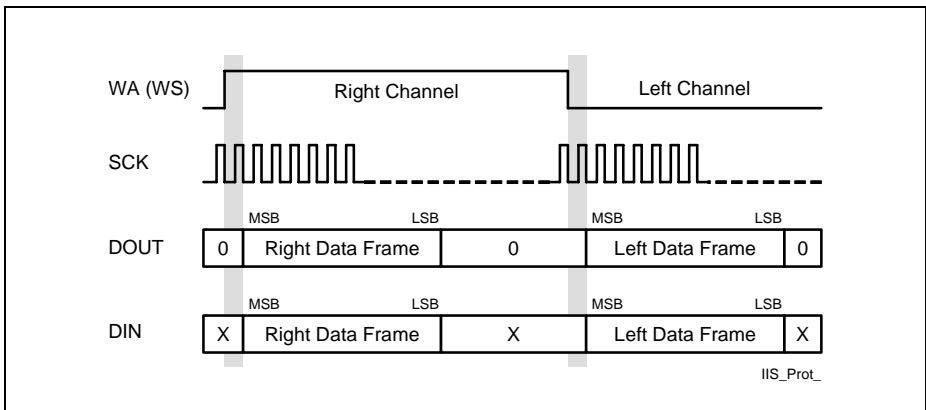


Figure 19-48 Protocol Overview

19.6.1.3 Transfer Delay

The transfer delay feature allows the transfer of data (transmission and reception) with a programmable delay (counted in shift clock periods).

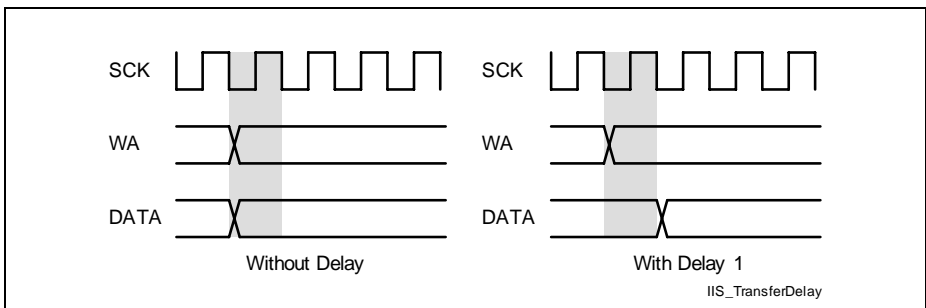


Figure 19-49 Transfer Delay for IIS

19.6.1.4 Connection of External Audio Components

The IIS signals can be used to communicate with external audio devices (such as Codecs) or other audio data sources/destinations.

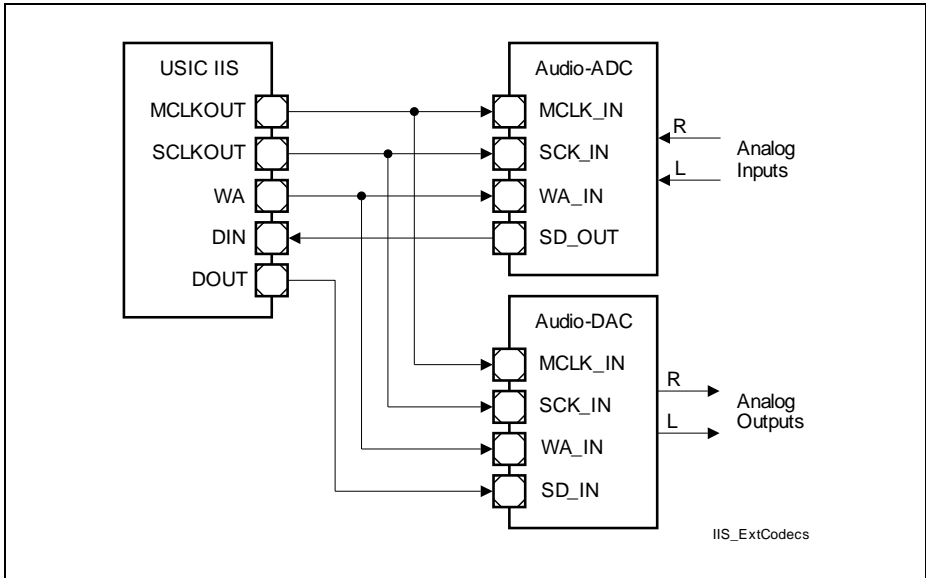


Figure 19-50 Connection of External Audio Devices

In some applications, especially for Audio-ADCs or Audio-DACs, a master clock signal is required with a fixed phase relation to the shift clock signal. The frequency of MCLKOUT is a multiple of the shift frequency SCLKOUT. This factor defines the oversampling factor of the external device (commonly used values: 256 or 384).

19.6.2 Operating the IIS

This chapter contains IIS issues, that are of general interest and not directly linked to master mode or slave mode.

19.6.2.1 Frame Length and Word Length Configuration

After each change of the WA signal, a complete data frame is intended to be transferred (frame length \leq system word length). The number of data bits transferred after a change of signal WA is defined by SCTR.H.FLE. A data frame can consist of several data words with a data word length defined by SCTR.H.WLE. The changes of signal WA define the system word length as the number of SCLK cycles between two changes of WA (number of bits available for the right channel and same number available for the left channel).

If the system word length is longer than the frame length defined by SCTR.H.FLE, the additional bits are transmitted with passive data level (SCTR.L.PDL). If the system word length is smaller than the device frame length, not all LSBs of the transmit data can be transferred.

It is recommended to program bits WLEMD, FLEMD and SELMD in register TCSRL to 0.

19.6.2.2 Automatic Shadow Mechanism

The baud rate and shift control setting are internally kept constant while a data frame is transferred by an automatic shadow mechanism. The registers can be programmed all the time with new settings that are taken into account for the next data frame. During a data frame, the applied (shadowed) setting is not changed, although new values have been written after the start of the data frame. The setting is internally "frozen" with the start of each data frame.

Although this shadow mechanism being implemented, it is recommended to change the baud rate and shift control setting only while the IIS protocol is switched off.

19.6.2.3 Mode Control Behavior

In IIS mode, the following kernel modes are supported:

- Run Mode 0/1:
Behavior as programmed, no impact on data transfers.
- Stop Mode 0/1:
Bit PCRL.WAGEN is internally considered as 0 (the bit itself is not changed). If WAGEN = 1, then the current system word cycle is finished and then the WA generation is stopped, but PSR.END is not set. The complete data frame is finished before entering stop mode, including a possible delay due to PCR.H.TDEL.
When leaving a stop mode with WAGEN = 1, the WA generation starts from the beginning.

19.6.2.4 Transfer Delay

The transfer delay can be used to synchronize a data transfer to an event (e.g. a change of the WA signal). This event has to be synchronously generated to the falling edge of the shift clock SCK (like the change of the transmit data), because the input signal for the event is directly sampled in the receiver (as a result, the transmitter can use the detection information with its next edge).

Event signals that are asynchronous to the shift clock while the shift clock is running must not be used. In the example in [Figure 19-49](#), the event (change of signal WA) is generated by the transfer master and as a result, is synchronous to the shift clock SCK. With the rising edge of SCK, signal WA is sampled and checked for a change. If a change is detected, a transfer delay counter TDC is automatically loaded with its programmable reload value (PCRH.TDEL), otherwise it is decremented with each rising edge of SCK until it reaches 0, where it stops. The transfer itself is started if the value of TDC has become 0. This can happen under two conditions:

- TDC is reloaded with a PCRH.TDEL = 0 when the event is detected
- TDC has reached 0 while counting down

The transfer delay counter is internal to the IIS protocol pre-processor and can not be observed by software. The transfer delay in SCK cycles is given by PCRH.TDEL+1.

In the example in [Figure 19-51](#), the reload value PCRH.TDEL for TDC is 0. When the samples taken on receiver side show the change of the WA signal, the counter TDC is reloaded. If the reload value is 0, the data transfer starts with 1 shift clock cycle delay compared to the change of WA.

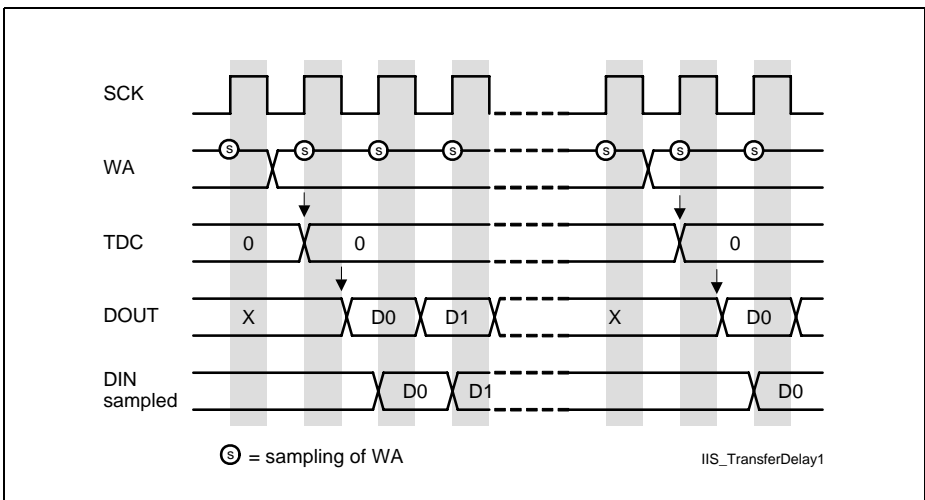


Figure 19-51 Transfer Delay with Delay 1

The ideal case without any transfer delay is shown in **Figure 19-52**. The WA signal changes and the data output value become valid at the same time. This implies that the transmitter “knows” in advance that the event signal will change with the next rising edge of TCLK. This is achieved by delaying the data transmission after the previously detected WA change the system word length minus 1.

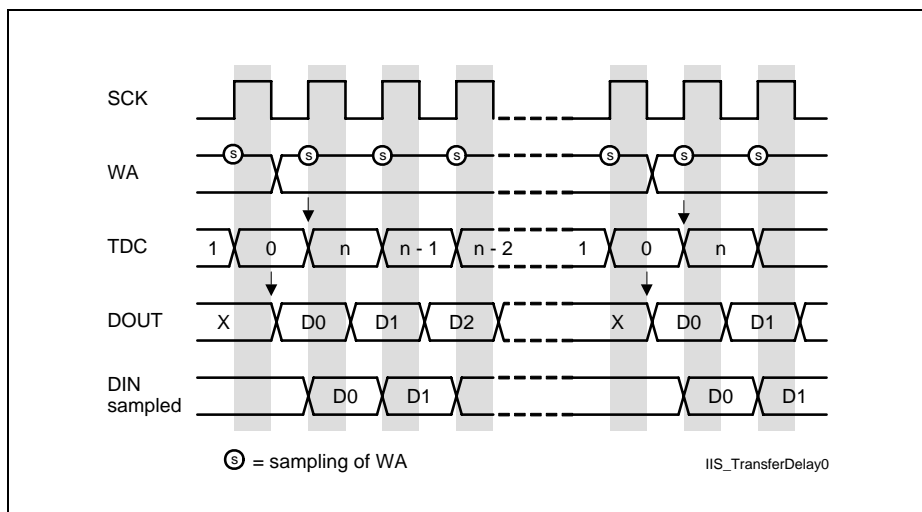


Figure 19-52 Transfer Delay with 0 Delay

If the end of the transfer delay is detected simultaneously to change of WA, the transfer is started and the delay counter is reloaded with PCRH.TDEL. This allows to run the USIC as IIS device without any delay. In this case, internally the delay from the previous event elapses just at the moment when a new event occurs. If PCRH.TDEL is set to a value bigger than the system word length, no transfer takes place.

19.6.2.5 Parity Mode

Parity generation is not supported in IIS mode and bit field CCR.PM = 00_B has to be programmed.

19.6.2.6 Transfer Mode

In IIS mode, bit field SCTRL.TRM = 11_B has to be programmed to allow data transfers. Setting SCTRL.TRM = 00_B disables and stops the data transfer immediately.

19.6.2.7 Data Transfer Interrupt Handling

The data transfer interrupts indicate events related to IIS frame handling.

- Transmit buffer interrupt TBI:
Bit PSR.TBIF is set after the start of first data bit of a data word.
- Transmit shift interrupt TSI:
Bit PSR.TSIF is set after the start of the last data bit of a data word.
- Receiver start interrupt RSI:
Bit PSR.RSIF is set after the reception of the first data bit of a data word.
With this event, bit TCSRL.TDV is cleared and new data can be loaded to the transmit buffer.
- Receiver interrupt RI and alternative interrupt AI:
Bit PSR.RIF is set at after the reception of the last data bit of a data word with WA = 0.
Bit RBUFSR.SOF indicates whether the received data word has been the first data word of a new data frame.
Bit PSR.AIF is set at after the reception of the last data bit of a data word with WA = 1.
Bit RBUFSR.SOF indicates whether the received data word has been the first data word of a new data frame.

19.6.2.8 Protocol-Related Argument and Error

In order to distinguish between data words received for the left or the right channel, the IIS protocol pre-processor samples the level of the WA input (just after the WA transition) and propagates it as protocol-related error (although it is not an error, but an indication) to the receive buffer status register at the bit position RBUFSR[9]. This bit position defines if either a standard receive interrupt (if RBUFSR[9] = 0) or an alternative receive interrupt (if RBUFSR[9] = 1) becomes activated when a new data word has been received. Incoming data can be handled by different interrupts or DMA mechanisms for the left and the right channel if the corresponding events are directed to different interrupt nodes. Flag PAR is always 0.

19.6.2.9 Transmit Data Handling

The IIS protocol pre-processor allows to distinguish between the left and the right channel for data transmission. Therefore, bit TCSRL.WA indicates on which channel the data in the buffer will be transmitted. If TCSRL.WA = 0, the data will be transmitted after a falling edge of WA. If TCSRL.WA = 1, the data will be transmitted after a rising edge of WA. The WA value sampled after the WA transition is considered to distinguish between both channels (referring to PSR.WA).

Bit TCSRL.WA can be automatically updated by the transmit control information TCI[4] for each data word if TCSRL.WAMD = 1. In this case, data written to TBUF[15:0] (or IN[15:0] if a FIFO data buffer is used) is considered as left channel data, whereas data

written to TBUF[31:16] (or IN[31:16] if a FIFO data buffer is used) is considered as right channel data.

19.6.2.10 Receive Buffer Handling

If a receive FIFO buffer is available (CCFG.RB = 1) and enabled for data handling (RBCTRH.SIZE > 0), it is recommended to set RBCTRH.RCIM = 11_B in IIS mode. This leads to an indication that the data word has been the first data word of a new data frame if bit OUTRH.RCI[0] = 1, and the channel indication by the sampled WA value is given by OUTRH.RCI[4].

The standard receive buffer event and the alternative receive buffer event can be used for the following operation in RCI mode (RBCTRH.RNM = 1):

- A standard receive buffer event indicates that a data word can be read from OUTRL that belongs to a data frame started when WA = 0.
- An alternative receive buffer event indicates that a data word can be read from OUTRL that belongs to a data frame started when WA = 1.

19.6.2.11 Loop-Delay Compensation

The synchronous signaling mechanism of the IIS protocol being similar to the one of the SSC protocol, the closed-loop delay has to be taken into account for the application setup. In IIS mode, loop-delay compensation in master mode is also possible to achieve higher baud rates.

Please refer to the more detailed description in the SSC chapter.

19.6.3 Operating the IIS in Master Mode

In order to operate the IIS in master mode, the following issues have to be considered:

- **Select IIS mode:**
It is recommended to configure all parameters of the IIS that do not change during run time while $CCR.MODE = 0000_B$. Bit field $SCTRL.TRM = 11_B$ has to be programmed. The configuration of the input stages has to be done while $CCR.MODE = 0000_B$ to avoid unintended edges of the input signals and the IIS mode can be enabled by $CCR.MODE = 0011_B$ afterwards.
- **Pin connection for data transfer:**
Establish a connection of input stage DX0 with the selected receive data input pin (DIN) with $DX0CR.INSW = 1$. Configure a transmit data output pin (DOUT) for a transmitter.
The data shift unit allowing full-duplex data transfers based on the same WA signal, the values delivered by the DX0 stage are considered as data bits (receive function can not be disabled independently from the transmitter). To receive IIS data, the transmitter does not necessarily need to be configured (no assignment of DOUT signal to a pin).
- **Baud rate generation:**
The desired baud rate setting has to be selected, comprising the fractional divider and the baud rate generator. Bit $DX1CR.INSW = 0$ has to be programmed to use the baud rate generator output SCLK directly as input for the data shift unit. Configure a shift clock output pin with the inverted signal SCLKOUT without additional delay ($BRGH.SCLKCFG = 01_B$).
- **Word address WA generation:**
The WA generation has to be enabled by setting $PCRL.WAGEN = 1$ and the programming of the number of shift clock cycles between the changes of WA. Bit $DX2CR.INSW = 0$ has to be programmed to use the WA generator as input for the data shift unit. Configure WA output pin for signal SELOx if needed.
- **Data format configuration:**
The word length, the frame length, and the shift direction have to be set up according to the application requirements by programming the registers SCTRL and SCTR. Generally, the MSB is shifted first ($SCTRL.SDIR = 1$).
Bit $TCSRL.WAMD$ can be set to use the transmit control information $TCI[4]$ to distinguish the data words for transmission while $WA = 0$ or while $WA = 1$.

19.6.3.1 Baud Rate Generation

The baud rate is defined by the frequency of the SCLK signal (one period of f_{SCLK} represents one data bit).

If the fractional divider mode is used to generate f_{PIN} , there can be an uncertainty of one period of f_{SYS} for f_{PIN} . This uncertainty does not accumulate over several SCLK cycles.

As a consequence, the average frequency is reached, whereas the duty cycle of 50% of the SCLK and MCLK signals can vary by one period of f_{SYS} .

In IIS applications, where the phase relation between the optional MCLK output signal and SCLK is not relevant, SCLK can be based on the frequency f_{PIN} (BRGL.PPPEN = 0). In the case that a fixed phase relation between the MCLK signal and SCLK is required (e.g. when using MCLK as clock reference for external devices), the additional divider by 2 stage has to be taken into account (BRGL.PPPEN = 1). This division is due to the fact that signal MCLK toggles with each cycle of f_{PIN} . Signal SCLK is then based on signal MCLK, see **Figure 19-53**.

The adjustable integer divider factor is defined by bit field BRGH.PDIV.

$$\begin{aligned} f_{\text{SCLK}} &= \frac{f_{\text{PIN}}}{2} \times \frac{1}{\text{PDIV} + 1} && \text{if PPPEN} = 0 \\ f_{\text{SCLK}} &= \frac{f_{\text{PIN}}}{2 \times 2} \times \frac{1}{\text{PDIV} + 1} && \text{if PPPEN} = 1 \end{aligned} \quad (19.12)$$

Note: In the IIS protocol, the master (unit generating the shift clock and the WA signal) changes the status of its data and WA output line with the falling edge of SCK. The slave transmitter also has to transmit on falling edges. The sampling of the received data is done with the rising edges of SCLK. The input stage DX1 and the SCLKOUT have to be programmed to invert the shift clock signal to fit to the internal signals.

19.6.3.2 WA Generation

The word address (or word select) line WA regularly toggles after N cycles of signal SCLK. The time between the changes of WA is called system word length and can be programmed by using the following bit fields.

In IIS master mode, the system word length is defined by:

- BRGL.CTQSEL = 10_B
to base the WA toggling on SCLK
- BRGL.PCTQ
to define the number N of SCLK cycles per system word length
- BRGL.DCTQ
to define the number N of SCLK cycles per system word length

$$N = (\text{PCTQ} + 1) \times (\text{DCTQ} + 1) \quad (19.13)$$

19.6.3.3 Master Clock Output

The master clock signal MCLK can be generated by the master of the IIS transfer (BRGL.PPPEN = 1). It is used especially to connect external Codec devices. It can be configured by bit BRGH.MCLKCFG in its polarity to become the output signal MCLKOUT.

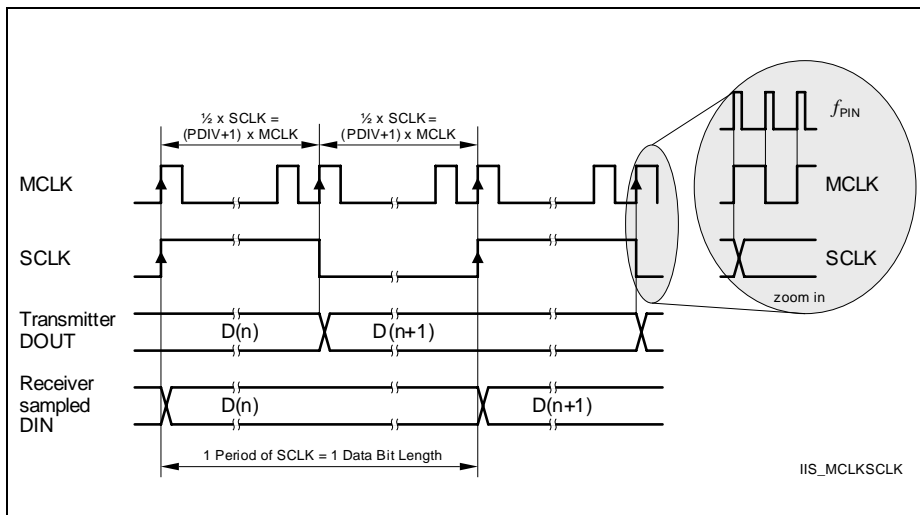


Figure 19-53 MCLK and SCLK for IIS

19.6.3.4 Protocol Interrupt Events

The following protocol-related events are generated in IIS mode and can lead to a protocol interrupt.

Please note that the bits in register PSR are not all automatically cleared by hardware and have to be cleared by software in order to monitor new incoming events.

- **WA rising/falling edge events:**
The WA generation block indicates two events that are monitored in register PSR. Flag PSR.WAFE is set with the falling edge, flag PSR.WARE with the rising edge of the WA signal. A protocol interrupt can be generated if PCRL.WAFEIEN = 1 for the falling edge, similar for PCRL.WAREIEN = 1 for a rising edge.
- **WA end event:**
The WA generation block also indicates when it has stopped the WA generation after it has been disabled by writing PCRL.WAGEN = 0. A protocol interrupt can be generated if PCRL.ENDIEN = 1.
- **DX2T event:**
An activation of the trigger signal DX2T is indicated by PSR.DX2TEV = 1 and can generate a protocol interrupt if PCRL.DX2TIEN = 1. This event can be evaluated instead of the WA rising/falling events if a delay compensation like in SSC mode (for details, refer to corresponding SSC section) is used.

19.6.4 Operating the IIS in Slave Mode

In order to operate the IIS in slave mode, the following issues have to be considered:

- **Select IIS mode:**
It is recommended to configure all parameters of the IIS that do not change during run time while $CCR.MODE = 0000_B$. Bit field $SCTRL.TRM = 11_B$ has to be programmed. The configuration of the input stages has to be done while $CCR.MODE = 0000_B$ to avoid unintended edges of the input signals and the IIS mode can be enabled by $CCR.MODE = 0011_B$ afterwards.
- **Pin connection for data transfer:**
Establish a connection of input stage DX0 with the selected receive data input pin (DIN) with $DX0CR.INSW = 1$. Configure a transmit data output pin (DOUT) for a transmitter.
The data shift unit allowing full-duplex data transfers based on the same WA signal, the values delivered by the DX0 stage are considered as data bits (receive function can not be disabled independently from the transmitter). To receive IIS data, the transmitter does not necessarily need to be configured (no assignment of DOUT signal to a pin).
- **Pin connection for shift clock:**
Establish a connection of input stage DX1 with the selected shift clock input pin (SCLKIN) with $DX1CR.INSW = 1$ and with inverted polarity ($DX1CR.DPOL = 1$).
- **Pin connection for WA input:**
Establish a connection of input stage DX2 with the WA input pin (SELIN) with $DX2CR.INSW = 1$.
- **Baud rate generation:**
The baud rate generator is not needed and can be switched off by the fractional divider.
- **WA generation:**
The WA generation is not needed and can be switched off ($PCRL.WAGEN = 0$).

19.6.4.1 Protocol Events and Interrupts

The following protocol-related event is generated in IIS mode and can lead to a protocol interrupt.

Please note that the bits in register PSR are not all automatically cleared by hardware and have to be cleared by software in order to monitor new incoming events.

- **WA rising/falling/end events:**
The WA generation being switched off, these events are not available.
- **DX2T event:**
An activation of the trigger signal DX2T is indicated by $PSR.DX2TEV = 1$ and can generate a protocol interrupt if $PCRL.DX2TIEN = 1$.

19.6.5 IIS Protocol Registers

In IIS mode, the registers PCRL, PCRH and PSR handle IIS related information.

19.6.5.1 IIS Protocol Control Registers

In IIS mode, the PCRL/PCRH register bits or bit fields are defined as described in this section.

PCRL

Protocol Control Register L [IIS Mode]

(40_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DX2 TIEN					0				END IEN	WAR EIEN	WAF EIEN	0	SELI NV	DT EN	WAG EN
rw					rw				rw	rw	rw	r	rw	rw	rw

Field	Bits	Type	Description
WAGEN	0	rw	WA Generation Enable This bit enables/disables the generation of word address control output signal WA. 0 _B The IIS can be used as slave. The generation of the word address signal is disabled. The output signal WA is 0. The MCLKO signal generation depends on PCRH.MCLK. 1 _B The IIS can be used as master. The generation of the word address signal is enabled. The signal starts with a 0 after being enabled. The generation of MCLK is enabled, independent of PCRH.MCLK. After clearing WAGEN, the USIC module stops the generation of the WA signal within the next 4 WA periods.
DTEN	1	rw	Data Transfers Enable This bit enables/disables the transfer of IIS frames as a reaction to changes of the input word address control line WA. 0 _B The changes of the WA input signal are ignored and no transfers take place. 1 _B Transfers are enabled.

Field	Bits	Type	Description
SELINV	2	rw	Select Inversion This bit defines if the polarity of the SELOx outputs in relation to the internally generated word address signal WA. 0 _B The SELOx outputs have the same polarity as the WA signal. 1 _B The SELOx outputs have the inverted polarity to the WA signal.
WAFEIEN	4	rw	WA Falling Edge Interrupt Enable This bit enables/disables the activation of a protocol interrupt when a falling edge of WA has been generated. 0 _B A protocol interrupt is not activated if a falling edge of WA is generated. 1 _B A protocol interrupt is activated if a falling edge of WA is generated.
WAREIEN	5	rw	WA Rising Edge Interrupt Enable This bit enables/disables the activation of a protocol interrupt when a rising edge of WA has been generated. 0 _B A protocol interrupt is not activated if a rising edge of WA is generated. 1 _B A protocol interrupt is activated if a rising edge of WA is generated.
ENDIEN	6	rw	END Interrupt Enable This bit enables/disables the activation of a protocol interrupt when the WA generation stops after clearing PCR.WAGEN (complete system word length is processed before stopping). 0 _B A protocol interrupt is not activated. 1 _B A protocol interrupt is activated.
DX2TIEN	15	rw	DX2T Interrupt Enable This bit enables/disables the generation of a protocol interrupt if the DX2T signal becomes activated (indicated by PSR.DX2TEV = 1). 0 _B A protocol interrupt is not generated if DX2T is active. 1 _B A protocol interrupt is generated if DX2T is active.
0	3, [14:7]	rw	Reserved Returns 0 if read; should be written with 0;

PCRH

Protocol Control Register H [IIS Mode]

(42_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
M					0							TDEL			
CLK															
rw					rw							rw			

Field	Bits	Type	Description
TDEL	[5:0]	rw	Transfer Delay This bit field defines the transfer delay when an event is detected. If bit field TDEL = 0, the additional delay functionality is switched off and a delay of one shift clock cycle is introduced.
0	[14:6]	rw	Reserved Returns 0 if read; should be written with 0.
MCLK	15	rw	Master Clock Enable This bit enables generation of the master clock MCLK (not directly used for IIC protocol, can be used as general frequency output). 0 _B The MCLK generation is disabled and MCLK is 0. 1 _B The MCLK generation is enabled.

19.6.5.2 IIS Protocol Status Register

The following PSR status bits or bit fields are available in IIS mode. Please note that the bits in register PSR are not cleared by hardware.

The flags in the PSR register can be cleared by writing a 1 to the corresponding bit position in register PSCR. Writing a 1 to a bit position in PSR sets the corresponding flag, but doesn't lead to further actions (no interrupt generation). Writing a 0 has no effect. These flags should be cleared by software before enabling a new protocol.

PSR

Protocol Status Register [IIS Mode] (44_H)

Reset Value: 0000_H

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AIF	RIF	TBIF	TSIF	DLIF	RSIF		0		END	WA RE	WA FE	DX2 TEV	0	DX2 S	WA
rwh	rwh	rwh	rwh	rwh	rwh		r		rwh	rwh	rwh	rwh	r	rwh	rwh

Field	Bits	Type	Description
WA	0	rwh	Word Address This bit indicates the status of the WA input signal, sampled after a transition of WA has been detected. This information is forwarded to the corresponding bit position RBUFSTR[9] to distinguish between data received for the right and the left channel. 0 _B WA has been sampled 0. 1 _B WA has been sampled 1.
DX2S	1	rwh	DX2S Status This bit indicates the current status of the DX2S signal, which is used as word address signal WA. 0 _B DX2S is 0. 1 _B DX2S is 1.
DX2TEV	3	rwh	DX2T Event Detected¹⁾ This bit indicates that the DX2T signal has been activated. In IIS slave mode, an activation of DX2T generates a protocol interrupt if PCRL.DX2TIEN = 1. 0 _B The DX2T signal has not been activated. 1 _B The DX2T signal has been activated.

Universal Serial Interface Channel

Field	Bits	Type	Description
WAFE	4	rwh	WA Falling Edge Event¹⁾ This bit indicates that a falling edge of the WA output signal has been generated. This event generates a protocol interrupt if PCRL.WAFEIEN = 1. 0 _B A WA falling edge has not been generated. 1 _B A WA falling edge has been generated.
WARE	5	rwh	WA Rising Edge Event¹⁾ This bit indicates that a rising edge of the WA output signal has been generated. This event generates a protocol interrupt if PCRL.WAREIEN = 1. 0 _B A WA rising edge has not been generated. 1 _B A WA rising edge has been generated.
END	6	rwh	WA Generation End¹⁾ This bit indicates that the WA generation has ended after clearing PCRL.WAGEN. This bit should be cleared by software before clearing WAGEN. 0 _B The WA generation has not yet ended (if it is running and WAGEN has been cleared). 1 _B The WA generation has ended (if it has been running).
RSIF	10	rwh	Receiver Start Indication Flag 0 _B A receiver start event has not occurred. 1 _B A receiver start event has occurred.
DLIF	11	rwh	Data Lost Indication Flag 0 _B A data lost event has not occurred. 1 _B A data lost event has occurred.
TSIF	12	rwh	Transmit Shift Indication Flag 0 _B A transmit shift event has not occurred. 1 _B A transmit shift event has occurred.
TBIF	13	rwh	Transmit Buffer Indication Flag 0 _B A transmit buffer event has not occurred. 1 _B A transmit buffer event has occurred.
RIF	14	rwh	Receive Indication Flag 0 _B A receive event has not occurred. 1 _B A receive event has occurred.
AIF	15	rwh	Alternative Receive Indication Flag 0 _B An alternative receive event has not occurred. 1 _B An alternative receive event has occurred.

Universal Serial Interface Channel

Field	Bits	Type	Description
0	2, [9:7]	r	Reserved Returns 0 if read; not modified in IIS mode.

1) This status bit can generate a protocol interrupt (see [Page 19-24](#)). The general interrupt status flags are described in the general interrupt chapter.

19.7 USIC Implementation in XE166U

This section describes the implementation specific details of the USIC modules in the XE166U. It contains details about:

- Implementation Overview (see [Page 19-205](#))
- Channel Features (see [Page 19-206](#))
- Address Map (see [Page 19-206](#))
- Module Identification Registers (see [Page 19-207](#))
- Interrupt Control Registers (see [Page 19-209](#))
- Input/Output Connections (see [Page 19-210](#))
- USIC Module 0 I/O Lines (see [Page 19-211](#))

19.7.1 Implementation Overview

The XE166U device contains one USIC module (USIC0) with 2 communication channels.

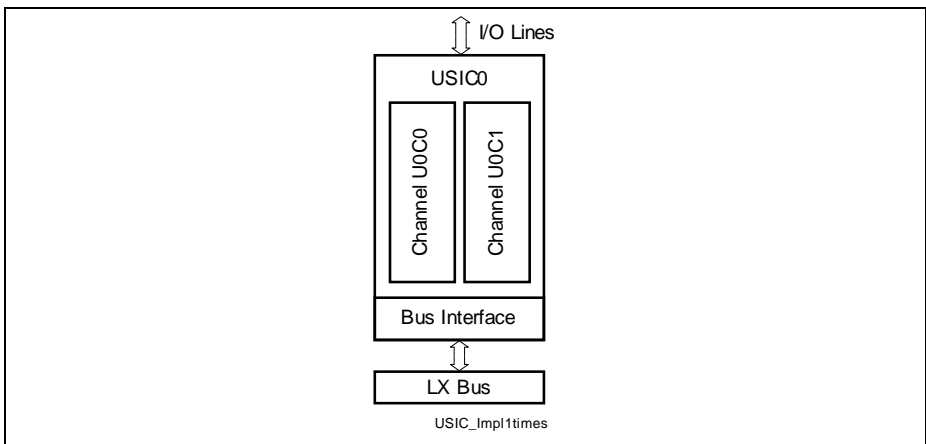


Figure 19-54 USIC Module Structure in XE166U

19.7.2 Channel Features

The USIC channel in the XE166U support the following functionality:

Table 19-11 USIC Module Feature Set

Channel	ASC Protocol	LIN Support	SSC Protocol	IIC Protocol	IIS Protocol	FIFO Buffer Entries	SELOx ¹⁾	
							64-Pins	48-Pins
U0C0	yes	yes	yes	yes	yes	64	4	4
U0C1	yes	yes	yes	yes	yes	shared	2	2

1) These are the maximum number of signals available in the 48-pin and 38-pin packages.

19.7.3 Address Map

The registers of the USIC communication channel are available at the following base addresses. The exact register address is given by the relative address of the register plus the channel base address (given in [Table 19-12](#)).

Table 19-12 Registers Address Space

Module	Base Address	End Address	Note
U0C0	204000 _H	2041FF _H	—
U0C1	204200 _H	2043FF _H	—
U0C0A	20B000 _H	20B1FF _H	Alternate Locations
U0C1A	20B200 _H	20B3FF _H	Alternate Locations

Field	Bits	Type	Description
MOD_NUMBER	[15:0]	r	Module Number Value This bit field defines the USIC module identification number (003A _μ = USIC).

19.7.5 Interrupt Control Registers

Each USIC channel provides 4 service request outputs SR[3:0] (not all of them are necessarily connected to independent interrupt registers UxCy_nIC). **Table 19-13** shows the assignment of the service request outputs to the interrupt control registers.

Each USIC communication channel is connected to 3 dedicated interrupt control registers (connected to UxCy_SR[2:0], e.g. one for transmission, one for reception, the third one for protocol or error handling, or for the alternative receive events). A fourth interrupt control register per communication channel (connected to UxCy_SR3) is shared with module CC2.

The interrupt control registers are located in the SFR area. They are described in the general interrupt chapter.

Table 19-13 USIC0 Interrupt Control Registers

Service Request Output Line	Interrupt Control Register/Bit
SR0 of USIC0 channel 0	U0C0_0IC
SR1 of USIC0 channel 0	U0C0_1IC
SR2 of USIC0 channel 0	U0C0_2IC
SR3 of USIC0 channel 0	CC2_CC20IC, selected by ISSR.ISS4 CCU60_T13HRG
SR0 of USIC0 channel 1	U0C1_0IC
SR1 of USIC0 channel 1	U0C1_1IC
SR2 of USIC0 channel 1	U0C1_2IC
SR3 of USIC0 channel 1	CC2_CC21IC, selected by ISSR.ISS5

19.7.6 Input/Output Connections

Figure 19-1 shows the I/O lines of one USIC channel. The tables in this section define the pin assignments and internal connections of the USIC channels I/O lines in the XE166U device. Naming convention: UxCy refers to USIC module x channel y.

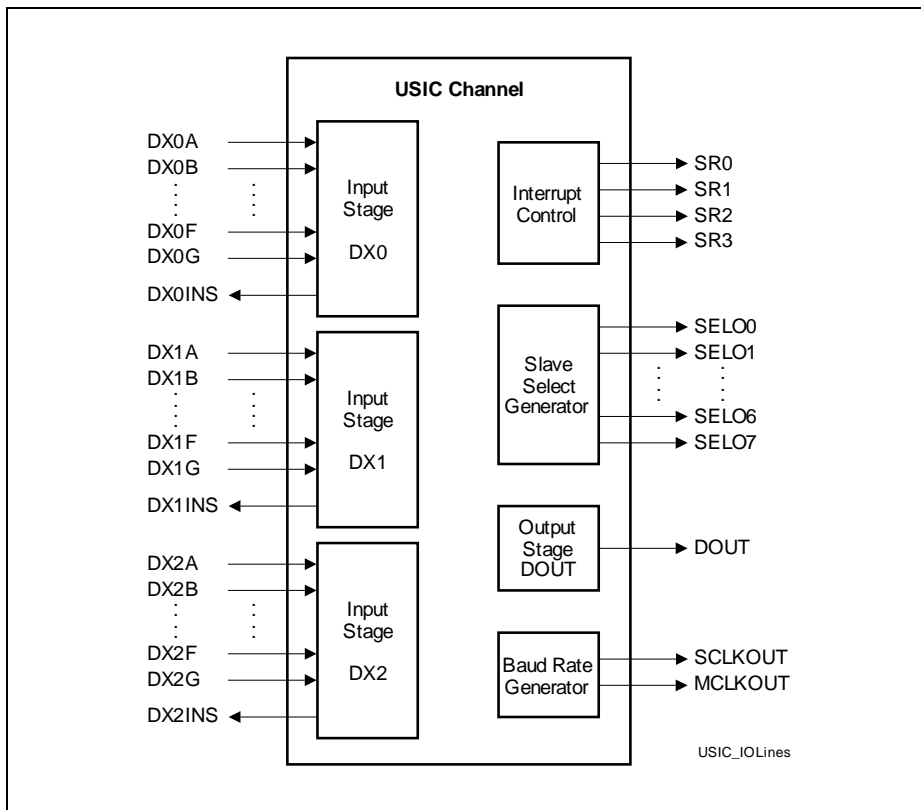


Figure 19-55 USIC Channel I/O Lines

The connections of the service request outputs SR[3:0] to the interrupt control registers are defined in [Table 19-13](#) on [Page 19-209](#).

19.7.6.1 USIC Module 0 I/O Lines

The signals of USIC module 0 have the prefix "U0C0_" for channel 0 and "U0C1_" for channel 1.

Table 19-14 I/O Connections of USIC0

Signal	Used as	From/To	
		Channel 0 – U0C0	Channel 1 – U0C1
Data Inputs			
DX0A	Shift data input	P10.0	P10.0
DX0B	Shift data input	P10.1	P10.7
DX0C	Shift data input	P10.6	0
DX0D	Shift data input	P10.12	P2.3
DX0E	Shift data input	P2.3	P2.10
DX0F	Shift data input	P2.4	0
DX0G	Loop back data shift input	U0C0_DOUT	U0C1_DOUT
Clock Inputs			
DX1A	Shift clock input	P10.1	P10.10
DX1B	Shift clock input	P10.2	P10.5
DX1C	Shift clock input	P10.8	0
DX1D	Shift clock input	P2.5	P2.8
DX1E	Shift clock input	0	0
DX1F	Input for single wire ASC collision detection	U0C0_DX0INS	U0C1_DX0INS
DX1G	Loop back shift clock input	U0C0_SCLKOUT	U0C1_SCLKOUT
Control Inputs			
DX2A	Shift control input	P10.3	P10.3
DX2B	Shift control input	P10.4	P10.4
DX2C	Shift control input	P10.10	P2.7
DX2D	Shift control input	P2.6	0
DX2E	Input for transmit data validation	CC2_24IO	RTC_T14INT
DX2F	Input for transmit data validation	CCU60_COUT63	CCU60_COUT63
DX2G	Loop back shift control input	U0C0_SELO0	U0C1_SELO0

Table 19-14 I/O Connections of USIC0 (cont'd)

Signal	Used as	From/To	
		Channel 0 – U0C0	Channel 1 – U0C1
Data Outputs			
DOUT	Shift data output	P2.3	P2.9
		P10.12	P2.10
		P10.1	–
		P10.6	P2.4
		–	P10.0
		–	P10.7
		–	–
		–	–
Clock Outputs			
MCLKOUT	Master clock output, e.g. for IIS	P10.8	P10.9
SCLKOUT	Shift clock output	P2.5	P2.8
		P10.2	P10.5
Control Outputs			
SELO0	Shift control output 0	P2.6	P2.7
		P10.10	P10.8
SELO1	Shift control output 1	P2.7	P2.6
SELO2	Shift control output 2	–	–
SELO3	Shift control output 3	P2.10	–
		P10.4	–
SELO4	Shift control output 5	–	–
		P10.9	–
SELO5	Shift control output 5	–	–
SELO6	Shift control output 6	–	–
SELO7	Shift control output 7	–	–

Table 19-14 I/O Connections of USIC0 (cont'd)

Signal	Used as	From/To	
		Channel 0 – U0C0	Channel 1 – U0C1
System Related Outputs			
DX0INS	External interrupt input for ERU (SCU)	ERU_0A2	ERU_0B2
	Single wire ASC collision detection	U0C0_DX1F	U0C1_DX1F
DX1INS	External interrupt input for ERU (SCU)	–	–
DX2INS	External interrupt input for ERU (SCU)	ERU_0A3	ERU_0B3
Loop Back Outputs			
DOUT	Loop back shift data output	U0C0_DX0G	U0C1_DX0G
SCLKOUT	Loop back shift clock output	U0C0_DX1G	U0C1_DX1G
SELO0	Loop back shift control output	U0C0_DX2G	U0C1_DX2G

20 Appendix: Functional and Operational Updates

The XE166U devices are the low end extensions of the XC2000 Family of microcontrollers. This new series of product types provides smaller memories, packages and an optimized feature set for low end cost sensitive applications.

A number of new enhancements are added but at the same time, some existing features had to be removed or adapted to realize the low cost design. For those adapted features, they are now controlled in a different way, while providing comparable functions.

This appendix summarizes both types of updates:

- **Functional updates:** new features that have been incorporated to add functionality to applications or features that are removed.
- **Operational updates:** existing features that are controlled in a different way.

Note: These hints help to exploit additional functionalities, to avoid malfunctions when migrating to the new series of microcontrollers, and to design software that can run on multiple types of products.

Memory Content Protection for RAMs

Single bit error detection and correction (ECC) of the on-chip RAMs is not supported. However, parity checking can be used to supervise the memory contents of these RAMs.

Startup Configuration

The number of GPIO pins required during hardware startup configuration ($\overline{\text{TRST}}$ pin is high) is reduced to two (P10.12 and P2.9). This allows more GPIOs to be available for the application right from the start. With these two pins, the following basic startup modes can be selected:

- UART Bootloader
- CAN Bootloader
- Internal start from Flash with JTAG debug support
- Startup and debug mode based on Boot Mode Index (BMI)

The BMI is a 32-bit word in Security Page 0 of the Flash configuration sector and it can be programmed to select additional startup modes.

Note: In XE166U, the SSC Bootloader and UART Enhanced Bootloader are not supported. And with less available GPIOs due to the small packages used, the specific set of interface pins used by the startup modes may be different from the rest of the family.

External Clock Output

The external clock output may not support a full voltage swing if the clock frequency is more than 10 MHz.

Appendix: Functional and Operational Updates**Wake-Up Timer Trigger**

Besides CCU60, the Wake-up Timer (WUT) trigger is also forwarded to the General Purpose Timer Units and CAPCOM2, to support the determination of Wake-up Period.

Power Domains

For simplification of the power concept, only one I/O power domain, DMP_B, and one core power domain, DMP_M, are implemented.

Standby Mode

With a single core power domain, DMP_M, it is no longer feasible to support the Standby power Mode. Therefore, the Standby Mode and the corresponding 8-Kbyte Standby RAM (SBRAM) are removed.

Temperature Compensation

The temperature compensation feature for port drivers is removed.

Watchdog Timer

An enhanced Watchdog Timer module, called Window Watchdog (WWD), is offered in XE166U with the following new features:

- Programmable window boundary
- WWD input clock source can be selected from the system clock or the independent clock from the Wake-up Oscillator
- WWD reset can additionally trigger a power reset for DMP_M power domain

Some existing features are removed:

- Double WDT reset detection
- Prewarning mode

Pin Configuration and Definition

In order to increase the number of available GPIOs, the pin sequence has to be rearranged. Therefore, the pin configuration may not always be compatible to other devices in the family.

And to allow greater port connection flexibility for applications, additional pin functions are defined for some of the existing GPIOs, for example, USIC0 shift data input and output functions are added to P10.12.

Port Driver Modes

A new set of port driver modes is provided in XE166U. Therefore, the electrical pad parameters will be different compared to other devices in the family.

Appendix: Functional and Operational Updates

External Bus Controller

The External Bus Controller (EBC) is not available in XE166U.

Debugging via SPD

The new Single Pin DAP (SPD) offers a single-wire debug interface in addition to the DAP and standard JTAG debug interfaces.

A/D Converter

The single ADC module is equipped with the following additional features:

- 8-bit, 10-bit or 12-bit programmable resolution
- Boundary flag control allows hall input signals of a CCU6x unit to be generated using the limit checking mechanisms
- Digital low pass filter for preprocessing of conversion results

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