OPTIREG™ PMIC TLF35585QUS02

Functional safety PMIC

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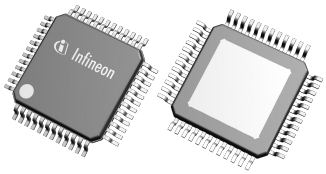
AEC Qualified | RoHS | ISO 26262 compliant

Features



- High efficient power management integrated circuit (PMIC)
- Serial step up and step down pre-regulator for wide input voltage range from 3.0 V to 40 V with full performance and low overall power loss
- Low drop post regulator 3.3 V/600 mA for microcontroller main supply (QUC)
- Low drop post regulator 5.0 V/200 mA for communication supply (QCO)
- Voltage reference (±1%) 5.0 V/150 mA for ADC supply (QVR)
- Two trackers for sensor supply following voltage reference 150 mA current capability each (QT1 and QT2)
- Standby regulator 3.3 V/10 mA (QST)
- Enable, sync out signal and voltage monitoring of an optional external post regulator for core supply
- Independent voltage monitoring block and error pin monitoring
- Configurable window watchdog and functional watchdog
- Safe State Control with two safe state signals with programmable delay
- 16-bit SPI, interrupt and reset function
- High junction temperature operation up to 175°C
- PRO-SIL™ Features:
  - ISO 26262 Safety Element out of Context for requirements up to ASIL D
  - Safety documentation for ISO 26262 compliant system integration
- Green Product (RoHS compliant)

Potential applications

- Electric power steering
- Battery management
- Engine management
- Domain control
- Traction inverter

Product validation

Qualified for automotive applications with higher temperature requirements. Product validation according to AEC-Q100, Grade 0.

Description

The OPTIREG™ PMIC TLF35585QUS02 is a highly efficient Functional Safety PMIC (Power management integrated circuit) for safety-relevant applications.

The power supply includes a boost-buck pre-regulator supplying post regulator rails for microcontroller supply, communication supply and a precise voltage reference. In addition, two trackers following the voltage reference are available to supply off-board sensors.

The OPTIREG™ PMIC TLF35585QUS02 comes with a configurable window watchdog (time based trigger) and functional watchdog (question and answer based trigger), error pin monitoring and voltage monitoring functions as major supervision functions. For microcontroller interaction a 16-bit SPI, interrupt and reset function are provided.

The device has been developed according to ISO 26262 targeting systems up to ASIL D and supports an extended junction temperature range of up to 175°C.

Type	Package	Marking (Line1 / Line2)
TLF35585QUS02	PG-TQFP-48-10	TLF35585 / S02

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1 Block diagram

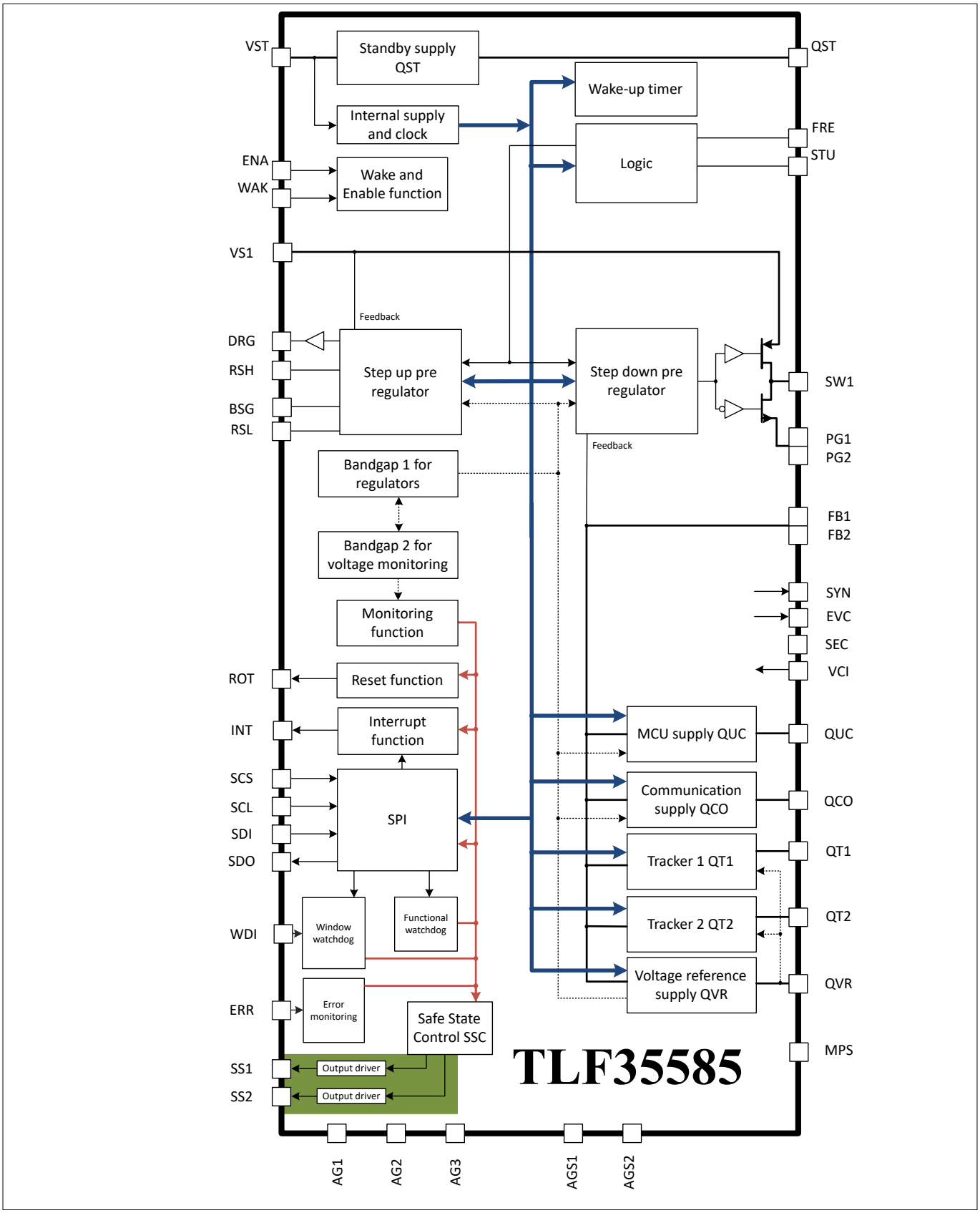


Figure 1 Block diagram

2 Pin configuration

2.1 Pin assignment

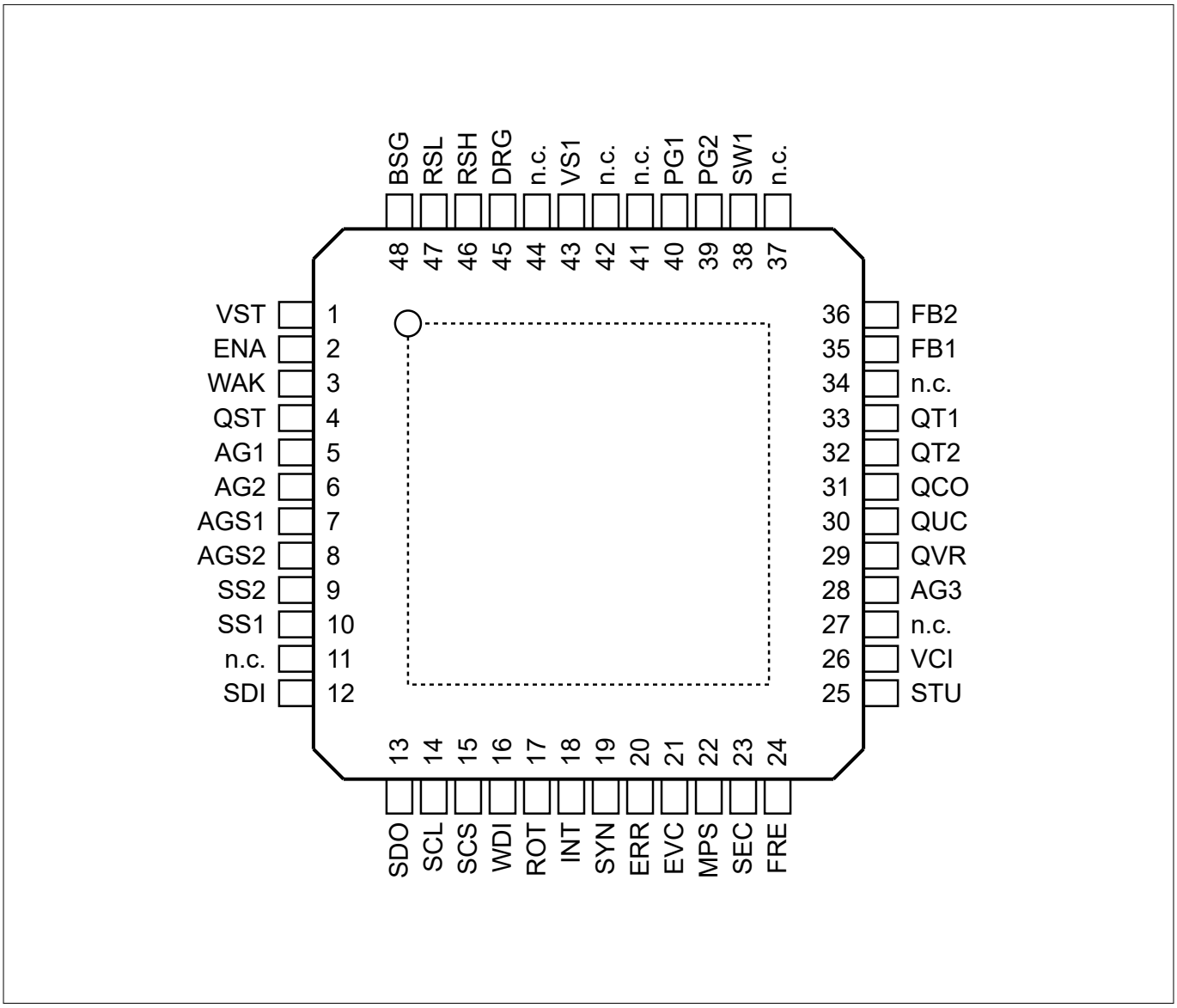


Figure 2 Pin assignment

2.2 Pin definitions and functions

Pin	Symbol	Function
1	VST	Standby and internal supply input: Connect this input directly to pin VS1. It is recommended to place a local capacitor between pin and ground.
2	ENA	Enable input: A rising edge signal at this pin generates a wake-up event for the device. In case of not used, connect to ground.

2 Pin configuration

Pin	Symbol	Function
3	WAK	Wake input: A "high" signal at this pin generates a wake-up event for the device. In case of not used, connect to ground.
4	QST	Standby supply output: Connect a capacitor as close as possible to pin.
5	AG1	Analog ground, pin 1: Connect this pin directly (low ohmic and low inductive) to ground.
6	AG2	Analog ground, pin 2: Connect this pin directly (low ohmic and low inductive) to ground.
7	AGS1	Analog ground safety, pin 1: Connect this pin directly (low ohmic and low inductive) to ground. In case a safety switch is used, connect directly to the source of the NMOS used.
8	AGS2	Analog ground safety, pin 2: Connect this pin directly (low ohmic and low inductive) to ground. In case a safety switch is used, connect directly to the source of the NMOS used.
9	SS2	Safe state signal 2: Safe state output signal 2, sets the application into a safe state. Signal is delayed against SS1, delay can be adjusted via SPI command. In case of not used, leave open.
10	SS1	Safe state signal 1: Safe state output signal 1, sets the application into a safe state.
11	N.C.	Internally not connected: This pin is electrically not connected internally and can be kept open/floating, connected to GND or any other signal. Consider neighboring signals for potential failures.
12	SDI	Serial peripheral interface, signal data input (MOSI): SPI signaling port, connect to SPI port "data output" (MOSI) of microcontroller to receive commands during SPI communication.
13	SDO	Serial peripheral interface, signal data output (MISO): SPI signaling port, connect to SPI port "data input" (MISO) of microcontroller to send status information during SPI communication.
14	SCL	Serial peripheral interface, signal clock input (SCLK): SPI signaling port, connect to SPI port "clock" (SCLK) of microcontroller to clock the device for SPI communication.
15	SCS	Serial peripheral interface, signal chip select input: SPI signaling port, connect to SPI port "chip select" of microcontroller to address the device for SPI communication.
16	WDI	Watchdog pin-trigger input: Input for trigger signal, connect the "trigger signal output" of the microcontroller to this pin. In case of not used, leave open (internal pull-down).

2 Pin configuration

Pin	Symbol	Function
17	ROT	Reset signal output: Open drain structure with internal pull-up current source. A low signal at this pin indicates a reset event.
18	INT	Interrupt signal output: Push-pull-stage. A low pulse at this pin indicates an interrupt, the microcontroller shall read out the SPI status registers. Connect to a non maskable interrupt port (NMI) of the microcontroller.
19	SYN	Synchronization signal output: Connect this output to the optional external switch mode post regulator synchronization input. The signal delivers the step down regulator switching frequency either in phase or shifted by 180° (selectable via SPI command). The switch mode post regulator shall synchronize to the rising edge. If not used, then leave open.
20	ERR	Error signal input: Input for error signal from microcontroller safety managing unit (SMU, internal failure detection of the microcontroller). Connect the "error signal output" (FSP) of the microcontroller to this pin. If the function is not used, then connect this pin to ground.
21	EVC	Enable signal output for external post regulator for core supply: Connect this pin to the enable input of the external post regulator. If not used, then leave open.
22	MPS	Microcontroller programming support input: Input to enable microcontroller programming support (MPS). For details please refer to Chapter 10.7. If the function is not used, then connect this pin to ground.
23	SEC	Hardware configuration pin for external post regulator for core supply: If the option external post regulator is not used, then connect this pin to ground. If the option external post regulator is used, then leave open.
24	FRE	Hardware configuration pin for step down pre-regulator base frequency: Connect this pin to ground for low frequency range or leave open for high frequency range.
25	STU	Hardware configuration pin for step up converter: If the option step up pre-regulator is not used, then connect this pin to ground . If the option step up pre regulator is used, then leave open.
26	VCI	Input for optional external post regulator output voltage monitoring (core supply): Connect an external resistor divider to adjust the residual overvoltage and undervoltage thresholds of the voltage monitoring input to the applications need. If the option external post regulator is not used, then leave open.

2 Pin configuration

Pin	Symbol	Function
27	N.C.	Internally not connected: This pin is electrically not connected internally and can be kept open/floating, connected to GND or any other signal. Consider neighboring signals for potential failures.
28	AG3	Analog ground, pin 3: Connect this pin directly (low ohmic and low inductive) to ground.
29	QVR	Voltage reference supply output: Connect a capacitor as close as possible to pin.
30	QUC	MCU supply output (microcontroller main supply): Connect a capacitor as close as possible to pin.
31	QCO	Communication supply output: Connect a capacitor as close as possible to pin.
32	QT2	Tracker 2 output: Connect a capacitor as close as possible to pin.
33	QT1	Tracker 1 output: Connect a capacitor as close as possible to pin.
34	N.C.	Internally not connected: This pin is electrically not connected internally and can be kept open/floating, connected to GND or any other signal. Consider neighboring signals for potential failures.
35	FB1	Step down pre-regulator feedback input and input for linear post regulators and trackers, pin 1: Connect the capacitor of the step down pre-regulator output filter with low ohmic and low inductive connection straight to this pin. Always connect in parallel with pin FB1 - FB2.
36	FB2	Step down pre-regulator feedback input and input for linear post regulators and trackers, pin 2: Connect the capacitor of the step down pre-regulator output filter with low ohmic and low inductive connection straight to this pin. Always connect in parallel with pin FB1 - FB2.
37	N.C.	Internally not connected: This pin is electrically not connected internally and can be kept open/floating, connected to GND or any other signal. Consider neighboring signals for potential failures.
38	SW1	Step down pre-regulator power stage output, pin 1: Connect this pin straight (low ohmic and low inductive) to the pre-regulator output filter.
39	PG2	Step down pre-regulator power ground, pin 2: Connect this pin straight (low ohmic and low inductive) to the step down pre-regulator input capacitances (attached to VS1) ground connection, to its output capacitances ground connection and to ground. Always connect in parallel with pin PG1.

2 Pin configuration

Pin	Symbol	Function
40	PG1	Step down pre-regulator power ground, pin 1: Connect this pin straight (low ohmic and low inductive) to the step down pre-regulator input capacitances (attached to VS1) ground connection, to its output capacitances ground connection and to ground. Always connect in parallel with pin PG2.
41	N.C.	Internally not connected: This pin is electrically not connected internally and can be kept open/floating, connected to GND or any other signal. Consider neighboring signals for potential failures.
42	N.C.	Internally not connected: This pin is electrically not connected internally and can be kept open/floating, connected to GND or any other signal. Consider neighboring signals for potential failures.
43	VS1	Supply voltage step down pre-regulator, pin 1, input: Connect this input directly to pin VST. Connect this input to the input pi-filter of the step down pre-regulator with reverse protection diode in front. If step up pre-regulator is used the filter may be shared with the output filter of the step-up pre regulator. A capacitor between VS1 and PGx very close to the pins is recommended as EMC filter.
44	N.C.	Internally not connected: This pin is electrically not connected internally and can be kept open/floating, connected to GND or any other signal. Consider neighboring signals for potential failures.
45	DRG	Driver output for external step up regulator power stage: Gate of low side switch of step up pre-regulator: Connect to the gate of an external N-channel MOSFET, line to be straight and as short as possible. If step up pre-regulator option is not used, then leave open.
46	RSH	Sense resistor input for external step up regulator power stage, high side: Connect this pin to the high side of an external current sense resistor to determine the maximum current threshold through the external N-channel MOSFET. If step up pre-regulator option is not used, then connect to ground.
47	RSL	Sense resistor input for external step up regulator power stage, low side: Connect this pin to the low side of an external current sense resistor to determine the maximum current threshold through the external N-channel MOSFET. If step up pre-regulator option is not used, then connect to ground.
48	BSG	Boost driver ground: Connect this pin to ground at the low side of an external current sense resistor to decouple the driver noise from the sensitive ground. If step up pre-regulator option is not used, connect to then ground.
Exposed diepad	GND	Exposed diepad. Connect externally to GND and heat sink area.

3 General product characteristics

3.1 Absolute maximum ratings

Table 1 Absolute maximum ratings[1)]

T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Voltages							
Boost driver ground	V_{BSG}	-0.3	–	0.3	V	–	P_4.1.1
Input standby supply	V_{VST}	-0.3	–	40	V	2) 3)	P_4.1.2
Input voltage pin 1 (pre-regulator)	V_{VS1}	-0.3	–	40	V	2) 3)	P_4.1.3
External step up power stage, gate	V_{DRG}	-0.3	–	40	V	2)	P_4.1.4
External power stage, sense resistor high	V_{RSH}	-0.3	–	40	V	2)	P_4.1.5
External power stage, sense resistor low	V_{RSL}	-0.3	–	2.5	V	–	P_4.1.6
Enable input	V_{ENA}	-0.3	–	40	V	2)	P_4.1.7
Enable input	I_{ENA}	-5	–	–	mA	4)	P_4.1.8
Wake input	V_{WAK}	-0.3	–	40	V	2)	P_4.1.9
Wake input	I_{WAK}	-5	–	–	mA	4)	P_4.1.10
Reset output	V_{ROT}	-0.3	–	40.0	V	–	P_4.1.11
SPI chip select input	V_{SCS}	-0.3	–	40.0	V	–	P_4.1.12
SPI clock input	V_{SCL}	-0.3	–	40.0	V	–	P_4.1.13
SPI data in (MOSI) input	V_{SDI}	-0.3	–	40.0	V	–	P_4.1.14
SPI data out (MISO output)	V_{SDO}	-0.3	–	40.0	V	–	P_4.1.15
Interrupt output	V_{INT}	-0.3	–	40.0	V	–	P_4.1.16
Window watchdog trigger input	V_{WDI}	-0.3	–	40.0	V	–	P_4.1.17
Error pin input	V_{ERR}	-0.3	–	40.0	V	–	P_4.1.18
Safe state 1 output	V_{SS1}	-0.3	–	40.0	V	–	P_4.1.19
Safe state 2 output	V_{SS2}	-0.3	–	40.0	V	–	P_4.1.20
Output voltage reference supply	V_{QVR}	-0.3	–	6.0	V	–	P_4.1.21
Output tracker 2	V_{QT2}	-1.0	–	40	V	–	P_4.1.22

(table continues...)

Table 1 (continued) Absolute maximum ratings[1)]

T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Output tracker 1	V_{QT1}	-1.0	–	40	V	–	P_4.1.23
Output communication supply	V_{QCO}	-0.3	–	6.0	V	–	P_4.1.24
Output microcontroller main supply	V_{QUC}	-0.3	–	6.0	V	–	P_4.1.25
External core voltage monitor input	V_{VCI}	-0.3	–	6.0	V	–	P_4.1.26
HW config: ext. core voltage monitor	V_{SEC}	-0.3	–	6.0	V	–	P_4.1.27
Synchronization output	V_{SYN}	-0.3	–	40.0	V	–	P_4.1.28
Enable output for ext. core supply	V_{EVC}	-0.3	–	40.0	V	–	P_4.1.29
Step down feedback input 2	V_{FB2}	-0.3	–	8.0	V	–	P_4.1.30
Step down feedback input 1	V_{FB1}	-0.3	–	8.0	V	–	P_4.1.31
Step down power ground 2	V_{PG2}	-0.3	–	0.3	V	–	P_4.1.32
Step down power ground 1	V_{PG1}	-0.3	–	0.3	V	–	P_4.1.33
Step down switching node	V_{SW1}	-0.3	–	40	V	[3)]	P_4.1.34
HW config: step up pre-regulator	V_{STU}	-0.3	–	6.0	V	–	P_4.1.35
HW config: step down frequency	V_{FRE}	-0.3	–	6.0	V	–	P_4.1.36
Output standby supply	V_{QST}	-0.3	–	6.0	V	–	P_4.1.37
Input MPS	V_{MPS}	-0.3	–	20	V	–	P_4.1.38
Temperatures							
Junction temperature	T_j	-40	–	175	°C	–	P_4.1.39
Storage temperature	T_{stg}	-55	–	175	°C	–	P_4.1.40
ESD susceptibility							
ESD robustness to GND	V_{ESD}	-2	–	2	kV	HBM [5)]	P_4.1.41
ESD robustness to GND	V_{ESD}	-500	–	500	V	CDM [6)]	P_4.1.42
ESD robustness (corner pins) to GND	$V_{ESD,Corner}$	-750	–	750	V	CDM [6)]	P_4.1.43

1) Not subject to production test, specified by design.
2) Maximum rating is 60 V, if rising slewrate of voltage at the pin is lower than 6 V/ms , for an overall time of 1 hour during the lifetime of the product
3) Maximum rating is 43.5 V, for an overall time of 10 s (in the range of 40 V to 43.5 V) during the lifetime of the product independent from the rise time.
4) Consider external series resistor for negative voltages < -0.3 V to ensure maximum rating of current

5) Human body model (HBM) robustness according to ANSI/ESDA/JEDEC JS-001 (1.5 kΩ, 100 pF).
6) Charged device model (CDM) robustness according to ESDA STM5.3.1 or ANSI/ESD S.5.3.1.

***Note**: This thermal data was generated in accordance with JEDEC JESD51 standards. For more information visit www.jedec.org.*

3.2 Functional range

Table 2 Functional range

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Supply voltage range for normal operation at input of the step up pre-regulator	V_{Bat}	3	–	40	V	with step up pre-regulator active in front of step down pre-regulator 1)	P_4.2.1
Supply voltage range for normal operation at pin VSx	V_{VS}	6	–	40	V	without step up pre-regulator active in front of step down pre regulator	P_4.2.2
Start-up voltage threshold for power sequencing	$V_{PS,start}$	4.9	5.0	5.1	V	V_{VS} increasing	P_4.2.3
Internal start-up time from POWERDOWN	$t_{tr,pwrd}$	–	1	2	ms	from first VS connection to start of power sequence	P_4.2.4
POWERDOWN shutdown threshold	$V_{PD,lo}$	2.2	3.0	3.5	V	2) V_{VS} decreasing; Except STANDBY-state	P_4.2.5
POWERDOWN shutdown threshold	$V_{PD,lo}$	1.25	3.0	4.5	V	2) V_{VS} decreasing; STANDBY-state	P_4.2.6
Junction temperature	T_j	-40	–	175	°C	–	P_4.2.7

1) The initial start-up of the device requires a minimum input voltage of $V_{PS,start}$ at the pin VSx for the time $t_{tr,pwrd}$.
2) Specified by design, not subject to production test

***Note**: Within the functional range, the IC operates as described in the circuit description. The electrical characteristics are specified within the conditions given in the electrical characteristics table.*

3.3 Thermal resistance

Table 3 Thermal resistance[1)]

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Junction to case (exposed diepad)	R_{thJC}	–	–	8	K/W	–	P_4.3.1
Junction to ambient	R_{thJA}	–	29	–	K/W	2)	P_4.3.6

1) Not subject to production test, specified by design.
2) Specified R_{thJA} value is according to JEDEC JESD51-2,-5,-7 at natural convection on FR4 2s2p board; the product (chip and package) was simulated on a 76.2 × 114.3 × 1.5 mm^3 board with two inner copper layers (2 × 70 µm Cu, 2 × 35 µm Cu). Where applicable, a thermal via array next to the package contacted the first inner copper layer.

***Note**: This thermal data was generated in accordance with JEDEC JESD51 standards. For more information visit www.jedec.org.*

3.4 Current consumption

Table 4 Current consumption [1)]

V_{VS} = 10 V to 28 V, T_j = -40°C to 85°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
INIT-,NORMAL-,WAKE-state	$I_{q,HF}$	–	–	45	mA	high switching frequency range (pin FRE open); [1)] $T_j \le 85°C$; 10 V ≤ V_{VS} ≤ 28 V	P_4.4.1
INIT-,NORMAL-,WAKE-state	$I_{q,LF}$	–	–	30	mA	low switching frequency range (pin FRE to GND); [1)] $T_j \le 85°C$; 10 V ≤ V_{VS} ≤ 28 V	P_4.4.2
STANDBY-state	I_q	–	7.5	10	µA	QST is disabled; [1)] $T_j \le 40°C$; 10 V ≤ V_{VS} ≤ 14 V; wake-up timer disabled	P_4.4.3
STANDBY-state	I_q	–	7.5	15	µA	QST is disabled; [1)] $T_j \le 85°C$; 10 V ≤ V_{VS} ≤ 28 V; wake-up timer disabled	P_4.4.4
STANDBY-state	I_q	–	–	50	µA	QST is disabled; [1)] $T_j \le 85°C$; 10 V ≤ V_{VS} ≤ 28 V; wake-up timer enabled	P_4.4.5
STANDBY-state	I_q	–	40	56	µA	QST is enabled; [1)] $T_j \le 40°C$; 10 V ≤ V_{VS} ≤ 28 V	P_4.4.6
STANDBY-state	I_q	–	40	70	µA	QST is enabled; [1)] $T_j \le 85°C$; 10 V ≤ V_{VS} ≤ 28 V	P_4.4.7
SLEEP-state	I_q	–	240	320	µA	[1)] $T_j \le 40°C$; 12 V ≤ V_{VS} ≤ 28 V	P_4.4.8
SLEEP-state	I_q	–	240	350	µA	[1)] $T_j \le 85°C$; 12 V ≤ V_{VS} ≤ 28 V	P_4.4.9

(table continues...)

Table 4 (continued) Current consumption [1)]

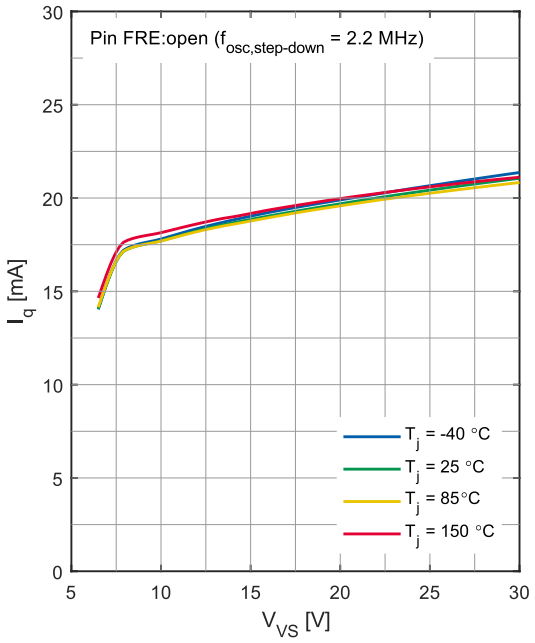
V_{VS} = 10 V to 28 V, T_j = -40°C to 85°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
SLEEP-state	I_q	–	240	400	µA	[1)] $T_j \le 85°C$; $10\ V \le V_{VS} \le 28\ V$	P_4.4.10
FAILSAFE-state	I_q	–	90	150	µA	[1)] $T_j \le 40°C$; $10\ V \le V_{VS} \le 18\ V$; $t_{FAILSAFE} > t_{FAILSAFE,min}$	P_4.4.11
FAILSAFE-state	I_q	–	90	200	µA	[1)] $T_j \le 85°C$; $10\ V \le V_{VS} \le 28\ V$; $t_{FAILSAFE} > t_{FAILSAFE,min}$	P_4.4.12

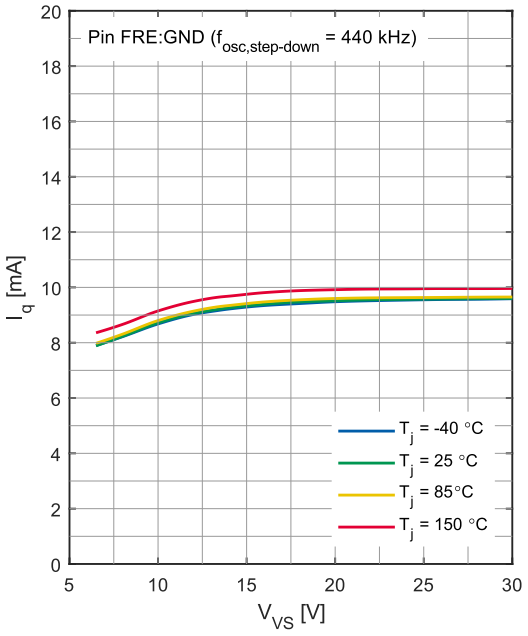
1) All quiescent current consumption parameters are measured with zero load and all selectable options (outputs, monitors, watchdog, timers, step up pre-regulator) switched off unless otherwise specified.

3.4.1 Typical performance characteristics current consumption

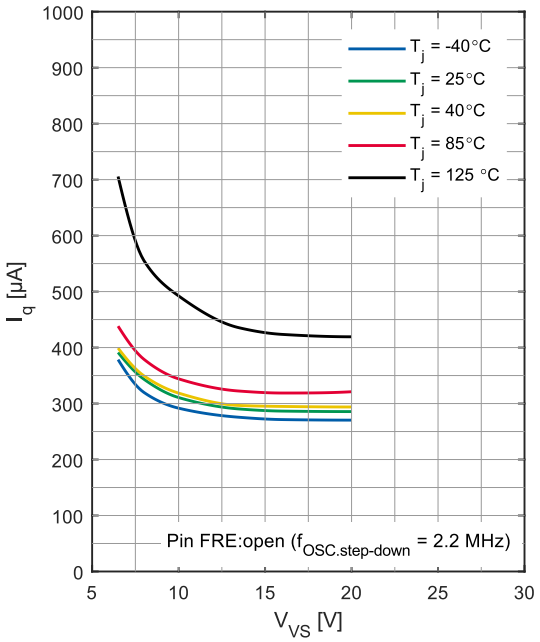
INIT, NORMAL and WAKE current consumption I_q versus supply voltage V_{VS} (Pin FRE:open)



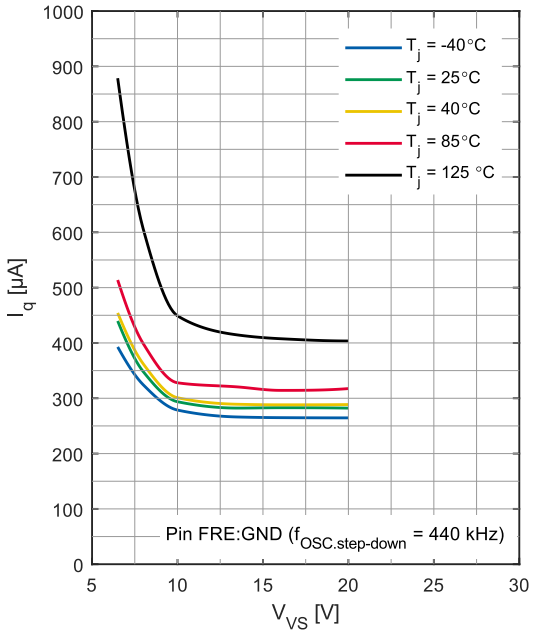
INIT, NORMAL and WAKE current consumption I_q versus supply voltage V_{VS} (Pin FRE:GND)



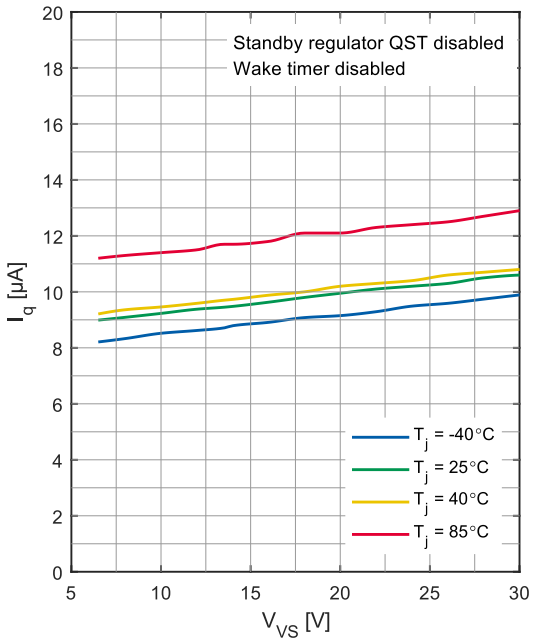
SLEEP current consumption I_q versus supply voltage V_{VS} (Pin FRE:open)



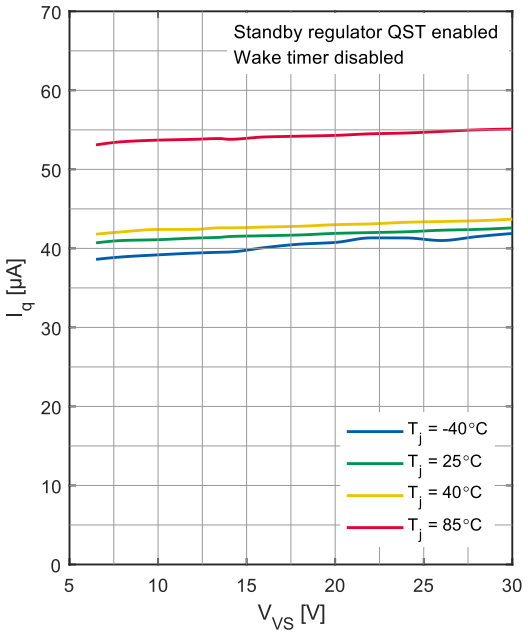
SLEEP current consumption I_q versus supply voltage V_{VS} (Pin FRE:GND)



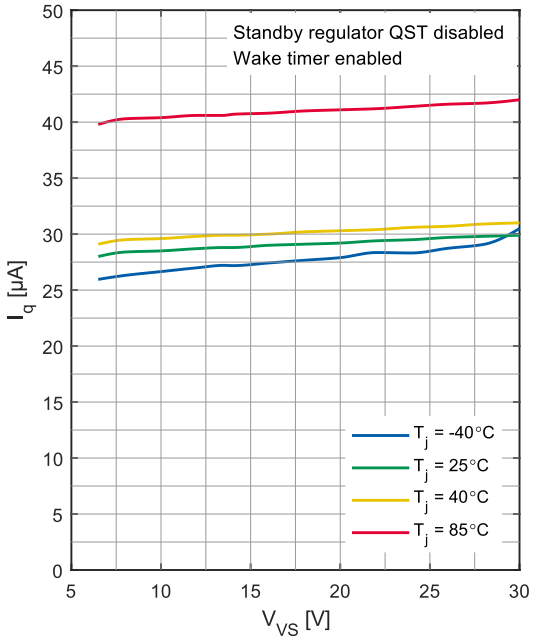
STANDBY current consumption I_q versus supply voltage V_{VS} (QST off WK timer off)



STANDBY current consumption I_q versus supply voltage V_{VS} (QST on; WK timer off)



STANDBY current consumption I_q versus supply voltage V_{VS} (QST off; WK timer on)



4 Wake and Enable function

4.1 Introduction Wake and Enable function

The device is automatically turned on when connected to a battery (Power-On-Reset POR to move the device out of POWERDOWN) and moves into INIT-state, where the device is available for configuration. After successful configuration and initial service of supervision functions, the device allows for transition to NORMAL-state via SPI command. From NORMAL or WAKE-state, the device can be sent to a low power state (SLEEP or STANDBY) via SPI commands. The WAK and ENA signal are external triggers to leave the low power states (or the FAILSAFE-state).

Wake (pin WAK - level triggered) / Enable (pin ENA - edge triggered)

The WAK and ENA input pins are battery voltage level capable. A signal, with a voltage higher than $V_{WAK,hi}$ applied at pin WAK for $t_{WAK,min}$ represents a valid Wake-Signal. A positive going edge at pin ENA represents a valid Wake-Signal as well. A valid Wake-Signal triggers a wake-up event and transitions the device from STANDBY to INIT-state, from SLEEP to WAKE-state or from FAILSAFE to INIT-state.

A low signal $V_{WAK,lo}$ at pin WAK as well as a negative going edge at pin ENA does not have a direct influence to the state machine and does not initiate a transition between states.

If the device detects a valid Wake-Signal during the transition phase from NORMAL to SLEEP-state, then the device initiates a transition to WAKE-state and generates an interrupt.

If the device detects a valid Wake-Signal during the transition phase from NORMAL to STANDBY-state, then the device initiates a transition to INIT-state and a Reset (ROT) event is generated.

Before sending a SPI transition command, pin ENA does not have to be brought below $V_{ENA,thrlo}$. Even if pin ENA is "high" (above $V_{ENA,thrhi}$), the SPI transition command instructs the device to move into SLEEP or STANDBY-state.

The interpretation of the present signal level at the pins ENA and WAK can be read via SPI from the register WKSF.ENAST (signal level at pin ENA) and WKSF.WAKST (signal level at pin WAK).

For further details refer to Chapter 10 State machine.

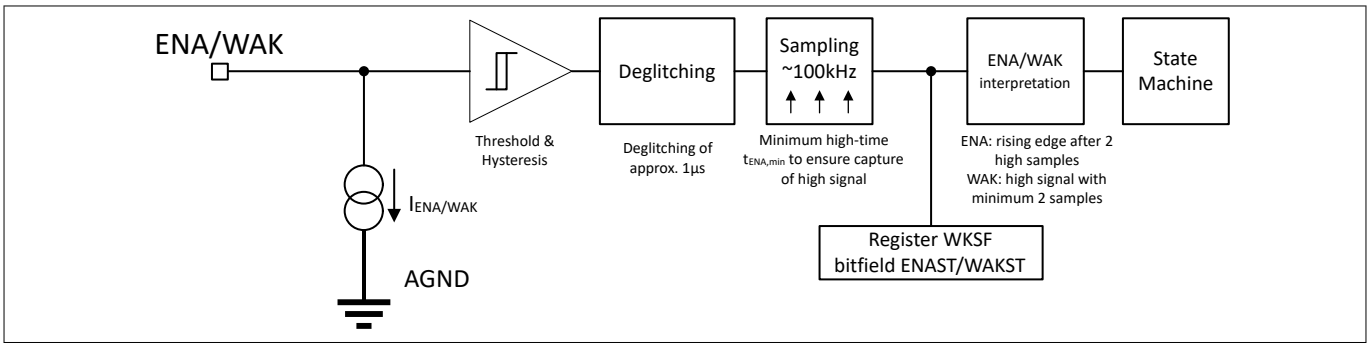


Figure 3 Principle of the enable and wake function

4.2 Electrical characteristics Enable signal

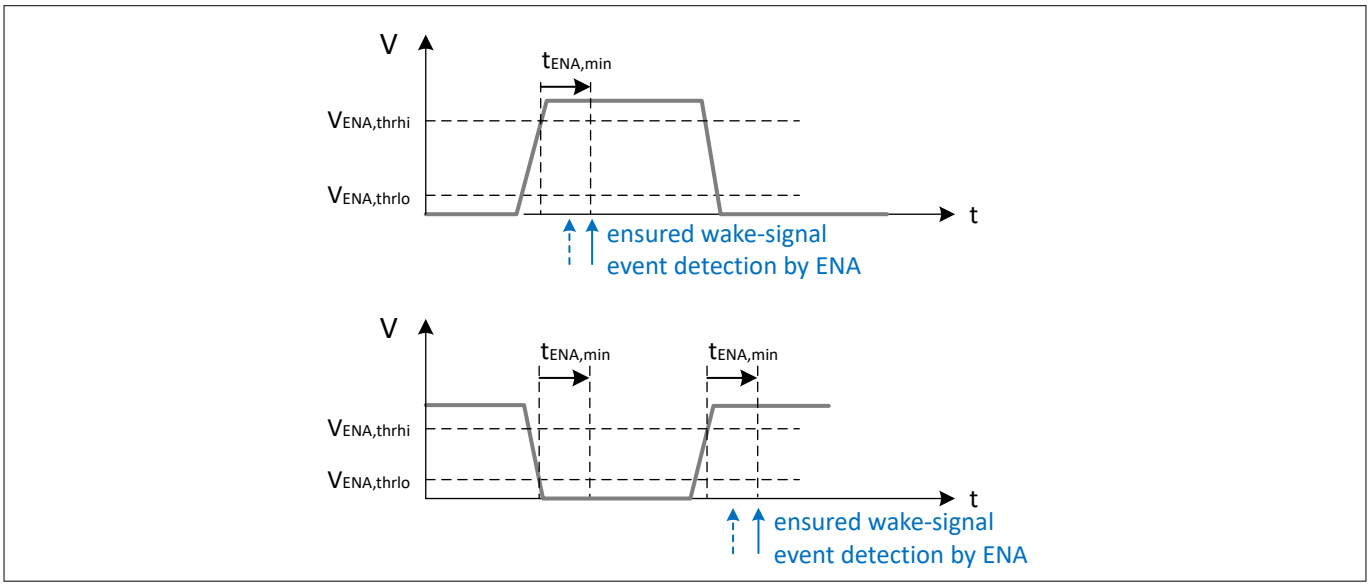


Figure 4 Valid enable signal

Table 5 Electrical characteristics Enable signal

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Enable EN							
Enable upper threshold	$V_{ENA,thrhi}$	–	–	1.95	V	V_{ENA} increasing	P_5.2.1
Enable lower threshold	$V_{ENA,thrlo}$	1.0	–	–	V	V_{ENA} decreasing	P_5.2.2
Enable threshold hysteresis	$V_{ENA,hyst}$	200	330	500	mV	–	P_5.2.3
Enable minimum signal time	$t_{ENA,min}$	20	–	–	µs	–	P_5.2.4
Enable "high" input current	$I_{ENA,hi}$	–	8	11	µA	V_{ENA} = 16 V	P_5.2.5
Enable "low" input current	$I_{ENA,lo}$	–	0.1	2	µA	V_{ENA} = 0.5 V	P_5.2.6

4.3 Electrical characteristics Wake signal

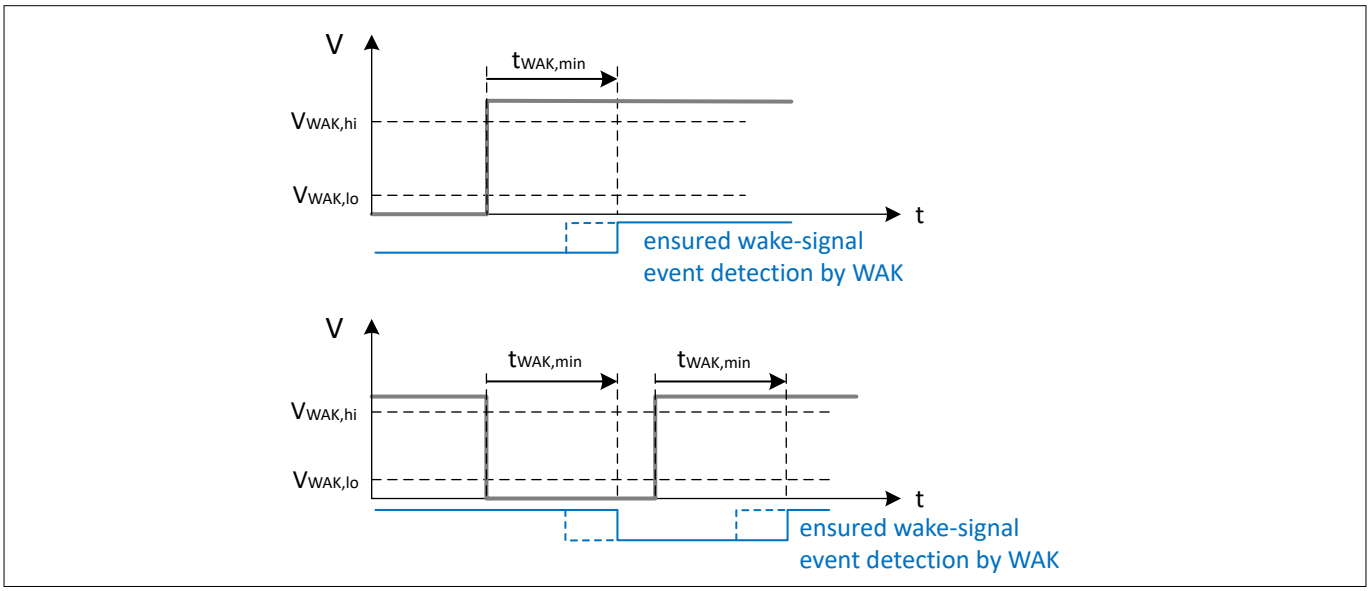


Figure 5 Valid wake signal

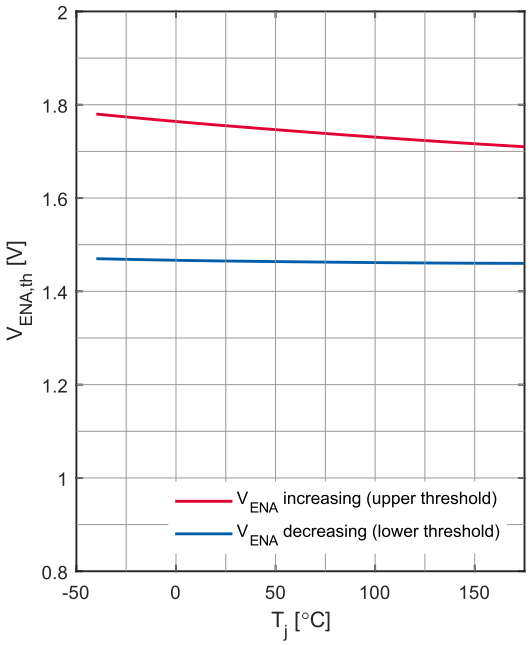
Table 6 Electrical characteristics Wake signal

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

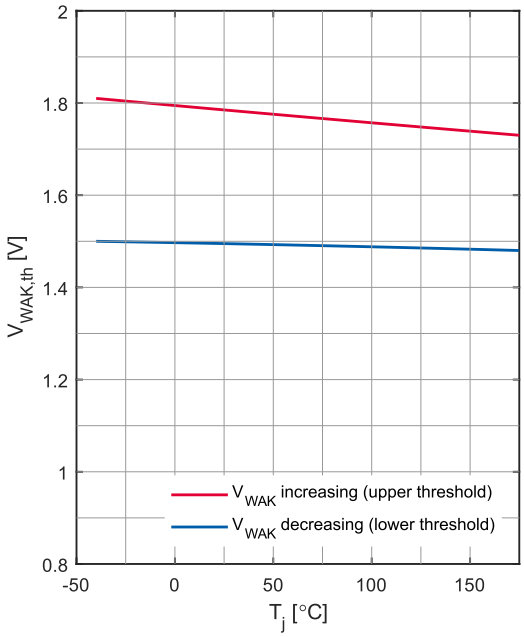
Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Wake/Inhibit							
Wake upper threshold	$V_{WAK,hi}$	–	–	1.95	V	V_{WAK} increasing	P_5.3.1
Wake lower threshold	$V_{WAK,lo}$	1.0	–	–	V	V_{WAK} decreasing	P_5.3.2
Wake signal hysteresis	$V_{WAK,hyst}$	200	330	500	mV	–	P_5.3.3
Wake signal minimum length	$t_{WAK,min}$	40	–	–	µs	–	P_5.3.4
Wake "high" input current	$I_{WAK,hi}$	–	8	11	µA	V_{WAK} = 5.0 V	P_5.3.5
Wake "low" input current	$I_{WAK,lo}$	–	0.1	2	µA	V_{WAK} = 0.5 V	P_5.3.6

4.4 Typical performance characteristics Wake and Enable signals

Enable input threshold voltage $V_{ENA,th}$ versus junction temperature T_j



Wake input threshold voltage $V_{WAK,th}$ versus junction temperature T_j



5 Pre-regulators

5.1 Introduction pre-regulators

The pre-regulator is mandatory to maintain a stabilized and constant intermediate circuit voltage to supply the post regulators. It consists of two independent regulators: a step-up converter with an external power stage to maintain a minimum input voltage to the subsequent step-down converter.

The step-up converter can be deactivated (if not needed) by connecting pin STU to ground. Leaving pin STU open activates the step-up regulator.

The step-down regulator frequency can be preset by leaving pin FRE open for the high switching frequency range or connecting to GND for the low switching frequency range.

The step-down converter operates continuously, providing a stabilized intermediate circuit voltage V_{PREREG} to supply the subsequent post regulators. The step-up converter is connected directly to the input voltage V_{Bat}. It only operates during low input voltage condition (i.e. cranking) when the input voltage drops below the threshold $V_{PREREG,boost,UV}$, to maintain an input voltage high enough for the subsequent step-down regulator. Low input voltage condition means that the input voltage at pin VSx is too low to provide an intermediate circuit voltage V_{PREREG} within the specified limits. An internal comparator connected to the input voltage path detects the threshold for turning on the step-up converter. In case the input voltage is above the step-up converter output voltage (threshold for switching on the step-up converter), this regulator is deactivated by the internal comparator. An internal logic switches the step-up converter on (and off again) whenever it is needed.

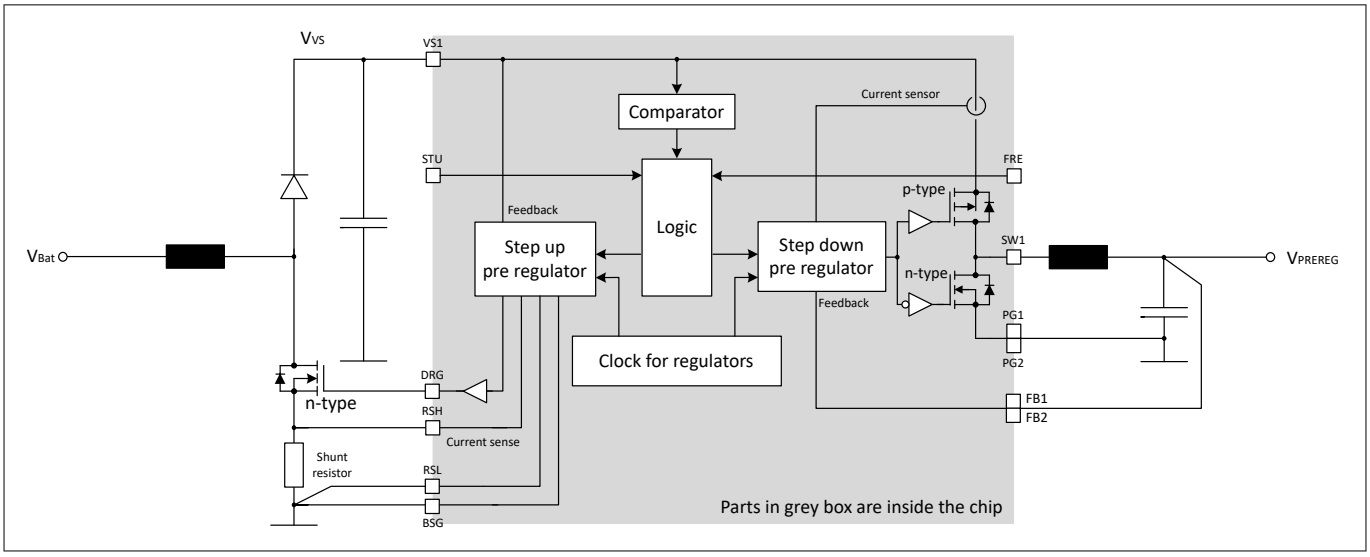


Figure 6 Principle pre-regulator stage

5.2 Step up pre-regulator

5.2.1 Functional description step up pre-regulator

The asynchronous step up pre-regulator provides a higher output voltage than the input voltage when operating. This is the case whenever the supply voltage should be too low to allow nominal values at the post regulator outputs. The boost pre regulator output voltage is well below the nominal supply (battery) voltage to make sure, that it only operates during low input voltage conditions.

Protection functions are implemented to prevent the regulator and the application from damage:

- To protect the external components of the step up pre-regulator from overstress, a shunt resistor based peak current limitation (specified by $V_{RSH-RSL}$) limits the duty cycle of the DRG pin to avoid excessive current flows, so the output voltage decreases. In case the step up pre-regulator operates in peak current limitation for more than $t_{StG,boost}$, the device moves into FAILSAFE-state. This event is stored in the SPI status register bitfield MONSF3.STUSG.
- An overcurrent pre-warning is implemented to provide an interrupt based warning, if the current through the shunt resistor is generating a voltage of more than $0.8 \times V_{RSH-RSL}$ switching cycle by switching cycle for more than 500 µs. The diagnosis of overcurrent pre-warning is indicated to CEFUMON.STUOC.

If the step up feature should not be necessary for the application, the external power elements (MOSFET, diode, shunt-resistor) could be skipped, the filter elements might be adjusted to the application requirements.

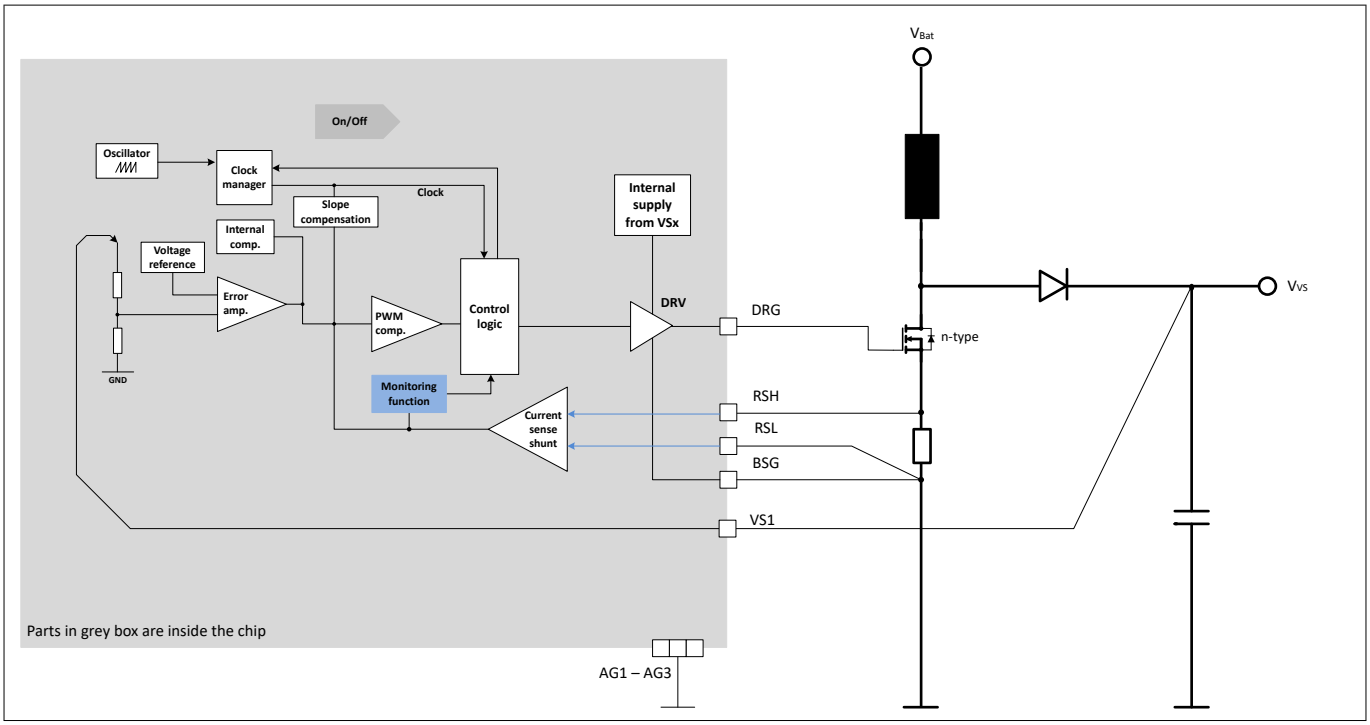


Figure 7 Step up regulator

5.2.2 Electrical characteristics step up pre-regulator

Table 7 Electrical characteristics step up pre-regulator

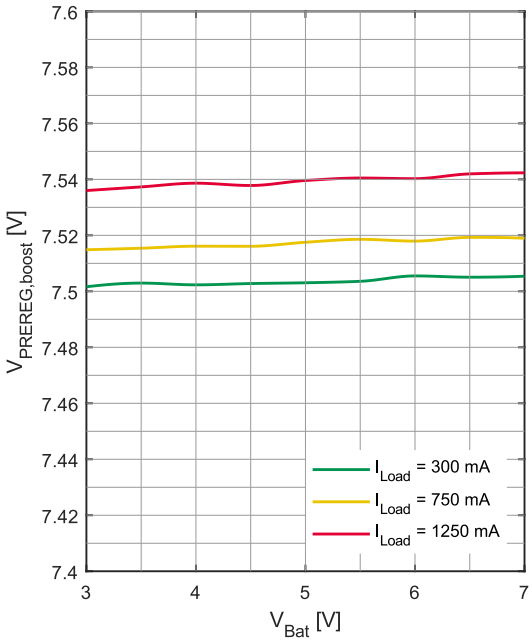
V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Step up pre-regulator							
Pre-regulator boost output voltage	$V_{PREREG,boost}$	7.00	7.5	8.00	V	–	P_6.2.2.1
Threshold external sense resistor for OC	$V_{RSH-RSL}$	190	210	230	mV	–	P_6.2.2.2
Low side sense input current	I_{RSL}	-45	-30	-15	µA	V_{RSL} = 0 V	P_6.2.2.3
High side sense input current	I_{RSH}	-45	-30	-15	µA	1) V_{RSH} = 0 V	P_6.2.2.4
Input undervoltage threshold	$V_{PREREG,boost,UV}$	8	8.3	8.6	V	–	P_6.2.2.5
Input undervoltage threshold hysteresis	$V_{PREREG,boost,UV,hyst}$	60	–	200	mV	–	P_6.2.2.6
Gate driver sourcing current	$I_{DRG,SRC}$	60	130	195	mA	measured at V_{DRG} = 2.5 V	P_6.2.2.7
Gate driver sinking current	$I_{DRG,SNK}$	55	100	160	mA	measured at V_{DRG} = 2.5 V	P_6.2.2.8
Gate driver sinking current (boost off)	$I_{DRG,SNK,off}$	12	35	65	mA	measured at V_{DRG} = 1.0 V	P_6.2.2.9
Gate driver output voltage	V_{DRG}	4.5	5	5.5	V	–	P_6.2.2.11
Maximum duty cycle	D_{MAX}	75	80	–	%	–	P_6.2.2.12
Blanking time	t_{Blank}		240		ns	–	P_6.2.2.13
Input inductor	L_{Boost}	15.4	22	28.6	µH	1)	P_6.2.2.14
Output main capacitor	C_{Boost}	56	100	220	µF	1)	P_6.2.2.15
Output main capacitor ESR	$ESR_{C,Boost}$	10	–	300	mΩ	1) 2)	P_6.2.2.16
Output support capacitor	C_{Boost2}	0.7	–	–	µF	1) ceramic capacitor	P_6.2.2.17
Output support capacitor ESR	$ESR_{C,Boost2}$	–	15	30	mΩ	1) 2)	P_6.2.2.18

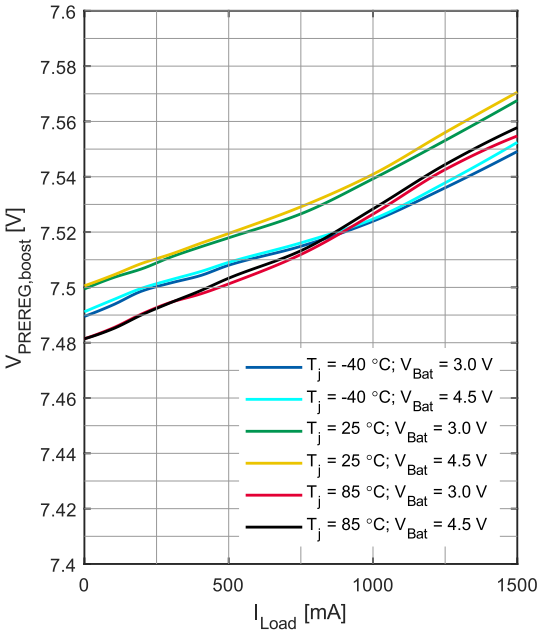
1) Specified by design, not subject to production test
2) Relevant ESR at capacitor's self-resonant frequency.

5.2.3 Typical performance characteristics step up pre-regulator

Pre-regulator boost output voltage $V_{PREREG,boost}$ versus battery voltage V_{Bat}



Pre-regulator boost output voltage $V_{PREREG,boost}$ versus load current I_{Load}



5.3 Step down pre-regulator

5.3.1 Functional description step down pre-regulator

The synchronous step down pre-regulator is continuously in operation providing a stable intermediate circuit voltage to supply the post regulators. The internal power stage consists of synchronous P-channel (high side) and N-channel (low side) MOSFETs. For start-up a softstart function is implemented.

The regulation loop operates in current mode.

In the operative states the step down pre-regulator operates in Continuous Conduction Mode(CCM) using Pulse Width Modulation (PWM). In SLEEP state under light load conditions the device operates in asynchronous mode using Pulse Frequency Modulation (PFM) whenever applicable to minimize the internal current consumption. Further details about the operating mode transitions in SLEEP state based on supply voltage V_{VS} and load current I_{PreReg} are referenced in the typical performance graphs of the step down pre-regulator.

The output filter of the step down regulator has to be sized to ensure an output voltage ripple of less than 100 mV in order to be in line with the PSRR specified for the post regulators.

The regulator features an active pull-down at the FBx pins that discharges the output upon disablement of the regulator.

Protection circuitry is installed to prevent the regulator and the application from damage:

- To protect the integrated power switches of the step down pre regulator and external filter components from overstress, a peak current limitation $I_{PREREG,max}$ in the low side switch and the high side switch limits the output current. In case the maximum current condition $I_{PREREG,max}$ is reached for the detection time of the current sense, the corresponding power stage is disabled for the remaining time of the switching cycle. The regulator is protected against short circuit to ground at its output FBx.
- The output voltage is monitored by the voltage monitoring.

  In case of overvoltage at pin FBx, the step down pre-regulator is switched off and the device moves into FAILSAFE-state. The event is stored in the SPI status register (MONSF1).

  In case of undervoltage at pin FBx, the event is indicated by an interrupt and stored in an SPI status register (MONSF2). The regulator is not switched off in case of output undervoltage, which is shorter than the short to ground detection time $t_{StG,HF}$ or $t_{StG,LF}$(depending on the configuration of pin FRE).

  In case the output voltage cannot be increased above the undervoltage threshold within $t_{StG,HF}$ or $t_{StG,LF}$ (depending on the configuration of pin FRE) during the start-up of the step down pre-regulator (power sequencing) and the voltage at pin VSx is above $V_{start,StG,buck}$, the device moves into FAILSAFE-state. This event is stored in an SPI status register as well (MONSF0). The transition to FAILSAFE is disabled once the output FBx reaches the undervoltage threshold.
- There is a dedicated temperature sensor for this regulator. In case the power stage temperature exceeds the pre-warning threshold, an interrupt indicates this event and it is stored in an SPI status register (OTWRNSF). If the power stage temperature exceeds the temperature shutdown threshold, the device moves into FAILSAFE-state, the regulator is switched off and the event is stored in an SPI status register (OTFAIL). The minimum off-time due to temperature shutdown is $t_{FAILSAFE,min}$ of 1 second. In very light load conditions and in PFM operation the thermal sensor is automatically disabled to support reduced current consumption.

5 Pre-regulators

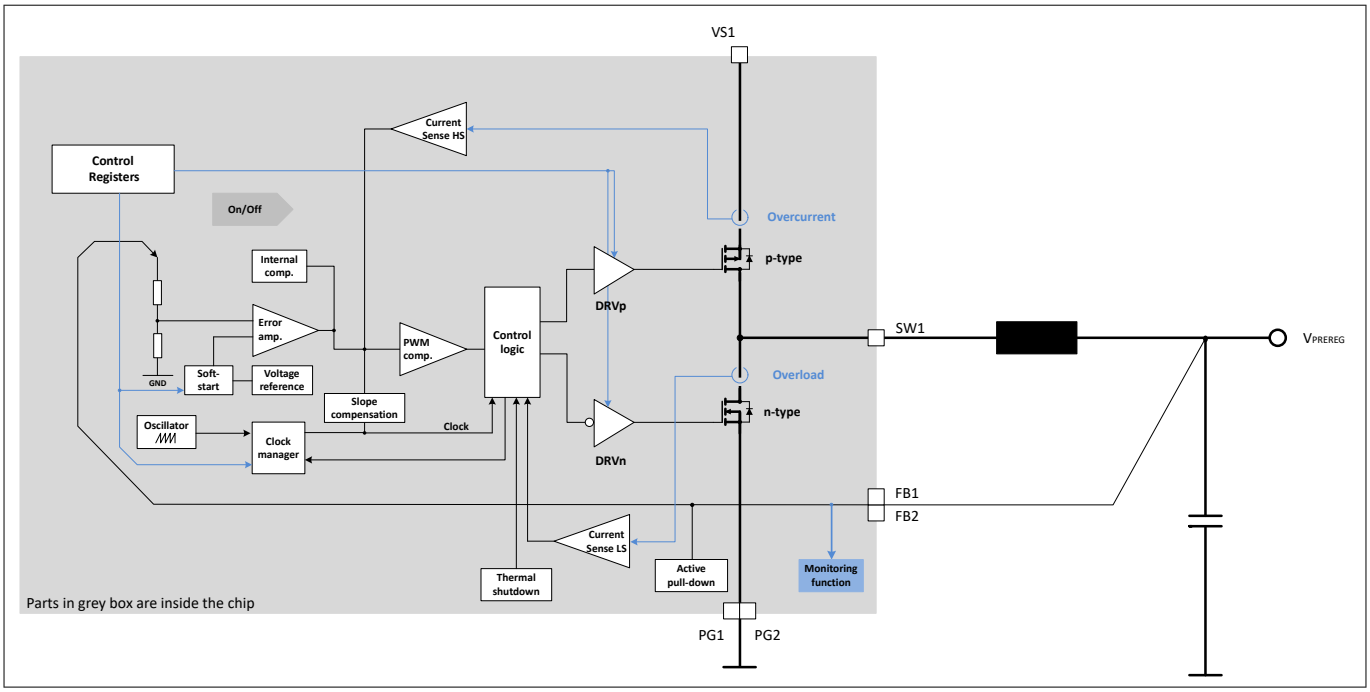


Figure 8 Step down regulator

5.3.2 Electrical characteristics step down pre-regulator

Table 8 Electrical characteristics step down pre-regulator

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Step down pre-regulator							
Output voltage	$V_{PREREG, BUCK}$	5.65	5.8	5.95	V	PWM-mode; $V_{VS} \geq 5.75\ V + (R_{ON,HS}[Max] + DCR_{ext}) * I_{PREREG,BUCK}$; $I_{PREREG,BUCK} \leq 1.5\ A$; $T_j \leq 150\ °C$	P_6.3.2.1
Output voltage	$V_{PREREG, BUCK,hot}$	5.65	5.8	6.10	V	PWM-mode; $V_{VS} \geq 5.75\ V + (R_{ON,HS,hot}[Max] + DCR_{ext}) * I_{PREREG,BUCK}$; $I_{PREREG,BUCK} \leq 1.2\ A$	P_6.3.2.2
Output voltage	$V_{PREREG, BUCK}$	5.6	5.8	6.00	V	PFM-mode; $V_{VS} \geq 5.7\ V + (R_{ON,HS}[Max] + DCR_{ext}) * I_{PREREG,BUCK}$; $T_j \leq 150\ °C$	P_6.3.2.3
Output voltage	$V_{PREREG, BUCK,hot}$	5.6	5.8	6.20	V	PFM-mode; $V_{VS} \geq 5.7\ V + (R_{ON,HS,hot}[Max] + DCR_{ext}) * I_{PREREG,BUCK}$;	P_6.3.2.4
Power stage high side switch on resistance	$R_{ON,HS}$	150	350	580	mΩ	$V_{VS} \geq 6\ V$; $T_j \leq 150\ °C$	P_6.3.2.5
Power stage high side switch on resistance	$R_{ON,HS,hot}$	150	350	720	mΩ	$V_{VS} \geq 6\ V$	P_6.3.2.6
Power stage low side switch on resistance	$R_{ON,LS}$	50	200	300	mΩ	$V_{VS} \geq 6\ V$; $T_j \leq 150\ °C$	P_6.3.2.7
Power stage low side switch on resistance	$R_{ON,LS,hot}$	50	200	345	mΩ	$V_{VS} \geq 6\ V$	P_6.3.2.8
Buck peak overcurrent limitation	$I_{PREREG,max}$	1.95	2.4	2.8	A	–	P_6.3.2.9

(table continues...)

Table 8 (continued) Electrical characteristics step down pre-regulator

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
SW rise time	$t_{R,Buck}$	1	6	14	ns	1) Not applicable in SLEEP state since in SLEEP state Weak driving stage is always activated 6.5V ≤ V_{VS} ≤ 18 V; I_{PREREG} ≥ 0.5 A	P_6.3.2.10
SW fall time	$t_{F,Buck}$	1	9	18	ns	1) 6.5V ≤ V_{VS} ≤ 18 V; I_{PREREG} ≥ 0.5 A	P_6.3.2.11
Maximum duty cycle	$D_{BUCK,max}$	-	-	100	%	–	P_6.3.2.12
Minimum switch on time	$t_{ON,min,HF}$	55	70	85	ns	high switching frequency range (pin FRE open); I_{PREREG} ≥ 0.5 A	P_6.3.2.13
Minimum switch on time	$t_{ON,min,LF}$	250	310	370	ns	low switching frequency range (pin FRE to GND); I_{PREREG} ≥ 0.5 A	P_6.3.2.28
Softstart ramp (HF)	$t_{SS,BUCK,HF}$	400	640	705	µs	1) $V_{PREREG,BUCK}$ rising from 5 % to 95 % of typ. $V_{PREREG,BUCK}$; high switching frequency range (pin FRE open), no load	P_6.3.2.14
Softstart ramp (LF)	$t_{SS,BUCK,LF}$	3.2	5.12	5.65	ms	1) $V_{PREREG,BUCK}$ rising from 5 % to 95 % of typ. $V_{PREREG,BUCK}$; low switching frequency range (pin FRE to GND), no load	P_6.3.2.15
Overtemperature warning threshold	$T_{j,OT,WRN}$	135	145	158	°C	1) T_j increasing	P_6.3.2.18

(table continues...)

Table 8 (continued) Electrical characteristics step down pre-regulator

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Overtemperature shutdown threshold	$T_{j,OT,\ shutdown}$	176	190	200	°C	1) T_j increasing	P_6.3.2.19
Overtemperature sensor hysteresis	$T_{j,OT,hyst}$	–	10	–	°C	1)	P_6.3.2.20
Output inductor (HF)	$L_{BUCK,HF}$	2.6	4.7	8.2	µH	1) 2) high switching frequency range (pin FRE open);	P_6.3.2.21
Output capacitor (HF)	$C_{BUCK,HF}$	8.0	22	82	µF	1) high switching frequency range (pin FRE open); Additional constraint defined in 2)	P_6.3.2.22
Output capacitor ESR (HF)	$ESR_{C,HF}$	1	–	150	mΩ	1) 3) high switching frequency range (pin FRE open);	P_6.3.2.23
Output inductor (LF)	$L_{BUCK,LF}$	12	22	56.4	µH	1) 4) low switching frequency range (pin FRE to GND);	P_6.3.2.24
Output capacitor (LF)	$C_{BUCK,LF}$	54	100	264	µF	1) low switching frequency range (pin FRE to GND); Additional constraint defined in 4)	P_6.3.2.25
Output capacitor ESR (LF)	$ESR_{C,LF}$	5	–	150	mΩ	1) 3) 5) low switching frequency range (pin FRE to GND);	P_6.3.2.26
Active discharge pull-down current when disabled	$I_{BUCK,pd}$	20	80	120	mA	1) 2.5 V ≤ $V_{PREREG,BUCK}$ ≤ 7 V	P_6.3.2.27

1) Specified by design, not subject to production test
2) The output filter consisting of inductance $L_{BUCK,HF}$ and capacitance $C_{BUCK,HF}$ is to be selected coherently. As a second constraint in addition to the defined minimum of $C_{BUCK,HF}$ in P_6.3.2.22, the following normalized equation is to be considered for the minimum output capacitance based on a selected inductance in order to grant stability: $C_{BUCK,HF} \geq 1.5 * L_{BUCK,HF}$ [µF/µH] + 4 [µF].
3) Relevant ESR at capacitor's self-resonant frequency.

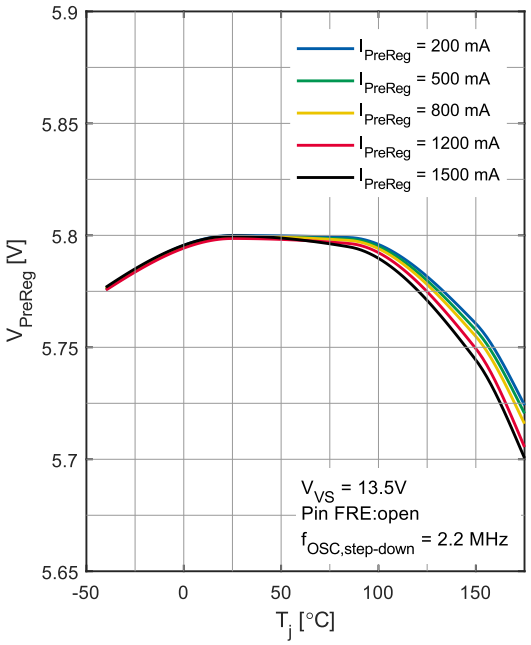
5 Pre-regulators

4) The output filter consisting of inductance $L_{BUCK,LF}$ and capacitance $C_{BUCK,LF}$ is to be selected coherently. As a second constraint in addition to the defined minimum of $C_{BUCK,LF}$ in P_6.3.2.25, the following normalized equation is to be considered for the minimum output capacitance based on a selected inductance in order to grant stability: $C_{BUCK,LF} \geq 1.5 * L_{BUCK,LF}$ [µF/µH] + 20 [µF].

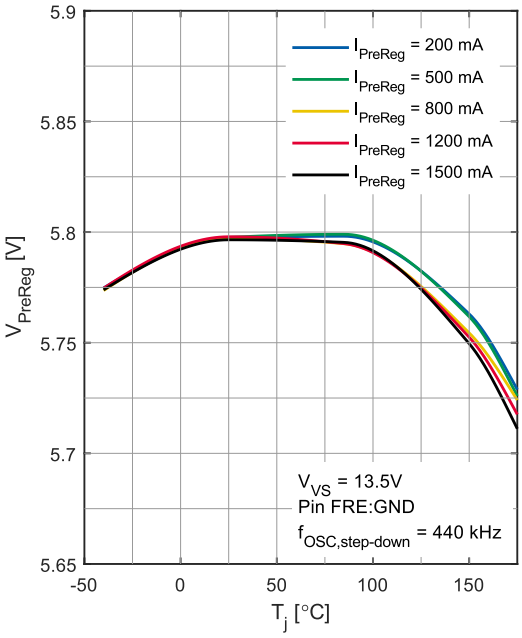
5) For the main capacitors $ESR_{C,LF}$ a maximum of 300 mΩ is allowed, if a second supportive capacitance of ≥ 33 µF is placed in addition.

5.3.3 Typical performance characteristics step down pre-regulator

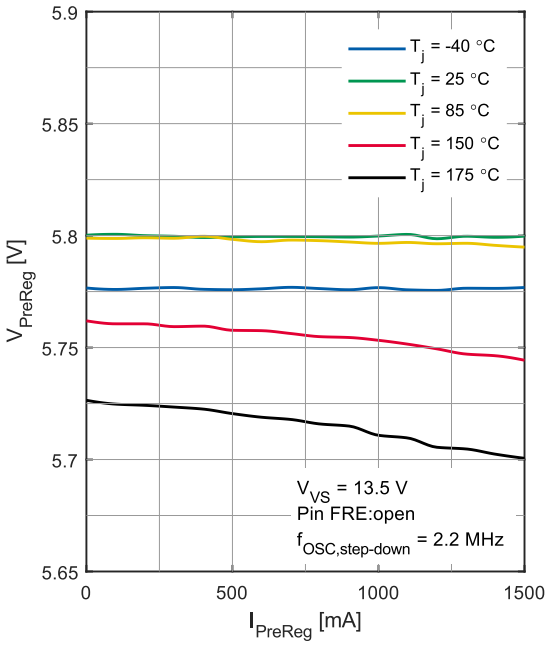
Pre-regulator output voltage V_{PreReg} versus junction temperature T_j (Pin FRE: open)



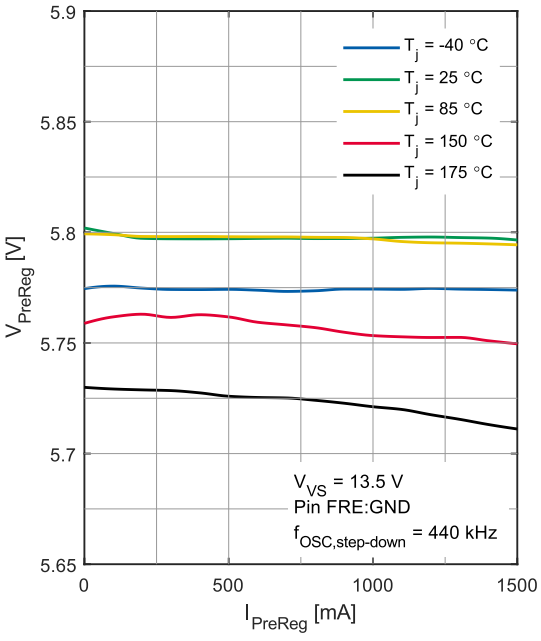
Pre-regulator output voltage V_{PreReg} versus junction temperature T_j (Pin FRE: GND)



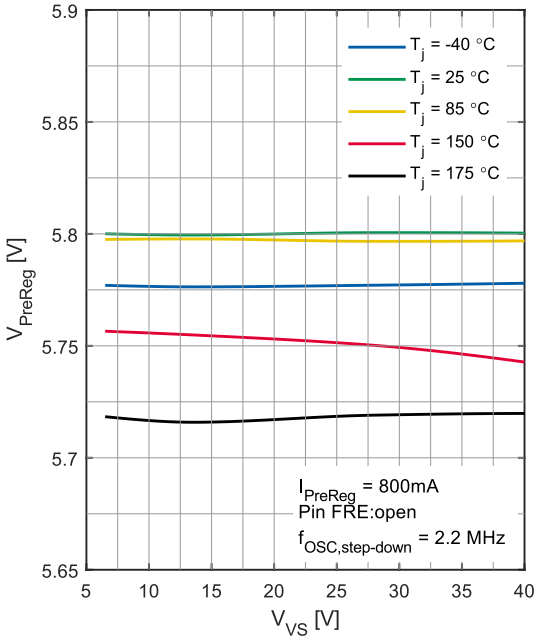
Pre-regulator output voltage V_{PreReg} versus load current I_{PreReg} (Pin FRE: open)



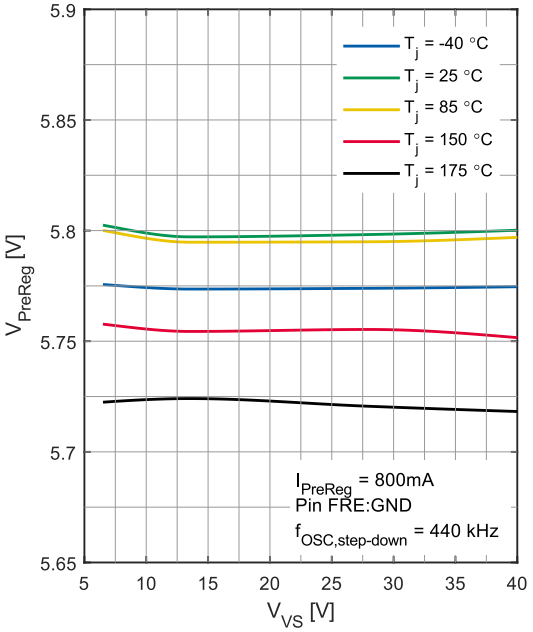
Pre-regulator output voltage V_{PreReg} versus load current I_{PreReg} (Pin FRE: GND)



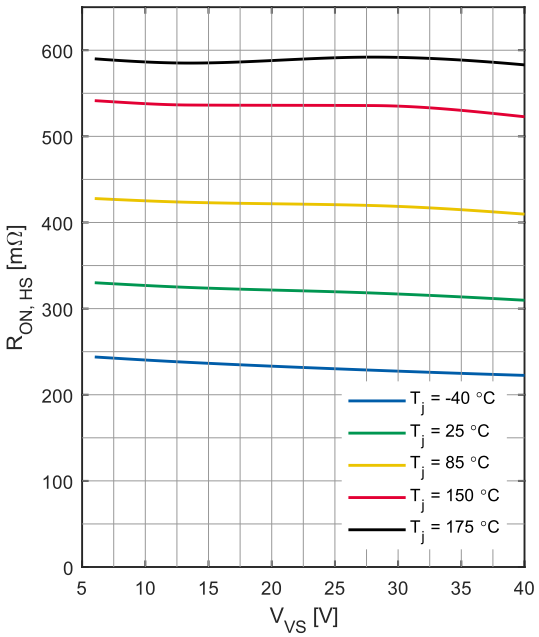
Pre-regulator output voltage V_{PreReg} versus supply voltage V_{VS} (Pin FRE: open)



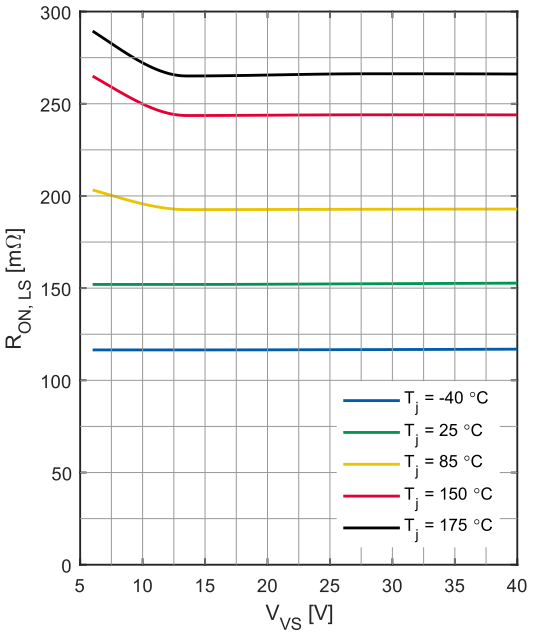
Pre-regulator output voltage V_{PreReg} versus supply voltage V_{VS} (Pin FRE: GND)



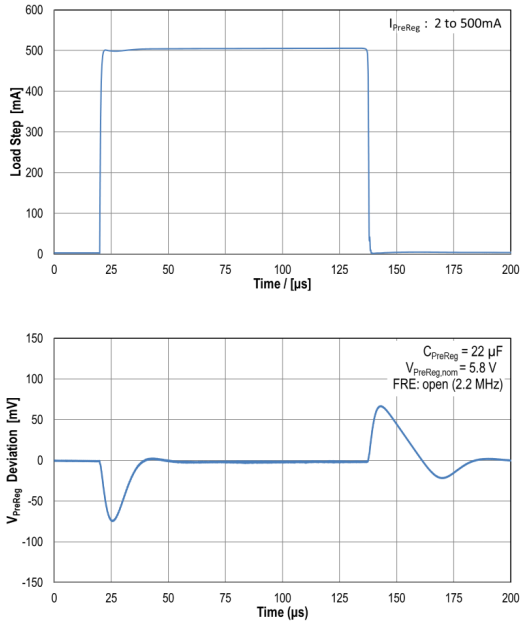
High-side switch ON resistance $R_{ON, HS}$ versus supply voltage V_{VS}



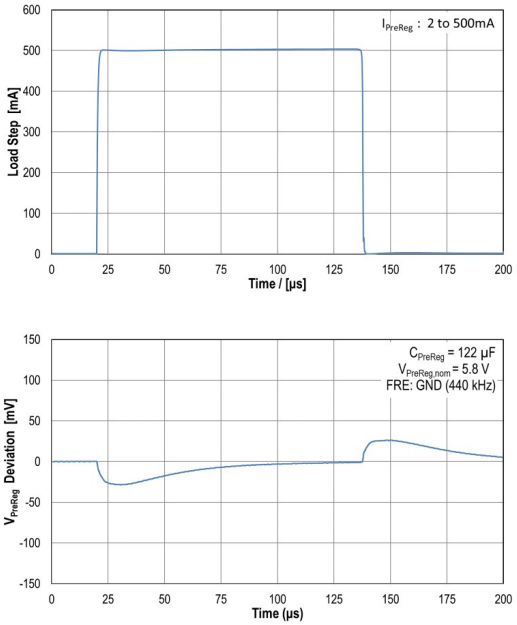
Low-Side switch ON resistance $R_{ON, LS}$ versus supply voltage V_{VS}



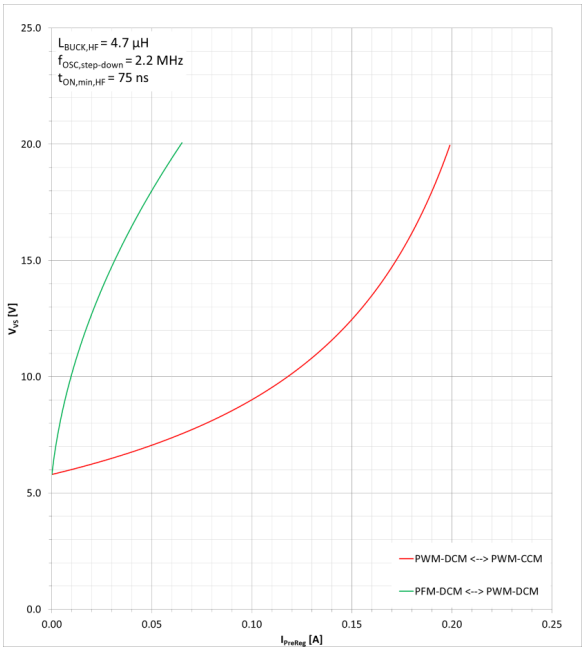
PreReg dynamic load response (2 mA to 500 mA)
(FRE-Pin: open; $V_{PreReg,nom}$ = 5.8 V)



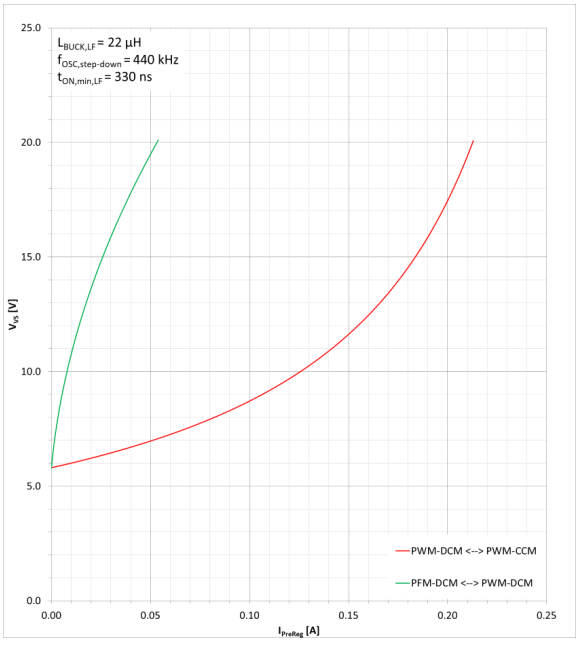
PreReg dynamic load response (2 mA to 500 mA)
(FRE-Pin: GND; $V_{PreReg,nom}$ = 5.8 V)



Operating modes in SLEEP state (Pin FRE: open) as function of supply voltage V_{VS} and load current I_{PreReg}



Operating modes in SLEEP state (Pin FRE: GND) as function of supply voltage V_{VS} and load current I_{PreReg}



5.4 Frequency setting

5.4.1 Introduction frequency setting

The frequency source supplies the step up pre-regulator and the step down pre-regulator with a constant frequency. The synchronous power switches of the step down pre-regulator are switching with the frequency f_{OSC}.

The frequency range of the step down pre-regulator can be set to the high switching frequency range by leaving pin FRE open or to the low switching frequency range by connecting the pin FRE to GND. The switching frequency is set to the default value of the chosen frequency range. Optionally it can be fine tuned by SPI command (BCK_FREQ_CHANGE) or the spread-spectrum option can be activated (BCK_FRE_SPREAD).

The switching frequency range of the step up pre-regulator is synchronized to the switching frequency range of the step down pre-regulator. For the low frequency range of the step down pre-regulator the ratio of the synchronization is 1:1. For the high frequency range of the step down pre-regulator the ratio of the synchronization is 1:5. The synchronization aligns the step down pre-regulator high-side switch activation (rising edge of buck switching node) with the step up pre regulators low side NMOS activation (falling edge of boost switching node) with a delay of approximately 10 ns.

The switching frequency signal of the step down pre-regulator can be made available by SPI configuration at pin SYN for the optional external switch mode post regulator for the MCU core supply.

In SLEEP-state an active synchronization function is preventing the step down pre-regulator to enter into PFM mode operation. Accordingly the SLEEP state does not reach its lowest quiescent current performance. Any of the following functions prevent the step down pre-regulator to enter PFM mode operation:

- active step up pre pregulator (if configured by STU pin open) and $V_{VS} \leq V_{PREREG,boost,UV} + V_{PREREG,boost,UV,hyst}$
- active synchronization output (pin SYN) of the external post regulator support (configurable by register bitfield DEVCFG2.ESYNEN)

The device cannot be synchronized to an external frequency source.

5.4.2 Electrical characteristics frequency setting

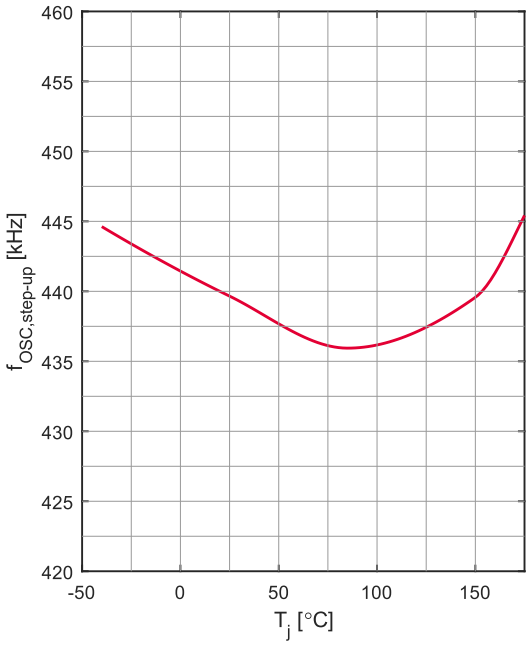
Table 9 Electrical characteristics frequency setting

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

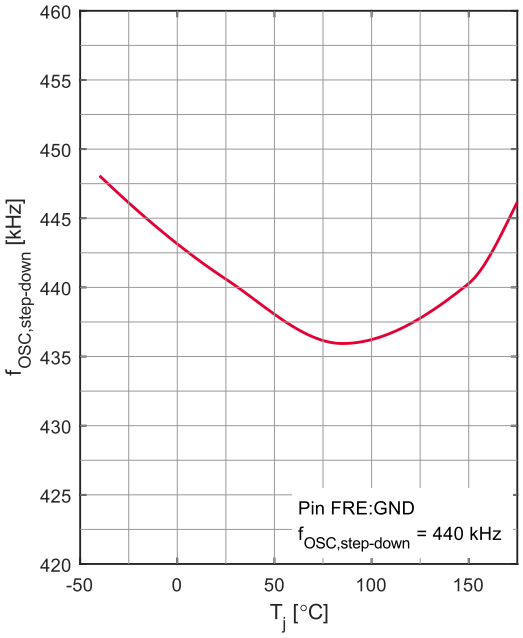
Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Frequency setting FREQ							
Step up frequency range	$f_{OSC,step-up}$	395	440	485	kHz	–	P_6.4.2.1
Step down low frequency range	$f_{OSC,step-down}$	395	440	485	kHz	low switching frequency range (pin FRE to GND)	P_6.4.2.2
Step down high frequency range	$f_{OSC,step-down}$	2000	2200	2400	kHz	high switching frequency range (pin FRE open)	P_6.4.2.3

5.4.3 Typical performance characteristics frequency setting

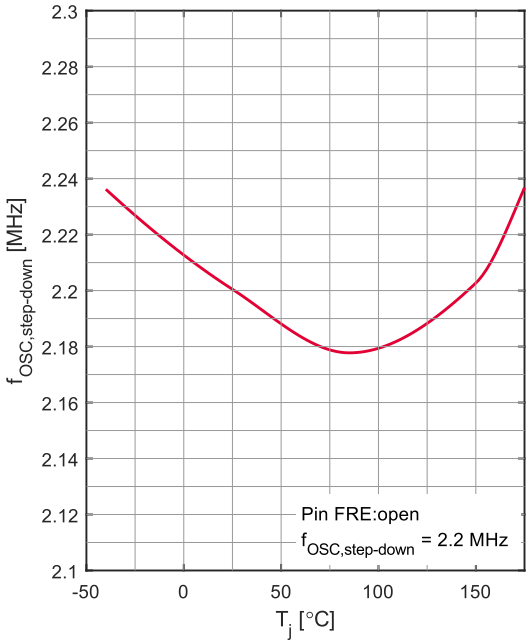
Step up switching frequency $f_{OSC,step-up}$versus junction temperature T_j (Pin FRE: open)



Step down switching frequency $f_{OSC,step-down}$versus junction temperature T_j (Pin FRE: GND)



Step down switching frequency $f_{OSC,step-down}$versus junction temperature T_j (Pin FRE: open)



6 Post regulators

6.1 Introduction post regulators

The device includes linear low drop post regulators and trackers. Further it offers the possibility to connect an external post regulator for the MCU core supply if needed.

The linear post regulators and trackers are supplied from pins FBx. The bandgap 1 for regulator block provides the reference voltage for the error amplifiers of microcontroller main supply (pin QUC), the communication supply (pin QCO) and the reference voltage supply (pin QVR). The trackers get their reference value from the reference voltage supply (pin QVR). The output voltages of trackers 1 and 2 (present at pins QT1 and QT2) follow the reference voltage supply QVR with the small difference ΔV_{QTx}.

An additional external post regulator can be added to deliver the core supply for the microcontroller. If this option is used, the configuration pin SEC must be left open. If the option is not used, pin SEC must be connected to ground.

The post regulator is to be connected external and uses its own reference voltage, the input is fed from the pre-regulator output voltage V_{PREREG} (which is similar to the values at pins FBx). The post regulator is enabled by a high signal at pin EVC and switched off with a low signal at pin EVC. A synchronization signal (in phase or shifted by 180 degree with the step down pre-regulator signal) is offered at pin SYN for usage of a switch mode post regulator.

All output voltages of the post regulators are connected to the voltage monitoring function (please refer to chapter Monitoring function).

In case of a detected overvoltage or short to ground condition the related post regulator is switched off, the shutdown signal is generated by the voltage monitoring function.

6 Post regulators

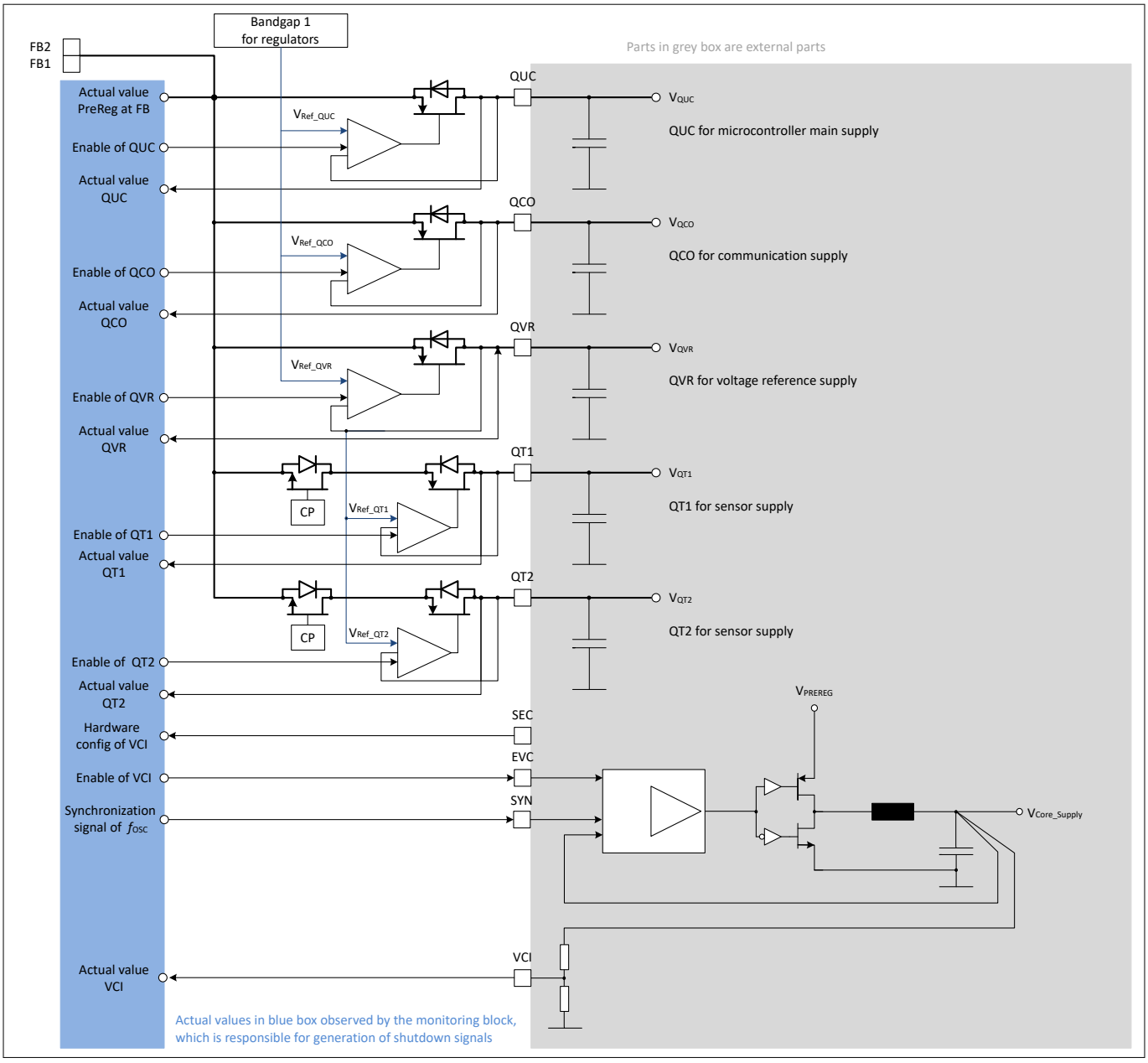


Figure 9 Principle post regulators

6.2 Microcontroller main supply QUC

6.2.1 Functional description microcontroller main supply

The linear low drop regulator QUC offers a precise 3.3 V output voltage for microcontroller main supply.

The regulator is supplied from the intermediate circuit voltage V_{PREREG} which provides a stabilized voltage. The output voltage V_{QUC} (at pin QUC) is controlled by the error amplifier. The actual value is compared to a reference voltage derived from bandgap 1 for regulators. The stability of the control loop depends on the load current, the characteristics of the output capacitor and the chip temperature. To ensure stable operation, the output capacitance needs to meet the requirements (capacitance value and electrical series resistance ESR) in Table 10. The input capacitor in the figure below is the output filter capacitor of the step down pre-regulator.

The regulator features an active pull-down at the output that discharges the output upon disablement of the regulator.

Protection circuitry is implemented to prevent the regulator and the application from damage:

- To protect the pass element of the QUC from overstress, the current limitation limits the output current to the maximum specified limit. Current sensing is done via a current mirror, no sense resistor is used. In case the maximum current condition is reached, the current is limited, so the output voltage decreases. The regulator is protected against short circuit to ground.
- The output voltage is monitored by the voltage monitoring. In case of overvoltage at pin QUC, the QUC is switched off and the device moves into FAILSAFE-state. The event is stored in the SPI status register (MONSF1). In case of undervoltage at pin QUC, the device moves into INIT-state, pin ROT is pulled "low" and the event is stored in an SPI status register (MONSF2). The regulator is not switched off in case of output undervoltage, which is shorter than the short to ground detection time t_{StG}. If the undervoltage is present for longer than t_{StG}, the device moves into FAILSAFE-state. This event is stored in an SPI status register as well (MONSF0).
- There is a dedicated temperature sensor for this regulator. In case the power stage temperature exceeds the pre-warning threshold, an interrupt indicates this event and it is stored in an SPI status register (OTWRNSF). If the power stage temperature exceeds the temperature shutdown threshold, the device moves into FAILSAFE-state, the regulator is switched off and the event is stored in an SPI status register (OTFAIL). The minimum off time due to temperature shut down is $t_{FAILSAFE,min}$ of 1 second. In very light load conditions the thermal sensor is automatically disabled to support reduced current consumption.

If the device enters FAILSAFE-state the ROT is pulled "low" and all supplies are switched off.

If the device enters STANDBY-state the QUC is switched off.

For further details refer to Chapter 10 State machine.

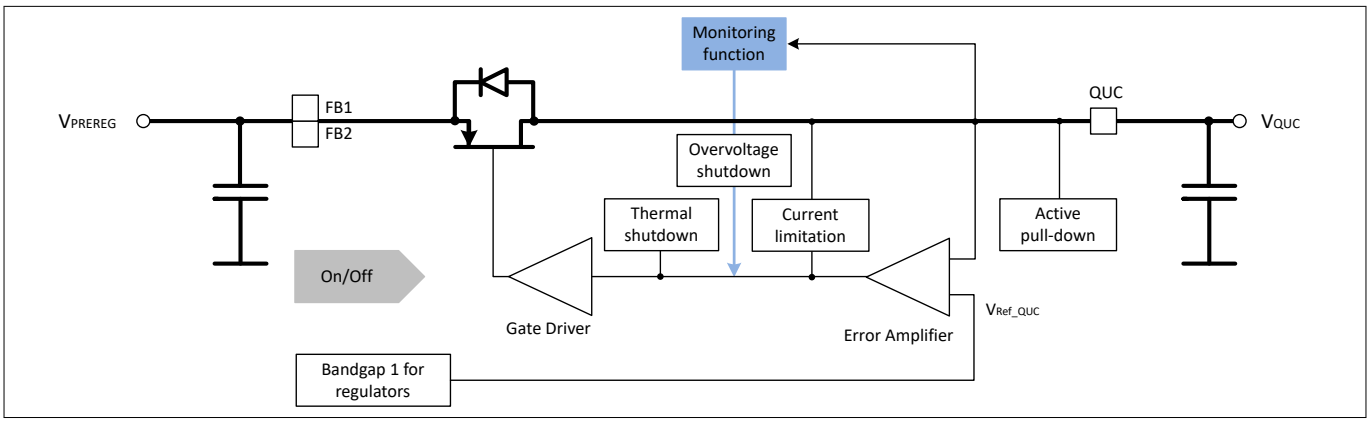


Figure 10 Low drop linear regulator for microcontroller main supply QUC

6.2.2 Electrical characteristics microcontroller main supply

Table 10 Electrical characteristics: microcontroller main supply

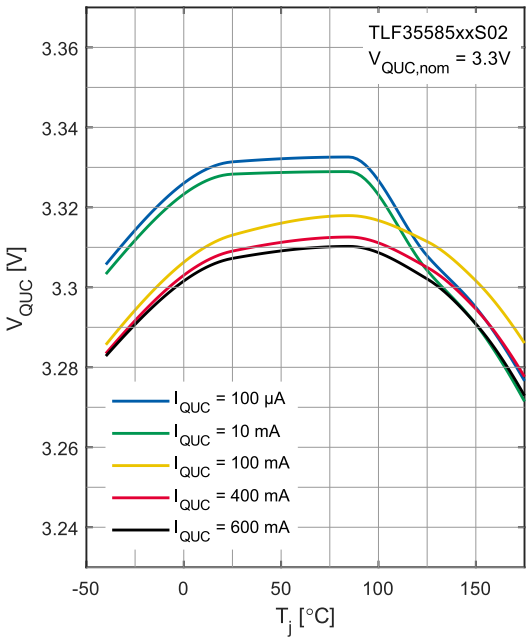
V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Microcontroller main supply QUC							
Output voltage	V_{QUC}	3.23	3.3	3.37	V	0 mA ≤ I_{QUC} ≤ 600 mA	P_7.2.2.2
Output current limitation	$I_{QUC,max}$	650	–	1100	mA	–	P_7.2.2.3
Drop voltage	$V_{dr,QUC}$	–	–	500	mV	1)	P_7.2.2.5
Load regulation	ΔV_{QUC}	–	39	60	mV	I_{QUC} = 50 mA to 600 mA	P_7.2.2.7
Power supply ripple rejection	$PSRR_{QUC}$	26	–	–	dB	2) V_{PREREG} = 5.8 V; $ESR_{C,QUC}$ ≤ 30 mΩ C_{QUC} ≥ 4.4 µF	P_7.2.2.8
Output capacitor	C_{QUC}	2.2	–	47	µF	2)	P_7.2.2.9
Output capacitor, ESR	$ESR_{C,QUC}$	0	–	200	mΩ	2) 3)	P_7.2.2.10
Overtemperature warning threshold	$T_{j,OT,WRN}$	135	145	158	°C	T_j increasing 2)	P_7.2.2.11
Overtemperature shutdown threshold	$T_{j,OT,shutdown}$	176	190	200	°C	T_j increasing 2)	P_7.2.2.12
Overtemperature sensor hysteresis	$T_{j,OT,hyst}$	–	10	–	°C	2)	P_7.2.2.13
Softstart time	$t_{SS,QUC}$	130	200	270	µs	2) C_{QUC} ≤ 15 µF; V_{QUC} rising from 10 % to 90 % of typ. V_{QUC}	P_7.2.2.14
Active discharge pull-down current when disabled	$I_{QUC,pd}$	8	30	65	mA	2) 1.8 V ≤ V_{QUC} ≤ 6 V	P_7.2.2.15

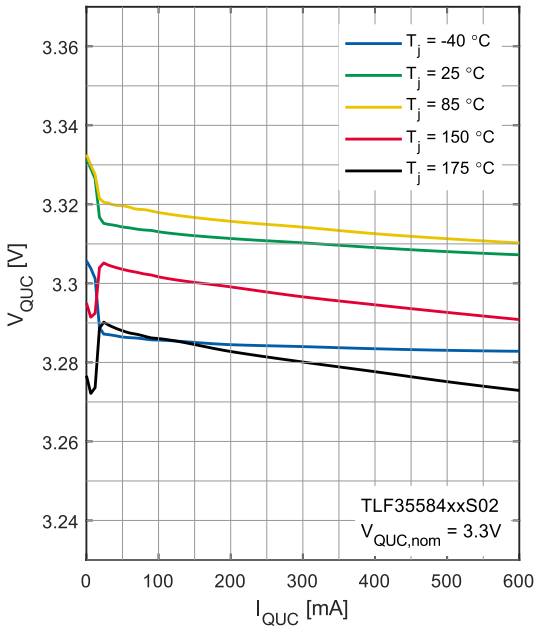
1) Dropout voltage is defined as the difference between input and output voltage when the output voltage decreases 100 mV from output voltage measured at V_{PreReg} = V_{QUC}[Max] + $V_{dr,QUC}$[Max] + 100 mV.
2) Specified by design, not subject to production test
3) Relevant ESR at capacitor's self-resonant frequency.

6.2.3 Typical performance characteristics microcontroller main supply

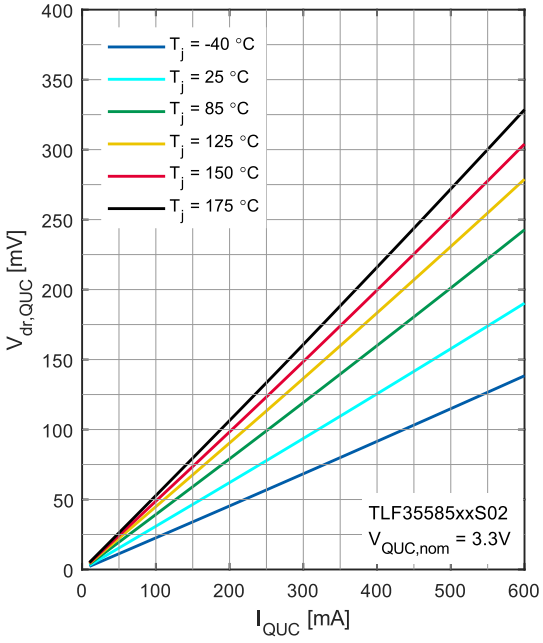
QUC output voltage V_{QUC} versus junction temperature T_j



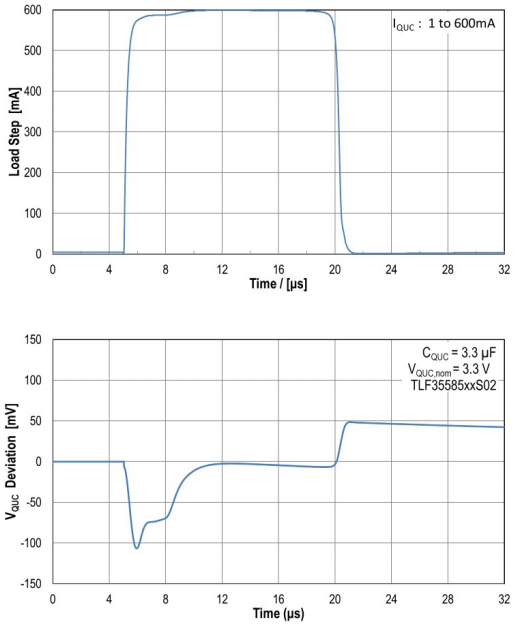
QUC output voltage V_{QUC} versus load current I_{QUC}



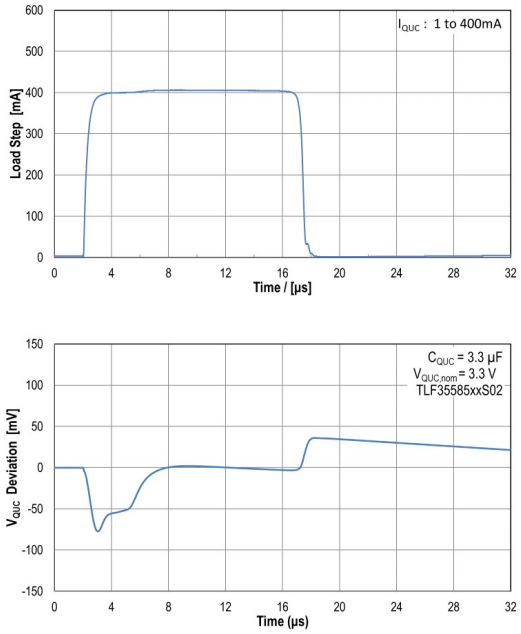
QUC dropout voltage $V_{dr,QUC}$ versus load current I_{QUC}



QUC dynamic load response (1 mA to 600 mA)



QUC dynamic load response (1 mA to 400 mA)



6.3 Communication supply QCO

6.3.1 Functional description communication supply

The linear low drop regulator QCO offers a precise 5.0 V output voltage for communication supply.

The regulator is supplied from the intermediate circuit voltage V_{PREREG}, which provides a stabilized voltage. The output voltage V_{QCO} (at pin QCO) is controlled by the error amplifier. The actual value is compared to a reference voltage derived from bandgap 1 for regulators. The stability of the control loop depends on the load current, the characteristics of the output capacitor and the chip temperature. To ensure stable operation, the output capacitance needs to meet the requirements (capacitance value and electrical series resistance ESR) in Table 11. The input capacitor shown in figure below is the output filter capacitor of the step down pre-regulator.

The regulator features an active pull-down at the output that discharges the output upon disablement of the regulator.

Protection circuitry is implemented to prevent the regulator and the application from damage:

- To protect the pass element of the QCO from overstress, the current limitation limits the output current. Current sensing is done via a current mirror, no sense resistor is used. In case the maximum current condition is reached, the current is limited, so the output voltage decreases. The regulator is protected against short circuit to ground.
- The output voltage is monitored by the voltage monitoring. In case of overvoltage at pin QCO, the QCO is switched off, the event is indicated by an interrupt and stored in an SPI status register (MONSF1). In case of undervoltage at pin QCO, the event is indicated by an interrupt and stored in an SPI status register (MONSF2). The regulator is not switched off in case of output undervoltage, which is shorter than the short to ground detection time t_{StG}. If the undervoltage is present for longer than t_{StG}, the regulator is switched off. This event is stored in the SPI status register (MONSF0) and an interrupt is generated. After events that lead to switch off QCO, the QCO can be re enabled via SPI command in order to recover its output, but a fault-handling strategy to avoid significant power exposure is recommended.
- There is a dedicated temperature sensor for this regulator. In case the power stage temperature exceeds the pre-warning threshold, an interrupt indicates this event and it is stored in an SPI status register (OTWRNSF). If the power stage temperature exceeds the temperature shutdown threshold, this event is stored in an SPI status register (OTFAIL), the regulator is switched off and an interrupt is generated. After a temperature related shut down of QCO, the QCO can be re enabled via SPI command in order to recover its output, but a fault-handling strategy to avoid significant power exposure is recommended. In very light load conditions the thermal sensor is automatically disabled to support reduced current consumption.

The regulator QCO is switched off in STANDBY and FAILSAFE-state. In INIT, SLEEP, NORMAL and WAKE-state QCO is ON or OFF depending on the SPI configuration.

For further details refer to Chapter 10 State machine.

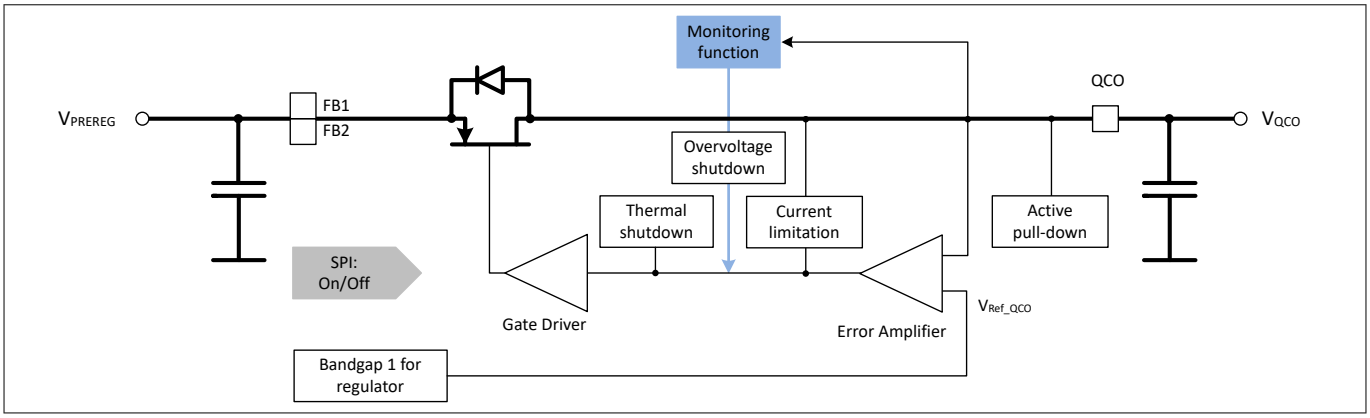


Figure 11 Low drop linear regulator for communications supply QCO

6.3.2 Electrical characteristics communication supply

Table 11 Electrical characteristics communication supply

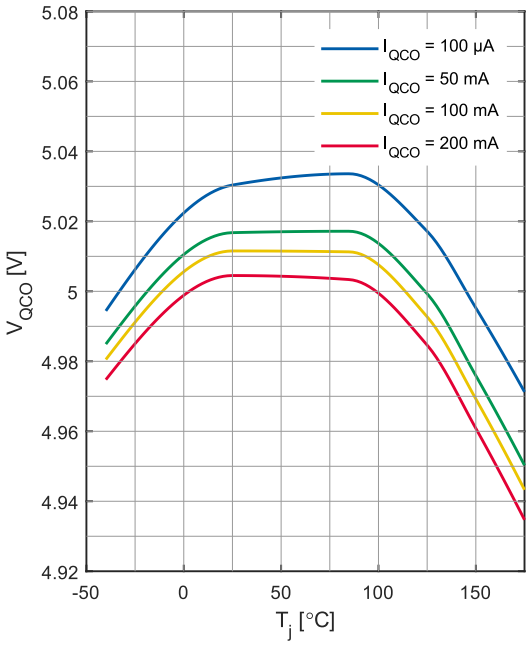
V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Communication supply QCO							
Output voltage	V_{QCO}	4.90	5.00	5.10	V	0 mA ≤ I_{QCO} ≤ 200 mA	P_7.3.2.1
Output current limitation	$I_{QCO,max}$	250	–	400	mA	–	P_7.3.2.2
Drop voltage	$V_{dr,QCO}$	–	–	400	mV	1)	P_7.3.2.3
Load regulation	ΔV_{QCO}	–	40	70	mV	I_{QCO} = 100µ to 200 mA	P_7.3.2.4
Power supply ripple rejection	$PSRR_{QCO}$	26	–	–	dB	2) V_{PREREG} = 5.8 V; $ESR_{C,QCO}$ ≤ 100mΩ	P_7.3.2.5
Output capacitor	C_{QCO}	1	–	47	µF	2)	P_7.3.2.6
Output capacitor, ESR	$ESR_{C,QCO}$	0	–	200	mΩ	2) 3)	P_7.3.2.7
Overtemperature warning threshold	$T_{j,OT,WRN}$	135	145	158	°C	T_j increasing 2)	P_7.3.2.8
Overtemperature shutdown threshold	$T_{j,OT,shutdown}$	176	190	200	°C	T_j increasing 2)	P_7.3.2.9
Overtemperature sensor hysteresis	$T_{j,OT,hyst}$	–	10	–	°C	2)	P_7.3.2.10
Softstart time	$t_{SS,QCO}$	130	200	500	µs	2) C_{QCO} ≤ 15 µF; V_{QCO} rising from 10 % to 90 % of typ. V_{QCO}	P_7.3.2.11
Active discharge pull-down current when disabled	$I_{QCO,pd}$	8	30	65	mA	2) 1.8 V ≤ V_{QCO} ≤ 6 V	P_7.3.2.12

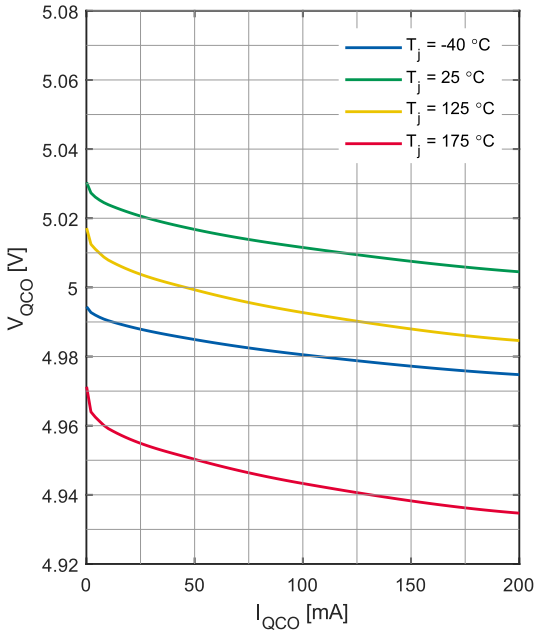
1) Dropout voltage is defined as the difference between input and output voltage when the output voltage decreases 100 mV from output voltage measured at $V_I = V_{Q,nom} + V_{dr,max}$ + 100 mV.
2) Specified by design, not subject to production test
3) Relevant ESR at capacitor's self-resonant frequency.

6.3.3 Typical performance characteristics communication supply

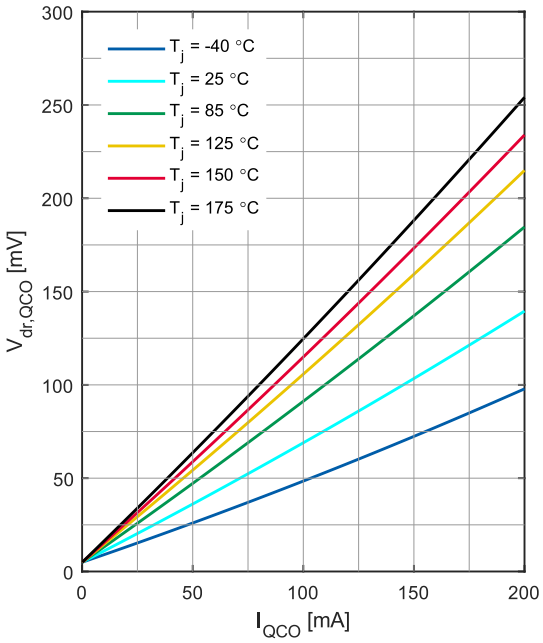
QCO output voltage V_{QCO} versus junction temperature T_j



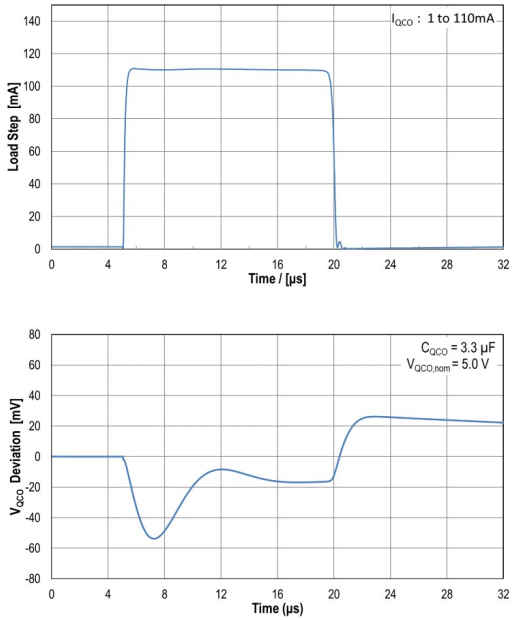
QCO output voltage V_{QCO} versus load current I_{QCO}



QCO dropout voltage $V_{dr,QCO}$ versus load current I_{QCO}



QCO dynamic load response (1 mA to 110 mA) ($V_{QCO,nom}$ = 5.0 V)



6.4 Voltage reference supply QVR

6.4.1 Functional description voltage reference supply

The linear low drop regulator QVR offers a highly precise 5.0 V output voltage as a voltage reference.

The regulator is supplied from the intermediate circuit voltage V_{PREREG}, which provides a stabilized voltage. The output voltage V_{QVR} at pin QVR is controlled by the error amplifier. The actual value is compared to a reference voltage derived from bandgap 1 for regulators. The stability of the control loop depends on the load current, the characteristics of the output capacitor and the chip temperature. To ensure a stable operation, the output capacitance needs to meet the requirements (capacitance value and electrical series resistance ESR) in Table 12. The input capacitor shown in figure below is the output filter capacitor of the step down pre-regulator.

The regulator features an active pull-down at the output that discharges the output upon disablement of the regulator.

Protection circuitry is implemented to prevent the regulator and the application from damage:

- To protect the pass element of the QVR from overstress, the current limitation limits the output current. Current sensing is done via a current mirror, no sense resistor is used. In case the maximum current condition is reached the current is limited, so the output voltage decreases. The regulator is protected against short circuit to ground.
- The output voltage is monitored by the voltage monitoring.

  In case of overvoltage at pin QVR, the QVR is switched off and the device moves into FAILSAFE-state. The event is stored in an SPI status register (MONSF1).

  In case of undervoltage at pin QVR, the event is indicated by an interrupt and stored in an SPI status register (MONSF2). The regulator is not switched off in case of output undervoltage, which is shorter than the short to ground detection time t_{StG}. If the undervoltage is present for longer than t_{StG}, the regulator is switched off. This event is stored in an SPI status register (MONSF0) and an interrupt is generated. After events that lead to switch off of QVR, the QVR can be re enabled via SPI command in order to recover its output, but a fault-handling strategy to avoid significant power exposure is recommended.
- There is no dedicated temperature sensor for this regulator. The temperature is sensed on the chip by other temperature sensors located at QUC and step down pre-regulator. If the chip temperature exceeds the pre-warning threshold, an interrupt indicates this event and it is stored in a SPI status register (OTWRNSF). If the chip temperature exceeds the temperature shutdown threshold, the regulator is switched off. The temperature switch off time is at least one second.
- An overload at QVR (overcurrent detected for more than 1 ms) is indicated by an interrupt and it is stored in a SPI status register (OTWRNSF).

If the device enters FAILSAFE-state the ROT is pulled low and all supplies are switched off.

The regulator QVR is switched off in STANDBY and FAILSAFE-state. In INIT, SLEEP, NORMAL and WAKE-state QVR is ON or OFF depending on the SPI configuration.

For further details refer to Chapter 10 State machine.

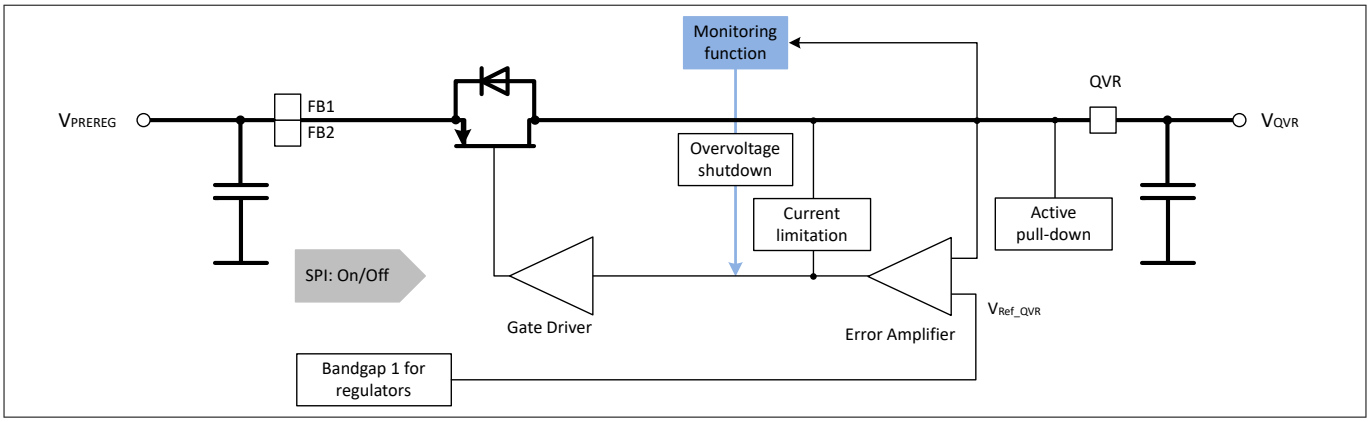


Figure 12 Precise low drop linear regulator as a voltage reference supply QVR

6.4.2 Electrical characteristics voltage reference supply

Table 12 Electrical characteristics voltage reference supply

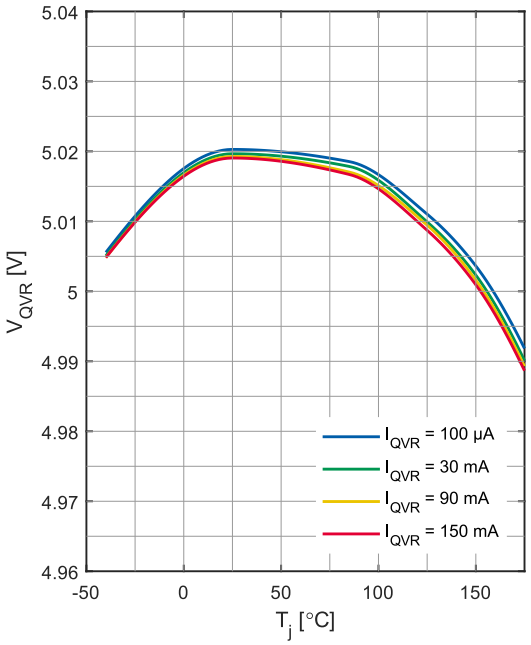
V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Voltage reference supply QVR							
Output voltage	V_{QVR}	4.95	5.00	5.05	V	0 mA ≤ I_{QVR} ≤ 150 mA	P_7.4.2.1
Output current limitation	$I_{QVR,max}$	170	–	345	mA	–	P_7.4.2.2
Drop voltage	$V_{dr,QVR}$	–	–	400	mV	1)	P_7.4.2.3
Load regulation	ΔV_{QVR}	–	4.5	9	mV	I_{QVR} = 100µ to 150 mA	P_7.4.2.4
Power supply ripple rejection	$PSRR_{QVR}$	26	–	–	dB	2) V_{PREREG} = 5.8 V; $ESR_{C,QVR}$ ≤ 100 mΩ	P_7.4.2.5
Output capacitor	C_{QVR}	1	–	10	µF	2)	P_7.4.2.6
Output capacitor, ESR	$ESR_{C,QVR}$	0	–	200	mΩ	2) 3)	P_7.4.2.7
Softstart time	$t_{SS,QVR}$	130	200	350	µs	2) C_{QVR} ≤ 10 µF; V_{QVR} rising from 10 % to 90 % of typ. V_{QVR}	P_7.4.2.8
Active discharge pull-down current when disabled	$I_{QVR,pd}$	8	30	65	mA	2) 1.8 V ≤ V_{QVR} ≤ 6 V	P_7.4.2.9

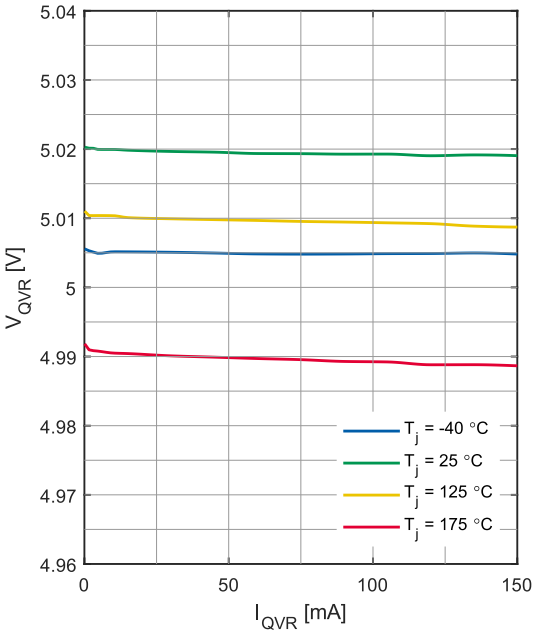
1) Dropout voltage is defined as the difference between input and output voltage when the output voltage decreases 100 mV from output voltage measured at $V_I = V_{Q,nom} + V_{dr,max}$ + 100 mV.
2) Specified by design, not subject to production test
3) Relevant ESR at capacitor's self-resonant frequency.

6.4.3 Typical performance characteristics voltage reference supply

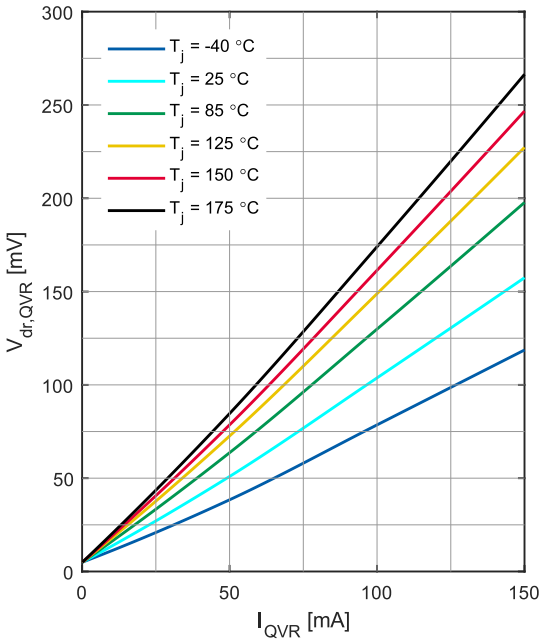
QVR output voltage V_{QVR} versus junction temperature T_j



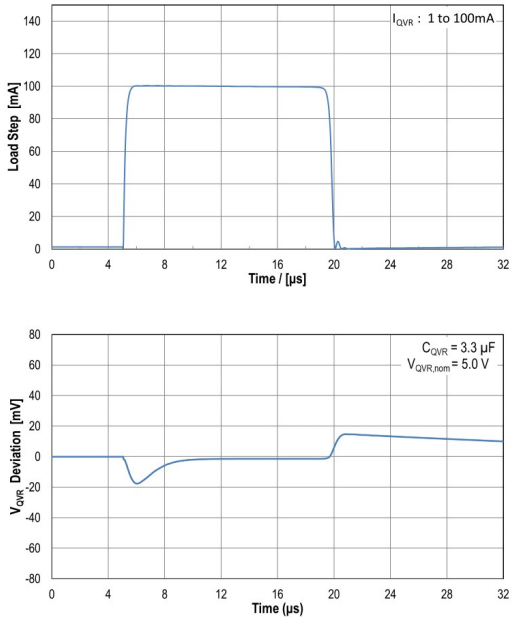
QVR output voltage V_{QVR} versus load current I_{QVR}



QVR dropout voltage $V_{dr,QVR}$ versus load current I_{QVR}



QVR dynamic load response (1 mA to 100 mA) ($V_{QVR,nom}$ = 5.0 V)



6.5 Tracker 1 QT1 and tracker 2 QT2

6.5.1 Functional description tracker 1 and tracker 2

The linear trackers 1 and 2 offer a sensor supply voltage with a very high accuracy related to voltage reference output (pin QVR).

Both trackers are supplied by the intermediate circuit voltage V_{PREREG}, which provides a stabilized voltage. The output voltage V_{QTx} at pin QTx is controlled by the error amplifier. The actual value is compared to a reference voltage provided by the reference voltage V_{QVR} at pin QVR. The tracker output voltages follow the reference voltage supply QVR with the small difference ΔV_{QTx}. The stability of the control loop depends on the load current, the characteristics of the output capacitor and the chip temperature. To ensure a stable operation, the output capacitance needs to meet the requirements (capacitance value and electrical series resistance ESR) in Table 13. The input capacitor shown in figure below is the output filter capacitor of the step down pre-regulator.

The regulator features an active pull-down at the output that discharges the output upon disablement of the regulator.

Protection circuitry is implemented to prevent damage to both trackers and the application:

- To protect the pass element of a tracker from overstress, the current limitation limits the output current. Current sensing is done via a current mirror, no sense resistor is used. In case the maximum current condition is reached, the current is limited and in consequence the output voltage decreases. A tracker is protected against short circuit to ground and short circuit to battery voltage.
- The output voltage is monitored by the voltage monitoring.

  In case of overvoltage at pin QTx, the corresponding tracker is switched off, the event is stored in an SPI status register (MONSF1) and an interrupt is generated.

  In case of undervoltage at pin QTx, the event is stored in an SPI status register (MONSF2) and an interrupt is generated. The tracker is not switched off in case of output undervoltage, which is shorter than the short to ground detection time t_{StG}. If the undervoltage is present for longer than t_{StG}, the regulator is switched off. This event is stored in an SPI status register (MONSF0) and an interrupt is generated. After events that lead to switch off of QTx, the QTx can be re enabled via SPI command in order to recover its output, but a fault-handling strategy to avoid significant power exposure is recommended.
- The trackers can withstand a short circuit either to ground or to battery voltage without damage.

  In case of a short circuit to battery voltage and if the battery voltage is above the tracker overvoltage threshold, the tracker is switched off, the event is stored in the SPI status register (MONSF1).
- There is no dedicated temperature sensor for this regulator. The temperature is sensed on the chip by other temperature sensors located at QUC and step down pre-regulator. If the chip temperature exceeds the pre-warning threshold, then the event is stored in an SPI status register (OTWRNSF) and an interrupt is generated. If the chip temperature exceeds the temperature shutdown threshold, the tracker is switched off. The temperature switch off time is at least one second.

Both trackers are switched off in STANDBY and FAILSAFE. In INIT, NORMAL, SLEEP and WAKE-state each tracker is ON or OFF depending on the SPI configuration.

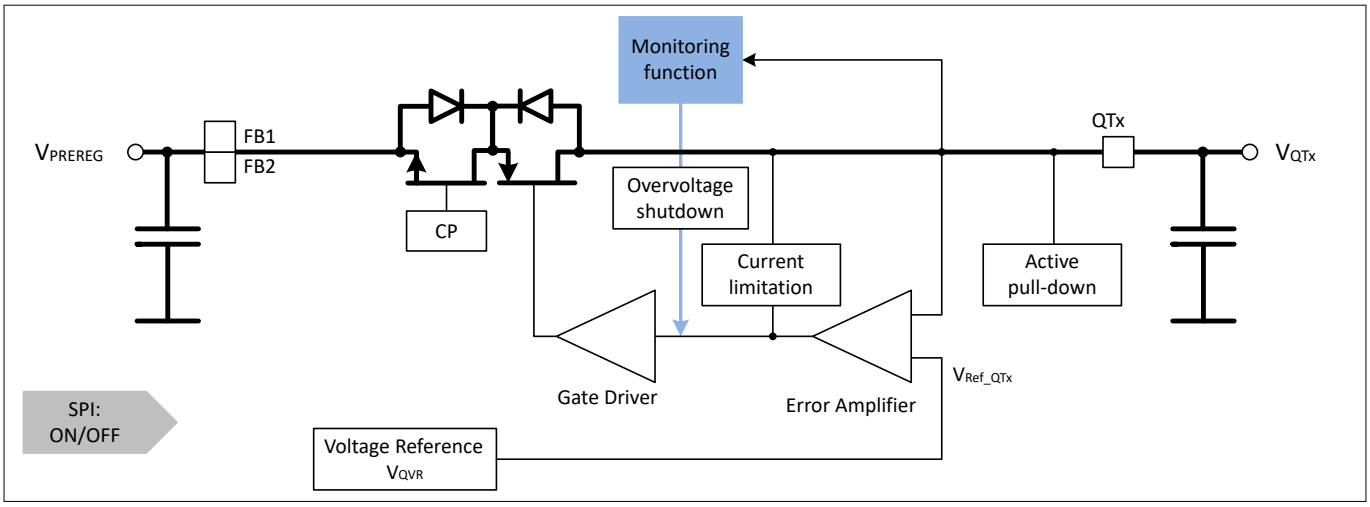


Figure 13 **Tracker 1 QT1 and tracker 2 QT2 for sensor supply**

6.5.2 Electrical characteristics tracker 1 and tracker 2

Table 13 **Electrical characteristics tracker 1 and tracker 2**

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

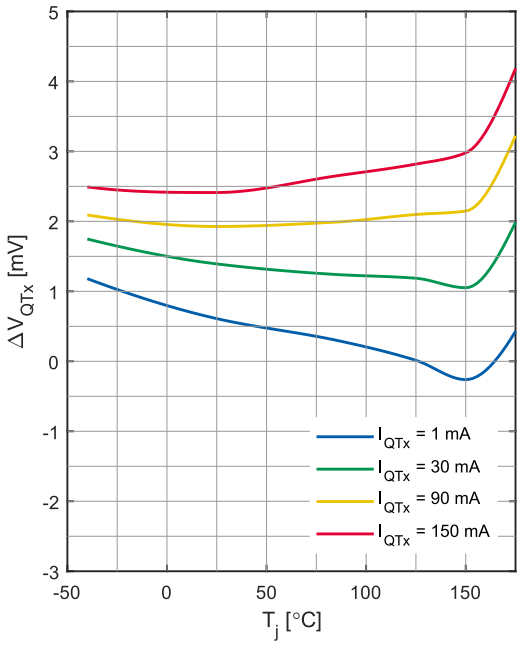
Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Tracker 1 QT1 and tracker 2 QT2							
Output voltage tracking accuracy to voltage reference [1]	ΔV_{QTx}	– 10	–	10	mV	0 mA ≤ I_{QTx} ≤ 150 mA;	P_7.5.2.1
Output current limitation	$I_{QTx,max}$	160	–	320	mA	–	P_7.5.2.2
Drop voltage	$V_{dr,QTx}$	–	–	400	mV	[2]	P_7.5.2.3
Power supply ripple rejection	$PSRR_{QTx}$	26	–	–	dB	[3] V_{PREREG} = 5.8 V ; $ESR_{C,QTx}$ ≤ 100 mΩ	P_7.5.2.4
Output capacitor	C_{QTx}	1	–	10	µF	[3]	P_7.5.2.5
Output capacitor, ESR	$ESR_{C,QTx}$	0	–	200	mΩ	[3] [4]	P_7.5.2.6
Softstart time	$t_{SS,QTx}$	130	200	270	µs	[3] I_{QTx} ≤ 75 mA; C_{QTx} ≤ 6 µF; V_{QTx} rising from 10 % to 90 % of typ. V_{QTx}	P_7.5.2.7
Active discharge pull-down resistor	$R_{QTx,pd}$	–	10	15	kΩ	[3]	P_7.5.2.8

1) The output voltage of the tracker (pin QTx) is derived from the output voltage of the voltage reference (pin QVR). If the voltage reference supply is switched off (voltage at pin QVR drops to 0 V), then the output voltage at pin QTx decreases to 0 V as well, if the tracker should be switched on as the tracker output voltage is derived from pin QVR. Still if the tracker is switched on and its output voltage drops to 0 V (because voltage at pin QVR drops), an undervoltage at pin QTx is detected and an interrupt is issued.

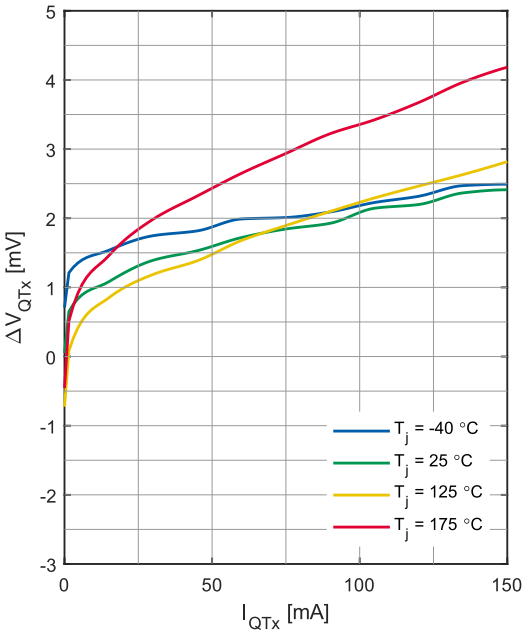
2) Dropout voltage is defined as the difference between input and output voltage when the output voltage decreases 100 mV from output voltage measured at $V_I = V_{Q,nom} + V_{dr,max} + 100$ mV.
3) Specified by design, not subject to production test
4) Relevant ESR at capacitor's self-resonant frequency.

6.5.3 Typical performance characteristics tracker 1 and tracker 2

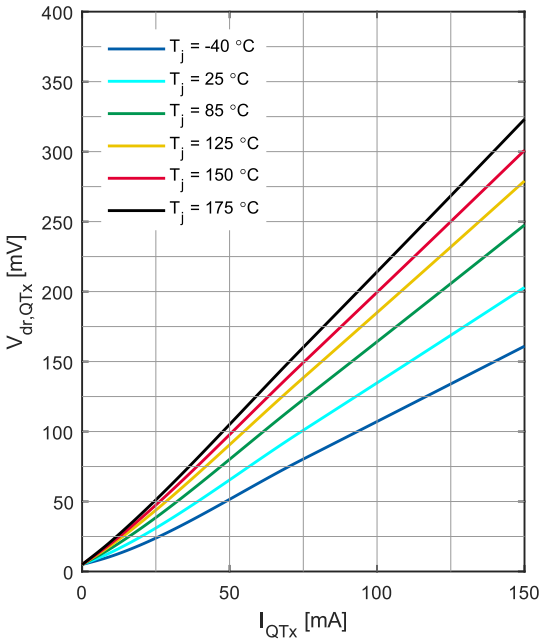
QTx tracking accuracy ΔV_{QTx} versus junction temperature T_j



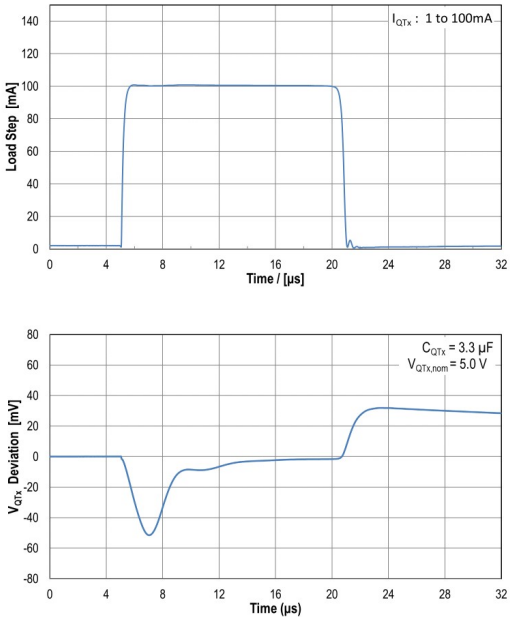
QTx tracking accuracy ΔV_{QTx} versus load current I_{QTx}



QTx dropout voltage $V_{dr,QTx}$ versus load current I_{QTx}



QTx dynamic load response (1 mA to 100 mA) ($V_{QTx,nom}$ = 5.0 V)



6.6 External post regulator for core supply (optional)

6.6.1 Functional description external post regulator support

An additional external post regulator may be added to the device to provide the core supply voltage V_{Core_Supply} for the MCU if needed. In this case the configuration pin SEC has to be left open to indicate that the external core voltage supply option is active. The configuration of the SEC pin is only read during the power sequencing at the point the core supply would be started (Movements to INIT, please refer to Figure 15 and Figure 16).

The regulator is fed from the intermediate circuit voltage V_{PREREG}.The post regulator is enabled by a "high" signal at pin EVC and switched off by a "low" signal at pin EVC. The EVC signal is controlled by the state machine. For example a detection of overvoltage at pin VCI creates a "low" signal at pin EVC and shuts down the post regulator to protect the MCU core. In case the external post regulator uses a softstart function, the start-up time has to be aligned with the short to ground detection time $t_{StG,VCI}$.

The device offers a synchronization signal of 50% duty cycle at pin SYN equal in phase (only with a very small delay) and frequency or shifted by 180 degrees to the internal step down pre-regulator (the selection is done via SPI command). It is highly recommended to synchronize the external switch mode post regulator to this signal to avoid interferences. The external post regulator is enabled as soon as the pre-regulator output voltage V_{PREREG} is present and the QUC output voltage V_{QUC} is above the lower monitoring threshold.

The output voltage of the post regulator V_{Core_Supply} is monitored by the reset function of the device. To obtain a proper monitoring, the output voltage of the post regulator has to be connected to the voltage monitoring input at pin VCI via a resistor divider. The resistor divider needs to be dimensioned to adjust the post regulator output voltage V_{Core_Supply} to the internal reset reference voltage V_{VCI}.

The synchronization signal at pin SYN can be switched on via SPI command, default configuration is off.

Protection circuitry should be implemented to prevent the external regulator and the application from damage:

- To protect the pass device(s) of the external post regulator from overstress, a current limitation function should limit the output current to the maximum specified limit. The regulator should be protected against short circuit to ground.
- The output voltage is monitored by the voltage monitoring of the device, no further reset function is required on the external post regulator. In case such a reset function should be present, it is not used or supported by the reset function of the device.

  In case of overvoltage at pin VCI, the external post regulator is switched off by pulling pin EVC to "low" and the device enters FAILSAFE-state. The event is stored in an SPI status register (MONSF1).

  In case of undervoltage at pin VCI, the device moves into INIT-state, pin ROT goes "low" and the event is stored in an SPI status register (MONSF2). The external post regulator is not switched off in case of output undervoltage, which is shorter than the short to ground detection time $t_{StG,VCI}$. If the undervoltage is present for more than $t_{StG,VCI}$, the device enters FAILSAFE-state. This event is stored in an SPI status register as well (MONSF0).
- There should be a temperature shutdown function at the external post regulator. If the power stage temperature should exceed the temperature shutdown threshold, the post regulator should be switched off by its own temperature shutdown. The device recognizes the undervoltage condition and reacts as described above.

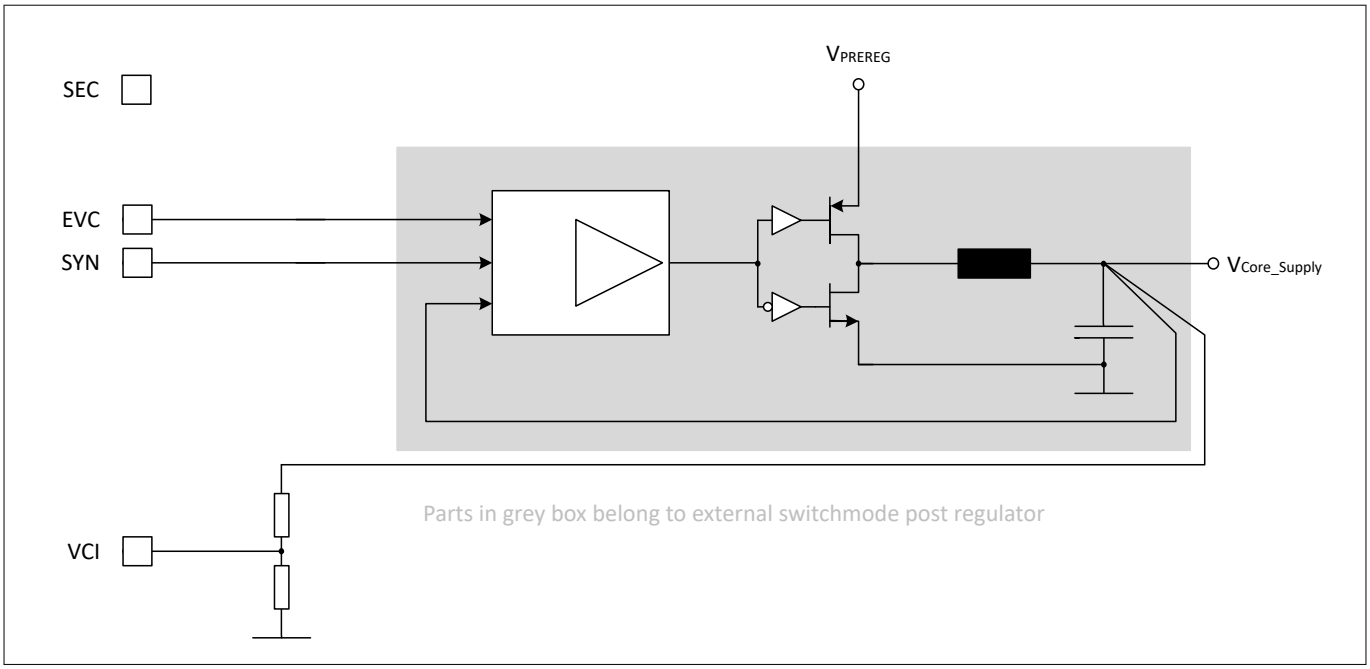


Figure 14 External switch mode post regulator for core supply

6.6.2 Electrical characteristics external post regulator support

Table 14 Electrical characteristics external post regulator

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Enable output signal, pin EVC							
Enable output high level	$V_{EVC, high}$	2.3	–	–	V	V_{QUC} = 3.3 V; I_{EVC} = -7 mA	P_7.6.0.4
Enable output high level	$V_{EVC, high}$	3.0	–	–	V	V_{QUC} ≥ 3.1 V; I_{EVC} = -0.5 mA	P_7.6.0.5
Enable output low level	$V_{EVC, low}$	–	–	0.7	V	V_{QUC} = 3.3 V; I_{EVC} = 5.5 mA	P_7.6.0.6
Enable output rise time	$t_{EVC, rise}$	–	–	25	ns	$C_{EVC, load}$ = 50 pF *1)*	P_7.6.0.7
Enable output fall time	$t_{EVC, fall}$	–	–	25	ns	$C_{EVC, load}$ = 50 pF *1)*	P_7.6.0.8
Synchronization output signal, pin SYN							
Synchronization output high level	$V_{SYN, high}$	2.3	–	–	V	V_{QUC} = 3.3 V; I_{SYN} = -7 mA	P_7.6.0.12
Synchronization output high level	$V_{SYN, high}$	3.0	–	–	V	V_{QUC} ≥ 3.1 V; I_{SYN} = -0.5 mA	P_7.6.0.13
Synchronization output low level	$V_{SYN, low}$	–	–	0.7	V	V_{QUC} = 3.3 V; I_{SYN} = 5.5 mA	P_7.6.0.14
Synchronization output signal duty cycle	D_{SYN}	–	50	–	%	–	P_7.6.0.15
Synchronization output signal rise time	$t_{SYN, rise}$	–	–	25	ns	$C_{SYN, load}$ = 50 pF *1)*	P_7.6.0.16
Synchronization output signal fall time	$t_{SYN, fall}$	–	–	25	ns	$C_{SYN, load}$ = 50 pF *1)*	P_7.6.0.17
Core voltage supply monitoring input, pin VCI							
Core voltage monitoring input pull-up current	I_{VCI}	–	100	130	nA	V_{VCI} = 0.8 V	P_7.6.0.18

1) specified by design, not subject to production test.

6.7 Power sequencing

The device includes a power sequencing function to ensure a proper ramp-up of all output voltages. After the internal Power-On-Reset (POR) is released to move out of POWERDOWN and the voltage at pin VSx V_{VS} increased above $V_{PS,start}$, the standby regulator and the pre-regulator(s) start to operate.

If one of the non microcontroller related voltages (QVR, QCO, QT1 or QT2) cannot be ramped up (e.g. short to GND), the power sequence is stopped, but the reset output is still released after the power-on reset delay time t_{rd}. The microcontroller should check the status of the outputs by reading the SPI status register (VMONSTAT).

If the microcontroller sends a SPI request to enable or disable any non microcontroller related supply (QVR, QCO, QT1 or QT2) during the power sequencing, the sequence is stopped and the requested configuration is executed.

6.7.1 Power sequencing from POWERDOWN to INIT-state

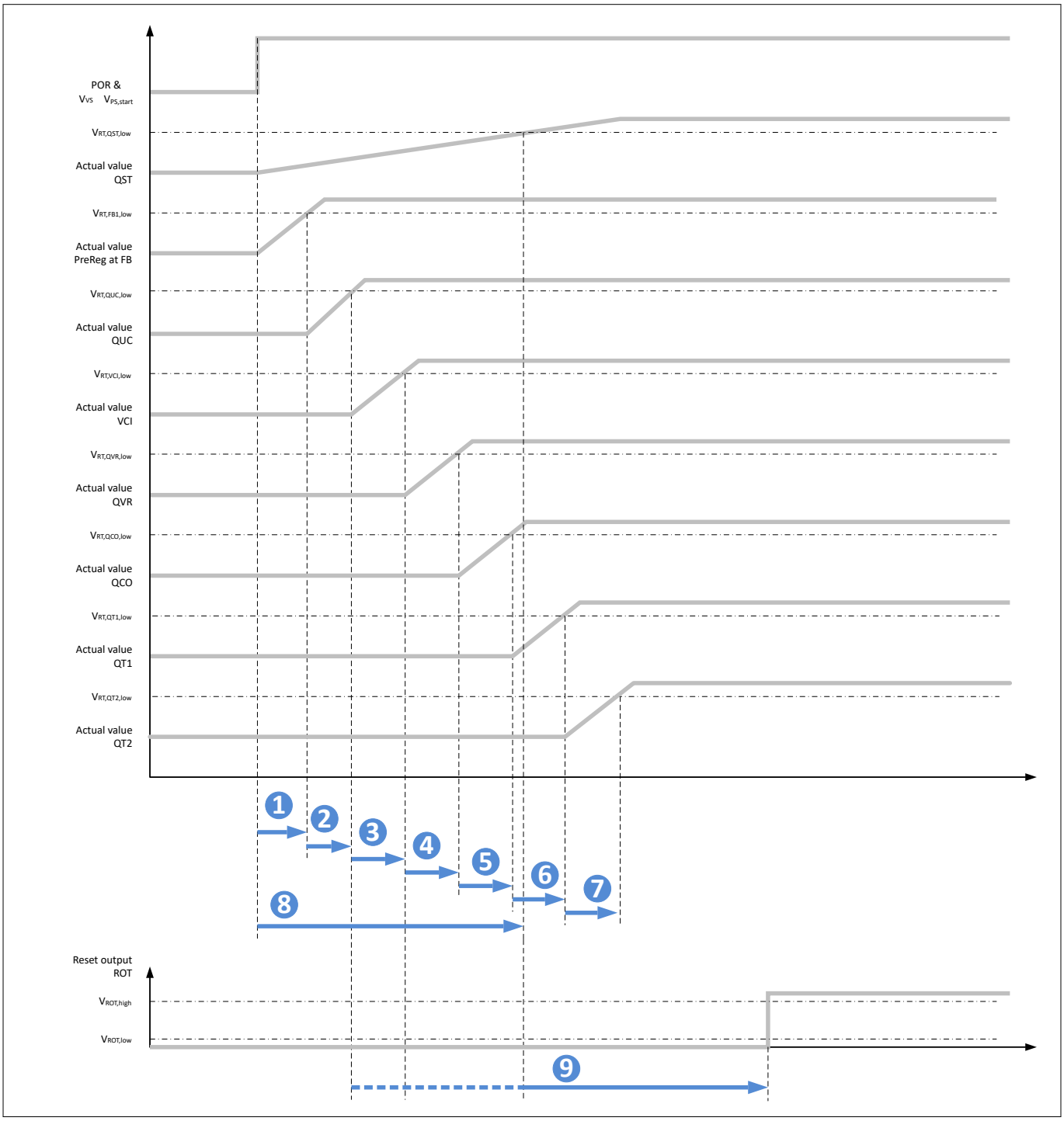


Figure 15 Power sequencing POWERDOWN to INIT-state

Description:

1. After POR is released (representing the exit from POWERDOWN) and V_{VS} is above $V_{PS,start}$, the standby supply (QST) and the pre-regulator start to operate.
2. As soon as V_{FB} is above the lower monitoring threshold $V_{RT,FB,low}$+$V_{RT,FB,UV\ hyst}$, the QUC starts to operate.
3. As soon as V_{QUC} is above the lower monitoring threshold $V_{RT,QUC,low}$+$V_{RT,QUC,UV\ hyst}$, the external core supply is enabled via EVC pin, if selected. If the external core supply is not selected, the QVR starts to operate.

4. If the external core supply is selected and V_{VCI} is above the lower monitoring threshold $V_{RT,VCI,low}$+$V_{RT,VCI,UV\ hyst}$, the QVR starts to operate.
5. As soon as V_{QVR} is above the lower monitoring threshold $V_{RT,QVR,low}$+$V_{RT,QVR,UV\ hyst}$, the QCO starts to operate.
6. As soon as V_{QCO} is above the lower monitoring threshold $V_{RT,QCO,low}$+$V_{RT,QCO,UV\ hyst}$, the QT1 starts to operate.
7. As soon as V_{QT1} is above the lower monitoring threshold $V_{RT,QT1,low}$+$V_{RT,QT1,UV\ hyst}$, the QT2 starts to operate.
8. This is the time from the enabling of the standby supply until its output V_{QST} is above the lower monitoring threshold $V_{RT,QST,low}$.
9. The reset delay time t_{RD} starts after QST, QUC and VCI (if external core supply selected by pin SEC) have reached their lower monitoring threshold $V_{RT,xxx,low}$+$V_{RT,xxx,UV\ hyst}$. The reset delay time is programmable via SPI. After the reset delay time is expired, the reset signal at pin ROT pin is released. The figure shows the possible range of the t_{RD} starting time.

Once the ROT is high, the microcontroller can change the configuration of the selectable supplies, which might change the power sequencing accordingly.

6.7.2 Power sequencing STANDBY to INIT-state

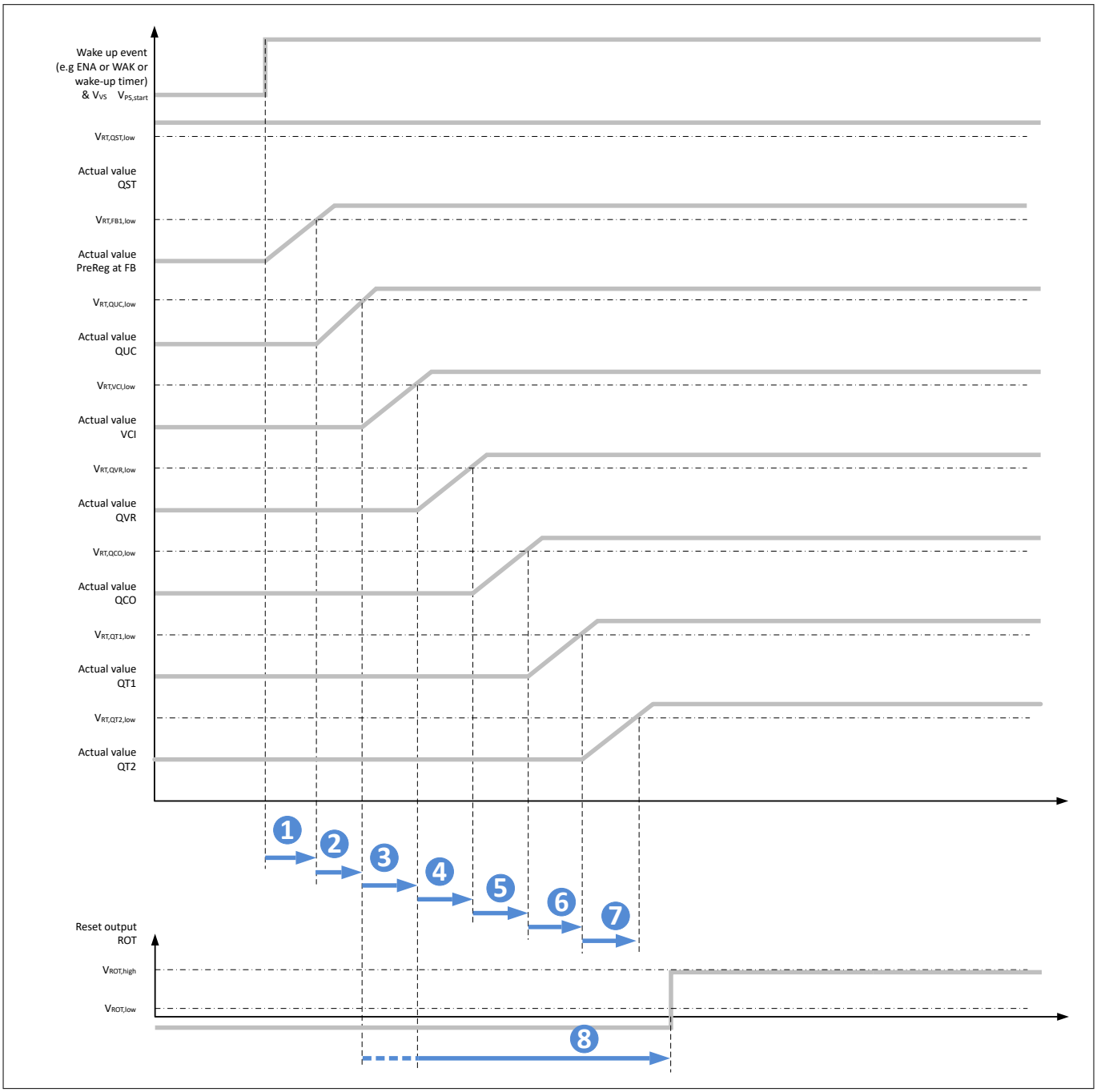


Figure 16 Power sequencing STANDBY to INIT-state

Description: Input voltage is present, device is in STANDBY-state, QST is active.

1. After a valid Wake-Signal or an expired wake-up timer the pre-regulator starts to operate as soon as V_{VS} is above $V_{PS,start}$.
2. As soon as V_{FB} is above the lower reset threshold $V_{RT,FB,low}$+$V_{RT,FB,UV\ hyst}$, the QUC starts to operate.
3. As soon as V_{QUC} is above the lower reset threshold $V_{RT,QUC,low}$+$V_{RT,QUC,UV\ hyst}$, the external core supply is enabled via EVC pin, if selected. If the external core supply is not selected, the QVR starts to operate.
4. If the external core supply is selected and V_{VCI} is above the lower monitoring threshold $V_{RT,VCI,low}$+$V_{RT,VCI,UV\ hyst}$, the QVR starts to operate.
5. As soon as V_{QVR} is above the lower reset threshold $V_{RT,QVR,low}$+$V_{RT,QVR,UV\ hyst}$, the QCO starts to operate.

6. As soon as V_{QCO} is above the lower reset threshold $V_{RT,QCO,low}$+$V_{RT,QCO,UV\ hyst}$, the QT1 starts to operate.
7. As soon as V_{QT1} is above the lower reset threshold $V_{RT,QT1,low}$+$V_{RT,QT1,UV\ hyst}$, the QT2 starts to operate.
8. The reset delay time t_{RD} starts after QUC and VCI (if external core supply selected by pin SEC) have reached their lower monitoring threshold $V_{RT,xxx,low}$+$V_{RT,xxx,UV\ hyst}$. The reset delay time is programmable via SPI. After the rest delay time is expired, the reset signal at pin ROT pin is released. The figure shows the possible range of the t_{RD} starting time.

6.7.3 Power sequencing SLEEP to WAKE-state

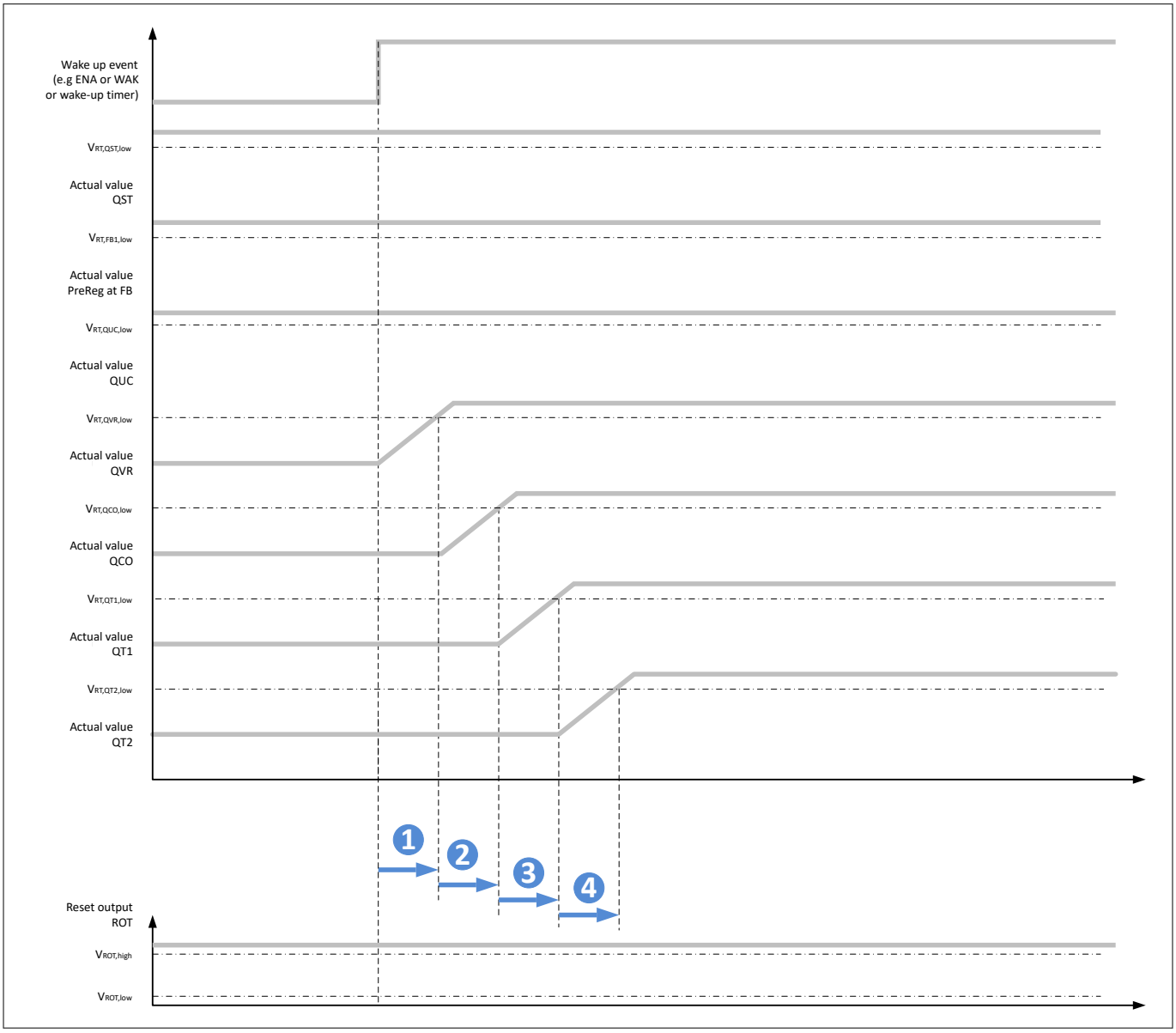


Figure 17 Power sequencing SLEEP to WAKE-state

Description: Input voltage is present, device is in SLEEP-state, all selectable supplies switched off in SLEEP-state, all selectable supplies were switched on in previous NORMAL-state:

1. After a valid Wake-Signal or an expired wake-up timer the voltage reference starts to operate.
2. As soon as V_{QVR} is above the lower monitoring threshold $V_{RT,QVR,low}$+$V_{RT,QVR,UV\ hyst}$, the QCO starts to operate.

3. As soon as V_{QCO} is above the lower monitoring threshold $V_{RT,QCO,low}$+$V_{RT,QCO,UV\ hyst}$, the QT1 starts to operate.
4. As soon as V_{QT1} is above the lower monitoring threshold $V_{RT,QT1,low}$+$V_{RT,QT1,UV\ hyst}$, the QT2 starts to operate.

The reset output ROT is high in SLEEP-state and is kept high for WAKE-state.

In case a selectable LDO was switched off in the previous NORMAL-state, it is not enabled during the transition from SLEEP to WAKE, the power sequencing follows up with the next LDO. In case a LDO was enabled during SLEEP-state and was enabled in the previous NORMAL-state, it remains enabled.

7 Monitoring function

7.1 Introduction monitoring function

The device includes an independent voltage monitoring function of all output voltages, including the external post regulator for MCU core supply, if in use.

The monitoring function consists of two comparators for each output voltage. One is for detecting overvoltage, the other is for detecting undervoltage. Both comparators get their reference voltage from an independent bandgap 2 only used for the voltage monitoring block. This bandgap is independent from the voltage regulator bandgap 1. The bandgap 2 provides the reference voltage for overvoltage detection (high voltage monitoring threshold $V_{RT,xxx,high}$) and for undervoltage detection (low voltage monitoring threshold $V_{RT,xxx,low}$). Under normal operation conditions the output voltage of the related regulator must remain within the voltage window defined by the upper limit $V_{RT,xxx,high}$ and the lower limit $V_{RT,xxx,low}$.

There is a dedicated temperature sensor for the monitoring block. If the power stage temperature exceeds the temperature shutdown threshold, the device moves into FAILSAFE-state, the regulators are switched off and the event is stored in an SPI status register (OTFAIL). The off time due to temperature shut down is at least one second.

Characteristics

Behavior of the overvoltage and undervoltage comparators is as following:

- The upper limits $V_{RT,xxx,high}$ and the lower limits $V_{RT,xxx,low}$ are unmodifiable.
- An overvoltage is detected if the regulator output voltage is above the related overvoltage monitoring threshold $V_{RT,xxx,high}$ for more than the monitoring reaction time t_{RR}. An overvoltage higher than the related overvoltage monitoring threshold $V_{RT,xxx,high}$ which is present for shorter than the monitoring reaction time t_{RR} is regarded as a spike and is not detected.

  An undervoltage is detected if the regulator output voltage is below the related undervoltage monitoring threshold $V_{RT,xxx,low}$ longer than the monitoring reaction time t_{RR}. An undervoltage lower than the related undervoltage monitoring threshold $V_{RT,xxx,low}$ which is present for shorter than the monitoring reaction time t_{RR} is regarded as a spike and is not detected.
- The monitoring reaction time t_{RR} is not valid for the internal voltage supplies in case of undervoltage and overvoltage.
- The detection of an overvoltage shuts down the related regulator immediately to protect the loads from harm or destruction.

  This shut down may lead (depending on the affected regulator) to further action, please refer to chapter State machine for details.
- The detection of an undervoltage does not shut down the related regulator.
- The post regulators (including the optional external post regulator for MCU core supply) and the step down pre-regulator have a short to ground detection.

  If the detected undervoltage is present for more than the short to ground detection time t_{StG}, the related regulator is shut down to protect it and the chip from overheating. This shutdown can lead (depending on the affected regulator) to further action, please refer to chapter State machine for details. (It is mandatory that the external post regulator for MCU core supply has an enable or inhibit function).
- The over and undervoltage detection is active only if the related regulator is in use (including the external post regulator for MCU core supply) and switched on.

Indication of over and undervoltage

Depending on the related regulator the indication of over and undervoltage is different, either by reset signal or by interrupt indication:

- Every over and undervoltage detection is stored in the SPI status register (MONSF0, MONSF1, MONSF2).
- For MCU related output voltages (V_{QST} , V_{QUC} , V_{VCI}), over and undervoltage are indicated by the hardware reset pin ROT. In case of an over or undervoltage, pin ROT is pulled to "low".
- In case of overvoltage or a detection of a short to ground at the external post regulator for MCU core supply, the pin EVC is pulled to "low" to shut down the regulator.
- For the pre-regulator output (V_{FB}) and the voltage reference output (V_{QVR}) only overvoltage is indicated by the hardware reset pin ROT. In case of an overvoltage, pin ROT is pulled to low.
- For the pre-regulator output and the voltage reference output, only undervoltage is indicated by an interrupt.
- For all not MCU related output voltages (V_{QCO} , V_{QT1} , V_{QT2}), over and undervoltage are indicated by an interrupt.
- For the internal supply voltages, over and undervoltage are indicated by the hardware reset pin ROT. In case of an over or undervoltage, pin ROT is pulled to "low".

This introduction is an overview, for details please refer to the following sub chapters.

7.2 Shutdown function

A short to ground detection time t_{StG} at the pre regulator output is only active during the power sequencing in INIT-state. If the output voltage of the pre-regulator is not within the specified limits within a certain time frame, the device moves into FAILSAFE-state. There is no reaction on a detected short to ground once the $V_{PREREG,BUCK}$ is in a valid range after crossing its undervoltage threshold for the first time(step 1 completed according to the power sequencing described in Chapter 6.7). If the output voltage of the pre-regulator is too low in other cases, the behavior of the device depends on the voltage monitoring of the post regulators.

On detection of an overvoltage at one of the output voltages V_{QUC}, V_{VCI}, V_{QST}, V_{QVR} or V_{FB} the device shuts down all regulators to protect the loads from harm or destruction and moves the device to FAILSAFE.

On detection of an overvoltage at one of the output voltages V_{QCO}, V_{QT1} and V_{QT2} the device shuts down the related regulator to protect the loads from harm or destruction and generates an interrupt event.

If the detected undervoltage at output voltages V_{QUC}, V_{VCI} or V_{QST} should be present for more than the short to ground detection time t_{StG}, all regulators are shut down to protect themselves and the chip from over heating and the device moves to FAILSAFE.

If the detected undervoltage at output voltages V_{QVR}, V_{QCO}, V_{QT1} or V_{QT2} should be present for more than the short to ground detection time t_{StG} , the related regulator shuts down to protect himself and the chip from over heating and generates an interrupt event.

If the step up pre-regulator operates in current limitation (based on $V_{RSH-RSL}$) switching cycle by switching cycle for longer than the short to ground detection time $t_{StG,boost}$, all regulators are shut down to protect the external boost components and the chip from over heating and the device moves to FAILSAFE.

7.3 Reset function

The reset generator starts to operate as soon as the device moves out of POWERDOWN.

"Soft Reset" versus "Hard Reset"

With a "Soft Reset" the pin ROT goes below $V_{ROT,low}$, but the pre and post regulator output voltages are not switched off.

With a "Hard Reset" the pin ROT goes below $V_{ROT,low}$ and the post regulator output voltages are switched off. The power sequencing is restarted after a delay of t_{SDT}. A "Hard Reset" applies to the second initialization timeout in a row.

Safe State Control trigger event

The Safe State Control function is connected to the monitoring block. If a Safe State Control trigger event is detected, pins Safe State Control outputs (SS1 and SS2) and ROT are pulled to ground. The Safe State Control trigger event is stored in an SPI register (respective bits in SYSFAIL, INITERR, MONSF1, MONSF2, MONSF3 or OTFAIL). For trigger conditions of safe state signal SS1 please refer to chapter Safe State Control function.

Reset output pin

The reset output pin ROT is an open drain structure. As soon as a reset condition occurs, the ROT pin is pulled below $V_{ROT,low}$. An small internal pull up current pulls the output towards V_{QUC}. An external pull up resistor according to the application needs is recommended.

ROT pull-down will be released only in the move to POWERDOWN cases due to $V_S \leq V_{PD,lo}$. If $V_S \leq V_{PD,lo}$, then ROT will be raised up to the residual QUC voltage value.

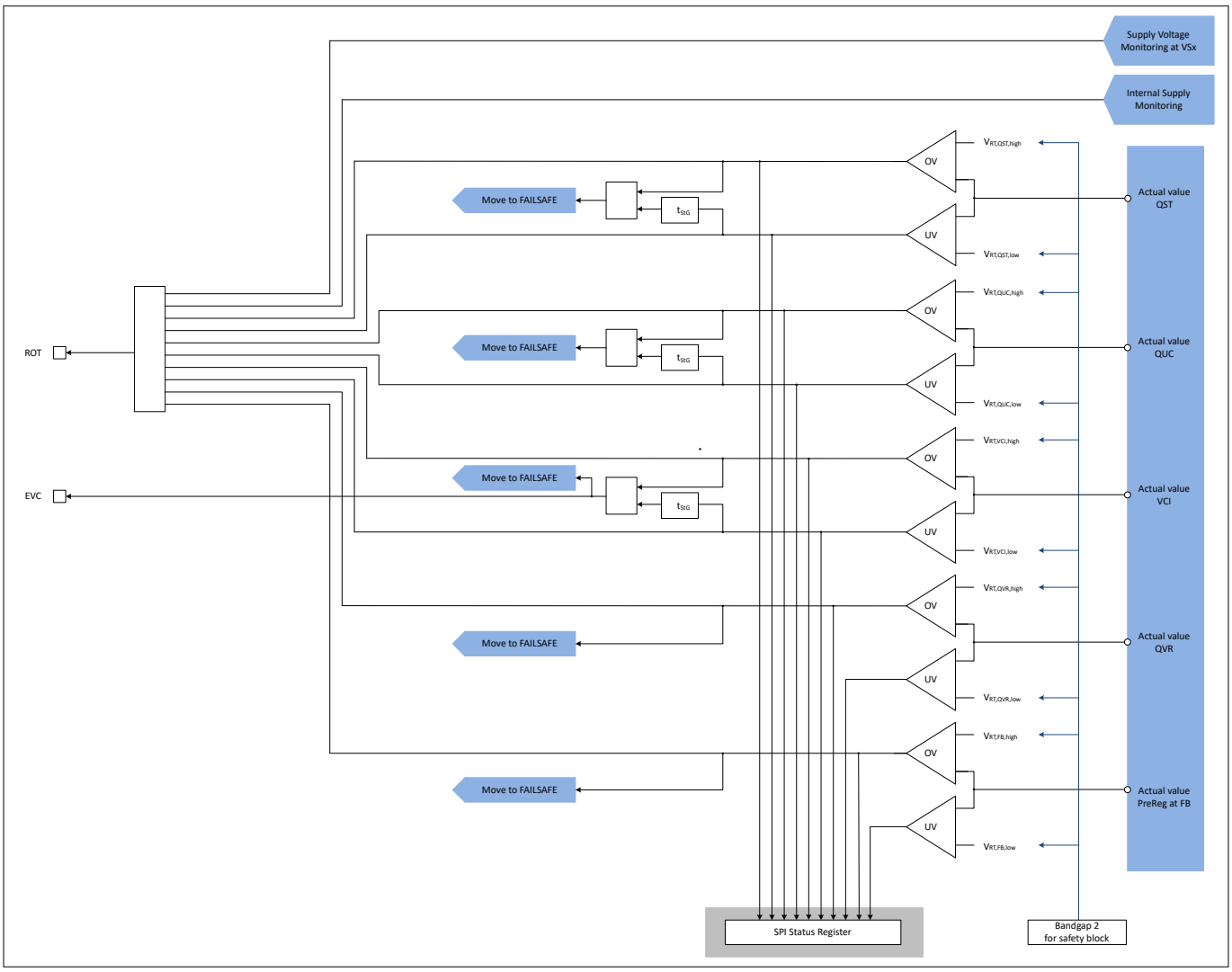


Figure 18 Principle reset function

Detailed description of the reset function (Figure 18):

The following regulators contribute to the reset function:

- Internal supply monitoring (not visible externally)
- The standby supply (QST): V_{QST}
- The microcontroller main supply (QUC): V_{QUC}

- The external post regulator for MCU core supply (VCI): V_{VCI}
- The voltage reference supply (QVR): V_{QVR} → only overvoltage, not undervoltage, not short to ground
- The pre-regulator (FB): V_{FB} → only overvoltage, not undervoltage
- The step up pre-regulator short to ground (overpower) detection

The actual values of these outputs are taken directly at the output pins and are monitored by two comparators for each regulator, one for overvoltage, one for undervoltage (OV, UV). The reference values $V_{RT,xxx,high}$ and $V_{RT,xxx,low}$ are provided by an independent bandgap 2 only related to the monitoring functions.

The internal supply's voltage monitoring and IBIAS monitoring contribute to trigger a reset. If one or both of the internal supply voltages should be out of their specified windows, the reliable function of the device is not ensured any more. The IBIAS monitor fault is stored in a status bit (BIASHI or BIASLOW of register MONSF3). These faults of the internal supplies trigger either a "Move to FAILSAFE" event or a "Move to POWERDOWN" event (please refer to chapter State machine for details).

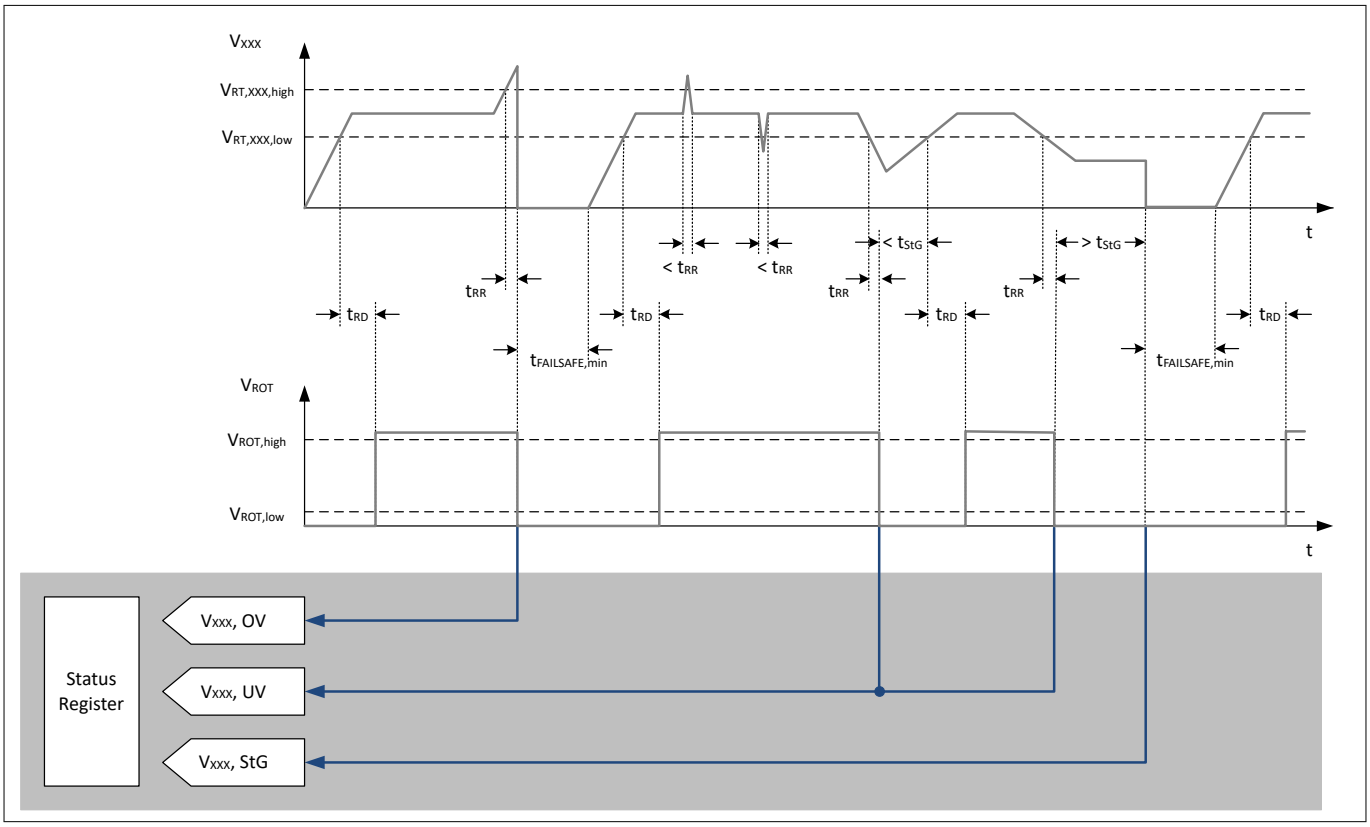


Figure 19 Timing diagram hardware reset signal ROT for output voltages

Description:

- V_{xxx} = Output voltage monitored by reset generator: V_{QUC}, V_{VCI}, V_{QST}, V_{QVR} or V_{FB}
- $V_{RT,xxx,high}$= Overvoltage monitoring threshold: $V_{RT,QUC,high}$, $V_{RT,VCI,high}$, $V_{RT,QST,high}$, $V_{RT,QVR,high}$ or $V_{RT,FB,high}$
- $V_{RT,xxx,low}$= Undervoltage monitoring threshold: $V_{RT,VCI,low}$, $V_{RT,QUC,low}$ or $V_{RT,QST,low}$
- t_{RD} = Reset delay time, adjustable by SPI command
- t_{RR} = Monitoring reaction time, time between detecting overvoltage and pulling ROT to low
- < t_{RR} = Not detectable, because shorter than monitoring reaction time
- > t_{StG} = Short to ground detection time, after which an undervoltage is considered a short to ground
- $t_{FAILSAFE,min}$ = System shutdown time (FAILSAFE), time between pulling ROT to low and restart of the device, for details please refer to chapter State machine
- V_{ROT} = Hardware reset signal, ROT
- $V_{ROT,high}$ = Hardware reset signal, high level

- $V_{ROT,low}$ = Hardware reset signal, low level
- $V_{xxx,OV}$ = Overvoltage detected for V_{xxx} and stored in SPI register MONSF1
- $V_{xxx,UV}$ = Undervoltage detected for V_{xxx} and stored in SPI register MONSF2
- $V_{xxx,StG}$ = Short to ground detected for V_{xxx} and stored in SPI register MONSF0
- Applies as well to bias current violations, supply overvoltage (MONSF3), temperature shutdown (OTFAIL) contributing to the reset function. Please refer to Figure 42 and Figure 49

7.4 Interrupt function

The interrupt generator starts to operate as soon as the internal POR is released, still the interrupt signal (pin INT) is only indicated when reset is released (pin ROT high).

The voltage monitoring function supervises the values of the non MCU related post regulator output voltages V_{QCO}, V_{QT1} and V_{QT2}, the pre regulator output voltage V_{FB} (undervoltage only) and the voltage reference output V_{QVR} (undervoltage and short to ground only). The result is written in a SPI status register (IF and MONSF0, MONSF1 or MONSF2) and indicated via interrupt (pin INT). The connection of all these monitoring signals is a logical OR.

The interrupt pin INT indicates interrupts due to other events in the device as well.

Interrupt output pin

The interrupt output pin INT is a push-pull structure. An interrupt is indicated by pulling the INT pin to ground.

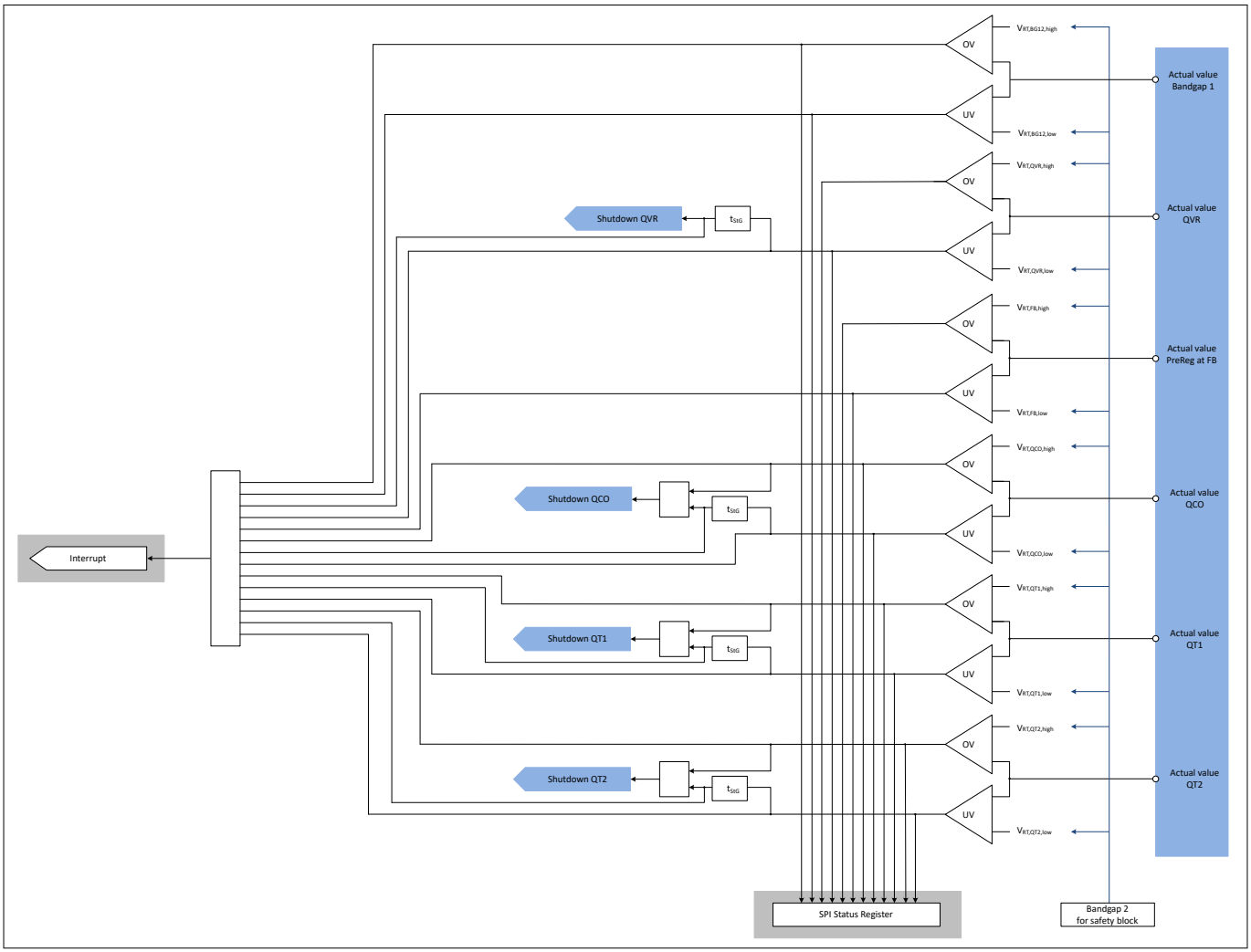


Figure 20 Principle indication of voltage monitoring via interrupt

Detailed description of the voltage monitoring via interrupt function (Figure 20)

The following regulators contribute to the voltage monitoring via interrupt function:

- The pre-regulator (FB): V_{FB} → only undervoltage
- The voltage reference supply (QVR): V_{QVR} → only undervoltage and short to GND
- The communication supply (QCO): V_{QCO}

- The tracker 1 for supplying sensors (QT1): V_{QT1}
- The tracker 2 for supplying sensors (QT2): V_{QT2}

The actual values of these outputs are taken directly at the output pins and monitored by two comparators for each regulator, one for overvoltage, one for undervoltage (OV, UV). The reference values $V_{RT,xxx,high}$ and $V_{RT,xxx,low}$ are provided by an independent bandgap 2 only related to the monitoring functions.

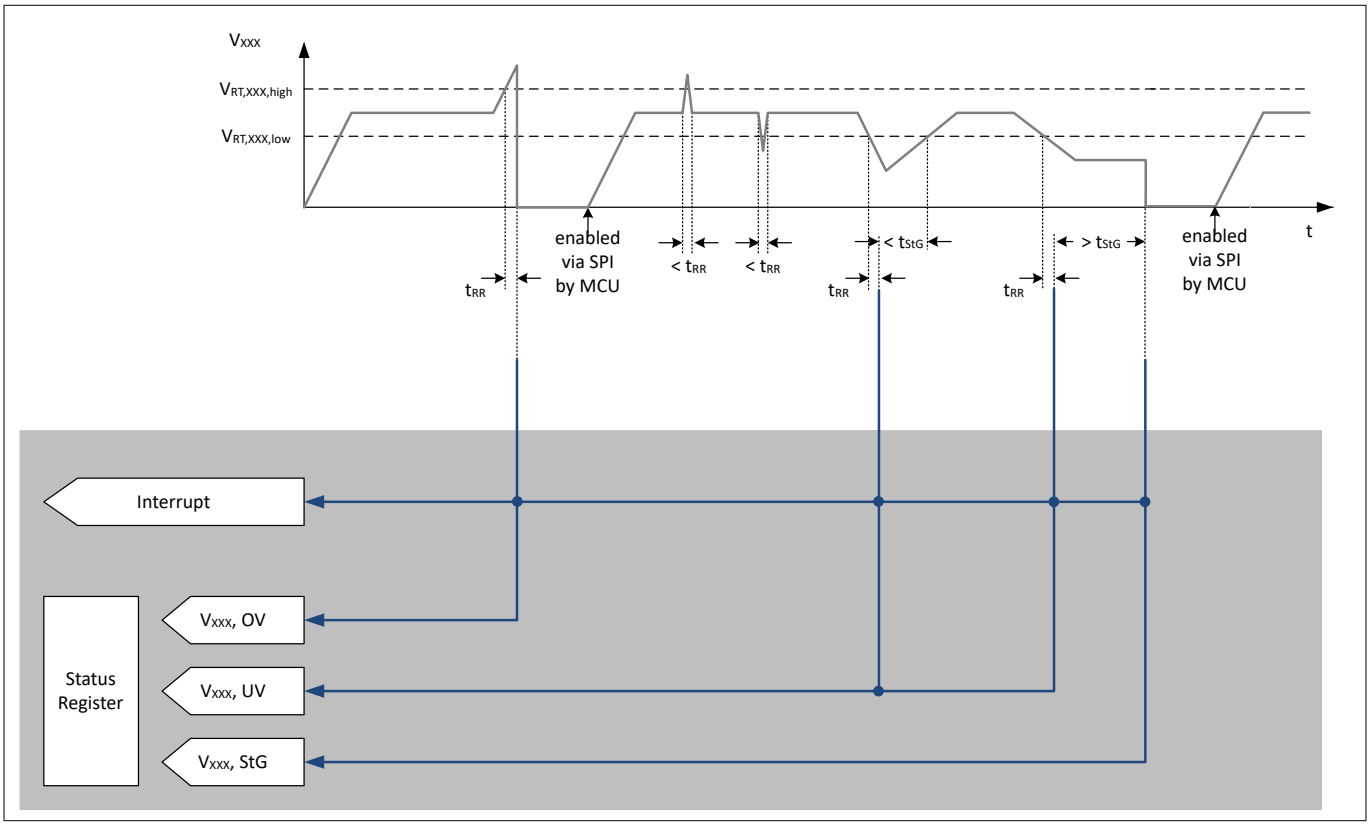


Figure 21 Timing diagram interrupt indication for output voltages

Description:

- V_{xxx} = Output voltage monitored by interrupt indication: V_{FB}, V_{QVR}, V_{QCO}, V_{QT1} or V_{QT2}
- $V_{RT,xxx,high}$= Overvoltage interrupt indication: $V_{RT,QCO,high}$, $V_{RT,QT1,high}$ or $V_{RT,QT2,high}$
- $V_{RT,xxx,low}$= Undervoltage interrupt indication: $V_{RT,FB,low}$, $V_{RT,QVR,low}$, $V_{RT,QCO,low}$, $V_{RT,QT1,low}$ or $V_{RT,QT2,low}$
- t_{RR} = Monitoring reaction time, time between detecting overvoltage and an interrupt is generated
- < t_{RR} = Not detectable, because shorter than monitoring reaction time
- > t_{StG} = Short to ground detection time, after which an undervoltage is considered a short to ground
- $V_{xxx,OV}$ = Overvoltage detected for V_{xxx} and stored in SPI register (MONSF1)
- $V_{xxx,UV}$ = Undervoltage detected for V_{xxx} and stored in SPI register (MONSF2)
- $V_{xxx,StG}$ = Short to ground detected for V_{xxx} and stored in SPI register (MONSF0)
- Applies as well to the detection of variations in the voltage of bandgap 1 to 2 (MONSF3), over-load and temperature events (OTWRNSF, OTFAIL) contributing to the interrupt function. Please refer to Figure 41.

7.5 Electrical characteristics voltage monitoring and reset function

Table 15 Electrical characteristics voltage monitoring and reset function

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Timing							
Reset cycle time	t_{CYCLE}	9.4	10	10.65	µs	–	P_8.5.1
Reset delay time, default value	t_{RD}	–	1000	–	t_{CYCLE}	–	P_8.5.2
Reset delay time, adjustable range by SPI command	t_{RD}	20	–	1500	t_{CYCLE}	1) Configurable in DEVCFG1.RESDEL	P_8.5.3
Monitoring reaction time	t_{RR}	8	–	20	µs	–	P_8.5.4
Monitoring reaction time, standby regulator	$t_{RR, STBY}$	8	–	40	µs	–	P_8.5.5
Short to ground detection time	t_{StG}	2.7	3	3.3	ms	–	P_8.5.6
Step down regulator short to ground detection time	$t_{StG,HF}$	2.7	3	3.3	ms	step down pre-regulator high switching frequency range (pin FRE open)	P_8.5.7
Step down regulator short to ground detection time	$t_{StG,LF}$	5.4	6	6.6	ms	step down pre-regulator low switching frequency range (pin FRE to GND)	P_8.5.8
Step down regulator short to ground activation threshold at pin VS	$V_{start,StG,buck}$	5.5	5.6	5.7	V	V_{VS} increasing	P_8.5.67
VCI short to ground detection time	$t_{StG,VCI}$	5.4	6	6.6	ms	–	P_8.5.9
Boost short to ground detection time	$t_{StG,boost}$	5.4	6	6.6	ms	–	P_8.5.10
System shutdown time	t_{SDT}	9	–	20	ms	–	P_8.5.11
Monitoring thresholds standby regulator, pin QST							
Overvoltage monitoring threshold	$V_{RT,QST,high}$	3.46	3.53	3.6	V	V_{QST} increasing	P_8.5.16
Overvoltage monitoring hysteresis	$V_{RT,QST,OV\ hyst}$	20	–	55	mV	–	P_8.5.17

(table continues...)

Table 15 (continued) Electrical characteristics voltage monitoring and reset function

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Undervoltage monitoring threshold	$V_{RT,QST,low}$	2.97	3.04	3.1	V	V_{QST} decreasing	P_8.5.18
Undervoltage monitoring hysteresis	$V_{RT,QST,UV\ hyst}$	15	–	50	mV	–	P_8.5.19
Monitoring thresholds microcontroller supply, pin QUC							
Overvoltage monitoring threshold	$V_{RT,QUC,high}$	3.46	3.53	3.6	V	V_{QUC} increasing	P_8.5.24
Overvoltage monitoring hysteresis	$V_{RT,QUC,OV\ hyst}$	20	–	55	mV	–	P_8.5.25
Undervoltage monitoring threshold	$V_{RT,QUC,low}$	2.97	3.04	3.1	V	V_{QUC} decreasing	P_8.5.26
Undervoltage monitoring hysteresis	$V_{RT,QUC,UV\ hyst}$	15	–	50	mV	–	P_8.5.27
Monitoring thresholds external core supply, pin VCI							
Overvoltage monitoring threshold	$V_{RT,VCI,high}$	848	864	880	mV	V_{VCI} increasing	P_8.5.28
Overvoltage monitoring hysteresis	$V_{RT,VCI,OV\ hyst}$	5	–	15	mV	2)	P_8.5.29
Undervoltage monitoring threshold	$V_{RT,VCI,low}$	720	736	752	mV	V_{VCI} decreasing	P_8.5.30
Undervoltage monitoring hysteresis	$V_{RT,VCI,UV\ hyst}$	5	–	15	mV	2)	P_8.5.31
Monitoring thresholds pre-regulator, pins FBx							
Overvoltage monitoring threshold	$V_{RT,FB,high}$	6.46	6.58	6.7	V	V_{FB} increasing	P_8.5.32
Overvoltage monitoring hysteresis	$V_{RT,FB,OV\ hyst}$	40	–	120	mV	–	P_8.5.33
Undervoltage monitoring threshold	$V_{RT,FB,low}$	5.0	5.1	5.2	V	V_{FB} decreasing	P_8.5.34
Undervoltage monitoring hysteresis	$V_{RT,FB,UV\ hyst}$	30	–	90	mV	–	P_8.5.35
Monitoring thresholds communication supply, pin QCO							
Overvoltage monitoring threshold	$V_{RT,QCO,high}$	5.15	5.25	5.35	V	V_{QCO} increasing	P_8.5.36

(table continues...)

Table 15 (continued) Electrical characteristics voltage monitoring and reset function

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Overvoltage monitoring hysteresis	$V_{RT,QCO,OV\ hyst}$	20	–	60	mV	–	P_8.5.37
Undervoltage monitoring threshold	$V_{RT,QCO,low}$	4.65	4.75	4.85	V	V_{QCO} decreasing	P_8.5.38
Undervoltage monitoring hysteresis	$V_{RT,QCO,UV\ hyst}$	20	–	60	mV	–	P_8.5.39
Monitoring thresholds voltage reference supply, pin QVR							
Overvoltage monitoring threshold	$V_{RT,QVR,high}$	5.10	5.20	5.30	V	V_{QVR} increasing	P_8.5.40
Overvoltage monitoring hysteresis	$V_{RT,QVR,OV\ hyst}$	20	–	60	mV	–	P_8.5.41
Undervoltage monitoring threshold	$V_{RT,QVR,low}$	4.70	4.80	4.90	V	V_{QVR} decreasing	P_8.5.42
Undervoltage monitoring hysteresis	$V_{RT,QVR,UV\ hyst}$	20	–	60	mV	–	P_8.5.43
Monitoring thresholds tracker 1, pin QT1							
Overvoltage monitoring threshold	$V_{RT,QT1,high}$	5.30	5.40	5.50	V	V_{QT1} increasing	P_8.5.44
Overvoltage monitoring hysteresis	$V_{RT,QT1,OV\ hyst}$	20	–	60	mV	–	P_8.5.45
Undervoltage monitoring threshold	$V_{RT,QT1,low}$	4.50	4.60	4.70	V	V_{QT1} decreasing	P_8.5.46
Undervoltage monitoring hysteresis	$V_{RT,QT1,UV\ hyst}$	20	–	60	mV	–	P_8.5.47
Monitoring thresholds tracker 2, pin QT2							
Overvoltage monitoring threshold	$V_{RT,QT2,high}$	5.30	5.40	5.50	V	V_{QT2} increasing	P_8.5.48
Overvoltage monitoring hysteresis	$V_{RT,QT2,OV\ hyst}$	20	–	60	mV	–	P_8.5.49
Undervoltage monitoring threshold	$V_{RT,QT2,low}$	4.50	4.60	4.70	V	V_{QT2} decreasing	P_8.5.50
Undervoltage monitoring hysteresis	$V_{RT,QT2,UV\ hyst}$	20	–	60	mV	–	P_8.5.51

(table continues...)

Table 15 (continued) Electrical characteristics voltage monitoring and reset function

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Input voltage VSx monitoring, pin VSx							
Input overvoltage monitoring threshold	$V_{VS,OV}$	40.5	42	43.5	V	–	P_8.5.52
Overtemperature protection of monitoring							
Overtemperature shutdown threshold	$T_{j,OT,\ shutdown}$	176	190	200	°C	T_j increasing 2)	P_8.5.53
Overtemperature shutdown hysteresis	$T_{j,OT,\ hyst}$	–	10	–	°C	2)	P_8.5.54
Reset output ROT							
Reset output, pull-up current	$I_{ROT,\ pu}$	-175	-110	-12	µA	$V_{ROT} \le 2.0$ V	P_8.5.55
Reset output, low level	$V_{ROT,\ low}$	–	–	0.7	V	1 V ≤ V_{QUC} ≤ 3.37 V; 3) I_{ROT} = 5.5 mA	P_8.5.58
Reset output, low level	$V_{ROT,\ low}$	–	–	0.4	V	1 V ≤ V_{QUC} ≤ 3.37 V; 3) I_{ROT} = 3 mA	P_8.5.59
Reset output fall time	$t_{ROT,\ fall}$	–	–	25	ns	2) $C_{ROT,load}$ = 50 pF	P_8.5.60
Interrupt output INT							
Interrupt output, high level	$V_{INT,\ high}$	2.3	–	–	V	V_{QUC} = 3.3 V; I_{INT} = -7 mA	P_8.5.63
Interrupt output, low level	$V_{INT,\ low}$	–	–	0.7	V	V_{QUC} = 3.3 V; I_{INT} = 5.5 mA	P_8.5.64
Interrupt output rise time	$t_{INT,\ rise}$	–	–	25	ns	2) $C_{INT,load}$ = 50 pF	P_8.5.65
Interrupt output fall time	$t_{INT,\ fall}$	–	–	25	ns	2) $C_{INT,load}$ = 50 pF	P_8.5.66

1) Due to internal delays the reset delay time can be enlarged by max 50 µs. Please consider the transition time into INIT-state $t_{tr,INIT}$ specified in Table 25 prior to the power sequencing started by entering INIT-state.
2) Specified by design, not subject to production test.
3) Pin ROT output low level is not forced on entering POWERDOWN state.

8 Standby supply and internal supplies

8.1 Standby supply QST

8.1.1 Functional description standby supply

The standby supply QST is independent from the pre-regulator stage and the other post regulators. It can be switched ON or OFF in all states (for details please refer to chapter State machine). The linear low drop regulator QST offers a precise 3.3 V output voltage for standby supply.

The QST keeps its configuration by leaving the STANDBY-state according to its previous configuration. For STANDBY-state, the status of QST (ON or OFF) has to be defined in previous states.

The regulator is supplied from pin VST and the pin VST is to be connected to the pin VS1. The output voltage V_{QST} (at pin QST) is controlled by the error amplifier. The stability of the control loop depends on the load current, the characteristics of the output capacitor and the chip temperature. To ensure stable operation, the output capacitance needs to meet the specified requirements (capacitance value and electrical series resistance ESR) in Table 16.

The regulator features an active pull-down at the output that discharges the output upon disablement of the regulator.

The QST regulator supports two operating modes based on the configuration RSYSPCFG0.DISOFFSET.

- Standalone regulation: the actual value of V_{QST} is regulated based on a reference voltage derived from bandgap 1 for regulators (DISOFFSET is set to 1_B). This configuration represents an usual dedicated regulator topology and is applicable for most applications. Please make sure to configure this option during the initial protected configuration as it is not the default after start-up.
- QUC dependent offset regulation: the actual value of V_{QST} is regulated to the voltage at pin QUC with an offset $\Delta V_{QST,QUC}$ (DISOFFSET is set to 0_B). Please mind that this configuration is the default setting after POWERDOWN state, as it represents a functional boundary condition for an optimized power topology using an external bypass switch between QUC and QST during operation when high loads to the standby voltage domain are expected. If no external bypass is equipped in the application, then this offset regulation is recommended to be disabled during initial protected configuration.

Protection circuitry is implemented to prevent the regulator and the application from damage:

- To protect the pass element from overstress, the current limitation limits the output current. Current sensing is done via a current mirror, no sense resistor is used. In case the maximum current should occur, it is limited, so the output voltage decreases. The regulator is protected against short circuit to ground. [1)].
- The output voltage is monitored by the voltage monitoring.

  In case of overvoltage at pin QST, the QST is switched off and the device moves into FAILSAFE-state. The event is stored in an SPI status register (MONSF1).

  In case of undervoltage at pin QST, the device moves into INIT-state, pin ROT is pulled low and the event is stored in an SPI status register (MONSF2). The regulator is not switched off in case of output undervoltage, which is shorter than the short to ground detection time t_{StG}. If the undervoltage should be present for more than t_{StG}, the device moves into FAILSAFE-state. This event is stored in an SPI status register as well (MONSF0).
- There is no dedicated temperature sensor for this regulator. The temperature is sensed on the chip by other temperature sensors located at QUC and step down pre-regulator. If the chip temperature exceeds the pre-warning threshold, an interrupt indicates this event and it is stored in a SPI status register (OTWRNSF).

1 In the particular case of an enabled offset regulation of QST (DISOFFSET is set to 0_B) and an applied fast short circuit to GND or fast significant overload, the failure condition may lead to a coupling influence to the regulators reference bandgap in a transient way. This may lead to a temporary influence to the other regulators output voltage (e.g. V_{QCO} at pin QCO or V_{QUC} at pin QUC if not bypassed to QST by external switch).

If the chip temperature exceeds the temperature shutdown threshold, the regulator is switched off. The temperature switch off time is at least one second.

The regulator QST may be configured to be ON or OFF in every state, except FAILSAFE. The selection for STANDBY-state needs to be done by SPI command before entering this state.

For further details please refer to Chapter 10 State machine.

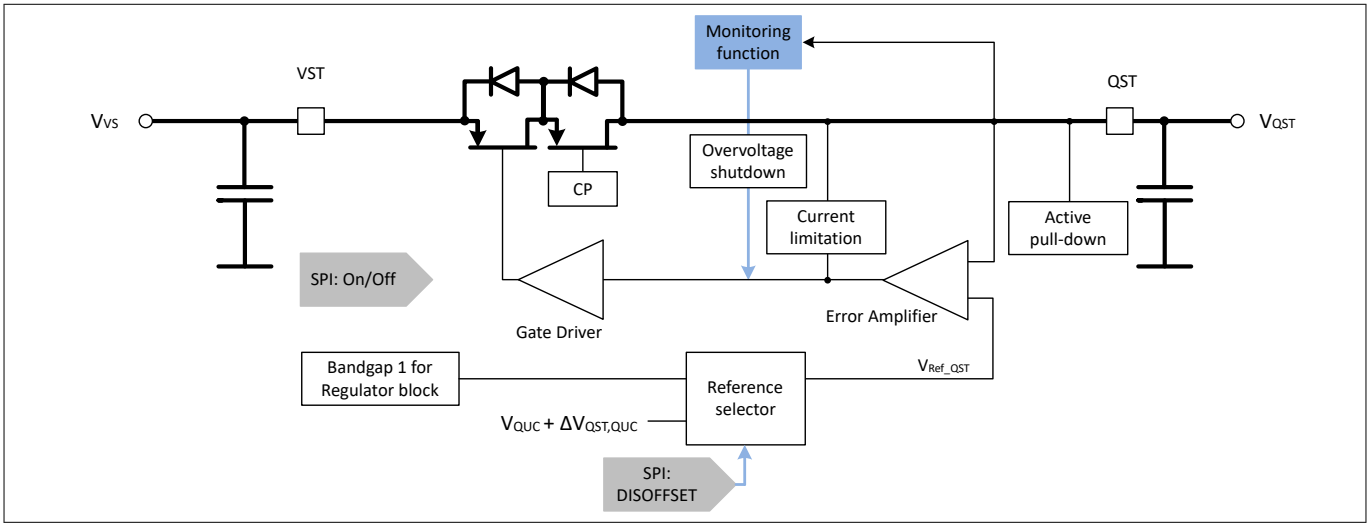


Figure 22 Low drop linear regulator for standby supply QST

8.1.2 Electrical characteristics standby supply

Table 16 Electrical characteristics standby supply

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

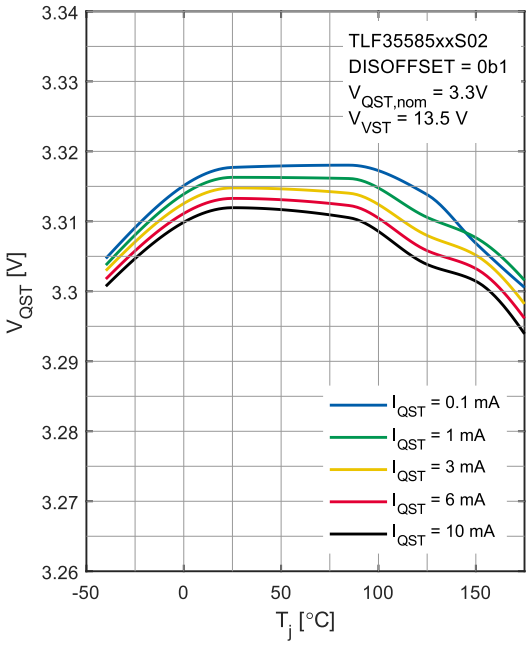
Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Standby supply QST							
Output voltage	V_{QST}	3.23	3.30	3.37	V	when QUC is off or when DISOFFSET is set to 1_B; 0 mA ≤ I_{QST} ≤ 10 mA	P_9.1.3
Output voltage offset QST to QUC	$\Delta V_{QST,QUC}$	-180	-135	-90	mV	when QST and QUC are active with DISOFFSET set to 0_B; 0 mA ≤ I_{QST} ≤ 10 mA	P_9.1.4
Output voltage QST headroom to undervoltage monitoring threshold	V_{QST} - $V_{RT,QST,low}$	60	–	–	mV	when QST and QUC are active with DISOFFSET set to 0_B; 0 mA ≤ I_{QST} ≤ 10 mA	P_9.1.15
Output current limitation	$I_{QST,max}$	25	–	40	mA	–	P_9.1.5
Drop voltage	$V_{dr,QST}$	–	–	400	mV	1) Limited to $V_{PD,lo}$ at pin VST	P_9.1.6
Load regulation	$\Delta V_{QST,load}$	–	25	40	mV	I_{QST} = 100 µA to 10 mA	P_9.1.7
Line regulation	$\Delta V_{QST,line}$	–	0.1	0.5	mV/V	10 V ≤ V_{VST} ≤ 40 V	P_9.1.8
Power supply ripple rejection	$PSRR_{QST}$	40	–	–	dB	2) f_{ripple} = 100 kHz $ESR_{C,QST}$ ≤ 100 mΩ	P_9.1.9
Output capacitor	C_{QST}	0.47	–	10	µF	2)	P_9.1.10
Output capacitor, ESR	$ESR_{C,QST}$	0	–	200	mΩ	2) 3)	P_9.1.11
Softstart time	$t_{SS,QST}$	130	200	700	µs	2) C_{QST} ≤ 3 µF; I_{QST} ≤ 8 mA; V_{QST} rising from 10 % to 90 % of $V_{QST,nominal}$	P_9.1.12
Active discharge pull-down current when disabled	$I_{QST,pd}$	8	30	65	mA	2) 1.8 V ≤ V_{QST} ≤ 6 V	P_9.1.13

1) Dropout voltage is defined as the difference between input and output voltage when the output voltage decreases 100 mV from output voltage measured at V_{VST} = V_{QST}[Max] + $V_{dr,QST}$[Max] + 100 mV.
2) Specified by design, not subject to production test.

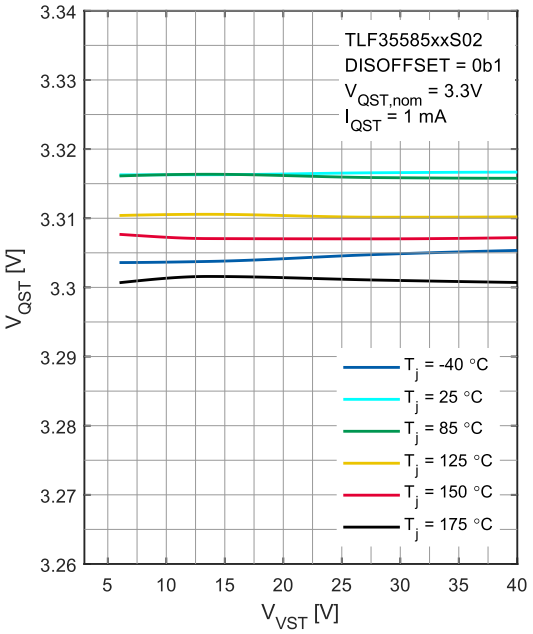
3) Relevant ESR at capacitor's self-resonant frequency.

8.1.3 Typical performance characteristics standby supply

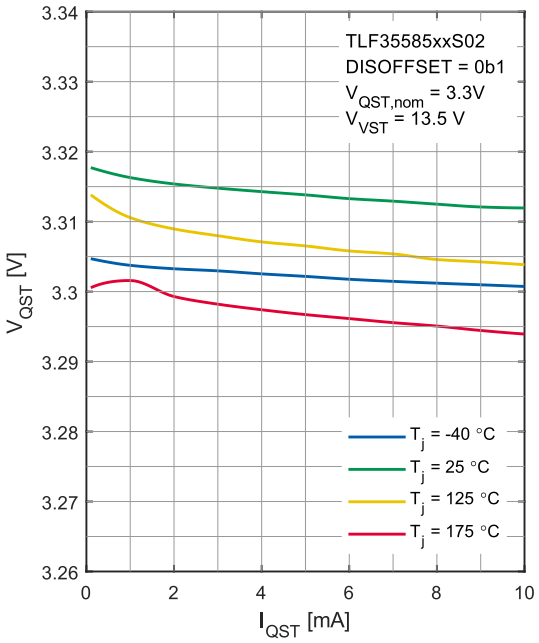
QST output voltage V_{QST} versus junction temperature T_j (DISOFFSET = 1_B)



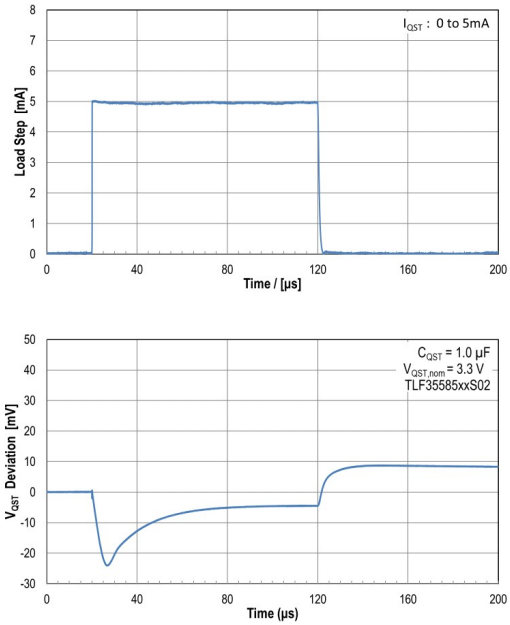
QST output voltage V_{QST} versus supply voltage V_{VS} (DISOFFSET = 1_B)



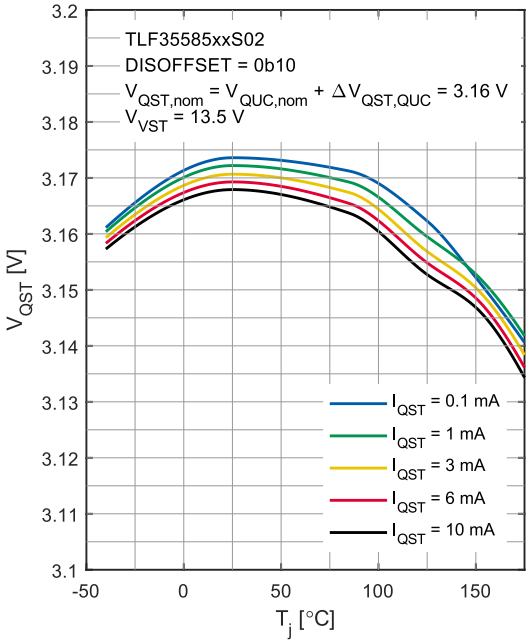
QST output voltage V_{QST} versus load current I_{QST} (DISOFFSET = 1_B)



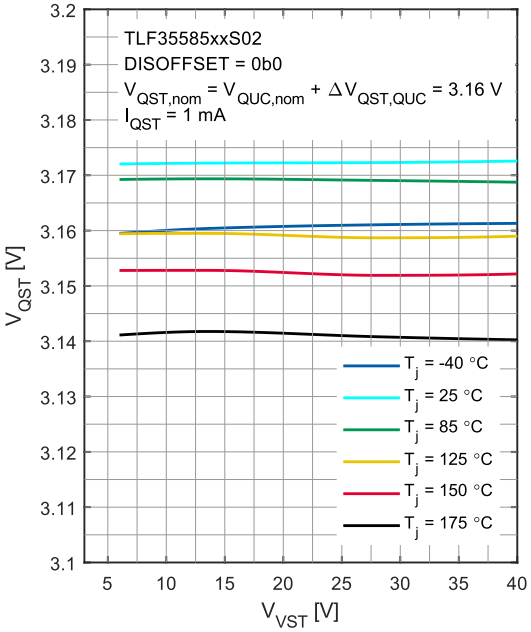
QST dynamic load response (0 mA to 5 mA; DISOFFSET = 1_B)



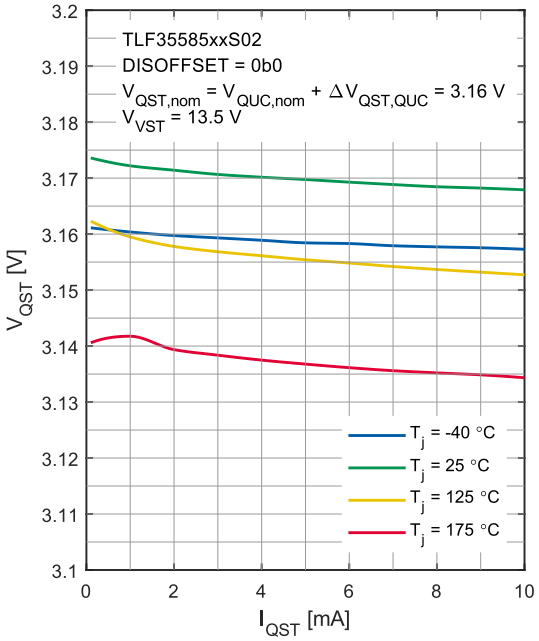
QST output voltage V_{QST} versus junction temperature T_j (DISOFFSET = 0_B)



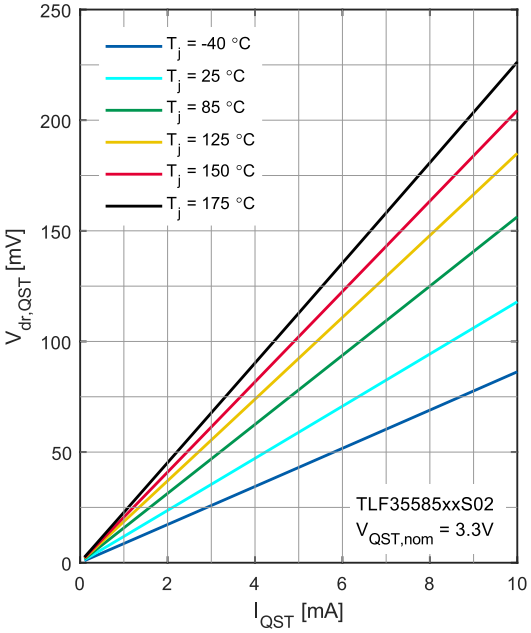
QST output voltage V_{QST} versus supply voltage V_{VS} (DISOFFSET = 0_B)



QST output voltage V_{QST} versus load current I_{QST} (DISOFFSET = 0_B)



QST dropout voltage $V_{dr,QST}$ versus load current I_{QST}



8.2 Internal supplies

The device includes internal voltage supplies and bias currents to operate all regulators, monitoring and logic functions. These internal supplies are monitored internally to ensure proper functionality of the functional blocks the device provides. The device reacts on internal failure conditions as described in the State machine, Monitoring function, Interrupt generation and Safe State Control function. The internal regulators do not require external components (i.e. capacitors). The internal voltages are not visible at any pin.

9 Wake-up timer

9.1 Description of wake-up timer

The wake-up timer is a function to wake up the device.

The wake-up timer value may be set by SPI in INIT, NORMAL and WAKE-state. The value is stored in the 24 bit wide wake-up timer register (WKTIMCFG0, WKTIMCFG1, WKTIMCFG2).The wake-up timer is implemented as a 24 bit counter which is clocked by a 100 kHz or 100 Hz clock (time-base). The time-base may be selected via SPI (WKTIMCYC). For the chosen time-base of 100 kHz the timer resolution is 10 µs and a wake-up time from 10 µs to 168 s can be configured via SPI.[2)] For the chosen time-base of 100 Hz the timer resolution is 10 ms and a wake-up time from 10 ms to 1.9 days can be configured via SPI. An additional pre-scaler of 100 can be activated via SPI (WKTIMPRESC) to further increase the time-base allowing to increase the wake-up time up to 190 days.

When entering STANDBY or SLEEP state, the counter is loaded with the value of the wake-up timer register and starts decrementing. At underflow, the timer wakes-up the device from either SLEEP or STANDBY-state and reports the event via WKSF.WKTIM. When leaving SLEEP-state, the wake-up timer register (WKTIMCFG0, WKTIMCFG1, WKTIMCFG2) is reset to '0' in case of WKSF.WKTIM='1'.

In case of a wake-up trigger event independent from the wake-up timer, the wake-up timer is stopped and the remaining timer value can be read-back via SPI from the wake-up timer register (WKTIMCFG0, WKTIMCFG1, WKTIMCFG2) in order to evaluate the theoretical time left until expiry and based on that the corresponding time elapsed. This read-back function is only applicable with the wake-up timer enabled by WKTIMEN.

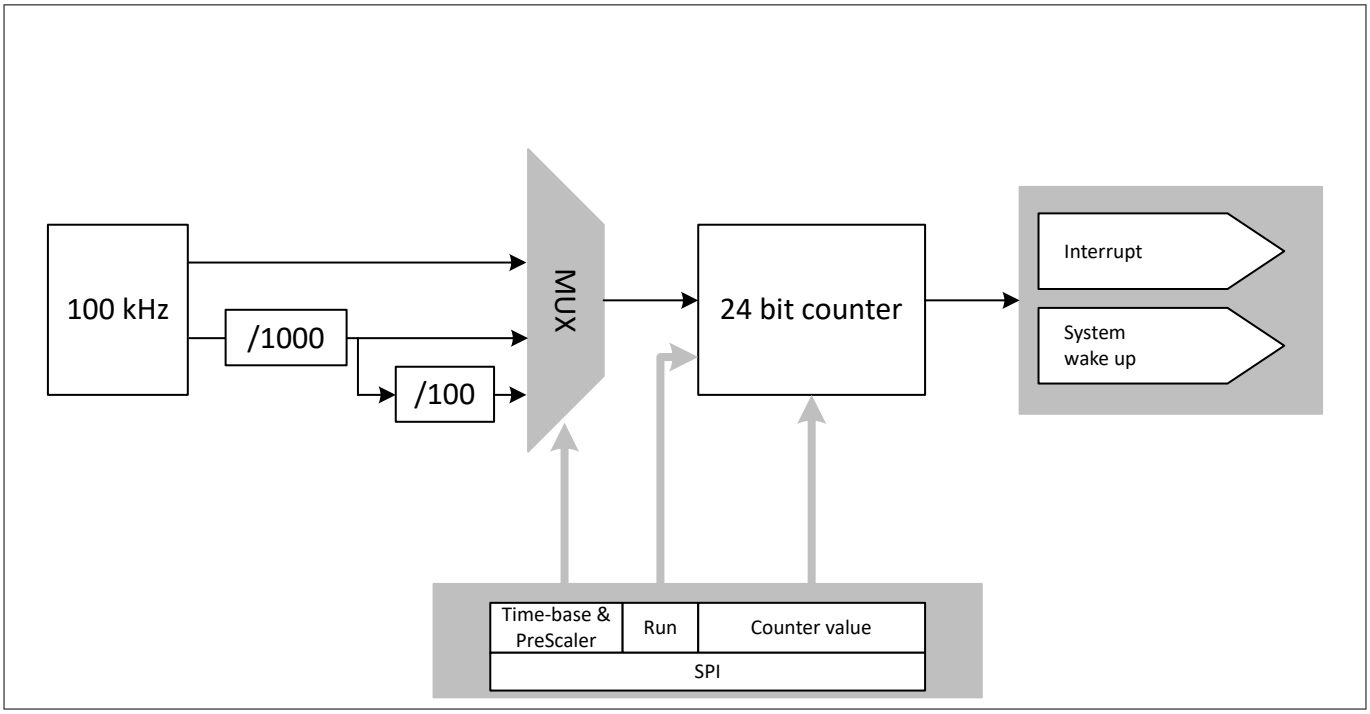


Figure 23 Wake-up timer principle

2 An additional activation delay time for the start of the wake-up timer of max. 50 µs has to be considered after entering SLEEP or STANDBY-state.

9.2 Electrical characteristics wake-up timer

Table 17 Electrical characteristics wake-up timer

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Wake-up timer							
Time base, resolution	$t_{WakeUpTimer}$	9.4	10	10.65	µs	1) WKTIMCYC = 0_B and WKTIM PRESC = 0_B	P_10.2.1
Time base, resolution	$t_{WakeUpTimer}$	9.4	10	10.65	ms	WKTIMCYC = 1_B and WKTIM PRESC = 0_B	P_10.2.2
Time base, resolution	$t_{WakeUpTimer}$	0.94	1	1.065	s	WKTIMCYC = 1_B and WKTIM PRESC = 1_B	P_10.2.3

1) An additional activation delay time for the start of the wake-up timer of max. 50 µs has to be considered after entering SLEEP or STANDBY-state.

10 State machine

10.1 Introduction state machine

The state machine describes the different states of operation, the device may get into. The following figure shows the state machine flow diagram, for detailed information please refer to following pages.

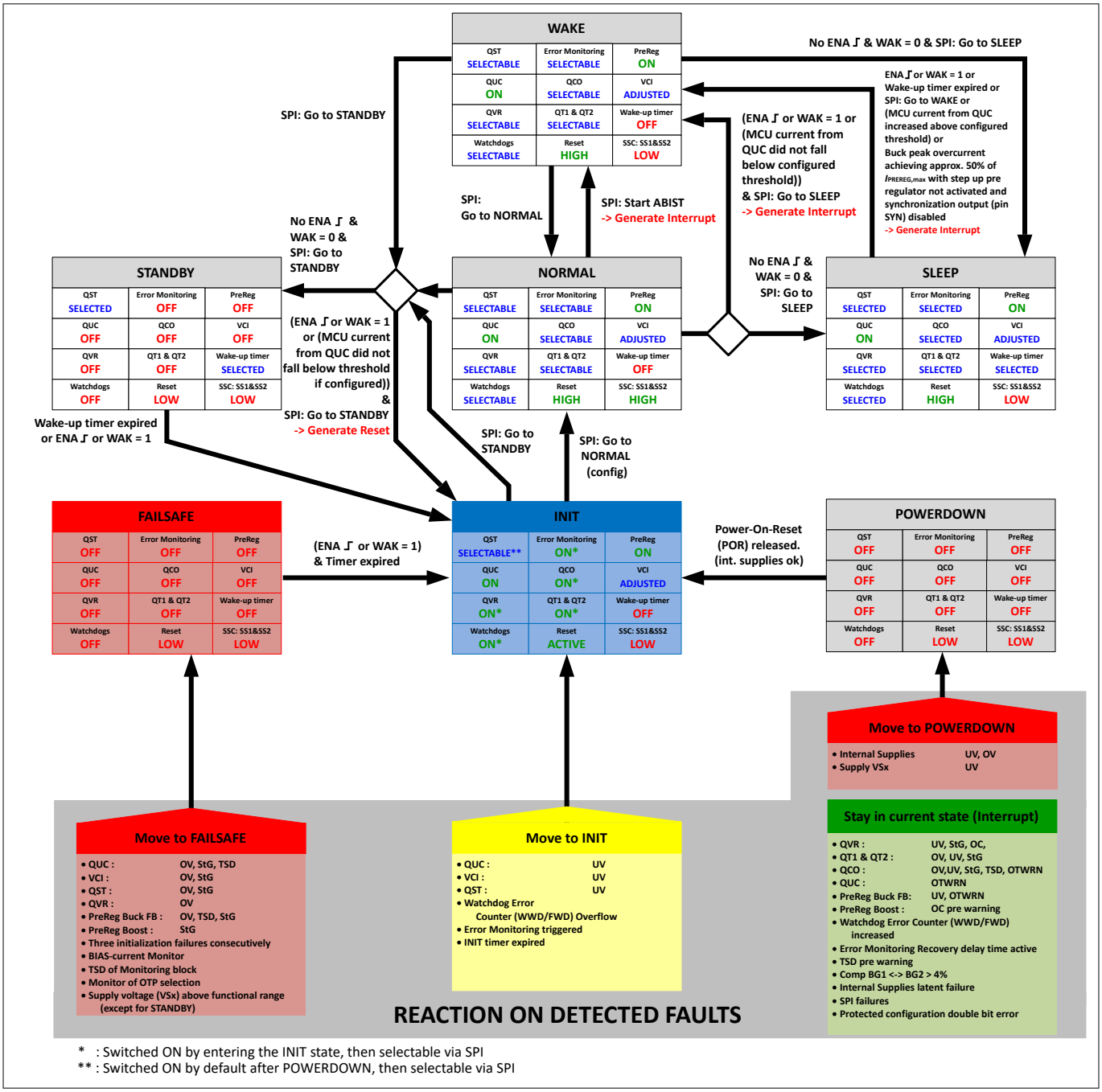


Figure 24 Flow diagram state machine

Description

- ON /OFF:= Switched ON or OFF, not configurable by SPI command
- ON*:= Switched ON by movement into INIT-state, then selectable via SPI

- SELECTED:= May be configured (switched ON or OFF) by SPI command in previous state or is selected by the state transition request (DEVCTRL) in case of supply configuration for SLEEP-state.
- SELECTABLE:= May be switched ON or OFF by SPI command in this state
- SELECTABLE**:= Switched ON by default after POWERDOWN, then selectable via SPI
- ADJUSTED:= Defined present or not present by configuration pin, not configurable by SPI command
- ACTIVE:= as described in INIT-state
- SSC, SS1 and SS2:= Safe State Control output signals 1 and 2
- LOW:= Signal is low
- HIGH:= Signal is high
- OV:= Overvoltage
- UV:= Undervoltage
- StG:= Short to ground
- TSD:= Thermal shut down
- OC:= Overcurrent
- ABIST:= Analog built in self test
- Comparator of BG1 versus BG2 > 4%: The difference between bandgap 1 and bandgap 2 is more than 4%

10.2 Description of states

10.2.1 POWERDOWN-state

The device is in POWERDOWN-state as long the Power-on-Reset (POR) is not released.

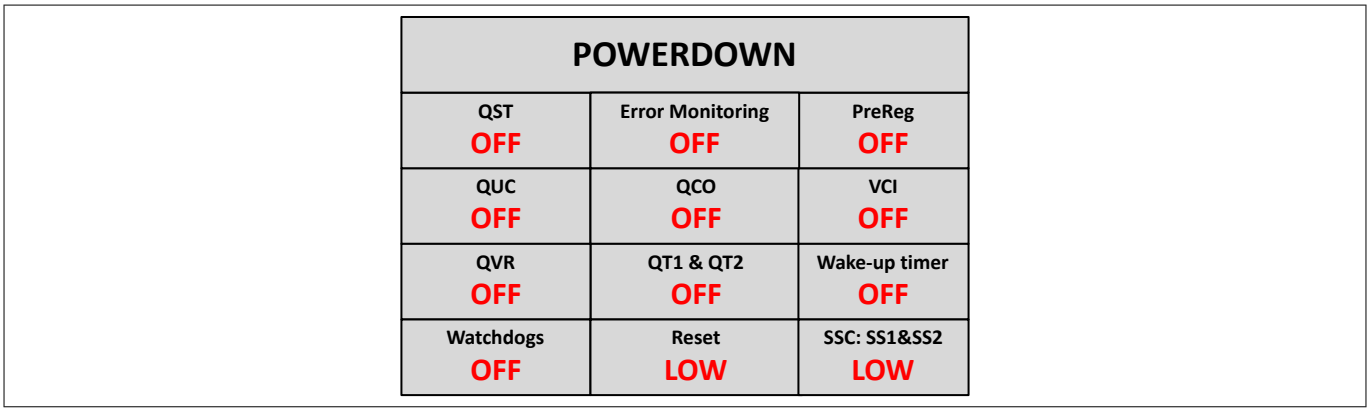


Figure 25 POWERDOWN-state

Table 18 POWERDOWN-state settings

Part/Function	Value	Description
QST	OFF	• The standby supply QST is off
PreReg	OFF	• The pre regulators are off
QUC	OFF	• The microcontroller main supply QUC is off
QCO	OFF	• The communication supply QCO is off
VCI	OFF	• The function external output voltage monitoring VCI is off
QVR	OFF	• The voltage reference supply QVR is off
QT1 and QT2	OFF	• Both trackers QT1 and QT2 are off
Wake-up timer	OFF	• The wake-up timer is off
Watchdogs	OFF	• The watchdogs are off
Error monitoring	OFF	• The Error monitoring is off
Reset	LOW	• The reset output is low
SSC: SS1 and SS2	LOW	• Both safe state signals are "low" and the application is in safe state

10.2.2 INIT-state

During INIT-state the device expects valid communication with the MCU within the INIT timer. Otherwise an initialization timeout occurs. The initialization timer starts with the rising edge of ROT.

The initialization timer is stopped as soon as three boundary conditions are fulfilled:

- Valid SPI communication received from MCU
- Watchdog(s) serviced once according to default configuration or according to reconfiguration
- ERR monitoring serviced properly (minimum 3 valid periods with appropriate timing according to $f_{ERR,valid}$ provided) or configured to be OFF

Alternatively the initialization is stopped by activation of microcontroller programming support (MPS). For details please refer to Chapter 10.7

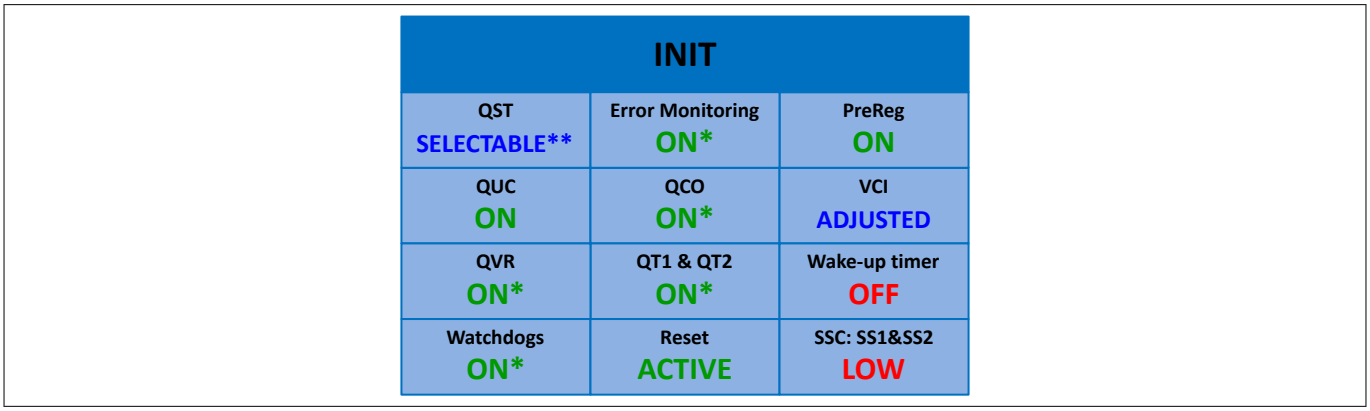


Figure 26 INIT-state

Table 19 INIT-state settings

Part/Function	Value	Description
QST	SELECTABLE**	• The standby supply QST is switched on when entering from POWERDOWN-state • It can be switched on or off by SPI command. This configuration is kept through all states, except POWERDOWN-state
PreReg	ON	• The step down pre-regulator is on • Step up pre-regulator is active depending on the input voltage and this option is selected by pin STU.
QUC	ON	• The microcontroller main supply QUC is on
QCO	ON*	• The communication supply QCO is switched on per default • The QCO can be switched off and on by SPI
VCI	ADJUSTED	• The external output voltage monitoring VCI is switched ON or OFF depending on pin SEC (SEC pin considered only during power-sequencing)
QVR	ON*	• The voltage reference supply QVR is switched on per default • The QVR can be switched off and on by SPI
QT1 and QT2	ON*	• Both trackers QT1 and QT2 are switched on per default • Both trackers QT1 and QT2 can be switched off and on by SPI independently

(table continues...)

Table 19 (continued) INIT-state settings

Part/Function	Value	Description
Wake-up timer	OFF	• The wake-up timer is off
Watchdogs	ON*	• The window watchdog is switched on per default in SPI triggered mode • The functional watchdog is switched off per default • The watchdogs can be configured and switched ON or OFF by SPI
Error monitoring	ON	• The Error monitoring is switched on per default • The Error monitoring can be configured and switched ON or OFF by SPI
Reset	ACTIVE	• The reset output goes HIGH as soon as all MCU related output voltages V_{QST} , V_{QUC} and V_{VCI} are above their undervoltage monitoring threshold, $V_{RT,xxx,low}$ delayed by the reset delay time t_{RD} .
SSC: SS1 and SS2	LOW	• Both safe state signals are "low" and the application is in safe state.

10.2.3 NORMAL-state

In NORMAL-state the device supplies the MCU and the applications. Safety and monitoring functions (like reset-block and Safe State Control) are active. The MCU can configure several post regulators of the device and the wake-up timer via SPI command for this state.

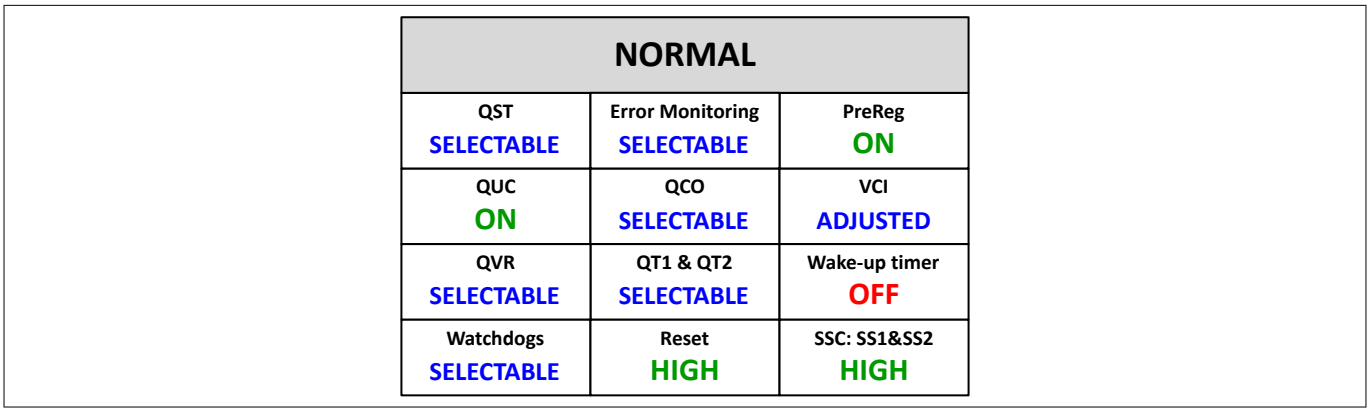


Figure 27 NORMAL-state

Table 20 NORMAL-state settings

Part/Function	Value	Description
QST	SELECTABLE	• The standby supply QST can be switched on or off by SPI command.
PreReg	ON	• The step down pre-regulator is on • Step up pre-regulator is active depending on the input voltage and this option is selected by pin STU.
QUC	ON	• The microcontroller main supply QUC is on
QCO	SELECTABLE	• The communication supply QCO can be switched on or off by SPI command
VCI	ADJUSTED	• The external output voltage monitoring VCI is switched ON or OFF depending on pin SEC (SEC pin considered only during power-sequencing)
QVR	SELECTABLE	• The voltage reference supply QVR can be switched on of off by SPI command
QT1 and QT2	SELECTABLE	• Both trackers QT1 and QT2 can be switched off and on by SPI independently
Wake-up timer	OFF	• The wake-up timer is switched off
Watchdogs	SELECTABLE	• The watchdogs can be configured and switched ON or OFF by SPI
Error monitoring	SELECTABLE	• The Error monitoring can be configured and switched ON or OFF by SPI
Reset	HIGH	• The reset output is "high"
SSC: SS1 and SS2	HIGH	• Both safe state signals are HIGH

10.2.4 STANDBY-state

The STANDBY-state is a low-power state which the device can enter upon SPI request to reduce the current consumption to a minimum when the application is not used for a long time. The application is in a safe state.

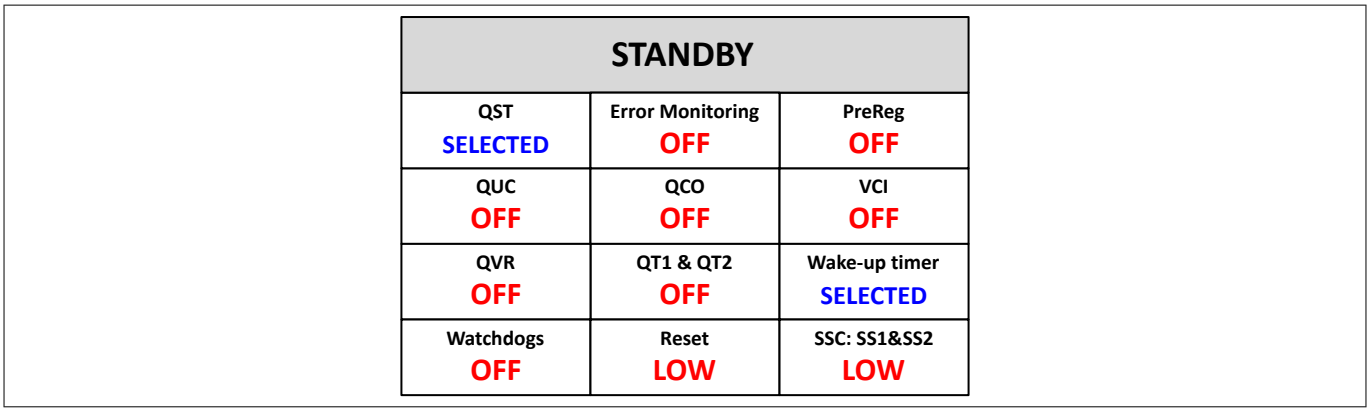


Figure 28 STANDBY-state

Table 21 STANDBY-state settings

Part/Function	Value	Description
QST	SELECTED	• The standby supply QST is ON or OFF depending on its configuration
PreReg	OFF	• The pre-regulator are off
QUC	OFF	• The microcontroller main supply QUC is off
QCO	OFF	• The communication supply QCO is off
VCI	OFF	• The function external output voltage monitoring VCI is off
QVR	OFF	• The voltage reference supply QVR is off
QT1 and QT2	OFF	• Both trackers QT1 and QT2 are off
Wake-up timer	SELECTED	• The wake-up timer is ON or OFF depending on its configuration
Watchdogs	OFF	• The watchdogs are off
Error monitoring	OFF	• The Error monitoring is off
Reset	LOW	• The reset output is low
SSC: SS1 and SS2	LOW	• Safe state signals 1 and 2 are low • The application is in a safe state

10.2.5 SLEEP-state

The SLEEP-state is a low power state which the MCU may enter to reduce the current consumption when the application is not used (e.g. microcontroller is in STOP mode). The MCU may configure the status of regulators and the safety functions via SPI command in the previous state. The application is in a safe state.

In order to reach lowest quiescent current consumption in SLEEP state, the device operates its modules in a low power mode where applicable. For example SPI operates at a lower clock frequency, regulators can go into lower power mode at light loads (lower bandwidth and disabled temperature sensor), interface pins can go into a higher impedance mode and reactions times can be higher.

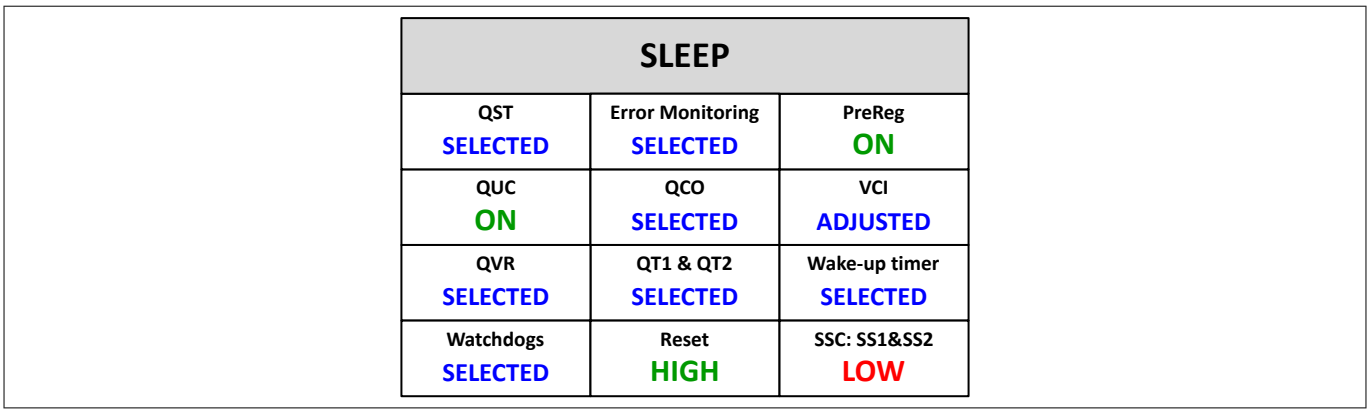


Figure 29 SLEEP-state

Table 22 SLEEP-state settings

Part/Function	Value	Description
QST	SELECTED	• The standby supply QST is switched ON or OFF according to its previous configuration.
PreReg	ON	• The step down pre-regulator is on • Step up pre-regulator is active depending on the input voltage and on whether this option is selected by pin STU • In SLEEP-state the device monitors the pre-regulator peak current: if step up pre regulator is not activated and synchronization output (pin SYN) is disabled, when the PreReg peak current exceeds approximatively 50% of $I_{PREREG,max}$, an interrupt is generated and the device moves to WAKE-state
QUC	ON	• The microcontroller main supply QUC is switched on • In SLEEP-state the device monitors the output current of QUC: If the QUC current exceeds the threshold $I_{QUC,att}+\Delta I_{QUC,att,hyst}$, an interrupt is generated and the device moves to WAKE-state
QCO	SELECTED	• The communication supply QCO is switched ON or OFF depending on the configuration by the state transition request to enter SLEEP and cannot be changed in SLEEP-state.
VCI	ADJUSTED	• The external output voltage monitoring VCI is switched ON or OFF depending on pin SEC (SEC pin considered only during power-sequencing)

(table continues...)

Table 22 (continued) SLEEP-state settings

Part/Function	Value	Description
QVR	SELECTED	• The voltage reference supply QVR is switched ON or OFF depending on the configuration by the state transition request to enter SLEEP and cannot be changed in SLEEP-state.
QT1 and QT2	SELECTED	• The trackers QT1 and QT2 are switched ON or OFF depending on the configuration by the state transition request to enter SLEEP and cannot be changed in SLEEP-state
Wake-up timer	SELECTED	• The wake-up timer is ON or OFF depending on its configuration
Watchdogs	SELECTED	• The watchdogs are ON or OFF depending on their configuration for SLEEP
Error monitoring	SELECTED	• The Error monitoring is ON or OFF depending on its configuration for SLEEP
Reset	HIGH	• The reset output is "high"
SSC: SS1 and SS2	LOW	• Both safe state signals are "low" and the application is in safe state

10.2.6 WAKE-state

The WAKE-state is an intermediate state between NORMAL and the low power states SLEEP and STANDBY. WAKE-state provides the same functionality as the NORMAL-state, but ensures the application being in safe state by keeping the safe state outputs "low". It serves to prepare the system for a correct and safe reentry to the NORMAL-state by servicing the watchdogs and the error monitoring (minimum one valid period with appropriate timing according to $f_{ERR,valid}$) according to the selected configuration. Furthermore it provides the possibility to move the device into the low power states SLEEP and STANDBY.

The device moves from SLEEP or from the transition to SLEEP into WAKE-state, if the output current from QUC exceeds a certain threshold $I_{QUC,att}$ +$\Delta I_{QUC,att,hyst}$ or (in the case of step up pre regulator not activated and synchronization output disabled) Buck peak overcurrent achieves approximatively 50% of IPREREG,max value (WKSF.CMON flagged), a valid ENA or WAK signal is recognized, wake-up timer expiration or the SPI command "Go to WAKE" is sent. Another transition into WAKE-state is initiated by the usage of the ABIST in NORMAL-state.

By entering WAKE-state an interrupt is generated and the supervision functions (watchdogs and ERR monitoring) become active according to their previous configuration in NORMAL-state. Upon entering the WAKE-state the configuration of the supplies resumes the one of the previous NORMAL-state. The application is in a safe state.

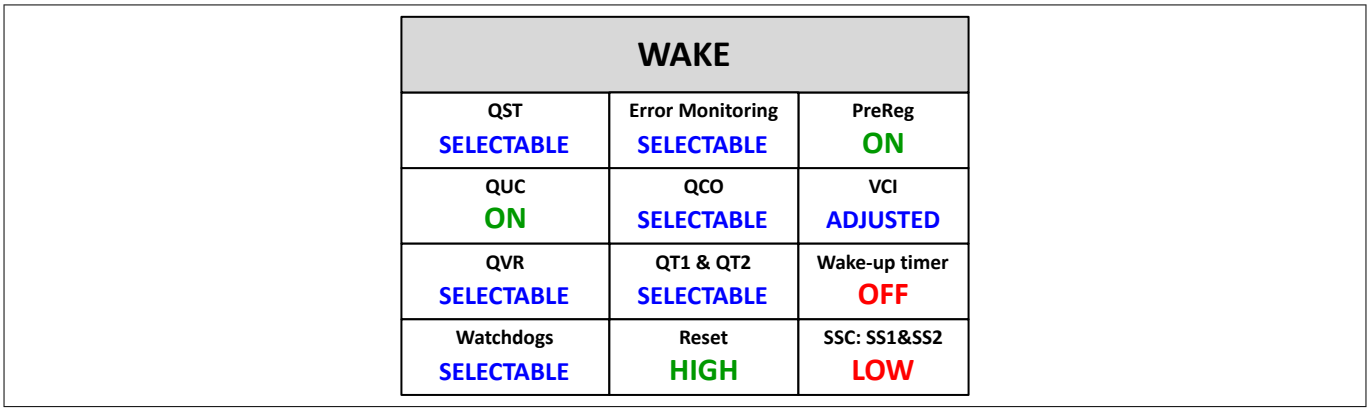


Figure 30 WAKE-state

Table 23 WAKE-states settings

Part/Function	Value	Description
QST	SELECTABLE	• The standby supply QST may be switched ON or OFF by SPI command.
PreReg	ON	• The step down pre-regulator is on • Step up pre-regulator is active depending on the input voltage and this option is selected by pin STU.
QUC	ON	• The microcontroller main supply QUC is on
QCO	SELECTABLE	• The communication supply QCO is switched ON or OFF depending on its configuration in the NORMAL-state prior to SLEEP-state when entering WAKE-state • It may be switched on of off by SPI command
VCI	ADJUSTED	• The external output voltage monitoring VCI is switched ON or OFF depending on pin SEC (SEC pin considered only during power-sequencing)

(table continues...)

Table 23 (continued) WAKE-states settings

Part/Function	Value	Description
QVR	SELECTABLE	• The voltage reference supply QVR is switched ON or OFF depending on its configuration in NORMAL-state prior to SLEEP-state when entering WAKE-state • It may be switched on of off by SPI command
QT1 and QT2	SELECTABLE	• Both trackers QT1 and QT2 is switched ON or OFF depending on their configuration in NORMAL-state prior to SLEEP-state when entering WAKE-state • It may be switched on of off by SPI command
Wake-up timer	OFF	• The wake-up timer is switched off
Watchdogs	SELECTABLE	• The watchdogs is switched ON or OFF depending on their configuration in NORMAL-State prior to SLEEP-state when entering WAKE-State • The watchdogs may be configured and switched ON or OFF by SPI
Error monitoring	SELECTABLE	• The Error monitoring is switched ON or OFF depending on the configuration in NORMAL-state prior to SLEEP-state when entering WAKE-state • The Error monitoring may be configured and switched ON or OFF by SPI
Reset	HIGH	• The reset output is "high"
SSC: SS1 and SS2	LOW	• Both safe state signals are "low" and the application is in safe state

10.2.7 FAILSAFE-state

On detection of a severe failure event the device enters FAILSAFE-state. In FAILSAFE-state all regulators are switched off. The application is in a safe state.

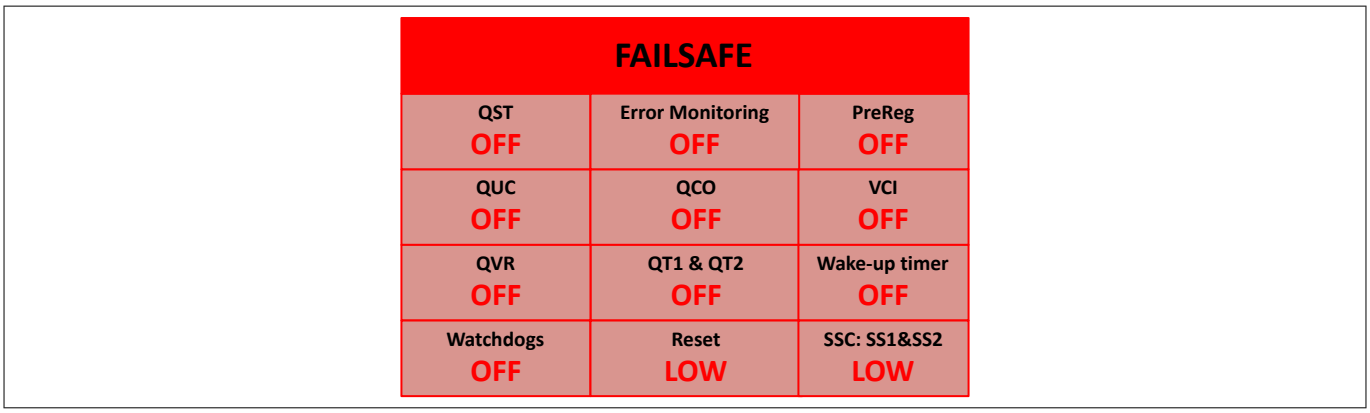


Figure 31 FAILSAFE-state

Table 24 FAILSAFE-state settings

Part/Function	Value	Description
QST	OFF	• The standby supply QST is off
PreReg	OFF	• The pre regulators are off
QUC	OFF	• The microcontroller main supply QUC is off
QCO	OFF	• The communication supply QCO is off
VCI	OFF	• The function external output voltage monitoring VCI is off
QVR	OFF	• The voltage reference supply QVR is off
QT1 and QT2	OFF	• Both trackers QT1 and QT2 are off
Wakeup-Timer	OFF	• The wake-up timer is off
Watchdogs	OFF	• The watchdogs are off
Error monitoring	OFF	• The Error monitoring is off
Reset	LOW	• The reset output is low
SSC: SS1 and SS2	LOW	• Both safe state signals are "low" and the application is in safe state

10.3 Transition between states

State transitions requested via SPI command are initiated with a valid positive going edge of the chip select (SCS).

10.3.1 POWERDOWN → INIT-state

If all of the following conditions are met, then the device performs the transition from POWERDOWN to INIT-state (representing the Power-on-Reset (POR) released) and starts the power-sequencing:

- V_{VS} above $V_{PS,start}$ when increasing
- no undervoltage or overvoltage on internal supplies

10.3.2 INIT → NORMAL-state

Prerequisites

- Watchdog(s) need to be serviced once according to default configuration or according to reconfiguration within the INIT timer
- ERR monitor needs to be serviced with a valid signal (minimum 3 valid periods with appropriate timing according to $f_{ERR,valid}$) or disabled within the INIT timer.
- If the functional watchdog is activated, valid FWD triggering is necessary.
- A delay of 60 µs after the provided services has to be considered to ensure proper release of internal validation signals.

Triggering events

- State transition is only initiated by the SPI command "Go to NORMAL".

Exceptions

- none

Timing diagram

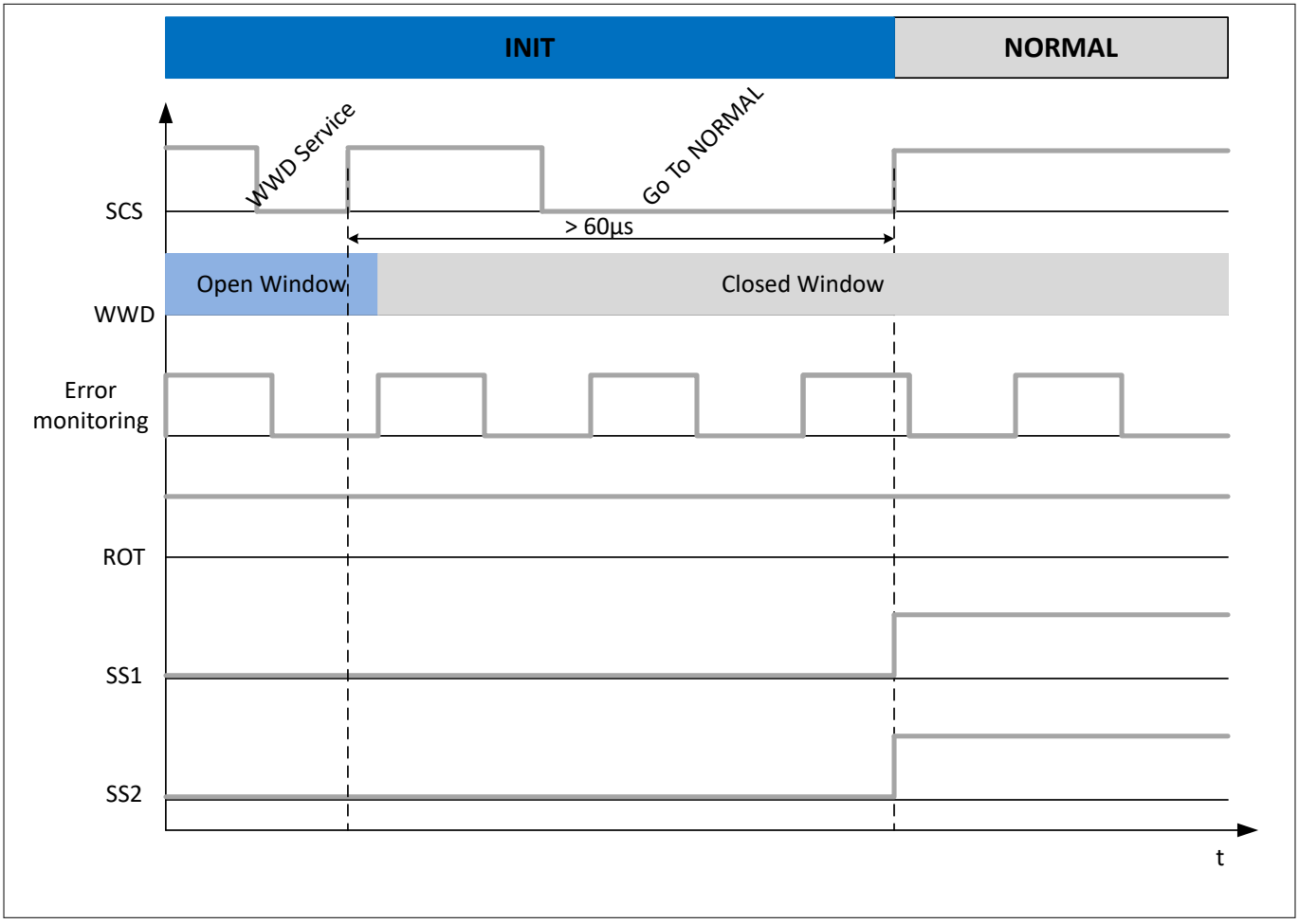


Figure 32 Transition from INIT to NORMAL-state

- A valid SPI command "Go to NORMAL" (valid with chip select high at pin SCS) moves the device from INIT-state to NORMAL-state.

- Reset pin ROT remains "high" as the post regulators are already active in INIT-state.
- With the positive edge of chip select high (at pin SCS) the safe state signals SS1 and SS2 are pulled to "high" at same time. (Internal reaction time for the safe state outputs according to Table 28 has to be considered)

10.3.3 Movements between NORMAL and SLEEP-state

10.3.3.1 NORMAL → SLEEP-state

Prerequisites

- Selection of QUC current monitor or absolute transition timer.
- Configured transition delay timer $t_{tr,del}$ or default is used.
- Optional: configured QUC current threshold or default is used.

Triggering events

- State transition is only initiated by the SPI command "Go to SLEEP".

Exceptions

- If a valid ENA (edge) or WAK (level) signal is detected in the transition to SLEEP-state, the devices enters WAKE-state and sends an interrupt (at pin INT).
- If the QUC current monitor is activated and the current consumption of the microcontroller is not below the selected QUC current threshold before the transition delay timer $t_{tr,del}$ has expired, the device enters WAKE-state and sends an interrupt (at pin INT).

Timing diagram

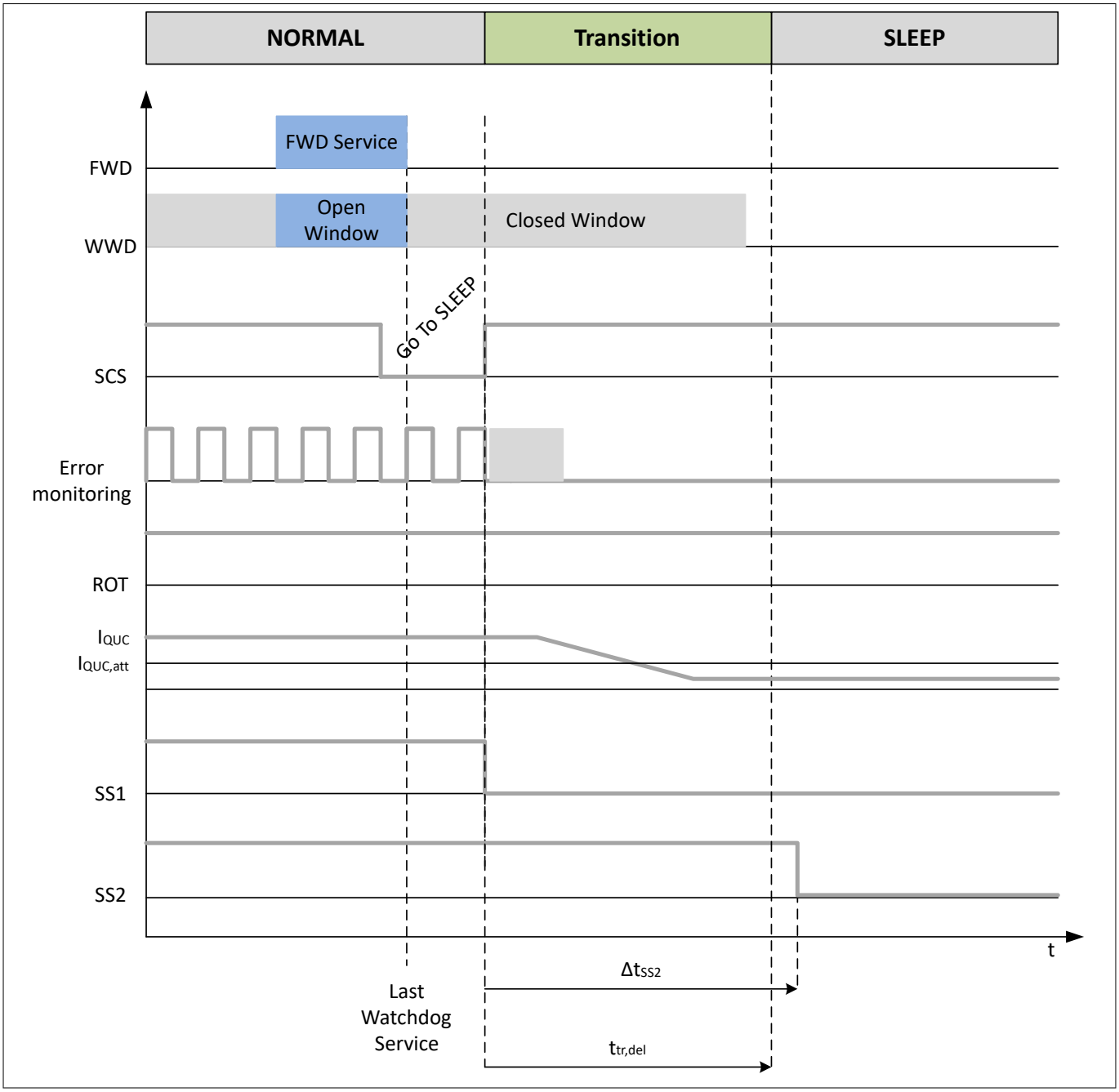


Figure 33 Transition from NORMAL to SLEEP-state

- Before the SPI command "Go to SLEEP" is applied, the watchdog(s), if in use, should be serviced, so that the positive edge of SCS signal occurs within the "closed window" of the window watchdog. This is recommended to avoid interference between a missing watchdog trigger and the transition command "Go to SLEEP"
- The positive edge of chip select (pin SCS) after the SPI command "Go to SLEEP" initiates the transition. With chip select high the safe state signal SS1 is pulled to "low" and the device exits NORMAL-state and enters the transition state (to SLEEP-state). (Internal reaction time for the safe state outputs according to Table 28 has to be considered)
- With chip select (pin SCS) high the error monitoring (pin ERR) is stopped, if disabled for SLEEP state and the toggling may be stopped with the positive edge at pin SCS. If the error monitoring should be selected to be active in SLEEP-state continuous toggling is mandatory.

- The monitoring of window watchdog and functional watchdog is stopped with the positive edge at pin SCS. If at least one watchdog is selected active in SLEEP-state continuous watchdog service is mandatory.
- Reset pin ROT remains "high" as the post regulators are not switched off.
- In case the absolute transition timer is selected, the device moves from transition state to SLEEP-state after the transition delay time $t_{tr,del}$. The transition time $t_{tr,del}$ can be determined by SPI command from 100 µs to 1.6 ms, the default setting is 900 µs. Ensure that the MCU current consumption has fallen below the QUC monitoring threshold $I_{QUC,att}$ before this transition time expires to allow successful transition to SLEEP-state.
- If the QUC current monitor is enabled, then the MCU current out of pin QUC must fall below the QUC monitoring threshold $I_{QUC,att}$ within the configured maximum transition time $t_{tr,del}$ in DEVCFG0.TRDEL. The transition is completed as soon as the MCU current falls below the configured QUC monitoring threshold $I_{QUC,att}$.
- After delay time Δt_{SS2} the safe state signal SS2 goes "low". The adjusted delay time Δt_{SS2} is independent from the transition delay time $t_{tr,del}$.

10.3.3.2 SLEEP → WAKE-state

Prerequisites

- none

Triggering events

Any of the following events triggers the transition from SLEEP to WAKE state:

- SPI command "Go to WAKE".
- Valid Wake-signal (ENA or WAK).
- Output current of QUC I_{QUC} exceeds the configured threshold $I_{QUC,att} + \Delta I_{QUC,att,hyst}$.
- Buck peak overcurrent achieving approx. 50% of $I_{PREREG,max}$ value when step up pre regulator is not activated and synchronization output (pin SYN) is disabled (WKSF.CMON flagged)
- Wake-up timer expired, if enabled

Exceptions

- none

Timing diagram

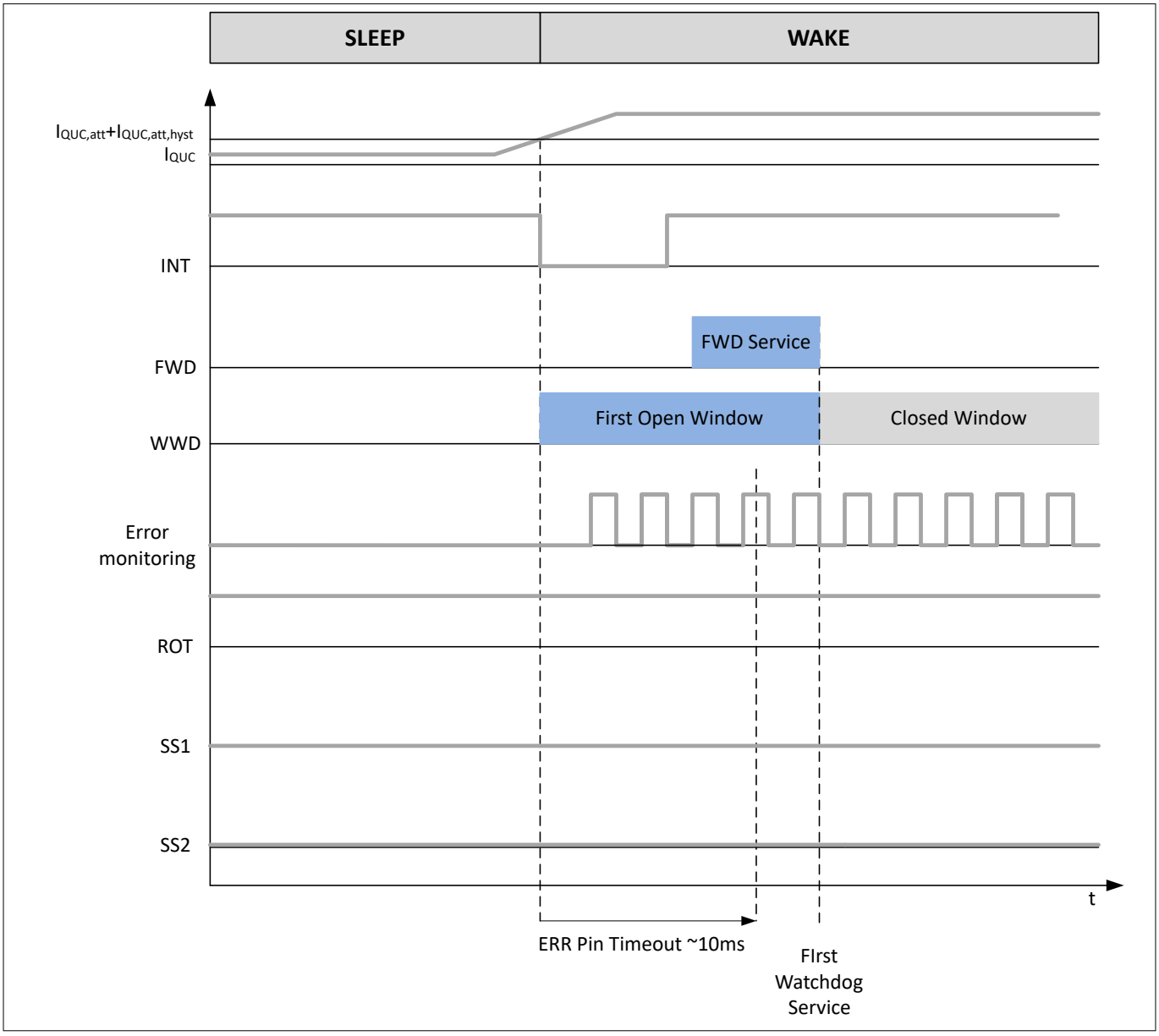


Figure 34 Transition from SLEEP to WAKE-state

- The state transition is indicated by an interrupt at pin INT and is completed after t_{tr}. The triggering event for the transition from SLEEP can be read from the status register WKSF.
- All three monitoring functions (window watchdog, functional watchdog and error monitoring) recover to the condition active or inactive (switched off) as they were in the NORMAL-state previous to the SLEEP-state.
- The configuration of the supplies recover to the condition active or inactive (switched off) as they were in the NORMAL-state previous to the SLEEP-state.
- In case the window watchdog was active in the previous NORMAL-state, with the negative edge of interrupt signal (at pin INT) the window watchdog opens the first Open Window, the time of this first Open Window depends on the configured cycle time and is 600 ms (WDCYC = 1) or 60 ms (WDCYC = 0) (if the window watchdog was disabled in SLEEP-state) and requires service. If the window watchdog was active in SLEEP-state, then continuous service is mandatory.
- In case the functional watchdog was active in the previous NORMAL-state, with the negative edge of interrupt signal (at pin INT) the functional watchdog starts the heartbeat timer (if the functional watchdog

was disabled in SLEEP-state) and requires service. If the functional watchdog was active in SLEEP-state, then continuous service is mandatory.

- In case the ERR pin monitoring was active in the previous NORMAL-state, with the negative edge of interrupt signal (at pin INT) the error monitoring becomes active again (if the ERR pin monitoring was disabled in SLEEP-state). Latest 10 ms after the activation a toggling signal (with at least three periods past) at pin ERR is required. If the error monitoring was active in SLEEP-state, then continuous toggling is mandatory.
- Reset pin ROT remains "high" as the post regulators are active in SLEEP-state and in WAKE-state.
- The safe state signals SS1 and SS2 stay "low" in SLEEP and in WAKE-state.
- If all active monitoring functions (window watchdog, functional watchdog and error monitoring) are serviced properly in WAKE-state, the device can remain in WAKE-state as long as necessary according to the applications need.
- If all three monitoring functions (window watchdog, functional watchdog and error monitoring) are inactive (switched off) in WAKE-state, the device can remain in WAKE-state as long as necessary according to the applications need.

10.3.3.3 WAKE → SLEEP-state

Prerequisites

- Selection of QUC current monitor or absolute transition timer.
- Configured transition delay timer $t_{tr,del}$ or default is used.
- Optional: configured QUC current threshold or default is used.

Triggering events

- State transition is only initiated by the SPI command "Go to SLEEP".

Exceptions

- If a valid ENA (edge) or WAK (level) signal is detected in the transition state to SLEEP-state, the device moves back to the WAKE-state and sends an interrupt (at pin INT)
- If the QUC current monitor is activated and the current consumption of the microcontroller is not below the selected QUC current threshold before the transition delay timer $t_{tr,del}$ has expired, the device enters WAKE-state and sends an interrupt (at pin INT)

Timing diagram

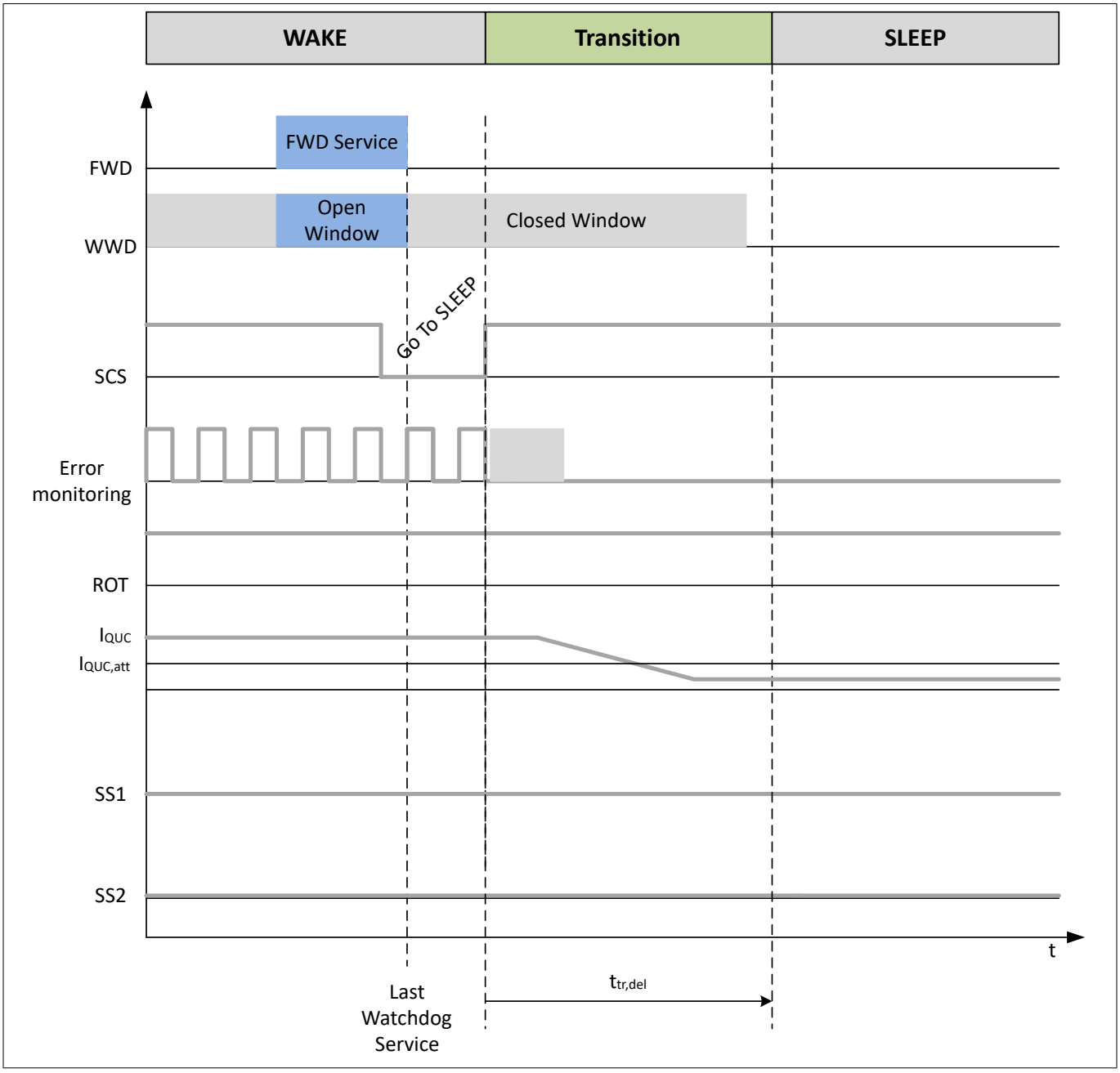


Figure 35 Transition from WAKE to SLEEP-state

- Before the SPI command "Go to SLEEP" is applied, the watchdog(s), if in use, should be serviced, so that the positive edge of SCS signal is well in between the "closed window" of the window watchdog. This is recommended to avoid interference between a missing watchdog trigger and the transition command "Go to SLEEP"
- The positive edge of chip select (pin SCS) after the SPI command "Go to SLEEP" initiates the transition. With chip select high the device leaves WAKE-state and enters the transition state (to SLEEP-state).
- With chip select (pin SCS) high the error monitoring (pin ERR) is stopped, if disabled for SLEEP state and the toggling may be stopped with the positive edge at pin SCS. If the error monitoring should be selected to be active in SLEEP-state continuous toggling is mandatory.
- The monitoring of window watchdog and functional watchdog is stopped with the positive edge at pin SCS. If one or both watchdogs should be selected to be active in SLEEP-state continuous watchdog service is mandatory.

- Reset pin ROT remains "high" as the post regulators are not switched off.
- If the QUC current monitor is enabled the MCU current out of pin QUC must fall below the QUC monitoring threshold $I_{QUC,att}$ within the configured maximum transition delay time $t_{tr,del}$. The time for the transition is depending how long it takes that the MCU current falls below the QUC monitoring threshold $I_{QUC,att}$, if it is below the transition is done.
- Safe state signals SS1 and SS2 remain "low" all the time.

10.3.4 Movements between NORMAL and STANDBY-state

10.3.4.1 NORMAL → STANDBY-state

Prerequisites

- Selection of QUC current monitor or absolute transition timer.
- Configured transition delay timer $t_{tr,del}$ or default is used.
- Optional: configured QUC current threshold or default is used.

Triggering events

- State transition is only initiated by the SPI command "Go to STANDBY".

Exceptions

- If a valid ENA (edge) or WAK (level) signal is detected in the transition state to STANDBY-state, the device moves to the INIT-state and a reset (ROT) is generated.
- If the QUC current monitor is activated and the current consumption of the microcontroller is not below the selected QUC current threshold before the transition delay timer $t_{tr,del}$ has expired, the device moves to the INIT-state and a reset (ROT) is generated.

Timing diagram

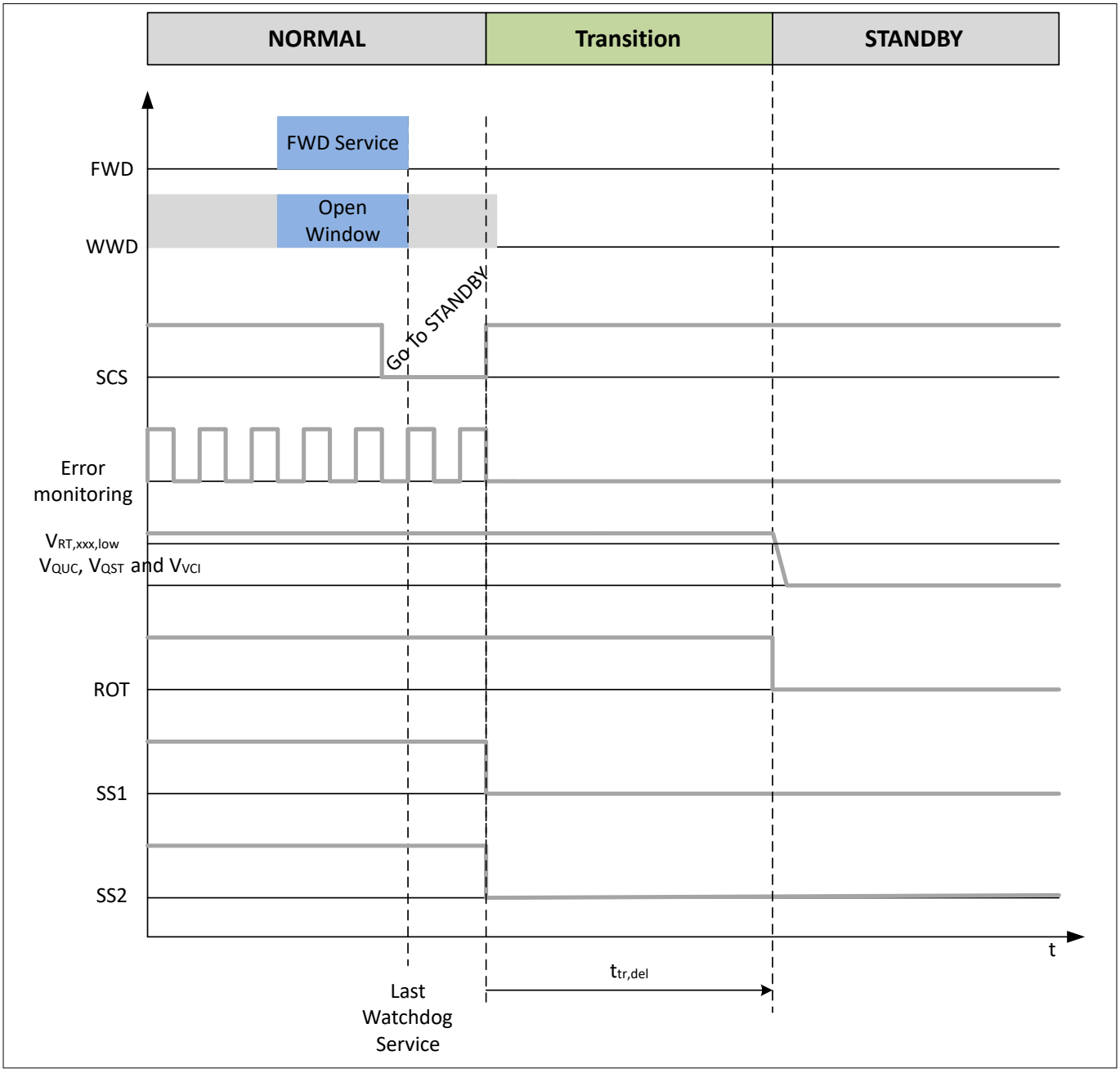


Figure 36 Transition from NORMAL to STANDBY-state

- Before the SPI command "Go to STANDBY" is applied, the watchdog(s), if in use, should be serviced, so that the positive edge of SCS signal is well in between the "closed window" of the window watchdog. This is recommended to avoid interference between a missing watchdog trigger and the transition command "Go to STANDBY"
- The positive edge of chip select (pin SCS) after the SPI command "Go to STANDBY" initiates the transition. With chip select high the safe state signals SS1 and SS2 are pulled to "low" at the same time (without Δt_{SS2}). The device exits NORMAL-state and enters the transition state (to STANDBY-state).
  (Internal reaction time for the safe state outputs according to Table 28 has to be considered)
- With chip select (pin SCS) high the error monitoring (pin ERR) is stopped, if disabled for SLEEP state and the toggling may be stopped with the positive edge at pin SCS.
- The monitoring of window watchdog and functional watchdog is stopped with the positive edge at pin SCS.

- During the transition from NORMAL to STANDBY-state the reset (ROT) is pulled to "low" after chip select (pin SCS) goes "high" and the transition time $t_{tr,del}$ elapses.
- All pre regulators and all post regulators (with the exception of the standby supply, which can be ON or OFF in STANDBY-state) are switched off at the point when the transition is completed after the reset (ROT) is pulled low.
- In case the absolute transition timer is selected, the device moves from transition state to STANDBY-state after the transition delay time $t_{tr,del}$. The transition time $t_{tr,del}$ can be determined by SPI command from 100 µs to 1.6 ms, the default setting is 900 µs.
- In case the QUC current monitor is selected for the transition, the device enters STANDBY-state at the point the current consumption measured at the QUC drops below the selected threshold before the transition delay timer $t_{tr,del}$ expires.

10.3.4.2 STANDBY → INIT-state

Prerequisites

- none

Triggering events

Any of the following events triggers the transition from STANDBY to INIT state:

- Valid ENA (edge) or WAK (level) signal.
- Wake-up timer expired, if enabled

Exceptions

- none

Timing diagram

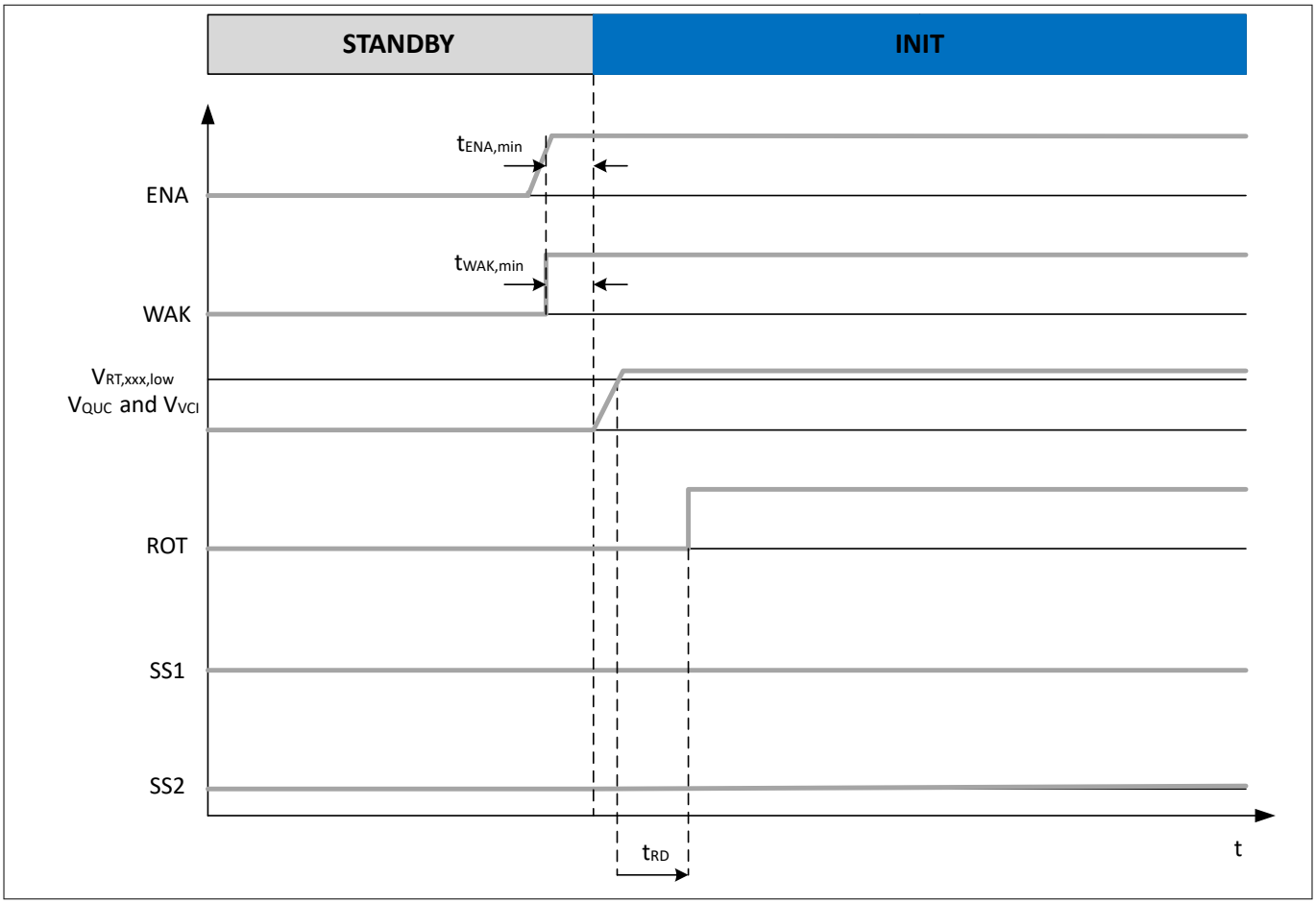


Figure 37 Transition from STANDBY to INIT-state

- All pre regulators and all post regulators are switched on according to the power sequencing, except QST, which remains ON or OFF according to its configuration (simplified in figure above).
- The power-on reset delay time starts as soon as the last of the MCU related regulators V_{QUC} or V_{VCI} (if enabled) exceeds the related undervoltage monitoring threshold $V_{RT,xxx,low}$.
- After the power-on reset delay time has expired the reset (ROT) is set to "high".
- The safe signals SS1 and SS2 stay "low" in STANDBY-state and in INIT-state.

10.3.4.3 INIT → NORMAL-state

For this state transition please refer to the Chapter 10.3.2.

10.3.5 NORMAL → WAKE-state

For this state transition please refer to the description of ABIST in Chapter 10.6.1.

10.3.6 WAKE → NORMAL-state

Prerequisites

- The activated supervision functions (e.g. window watchdog, functional watchdog, ERR pin monitoring) need to be serviced at least once (minimum 1 valid period with appropriate timing according to $f_{ERR,valid}$ for ERR monitoring) in the active WAKE-state, if they are restarted/reinitialized in WAKE-state (e.g. watchdog disabled in previous SLEEP-state)

Triggering events

- State transition is only initiated by the SPI command "Go to NORMAL".

Exceptions

- none

Timing diagram

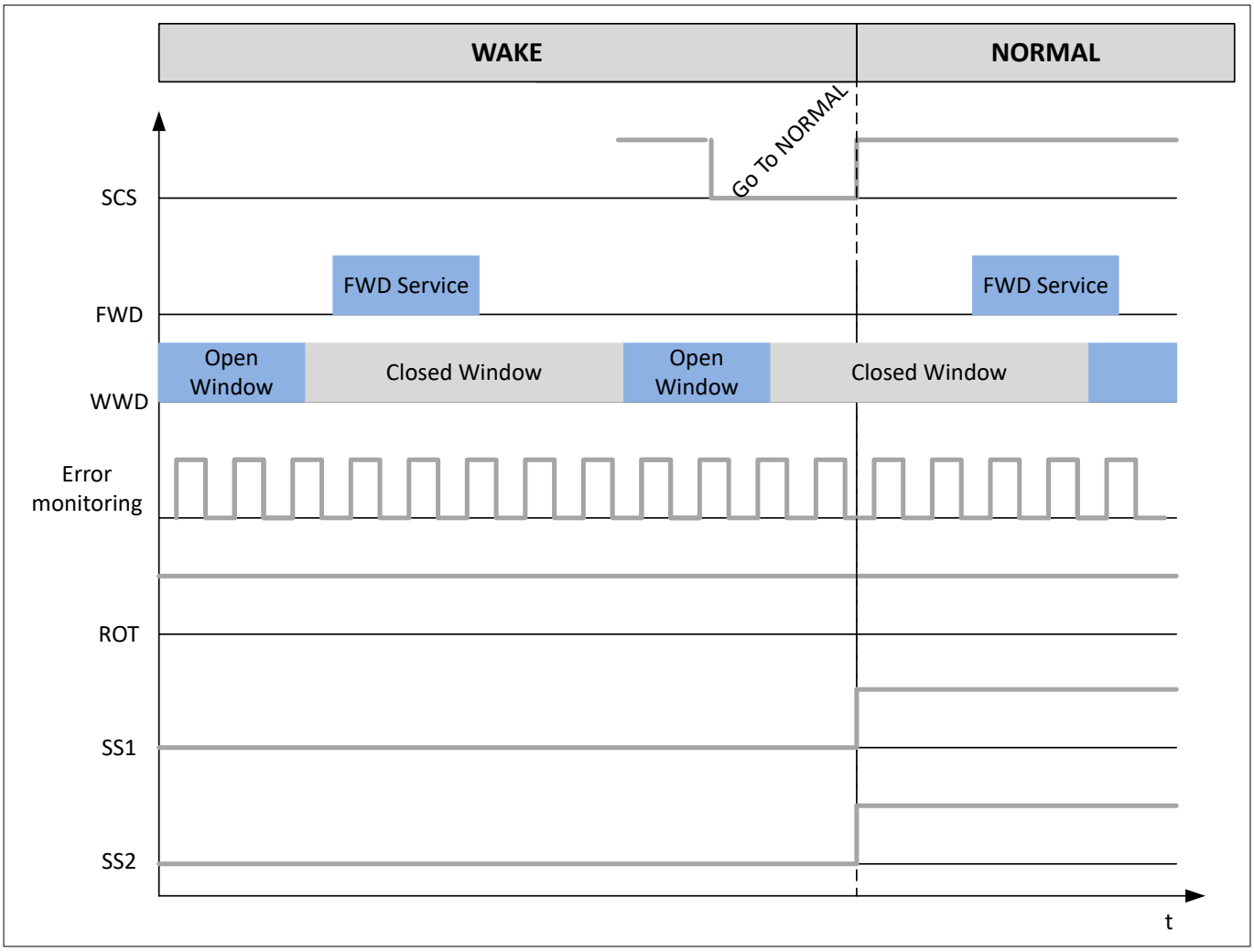


Figure 38 Transition from WAKE to NORMAL-state

- The window watchdog (if active in WAKE-state) requires continuous service - not synchronized to the transition from WAKE-state to NORMAL-state.
- The functional watchdog (if active in WAKE-state) requires continuous service - not synchronized to the transition from WAKE-state to NORMAL-state.
- The error monitoring of pin ERR (if active in WAKE-state) requires a continuous toggling signal - not synchronized to the transition from WAKE-state to NORMAL-state, but minimum 2 valid edges with appropriate timing according to minimum 1 valid period with appropriate timing according to $f_{ERR,valid}$ are required for the device to enter NORMAL-state.
- Reset pin ROT remains "high" as the post regulators are active in WAKE-state and in NORMAL-state.
- With the positive edge of chip select high (at pin SCS) the safe state signals SS1 and SS2 are pulled to "high" at same time. (Internal reaction time for the safe state outputs according to Table 28 has to be considered)

10.3.7 INIT/WAKE → STANDBY-state

Prerequisites

- Selection of QUC current monitor or absolute transition timer.
- Configured transition delay timer $t_{tr,del}$ or default is used.
- Optional: configured QUC current threshold or default is used.

Triggering events

- State transition is only initiated by the SPI command "Go to STANDBY".

Exceptions

- If a valid ENA (edge) or WAK (level) signal is detected in the transition state to STANDBY-state, the device moves to the INIT-state and a reset (ROT) is generated.
- If the QUC current monitor is activated and the current consumption of the microcontroller is not below the selected current threshold before the transition timer has expired, the device moves to the INIT-state and a reset (ROT) event is generated.

Timing diagram

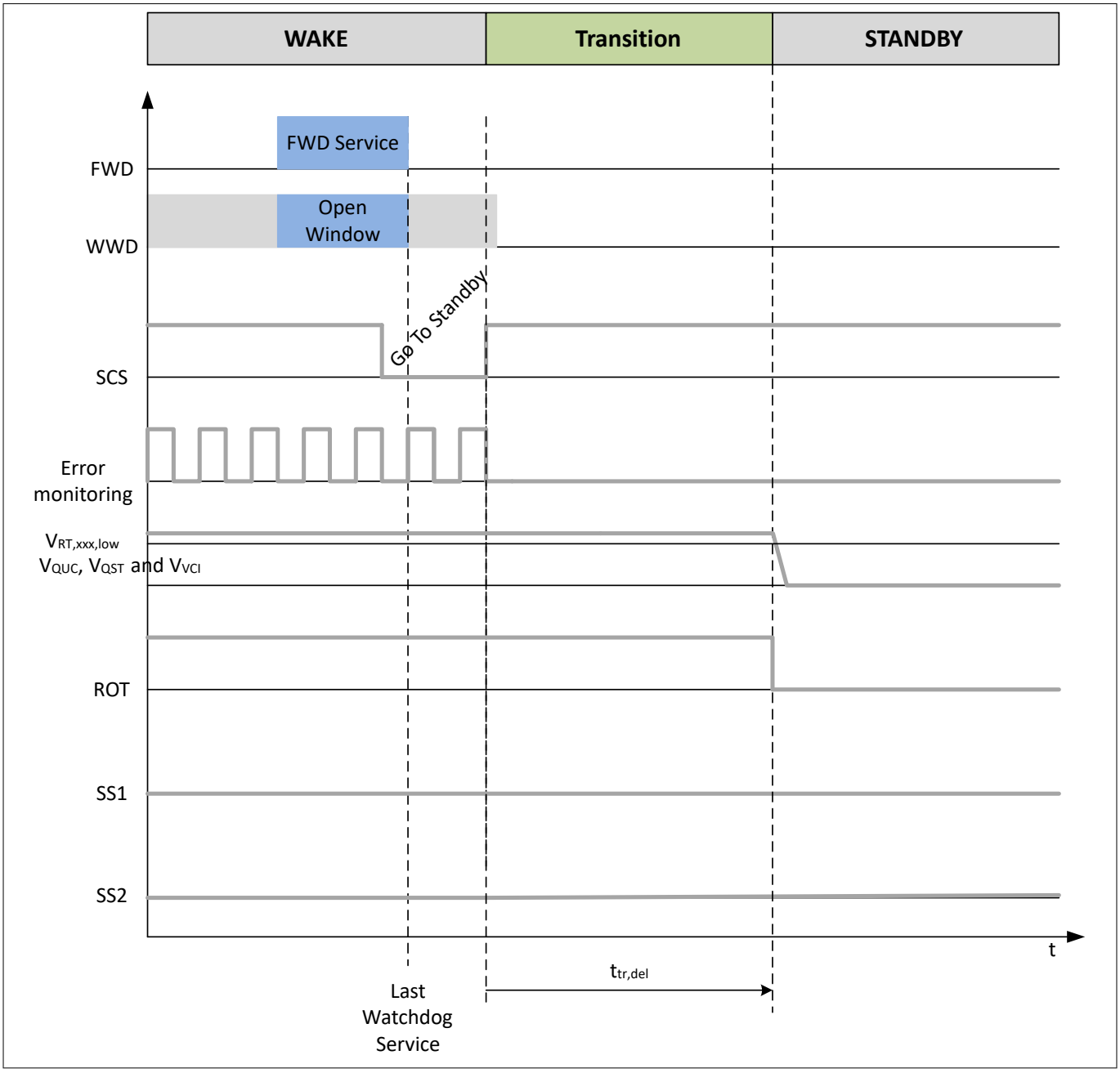


Figure 39 Transition from INIT or WAKE to STANDBY-state

- Before the SPI command "Go to STANDBY" is applied, the watchdog(s) - if in use should be serviced, so that the positive edge of SCS signal is well in between the "closed window" of the window watchdog. This is recommended to avoid interference between a missing watchdog trigger and the transition command "Go to STANDBY"
- The positive edge of chip select (pin SCS) after the SPI command "Go to STANDBY" initiates the transition. In the INIT or WAKE-state the safe state signals SS1 and SS2 are "low" and is kept LOW for the transition to STANDBY. The device leaves INIT or WAKE-state and enters the transition state (to STANDBY-state).
- With chip select (pin SCS) high the error monitoring (pin ERR) is stopped - the toggling may end with the positive edge at pin SCS.
- The monitoring of window watchdog and functional watchdog is stopped with the positive edge at pin SCS.

- During the transition from INIT or WAKE to STANDBY-state the reset (ROT) is pulled to "low" after chip select (pin SCS) goes "high" and the transition time $t_{tr,del}$ elapses.
- All pre regulators and all post regulators (with the exception of the standby supply - it may be ON or OFF in STANDBY-state) are switched off at the point when the transition is completed after the reset (ROT) is pulled low.
- In case the absolute transition timer is selected, the device moves from transition state to STANDBY-state after the transition time $t_{tr,del}$. The transition time $t_{tr,del}$ can be determined by SPI command between 100 µs to 1.6 ms, the default setting is 900 µs.
- In case the QUC current monitor is selected for the transition, the device moves from transition state to STANDBY-state at the point the current consumption measured at the QUC drops below the selected threshold before the transition delay timer $t_{tr,del}$ has expired.

10.3.8 FAILSAFE → INIT-state

Prerequisites

- FAILSAFE timer expired.
- $V_{VS} > V_{PS,start}$

Triggering events

Any of the following events triggers the transition from FAILSAFE to INIT state:

- Self triggered transition after the prerequisites are fulfilled.
- Valid ENA (edge) or WAK (level) signal (only needed if exception applies)

Exceptions

- In case the FAILSAFE is entered three times in a row with the same failure the self-triggered transition is blocked.

Timing diagram

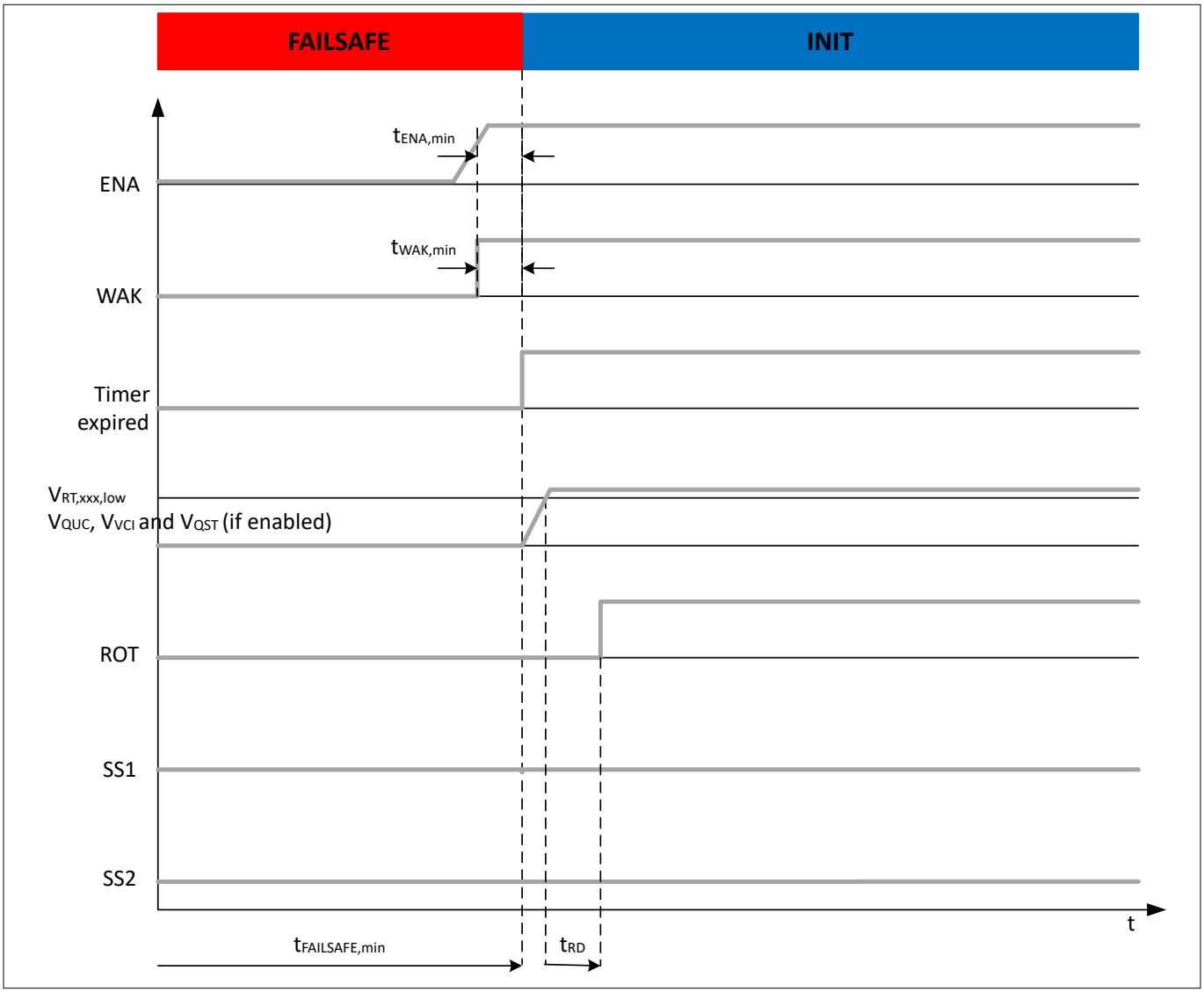


Figure 40 Transition from FAILSAFE to INIT-state

- The device transition from FAILSAFE-state to INIT-state occurs earliest after the minimum FAILSAFE time $t_{FAILSAFE,min}$, which is 20 ms for all failures except a thermal shutdown. In case of a thermal shutdown the minimum FAILSAFE time $t_{FAILSAFE,min}$ is 1 s. A transition before the minimum FAILSAFE time $t_{FAILSAFE,min}$ has expired, is not possible.
- After entering INIT-state the voltage regulators ramps up according to the power-sequencing.
- The power-on reset delay time is started as soon as the last of the MCU related regulators V_{QUC}, V_{VCI} or V_{QST} (according to the previous configuration) exceeds the related undervoltage monitoring threshold $V_{RT,xxx,low}$ on the way up.
- After the power-on reset delay time has expired the reset (ROT) is set to "high".
- The device needs to be configured and initialized. All settings done in configuration registers before entering FAILSAFE-state are reset to their default, except the configuration of the QST (RSYSPCFG0) and the reset delay time (DEVCFG1).
- The safe state signal SS1 and SS2 are "low" in FAILSAFE-state and is "low" in INIT-state

10.4 Reaction on detected faults

Errors are classified into the following error classes according to their severity:

- Stay in Current state - Failures affecting peripherals without direct risk for the microcontroller, that are indicated by an interrupt to allow analysis by the microcontroller without changing the state.
- Move to INIT - Medium severity errors that bring the device back to INIT-state and generate a reset for the microcontroller.
- Move to FAILSAFE - Critical error with high risk of damaging the microcontroller.
- Move to POWERDOWN - Most critical error with high risk of damaging the device itself and the microcontroller

The error classes are overruled according to their severity, e.g. movement to POWERDOWN takes precedence over movement to FAILSAFE which takes precedence over movement to INIT.

The move to INIT, FAILSAFE and POWERDOWN errors are named "error triggered state transitions" in this document.

10.4.1 Stay in current state (Interrupt event)

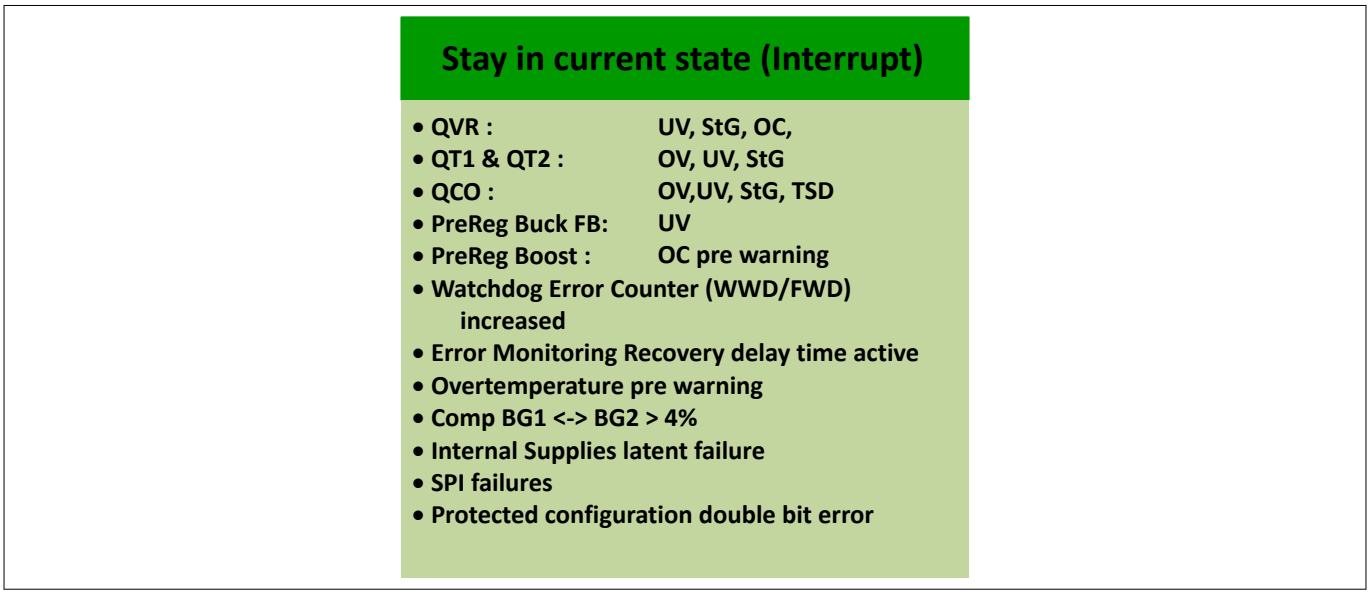


Figure 41 Stay in current state (Interrupt event)

Any of the following failures does not trigger state transition, but indicates the failure by an interrupt event:

- Detection of undervoltage or a short to ground or overload detection at voltage reference, if in use
- Detection of overvoltage, undervoltage or a short to ground at trackers 1 or 2, if in use
- Detection of overvoltage, undervoltage, a short to ground or thermal shutdown at QCO, if in use
- Detection of undervoltage at step down pre-regulator, if in use
- Detection of overcurrent pre-warning of step up pre-regulator, if in use
- Increase of a watchdog error counter (WWD or FWD) that results in a value below the configured threshold
- ERR signal stopped toggling and error monitoring recovery delay time runs, if configured active
- Thermal shutdown pre-warning (Step down pre-regulator or/and QUC or/and QCO), if in use (except for STANDBY and SLEEP state)
- Bandgap monitoring: If the deviation between both bandgaps is greater than 4% (except for STANDBY and SLEEP state)
- Detection of internal supplies latent failure

- SPI failures according to SPISF
- Protected configuration double bit error (CFGE)

The interrupt is not visible on the INT pin in STANDBY and FAILSAFE-state due to the disabled microcontroller supplies. The event is stored in the status flags (IF, SYSSF, MONSF0, MONSF1, MONSF2, OTWRNSF, OTFAIL, CEFUMON).

10.4.2 Transition to INIT-state

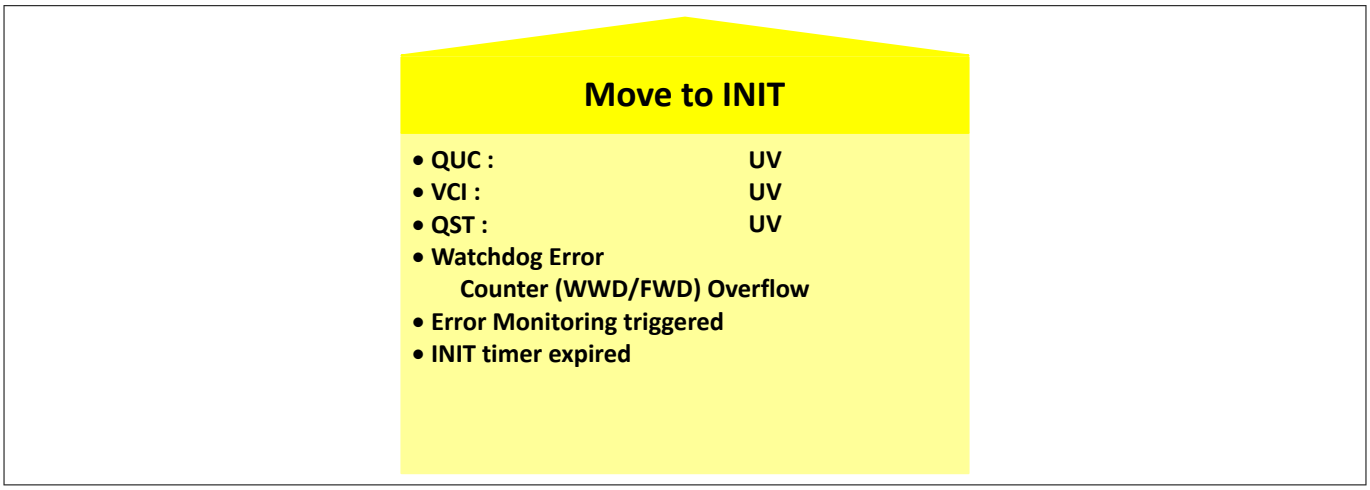


Figure 42 Move to INIT

On any of the following failures the device enters INIT-state:

- Detection of undervoltage at QUC, VCI or QST, if in use
- Detection of watchdog error counter overflow (WWD or FWD)
- ERR signal stopped toggling (immediate reaction mode) or ERR signal was out of valid range for longer than the recovery delay time (recovery mode)
- Initialization timer expires once or twice (configuration in INIT-state failed). The initialization timer can be stopped by the MPS function described in Chapter 10.7.

10.4.2.1 INIT → INIT-state due to detected fault

10.4.2.1.1 INIT → INIT-state due to INIT timer expired for the first time

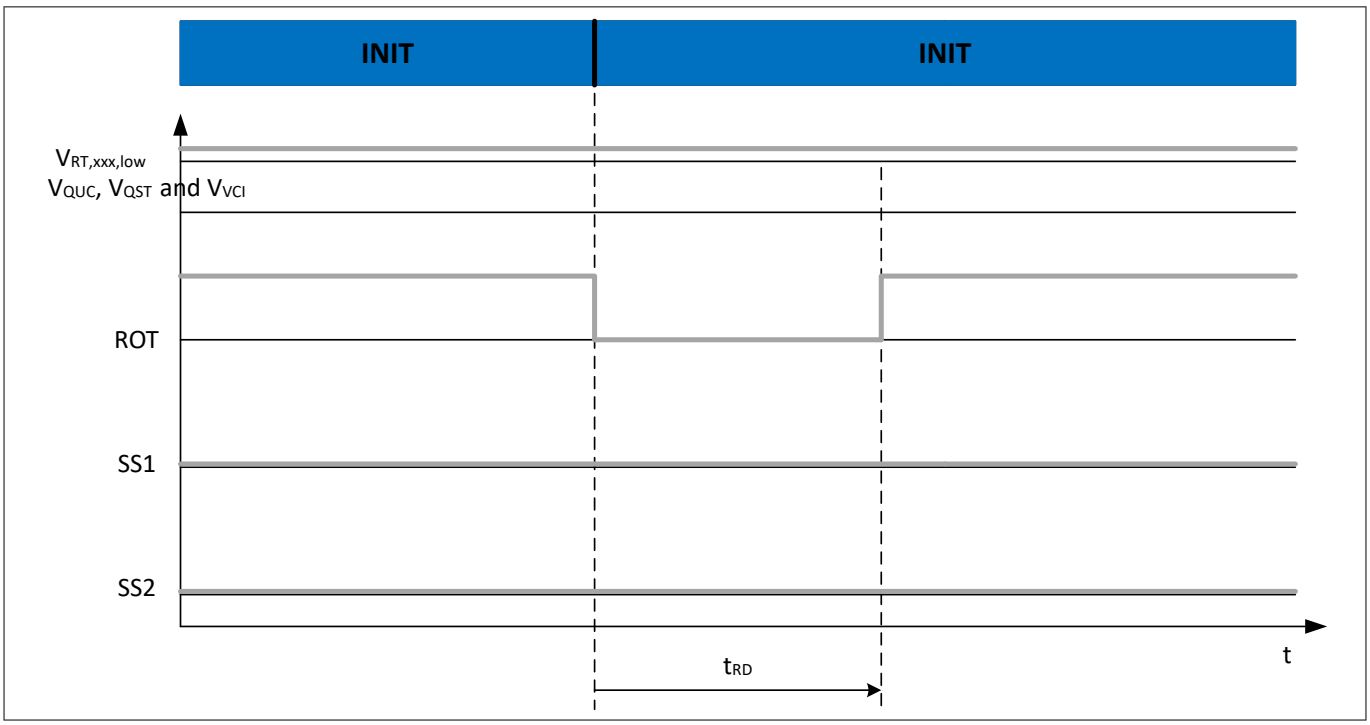


Figure 43 Transition from INIT to INIT-state - first movement

Description:

- The state transition from INIT back to INIT-state (device remains in INIT-state) due to expiry of the initialization timer for the first time issues a "soft reset". Pin ROT is pulled to "low" for the reset delay time t_{RD} in case all MCU related voltages are in valid range. The power sequence is started after entering the INIT-state: the disabled outputs are re-activated, the other ones remain enabled, except the QST keeps its configuration, ON or OFF.

10.4.2.1.2 INIT → INIT-state due to INIT timer expired for the second time

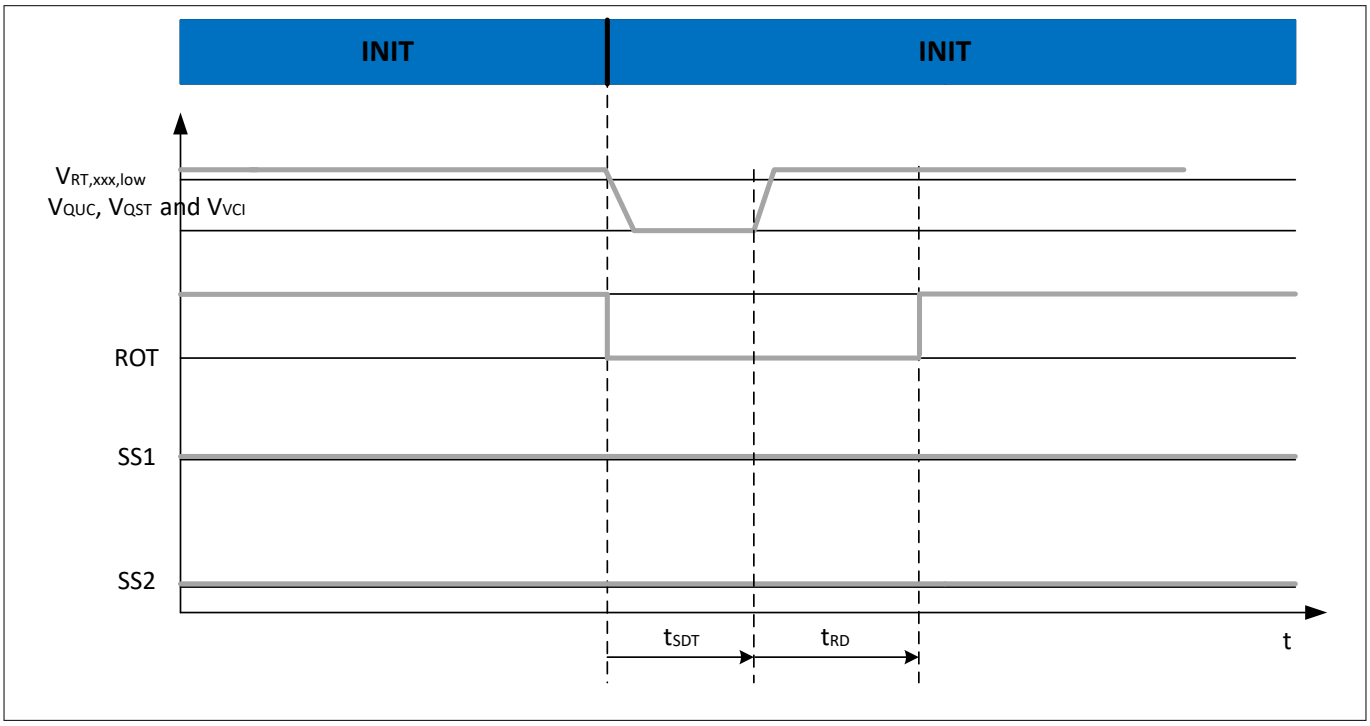


Figure 44 Transition from INIT to INIT-state - second movement

Description:

- The state transition from INIT back to INIT-state (device remains in INIT-state) due to expiry of the initialization timer for the second time issues a "hard reset" - pin ROT is pulled to "low" and all outputs are disabled for the time t_{SDT} and are restarted according to the power sequencing (Please refer to Chapter 7.3), except the QST restores its configuration, ON or OFF.
- The ROT pin is released according to the power sequencing using the reset delay time t_{rd}.

***Note**: See also to the transition INIT to FAILSAFE*

10.4.2.2 NORMAL → INIT-state due to detected fault

Timing diagram

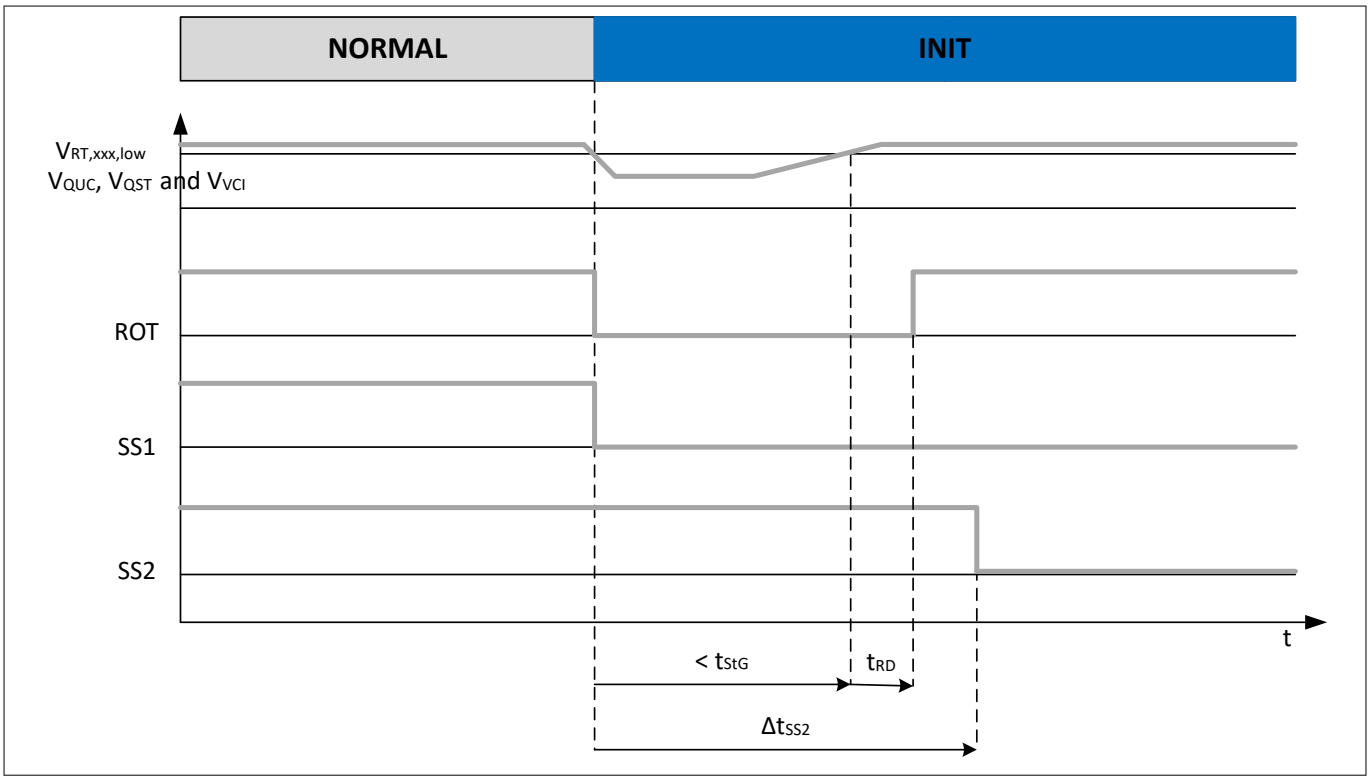


Figure 45 Transition from NORMAL to INIT-state

Description:

- The device transitions from NORMAL into INIT-state issuing a "soft reset" - pin ROT is pulled to "low" and all the outputs are enabled, except the QST keeps its configuration, ON or OFF. Outputs that were disabled in NORMAL-state are switched on again.
- An undervoltage of the MCU related voltages V_{QUC}, V_{QST} or V_{VCI} can trigger the transition as shown in the figure. The undervoltage is shorter than the short to ground detection time t_{StG}. The reset delay time t_{RD} starts as soon as all MCU related voltages V_{QUC}, V_{QST} or V_{VCI} return to the valid range. The ROT pin is released accordingly. An undervoltage longer than the short to ground detection time t_{StG} would first lead to a transition from NORMAL to INIT-state and then, after the short to ground detection time t_{StG} has expired, to a transition from INIT to FAILSAFE-state.
- The "soft reset" can also be initiated by a window watchdog error counter overflow (> ΣWWO), a functional watchdog error counter overflow (> ΣFWO), an error indication (immediate or recovery delay time mode), if these monitoring functions are in use. In this case the reset delay time t_{RD} is started at the falling edge of the ROT pin. Please consider the state transition time to INIT-state in Table 25.
- SS1 is pulled to "low" immediately with pin ROT, SS2 is pulled to "low" after the selected Δt_{SS2}.
- Please mind that in case of an undervoltage event on QUC, a delayed SS2 signal follows V_{QUC} as it is supplied from QUC.

***Note**: In case the device enters NORMAL-state again before the configured Δt_{SS2} has expired, the SS2 remains "high" without being set to "low".*

10.4.2.3 STANDBY → INIT-state due to detected fault

Timing diagram

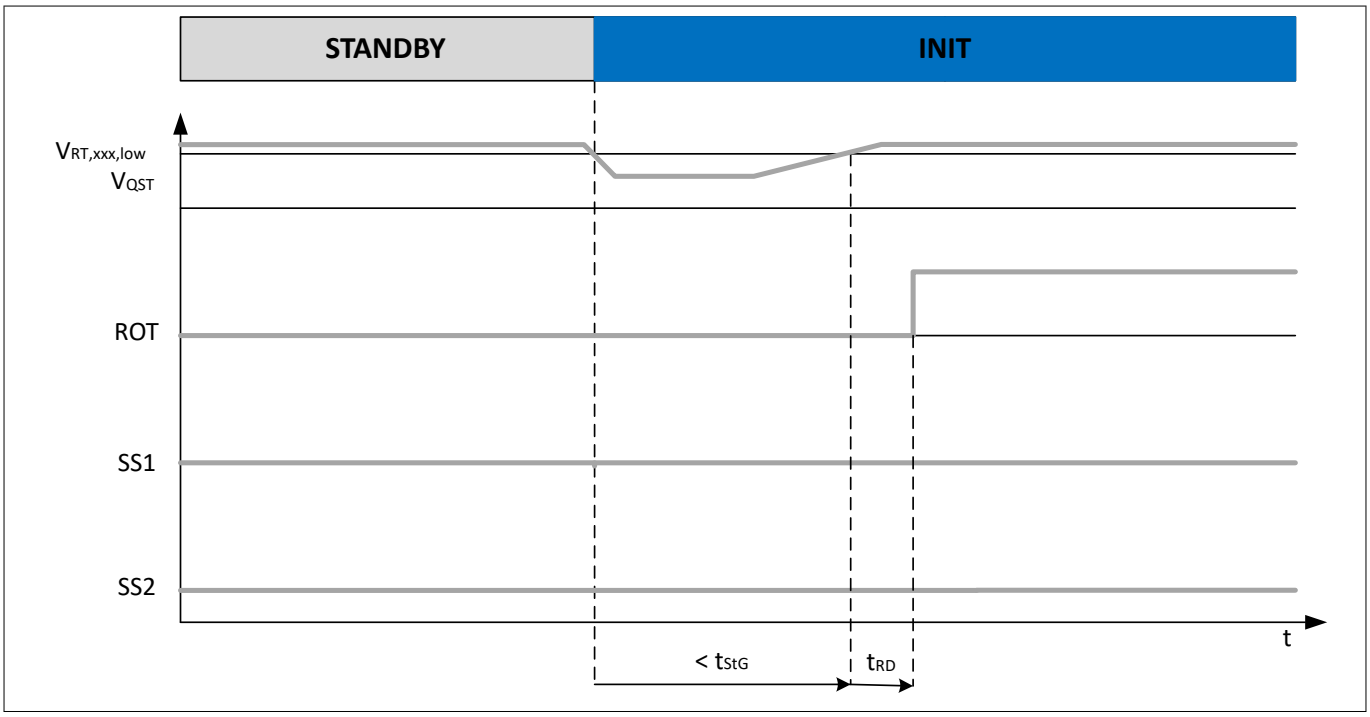


Figure 46 Transition from STANDBY to INIT-state

Description:

- The device performs a transition from STANDBY to INIT due to detected undervoltage of the MCU related voltage V_{QST} as shown in the figure. The undervoltage is shorter than the short to ground detection time t_{StG}. An undervoltage longer than the short to ground detection time t_{StG} would first lead to a transition from STANDBY to INIT-state and then, after the short to ground detection time t_{StG} has expired, to a transition from INIT to FAILSAFE-state.
- The power sequence is started after entering the INIT-state: the disabled outputs are re-activated. The QST keeps its configuration being ON.
- The power-on reset delay time is started according to the power sequencing and releases the ROT accordingly.
- The safe state signals SS1 and SS2 are "low" in STANDBY-state and remain "low" in INIT-state.

10.4.2.4 SLEEP → INIT-state due to detected fault

Timing diagram

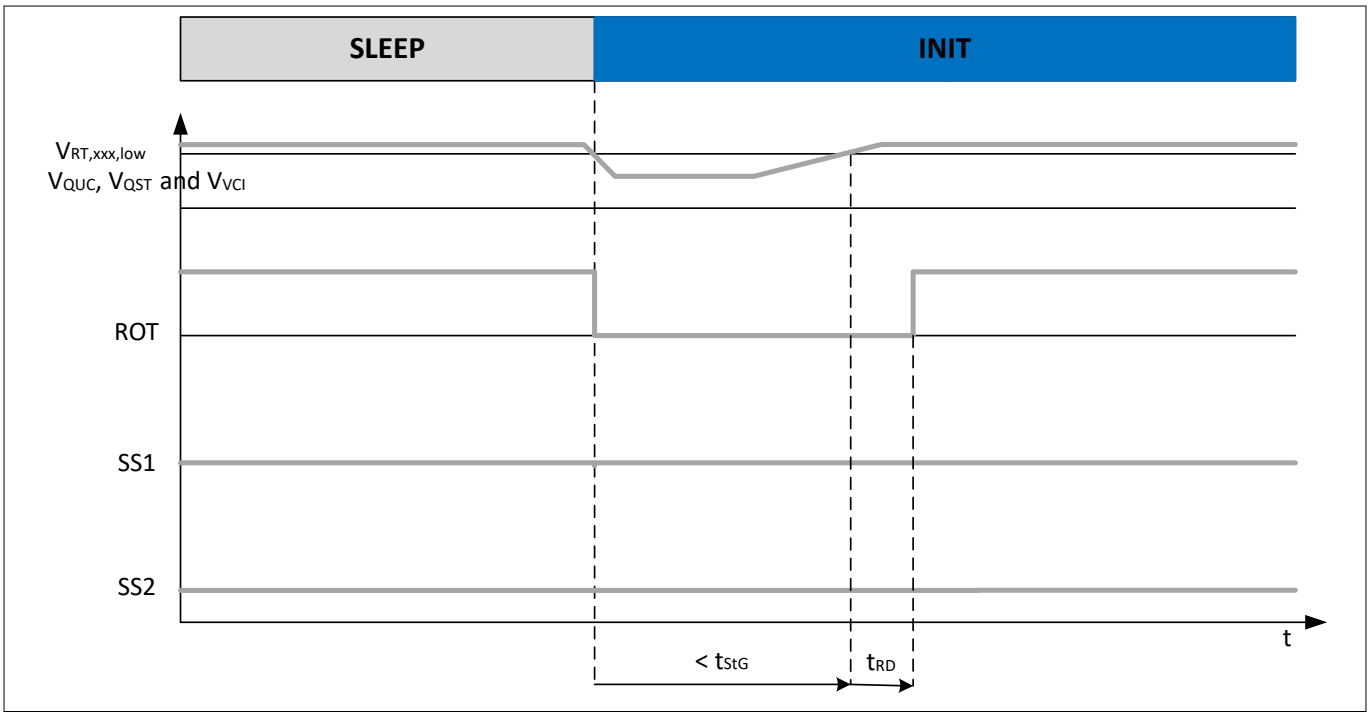


Figure 47 Transition from SLEEP to INIT-state

Description:

- The device transitions from SLEEP into INIT-state issuing a "soft reset" - pin ROT is pulled to "low" for a certain time t_{RD} and all the outputs are kept enabled. Outputs previously disabled in SLEEP-state get switched on again, except the QST keeps its configuration, ON or OFF.
- This might be issued by an undervoltage of the MCU related voltages V_{QUC}, V_{QST} or V_{VCI} as shown in the figure. The undervoltage is shorter than the short to ground detection time t_{StG}. The reset delay time t_{RD} is started as soon as all MCU related voltages V_{QUC}, V_{QST} or V_{VCI} are back in the valid range. The ROT pin is released accordingly. An undervoltage longer than the short to ground detection time t_{StG} would first lead to a transition from SLEEP to INIT-state and then, after the short to ground detection time t_{StG} has expired, to a transition from INIT to FAILSAFE-state.
- The "soft reset" can also be initiated by a window watchdog error counter overflow (> ΣWWO), a functional watchdog error counter overflow (> ΣFWO), an error indication (immediate or recovery delay time mode), if these monitoring functions are in use. In this case the reset delay time t_{RD} is started at the falling edge of the ROT pin. Please consider the state transition time to INIT-state in Table 25.
- The safe state signals SS1 and SS2 are "low" in SLEEP-state and remain "low" in INIT-state.

10.4.2.5 WAKE → INIT-state due to detected fault

Timing diagram

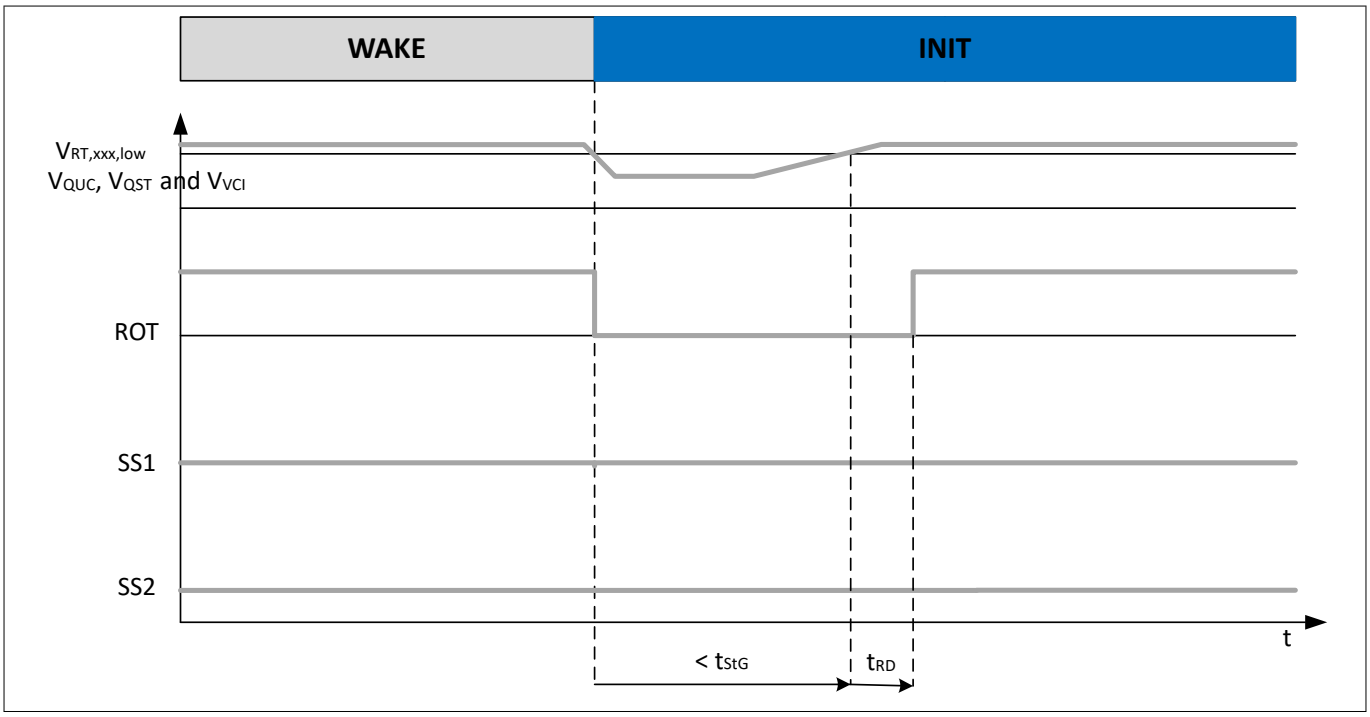


Figure 48 Transition from WAKE to INIT-state

Description:

- The device transitions from WAKE into INIT-state issuing a "soft reset" - pin ROT is pulled to "low" for a certain time t_{RD} and all the outputs are kept enabled. Outputs that were disabled in WAKE-state get switched on again, except the QST keeps its configuration, ON or OFF.
- This might be issued by an undervoltage of the MCU related voltages V_{QUC}, V_{QST} or V_{VCI} as shown in the figure. The undervoltage is shorter than the short to ground detection time t_{StG}. The reset delay time t_{RD} is started as soon as all MCU related voltages V_{QUC}, V_{QST} or V_{VCI} are back in the valid range. The ROT pin is released accordingly. An undervoltage longer than the short to ground detection time t_{StG} would first lead to a transition from WAKE to INIT-state and then, after the short to ground detection time t_{StG} has expired, to a transition from INIT to FAILSAFE-state.
- The "soft reset" can also be initiated by a window watchdog error counter overflow (> ΣWWO), a functional watchdog error counter overflow (> ΣFWO), an error indication (immediate or recovery delay time mode), if these monitoring functions are in use. In this case the reset delay time t_{RD} is started at the falling edge of the ROT pin. Please consider the state transition time to INIT-state in Table 25.
- The safe state signals SS1 and SS2 are "low" in WAKE-state and remain "low" in INIT-state.

10.4.3 Transition to FAILSAFE-state

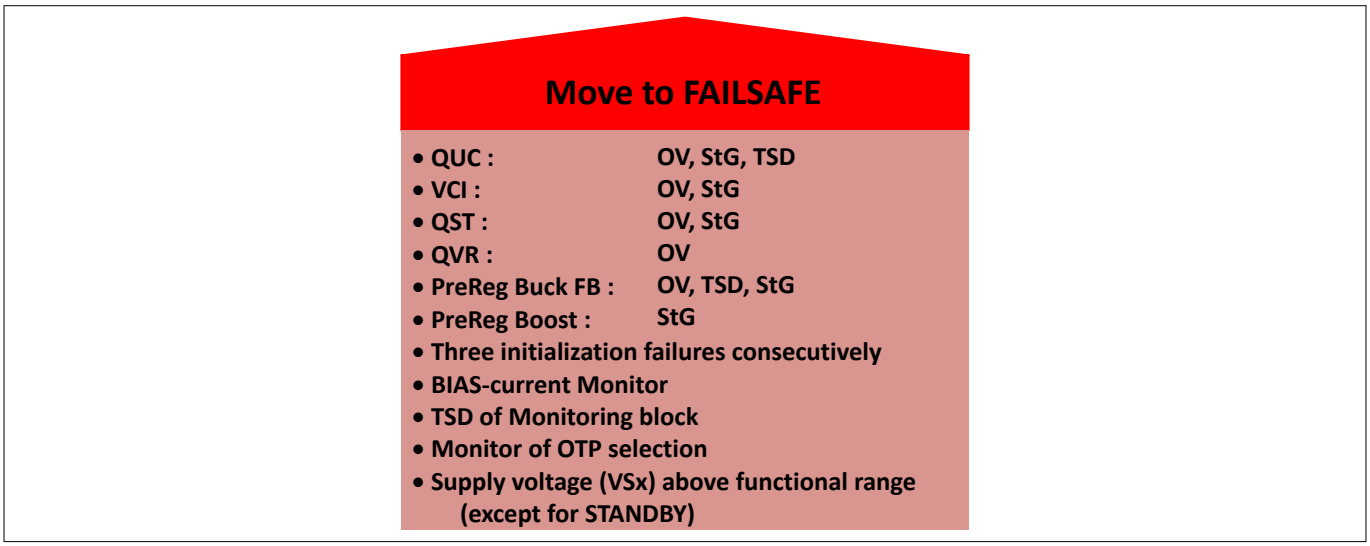


Figure 49 Move to FAILSAFE

On any of the following failures the device enters FAILSAFE-state:

- Detection of overvoltage, a short to ground at QUC, if in use
- Detection of thermal shutdown of QUC (except for STANDBY and SLEEP state)
- Detection of overvoltage or a short to ground at VCI or QST, if in use
- Detection of overvoltage at voltage reference, if in use
- Detection of overvoltage or short to ground (during start-up) at the step down pre-regulator, if in use. Short to ground detection is only active during start-up phase (power-sequencing) in INIT-state until the output voltage of the step-down pre regulator exceeds the undervoltage threshold and hysteresis ($V_{RT,FB,low}$+$V_{RT,FB,UV\ hyst}$). For increasing voltage V_{VS} at pin VS below functional range, the short to ground detection of pin FB gets only activated if the voltage at pin VS increases above $V_{start,StG,buck}$ to prevent movement to FAILSAFE in case of slow increasing input supply voltage (e.g. without step up pre-regulator).
- Detection of thermal shutdown of the step down pre-regulator (except for STANDBY and SLEEP state)
- Detection of short to ground (long term operation in current limit) of the step up pre-regulator, if in use
- Three consecutive initialization failures (e.g. configuration in INIT-state failed)
- A BIAS current monitor failure (except for STANDBY and SLEEP state)
- A overtemperature shutdown due to exceeded temperature in the monitoring block (except for STANDBY and SLEEP state)
- An OTP selection monitor failure due to a not correctable read error of internal one-time-programmed (OTP) information for trimming and output voltage configurations.
- An overvoltage at the supply pins (VSx) triggers the overvoltage protection and moves the device into FAILSAFE-state (except for STANDBY-state)

10.4.3.1 INIT → FAILSAFE-state due to detected fault

Timing diagram

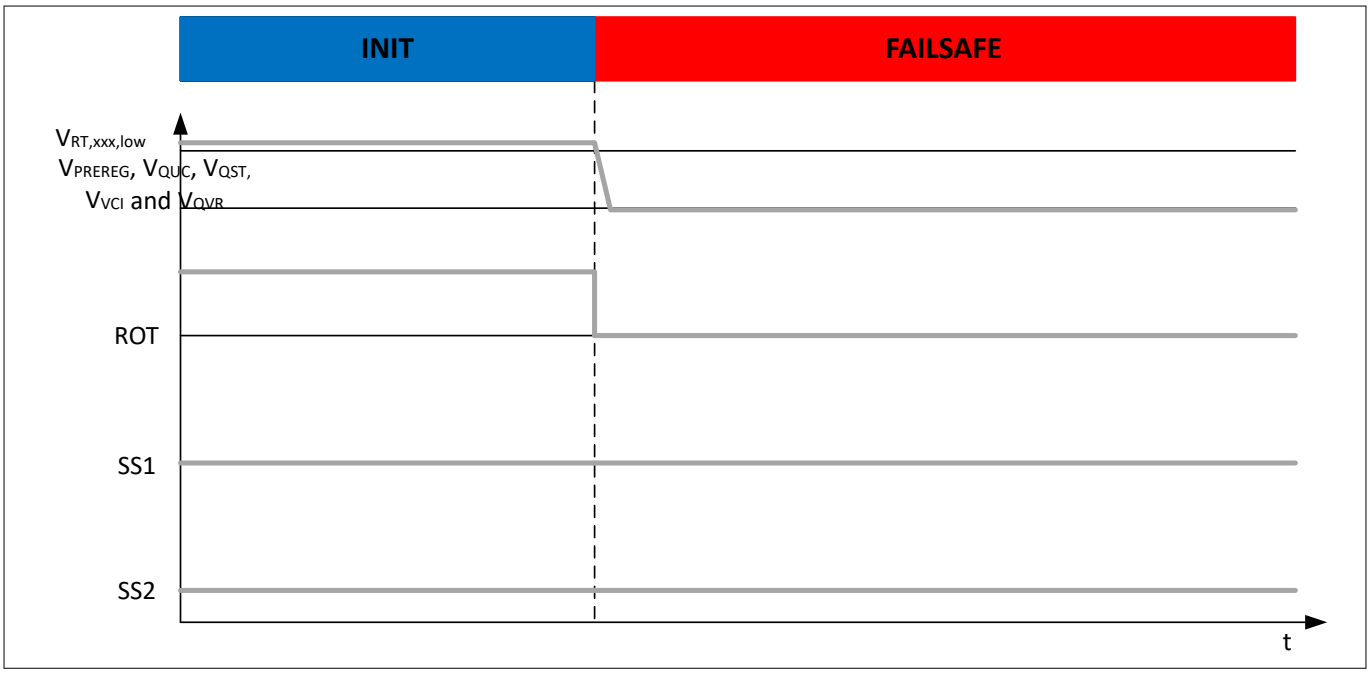


Figure 50 Transition from INIT to FAILSAFE-state

Description:

- The transition from INIT-state into FAILSAFE-state is initiated by any failure (external or internal) case mentioned in Chapter 10.4.3.
- Pin ROT is pulled to "low" as soon as one of the "Move to FAILSAFE" failures is detected, if is not already LOW due to an undervoltage on a MCU related regulator.
- All regulators are switched off, when the device turns from INIT into FAILSAFE-state, regardless of overvoltage condition.
- The safe state signals SS1 and SS2 are "low" in INIT-state and remain "low" in FAILSAFE-state.

10.4.3.2 XXXX → INIT → FAILSAFE-state due to detected fault

Timing diagram

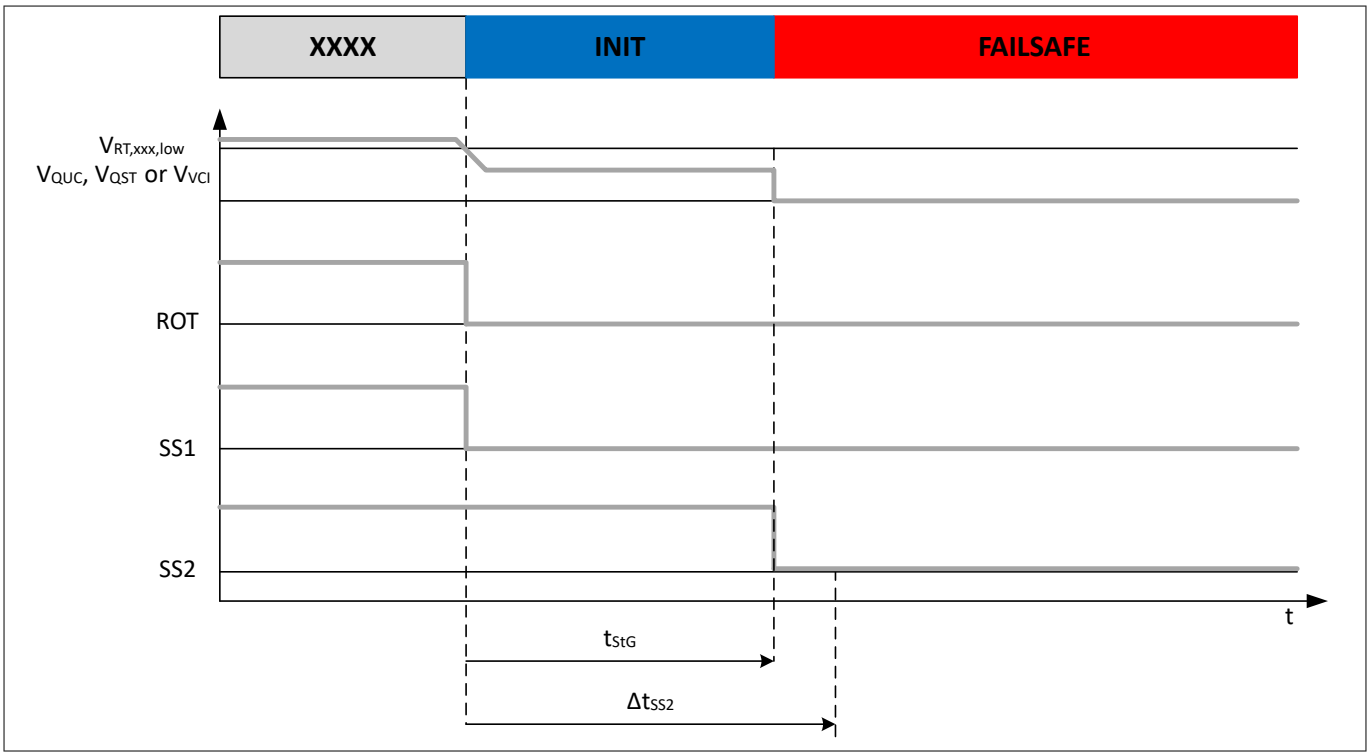


Figure 51 Transition from XXXX to INIT to FAILSAFE-state after detection of short to ground

Description:

- The detection of an undervoltage of the MCU related voltages V_{QUC}, V_{QST} or V_{VCI} as shown in the figure initiates the transition into INIT-state. (please refer to previous chapter Transition into INIT-state)
- Pin ROT is pulled to "low" as soon as the undervoltage is detected (at one or more of the regulators mentioned above)
- The safe state signal SS1 is pulled to "low" together with pin ROT going to low
- If the undervoltage condition of the MCU related voltages V_{QUC}, V_{QST} or V_{VCI} remains for longer than the short to ground detection time t_{StG} a short to ground event is detected.
- All regulators are switched off upon detection of short to GND event of the MCU related voltages V_{QUC}, V_{QST} or V_{VCI}, regardless if they are in undervoltage condition or not.
- The device moves from INIT-state to FAILSAFE-state
- The safe state signal SS2 is pulled to "low" together with the transition from INIT to FAILSAFE-state, even if the delay time Δt_{SS2} has not expired yet, because QUC is switched off (QUC is switched on in INIT-state, but switched off in FAILSAFE-state).

10.4.3.3 NORMAL → FAILSAFE-state due to detected fault

Timing diagram

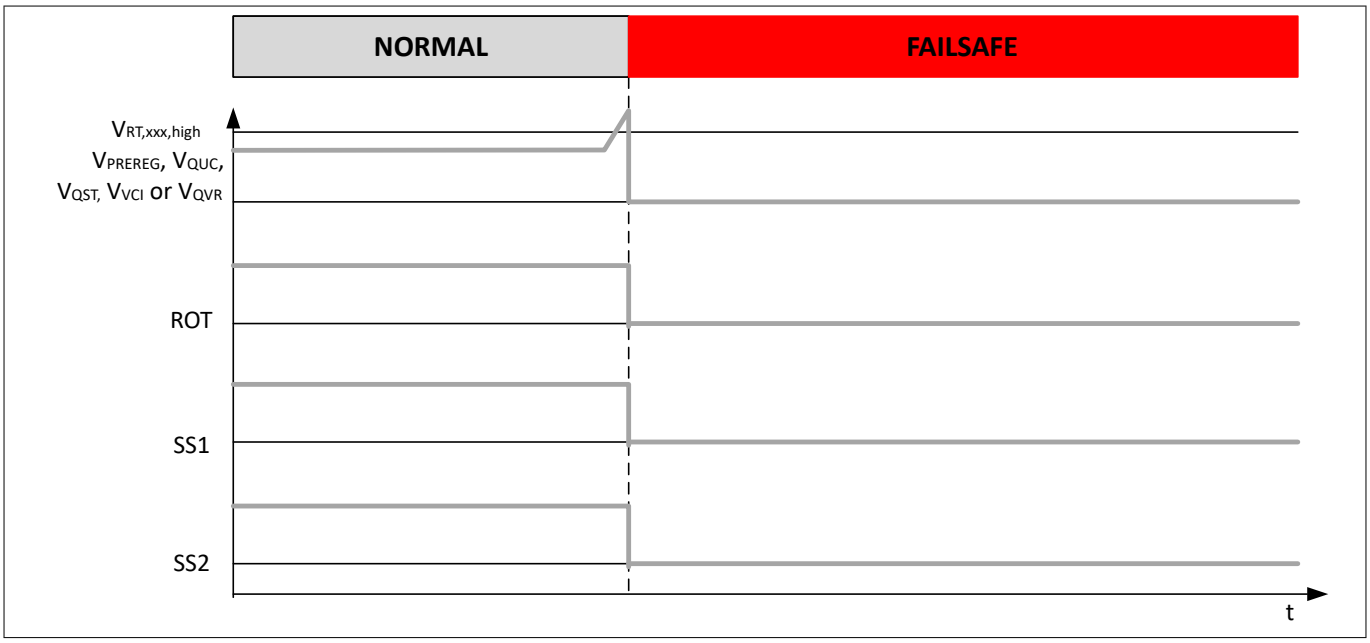


Figure 52 Transition from NORMAL to FAILSAFE-state

Description:

- The detection of an overvoltage of the pre-regulator voltage V_{PREREG} or the MCU related voltages V_{QUC}, V_{QST}, V_{VCI} or V_{QVR} as shown in the figure initiates the transition from NORMAL-state to FAILSAFE-state.
- Pin ROT is pulled to "low" as soon as the overvoltage event is detected (at one or more of the regulators mentioned above).
- All regulators are switched off, if the device enters FAILSAFE-state, regardless if they are in overvoltage condition or not.
- The safe state signals are pulled to "low" immediately with pin ROT pulled to "low", because the QUC is switched off.
- The transition from NORMAL-state into FAILSAFE-state is initiated by any failure (external or internal) case mentioned in Chapter 10.4.3.

10.4.3.4 STANDBY → FAILSAFE-state due to detected fault

Timing diagram

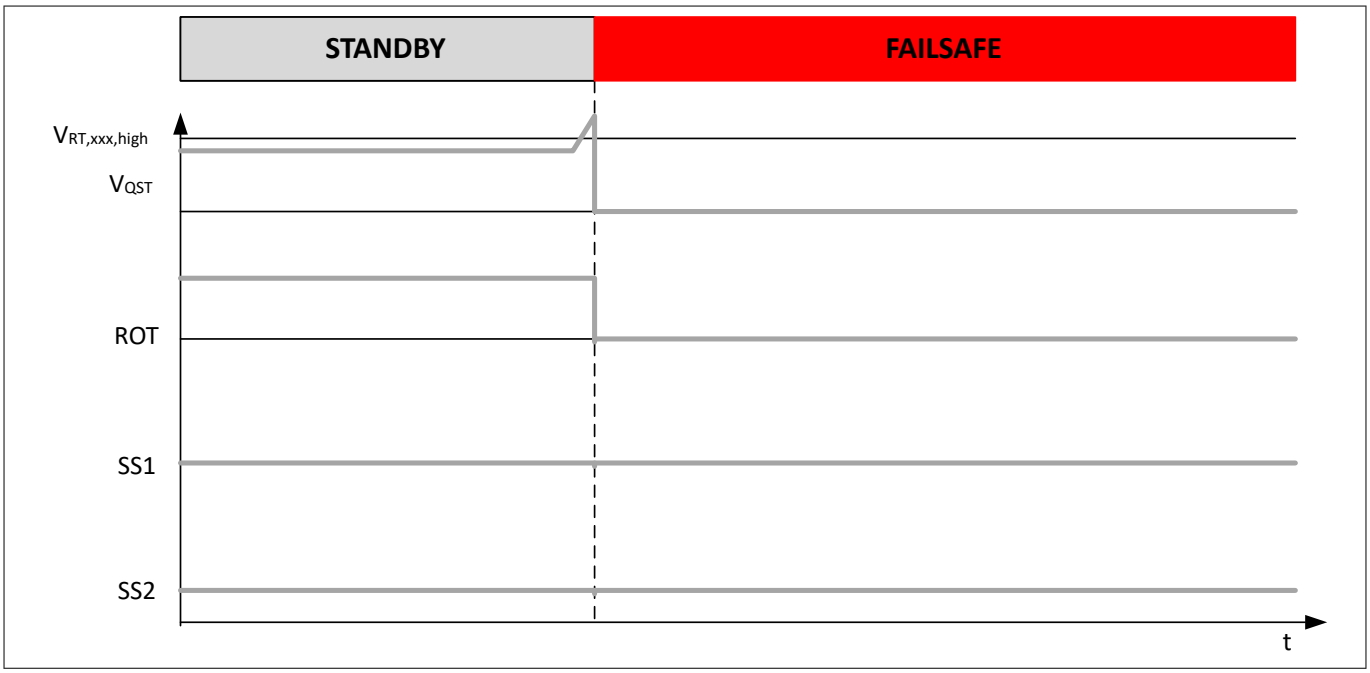


Figure 53 Transition from STANDBY to FAILSAFE-state

Description:

- The detection of an overvoltage of the MCU related voltage V_{QST} as shown in the figure initiates the transition from STANDBY-state to FAILSAFE-state.
- Pin ROT is "low" in STANDBY-state and remains "low" in FAILSAFE-state.
- The safe state signals SS1 and SS2 are "low" in STANDBY-state and remain "low" in FAILSAFE-state.

10.4.3.5 SLEEP → FAILSAFE-state due to detected fault

Timing diagram

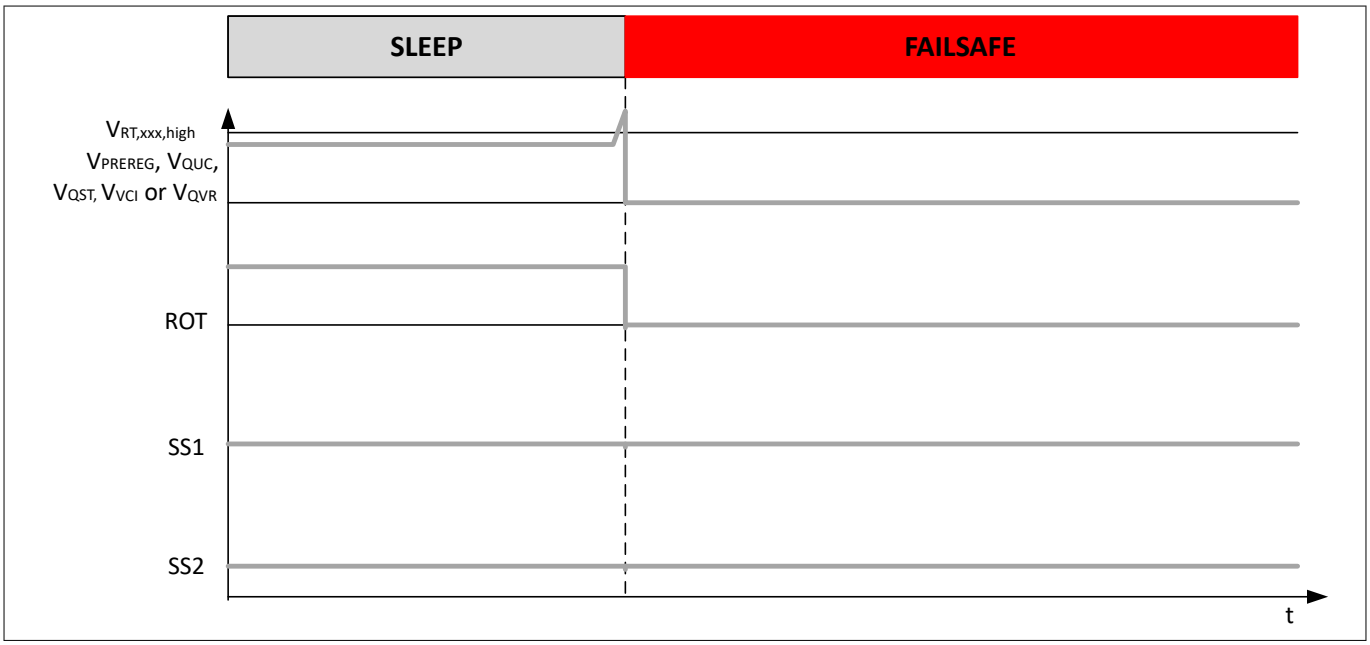


Figure 54 Transition from SLEEP to FAILSAFE-state

Description:

- The detection of an overvoltage of the pre-regulator voltage V_{PREREG} or the MCU related voltages V_{QUC}, V_{QST}, V_{VCI} or V_{QVR} as shown in the figure initiates the transition from SLEEP-state to FAILSAFE-state.
- Pin ROT is pulled to "low" as soon as the overvoltage event is detected (at one or more of the regulators mentioned above).
- All regulators are switched off, if the device transitions from SLEEP into FAILSAFE-state, regardless of overvoltage condition.
- The safe state signals remain at "low" as in the SLEEP-state.
- The transition from SLEEP-state into FAILSAFE-state is initiated by any failure (external or internal) case mentioned in Chapter 10.4.3.

10.4.3.6 WAKE → FAILSAFE-state due to detected fault

Timing diagram

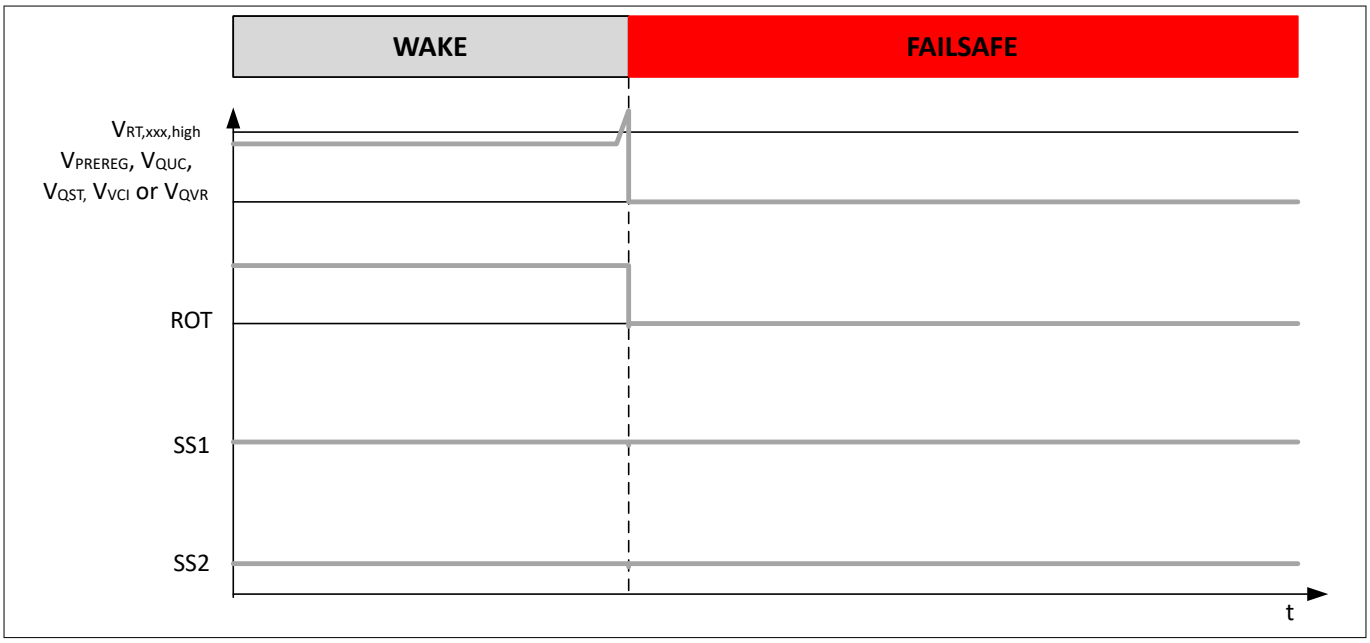


Figure 55 Transition from WAKE to FAILSAFE-state

Description:

- The detection of an overvoltage of the pre-regulator voltage V_{PREREG} or the MCU related voltages V_{QUC}, V_{QST}, V_{VCI} or V_{QVR} as shown in the figure initiates the transition from WAKE-state to FAILSAFE-state.
- Pin ROT is pulled to "low" as soon as the overvoltage event is detected (at one or more of the regulators mentioned above).
- All regulators are switched off, if the device transitions from WAKE into FAILSAFE-state, regardless of overvoltage condition.
- The safe state signals remain "low" as in the WAKE-state.
- The transition from WAKE-state into FAILSAFE-state is initiated by any failure (external or internal) case mentioned in Chapter 10.4.3.

10.4.3.7 Transition to FAILSAFE-state due to thermal shutdown

Timing diagram

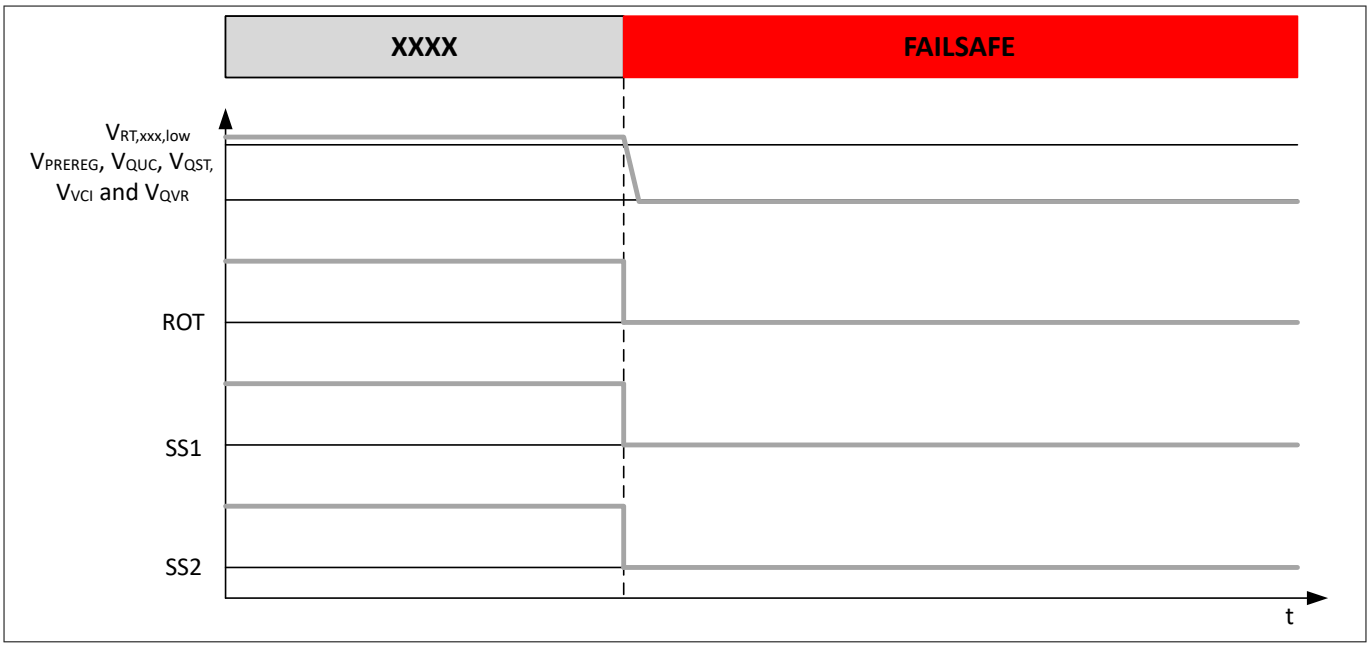


Figure 56 Transition to to FAILSAFE-state due to thermal shutdown

Description:

- The transition from any state into FAILSAFE-state is initiated by a thermal shutdown (TSD).
- Pin ROT is pulled to "low" as soon as the thermal shutdown is detected.
- All regulators are switched off, if the device transitions from XXXX into FAILSAFE-state, regardless of overtemperature condition.
- Out of NORMAL-state the safe state signals SS1 and SS2 are pulled to "low" immediately with pin ROT going to "low", because the QUC is switched off. Out of any other state the safe state signals SS1 and SS2 are "low" and remain "low".
- The device remains in FAILSAFE-state after a thermal shutdown (TSD) at least for $t_{FAILSAFE,min}$ of 1 second.

10.4.4 Transition to POWERDOWN

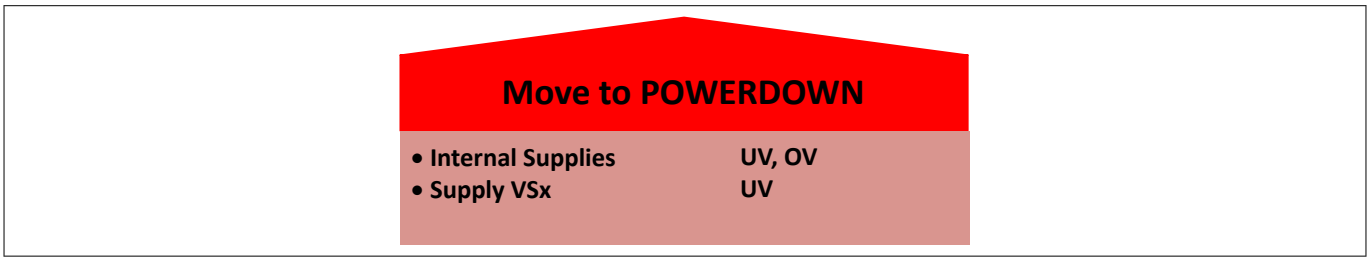


Figure 57 Move to POWERDOWN

On any of the following failures the device enters POWERDOWN always with highest priority:

- $V_{VS} < V_{PD,lo,min}$ when decreasing
- Detection of overvoltage or undervoltage on internal supplies

10.5 Electrical characteristics state machine

Table 25 Electrical characteristics state machine

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
INIT timer / Initialization time-out	t_{INIT}	550	600	650	ms	–	P_11.5.1
FAILSAFE time	$t_{FAILSAFE,min}$	18	20	22	ms	–	P_11.5.2
FAILSAFE time TSD	$t_{FAILSAFE,min}$	0.9	1	1.1	s	for thermal shutdown TSD	P_11.5.3
Transition delay timer accuracy	$\Delta t_{tr,del}$	-20	–	+20	%	[1] Configurable in DEVCFG0.TRDEL	P_11.5.4
QUC current monitoring for entering low power states	$\Delta I_{QUC,att}$	-40	–	+40	%	Configurable value DEVCFG2.CTHR ; I_{QUC} decreasing ; $V_{PREREG} > V_{QUC} + V_{dr,QUC}$	P_11.5.5
QUC current monitoring hysteresis for leaving low power states	$\Delta I_{QUC,att,hyst}$	+12	+33	+55	%	[2] Hysteresis is relative to the configurable value DEVCFG2.CTHR of $I_{QUC,att}$; I_{QUC} increasing ; $V_{PREREG} > V_{QUC} + V_{dr,QUC}$	P_11.5.9
State transition time	t_{tr}	–	–	100	µs	except transitions to SLEEP, to STANDBY [3] or from STANDBY	P_11.5.6
State transition time to INIT	$t_{tr,INIT}$	–	–	200	µs	valid for "Move to INIT" events excluding transitions from STANDBY, FAILSAFE and POWERDOWN	P_11.5.7
State transition time to INIT	$t_{tr,INIT}$	–	–	800	µs	valid for transitions from STANDBY, FAILSAFE and interrupted transition to STANDBY	P_11.5.8

1) Due to internal delays the transition delay time can increase by max 30 µs.

2) Specified by design, not subject to production test.
3) For transition times to SLEEP or STANDBY please refer to the transition delay timer configurable value DEVCFG0.TRDEL and its accuracy specified in Table 25.

10.6 Built in self test (BIST) features

The microcontroller can perform certain observation functions in the device via built in self-test features.

10.6.1 Analog Built In Self Test (ABIST)

TLF35585QUS02 provides the option to test the comparator and evaluation logic related to the monitoring functions contributing to the activation of the secondary safety shutdown path and the generation of an interrupt. Furthermore additional comparators and evaluation logic related to the Safe State Control itself can be tested (SSC overvoltage watchdog and toggling monitor). This is accomplished via an internal ABIST controller which performs tests on each comparator generating artificial undervoltage and overvoltage (or current) conditions, checks the result and generates the information which needs to be evaluated by the MCU to check, whether the ABIST operation was successful.

The following status information on ABIST operation is generated by the system:

- An ABIST operation requested by the MCU delivers the status as a result inABIST_CTRL0.STATUS. This status needs to be evaluated by the MCU. The provided status is just a GO-NOGO information, which means information about a particularly tested path is provided. The basic comparator function is tested, but not the respective threshold values.

The test of the monitoring and safety relevant output functions can run on three different areas in the system:

- The functionality of a comparator and its corresponding deglitching logic can be tested by a "comparator only" test. This test is performed by generating the failure condition for a time shorter than the deglitching time, so neither the secondary safety shutdown path nor an interrupt is triggered due to the injected failure. During this test only the selected comparator(s) are tested. In case more than one comparator is selected, the test is performed with a fixed sequence of comparators to be tested. The completion of the test is indicated by an interrupt.
- The functionality of a comparator including its corresponding deglitching logic and the contribution to the respective safety measure can be tested. The safety measure is either the activation of the secondary safety shutdown path or the generation of an interrupt. This test is performed in a time longer than the deglitching time.
- While the device provides information about the status for the first and the second ABIST, further microcontroller cooperation is required for the third area. The MCU needs to check for either successful activation of the secondary safety shutdown path (SS1/SS2 are set "low") or an interrupt event.

***Note**: After the first undervoltage (UV) comparator test in the ABIST full-path sequence related to QST and/or QUC, the DISOFFSET feature is disabled following the deglitching time and re-enabled before the ABIST sequence ends.*

10.6.1.1 How to run the ABIST

During ABIST, servicing of the watchdog(s) and error monitoring is necessary according to the configuration by the microcontroller. Otherwise the failure events in these functions lead to the assertion of interrupt, reset or safe state output, which distorts the ABIST results. Optionally watchdog functionality and/or error monitoring can be disabled during ABIST operation via a protected register access. In this case, no servicing is required.

During ABIST including the deglitching logic the status flag registers (SYSFAIL, INITERR, IF) as well as the status information (MONSF1, MONSF2, MONSF3) are triggered and updated by out of range conditions caused by the ABIST functionality, which has to be considered beside the results provided in the ABIST related registers (ABIST_CTRL0 to ABIST_SELECT2).

During ABIST the assertion of ROT due to the occurrence of any event which is supposed to trigger the respective action and is part of the logic which is affected by the ABIST control is blocked. In addition, the state machine does not change its state according to the reaction on detected faults described in Chapter 10.4. In case an ABIST contributing to the secondary safety shutdown path is started and the device is in NORMAL-state, the state machine moves from NORMAL to WAKE-state. All voltages remain enabled regardless of any out of range detection caused by ABIST itself.

The test of a single functionality is performed in the following way:

- All comparators are assumed to be enabled in case they are selected to be tested. Accordingly, configurable supplies have to be enabled before they can be tested. On the other hand the ABIST test on a comparator which is not used by the system is not required to be performed.
- The comparators to be tested shall be selected by setting the individual bit(s) in the respective register(s) (ABIST_SELECT0, ABIST_SELECT1 and ABIST_SELECT2). For this selection it is necessary to differentiate by the contribution to the different safety measures, see Table 26.
- The microcontroller shall configure the register ABIST_CTRL0 according to the functionality to be tested. The configuration consists of the tested safety measure (ABIST_CTRL0.INT), the tested area/coverage by the ABIST (ABIST_CTRL0.PATH) and the configuration whether one single or more comparators in sequence shall be tested (ABIST_CTRL0.SINGLE).
- The microcontroller shall set the global ABIST start bit (ABIST_CTRL0.START) to start the ABIST. The global ABIST start bit shall be read by the MCU. If this bit is still set, ABIST is ongoing. Upon completion of the selected ABIST operation(s) the start bit is cleared and an interrupt event is generated. Each bit which has been set to select the test of a dedicated comparator (ABIST_SELECT0, ABIST_SELECT1 and ABIST_SELECT2) is cleared once a successful ABIST operation has been performed on the particular comparator. Each bit which has been set to select the test of a dedicated comparator is kept unchanged if the ABIST operation on this particular comparator has not been performed successfully.

In this way the MCU can determine which comparator failed in case the ABIST status information shows a failing ABIST operation.

Table 26 Contribution of comparators to safety measures

Comparator	Secondary safety shutdown path	Interrupt	ABIST_Select register bit
QUC Overvoltage	X		ABIST_SELECT0.UCOV
Core_Sup Overvoltage	X		ABIST_SELECT0.VCOREOV
QST Overvoltage	X		ABIST_SELECT0.STBYOV
QVR Overvoltage	X		ABIST_SELECT0.VREFOV
PreReg Overvoltage	X		ABIST_SELECT0.PREGOV
QUC Undervoltage	X		ABIST_SELECT1.UCUV

(table continues...)

Table 26 (continued) Contribution of comparators to safety measures

Comparator	Secondary safety shutdown path	Interrupt	ABIST_Select register bit
Core_Sup Undervoltage	X		ABIST_SELECT1.VCOREUV
QST Undervoltage	X		ABIST_SELECT1.STBYUV
BIAS current low	X		ABIST_SELECT2.BIASLOW
BIAS current high	X		ABIST_SELECT2.BIASHI
Supply VS Overvoltage	X		ABIST_SELECT2.VBATOV
Tracker 1 Overvoltage		X	ABIST_SELECT0.TRK1OV
Tracker 2 Overvoltage		X	ABIST_SELECT0.TRK2OV
QCO Overvoltage		X	ABIST_SELECT0.COMOV
QVR Undervoltage		X	ABIST_SELECT1.VREFUV
Tracker 1 Undervoltage		X	ABIST_SELECT1.TRK1UV
Tracker 2 Undervoltage		X	ABIST_SELECT1.TRK2UV
QCO Undervoltage		X	ABIST_SELECT1.COMUV
Pre_Reg Undervoltage		X	ABIST_SELECT1.PREGUV
V_{BG1} - 4% ≤ V_{BG2}		X	ABIST_SELECT2.BG12UV
V_{BG1} + 4% ≥ V_{BG2}		X	ABIST_SELECT2.BG12OV

10.6.1.2 Testing the comparator logic only

During the ABIST operation the comparators are triggered by the ABIST controller for a time shorter than the internal deglitching time t_{rr} (monitoring reaction time). A properly working comparator signals an out of range condition to its output for the time the failure condition is applied.

The provided information of each comparator is checked against the expected value. If the comparator output value matches the expected value this is considered a passed test by the ABIST controller. If any of the provided output values does not match the expected value, this is considered a failed test. The general result of the ABIST is provided by the STATUS in the register ABIST_CTRL0. The detailed result for each selected comparator can be checked by the registers ABIST_SELECT0, ABIST_SELECT1 and ABIST_SELECT2. In case the previously selected bits are reset after the test is finished, it can be considered passed. A bit which remains set, indicates the failing comparator(s), leading to the overall STATUS failed.

The maximum selection[3)] for the comparator test is:

Secondary safety shutdown path (SS1/2) related:

- ABIST_SELECT0: 00101111_B ($2F_H$)
- ABIST_SELECT1: 00001110_B ($0E_H$)
- ABIST_SELECT2: 11000001_B ($C1_H$)
- Start of the test by ABIST_CTRL0: 00000001_B (01_H)

Interrupt (INT) related:

- ABIST_SELECT0: 11010000_B ($D0_H$)
- ABIST_SELECT1: 11110001_B ($F1_H$)
- ABIST_SELECT2: 00110000_B (30_H)
- Start of the test by ABIST_CTRL0: 00001001_B (09_H)

This type of ABIST can be performed in the following states: INIT, NORMAL, WAKE. In case of a successful ABIST, there shall be no reaction of secondary safety shutdown path SS1, SS2 and only an interrupt generated due to the finished ABIST (IF.ABIST set and IF.MON not set, considering cleared interrupt flags prior to the ABIST and no real failure events during the ABIST).

3 Please mind that for a test of a comparator the corresponding output has to be enabled.

10.6.1.3 Testing the comparator logic and the corresponding deglitching logic

During the ABIST operation the comparators are triggered by the ABIST controller for a time longer than the internal deglitching time t_{rr} (monitoring reaction time). A properly working comparator signals an out of range condition to its output for the time the failure condition is applied. The deglitching logic forwards the failure trigger after t_{rr} and makes the device react on the recognized failure event. This reaction consists of the storage of the respective monitoring failure flags and of the triggering of the respective output function, which is either the interrupt INT or the secondary safety shutdown path SS1/2. The reaction of the safe state outputs SS1/2 can only be observed in case the test is started in NORMAL-state.

Furthermore the provided information of each deglitching logic output is checked against the expected value. If the deglitching logic output value matches the expected value this is considered as a passing test by the ABIST controller. If any of the provided output values do not match the expected value, this is considered as a failing test. The general result of the ABIST is provided by the STATUS in the register ABIST_CTRL0. The detailed result for each selected comparator can be checked by the registers ABIST_SELECT0, ABIST_SELECT1 and ABIST_SELECT2. In case the previously selected bits are reset after the test is finished, it can be considered as pass recognized by the ABIST controller. A bit which is still set, would indicated the failing comparator(s), that makes the overall STATUS to be failed.

Beside the results read from the ABIST controller related registers, the result provided in the failure/interrupt flags (SYSFAIL, INITERR and IF) and monitoring status flags (MONSF1, MONSF2 or MONSF3) have to be read and checked by the microcontroller against the expected result considering the configuration set before the start of the ABIST.

The maximum selection[4)] for the comparator and deglitching logic test would be the following:

Secondary safety shutdown path (SS1/2) related:

- ABIST_SELECT0: 00101111_B ($2F_H$)
- ABIST_SELECT1: 00001110_B ($0E_H$)
- ABIST_SELECT2: 11000001_B ($C1_H$)
- Start of the test by ABIST_CTRL0: 00000011_B (03_H)

Interrupt (INT) related:

- ABIST_SELECT0: 11010000_B ($D0_H$)
- ABIST_SELECT1: 11110001_B ($F1_H$)
- ABIST_SELECT2: 00110000_B (30_H)
- Start of the test by ABIST_CTRL0: 00001011_B ($0B_H$)

4 Please mind that for a test of a comparator the corresponding output has to be enabled.

The analysis based on the maximum possible selection consist of the following:

Secondary safety shutdown path (SS1/2) related:

- IF: 01000000_B (40_H)
- INITERR: 00000100_B (04_H)
- SYSFAIL: 00000100_B (04_H)
- MONSF1: 00101111_B ($2F_H$)
- MONSF2: 00001110_B ($0E_H$)
- MONSF3: 11000001_B ($C1_H$)

Interrupt (INT) related:

- IF: 01001000_B (48_H)
- INITERR: 00000000_B (00_H)
- SYSFAIL: 00000000_B (00_H)
- MONSF1: 11010000_B ($D0_H$)
- MONSF2: 11110001_B ($F1_H$)
- MONSF3: 00110000_B (30_H)

This type of ABIST can be performed in the following states of the State machine: INIT, WAKE, NORMAL. If this test is run in NORMAL-state on comparators contributing to the secondary safety shutdown path the device switches the safe state outputs SS1, SS2 to "low"and the State machine moves to WAKE-state, without triggering a reset ROT.

It has to be considered, that testing the complete monitoring chain to the respective output (SS1/2 or INT) in this way covers only the first comparator in the sequence, as this one triggers the output reaction. For further details, please refer to Chapter 10.6.1.4.

If this test is run in INIT or WAKE-state, contribution to activation of the secondary safety shutdown path cannot be tested. The system is in a safe state already and the secondary safety shutdown path is already activated.

The proper behavior of the secondary shutdown path as well as the interrupt signal needs to be checked by the microcontroller.

10.6.1.4 Testing the complete monitoring chain (comparators, deglitching and output)

The testing of the complete monitoring chain from the comparator till the respective output function has to be divided into the two functions available in the device. First the secondary safety shutdown path called SS1/2 for severe microcontroller related failure events and secondly the interrupt function INT for peripheral related failure events in terms of voltage and current monitoring.

10.6.1.4.1 Testing the activation of the secondary safety shutdown path

Testing the activation of the secondary safety shutdown path, the device must be in NORMAL-state. The MCU shall check if the secondary safety shutdown path has been de-activated successfully (SS1/2 high).

Once in NORMAL-state a single comparator contributing to the secondary safety shutdown path shall be selected. A single bit ('x') has to be set for a corresponding comparator in registers ABIST_SELECT0 ($00x0xxxx_B$), ABIST_SELECT1 ($0000xxx0_B$) or ABIST_SELECT2 ($xx00000x_B$). A random selection by the microcontroller ensures maximum coverage of the contributions to the secondary safety shutdown path. Then a single comparator ABIST operation on the full path of the secondary safety shutdown path needs to be started (register ABIST_CTRL0: 00000111_B (07_H)). Upon completion of the requested ABIST operation the device enters WAKE-state and an interrupt event is generated. An interrupt event indicates the completion of the ABIST (IF.ABIST). Furthermore the respective monitoring failure flag for the selected comparator is set (either INITERR.VMONF for "Figure 42" failures or SYSFAIL.VMONF for "Figure 49" failures) which has to be checked and cleared by the microcontroller.

The secondary safety shutdown path shall be activated (SS1/2 "low"). It is the responsibility of the MCU to check the activation of the secondary safety shutdown path. If SS2 delay is enabled, this delay is applied when the ABIST operation is performed, i.e. the activation of the shutdown path connected to SS2 is delayed according to the programmed value for failure cases not leading to FAILSAFE. The MCU needs to read and check the status of the requested ABIST operation (ABIST_CTRL0.STATUS), the respective monitoring status flag (MONSF1, MONSF2 or MONSF3) to be set according to the previous selection and ABIST_SELECT0, ABIST_SELECT1 and ABIST_SELECT2 bits to be cleared.

Furthermore, the microcontroller has to proceed with the following steps to check the Safe State Control and the safe state outputs:

- Check that the secondary safety shutdown path has been activated successfully (SS1/2 "low")
- Enable the overvoltage trigger and the generation of valid local toggling signal of the Safe State Control (set ABIST_CTRL1.OV_TRIG and ABIST_CTRL1.ABIST_CLK_EN)
- Wait for 50 µs and check that the secondary safety shutdown path is still activated (SS1/2 "low")
- De-select the generation of local toggling signal and the overvoltage trigger for the Safe State Control (reset ABIST_CTRL1.ABIST_CLK_EN and ABIST_CTRL1.OV_TRIG)
- Wait for 50 µs and check that the secondary safety shutdown path is still activated (SS1/2 "low")

Afterwards a test of all comparators which contribute to the activation of the secondary safety shutdown path shall be configured and started according to Chapter 10.6.1.3.

10.6.1.4.2 Testing the generation of an interrupt event

The test of the generation of an interrupt event can be done in the states INIT, NORMAL and WAKE-state. Even though it is recommended to have the application in safe state (INIT or WAKE-state).

For this test first a single comparator contributing to the interrupt function shall be selected. A single bit ('x') has to be set for a corresponding comparator in registers ABIST_SELECT0 ($xx0x0000_B$), ABIST_SELECT1 ($xxxx000x_B$) or ABIST_SELECT2 ($00xx0000_B$). A randomized selection by the microcontroller ensures maximum coverage of the contributions to the interrupt function. Then a single comparator ABIST operation on the full path of the interrupt needs to be started (register ABIST_CTRL0: 00001111_B ($0F_H$)). The artificial failure, triggered by the ABIST controller, on the selected comparator generates an interrupt (INT) event. It is the responsibility of the MCU to check the generation of this interrupt event on the triggered failure. As this is a test of the generation of an interrupt based on a failure event, there is no dedicated ABIST completion event via interrupt function, but only the ABIST bit in the interrupt flags is set. After the interrupt related to the injected fault has been generated, the interrupt flag register shall be checked for the monitoring bit (IF.MON) set and the ABIST completion bit (IF.ABIST) set.

The MCU needs to read and check the status of the requested ABIST operation (ABIST_CTRL0.STATUS), the respective monitoring status flag (MONSF1, MONSF2 or MONSF3) to be set according to the previous selection and ABIST_SELECT0, ABIST_SELECT1 and ABIST_SELECT2 bits to be cleared.

Afterwards a test of all comparators which contribute to the interrupt generation shall be configured and started according to Chapter 10.6.1.3.

10.6.1.5 Abort conditions for ABIST operation

In case of a severe monitoring failure event (contribution to the secondary safety shutdown path) detected on a not selected comparator[5)] or a severe failure event not related to the voltage or bias current monitoring function during the proceeding of an ABIST operation on the comparators only (ABIST_CTRL0.PATH not set), the device reacts like outside ABIST. Accordingly the monitoring, reset and Safe State Control react. Bringing the device into safe state and trigger the State machine to move into FAILSAFE or INIT-state. The ABIST is aborted in this case.

In case of an ABIST operation on the full path (ABIST_CTRL0.PATH set) the comparators for voltage and bias current monitoring are not operational during ABIST operation on the particular comparator. Therefore it is recommended to do the test in safe state unless it is needed to start the test in NORMAL-state (e.g. test of activation of secondary safety shutdown path described in Chapter 10.6.1.4.1). Severe failure events not related to the voltage and bias current monitoring trigger the same device reaction as outside ABIST: the device enters safe state and triggers a transition to FAILSAFE or INIT-state. The ABIST is aborted in this case.

This ABIST abort is shown by the device in the register SYSFAIL.ABISTERR. The artificial failure events, that have been generated until the abort of the ABIST due to the detected real failure, is stored as well in the monitoring registers. In such case the ABIST should be repeated.

5 Please mind that selected comparators are not operational during ABIST operation on the particular comparator. Therefore it is recommended to do the test in safe state unless it is necessary to start the test in NORMAL-state (e.g. test of activation of secondary safety shutdown path described in Chapter 10.6.1.4.1).

10.6.2 Logic supervision self test

No dedicated Built In Self Test for the digital monitoring functions exists in the device. It is assumed that any test which is related to the digital monitoring functions is performed by the MCU in a functional way.

The following blocks inside the digital supervision functions can be tested by the MCU:

- FWD/WWD
- Error monitoring

In order to verify correct functionality of these blocks and to check their contribution to ROT/INT and finally SS1/2 the MCU shall generate an error condition on the particular block and check the expected system behavior.

- For the watchdog functionality this means either stop triggering the WD(s) and/or generate false trigger events. This generates either an interrupt or even asserts the reset. Finally the secondary safety shutdown path is activated (SS1/2 set to "low"), the MCU is reset and the device moves into INIT-state. In order to verify the activation of the secondary shutdown path, this kind of test shall only be executed after the device entered NORMAL-state.
- For the error monitoring block, this means that the toggling at the ERR pin needs to be stopped in order to observe the required system behavior. It is up to the MCU to make use of the error recovery mechanism.

The microcontroller programming support function can suppress the reset (ROT) event for the supervision functions mentioned above keeping the interrupt and safe state contribution unchanged. This may be used to optimize the logic supervision self test focusing on the safety relevant output functions (INT and SSx). For details please refer to Chapter 10.7.

10.7 Microcontroller programming support

The device offers a microcontroller programming support feature, that can be used to avoid periodic reset triggering due to missing triggering of the window watchdog and error monitoring within the INIT timer.

The activation of the microcontroller programming support feature is supported by (OR combined):

- pulling the MPS pin to a voltage $V_{MPS,hi}$. The voltage shall be provided earliest with the enabling of the microcontroller supply QUC. Therefore during microcontroller programming or debugging, it is an option to connect the MPS pin to the output of QVR or QUC.
- sending a SPI command to MCSMON.MPS

The status bit field MCSMON.MPSPIN represents the actual activation status controlled by the MPS pin.

The active microcontroller programming support (MPS) feature includes the following changes to the normal operation of the device:

- The initialization timer is stopped.
- The contribution of the window watchdog error counter overflow to the reset ROT output is blocked.
- The contribution of the functional watchdog error counter overflow to the reset output ROT is blocked.
- The contribution of the error monitoring to the reset output ROT is blocked.

The state machine, interrupt function and Safe State Control (SSC) function are not affected. An invalid watchdog service warning or an ERR monitoring warning (if recovery delay configured) still issues an interrupt event. An overflow of a watchdog error counter and a detected ERR monitoring failure triggers a "Move to INIT" event and the corresponding SSC reaction to set SS1/SS2 to low, but without issuing a reset (ROT) of the microcontroller. This feature may be used for time-optimized fault-injection tests of the digital supervision functions (WWD, FWD, ERR) as well as for application boundary conditions where no reset of the microcontroller is desired for watchdog or error monitoring failures, but maintaining active the safety related supervision and output functions. The chapter below describes exceptions and special treatments to MPS function.

For example, if the MPS pin is "high" or bitfield MPSPIN is set in NORMAL and there is a watchdog error counter overflow, then the device enters INIT without issuing a reset at pin ROT, but still sets SS1 and SS2 "low".

Table 27 Electrical characteristics: microcontroller programming support

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
MPS valid high level	$V_{MPS,hi}$	2.0	–	–	V	–	P_11.7.1
MPS valid low level	$V_{MPS,lo}$	–	–	0.8	V	–	P_11.7.2
MPS pin pull-down current	I_{MPS}	–	150	330	µA	–	P_11.7.4

11 Safe State Control function

11.1 Introduction Safe State Control function

The Safe State Control monitors safety related signals and controls the safe state signals SS1 and SS2.

The following description summarizes the contributors to the Safe State Control function and the possibilities to adjust them.

Principle of operation

The Safe State Control function monitors the following inputs:

- Result of the Error Monitoring. Signal at pin ERR is expected to be a toggling signal. A permanent "low" or "high" signal is detected as an error.
- Over and undervoltage of the microcontroller related regulators (for details please refer to chapter Monitoring function)
- Result of Window Watchdog error counter threshold comparator. Whether threshold ΣWWO for "Invalid window watchdog triggering" has been reached or exceeded.
- Result of Functional Watchdog error counter threshold comparator: Whether threshold ΣFWO for "Invalid functional watchdog triggering" has been reached or exceeded.
- Thermal shutdown signal (TSD) for relevant events moving the device into FAILSAFE-state.
- Internal clock
- SPI state transition request. A "Go to NORMAL" command triggers the signals SS1/2 to switch "high" in case the other boundary conditions are fulfilled. Moving the device out of NORMAL-state by SPI command switches the signals SS1 and SS2 (optionally delayed by Δt_{SS2}) to low.

The following parameters of the Safe State Control function are programmable via SPI. These settings can be done during INIT, NORMAL and WAKE-state, WWD and FWD configuration and error pin configuration including disabling of individual functionality via protected register (for description of states please refer to chapter State machine):

- Number of invalid watchdog triggers, that lead to activating SS1 and SS2: there are two watchdog trigger error counters implemented, one for the window watchdog the other for the functional watchdog. Every counter increments by two at every invalid watchdog triggering and decrements by one at every valid watchdog triggering, see chapter Functional watchdog. An incrementing change is indicated by an interrupt. A decrementing change is not indicated by an interrupt. The thresholds can be programmed by SPI command for each counter individually. This function might be used to test the watchdog function.
- Immediate reaction or recovery delay reaction, only related to input signal ERR: this parameter determines whether the Safe State Control reacts immediately to an error indicated by SMU or reacts after a certain delay, if the error indication is still present. In recovery delay reaction the Safe State Control generates an interrupt and starts the programmed recovery delay time. If the error disappears within this time because the error signal toggles again, the Safe State Control keeps the safe state output SS1/2 high. If within this time the error should not disappear and maintain the error indication (means the error signal should not toggle again, before the recovery delay time has ended), the Safe State Control activates the safe state signals SS1 and SS2 after the recovery delay time has ended. Immediate reaction means reaction after signal detection delay time.
- Recovery delay time Δt_{REC}, only related to input signal ERR: only errors (violation of valid ERR signal) which persist longer than this delay time activate the safe state signals SS1 and SS2. This delay time is only active if recovery delay time mode was selected.
- Delay time Δt_{SS2} between safe state signal 1 and safe state signal 2

The safe state function offers two output signals, both of them as output stages to drive external switches (additional driver stage is necessary):

- Safe state signal 1 (present at pin SS1)
- Safe state signal 2 (present at pin SS2) can be delayed compared to safe state signal 1 by an adjustable delay time Δt_{SS2} (via SPI)

Error signal from microcontroller safety management unit (SMU) at pin ERR

The error monitoring function requires a toggling signal at pin ERR with a determined timing in case of fault-free operation of the microcontroller by its SMU. This toggling signal is considered a "being alive" indication. An error should be indicated by a constant low signal. A constant high signal is regarded as a failure indication as well, probably caused by a short circuit. The result is given to the Safe State Control.

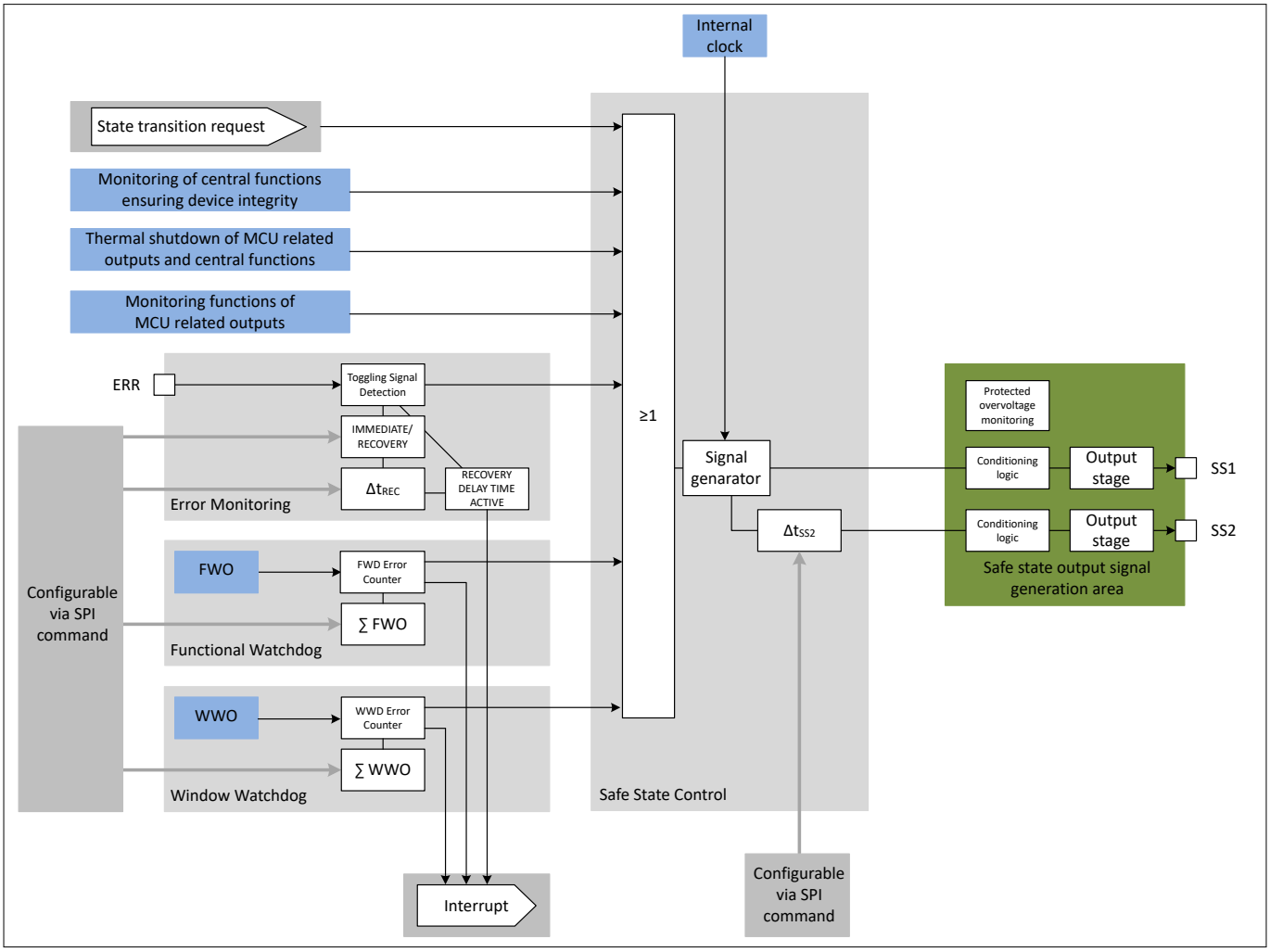


Figure 58 Principle Safe State Control function

Description:

- State transition request = Microcontroller can request a deactivation of the secondary safety shutdown path (SS1/2 high) via SPI. In NORMAL-state the microcontroller can activate the Secondary Safety Shutdown path (SS1/2 "low") by moving the device out of NORMAL-state via SPI.
- Monitoring of central functions ensuring device integrity
- TSD = Thermal shutdown
- Monitoring functions of MCU related outputs
- ERR monitoring = Error pin connected to safety management unit (SMU) of microcontroller
- ΣWWO = Number of "Invalid WWD triggering", after Safe State Control shall activate the safe state signal SS1 and SS2, located in window watchdog block
- ΣFWO = Number of "Invalid FWD triggering", after Safe State Control shall activate the safe state signal SS1 and SS2, locked in functional watchdog block

- IMMEDIATE/RECOVERY = Distinguish between immediate reaction to SMU signal or recovery delay time, located in error monitoring block
- Δt_{REC} = Recovery delay time for SMU signal at pin ERR, located in error monitoring block
- Δt_{SS2} = Delay time between safe state signal 1 and safe state signal 2
- SS1 = Safe state signal 1
- SS2 = Safe state signal 2

11.2 Electrical characteristics Safe State Control

Table 28 Electrical characteristics Safe State Control

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
ERR pin							
ERR valid high level	$V_{ERR,hi}$	2.0	–	–	V	V_{ERR} increasing; V_{QUC} = 3.3 V	P_12.2.4
ERR valid low level	$V_{ERR,lo}$	–	–	0.8	V	V_{ERR} decreasing; V_{QUC} = 3.3 V	P_12.2.5
ERR hysteresis	$V_{ERR,hyst}$	100	300	600	mV	V_{QUC} = 3.3 V	P_12.2.6
ERR pull-down current	I_{ERR}	–	150	330	µA	$V_{ERR} = V_{QUC}$	P_12.2.7
ERR input capacitance	C_{ERR}	–	4	15	pF	1)	P_12.2.8
Valid ERR input signal frequency	$f_{ERR,valid}$	10	–	45	kHz	considering a duty cycle of 50 %	P_12.2.9
Invalid ERR input signal frequency (low frequency)	$f_{ERR,invalid,LF}$	0	–	5	kHz	considering a duty cycle of 50 %	P_12.2.10
Invalid ERR input signal frequency (high frequency)	$f_{ERR,invalid,HF}$	96.2	–	500	kHz	considering a duty cycle of 50 %	P_12.2.11
Invalid ERR input signal detection time (low frequency)	$\Delta t_{DET,LF}$	50.1	–	99.9	µs	derived from $f_{ERR,valid}$ and $f_{ERR,invalid,LF}$	P_12.2.12
Invalid ERR input signal detection time (high frequency)	$\Delta t_{DET,HF}$	5.2	–	11.1	µs	derived from $f_{ERR,valid}$ and $f_{ERR,invalid,HF}$	P_12.2.13
ERR reactivation time-out	$t_{ERR,TO}$	9	10	11	ms	after SLEEP	P_12.2.14
ERR reactivation time-out (first edge expected)	$t_{ERR,ren}$	50.1	–	110	µs	after re-enabling via SPI 2)	P_12.2.15
Safe state signal 1 pin SS1							
SS1 output, high level	$V_{SS1,hi}$	2.9	3.2	V_{QUC}	V	$I_{SS1} \geq$ -1 mA; V_{QUC} = 3.3 V	P_12.2.18
SS1 output, high level	$V_{SS1,hi}$	2.0	2.8	V_{QUC}	V	$I_{SS1} \geq$ -5 mA; V_{QUC} = 3.3 V	P_12.2.19
SS1 pull-down resistor	$R_{SS1,pd}$	70	100	130	kΩ	–	P_12.2.20

(table continues...)

Table 28 (continued) Electrical characteristics Safe State Control

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
SS1 output, low level	$V_{SS1,lo}$	–	0	0.8	V	3) 4) $R_{SS1,pd,ext}$ ≤ 100 kΩ; $C_{SS1,ext}$ ≥ 50 pF; QUC active ; V_{QUC} ≥ 2 V	P_12.2.21
SS1 internal reaction time	$t_{SS1,act}$	–	12	30	µs	5)	P_12.2.22
Safe state signal 2 pin SS2							
SS2 output, high level	$V_{SS2,hi}$	2.9	3.2	V_{QUC}	V	I_{SS2} ≥ -1 mA; V_{QUC} = 3.3 V	P_12.2.25
SS2 output, high level	$V_{SS2,hi}$	2.0	2.8	V_{QUC}	V	I_{SS2} ≥ -5 mA; V_{QUC} = 3.3 V	P_12.2.26
SS2 pull-down resistor	$R_{SS2,pd}$	70	100	130	kΩ	–	P_12.2.27
SS2 output, low level	$V_{SS2,lo}$	–	0	0.8	V	3) 4) $R_{SS2,pd,ext}$ ≤ 100 kΩ; $C_{SS2,ext}$ ≥ 50 pF; QUC active ; V_{QUC} ≥ 2 V	P_12.2.28
SS2 internal reaction time	$t_{SS2,act}$	–	12	30	µs	5)	P_12.2.29
Adjustable parameters							
SSC time base accuracy	t_{SSC}	-10	–	10	%	timebase for Δt_{REC} and Δt_{SS2}	P_12.2.30
Adjustable recovery delay time	Δt_{REC}	0	–	10	ms	selectable 0, 1.0, 2.5, 5.0 and 10 ms; t_{SSC} to be considered	P_12.2.31
Adjustable delay time between SS1 and SS2	Δt_{SS2}	0	–	2500	ms	selectable 0, 10,50, 100, 250, 1250 and 2500 ms; t_{SSC} to be considered	P_12.2.32

1) Specified by design, not subject to production test
2) It is recommended to provide the ERR signal to the ERR pin before activating the function again via SPI.
3) Internal and external pull-down resistors have to be considered for failure cases with QUC switched off or unavailable.
4) Considering loss of analog safety ground (AGS1 and AGS2).
5) SSx internal reaction time represents the time to switch off the high level driver upon request or event. For the release of SSx outputs to "high" level the SSx internal reaction time is to be accounted twice (max. 60 µs).

11.3 Reaction on microcontroller Safety Management Unit (SMU - pin ERR):

11.3.1 Immediate reaction on ERR monitoring failure

The microcontroller safety management unit (SMU) indicates a serious error by stopping the toggling signal at pin ERR, immediate reaction to error signal is set:

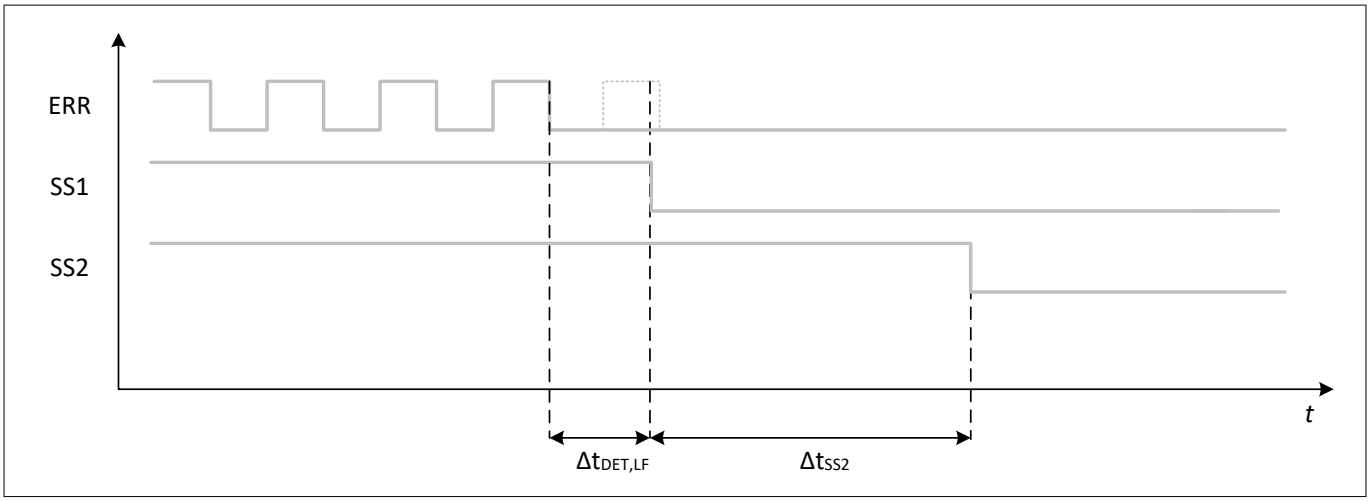


Figure 59 Flow diagram reaction on SMU signal (ERR signal remains low)

Description:

- The ERR signal stops toggling and remains low.
- This is detected as an error after the expiration of the detection time $\Delta t_{DET,LF}$.
- $\Delta t_{DET,LF}$ is measured from the last recognized falling edge.
- The safe state signal 1 (at pin SS1) is pulled to "low"
- The safe state signal 2 (at pin SS2) is pulled to "low" after an optional delay time Δt_{SS2}

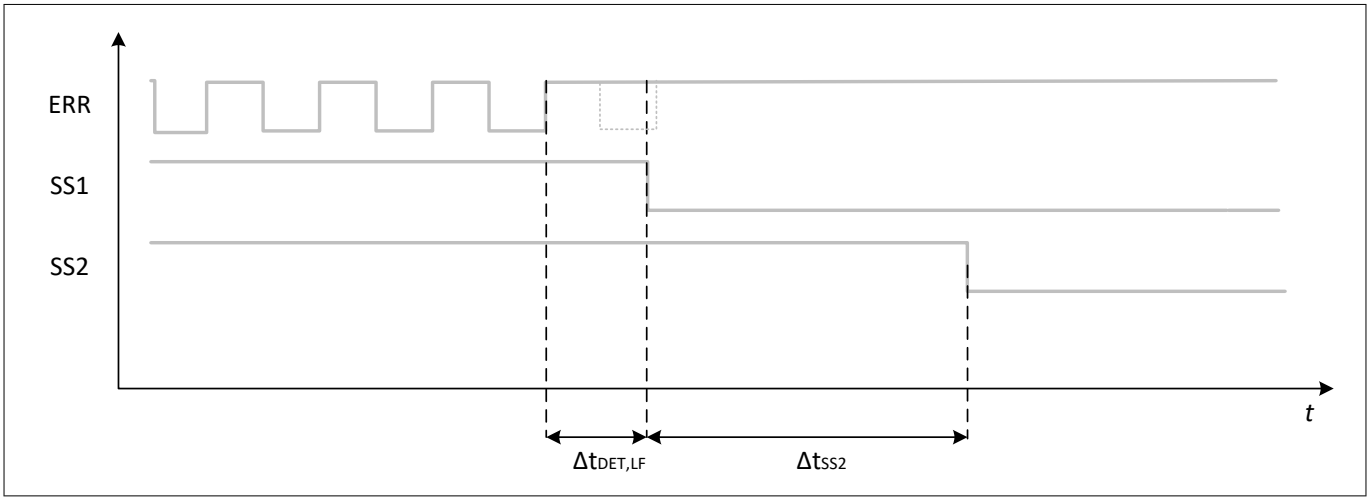


Figure 60 Flow diagram reaction on SMU signal (ERR signal remains high)

Description:

- The ERR signal stops toggling and remains high.
- This is detected as an error after the expiration of the detection time $\Delta t_{DET,LF}$.
- $\Delta t_{DET,LF}$ is measured from the last recognized rising edge.

- The safe state signal 1 (at pin SS1) is pulled to "low"
- The safe state signal 2 (at pin SS2) is pulled to "low" after an optional delay time Δt_{SS2}

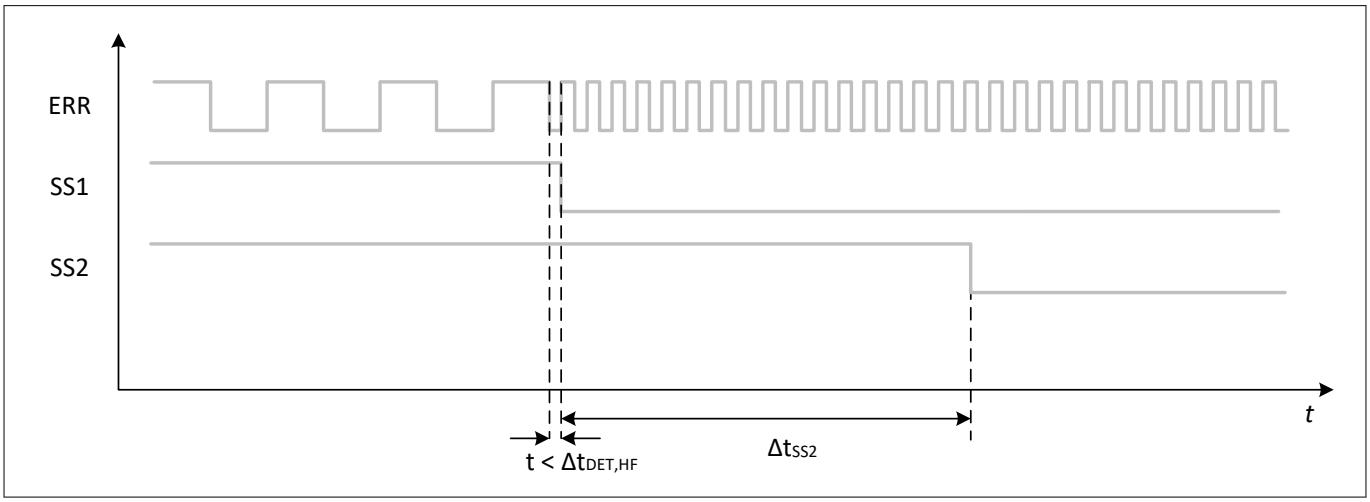


Figure 61 Flow diagram reaction on SMU signal (ERR signal frequency too high)

Description:

- The ERR signal starts toggling with a frequency of $f_{ERR,invalid,HF}$.
- This is detected as an error as soon as the edge-to-edge time is shorter than the detection time $\Delta t_{DET,HF}$.
- The safe state signal 1 (at pin SS1) is pulled to "low".
- The safe state signal 2 (at pin SS2) is pulled to "low" after an optional delay time Δt_{SS2}.

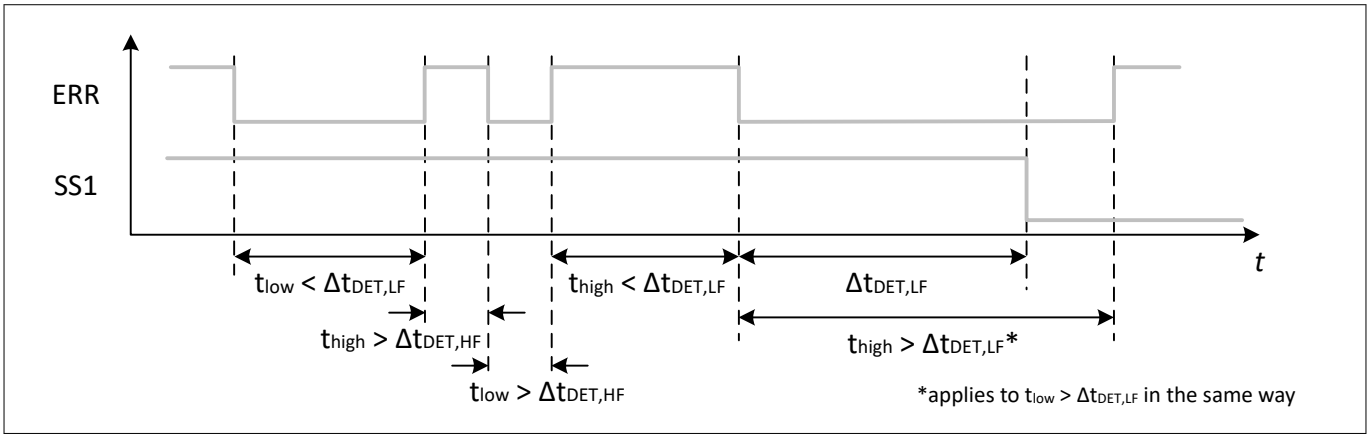


Figure 62 Flow diagram reaction on SMU signal (duty-cycle different than 50%, t_{low} or t_{high} too long)

Description:

- The ERR signal toggles with changing high and low times (duty cycle can vary as well), but t_{low} and t_{high} are in the valid range between $t_{DET,HF}$ and $t_{DET,LF}$ first.
- Then a low pulse of ERR shown in the figure is longer than the detection time $t_{DET,LF}$.
- This is detected as an error as soon as the edge-to-edge time is longer than the detection time $\Delta t_{DET,LF}$.
- The safe state signal 1 (at pin SS1) is pulled to "low".
- The safe state signal 2 (at pin SS2) is pulled to "low" accordingly after an optional delay time Δt_{SS2}.(not in figure)
- The condition can be applied to the high pulse being longer than the detection time $t_{DET,LF}$ in the same way.

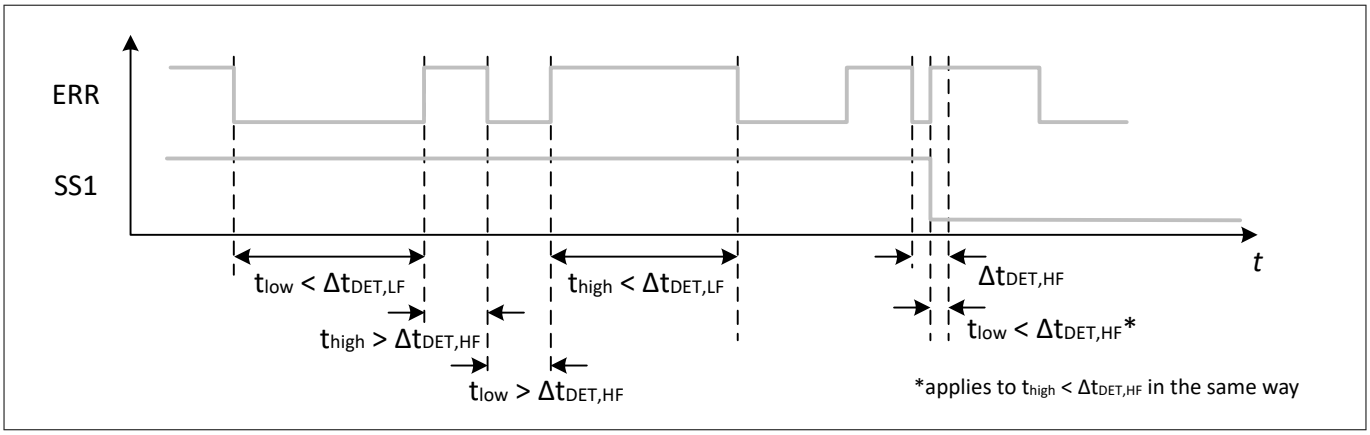


Figure 63 Flow diagram reaction on SMU signal (duty-cycle different than 50%, t_{low} or t_{high} too short)

Description:

- The ERR signal toggles with changing high and low times (duty cycle can vary as well), but t_{low} and t_{high} are in the valid range between $t_{DET,HF}$ and $t_{DET,LF}$ first.
- Then a low pulse of ERR shown in the figure is shorter than the detection time $t_{DET,HF}$.
- This is detected as an error as soon as the edge-to-edge time is shorter than the detection time $\Delta t_{DET,HF}$.
- The safe state signal 1 (at pin SS1) is pulled to "low".
- The safe state signal 2 (at pin SS2) is pulled to "low" accordingly after an optional delay time Δt_{SS2}.(not in figure)
- The condition can be applied to the high pulse being shorter than the detection time $t_{DET,HF}$ in the same way.

11.3.2 Recovery delay reaction on ERR monitoring failure

The microcontroller safety management unit (SMU) indicates a serious error by stopping the toggling signal at pin ERR, recovery delay time reaction to error signal is set - the SMU is given time to recover:

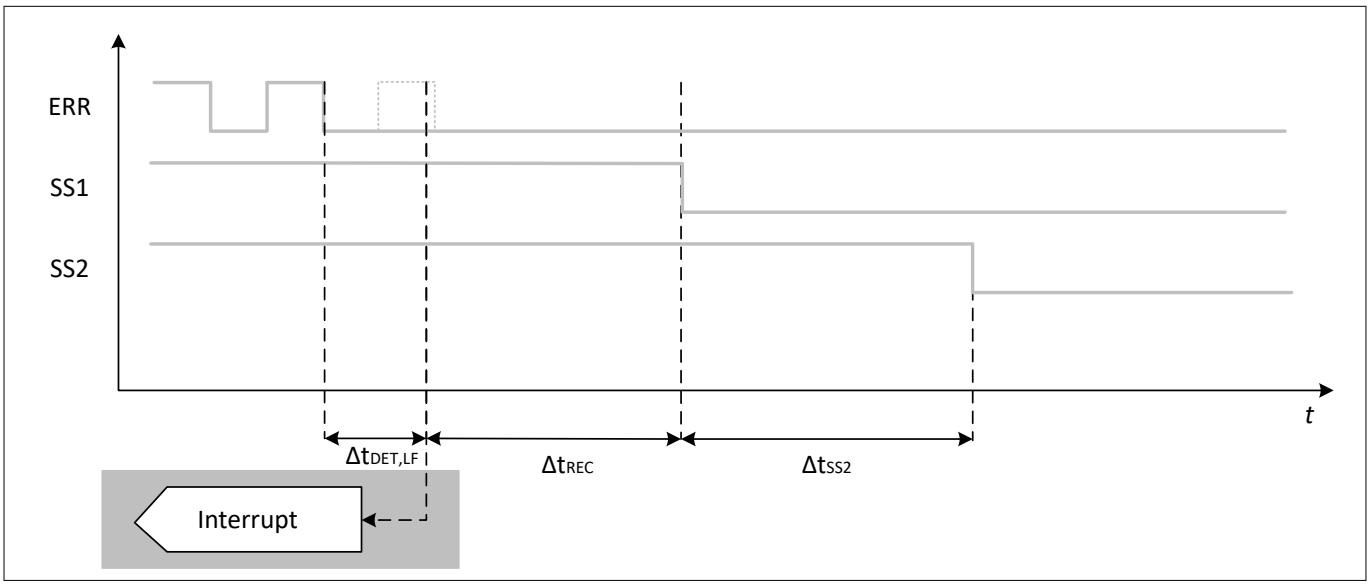


Figure 64 Flow diagram reaction on SMU signal, error longer than recovery delay time

Description:

- The ERR signal stops toggling and remains low (or high).

- This is detected as an error after the expiration of the detection time $\Delta t_{DET,LF}$.
- $\Delta t_{DET,LF}$ is measured from the last recognized edge.
- An interrupt is generated after the detection to indicate the start of the recovery delay time Δt_{REC}
- The safe state signal 1 (at pin SS1) is pulled to "low" after Δt_{REC} has expired
- The safe state signal 2 (at pin SS2) is pulled to "low" after an optional delay time Δt_{SS2}

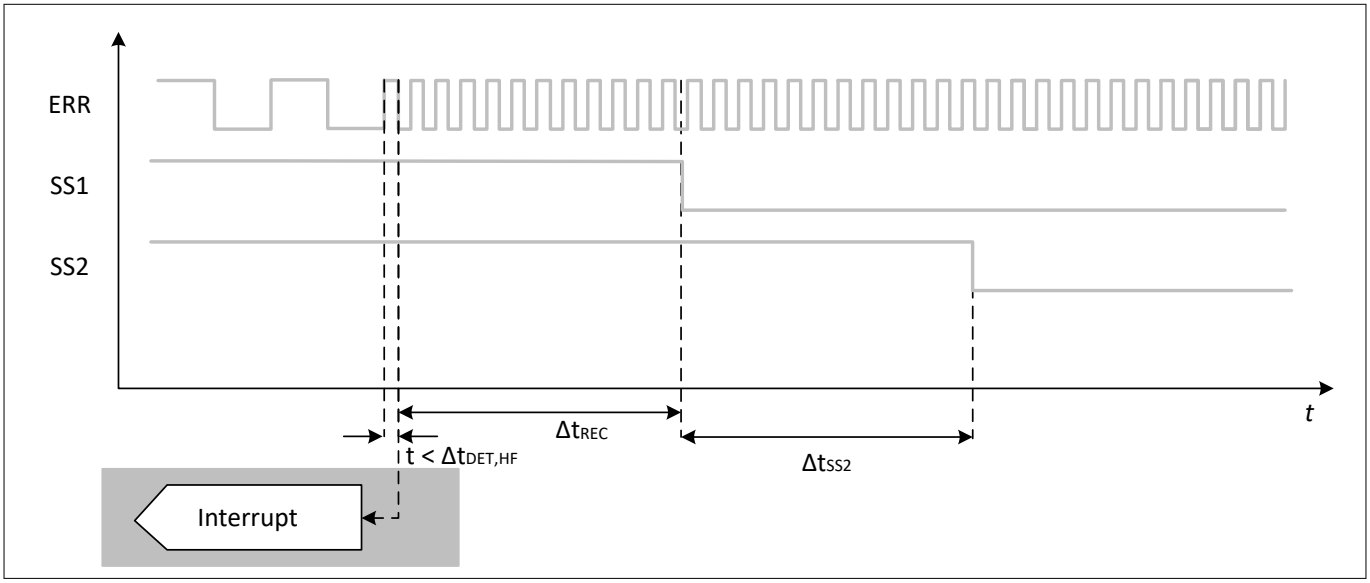


Figure 65 Flow diagram reaction on SMU signal, error longer than recovery delay time (ERR signal) frequency too high)

Description:

- The ERR signal starts toggling with a frequency of $f_{ERR,invalid,HF}$.
- This is detected as an error as soon as the edge-to-edge time is shorter than the detection time $\Delta t_{DET,HF}$.
- An interrupt is generated after the detection to indicate the start of the recovery delay time Δt_{REC}
- The safe state signal 1 (at pin SS1) is pulled to "low" after Δt_{REC} has expired
- The safe state signal 2 (at pin SS2) is pulled to "low" after an optional delay time Δt_{SS2}

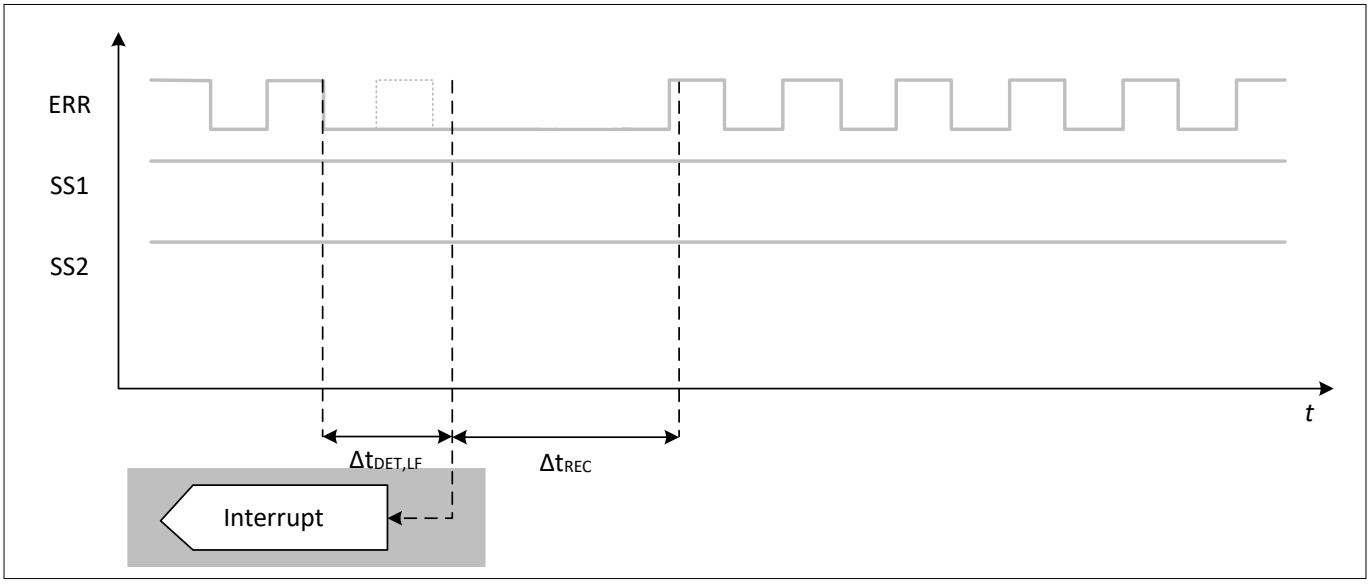


Figure 66 Flow diagram reaction on SMU signal, error shorter than recovery delay time

Description:

- The ERR signal stops toggling and remains low (or high).
- This is detected as an error after the expiration of the detection time $\Delta t_{DET,LF}$.
- $\Delta t_{DET,LF}$ is measured from the last recognized edge.
- An interrupt is generated after the detection to indicate the start of the recovery delay time Δt_{REC}
- The ERR signal resumes toggling before Δt_{REC} expires.
- The safe state signals 1 (at pin SS1) and 2 (at pin SS2) are kept high all the time.

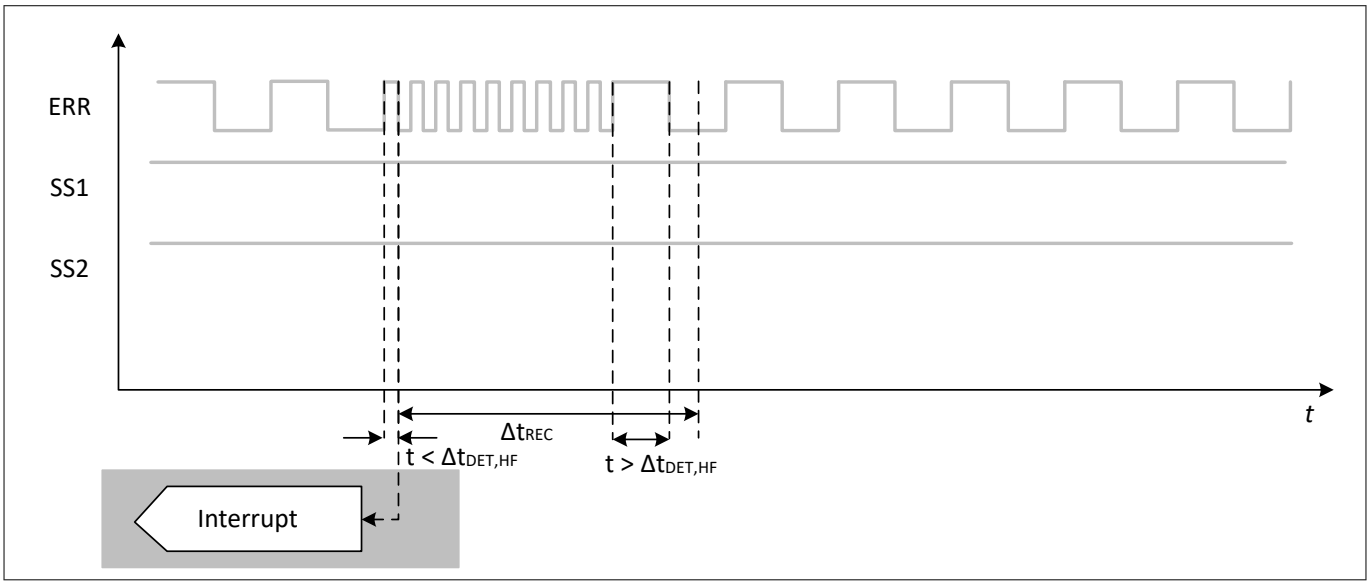


Figure 67 Flow diagram reaction on SMU signal, error shorter than recovery delay time (ERR signal frequency too high)

Description:

- The ERR signal starts toggling with a frequency of $f_{ERR,invalid,HF}$.
- This is detected as an error as soon as the edge-to-edge time is shorter than the detection time $\Delta t_{DET,HF}$.
- An interrupt is generated after the detection to indicate the start of the recovery delay time Δt_{REC}
- Before Δt_{REC} has expired the ERR signal resumes toggling with a valid frequency.
- The safe state signals 1 (at pin SS1) and 2 (at pin SS2) are kept high all the time.

11.4 Reaction on error-triggered state transitions

The reset output (ROT) indicates the behavior of the microcontroller related regulators (for details please refer to chapter voltage monitoring and reset function).

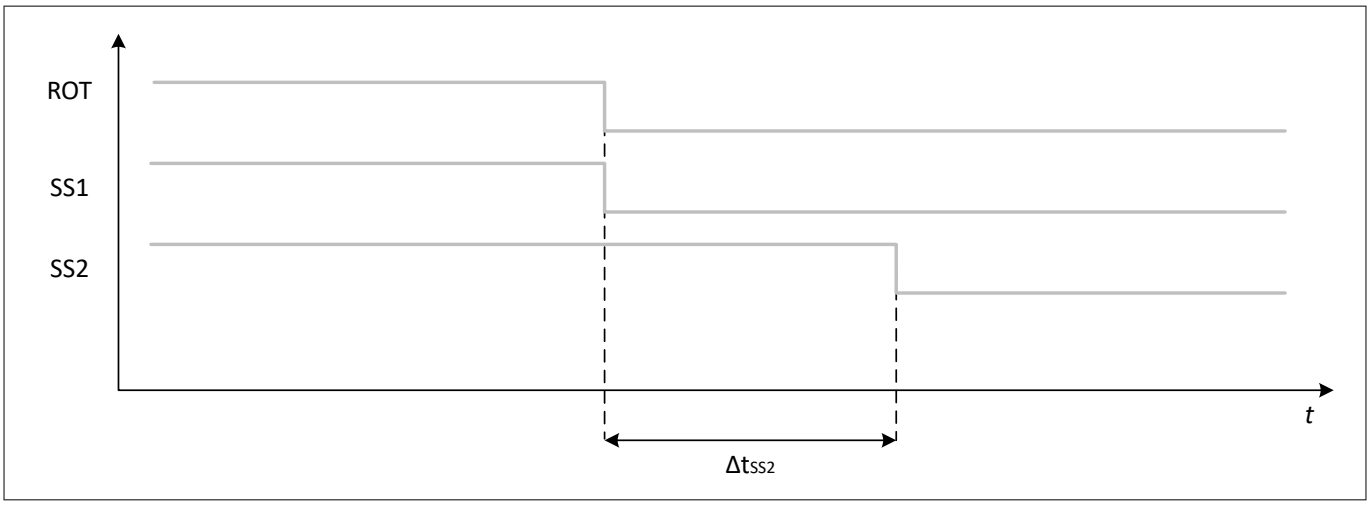


Figure 68 Flow diagram reaction on an error triggered state transition- soft reset

Description:

- The falling edge of ROT signal indicates an error
- Safe state signal 1 (at pin SS1) goes to "low" on error immediately.
- Safe state signal 2 (at pin SS2) goes to "low" after a delay time Δt_{SS2} which was set by SPI command.
- On an undervoltage event on QUC, a delayed SS2 signal follows V_{QUC} as it is supplied from QUC.

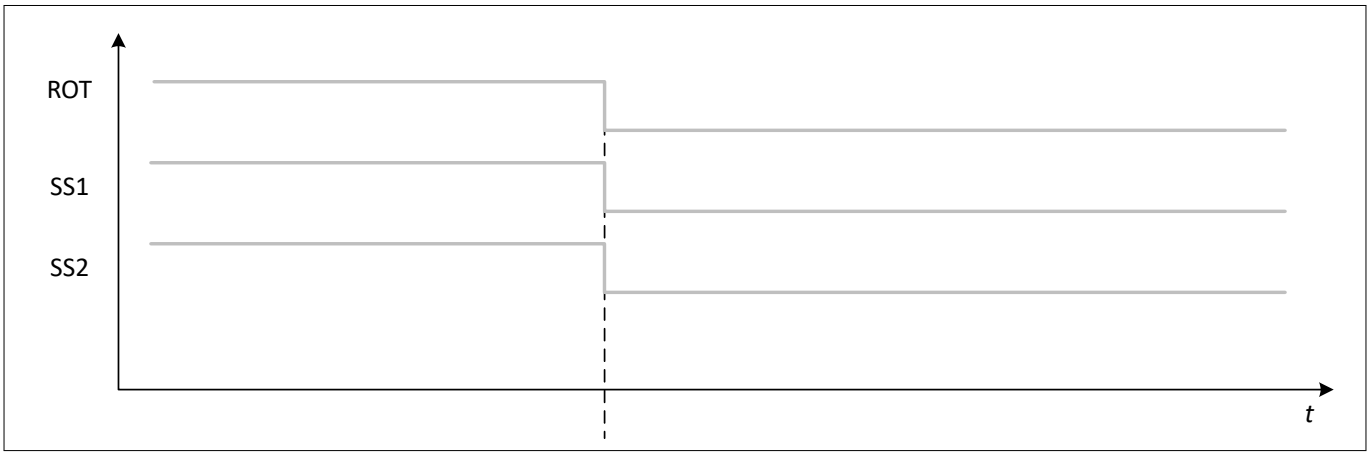


Figure 69 Flow diagram reaction on an error triggered state transitions - hard reset

Description:

- The falling edge of ROT signal indicates an error.
- Safe state signal 1 (at pin SS1) goes to "low" immediately with the occurrence of the error.
- Safe state signal 2 (at pin SS2) goes to "low" together with SS1 as the supplying post regulator QUC is switched off when pin ROT goes to "low".

11.5 Reaction on Window Watchdog Output (WWO)

The window watchdog error counter (WWDSTAT.WWDECNT) of the device increments by two at every invalid window watchdog triggering and decrements by one at every valid window watchdog triggering, see chapter Window watchdog.

Any incrementation of the window watchdog error counter is indicated by an interrupt. Any decrement of the window watchdog error counter is not indicated by an interrupt. The value of the window watchdog error counter saturates to a minimum of 0_D.

The threshold for activating the safe state signals SS1 and SS2 ΣWWO can be changed in INIT, NORMAL and WAKE-state. (WDCFG0.WWDETHR)

The content of the error counter is compared to the programmed threshold ΣWWO (RWDCFG0.WWDETHR). If the content of the error counter is equal or higher than ΣWWO, the safe state signals SS1 and SS2 are activated (low).

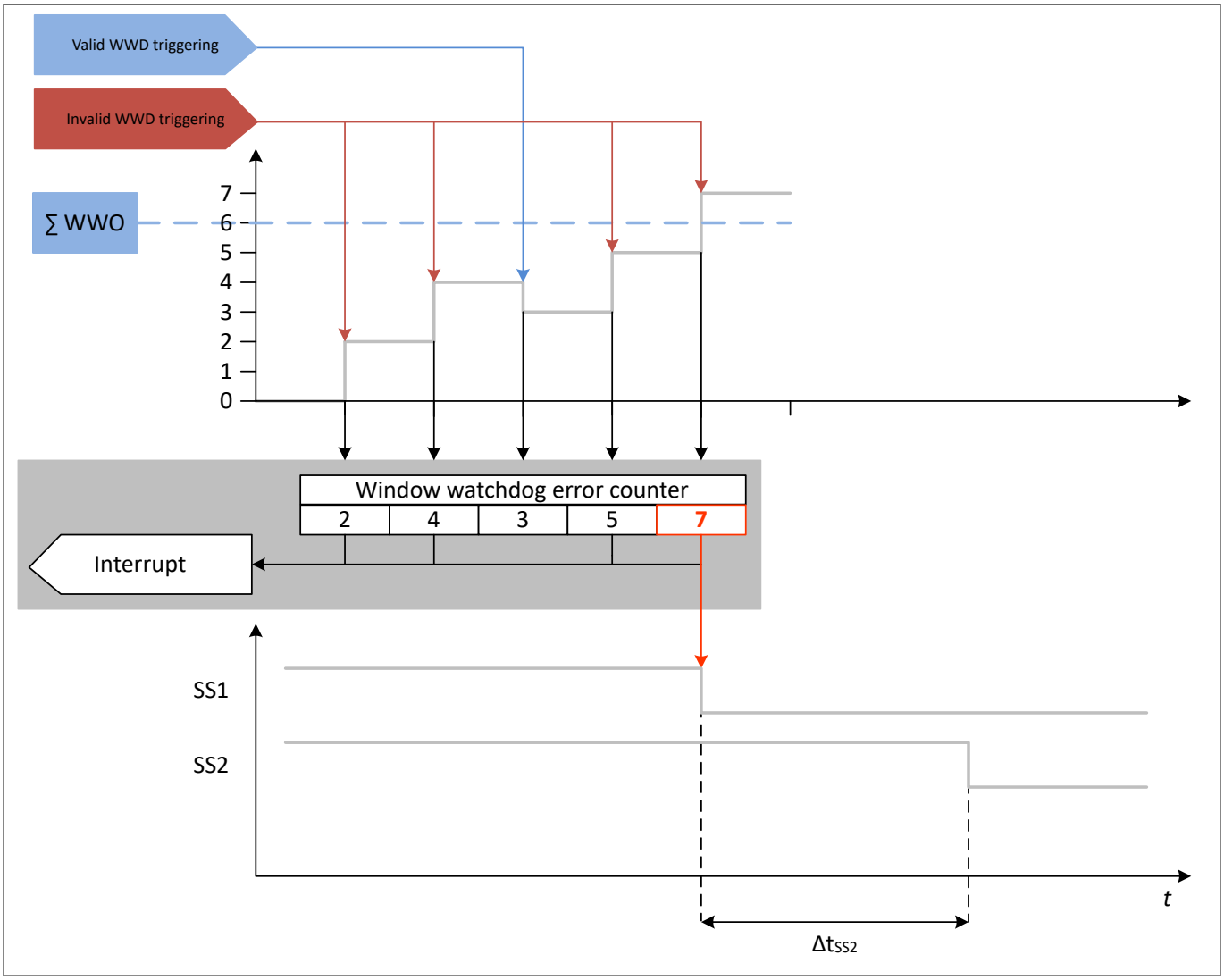


Figure 70 Flow diagram reaction on WWO

Description:

- The threshold ΣWWO is set to 6_D (example)
- An invalid watchdog triggering increments the window watchdog error counter by two, this is indicated by an interrupt.

- A valid watchdog triggering decrements the window watchdog error counter by one, this is not indicated by an interrupt.
- The error counter value 7 is recognized as an error.
- Safe state signal 1 (at pin SS1) goes to "low" immediately with the counter status change.
- Safe state signal 2 (at pin SS2) goes to "low" after a delay time Δt_{SS2} which was set by SPI command.

11.6 Reaction on Functional Watchdog Output (FWO)

The functional watchdog error counter (FWDSTAT1.FWDECNT) of the device increments by two at every invalid functional watchdog triggering and decrements by one at every valid functional watchdog triggering, see chapter Functional watchdog.

Any incrementation of the functional watchdog error counter is indicated by an interrupt. Any decrement of the functional watchdog error counter is not indicated by an interrupt. The value of the functional watchdog error counter saturates to a minimum of 0_D.

The threshold for activating the safe state signals SS1 and SS2 ΣFWO can be changed in INIT, NORMAL and WAKE-state. (WDCFG1.FWDETHR)

The content of the error counter is compared to the programmed threshold ΣFWO (RWDCFG1.FWDETHR). If the content of the error counter is equal or higher than ΣFWO, the safe state signals SS1 and SS2 are activated (low).

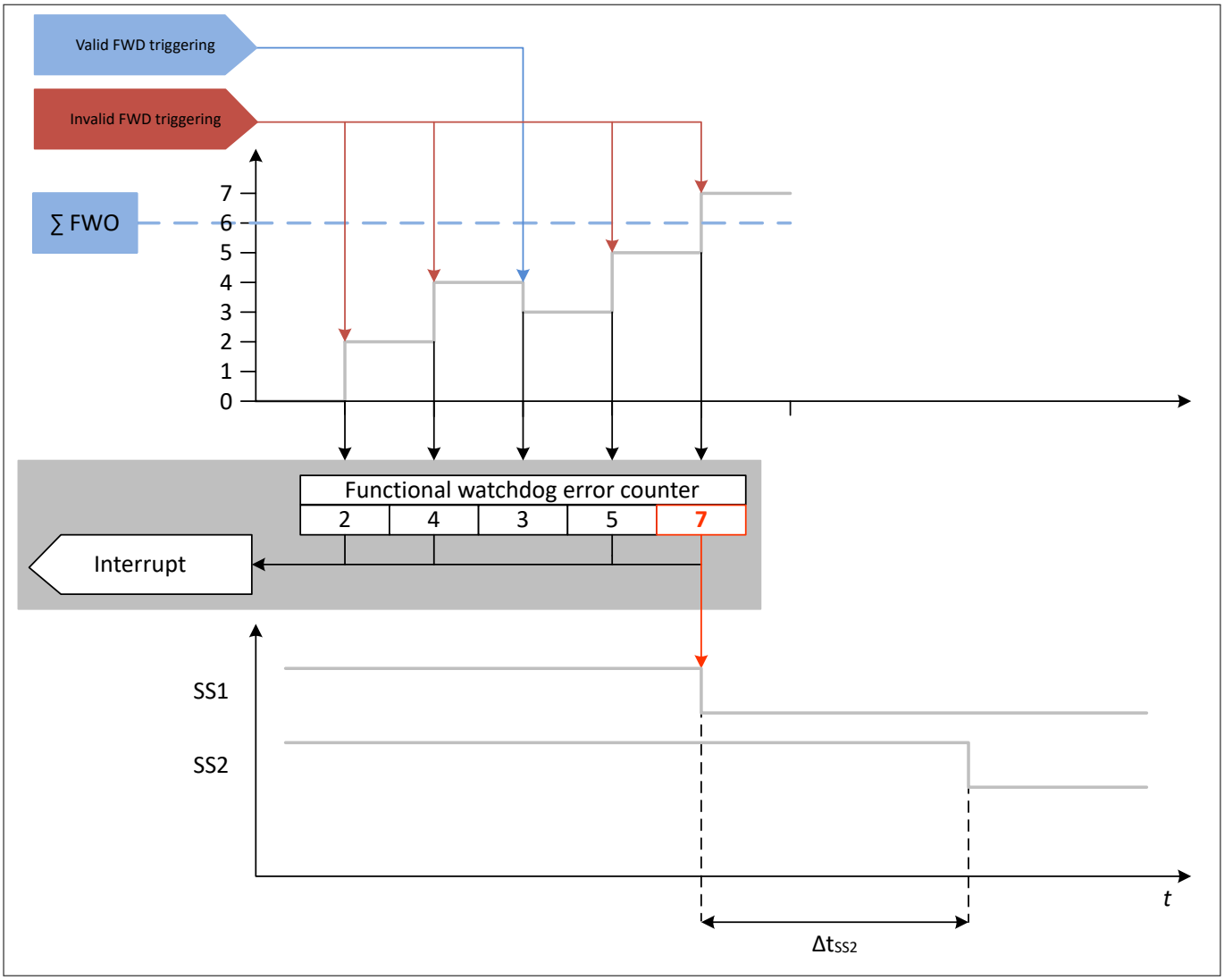


Figure 71 Flow diagram reaction on FWO

Description:

- The threshold ΣFWO is set to 6_D (example).
- An invalid watchdog triggering increments the functional watchdog error counter by two, this is indicated by an interrupt.
- A valid watchdog triggering decrements the functional watchdog error counter by one, this is not indicated by an interrupt.
- The error counter value 7 is recognized as an error.
- Safe state signal 1 (at pin SS1) goes to "low" immediately with the counter status change.
- Safe state signal 2 (at pin SS2) goes to "low" after a delay time Δt_{SS2} which was set by SPI command.

11.7 Reaction on Thermal Shutdown (TSD)

The thermal shutdown (TSD) indicates temperature overstress on the chip. As a consequence all pre and post regulators are shut down immediately (except for temperature sensor of QCO).

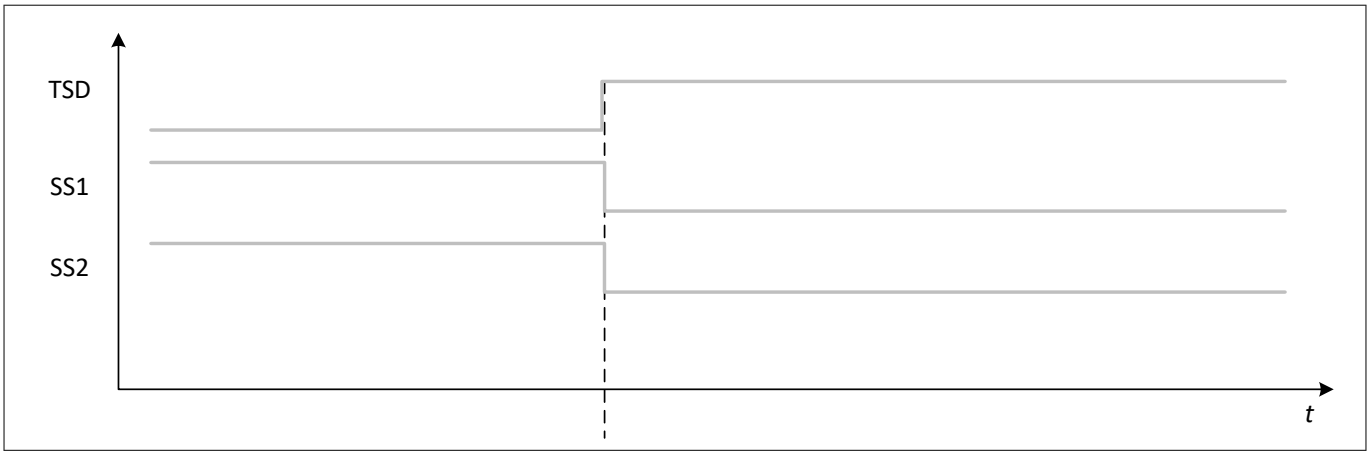


Figure 72 Flow diagram reaction on TSD

Description:

- The rising edge of TSD signal (internal) is recognized as an error.
- Safe state signal 1 (at pin SS1) goes to "low" immediately with the rising edge of TSD.
- Safe state signal 2 (at pin SS2) goes to "low" together with SS1 as the supplying post regulator QUC is switched off when pin ROT goes to "low".

12 SPI (Serial Peripheral Interface)

12.1 Introduction SPI

Main functions

The serial peripheral interface bus is a full duplex synchronous serial data link. The device communicates in slave mode where the master (MCU) initiates the data frame. The device is to be addressed via a dedicated chip select line. This allows a connection of other slave devices to the SPI bus.

Data transmission

To begin a communication, the MCU first configures the clock, using a frequency less than or equal to the maximum frequency the device supports. The MCU pulls down the chip select for the device.

Functional description

SPI basic access: All data on MOSI (pin SDI) is captured on the rising edge of SPI clock signal (pin SCL) and shifted on the falling edge of SPI clock signal (pin SCL). The same methodology needs to be applied in the SPI master for MISO (SDO). A read operation has to start with CMD-bit at 0_B and a write operation has to start with CMD-bit being 1_B.

Write commands written to SDI are looped back to SDO.

For read commands the parity is calculated based on the output data stream. The data for the calculation consists of 1_B, status [5:0] and rd_data[7:0]. The parity bit is set to 1_B if the number of bits at 1_B in the output data stream is odd, i.e. XOR function between all 15 bits sent out.

Parity is checked on write data. The parity is calculated on the incoming bit stream for the CMD-bit, the six address bits and the eight data bits.

Configuration via SPI can be done anytime, if the state machine is in INIT-state, NORMAL-state, WAKE-state or SLEEP-state. In SLEEP-state the SPI maximum clock frequency is reduced, for details refer to Table 29.

SPI access timing are defined in the following diagram:

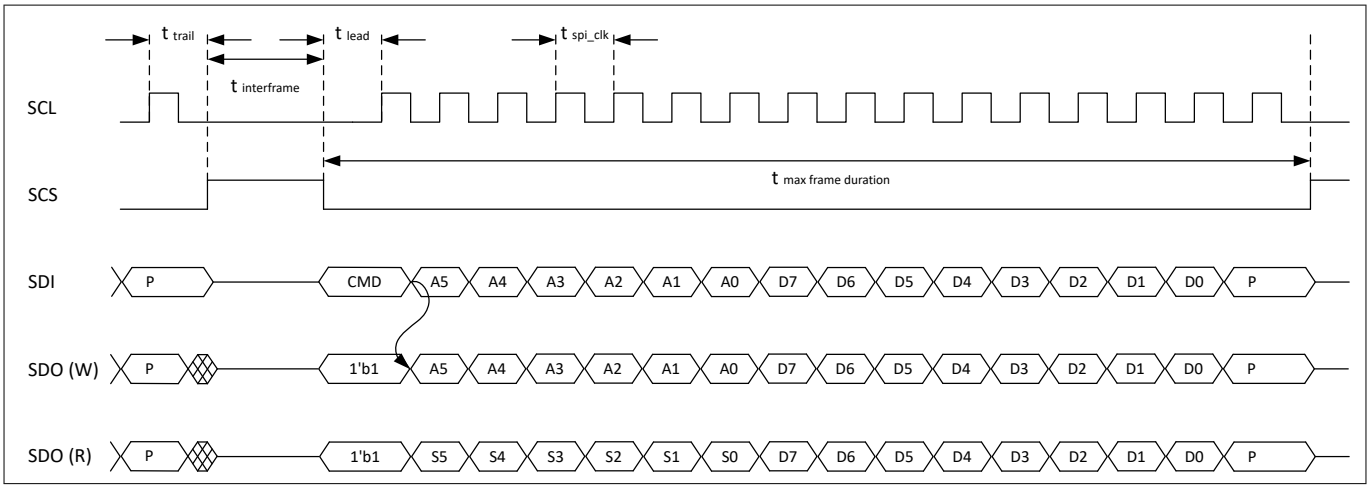


Figure 73 SPI - frame in normal mode

SPI MISO:

- During write, data from MOSI is directly looped back, during read, the addressed register content is provided in the same SPI frame
- The CMD-bit is always set to 1_B. All other status bits are set to 0_B.

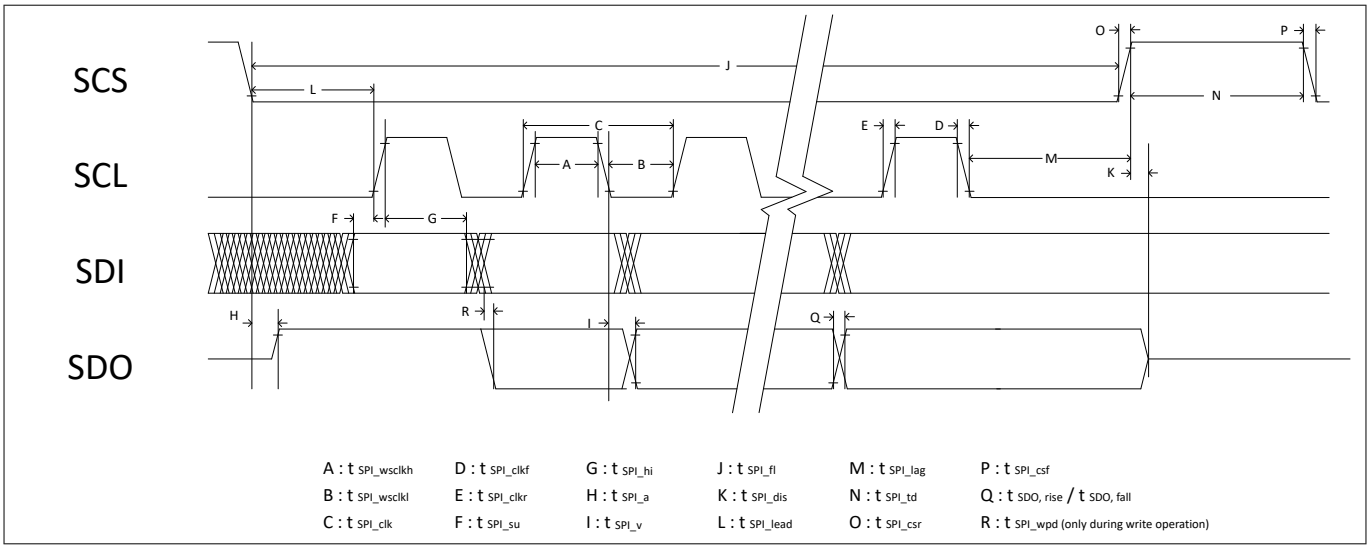


Figure 74 SPI - timings

Table 29 Electrical characteristics SPI - timings

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
CLK_SPI Operating Frequency	f_{SPI_clk}	–	–	10	MHz	1)	P_13.1.1
CLK_SPI Operating Frequency	f_{SPI_clk}	–	–	1.5	MHz	SLEEP-state	P_13.1.2
CLK Signal duty cycle	D_{SCL}	45	50	55	%	–	P_13.1.3
CLK_SPI Operating Period	t_{SPI_clk}	100	–	–	ns	–	P_13.1.4
CLK_SPI high time	t_{SPI_wsclkh}	45	–	–	ns	–	P_13.1.5
CLK_SPI low time	t_{SPI_wsclkl}	45	–	–	ns	–	P_13.1.6
CLK_SPI fall time	t_{SPI_clkf}	–	–	0.1×t_{SPI_fact}	[ns]	2) $t_{SPI\_fact} \leq t_{SPI\_clk}$; 100 ns ≤ t_{SPI_fact} ≤ 1 µs	P_13.1.7
CLK_SPI rise time	t_{SPI_clkr}	–	–	0.1×t_{SPI_fact}	[ns]	2) $t_{SPI\_fact} \leq t_{SPI\_clk}$; 100 ns ≤ t_{SPI_fact} ≤ 1 µs	P_13.1.8
CLK_SPI lead time	t_{SPI_lead}	100	–	–	ns	for INIT, NORMAL, WAKE state	P_13.1.9
CLK_SPI lead time (SLEEP state)	t_{SPI_lead}	4	–	–	µs	for SLEEP state	P_13.1.10
CLK_SPI lag time	t_{SPI_lag}	50	–	–	ns	–	P_13.1.11

(table continues...)

Table 29 (continued) Electrical characteristics SPI - timings

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
SPI Chip Select (SCS) rise time	t_{SPI_csr}	–	–	0.2×t_{SPI_fact}	[ns]	2) $t_{SPI\_fact} \le t_{SPI\_lag}$; 50 ns ≤ t_{SPI_fact} ≤ 500 ns	P_13.1.12
SPI Chip Select (SCS) fall time	t_{SPI_csf}	–	–	0.2×t_{SPI_fact}	[ns]	2) $t_{SPI\_fact} \le t_{SPI\_lead}$; 100 ns ≤ t_{SPI_fact} ≤ 1 µs	P_13.1.13
SPI Data Input (SDI) setup	t_{SPI_su}	10	–	–	ns	–	P_13.1.14
SPI Data Input (SDI) hold time	t_{SPI_hi}	10	–	–	ns	–	P_13.1.15
SPI Data Output (SDO) valid after CLK_SPI	t_{SPI_v}	–	–	(0.1×t_{SPI_fact})+36	[ns]	$C_{SDO,load}$= 50 pF; 2) $t_{SPI\_fact} \ge t_{SPI\_clkf}$; 10 ns ≤ t_{SPI_fact} ≤ 100 ns	P_13.1.16
SPI write propagation delay SDI to SDO	t_{SPI_wpd}	–	–	35	ns	–	P_13.1.17
SPI Data Output (SDO) access	t_{SPI_a}	–	–	50	ns	$C_{SDO,load}$ = 50 pF	P_13.1.18
SPI Data Output (SDO) disable time	t_{SPI_dis}		–	100	ns	$C_{SDO,load}$ = 50 pF	P_13.1.19
Sequential transfer delay	t_{SPI_td}	350	–	–	ns	–	P_13.1.20
Sequential transfer delay	t_{SPI_td}	2	–	–	µs	SLEEP-state	P_13.1.21
Frame duration (SCS low)	t_{SPI_fl}		–	1.85	ms	–	P_13.1.22

1) For max. achievable CLK_SPI operating frequency, please consider the CLK_SPI rise- and fall times (t_{SPI_clkr} and t_{SPI_clkf}).

2) t_{SPI_fact} is used as a supportive factor inside this specification row. It must be considered valid only within one row and is not the same across multiple rows of the specification.

SPI errors:

- Wrong parity bit during write, write data is ignored.
- Write to invalid address, write data is ignored.
- Wrong number of SPI clock cycles while SCS is low, write data is ignored, read data is provided by the device with each SPI clock cycle.
- Read from invalid address (all data bits zero returned on MISO for read data). For this case the parity bit is inverted/corrupted after complete calculation by the device.

- Invalid frame duration, write data is ignored and the output driver for SDO is turned off internally by the device after t_{SPI_fl}. Read data is provided with each SPI clock cycle as long as SCS is low for less than t_{SPI_fl}.
- If the number of SPI clock cycles is different from 16 and an invalid frame duration error is detected by the device, the invalid frame duration status flag is set and the wrong number of SPI clock cycle status flag is set.

If an SPI error occurs, an interrupt is generated.

Interrupts on SPI errors are initiated only after SCS has going "high" or after frame time-out.

12.2 SPI write access to protected registers

Certain internal registers (SYSPCFG0, SYSPCFG1, WDCFG0, WDCFG1, FWDCFG, WWDCFG0, WWDCFG1) are protected against accidental overwriting. The status of the protection can be checked by reading the LOCK bit in the register PROTSTAT.

Write access to the protected registers is only possible after a dedicated 32 bit UNLOCK sequence via SPI in INIT, NORMAL or WAKE-state. The UNLOCK sequence consists of a 32-bit sequence of 4 consecutive bytes (1: AB_H; 2: EF_H; 3: 56_H; 4: 12_H) which have to be sent with no other SPI write access in between. The correctness of every written byte can be checked by reading the register PROTSTAT. Any wrong UNLOCK byte sent to KEY1OK within the sequence is identifiable by the corresponding KEYxOK bit (e.g. PROTSTAT.KEY1OK). After writing a wrong byte, the UNLOCK sequence must be repeated.

If a write access to any other register than PROTCFG is detected in between the UNLOCK sequence, an interrupt is generated (SPISF.LOCK) and the number of successfully detected UNLOCK sequence bytes is set to zero. In order to recover the sequence, the first UNLOCK byte must be sent again until the PROTSTAT.KEY1OK becomes equal to 1_B, meaning a new UNLOCK sequence has started and the first correct byte has been received. Further, if a wrong UNLOCK sequence byte was received in 1st, 2nd or 3rd position byte of the sequence, an interrupt is generated as well (SPISF.LOCK) after the complete sequence (4th byte) received. A wrong byte in the 4th position of the sequence does not generate an interrupt, but is identifiable by the KEY4OK bit at 0_B and LOCK bit still at 1_B (locked) in register PROTSTAT.

Once the UNLOCK sequence has been performed successfully, any protected configuration request register can be written.

In order to ensure proper writing to the protected configuration request registers the microcontroller shall read back the register values and verify the correctness by checking data. The data bits written to the protected configuration request registers are sent back inverted during read operation, that means the microcontroller can calculate an XOR of the register data read and expected. For correct register data the result is FF_H. The device does not check the correctness of the values in the register.

All protected configuration request register values are captured by the respective functions only after a successful LOCK sequence [6]. A successful LOCK sequence consists of a 32-bit sequence of 4 consecutive bytes (1: DF_H; 2: 34_H; 3: BE_H; 4: CA_H) which have to be sent with no other SPI write access in between. The correctness of every written byte can be checked by reading the register PROTSTAT. Any wrong LOCK byte sent to KEY1OK within the sequence is identifiable by the corresponding KEYxOK bit (e.g. PROTSTAT.KEY1OK). After writing a wrong byte, the LOCK sequence must be repeated.

If a write access to any other register than PROTCFG is detected in between the LOCK sequence, an interrupt is generated (SPISF.LOCK) and the number of successfully detected UNLOCK sequence bytes is set to zero. In order to recover the sequence, the first LOCK byte must be sent again until the PROTSTAT.KEY1OK becomes equal to 1_B, meaning a new LOCK sequence has started and the first correct byte has been received. Further, if a wrong LOCK sequence byte was received in 1st, 2nd or 3rd position byte of the sequence, an interrupt is generated as well (SPISF.LOCK) after the complete sequence (4th byte) received. A wrong byte in the 4th position of the sequence does not generate an interrupt, but is identifiable by the KEY4OK bit at 0_B and LOCK bit still at 0_B (unlocked) in register PROTSTAT.

Upon detection of a successful LOCK sequence the configuration registers and all internal functions are updated with the values from the protected configuration request registers.

It is the responsibility of the microcontroller to ensure all registers are configured properly by either writing a new value into a particular register or by reading back a register which is supposed to be unchanged. Partial reconfiguration of the protected registers, i.e. configuring just a single function and leaving other functions unchanged is not supported as with the successful LOCK sequence all protected configuration request registers are taken over into the configuration (RSYSPCFG0, RSYSPCFG1, RWDCFG0, RWDCFG1, RFWDCFG, RWWDCFG0, RWWDCFG1).

After the LOCK sequence an internal configuration time of max. 60 µs has to be considered to ensure that the new configuration is taken over.

Affected functions:

- All watchdog configuration registers for WWD and FWD including their configuration for SLEEP-state.

[6] Exceptions present for SYSPCFG1.SS2DEL and SYSPCFG0.DISOFFSET, refer to bitfield descriptions.

- All Error monitoring configuration registers including their configuration for SLEEP-state.
- A dedicated register to enable or disable the standby supply and to configure its operating mode.
- Configuration of SS2 delay time.

Read access to any protected configuration request register is always possible.

12.3 SPI write initiated state transition request and regulator configuration

A state machine transition can be initiated via SPI command(s). In case the state of any selectable post regulator is expected to change for the next state, this information has to be sent together with the command into the same register. In case the setting for the selectable post regulator is supposed to change, but without changing the state, then the SPI command needs to contain the current state and a different setting for the configuration of the post regulators.

In order to request a state transition and/or a change of the supply configuration the request data must be written to register DEVCTRL first and then to DEVCTRLN consequently after each other. The data written to DEVCTRLN have to be inverted bitwise compared to the data written to DEVCTRL. The request is taken over with the rising edge of the SCS at the end of the second command.

In case of an invalid request (wrong sequence or DEVCTRLN not inverted to DEVCTRL) it is rejected, an interrupt is generated and the corresponding status flag (NO_OP) is set. In case of an invalid state transition request according to the State machine in Chapter 10 the request is ignored without issuing an interrupt.

12.4 Registers description

Table 30 Abbreviations

*R0)	Registers that are reset only in case of transition from STANDBY (with disabled QST and wake-up timer) and POWERDOWN state.
*R1)	Registers that are reset only in case of transition from STANDBY (with any configuration of QST and wake-up timer) and POWERDOWN state.
*R2)	Registers that are reset only in case of transition from FAILSAFE, STANDBY and POWERDOWN state.
*R3)	Registers that are reset in case of "Move to INIT" event and transition from FAILSAFE, STANDBY and POWERDOWN state.
r	Bits that are readable (read)
rw	Bits that are readable and writable (read-write)
rwp	Bits that are readable and writable, but protected by register PROTCFG (read-write-protected)
rw1c	Bits that are readable and which can be cleared by writing a 1 to it. (read-write-1-to-clear). Flag-bits are updated based on the occurred condition.
rwhc	Bits that are readable and writable, after writing the operation is triggered, once this is done successfully the bit is cleared by hardware. (read-write-hardware-cleared)
rwhu	Bits that are readable and writable, after the operation the bit is updated by hardware. (read-write-hardware-updated)

Table 31 Registers Address Space

Module	Base Address	End Address	Note
Bus Interface	0_H	$3F_H$	Slave interface

Table 32 Registers Overview

Register Short Name	Register Long Name	Offset Address	Reset Value
DEVCFG0	Device configuration 0 *R2)	00_H	08_H
DEVCFG1	Device configuration 1 *R0)	01_H	06_H
DEVCFG2	Device configuration 2 *R2) [1)]	02_H	00_H
PROTCFG	Protection register *R2)	03_H	00_H
SYSPCFG0	Protected System configuration request 0 *R1)	04_H	01_H
SYSPCFG1	Protected System configuration request 1 *R2)	05_H	08_H
WDCFG0	Protected Watchdog configuration request 0 *R2)	06_H	$9B_H$
WDCFG1	Protected Watchdog configuration request 1 *R2)	07_H	09_H
FWDCFG	Protected Functional watchdog configuration request *R2)	08_H	$0B_H$
WWDCFG0	Protected Window watchdog configuration request 0 *R2)	09_H	06_H

(table continues...)

Table 32 (continued) Registers Overview

Register Short Name	Register Long Name	Offset Address	Reset Value
WWDCFG1	Protected Window watchdog configuration request 1 *R2)	$0A_H$	$0B_H$
RSYSPCFG0	System configuration 0 status *R1)	$0B_H$	01_H
RSYSPCFG1	System configuration 1 status *R3) [1)]	$0C_H$	08_H
RWDCFG0	Watchdog configuration 0 status *R3)	$0D_H$	$9B_H$
RWDCFG1	Watchdog configuration 1 status *R3)	$0E_H$	09_H
RFWDCFG	Functional watchdog configuration status *R3)	$0F_H$	$0B_H$
RWWDCFG0	Window watchdog configuration 0 status *R3)	10_H	06_H
RWWDCFG1	Window watchdog configuration 1 status *R3)	11_H	09_H
WKTIMCFG0	Wake-up timer configuration 0 *R0)	12_H	00_H
WKTIMCFG1	Wake-up timer configuration 1 *R0)	13_H	00_H
WKTIMCFG2	Wake-up timer configuration 2 *R0)	14_H	00_H
DEVCTRL	Device control request *R2)	15_H	00_H
DEVCTRLN	Device control inverted request *R2)	16_H	00_H
WWDSCMD	Window watchdog service command *R2)	17_H	00_H
FWDRSP	Functional watchdog response command *R2)	18_H	00_H
FWDRSPSYNC	Functional watchdog response command with synchronization *R2)	19_H	00_H
SYSFAIL	FAILSAFE error status flags *R1)	$1A_H$	00_H
INITERR	INIT error status flags *R2)	$1B_H$	00_H
IF	Interrupt flags *R2)	$1C_H$	00_H
SYSSF	System status flags *R2)	$1D_H$	00_H
WKSF	Wake-up status flags *R2)	$1E_H$	00_H
SPISF	SPI status flags *R2)	$1F_H$	00_H
MONSF0	Monitor status flags 0 *R1)	20_H	00_H
MONSF1	Monitor status flags 1 *R1)	21_H	00_H
MONSF2	Monitor status flags 2 *R2)	22_H	00_H
MONSF3	Monitor status flags 3 *R1)	23_H	00_H
OTFAIL	Overtemperature failure status flags *R1)	24_H	00_H
OTWRNSF	Overtemperature warning status flags *R2)	25_H	00_H
VMONSTAT	Voltage monitor status	26_H	00_H
DEVSTAT	Device status	27_H	00_H
PROTSTAT	Protection status *R1)	28_H	01_H
WWDSTAT	Window watchdog status *R3)	29_H	00_H

(table continues...)

Table 32 (continued) Registers Overview

Register Short Name	Register Long Name	Offset Address	Reset Value
FWDSTAT0	Functional watchdog status 0 *R3)	$2A_H$	30_H
FWDSTAT1	Functional watchdog status 1 *R3)	$2B_H$	00_H
ABIST_CTRL0	ABIST control 0 *R2) [1]	$2C_H$	00_H
ABIST_CTRL1	ABIST control 1 *R2)	$2D_H$	00_H
ABIST_SELECT0	ABIST select 0 *R2)	$2E_H$	00_H
ABIST_SELECT1	ABIST select 1 *R2)	$2F_H$	00_H
ABIST_SELECT2	ABIST select 2 *R2)	30_H	00_H
BCK_FREQ_CHANGE	Buck switching frequency change *R2)	31_H	00_H
BCK_FRE_SPREAD	Buck Frequency spread *R2)	32_H	00_H
CEFUMON	Central functions monitor status flags *R2)	$3B_H$	00_H
MCSMON	Microcontroller supervision monitor *R2)	$3C_H$	00_H
DEVINFO	Device info *R2)	$3D_H$	00_H
GTM	Global testmode *R1)	$3F_H$	02_H

1) Reset class of single bits is different. See register for details.

Registers Access

The registers are addressed word-wise

12.4.1 Device registers

12.4.1.1 Device configuration 0 *R2)

DEVCFG0 Address: 00_H

Device configuration 0 *R2) Reset value: 08_H

7	6	5	4	3	2	1	0
WKTIMEN	**WKTIMCYC**	**WKTIM PRESC**	**nu**	**TRDEL**			
rw	rw	rw	none	rw			

Field	Bits	Type	Description
WKTIMEN	7	rw	**Wake timer enable** 0_D Wake timer disabled 1_D Wake timer enabled in SLEEP or STANDBY-state Reset: 0_H

(table continues...)

(continued)

Field	Bits	Type	Description
WKTIMCYC	6	rw	**Wake timer cycle period** 0_D 10 us 1_D 10 ms Reset: 0_H
WKTIMPRESC	5	rw	**Wake timer cycle period pre-scaler** 0_D 1 1_D 100 Reset: 0_H
nu	4	none	Reset: 0_H
TRDEL	3:0	rw	**Transition delay into low power states** For STANDBY and SLEEP transition. Defined as a step of 100 us. 0_D 100 us 1_D 200 us 2_D 300 us ..$_D$ ... 15_D 1600 us Reset: 8_H

12.4.1.2 Device configuration 1 *R0)

DEVCFG1 Address: 01_H

Device configuration 1 *R0) Reset value: 06_H

7	6	5	4	3	2	1	0
nu					**RESDEL**		
none					rw		

Field	Bits	Type	Description
nu	7:3	none	Reset: 00_H
RESDEL	2:0	rw	**Reset release delay time** 0_D 200 us 1_D 400 us 2_D 800 us 3_D 1ms 4_D 2 ms 5_D 4 ms 6_D 10 ms 7_D 15 ms Reset: 6_H

12.4.1.3 Device configuration 2 *R2) [7)]

DEVCFG2 Address: 02_H

Device configuration 2 *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
EVCEN	**STU**	**FRE**	**CMONEN**	**CTHR**		**ESYNPHA**	**ESYNEN**
r	r	r	rw	rw		rw	rw

Field	Bits	Type	Description
EVCEN	7	r	**External core supply enable status** Bitfield does not follow the reset class as it indicates the status of a hardware configuration (pin SEC). 0_D External core supply disabled 1_D External core supply enabled Reset: 0_H
STU	6	r	**Step up pre-regulator enable status** Bitfield does not follow the reset class as it indicates the status of a hardware configuration (pin STU). 0_D Disabled 1_D Enabled Reset: 0_H
FRE	5	r	**Step down pre-regulator frequency selection status** Bitfield does not follow the reset class as it indicates the status of a hardware configuration (pin FRE). 0_D Step down pre-regulator runs on low frequency range 1_D Step down pre-regulator runs on high frequency range Reset: 0_H
CMONEN	4	rw	**QUC current monitor enable for transition to a low power state** For STANDBY and SLEEP transition. The setting is overwritten in SLEEP as current monitoring is always enabled. 0_D Disabled 1_D Enabled Reset: 0_H
CTHR	3:2	rw	**QUC current monitoring threshold value** 0_D 10 mA 1_D 30 mA 2_D 60 mA 3_D 100 mA Reset: 0_H

(table continues...)

7 Reset class of single bits is different. See register for details.

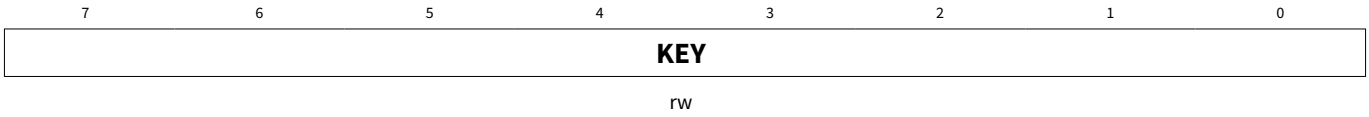
(continued)

Field	Bits	Type	Description
ESYNPHA	1	rw	**External synchronization output phase** 0_D No phase shift 1_D 180 phase shift Reset: 0_H
ESYNEN	0	rw	**Synchronization output for external switchmode regulator enable** 0_D Disable 1_D Enable Reset: 0_H

12.4.1.4 Protection register *R2)

PROTCFG Address: 03_H

Protection register *R2) Reset value: 00_H



Field	Bits	Type	Description
KEY	7:0	rw	**Protection key** Protection key register to request write access to protected registers. Unlock: write 32-bit sequence of 4 consecutive bytes (1: AB_H; 2: EF_H; 3: 56_H; 4: 12_H) to unlock access to protected registers. Lock: write 32-bit sequence of 4 consecutive bytes (1: DF_H; 2: 34_H; 3: BE_H; 4: CA_H) to lock access to protected registers. All configured values are applied to SSC and WD module after the lock. AB_H Key 1 to unlock protected registers. EF_H Key 2 to unlock protected registers. 56_H Key 3 to unlock protected registers. 12_H Key 4 to unlock protected registers. DF_H Key 1 to lock protected registers. 34_H Key 2 to lock protected registers. BE_H Key 3 to lock protected registers. CA_H Key 4 to lock protected registers. Reset: 00_H

12.4.1.5 Protected system configuration request 0 *R1)

SYSPCFG0 Address: 04_H

Protected System configuration request 0 *R1) Reset value: 01_H

7	6	5	4	3	2	1	0
DISOFFSET	**nu**						**STBYEN**
rwp	none						rwp

Field	Bits	Type	Description
DISOFFSET	7	rwp	**Request for disable of offset regulation of regulator QST related to QUC.** Valid for all device states except FAILSAFE and STANDBY. The configuration behind this bitfield is does not follow the LOCK mechanism and is applied directly when reconfiguring the bitfield, if write protection is unlocked. Data bits are sent inverted to SPI upon read access. 0_D Offset regulation enabled[1)] 1_D Offset regulation disabled Reset: 0_H
nu	6:1	none	**Not used bits shall be written as 0 and will always return 1 upon read** Reset: 00_H
STBYEN	0	rwp	**Request standby regulator QST enable** Valid for all device states except FAILSAFE. Data bits are sent inverted to SPI upon read access. 0_D Disabled 1_D Enabled Reset: 1_H

1) For the particular case of an interrupted transition to STANDBY (identifiable by SYSSF.TRFAIL) after reset (ROT asserted and released) and an intended activation of the offset regulation, the bitfield SYSPCFG0.DISOFFSET must be written to 1_B first and second back to 0_B

12.4.1.6 Protected system configuration request 1 *R2)

SYSPCFG1 Address: 05_H

Protected System configuration request 1 *R2) Reset value: 08_H

7	6	5	4	3	2	1	0
SS2DEL			**ERRSLPEN**	**ERREN**	**ERRRECEN**	**ERRREC**	
rwp			rwp	rwp	rwp	rwp	

Field	Bits	Type	Description
SS2DEL	7:5	rwp	**Request safe state 2 delay** Applied for transitions from NORMAL to INIT, WAKE and SLEEP-state. The configuration behind this bitfield is not following the LOCK mechanism and is applied directly when reconfiguring the bitfield, if write protection is unlocked. Data bits are sent inverted to SPI upon read access. 0_D no delay 1_D 10 ms 2_D 50 ms 3_D 100 ms 4_D 250 ms 5_D 1250 ms 6_D 2500 ms 7_D RESERVED Reset: 0_H
ERRSLPEN	4	rwp	**Request ERR pin monitor functionality enable while the system is in SLEEP** Data bits are sent inverted to SPI upon read access. 0_D ERR pin monitor is disabled in SLEEP 1_D ERR pin monitor can be active in SLEEP depending on ERREN bit value. Reset: 0_H
ERREN	3	rwp	**Request ERR pin monitor enable** Data bits are sent inverted to SPI upon read access. 0_D Disabled 1_D Enabled Reset: 1_H
ERRRECEN	2	rwp	**Request ERR pin monitor recovery enable** Data bits are sent inverted to SPI upon read access. 0_D Disabled 1_D Enabled Reset: 0_H

(table continues...)

(continued)

Field	Bits	Type	Description
ERRREC	1:0	rwp	**Request ERR pin monitor recovery time** Data bits are sent inverted to SPI upon read access. 0_D 1 ms 1_D 2.5 ms 2_D 5 ms 3_D 10 ms Reset: 0_H

12.4.1.7 Protected watchdog configuration request 0 *R2)

WDCFG0 Address: 06_H

Protected Watchdog configuration request 0 *R2) Reset value: $9B_H$

7	6	5	4	3	2	1	0
WWDETHR				**WWDEN**	**FWDEN**	**WWDTSEL**	**WDCYC**
rwp				rwp	rwp	rwp	rwp

Field	Bits	Type	Description
WWDETHR	7:4	rwp	**Request window watchdog error threshold** WWD error threshold to generate reset and enter into INIT-state. Data bits are sent inverted to SPI upon read access. Reset: 9_H
WWDEN	3	rwp	**Request window watchdog enable** Data bits are sent inverted to SPI upon read access. 0_D Disabled 1_D Enabled Reset: 1_H
FWDEN	2	rwp	**Request functional watchdog enable** Data bits are sent inverted to SPI upon read access. 0_D Disabled 1_D Enabled Reset: 0_H
WWDTSEL	1	rwp	**Request window watchdog trigger selection** This is ignored when window watchdog is disabled. Data bits are sent inverted to SPI upon read access. 0_D External WDI input used as a WWD trigger [1)] 1_D WWD is triggered by SPI write to WWDSCMD register Reset: 1_H
WDCYC	0	rwp	**Request watchdog cycle time** Data bits are sent inverted to SPI upon read access. 0_D 0,1 ms tick period 1_D 1 ms tick period Reset: 1_H

1) When using pin WDI as window watchdog trigger, any timing configurations of "Open Window" and "Closed Window", that are close to t_{SAM} (e.g. < 8* t_{SAM}) are to be prevented to allow reasonable service signaling from the application and reliable capturing of the WDI input.

12.4.1.8 Protected watchdog configuration request 1 *R2)

WDCFG1 Address: 07_H

Protected Watchdog configuration request 1 *R2) Reset value: 09_H

7	6	5	4	3	2	1	0
nu	**WDCYCDIV**	**nu**	**WDSLPEN**	**FWDETHR**			
none	rwp	none	rwp	rwp			

Field	Bits	Type	Description
nu	7	none	**not used bits shall be written as 0 and will always return 1 upon read** Reset: 0_H
WDCYCDIV	6	rwp	**Request enable of additional divider by 10 for watchdog cycle time (WDCYC) configuration** Data bits are sent inverted to SPI upon read access. 0_D Disabled 1_D Enabled, additional divider by 10 for watchdog cycle time (WDCYC) configuration is enabled Reset: 0_H
nu	5	none	**not used bits shall be written as 0 and will always return 1 upon read** Reset: 0_H
WDSLPEN	4	rwp	**Request watchdog functionality enable while the device is in SLEEP** Data bits are sent inverted to SPI upon read access. 0_D Disabled 1_D Enabled, the watchdogs work based on individual configuration (WWDEN and FWDEN) settings while the system is in SLEEP mode Reset: 0_H
FWDETHR	3:0	rwp	**Request functional watchdog error threshold** FWD error threshold to generate reset and enter into INIT-state. Data bits are sent inverted to SPI upon read access. Reset: 9_H

12.4.1.9 Protected Functional watchdog configuration request *R2)

FWDCFG Address: 08_H

Protected Functional watchdog configuration request *R2) Reset value: $0B_H$

7	6	5	4	3	2	1	0
nu			**WDHBTP**				
none			rwp				

Field	Bits	Type	Description
nu	7:5	none	**not used bits shall be written as 0 and will always return 1 upon read** Reset: 0_H
WDHBTP	4:0	rwp	**Request functional watchdog heartbeat timer period** Defined as a multiple of 50 watchdog cycles (RWDCFG0.WDCYC). Data bits are sent inverted to SPI upon read access. 0_D 50 wd cycles 1_D 100 wd cycles 2_D 150 wd cycles ..D ... 31_D 1600 wd cycles Reset: $0B_H$

12.4.1.10 Protected window watchdog configuration request 0 *R2)

WWDCFG0 Address: 09_H

Protected Window watchdog configuration request 0 *R2) Reset value: 06_H

7	6	5	4	3	2	1	0
nu			**CW**				
none			rwp				

Field	Bits	Type	Description
nu	7:5	none	**not used bits shall be written as 0 and will always return 1 upon read** Reset: 0_H
CW	4:0	rwp	**Request window watchdog closed window time** Defined as a multiple of 50 watchdog cycles (RWDCFG0.WDCYC). Data bits are sent inverted to SPI upon read access. 0_D 50 wd cycles 1_D 100 wd cycles 2_D 150 wd cycles ..D ... 31_D 1600 wd cycles Reset: 06_H

12.4.1.11 Protected window watchdog configuration request 1 *R2)

WWDCFG1 Address: $0A_H$

Protected Window watchdog configuration request 1 *R2) Reset value: $0B_H$

7	6	5	4	3	2	1	0
nu			**OW**				
none			rwp				

Field	Bits	Type	Description
nu	7:5	none	**not used bits shall be written as 0 and will always return 1 upon read** Reset: 0_H
OW	4:0	rwp	**Request window watchdog open window time** Defined as a multiple of 50 watchdog cycles (RWDCFG0.WDCYC). Data bits are sent inverted to SPI upon read access. 0_D 50 wd cycles 1_D 100 wd cycles 2_D 150 wd cycles ..D ... 31_D 1600 wd cycles Reset: $0B_H$

12.4.1.12 System configuration 0 status *R1)

RSYSPCFG0 Address: $0B_H$

System configuration 0 status *R1) Reset value: 01_H

7	6	5	4	3	2	1	0
DISOFFSET	**nu**						**STBYEN**
r	none						r

Field	Bits	Type	Description
DISOFFSET	7	r	**Offset regulation of regulator QST related to QUC disable status.** 1) Valid for all device states except FAILSAFE and STANDBY. 0_D Offset regulation enabled 1_D Offset regulation disabled or QST disabled by STBYEN Reset: 0_H
nu	6:1	none	Reset: 00_H
STBYEN	0	r	**Standby regulator QST enable status** Current configuration of standby regulator QST enable. Valid for all device states except FAILSAFE. 0_D Disabled 1_D Enabled Reset: 1_H

1) In case the status bitfield does not change to 0_B after request via SYSPCFG0.DISOFFSET, the bitfield SYSPCFG0.DISOFFSET must be written to 1_B first and second back to 0_B

12.4.1.13 System configuration 1 status *R3) [8)]

RSYSPCFG1 Address: $0C_H$

System configuration 1 status *R3) Reset value: 08_H

7	6	5	4	3	2	1	0
SS2DEL			**ERRSLPEN**	**ERREN**	**ERRRECEN**	**ERRREC**	
r			r	r	r	r	

Field	Bits	Type	Description
SS2DEL	7:5	r	**Safe state 2 delay status** Current configuration of safe state 2 delay applied for transitions from NORMAL to INIT, WAKE and SLEEP-state. Bitfield has different reset class than whole register. The bitfield is reset according to *R1), but with the exception that it is still reset if a Move-to-FAILSAFE event occurs during the configured SS2DEL time after exiting NORMAL state. 0_D no delay 1_D 10 ms 2_D 50 ms 3_D 100 ms 4_D 250 ms 5_D 1250 ms 6_D 2500 ms 7_D RESERVED Reset: 0_H
ERRSLPEN	4	r	**ERR pin monitor functionality enable status while the device is in SLEEP** Current configuration of ERR pin monitor functionality enable for SLEEP. 0_D ERR pin monitor is disabled in SLEEP 1_D ERR pin monitor can be active in SLEEP depending on ERREN bit value. Reset: 0_H
ERREN	3	r	**ERR pin monitor enable status** Current configuration of ERR pin monitor enable. 0_D Disabled 1_D Enabled Reset: 1_H
ERRRECEN	2	r	**ERR pin monitor recovery enable status** Current configuration of ERR pin monitor recovery enable. 0_D Disabled 1_D Enabled Reset: 0_H

(table continues...)

8 Reset class of single bits is different. See register for details.

(continued)

Field	Bits	Type	Description
ERRREC	1:0	r	**ERR pin monitor recovery time status** Current configuration of ERR pin monitor recovery time. 0_D 1 ms 1_D 2.5 ms 2_D 5 ms 3_D 10 ms Reset: 0_H

12.4.1.14 Watchdog configuration 0 status *R3)

RWDCFG0 Address: $0D_H$

Watchdog configuration 0 status *R3) Reset value: $9B_H$

7	6	5	4	3	2	1	0
WWDETHR				**WWDEN**	**FWDEN**	**WWDTSEL**	**WDCYC**
r				r	r	r	r

Field	Bits	Type	Description
WWDETHR	7:4	r	**Window watchdog error threshold status** Current configuration of WWD error threshold to generate reset and enter into INIT-state. Reset: 9_H
WWDEN	3	r	**Window watchdog enable status** Current configuration of WWD enable. 0_D Disabled 1_D Enabled Reset: 1_H
FWDEN	2	r	**Functional watchdog enable status** Current configuration of FWD enable. 0_D Disabled 1_D Enabled Reset: 0_H
WWDTSEL	1	r	**Window watchdog trigger selection status** Current configuration of WWD trigger selection. This is ignored when window watchdog is disabled. 0_D External WDI input used as a WWD trigger 1) 1_D WWD is triggered by SPI write to WWDSCMD register Reset: 1_H
WDCYC	0	r	**Watchdog cycle time status** Current configuration of watchdog cycle time. 0_D 0,1 ms tick period 1_D 1 ms tick period Reset: 1_H

1) When using pin WDI as window watchdog trigger, any timing configurations of "Open Window" and "Closed Window", that are close to t_{SAM} (e.g. < 8* t_{SAM}) are to be prevented to allow reasonable service signaling from the application and reliable capturing of the WDI input.

12.4.1.15 Watchdog configuration 1 status *R3)

RWDCFG1 Address: $0E_H$

Watchdog configuration 1 status *R3) Reset value: 09_H

7	6	5	4	3	2	1	0
nu	**WDCYCDIV**	**nu**	**WDSLPEN**	**FWDETHR**			
none	r	none	r	r			

Field	Bits	Type	Description
nu	7	none	Reset: 00_H
WDCYCDIV	6	r	**Additional divider by 10 for watchdog cycle time (WDCYC) configuration enable status** 0_D Disabled 1_D Enabled, additional divider by 10 for watchdog cycle time (WDCYC) configuration is enabled Reset: 0_H
nu	5	none	Reset: 00_H
WDSLPEN	4	r	**Watchdog functionality enable status while the device is in SLEEP** Current configuration of WD functionality enable for SLEEP. 0_D Disabled 1_D Enabled, the watchdogs work based on individual configuration (WWDEN and FWDEN) settings while the system is in SLEEP mode Reset: 0_H
FWDETHR	3:0	r	**Functional watchdog error threshold status** Current configuration of FWD error threshold to generate reset and enter into INIT-state. Reset: 9_H

12.4.1.16 Functional watchdog configuration status *R3)

RFWDCFG Address: $0F_H$

Functional watchdog configuration status *R3) Reset value: $0B_H$

7	6	5	4	3	2	1	0
nu			**WDHBTP**				
none			r				

Field	Bits	Type	Description
nu	7:5	none	Reset: 0_H
WDHBTP	4:0	r	**Functional watchdog heartbeat timer period status** Current configuration of FWD heartbeat timer period defined as a multiple of 50 watchdog cycles (RWDCFG0.WDCYC). 0_D 50 wd cycles 1_D 100 wd cycles 2_D 150 wd cycles ..$_D$ ... 31_D 1600 wd cycles Reset: $0B_H$

12.4.1.17 Window watchdog configuration 0 status *R3)

RWWDCFG0 Address: 10_H

Window watchdog configuration 0 status *R3) Reset value: 06_H

7	6	5	4	3	2	1	0
nu			**CW**				
none			r				

Field	Bits	Type	Description
nu	7:5	none	Reset: 0_H
CW	4:0	r	**Window watchdog closed window time status** Current configuration of WWD closed window time defined as a multiple of 50 watchdog cycles (RWDCFG0.WDCYC). 0_D 50 wd cycles 1_D 100 wd cycles 2_D 150 wd cycles ..$_D$ ... 31_D 1600 wd cycles Reset: 06_H

12.4.1.18 Window watchdog configuration 1 status *R3)

RWWDCFG1 Address: 11_H

Window watchdog configuration 1 status *R3) Reset value: $0B_H$

7	6	5	4	3	2	1	0
nu			**OW**				
none			r				

Field	Bits	Type	Description
nu	7:5	none	Reset: 0_H
OW	4:0	r	**Window watchdog open window time status** Current configuration of WWD open window time defined as a multiple of 50 watchdog cycles (RWDCFG0.WDCYC). 0_D 50 wd cycles 1_D 100 wd cycles 2_D 150 wd cycles ..$_D$ ... 31_D 1600 wd cycles Reset: $0B_H$

12.4.1.19 Wake-up timer configuration 0 *R0)

WKTIMCFG0 Address: 12_H

Wake-up timer configuration 0 *R0) Reset value: 00_H

7	6	5	4	3	2	1	0
TIMVALL							
rw							

Field	Bits	Type	Description
TIMVALL	7:0	rw	**Wake-up timer value lower bits** Bits (7:0) of wake-up time defined as a multiple of wake-up timer cycles (DEVCFG0.WKTIMCYC). Do not configure the bits (7:0) to 01_H or 00_H for the desired wake-up time in case WKTIMCFG1 and WKTIMCFG2 as bits(23:8) of desired wake-up time are configured to 0000_H. (000001_H and 000000_H preload of 24 bit wake up timer register is to be reserved if WKTIMEN is enabled) Reset: 00_H The wake-up timer enables transition from the STANDBY state to the INIT state or from the SLEEP state to the WAKE state. However, this feature only works when the minimum timer setting is 30 µs or higher. If the timer setting is below this minimum value, then the wake-up timer does not operate as intended, thus the device remains in STANDBY state or SLEEP state.

12.4.1.20 Wake-up timer configuration 1 *R0)

WKTIMCFG1 Address: 13_H

Wake-up timer configuration 1 *R0) Reset value: 00_H

7	6	5	4	3	2	1	0
TIMVALM							
rw							

Field	Bits	Type	Description
TIMVALM	7:0	rw	**Wake-up timer value middle bits** Bits (15:8) of wake time-up defined as a multiple of wake-up timer cycles (DEVCFG0.WKTIMCYC). Reset: 00_H

12.4.1.21 Wake-up timer configuration 2 *R0)

WKTIMCFG2 Address: 14_H

Wake-up timer configuration 2 *R0) Reset value: 00_H

7	6	5	4	3	2	1	0
TIMVALH							
rw							

Field	Bits	Type	Description
TIMVALH	7:0	rw	**Wake-up timer value higher bits** Bits (23:16) of wake-up time defined as a multiple of wake-up timer cycles (DEVCFG0.WKTIMCYC). Reset: 00_H

12.4.1.22 Device control request *R2)

DEVCTRL Address: 15_H

Device control request *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
TRK2EN	**TRK1EN**	**COMEN**	**nu**	**VREFEN**	**STATEREQ**		
rw	rw	rw	none	rw	rwhc		

Field	Bits	Type	Description
TRK2EN	7	rw	**Request tracker 2 QT2 enable** 0_D QT2 is disabled after valid request 1_D QT2 is enabled after valid request Reset: 0_H
TRK1EN	6	rw	**Request tracker 1 QT1 enable** 0_D QT1 is disabled after valid request 1_D QT1 is enabled after valid request Reset: 0_H
COMEN	5	rw	**Request communication supply QCO enable** 0_D QCO is disabled after valid request 1_D QCO is enabled after valid request Reset: 0_H
nu	4	none	Reset: 0_H
VREFEN	3	rw	**Request voltage reference supply QVR enable** 0_D QVR is disabled after valid request 1_D QVR is enabled after valid request Reset: 0_H
STATEREQ	2:0	rwhc	**Request for device state transition** Cleared to 000_B by the HW after the request is processed. After writing a new state value a user should not change the value before it's cleared by HW. 7_D RESERVED 6_D RESERVED 5_D WAKE 4_D STANDBY 3_D SLEEP 2_D NORMAL 1_D INIT 0_D NONE Reset: 0_H

12.4.1.23 Device control inverted request *R2)

DEVCTRLN Address: 16_H

Device control inverted request *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
TRK2EN	**TRK1EN**	**COMEN**	**nu**	**VREFEN**	**STATEREQ**		
rw	rw	rw	none	rw	rwhc		

Field	Bits	Type	Description
TRK2EN	7	rw	**Request tracker 2 QT2 enable** 1_D QT2 is disabled after valid request 0_D QT2 is enabled after valid request Reset: 0_H
TRK1EN	6	rw	**Request tracker 1 QT1 enable** 1_D QT1 is disabled after valid request 0_D QT1 is enabled after valid request Reset: 0_H
COMEN	5	rw	**Request communication supply QCO enable** 1_D QCO is disabled after valid request 0_D QCO is enabled after valid request Reset: 0_H
nu	4	none	Reset: 0_H
VREFEN	3	rw	**Request voltage reference supply QVR enable** 1_D QVR is disabled after valid request 0_D QVR is enabled after valid request Reset: 0_H
STATEREQ	2:0	rwhc	**Request for device state transition** Cleared to 000_B by the HW after the request is processed. After writing a new state value a user should not change the value before it's cleared by HW. 7_D NONE 6_D INIT 5_D NORMAL 4_D SLEEP 3_D STANDBY 2_D WAKE 1_D RESERVED 0_D RESERVED Reset: 0_H

12.4.1.24 Window watchdog service command *R2)

WWDSCMD Address: 17_H

Window watchdog service command *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
TRIG_STATUS	**nu**						**TRIG**
r	none						rw

Field	Bits	Type	Description
TRIG_STATUS	7	r	**Last SPI trigger received** Reset: 0_H
nu	6:1	none	Reset: 00_H
TRIG	0	rw	**Window watchdog SPI trigger command** Read TRIG_STATUS bit first and write inverted value to TRIG bit. Reset: 0_H

12.4.1.25 Functional watchdog response command *R2)

FWDRSP Address: 18_H

Functional watchdog response command *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
FWDRSP							
rw							

Field	Bits	Type	Description
FWDRSP	7:0	rw	**Functional watchdog response** Write functional watchdog response bytes to this field. Reset: 00_H

12.4.1.26 Functional watchdog response command with synchronization *R2)

FWDRSPSYNC

Address: 19_H

Functional watchdog response command with synchronization *R2)

Reset value: 00_H

7	6	5	4	3	2	1	0
FWDRSPS							
rw							

Field	Bits	Type	Description
FWDRSPS	7:0	rw	**Functional watchdog heartbeat synchronization response** Write the last functional watchdog response byte to this field to synchronize/restart the heartbeat. Reset: 00_H

12.4.1.27 FAILSAFE error status flags *R1)

SYSFAIL Address: $1A_H$

FAILSAFE error status flags *R1) Reset value: 00_H

7	6	5	4	3	2	1	0
INITF	**ABISTERR**	**nu**		**BUCKHS**	**VMONF**	**OTF**	**VOLTSELERR**
rw1c	rw1c	none		rw1c	rw1c	rw1c	rw1c

Field	Bits	Type	Description
INITF	7	rw1c	**3rd initialization timeout failure flag** 3rd initialization timeout failure due to the third consecutive initialization timeout failure. i.e. The device restarts INIT phase from FAILSAFE. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags Reset: 0_H
ABISTERR	6	rw1c	**ABIST operation interrupted flag** ABIST interrupted by any fault/event which is not part of ABIST. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags Reset: 0_H
nu	5:4	none	Reset: 0_H
BUCKHS	3	rw1c	**Buck converter monitor failure flag** Buck converter failure occurred which lead to FAILSAFE. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags Reset: 0_H
VMONF	2	rw1c	**Voltage monitor failure flag** Voltage monitor failure occurred which lead to FAILSAFE. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags, read MONSF0, MONSF1 and MONSF3 for details Reset: 0_H
OTF	1	rw1c	**Overtemperature failure flag** 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags, read OTFAIL for details Reset: 0_H

(table continues...)

(continued)

Field	Bits	Type	Description
VOLTSELERR	0	rw1c	**Double Bit error on voltage selection flag** Device entered FAILSAFE-state due to internal voltage selection failure. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags Reset: 0_H

12.4.1.28 INIT error status flags *R2)

INITERR Address: $1B_H$

INIT error status flags *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
HARDRES	**SOFTRES**	**ERRF**	**FWDF**	**WWDF**	**VMONF**	**nu**	
rw1c	rw1c	rw1c	rw1c	rw1c	rw1c	none	

Field	Bits	Type	Description
HARDRES	7	rw1c	**Hard reset flag** Hard reset has been generated due to the second consecutive initialization timeout failure. i.e. The device restarts INIT phase for the third time. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags Reset: 0_H
SOFTRES	6	rw1c	**Soft reset flag** Soft reset has been generated due to the first initialization timeout failure. i.e. The device restarts INIT phase for the 2nd time. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags Reset: 0_H
ERRF	5	rw1c	**Error monitoring failure flag** 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags Reset: 0_H
FWDF	4	rw1c	**Functional watchdog error counter overflow failure flag** Functional watchdog error counter reached the error threshold. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags Reset: 0_H
WWDF	3	rw1c	**Window watchdog error counter overflow failure flag** Window watchdog error counter reached the error threshold. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags Reset: 0_H
VMONF	2	rw1c	**Voltage monitor failure flag** Voltage monitor failure occurred which lead to INIT. 0_D No fault, write 0 - no action 1_D Fault occurred, write 1 to clear the flags, read MONSF2 for details Reset: 0_H
nu	1:0	none	Reset: 0_H

12.4.1.29 Interrupt flags *R2)

IF Address: $1C_H$

Interrupt flags *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
INTMISS	**ABIST**	**OTF**	**OTW**	**MON**	**SPI**	**WK**	**SYS**
r	rw1c	rw1c	rw1c	rw1c	rw1c	rw1c	rw1c

Field	Bits	Type	Description
INTMISS	7	r	**Interrupt not serviced in time flag** Interrupt has not been serviced within $t_{INT,TO}$ time 0_D No interrupt timeout happened 1_D Interrupt timeout happened, cleared by hardware when all other flags in IF are cleared. Reset: 0_H
ABIST	6	rw1c	**Requested ABIST operation performed flag** 0_D No interrupt, write 0 - no action 1_D Interrupt flag active, write 1 to clear the flag Reset: 0_H
OTF	5	rw1c	**Overtemperature failure interrupt flag** 0_D No interrupt, write 0 - no action 1_D Interrupt flag active, write 1 to clear the flag, read OTFAIL for details Reset: 0_H
OTW	4	rw1c	**Overtemperature warning interrupt flag** 0_D No interrupt, write 0 - no action 1_D Interrupt flag active, write 1 to clear the flag, read OTWRNSF for details Reset: 0_H
MON	3	rw1c	**Monitor interrupt flag** 0_D No interrupt, write 0 - no action 1_D Interrupt flag active, write 1 to clear the flag, read MONSF0, MONSF1, MONSF2 and MONSF3 for details Reset: 0_H
SPI	2	rw1c	**SPI interrupt flag** 0_D No interrupt, write 0 - no action 1_D Interrupt flag active, write 1 to clear the flag, read SPISF for details Reset: 0_H

(table continues...)

(continued)

Field	Bits	Type	Description
WK	1	rw1c	**Wake interrupt flag** Only set if device generates an interrupt when leaving SLEEP-state. 0_D No interrupt, write 0 - no action 1_D Interrupt flag active, write 1 to clear the flag, read WKSF for details Reset: 0_H
SYS	0	rw1c	**System interrupt flag** 0_D No interrupt, write 0 - no action 1_D Interrupt flag active, write 1 to clear the flag, read SYSSF for details Reset: 0_H

12.4.1.30 System status flags *R2)

SYSSF Address: $1D_H$

System status flags *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
nu		**NO_OP**	**TRFAIL**	**ERRMISS**	**FWDE**	**WWDE**	**CFGE**
none		rw1c	rw1c	rw1c	rw1c	rw1c	rw1c

Field	Bits	Type	Description
nu	7:6	none	Reset: 0_H
NO_OP	5	rw1c	**State transition request failure flag** Requested state transition via DEVCTRL and DEVCTRLN could not be performed because of wrong protocol (other write command in between DEVCTRL and DEVCTRLN). In case of this failure event during SLEEP state, only this flag will be set, but there is not interrupt indicated at pin INT. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
TRFAIL	4	rw1c	**Transition to low power failed flag** Transition to low power failed either due to the QUC current monitor, WAK high level or a rising edge on ENA during TRDEL time. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
ERRMISS	3	rw1c	**MCU error miss status flag** Set only when RSYSPCFG1.ERRRECEN='1' 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
FWDE	2	rw1c	**Functional watchdog error interrupt flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
WWDE	1	rw1c	**Window watchdog error interrupt flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

(table continues...)

(continued)

Field	Bits	Type	Description
CFGE	0	rw1c	**Protected configuration double bit error flag** Double bit error occurred on protected configuration register. Status registers shall be read in order to determine which configuration has changed. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

12.4.1.31 Wake-up status flags *R2)

WKSF

Address: $1E_H$

Wake-up status flags *R2)

Reset value: 00_H

7	6	5	4	3	2	1	0
WAKST	**ENAST**	**nu**	**WKSPI**	**WKTIM**	**CMON**	**ENA**	**WAK**
r	r	none	rw1c	rw1c	rw1c	rw1c	rw1c

Field	Bits	Type	Description
WAKST	7	r	**WAK input status** 0_D Voltage at pin WAK is in low level signal range 1_D Voltage at pin WAK is in high level signal range Reset: 0_H
ENAST	6	r	**ENA input status** 0_D Voltage at pin ENA is in low level signal range 1_D Voltage at pin ENA is in high level signal range Reset: 0_H
nu	5	none	Reset: 0_H
WKSPI	4	rw1c	**Wake-up from SLEEP by SPI flag ("Go to WAKE" command)** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
WKTIM	3	rw1c	**Wake-up by wake-up timer expiry flag** Bit is set as well if STANDBY-state left because of wake timer expired. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
CMON	2	rw1c	**QUC current monitor threshold wake-up flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H CMON flagged in case of device is achieving a step down peak current of approx. 50% of buck peak overcurrent limitation ($I_{PREREG,max}$) with step up pre regulator not activated and synchronization output (pin SYN) disabled. Those conditions are achievable only in SLEEP state
ENA	1	rw1c	**Wake-up by ENA signal flag** Bit is set as well if FAILSAFE or STANDBY-state left because of ENA. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

(table continues...)

(continued)

Field	Bits	Type	Description
WAK	0	rw1c	**Wake-up by WAK signal flag** Bit is set as well if FAILSAFE or STANDBY-state left because of WAK. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

12.4.1.32 SPI status flags *R2)

SPISF Address: $1F_H$

SPI status flags *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
nu			**LOCK**	**DURE**	**ADDRE**	**LENE**	**PARE**
none			rw1c	rw1c	rw1c	rw1c	rw1c

Field	Bits	Type	Description
nu	7:5	none	Reset: 0_H
LOCK	4	rw1c	**LOCK or UNLOCK procedure error flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
DURE	3	rw1c	**SPI frame duration error flag** SCS low for more than 2 ms. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
ADDRE	2	rw1c	**SPI address invalid flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
LENE	1	rw1c	**SPI frame length invalid flag** Number of detected SPI clock cycles different than 16. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
PARE	0	rw1c	**SPI frame parity error flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

12.4.1.33 Monitor status flags 0 *R1)

MONSF0 Address: 20_H

Monitor status flags 0 *R1) Reset value: 00_H

7	6	5	4	3	2	1	0
TRK2SG	**TRK1SG**	**VREFSG**	**COMSG**	**VCORESG**	**STBYSG**	**UCSG**	**PREGSG**
rw1c	rw1c	rw1c	rw1c	rw1c	rw1c	rw1c	rw1c

Field	Bits	Type	Description
TRK2SG	7	rw1c	**Tracker 2 (QT2) short to ground status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
TRK1SG	6	rw1c	**Tracker 1 (QT1) short to ground status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
VREFSG	5	rw1c	**Voltage reference supply (QVR) short to ground status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
COMSG	4	rw1c	**Communication supply (QCO) short to ground status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
VCORESG	3	rw1c	**Core voltage monitor (VCI) short to ground status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
STBYSG	2	rw1c	**Standby supply (QST) short to ground status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
UCSG	1	rw1c	**MCU supply (QUC) short to ground status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
PREGSG	0	rw1c	**Pre-regulator (FB) short to ground status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

12.4.1.34 Monitor status flags 1 *R1)

MONSF1 Address: 21_H

Monitor status flags 1 *R1) Reset value: 00_H

VR

7	6	5	4	3	2	1	0
TRK2OV	**TRK1OV**	**VREFOV**	**COMOV**	**VCOREOV**	**STBYOV**	**UCOV**	**PREGOV**
rw1c	rw1c	rw1c	rw1c	rw1c	rw1c	rw1c	rw1c

Field	Bits	Type	Description
TRK2OV	7	rw1c	**Tracker 2 (QT2) overvoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
TRK1OV	6	rw1c	**Tracker 1 (QT1) supply overvoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
VREFOV	5	rw1c	**Voltage reference supply (QVR) overvoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
COMOV	4	rw1c	**Communication supply (QCO) overvoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
VCOREOV	3	rw1c	**Core voltage monitor (VCI) overvoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
STBYOV	2	rw1c	**Standby supply (QST) overvoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
UCOV	1	rw1c	**MCU supply (QUC) overvoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
PREGOV	0	rw1c	**Pre-regulator (FB) overvoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

12.4.1.35 Monitor status flags 2 *R2)

MONSF2 Address: 22_H

Monitor status flags 2 *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
TRK2UV	**TRK1UV**	**VREFUV**	**COMUV**	**VCOREUV**	**STBYUV**	**UCUV**	**PREGUV**
rw1c	rw1c	rw1c	rw1c	rw1c	rw1c	rw1c	rw1c

Field	Bits	Type	Description
TRK2UV	7	rw1c	**Tracker 2 (QT2) undervoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
TRK1UV	6	rw1c	**Tracker 1 (QT1) undervoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
VREFUV	5	rw1c	**Voltage reference supply (QVR) undervoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
COMUV	4	rw1c	**Communication supply (QCO) undervoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
VCOREUV	3	rw1c	**Core voltage monitor (VCI) undervoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
STBYUV	2	rw1c	**Standby supply (QST) undervoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
UCUV	1	rw1c	**MCU supply (QUC) undervoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
PREGUV	0	rw1c	**Pre-regulator (FB) undervoltage status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

12.4.1.36 Monitor status flags 3 *R1)

MONSF3 Address: 23_H

Monitor status flags 3 *R1) Reset value: 00_H

7	6	5	4	3	2	1	0
BIASHI	**BIASLOW**	**BG12OV**	**BG12UV**	**nu**		**STUSG**	**VBATOV**
rw1c	rw1c	rw1c	rw1c	none		rw1c	rw1c

Field	Bits	Type	Description
BIASHI	7	rw1c	**Bias current too high flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
BIASLOW	6	rw1c	**Bias current too low flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
BG12OV	5	rw1c	**Bandgap comparator overvoltage condition flag** (VBG1 ≥ VBG2 + 4%) This diagnostic will re-trigger an INT event raising the flag repetitively after t_{INTTO} as long as the out of range condition is present. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
BG12UV	4	rw1c	**Bandgap comparator undervoltage condition flag** (VBG1 ≤ VBG2 - 4%) There are exceptional conditions described in [1)] and [2)], that may trigger this flag during operation. For these conditions the flag is to be seen as an exaggerated reaction and is to be cleared without further action required. This diagnostic will re-trigger an INT event raising the flag repetitively after t_{INTTO} as long as the out of range condition is present. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
nu	3:2	none	Reset: 0_H
STUSG	1	rw1c	**Step up regulator short to ground status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

(table continues...)

(continued)

Field	Bits	Type	Description
VBATOV	0	rw1c	**Supply voltage VSx overvoltage flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

1) In the particular case of an enabled offset regulation of QST (DISOFFSET is set to 0_B) and a "Move-to-INIT"(due to QUC/QST UV) or a "Move to FAILSAFE" event happens, this flag may be set and be readable after ROT release. Due to the fact that the flag is an interrupt contributor, it can be disregarded and cleared after ROT release.

2) In the particular case of a disablement of QST followed by an enablement of QST via SYSPCFG0.STBYEN (including LOCK sequences for both configurations) within less than 2 ms, this flag may be set and trigger and interrupt event.

12.4.1.37 Overtemperature failure status flags *R1)

OTFAIL Address: 24_H

Overtemperature failure status flags *R1) Reset value: 00_H

7	6	5	4	3	2	1	0
MON	**nu**		**COM**	**nu**		**UC**	**PREG**
rw1c	none		rw1c	none		rw1c	rw1c

Field	Bits	Type	Description
MON	7	rw1c	**Monitoring overtemperature flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
nu	6:5	none	Reset: 0_H
COM	4	rw1c	**Communication supply (QCO) overtemperature flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
nu	3:2	none	Reset: 0_H
UC	1	rw1c	**MCU supply (QUC) overtemperature flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
PREG	0	rw1c	**Pre-regulator overtemperature flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

12.4.1.38 Overtemperature warning status flags *R2)

OTWRNSF Address: 25_H

Overtemperature warning status flags *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
nu		**VREF**	**COM**	**nu**		**UC**	**PREG**
none		rw1c	rw1c	none		rw1c	rw1c

Field	Bits	Type	Description
nu	7:6	none	Reset: 0_H
VREF	5	rw1c	**Voltage reference supply (QVR) overload flag** Flag is raised if output current is in overload condition (close to current limitation) for more than 1 ms. Please note that this flag may also be raised in case the regulator enters into dropout condition. 0_D Write 0 no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
COM	4	rw1c	**Communication supply (QCO) overtemperature warning flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
nu	3:2	none	Reset: 0_H
UC	1	rw1c	**MCU supply (QUC) overtemperature warning flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
PREG	0	rw1c	**Pre-regulator overtemperature warning flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

12.4.1.39 Voltage monitor status

VMONSTAT Address: 26_H

Voltage monitor status Reset value: 00_H

7	6	5	4	3	2	1	0
TRK2ST	**TRK1ST**	**VREFST**	**COMST**	**VCOREST**	**STBYST**	**nu**	**PREGST**
r	r	r	r	r	r	none	r

Field	Bits	Type	Description
TRK2ST	7	r	**Tracker 2 (QT2) voltage status** 0_D Voltage is out of range or not enabled 1_D Voltage is OK Reset: 0_H
TRK1ST	6	r	**Tracker 1 (QT1) voltage status** 0_D Voltage is out of range or not enabled 1_D Voltage is OK Reset: 0_H
VREFST	5	r	**Voltage reference supply (QVR) voltage status** 0_D Voltage is out of range or not enabled 1_D Voltage is OK Reset: 0_H
COMST	4	r	**Communication supply (QCO) voltage status** 0_D Voltage is out of range or not enabled 1_D Voltage is OK Reset: 0_H
VCOREST	3	r	**Core voltage monitor (VCI) voltage status** 0_D Voltage is out of range or not enabled 1_D Voltage is OK Reset: 0_H
STBYST	2	r	**Standby supply (QST) voltage status** 0_D Voltage is out of range or not enabled 1_D Voltage is OK Reset: 0_H
nu	1	none	Reset: 0_H
PREGST	0	r	**Pre-regulator (FB) voltage status** 0_D Voltage is out of range or not enabled 1_D Voltage is OK Reset: 0_H

12.4.1.40 Device status

DEVSTAT Address: 27_H

Device status Reset value: 00_H

7	6	5	4	3	2	1	0
TRK2EN	**TRK1EN**	**COMEN**	**STBYEN**	**VREFEN**	**STATE**		
r	r	r	r	r	r		

Field	Bits	Type	Description
TRK2EN	7	r	**Tracker 2 (QT2) enable status** 0_D Voltage is disabled 1_D Voltage is enabled Reset: 0_H
TRK1EN	6	r	**Tracker 1 (QT1) enable status** 0_D Voltage is disabled 1_D Voltage is enabled Reset: 0_H
COMEN	5	r	**Communication supply (QCO) enable status** 0_D Voltage is disabled 1_D Voltage is enabled Reset: 0_H
STBYEN	4	r	**Standby supply (QST) enable status** 0_D Voltage is disabled 1_D Voltage is enabled Reset: 0_H
VREFEN	3	r	**Reference voltage supply (QVR) enable status** 0_D Voltage is disabled 1_D Voltage is enabled Reset: 0_H
STATE	2:0	r	**Device state** 7_D RESERVED 6_D RESERVED 5_D WAKE 4_D STANDBY 3_D SLEEP 2_D NORMAL 1_D INIT 0_D RESERVED Reset: 0_H

12.4.1.41 Protection status *R1)

PROTSTAT Address: 28_H

Protection status *R1) Reset value: 01_H

7	6	5	4	3	2	1	0
KEY4OK	**KEY3OK**	**KEY2OK**	**KEY1OK**	**nu**			**LOCK**
r	r	r	r	none			r

Field	Bits	Type	Description
KEY4OK	7	r	**Key4 ok status** Information about validity of the 4th received protection key byte 0_D Key not valid 1_D Key valid Reset: 0_H
KEY3OK	6	r	**Key3 ok status** Information about validity of the 3rd received protection key byte 0_D Key not valid 1_D Key valid Reset: 0_H
KEY2OK	5	r	**Key2 ok status** Information about validity of the 2nd received protection key byte 0_D Key not valid 1_D Key valid Reset: 0_H
KEY1OK	4	r	**Key1 ok status** Information about validity of the 1st received protection key byte 0_D Key not valid 1_D Key valid Reset: 0_H
nu	3:1	none	Reset: 0_H
LOCK	0	r	**Protected register lock status** 0_D Access is unlocked 1_D Access is locked Reset: 1_H

12.4.1.42 Window watchdog status *R3)

WWDSTAT Address: 29_H

Window watchdog status *R3) Reset value: 00_H

7	6	5	4	3	2	1	0
nu				**WWDECNT**			
none				r			

Field	Bits	Type	Description
nu	7:4	none	Reset: 0_H
WWDECNT	3:0	r	**Window watchdog error counter status** Reset: 0_H

12.4.1.43 Functional watchdog status 0 *R3)

FWDSTAT0 Address: $2A_H$

Functional watchdog status 0 *R3) Reset value: 30_H

7	6	5	4	3	2	1	0
nu	**FWDRSPOK**	**FWDRSPC**		**FWDQUEST**			
none	r	r		r			

Field	Bits	Type	Description
nu	7	none	Reset: 0_H
FWDRSPOK	6	r	**Functional watchdog response check error status** 0_D Response message is wrong 1_D All received bytes in response message are correct Reset: 0_H
FWDRSPC	5:4	r	**Functional watchdog response counter value** Reset: 3_H
FWDQUEST	3:0	r	**Functional watchdog question** Reset: 0_H

12.4.1.44 Functional watchdog status 1 *R3)

FWDSTAT1 Address: $2B_H$

Functional watchdog status 1 *R3) Reset value: 00_H

7	6	5	4	3	2	1	0
nu				**FWDECNT**			
none				r			

Field	Bits	Type	Description
nu	7:4	none	Reset: 0_H
FWDECNT	3:0	r	**Functional watchdog error counter status** Reset: 0_H

12.4.1.45 ABIST control 0 *R2) [9)]

ABIST_CTRL0 Address: $2C_H$

ABIST control0 *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
STATUS				**INT**	**SINGLE**	**PATH**	**START**
r				rw	rw	rw	rwhc

Field	Bits	Type	Description
STATUS	7:4	r	**ABIST global error status** ABIST status information after requested operation has been performed, information shall only be considered valid, once START bit is cleared. Bits have different reset class than whole register. Bitfield has different reset class than whole register. The bitfield is reset according to *R1). 5_D Selected ABIST operation performed with no errors 10_D Selected ABIST operation performed with errors, check respective SELECT registers Reset: 0_H
INT	3	rw	**Safety path selection** Select whether safe state or interrupt related comparator shall be tested. 0_D safe state related comparators shall be tested 1_D interrupt related comparators shall be tested Reset: 0_H
SINGLE	2	rw	**ABIST Sequence selection** Select whether a single comparator shall be tested or all comparators in predefined sequence 0_D Predefined sequence 1_D Single comparator test Reset: 0_H
PATH	1	rw	**Full path test selection** Select the path which should be covered by ABIST operation 0_D Comparator only 1_D Comparator and corresponding deglitching logic, shall be selected in case contribution to respective safety measure needs to be tested Reset: 0_H

(table continues...)

9 Reset class of single bits is different. See register for details.

(continued)

Field	Bits	Type	Description
START	0	rwhc	**Start ABIST operation** The ABIST operation itself is started. This bit is cleared after ABIST operation has been performed 0_D Operation done 1_D Start operation Reset: 0_H

12.4.1.46 ABIST control 1 *R2)

ABIST_CTRL1 Address: $2D_H$

ABIST control1 *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
nu						**ABIST_CLK_EN**	**OV_TRIG**
none						rw	rw

Field	Bits	Type	Description
nu	7:2	none	Reset: 00_H
ABIST_CLK_EN	1	rw	**ABIST clock check enable** Select ABIST clock to check its functionality 0_D Disable 1_D Enable Reset: 0_H
OV_TRIG	0	rw	**Overvoltage trigger for secondary internal monitor enable** 0_D Disable 1_D Enable Reset: 0_H

12.4.1.47 ABIST select 0 *R2)

ABIST_SELECT0 Address: $2E_H$

ABIST select 0 *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
TRK2OV	**TRK1OV**	**VREFOV**	**COMOV**	**VCOREOV**	**STBYOV**	**UCOV**	**PREGOV**
rwhu	rwhu	rwhu	rwhu	rwhu	rwhu	rwhu	rwhu

Field	Bits	Type	Description
TRK2OV	7	rwhu	**Select tracker 2 (QT2) OV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
TRK1OV	6	rwhu	**Select tracker 1 (QT1) OV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
VREFOV	5	rwhu	**Select voltage reference supply (QVR) OV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
COMOV	4	rwhu	**Select communication supply (QCO) OV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
VCOREOV	3	rwhu	**Select core voltage monitor (VCI) OV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H

(table continues...)

(continued)

Field	Bits	Type	Description
STBYOV	2	rwhu	**Select standby supply (QST) OV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
UCOV	1	rwhu	**Select MCU supply (QUC) OV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
PREGOV	0	rwhu	**Select pre-regulator (FB) OV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H

12.4.1.48 ABIST select 1 *R2)

ABIST_SELECT1 Address: $2F_H$

ABIST select 1 *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
TRK2UV	**TRK1UV**	**VREFUV**	**COMUV**	**VCOREUV**	**STBYUV**	**UCUV**	**PREGUV**
rwhu	rwhu	rwhu	rwhu	rwhu	rwhu	rwhu	rwhu

Field	Bits	Type	Description
TRK2UV	7	rwhu	**Select tracker 2 (QT2) UV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
TRK1UV	6	rwhu	**Select tracker 1 (QT1) UV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this voltage Reset: 0_H
VREFUV	5	rwhu	**Select voltage reference supply (QVR) UV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
COMUV	4	rwhu	**Select communication supply (QCO) UV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
VCOREUV	3	rwhu	**Select core voltage monitor (VCI) UV comparator for ABIST operation** 0_D Not selected 1_D selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H

(table continues...)

(continued)

Field	Bits	Type	Description
STBYUV	2	rwhu	**Select standby supply (QST) UV comparator for ABIST operation** 0_D Not selected 1_D selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
UCUV	1	rwhu	**Select MCU supply (QUC) UV comparator for ABIST operation** 0_D Not selected 1_D selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
PREGUV	0	rwhu	**Select pre-regulator (FB) UV comparator for ABIST operation** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H

12.4.1.49 ABIST select 2 *R2)

ABIST_SELECT2 Address: 30_H

ABIST select 2 *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
BIASHI	**BIASLOW**	**BG12OV**	**BG12UV**	**nu**			**VBATOV**
rwhu	rwhu	rwhu	rwhu	none			rwhu

Field	Bits	Type	Description
BIASHI	7	rwhu	**Select bias current too high** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
BIASLOW	6	rwhu	**Select bias current too low** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
BG12OV	5	rwhu	**Select bandgap comparator OV condition** (VBG1 ≥ VBG2 + 4%) 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
BG12UV	4	rwhu	**Select bandgap comparator UV condition** (VBG1 ≤ VBG2 - 4%) 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H
nu	3:1	none	Reset: 0_H
VBATOV	0	rwhu	**Select supply VSx overvoltage** 0_D Not selected 1_D Selected, bit will be cleared upon successful ABIST operation on comparator, bit will be set in case of ABIST fail for this comparator Reset: 0_H

12.4.1.50 Buck switching frequency change *R2)

BCK_FREQ_CHANGE Address: 31_H

Buck switching frequency change *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
BCK_DRV_STGE	**nu**				**BCK_FREQ_SEL**		
rw	none				rw		

Field	Bits	Type	Description
BCK_DRV_STGE	7	rw	**BUCK driving stage selection** The switching speed of the step down regulator power stages can be adjusted in two configurations to optimize for efficiency or emissions. 1_D Weak driving stage for slower switching 0_D Strong driving stage for faster switching Reset: 0_H ***Note**: This bit will be ignored in SLEEP. In SLEEP state the driving stage is always set to work in "weak" mode. Any configuration will take effect when exiting from SLEEP state.*
nu	6:3	none	Reset: 00_H
BCK_FREQ_SEL	2:0	rw	**BUCK switching frequency change** For manual adjustment of buck frequency in fixed variations from the nominal frequency $f_{OSC,step-down}$ 7_D Change buck frequency by approx. -5.0% from $f_{OSC,step-down}$ 6_D Change buck frequency by approx. -3.3% from $f_{OSC,step-down}$ 5_D Change buck frequency by approx. -1.7% from $f_{OSC,step-down}$ 4_D No change 3_D Change buck frequency by approx. +5.0% from $f_{OSC,step-down}$ 2_D Change buck frequency by approx. +3.3% from $f_{OSC,step-down}$ 1_D Change buck frequency by approx. +1.7% from $f_{OSC,step-down}$ 0_D No Change Reset: 0_H

12.4.1.51 Buck Frequency spread *R2)

BCK_FRE_SPREAD Address: 32_H

Buck Frequency spread *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
FRE_SP_THR							
rw							

Field	Bits	Type	Description
FRE_SP_THR	7:0	rw	**Spread spectrum** Select the percentage of frequency spread(±). The mean frequency is reduced by the percentage as well keeping the maximum frequency at the nominal frequency selected by FRE. 00_H No spread 55_H +0% / -2.5% frequency spread 80_H +/-2.5% frequency spread AA_H +/-5.0% frequency spread $D5_H$ +/-7.5% frequency spread FF_H +7.5% / -10.0% frequency spread others not used Reset: 00_H

12.4.1.52 Central functions monitor status flags *R2)

CEFUMON Address: $3B_H$

Central functions monitor status flags *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
STUOC	**nu**			**CEFU3**	**CEFU2**	**CEFU1**	**CEFU0**
rw1c	none			rw1c	rw1c	rw1c	rw1c

Field	Bits	Type	Description
STUOC	7	rw1c	**Step up pre-regulator over-current pre-warning status flag** This diagnostic will re-trigger an INT event raising the flag repetitively every 500 µs as long as the over-current pre-warning condition is reached. 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
nu	6:4	none	Reset: 0_H
CEFU3	3	rw1c	**Internal regulator backup for switchable power domain failure status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
CEFU2	2	rw1c	**Internal regulator for switchable power domain failure status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
CEFU1	1	rw1c	**Internal regulator backup for always on power domain failure status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H
CEFU0	0	rw1c	**Internal regulator for always on power domain failure status flag** 0_D Write 0 - no action 1_D Event detected, write 1 to clear the flag Reset: 0_H

12.4.1.53 Microcontroller supervision monitor *R2)

MCSMON Address: $3C_H$

Microcontroller supervision monitor *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
MPS	**MPSPIN**	**CYCMON**					
rw	r	r					

Field	Bits	Type	Description
MPS	7	rw	**Microcontroller programming support enable (OR combination with MPS pin)** 0_D Disabled via SPI (unless enabled by MPS pin high) 1_D Enabled via SPI (independent of MPS pin) Reset: 0_H
MPSPIN	6	r	**Microcontroller programming support enable (OR combination with MPS bitfield)** 0_D Disabled via pin MPS (unless enabled by MPS bitfield being set) 1_D Enabled via pin MPS (independent of MPS bitfield) Reset: 0_H
CYCMON	5:0	r	**Watchdog cycle timer monitor** 0_D 0 wd cycles passed 1_D 1 wd cycles passed 2_D 2 wd cycles passed 50_D 50 wd cycles passed 51_D not used 63_D not used Reset: 0_H

12.4.1.54 Device info *R2)

DEVINFO Address: $3D_H$

Device info *R2) Reset value: 00_H

7	6	5	4	3	2	1	0
nu	**CHIPSTEP**						
none	r						

Field	Bits	Type	Description
nu	7	none	Reset: 0_H
CHIPSTEP	6:0	r	**Chip design step identification** 00_H Blocked for predecessor device TLF35584 33_H TLF35585xxS01 (5V0) B21-Step $5A_H$ TLF35585xxS02 (3V3) B21-Step 19_H TLF35585xxS01 (5V0) B22-Step 70_H TLF35585xxS02 (3V3) B22-Step $0F_H$ TLF35585xxS01 (5V0) B23-Step 66_H TLF35585xxS02 (3V3) B23-Step 25_H TLF35585xxS02 (5V0) B30-Step $4C_H$ TLF35585xxS02 (3V3) B30-Step Reset: 0_H

12.4.1.55 Global testmode *R1)

GTM Address: $3F_H$

Global testmode *R1) Reset value: 02_H

7	6	5	4	3	2	1	0
nu						**NTM**	**TM**
none						r	r

Field	Bits	Type	Description
nu	7:2	none	Reset: 00_H
NTM	1	r	**Test mode inverted status** 0_D Device is in test mode 1_D Device is in normal mode Reset: 1_H
TM	0	r	**Test mode status** 0_D Device is in normal mode 1_D Device is in test mode Reset: 0_H

12.5 Electrical characteristics SPI signals

Table 33 Electrical characteristics SPI signals

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Pin SCS, Chip Select							
Chip select valid high level	$V_{SCS, hi}$	2.0	–	–	V	V_{SCS} increasing; V_{QUC} = 3.3 V	P_13.5.4
Chip select valid low level	$V_{SCS, lo}$	–	–	0.8	V	V_{SCS} decreasing; V_{QUC} = 3.3 V	P_13.5.5
Chip select hysteresis	$V_{SCS, hyst}$	100	300	600	mV	V_{QUC} = 3.3 V	P_13.5.6
Chip select pull-up current	I_{SCS}	-175	-120	–	µA	V_{SCS} = 0 V	P_13.5.7
Chip select input capacitance	C_{SCS}	–	4	15	pF	1)	P_13.5.8
Pin SCL, Clock							
Clock signal valid high level	$V_{SCL, hi}$	2.0	–	–	V	V_{SCL} increasing; V_{QUC} = 3.3 V	P_13.5.12
Clock signal valid low level	$V_{SCL, lo}$	–	–	0.8	V	V_{SCL} decreasing; V_{QUC} = 3.3 V	P_13.5.13
Clock hysteresis	$V_{SCL, hyst}$	100	300	600	mV	V_{QUC} = 3.3 V	P_13.5.14
Clock signal pull-down current	I_{SCL}	–	150	330	µA	V_{SCL} = V_{QUC}	P_13.5.15
Clock input capacitance	C_{SCL}	–	4	15	pF	1)	P_13.5.16
Pin SDI, data input, MOSI							
Data input valid high level	$V_{SDI, hi}$	2.0	–	–	V	V_{SDI} increasing; V_{QUC} = 3.3 V	P_13.5.20
Data input valid low level	$V_{SDI, lo}$	–	–	0.8	V	V_{SDI} decreasing; V_{QUC} = 3.3 V	P_13.5.21
Data input hysteresis	$V_{SDI, hyst}$	100	300	600	mV	V_{QUC} = 3.3 V	P_13.5.22
Data input signal pull-down current	I_{SDI}	–	150	330	µA	V_{SDI} = V_{QUC}	P_13.5.23
Data input capacitance	C_{SDI}	–	4	15	pF	1)	P_13.5.24
Pin SDO, data output, MISO							
Data output high level	$V_{SDO, hi}$	2.3	–	–	V	V_{QUC} = 3.3 V; I_{SDO} = -7 mA	P_13.5.27
Data output low level	$V_{SDO, lo}$	–	–	0.7	V	V_{QUC} = 3.3 V; I_{SDO} = 5.5 mA	P_13.5.28

(table continues...)

Table 33 (continued) Electrical characteristics SPI signals

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Data output rise time	$t_{SDO,\ rise}$	–	–	25	ns	1) $C_{SDO,load}$ = 50 pF	P_13.5.29
Data output fall time	$t_{SDO,\ fall}$	–	–	25	ns	1) $C_{SDO,load}$ = 50 pF	P_13.5.30
Data output tristate capacitance	$C_{SDO,\ tri}$	–	4	15	pF	1)	P_13.5.31
Data output tristate leakage	$I_{SDO,\ tri,\ leak}$	-10	–	10	µA	–	P_13.5.32

1) Specified by design, not subject to production test

13 Interrupt generation

The interrupt generation block handles requests from the following sources to generate interrupts:

- State machine:
  - A requested state transition has not been performed successfully, e.g. SLEEP-state could not be entered because of QUC current consumption above the selected threshold level.
  - A requested state transition from SLEEP has been performed successfully, i.e. the device entered WAKE-state. The MCU may only send (additional) SPI commands after an interrupt event has been generated by the system. The purpose of the interrupt event is to inform the MCU, that the device entered WAKE-state and that the device is capable of performing SPI communication at the full transmission rate.
- Watchdog: an interrupt request is generated if the Watchdog is not serviced properly and configured in a way to allow service errors to occur, i.e. an error counter threshold value of more than 2 is configured. In this case an interrupt is generated only if the error counter threshold is not reached or exceeded due to this error.
- Error pin monitoring: an interrupt request is generated if the error pin monitoring block detects an error and is configured in a way to allow occurrence of this error for a certain amount of time (recovery delay action enabled). In this case an interrupt is requested if an error is detected by the error pin monitoring and the recovery delay has not expired.
- Monitoring block: an interrupt request is generated based on the defined system reaction described in Chapter 10.4.
- Overtemperature warnings and overtemperature shutdown of communication supply (QCO).
- SPI block due to SPI error.
- ABIST operation completed.
- Double bit error in the protected configuration.

An interrupt is generated to inform a connected MCU about a non-severe system condition. This allows the MCU to perform proper action based on the source of the interrupt. A single interrupt line exists, which is high on default. All Internal interrupt sources are enabled by default and cannot be disabled.

An interrupt is signaled by pulling the interrupt line low for at least $t_{INT,min}$ (interrupt minimum pulse width) after an internal interrupt. The interrupt line is driven high if all of the IF register flag(s) has/have been cleared via SPI operation earliest after $t_{INT,min}$ but latest after t_{INTTO}.

Special cases:

- If an interrupt is signaled by pulling INT low and not all interrupt status flags are cleared by the MCU within t_{INTTO}, the INT stays low until t_{INTTO} has expired, but no additional interrupt event is generated. Information about a pending interrupt event can be derived via the INTMISS status flag. This status flag is cleared each time the interrupt line is driven low.
- If an interrupt is signaled by pulling INT low and an additional bit is set in the IF register interrupt flag after the interrupt bits have been read by the MCU and this outdated information is used to clear the interrupt flags, the interrupt line stays low until t_{INTTO} has expired, but no additional interrupt event is generated. Information about a pending interrupt event can be derived via a status flag.
- After releasing the interrupt line to high, the interrupt line stays high for at least t_{INTTO} regardless of any additional internal interrupt condition. If another interrupt event occurs during the delay time out (t_{INTTO}), this is signaled by generating a new pulse after the delay time out t_{INTTO}.

All interrupt sources can only be cleared by a "write-1-to-clear" (w1c) SPI operation, i.e. writing the value 1_B to the corresponding bit(s) in the interrupt register clears the event flag.

Interrupt events are organized in a two level approach. The first level (interrupt flag) provides information about different groups of interrupt events. The second level (status flags) provides detailed information about which particular event(s) generated the interrupt. To service an interrupt it is necessary to write the interrupt

flag register (IF). The status flag registers are only meant to provide detailed information. However all status flags can be cleared as well.

Recommended interrupt service routine

After an interrupt detected by the MCU, the recommended interrupt service routine consists of the following steps:

1. Read interrupt flag register (IF).
2. Read status flag register(s) based on information from interrupt flag register.
3. Take the proper action based on interrupt flag(s) and status flag(s).
4. Write the status flag register(s) with the previously read values to clear.
5. Write the interrupt flag register (IF) with the previously read value to clear.
6. Read interrupt flag register (IF) again to check for another interrupt event during the time of the routine. If this applies, then return to step 2.

Writing back the interrupt register (IF) releases the interrupt line INT, if all bits are cleared (interrupt timing requirements is fulfilled)

An interrupt is only generated after the reset signal to the MCU has been released. An interrupt event which occurs while the reset for the MCU (pin ROT) is still active is not signaled at the interrupt line but the particular status bit for this event is set.

The following figure shows the timing aspects of the interrupt line:

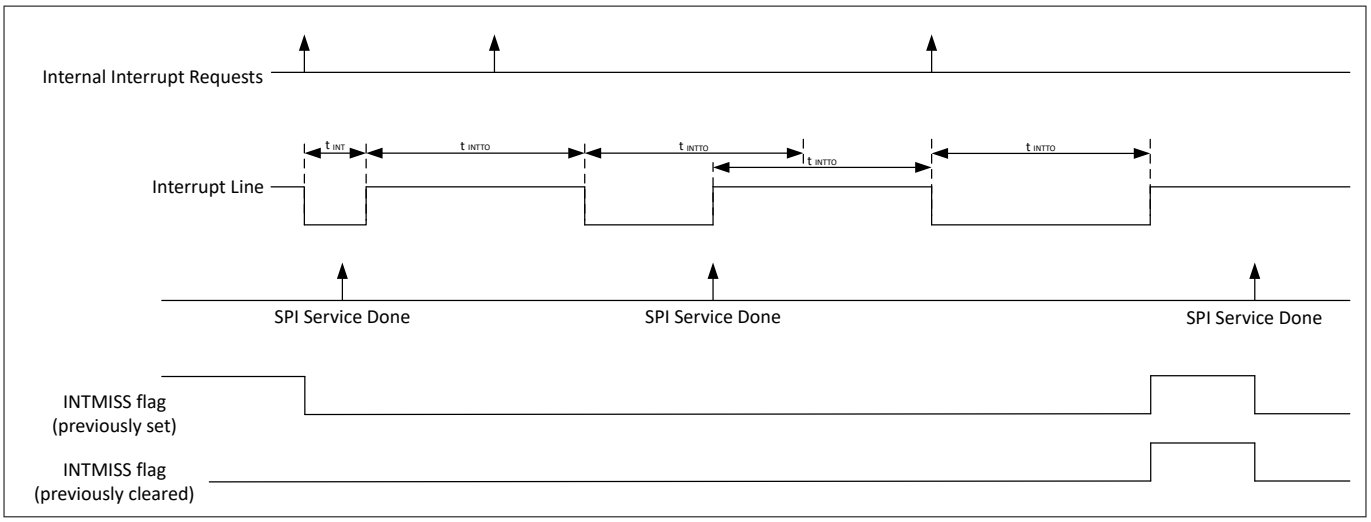


Figure 75 Interrupt timing

Details about the system behavior in case not all interrupt status flags have been cleared are depicted in the following figure:

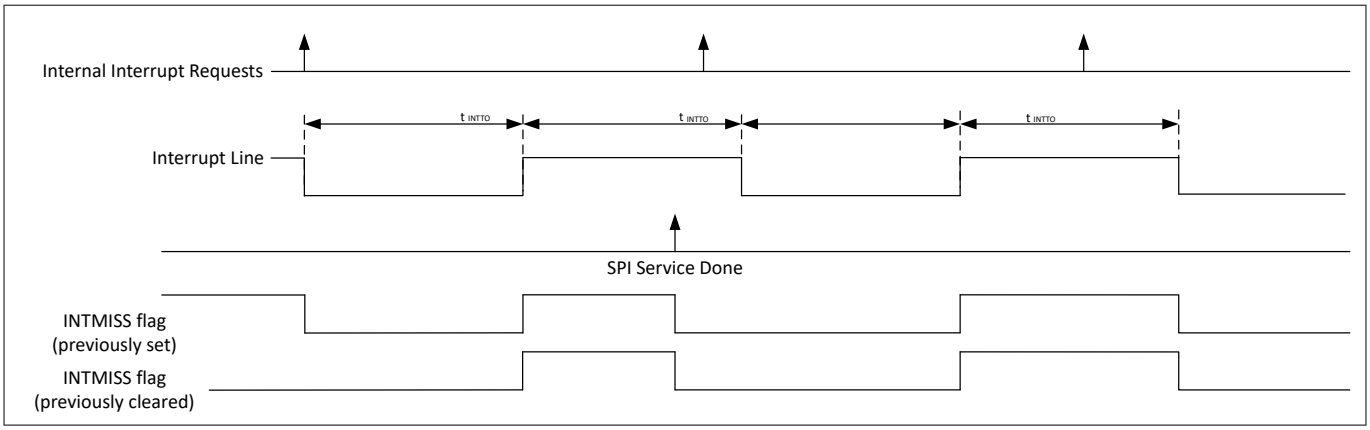


Figure 76 Interrupt timing without timely service

An interrupt is always generated if an internal status flag is set, irrespective of the current state of this status flag. For example, if a parity error on SPI communication is detected for the first time, the flag SPISF.PARE is set and an interrupt is generated. This flag sets the corresponding SPI interrupt flag (IF.SPI) as well. If the flag IF.SPI is not cleared, but a second SPI parity error occurs, a new interrupt is generated. The timings shown in the two figures above are fulfilled for generating a new interrupt.

13.1 Electrical characteristics interrupt generation

Table 34 Electrical characteristics interrupt - timings

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
Minimum interrupt pulse width	$t_{INT,min}$	90	100	150	µs	–	P_14.1
Interrupt time out	t_{INTTO}	270	300	350	µs	–	P_14.2

14 Watchdog supervision

14.1 Introduction window watchdog and functional watchdog

Two independent types of watchdogs are implemented in the device:

- A standalone window watchdog (WWD) with programmable input trigger signal (either pin WDI or trigger via SPI command to WWDSCMD register)
- A standalone functional question-answer based watchdog (FWD).

The watchdogs have independent timers and error counters, which allows to run both watchdogs in parallel.

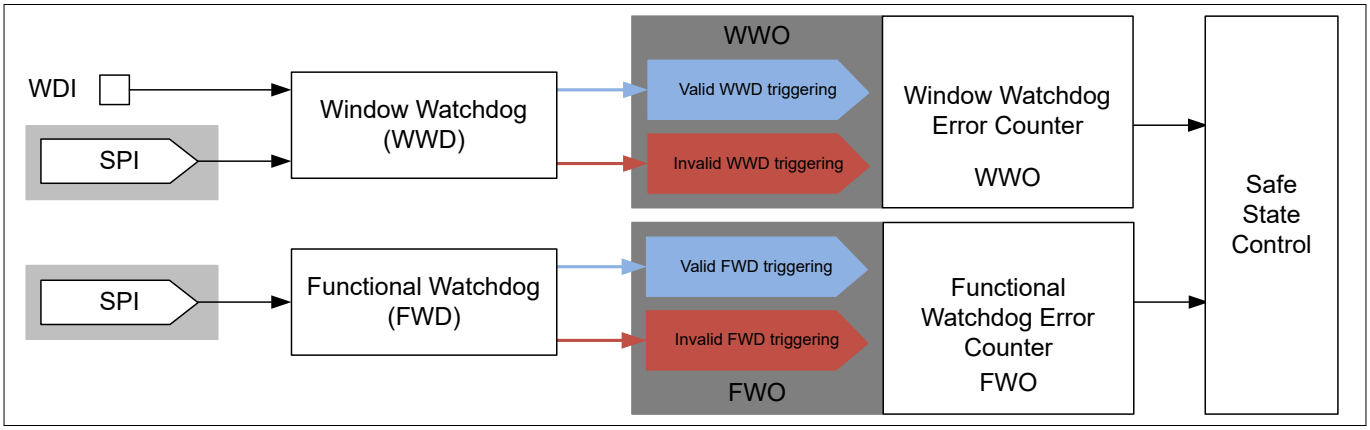


Figure 77 Window watchdog and functional watchdog

Description:

- The functional watchdog is not synchronized to the window watchdog, both are independent.
- The functional watchdog and the window watchdog can be activated and deactivated independently.
- The result of each watchdog (valid or invalid triggering) is monitored independently by the related watchdog error counters.
- The internal window watchdog output (WWO) provides the status of the window watchdog: "Valid WWD triggering" or "Invalid WWD triggering".
- The internal functional watchdog output (FWO)provides the status of the functional watchdog: "Valid FWD triggering" or "Invalid FWD triggering".
- Chapter Safe State Control function describes the influence of the settings of both watchdogs on Safe State Control.

14.2 Window watchdog

Principle of operation

The purpose of the window watchdog is to monitor the microcontroller. The monitored microcontroller needs to provide periodical triggering within the "Open Windows". A triggering can consist of a falling edge on the WDI pin or writing to the register WWDSCMD by an SPI command depending on the configuration. This triggering terminates the "Open Window". The watchdog output indicates a valid or invalid WWD triggering to the WWD error counter. In case of a valid triggering a "Closed Window" is started. If there is no triggering during the "Open Window" or a triggering during a "Closed Window", the watchdog output indicates an "Invalid WWD triggering" to the WWD error counter and a new "Open Window" is started.

If the microcontroller does not trigger the window watchdog with correct timing, it is assumed that the microcontroller does not work as expected. The microcontroller is informed by the device via interrupt function and by a reset in case of multiple failure events. (assuming that the window watchdog error counter threshold is configured to a value greater than 2)

Configuration

The following parameters of the window watchdog can be configured in INIT, NORMAL and WAKE-state:

- The trigger source can be set to pin WDI or to SPI command via register WWDSCMD(default: SPI).
- The duration of open and closed window can be modified according to the application needs by SPI. (combination of cycle time WDCYC, cycle time divider WDCYCDIV and number of cycles for open OW and closed CW window)
- The threshold for the window watchdog error counter overflow can defined by SPI

Initialization

The window watchdog becomes active in INIT-state as soon as reset output pin ROT goes "high". After activation the watchdog opens a "Long Open Window" (LOW) of duration of t_{LOW}. During the "Long Open Window" the window watchdog expects a valid triggering, which has to be provided via SPI in case the default configuration is kept, since any signal to watchdog trigger pin WDI is ignored. This is to avoid wrong triggering at pin WDI due to glitches at the microcontroller outputs during start-up and initialization.

The microcontroller can change the configuration of the window watchdog during the "Long Open Window" to change the trigger source and the duration of the "Open" and "Closed Window". On a reconfiguration the window watchdog restarts with the new configuration. A "Open Window" is started accordingly, expecting a valid triggering by the selected trigger source.

If no valid triggering or configuration of the watchdog occurs during the "Long Open Window", the window watchdog recognizes an "invalid WWD triggering". If the INIT timer expires with an invalid WWD triggering present, a "Soft Reset" is issued. After the "Soft-Reset" the window watchdog opens a new "Long Open Window". This is not indicated by interrupt. The repetition of "Long Open Windows" is limited. If the window watchdog is not triggered correctly within the second "Long Open Window",then a "Hard Reset" is issued: pin ROT goes "low" and the post regulator output voltages are switched off. If the window watchdog is not triggered correctly within the third "Long Open Window" in a row, then the device enters FAILSAFE-state, see chapter State machine.

Normal operation

A trigger signal within the "Long Open Window" terminates the "Long Open Window" and start the "Closed Window". The "Closed Window" has a fixed duration for operation without invalid triggering. During normal operation no valid trigger signal is allowed during the "Closed Window". On a WWD triggering within the "Closed Window" the window watchdog recognizes "invalid WWD triggering". The "Closed Window" is terminated with this invalid triggering and an "Open Window" is started.

An "invalid WWD triggering" increments the window watchdog error counter by two. This is indicated by an interrupt.

After the "Closed Window" the window watchdog starts an "Open Window".

Within the "Open Window" a valid trigger signal is expected. If a valid trigger signal is received within the "Open Window" the watchdog terminates the "Open Window" and starts the "Closed Window". "Valid WWD triggering" decrements the window watchdog error counter by one in case it is greater than zero, this is not indicated by interrupt.

If no valid triggering should be received during the "Open Window", the window watchdog recognizes "Invalid WWD triggering" and increments the window watchdog error counter by two and a new "Open Window" is started. This is indicated by interrupt.

In normal operation, the watchdog continues to alternate between the "Open Window" and "Closed Window" as long as valid triggering is received.

Window watchdog output WWO

The window watchdog output WWO is an internal signal. It is connected to the safe window watchdog error counter. The value of WWO is either "Valid WWD triggering" or "Invalid WWD Triggering".

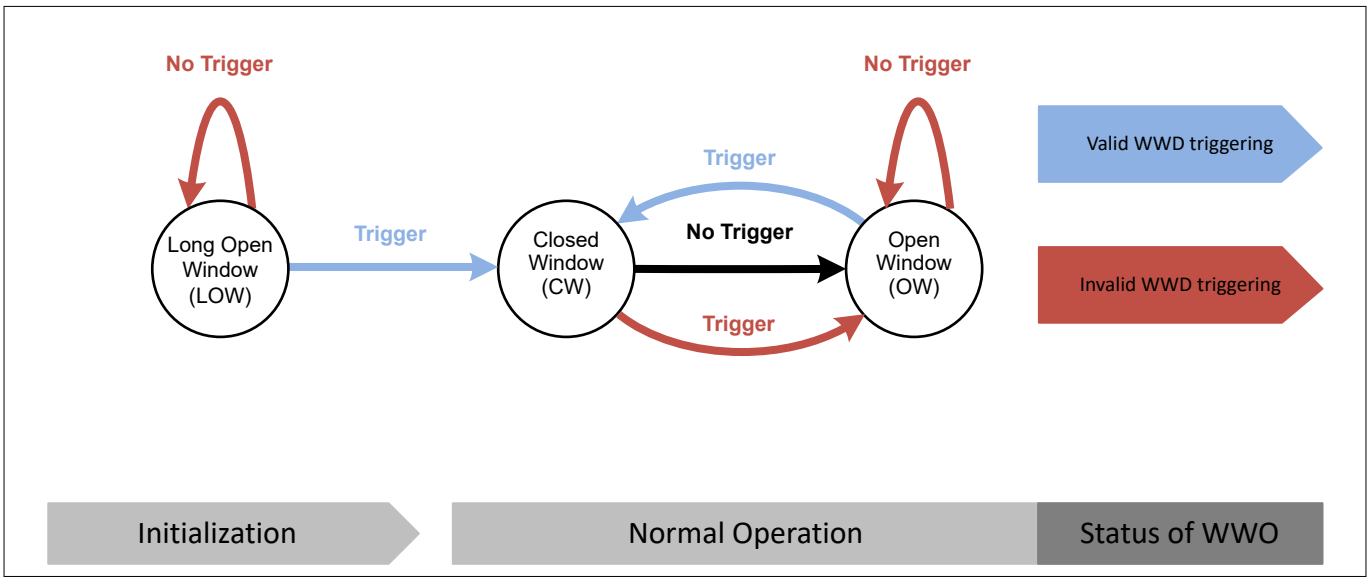


Figure 78 Watchdog state diagram

Description:

- "Trigger" is either an SPI command to WWDSCMD register as WWD triggering or a valid watchdog trigger at pin WDI
- "No Trigger" in the "Long open Window" is considered as "Invalid WWD triggering", the watchdog opens again a "Long Open Window"
- "Trigger" within the "Long Open Window" is considered as "Valid WWD triggering", the watchdog closes the "Long Open Window" and opens the "Closed Window"
- "Trigger" within the "Closed Window" is considered as "Invalid WWD triggering"
- After a "Closed Window" with "No Trigger" the watchdog starts the "Open Window".
- "Trigger" within the "Open Window" is considered as "Valid WWD triggering", the watchdog closes the "Open Window" and opens the "Closed Window"
- "No Trigger" in the "Open Window" is considered as "Invalid WWD triggering".

Window watchdog trigger pin WDI

The watchdog input pin WDI has an integrated pull-down current source I_{WDI}. The watchdog input WDI can transition to high within the "Closed Window" or during the following "Open Window".

The watchdog input WDI is periodically sampled with a period of t_{SAM}. When using pin WDI as window watchdog trigger, any timing configurations of "Open Window" and "Closed Window", that are close to t_{SAM} (e.g. < 8* t_{SAM})

are to be prevented to allow reasonable service signaling from the application and reliable capturing of the WDI input.

Valid trigger signal at WDI

A valid trigger signal is a falling edge from $V_{WDI,high}$ to $V_{WDI,low}$. To improve immunity against noise or glitches on the WDI input, at least two "high" samples followed by two "low" samples are required for a valid trigger signal. Valid triggering is recognized at the second consecutive sampling point having a "low" signal. For example, if the first three samples (two high one low) of the trigger pulse at pin WDI are inside the "Closed Window" and only the fourth sample (the second low sample) is taken in the "Open Window" then the watchdog output WWO indicates "valid WWD triggering".

Invalid triggering at WDI

No trigger signal detected during the "Open Window" or a trigger signal detected during the "Closed Window", is considered invalid triggering. The watchdog output WWO indicates "invalid triggering" immediately after no valid trigger during the "Open Window" or immediately if a trigger signal is detected during the "Closed Window".

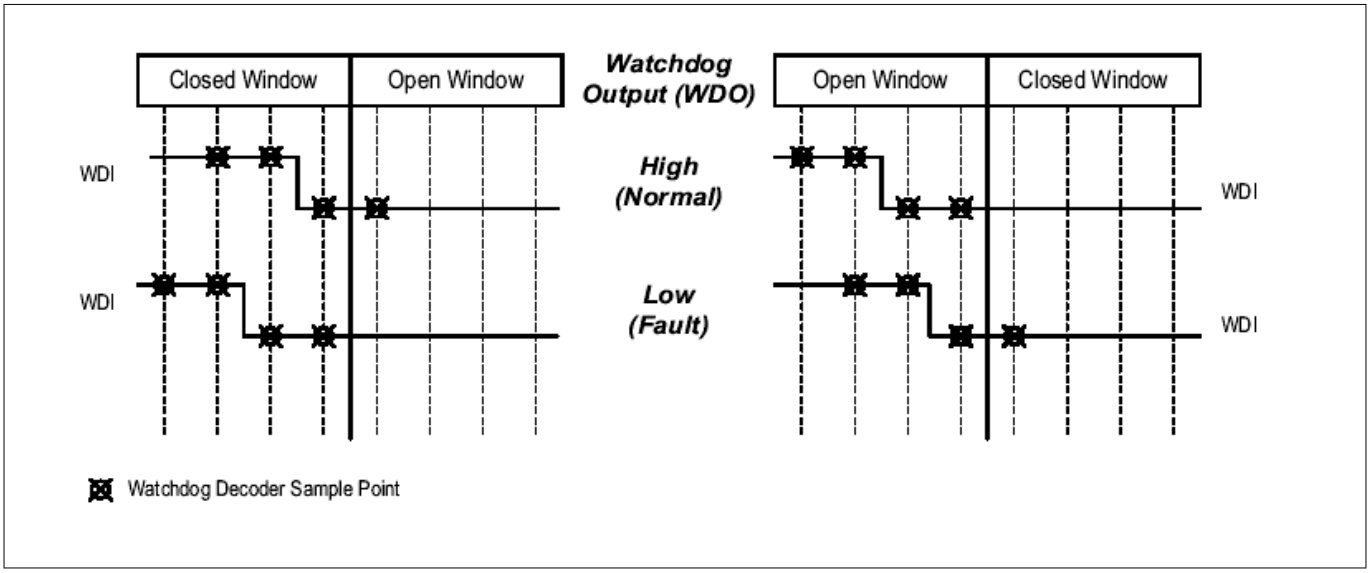


Figure 79 Valid and invalid trigger pulses at pin WDI

14.2.1 Timing diagrams window watchdog

14.2.1.1 Normal operation: correct triggering

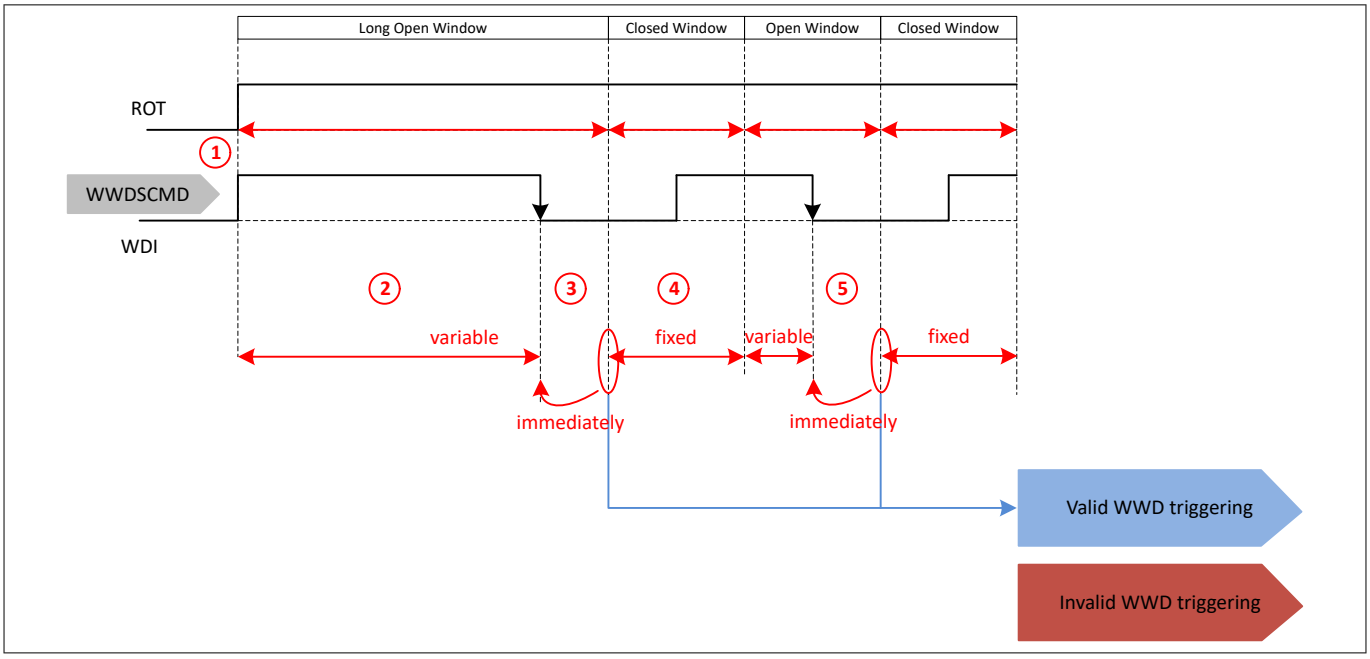


Figure 80 Normal operation: correct triggering

1. The "Long Open Window" starts in INIT-state if the reset output ROT (monitoring the microcontroller related voltages) goes "high". In case the window watchdog was deactivated in SLEEP, the first Open Window starts with the transition from SLEEP-state to WAKE-state which is indicated by interrupt. The time of this first Open Window after SLEEP depends on the configured cycle time and cycle time divider, it is 600 ms (WDCYC = 1_B and WDCYCDIV = 0_B) or 60 ms (WDCYC = 0_B and WDCYCDIV = 0_B) or 6 ms (WDCYC = 0_B and WDCYCDIV = 1_B).
2. During the "Long Open Window" valid triggering of the WWD according to the configured trigger source is expected. The maximum time of the "Long Open Window" is fixed, but it ends as soon as a "Valid WWD triggering" is recognized.
3. The window watchdog enters the "Closed Window". After receiving this first valid trigger the device is allowed to move from INIT to NORMAL-state or from WAKE to NORMAL-state.
4. The "Closed Window" has a fixed duration $t_{WD,CW}$ (can be determined by SPI command). It starts right after the valid trigger signal, that closes the "Open Window" or the "Long Open Window". During the "Closed Window" no trigger signal should be applied. A transition from low to high at the WDI pin is not detected and does not lead to a trigger event.
5. A valid trigger signal terminates the "Open Window" immediately, thus the time of the "Open Window" is variable and depending on the time for which the microcontroller schedules the triggering. This is counted as a "Valid WWD triggering".

14.2.1.2 Fault operation: no trigger in open window after initialization

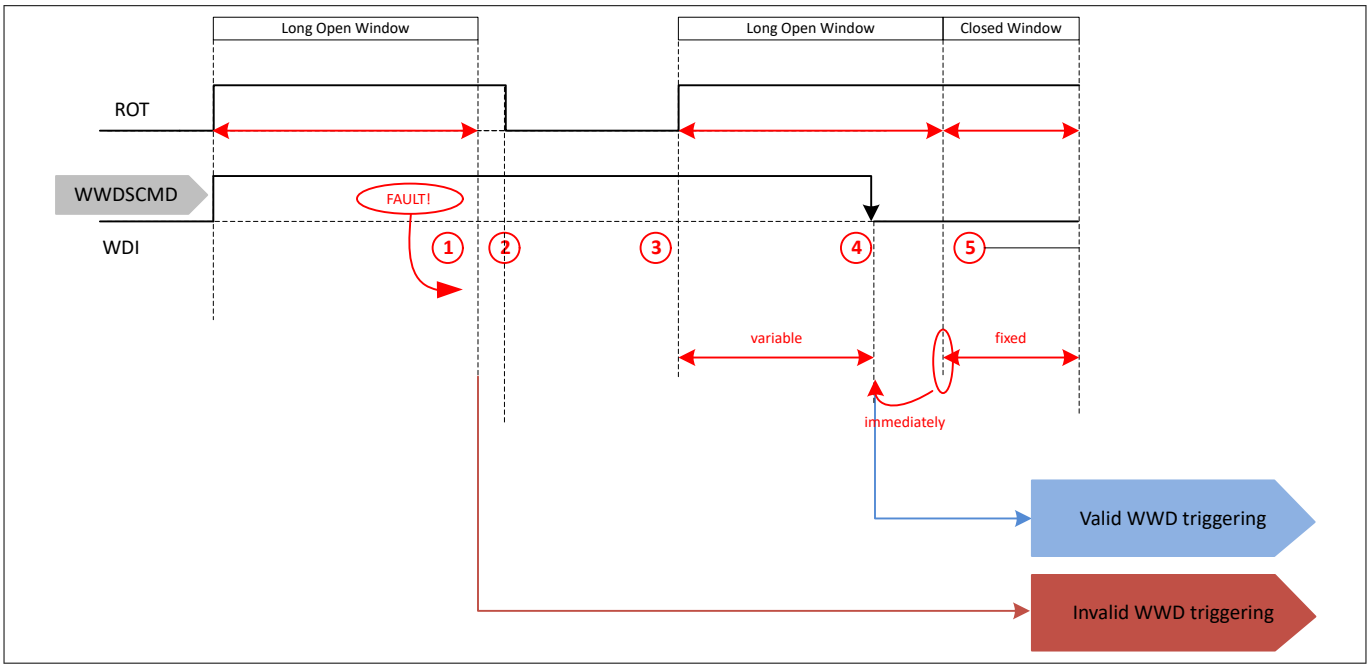


Figure 81 Fault operation: no trigger in open window after initialization

1. The initialization timeout and the long open window (LOW) have the same typical length. Usually this leads to the initialization timeout slightly before or at same time as the LOW, which skips the interrupt event (1). The missing "Valid WWD triggering within the "Long Open Window" can lead to an interrupt event after the LOW which increments the window watchdog error counter by two.
2. The INIT-state timer expires for the first time. Due to no "Valid WWD Triggering" of the window watchdog was received during INIT-state, a "Soft-Reset" is issued: pin ROT goes "low". The output voltages of the post regulators remain on.

   Additional information: In case the window watchdog should not be triggered correctly within the next "Long Open Window" of the following INIT phase, a "Hard-Reset" is issued, which means pin ROT goes to zero and the output voltages are switched off. After a third invalid triggering during INIT phase the device transitions into FAILSAFE-state.
3. After the so-called "Soft-Reset" pin ROT turns high again after the power-on reset delay time t_{rd} and the watchdog opens a "Long Open Window" to give the microcontroller the chance to trigger and synchronize to the watchdog period.
4. A valid triggering terminates the "Long Open Window", which makes the duration of the "Long Open Window" variable and depending on the triggering. This is counted as a "Valid WWD triggering" and a "Closed Window" is started. The window watchdog error counter is decremented by one without an interrupt issued.
5. The duration of the subsequent "Closed Window" is $t_{WD,CW}$. Triggering within this time is considered as an "Invalid WWD triggering".

14.2.1.3 Fault operation: no trigger in open window in steady state

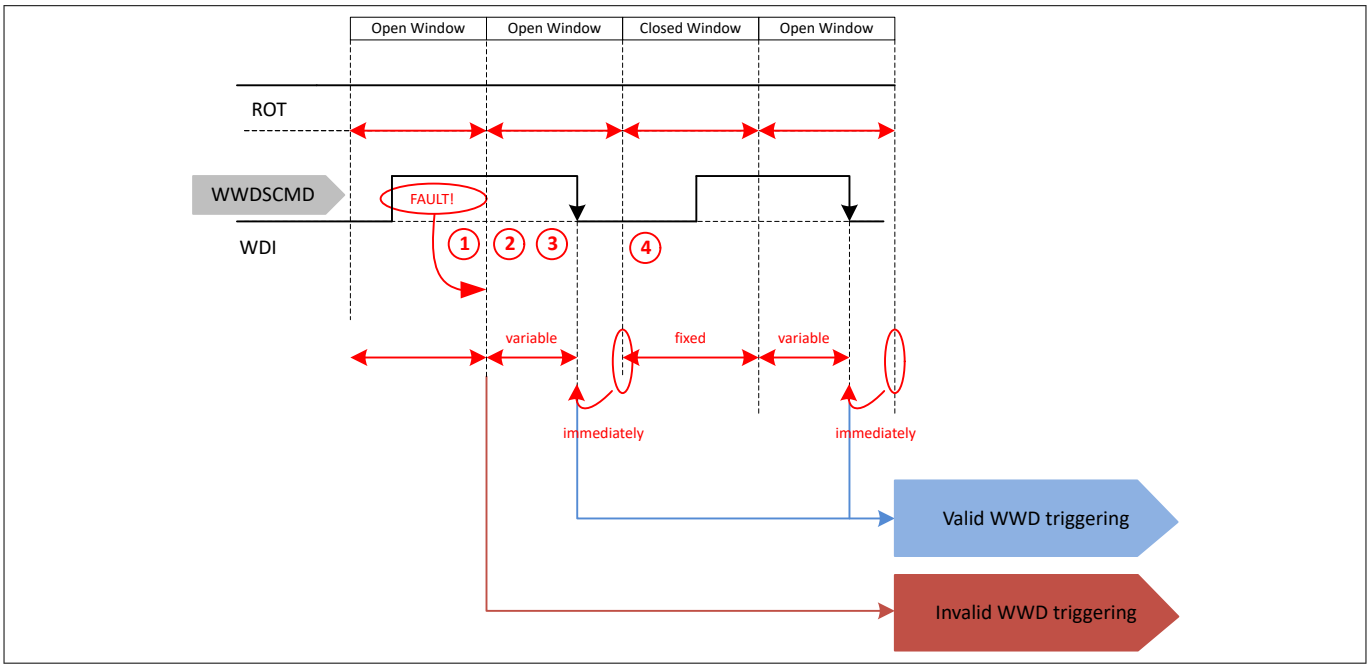


Figure 82 Fault operation: no trigger in open window in steady state

1. An "Open Window" with missing "Valid WWD Triggering" leads to an "Invalid WWD triggering". This event is indicated by an interrupt, the window watchdog error counter increases by two.
2. On detecting an "Invalid WWD triggering" the watchdog starts a new "Open Window" with duration $t_{WD,OW}$ to give the microcontroller the chance to trigger and synchronize to the watchdog period.
3. A valid triggering terminates the "Open Window", which makes the duration of the "Open Window" variable and depending on the triggering. This is counted as a "Valid WWD triggering" and a "Closed Window" is started. The window watchdog error counter is decremented by one without an interrupt issued.

   On repeated "Invalid WWD triggering" within "Open Windows"(missing trigger) the window watchdog error counter increments by two on each occurrence until it reaches the configured threshold. In this case a reset is issued.
4. The duration of the subsequent "Closed Window" is $t_{WD,CW}$. Triggering within this time is considered as an "Invalid WWD triggering".

The behavior of pin ROT depends on the value of ΣWWO. In the example above the invalid triggering does not reach or exceed the configured threshold ΣWWO.

14.2.1.4 Fault operation: false trigger in closed window after initialization

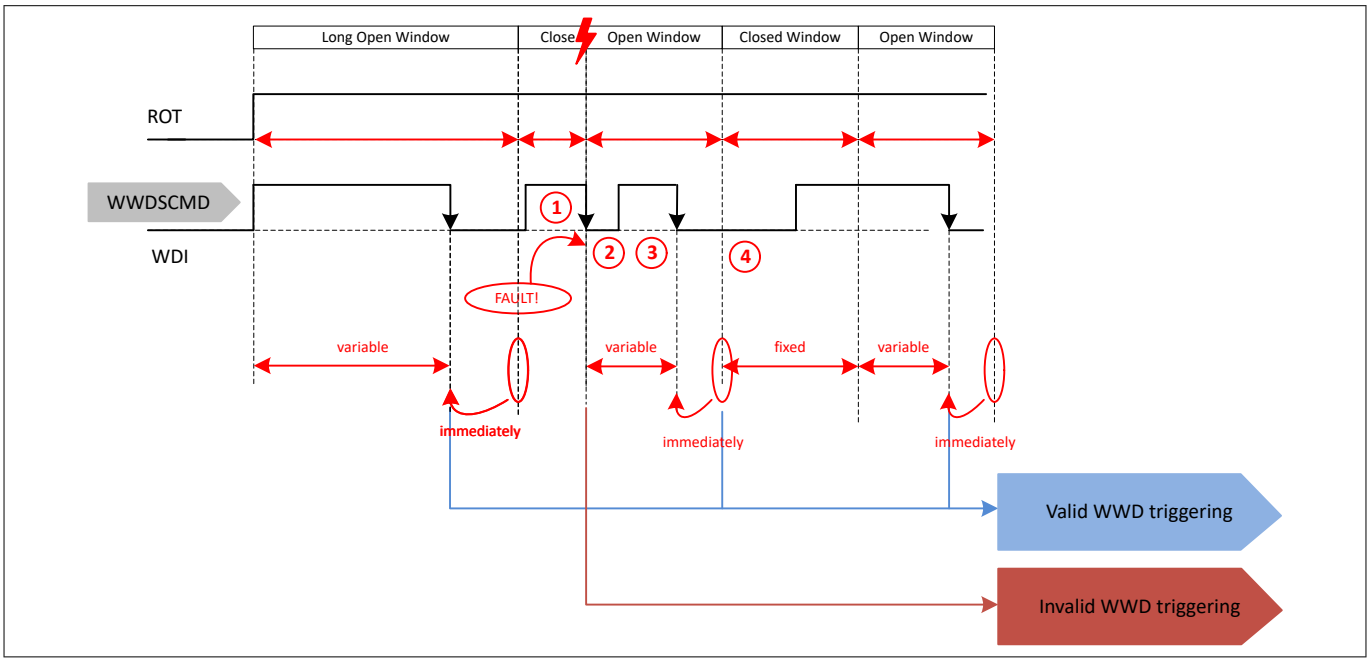


Figure 83 Fault operation: False trigger in closed window after initialization

1. A triggering during the "Closed Window" is indicated as "Invalid WWD triggering". This event is indicated by an interrupt and the window watchdog error counter increases by two.
2. The "Closed Window" ends with the "Invalid WWD triggering" before $t_{WD,CW}$. The false triggering terminates the "Closed Window" and starts an "Open Window" to give the microcontroller the opportunity to synchronize to the window watchdog period.
3. Within this "Open Window" a valid triggering is expected. A valid triggering terminates the "Open Window", which makes the duration of the "Open Window" variable and depending on the triggering. This is counted as a "Valid WWD triggering" and a "Closed Window" is started. The window watchdog error counter is decremented by one without an interrupt issued.
4. The following "Closed Window" lasts for the time $t_{WD,CW}$. Triggering within this time is considered as an "Invalid WWD triggering".

The behavior of pin ROT depends on the value of ΣWWO. In the example above the invalid triggering does not reach or exceed the configured threshold ΣWWO.

14.2.1.5 Fault operation: false trigger in closed window in steady state

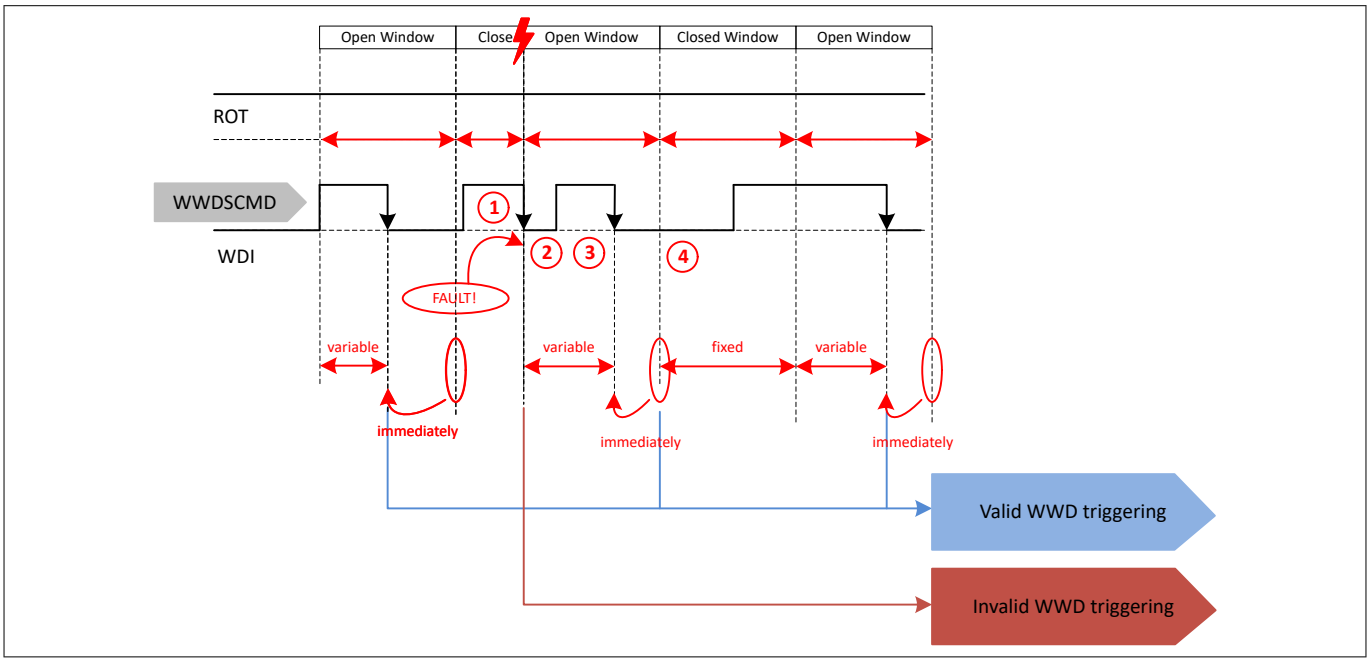


Figure 84 Fault operation: false trigger in closed window

1. A triggering during the "Closed Window" is indicated as "Invalid WWD triggering". This event is indicated by an interrupt and the window watchdog error counter increases by two.
2. The "Closed Window" is closed with the "Invalid WWD triggering". Originally it would last for the time $t_{WD,CW}$. The false triggering terminates the "Closed Window" and starts an "Open Window" to give the microcontroller the opportunity to synchronize to the window watchdog period.
3. Within this "Open Window" a valid triggering is expected. A valid triggering terminates the "Open Window", which makes the duration of the "Open Window" variable and depending on the triggering. This is counted as a "Valid WWD triggering" and a "Closed Window" is started. The window watchdog error counter is decremented by one without an interrupt issued.
4. The following "Closed Window" lasts for the time $t_{WD,CW}$. Triggering within this time is considered as an "Invalid WWD triggering".

The behavior of pin ROT depends on the value of ΣWWO. In the example above the invalid triggering does not reach or exceed the configured threshold ΣWWO.

14.2.2 Electrical characteristics window watchdog

Table 35 Electrical characteristics window watchdog function

V_{VS} = 6 V to 40 V, T_j = -40°C to 175°C, all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	Number
		Min.	Typ.	Max.			
General timing parameters watchdog (WWD and FWD)							
Watchdog cycle time	t_{CYCLE}	94	100	106.5	µs	1) selectable by SPI command	P_15.2.2.1
Watchdog cycle time, default setting	t_{CYCLE}	940	1000	1065	µs	1) selectable by SPI command	P_15.2.2.2
Long open window time	t_{LOW}	564	600	639	ms	–	P_15.2.2.3
Watchdog input WDI							
Watchdog sampling time	t_{SAM}	188	200	213	µs	–	P_15.2.2.4
WDI valid high level	$V_{WDI, high}$	2.0	–	–	V	V_{WDI} increasing; V_{QUC} = 3.3 V	P_15.2.2.8
WDI valid low level	$V_{WDI, low}$	–	–	0.8	V	V_{WDI} decreasing; V_{QUC} = 3.3 V	P_15.2.2.9
WDI hysteresis	$V_{WDI, hyst}$	100	200	600	mV	V_{QUC} = 3.3 V	P_15.2.2.10
WDI pull-down current	I_{WDI}	–	150	330	µA	$V_{WDI} = V_{QUC}$	P_15.2.2.11
WDI input capacitance	C_{WDI}	–	4	15	pF	2)	P_15.2.2.12

1) Due to internal processing of the watchdog services an additional uncertainty of propagation time of up to 55 µs is to be considered between triggering provided (via SPI or pin WDI) and triggering received by the functions.
2) Specified by design, not subject to production test

14.3 Functional watchdog

Principle of operation

The purpose of the functional (or question-answer) watchdog is to monitor the microcontroller. A question is generated (based on the defined table below), in parallel the heartbeat counter starts counting from zero. The heartbeat counter counts up, until the heartbeat period ends. The default duration of the heartbeat period can be adjusted via SPI command. The question consists of 4 bits, the expected answer consists of 4 responses of 8 bits each. The four responses need be sent before the heartbeat period has ended. The last response shall be written to the synchronized response register to reset the heartbeat counter.

Initialization

The functional watchdog is off per default when the device is powered up for the first time. It can be enabled by SPI writing to WDCFG0.FWDEN.

Configuration

The functional watchdog can be configured in INIT, NORMAL and WAKE-state as follows:

- The duration of the heartbeat period can be modified by SPI command, depending on the needs of the application. (combination of cycle time WDCYC, cycle time divider WDCYCDIV and number of cycles for heartbeat WDHBTP)
- The threshold for the functional watchdog error counter overflow can be defined by SPI

The heartbeat period is based on the cycle time t_{CYCLE} specified in Table 35.

Normal operation

The question is based on Table 36, the correct response to a question is listed in the same row, respectively. The correct sequence of responses must be kept and can be derived from the response counter FWDSTAT0.FWDRSPC before sending the response.

The correct response to the question consists of four subsequent response bytes. To give a correct response to the given question in FWDSTAT0.FWDQUEST:

- Write the first three responses to FWDRSP
- Write the last response to FWDRSPSYNC to reset the heartbeat timer

All four responses must be written before the heartbeat period expires.

If the complete response (32 bits) is correct and if the last response byte was sent with synchronized response, the heartbeat counter is reset and set to zero. If the complete answer (all four responses - 32 bits) is correct, it is regarded as "Valid FWD triggering", the functional watchdog error counter ΣFWO is decremented by 1. If the last response was sent with synchronized response, the heartbeat counter is reset, but if the answer is wrong, this is regarded as "Invalid FWD triggering" and the functional watchdog error counter ΣFWO is incremented by 2.

An overflow of the functional watchdog error counter ΣFWO triggers a "Move to INIT" event, resets the heartbeat counter and sets the functional watchdog error counter ΣFWO to zero.

Table 36 Functional watchdog response definition

QUESTION	RESP3	RESP2	RESP1	RESP0
0	FF	0F	F0	00
1	B0	40	BF	4F
2	E9	19	E6	16
3	A6	56	A9	59
4	75	85	7A	8A
5	3A	CA	35	C5

(table continues...)

Table 36 (continued) Functional watchdog response definition

QUESTION	RESP3	RESP2	RESP1	RESP0
6	63	93	6C	9C
7	2C	DC	23	D3
8	D2	22	DD	2D
9	9D	6D	92	62
A	C4	34	CB	3B
B	8B	7B	84	74
C	58	A8	57	A7
D	17	E7	18	E8
E	4E	BE	41	B1
F	01	F1	0E	FE

Functional watchdog output FWO

The functional watchdog output FWO is an internal signal: It is connected to the FWD error counter. The value of the functional watchdog FWO output is either "Valid FWD triggering" or "Invalid FWD Triggering".

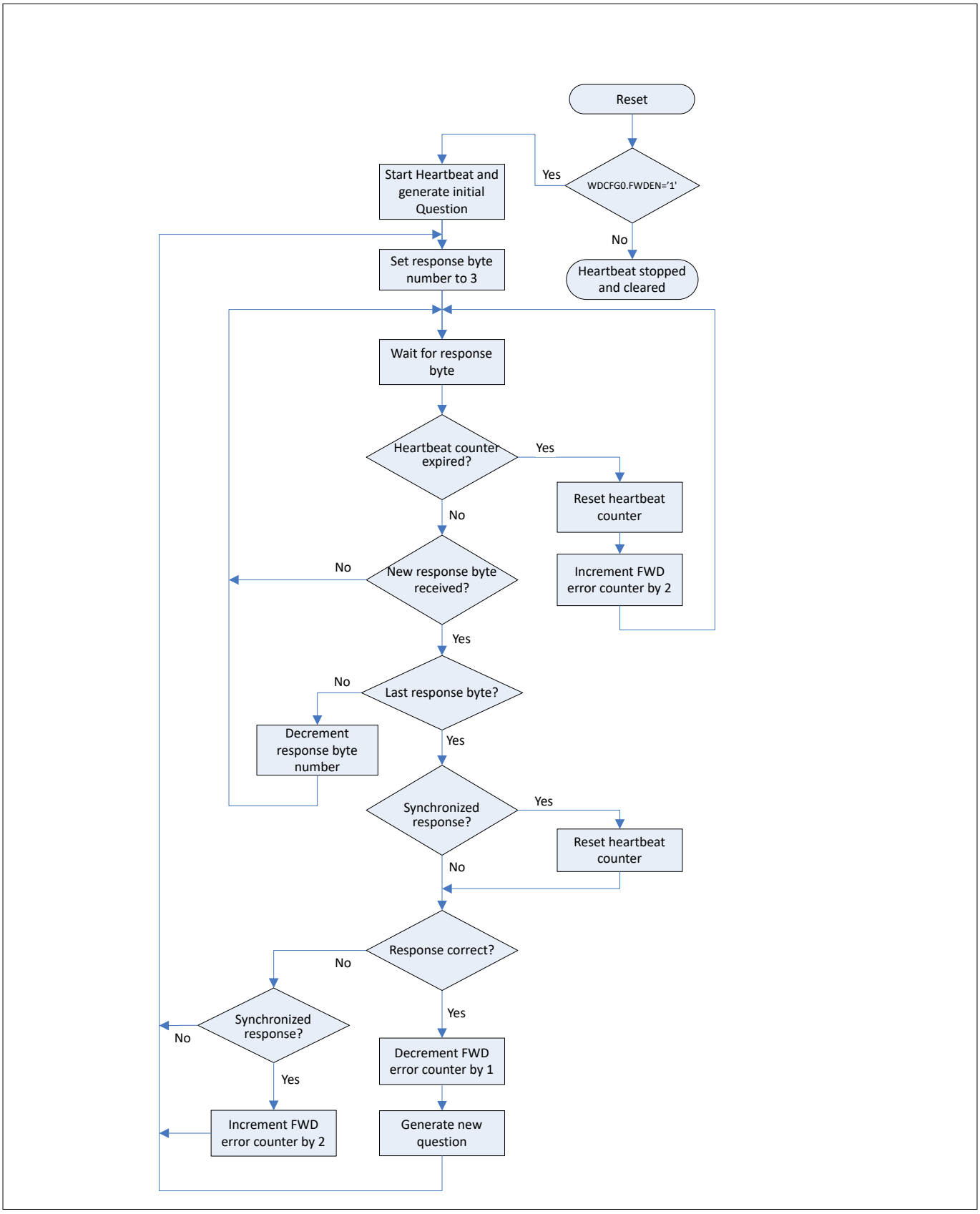


Figure 85 Functional watchdog flowchart diagram

14.3.1 Timing diagrams functional watchdog

14.3.1.1 Normal operation: correct triggering

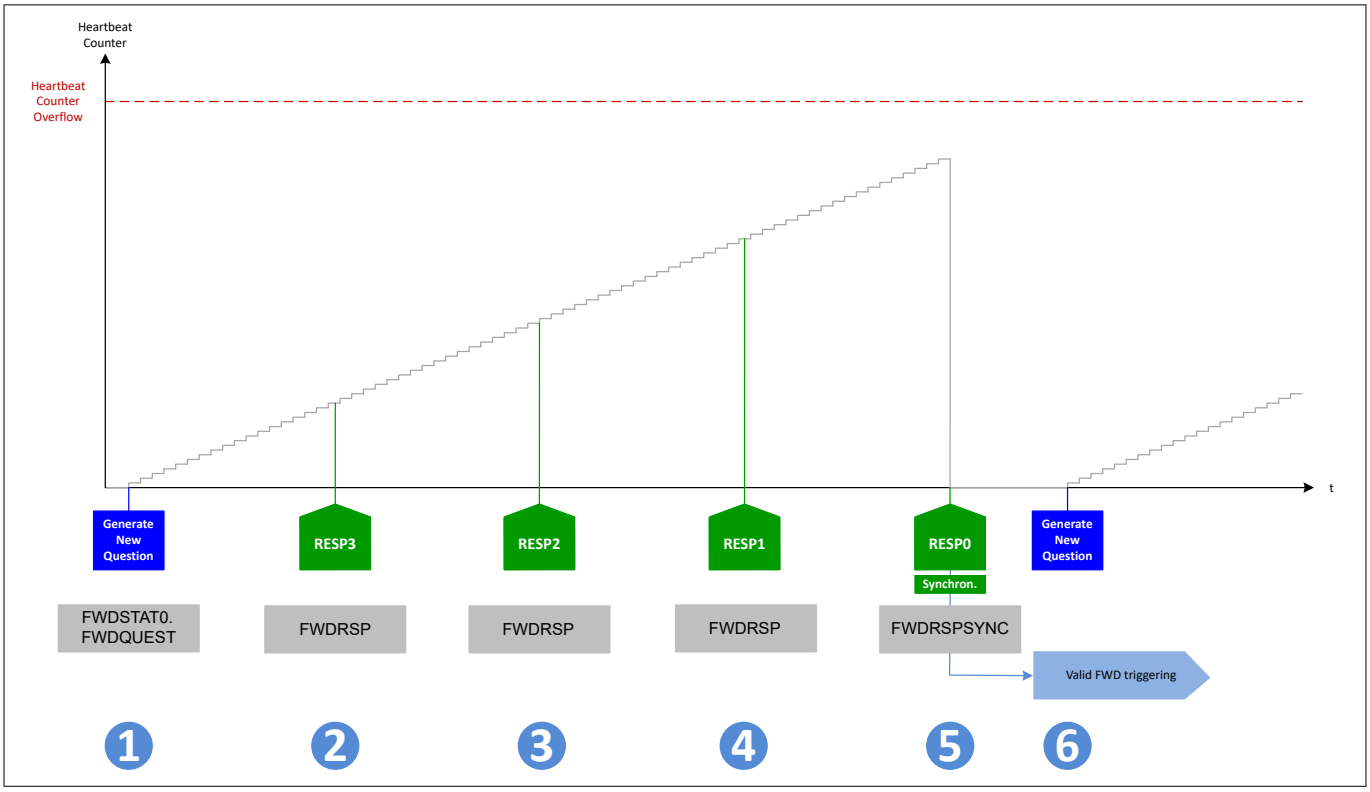


Figure 86 Normal operation: correct triggering

1. A new question is generated, in parallel the heartbeat counter starts after "Valid FWD triggering".
2. A correct response is received (RESP3).
3. A correct response is received (RESP2).
4. A correct response is received (RESP1).
5. A correct synchronized response is received (RESP0). All responses are correct, the sequence of responses is correct and the last synchronized response was received before the heartbeat counter overflowed. The heartbeat counter is reset (set to zero). This is regarded as "Valid FWD triggering", the functional watchdog error counter ΣFWO is decremented by 1 (if the functional watchdog error counter value is higher than zero).
6. A new question is generated, in parallel the heartbeat counter starts.

14.3.1.2 Fault operation: missing synchronization

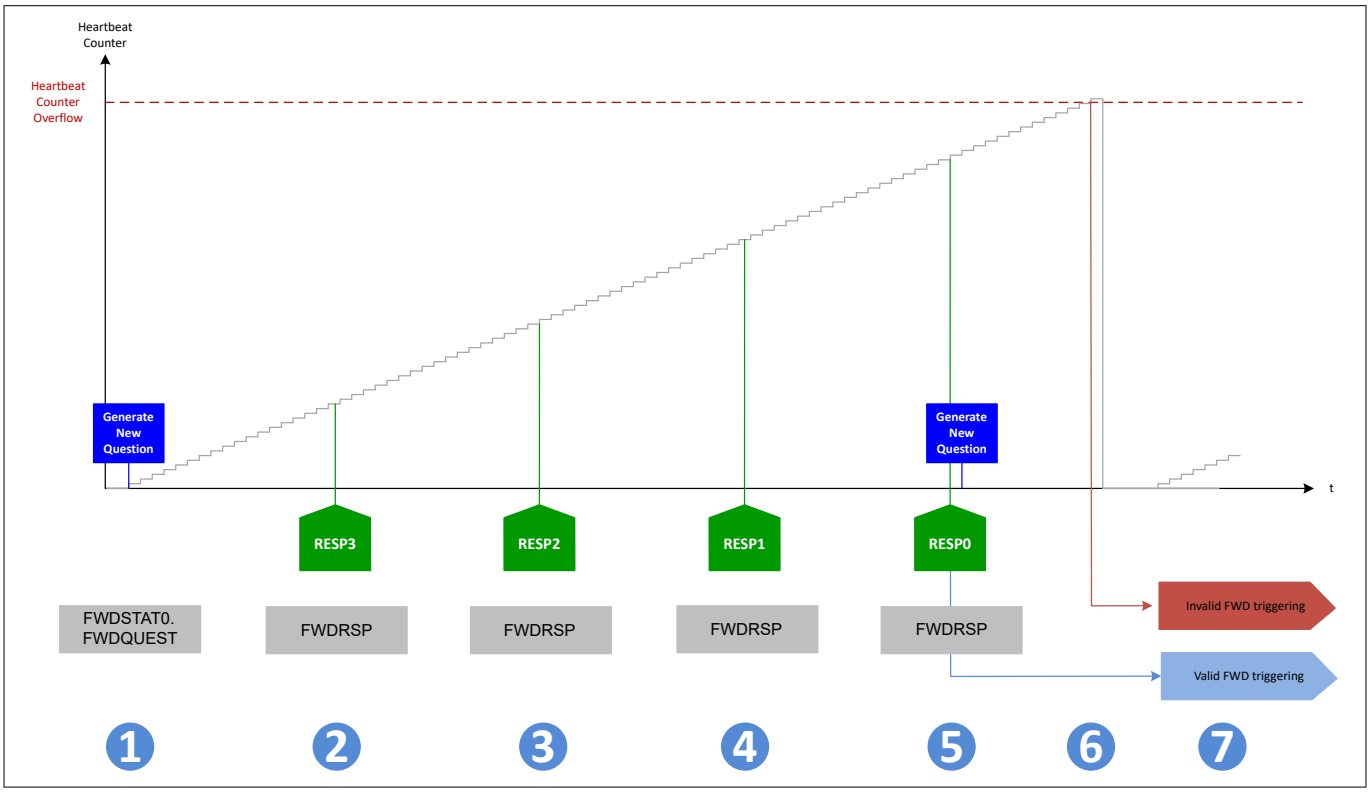


Figure 87 Fault operation: synchronization is missing

1. A new question is generated, in parallel the heartbeat counter starts counting up (It is assumed, that a "Valid FWD triggering" has happened before).
2. A correct response is received (RESP3)
3. A correct response is received (RESP2)
4. A correct response is received (RESP1)
5. A correct response is received (RESP0), but not synchronized (written to wrong register). So far, all responses are correct, the sequence of responses is correct and the last not synchronized response is received before the heartbeat counter overflows. The heartbeat counter is not reset and continues to count. This is regarded as "Valid FWD triggering", the functional watchdog error counter ΣFWO is decremented by 1 (if the functional watchdog error counter value is higher than zero). A new question is generated.
6. The heartbeat counter still counts up, waiting for the answer to the new question. Later the heartbeat counter overflows. This is regarded as "Invalid FWD triggering". The functional watchdog error counter ΣFWO is incremented by 2. The heartbeat counter is reset.
7. The heartbeat counter starts counting up. No new question is generated.

14.3.1.3 Fault operation: wrong answer

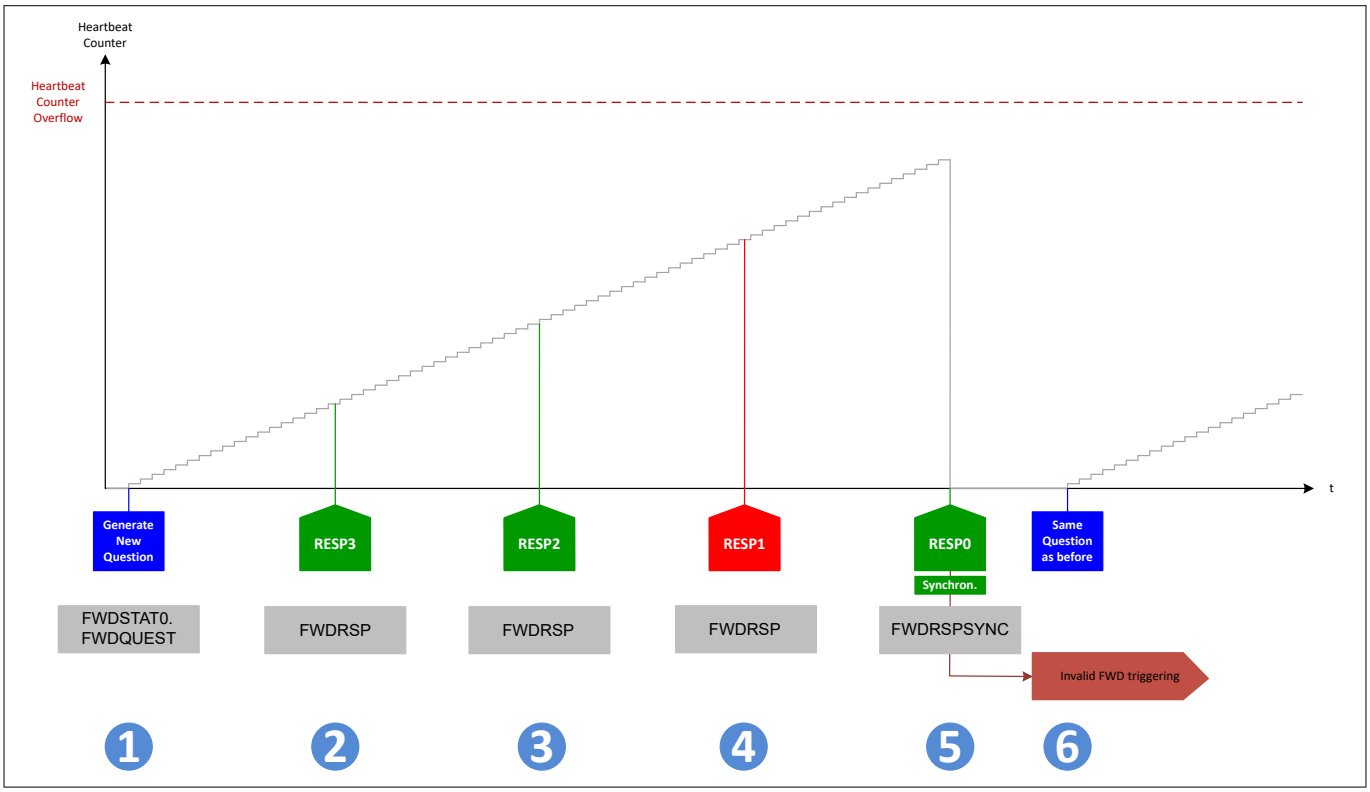


Figure 88 Fault operation: answer is wrong

1. A new question is generated, in parallel the heartbeat counter starts counting up (It is assumed, that a "Valid FWD triggering" has happened before)
2. A correct response is received (RESP3)
3. A correct response is received (RESP2)
4. An incorrect response is received (RESP1)
5. A correct response is received (RESP0). The heartbeat counter is reset (set to zero). The complete answer is not correct. This is regarded as "Invalid FWD triggering". The functional watchdog error counter ΣFWO is incremented by 2. The heartbeat counter is reset.
6. No new question is generated, but the heartbeat counter starts counting up.

***Note**: If i.e. RESP2 and RESP1 are mixed-up, then both responses are incorrect - the responses must to be sent in correct order.*

14.3.1.4 Fault operation: missing response

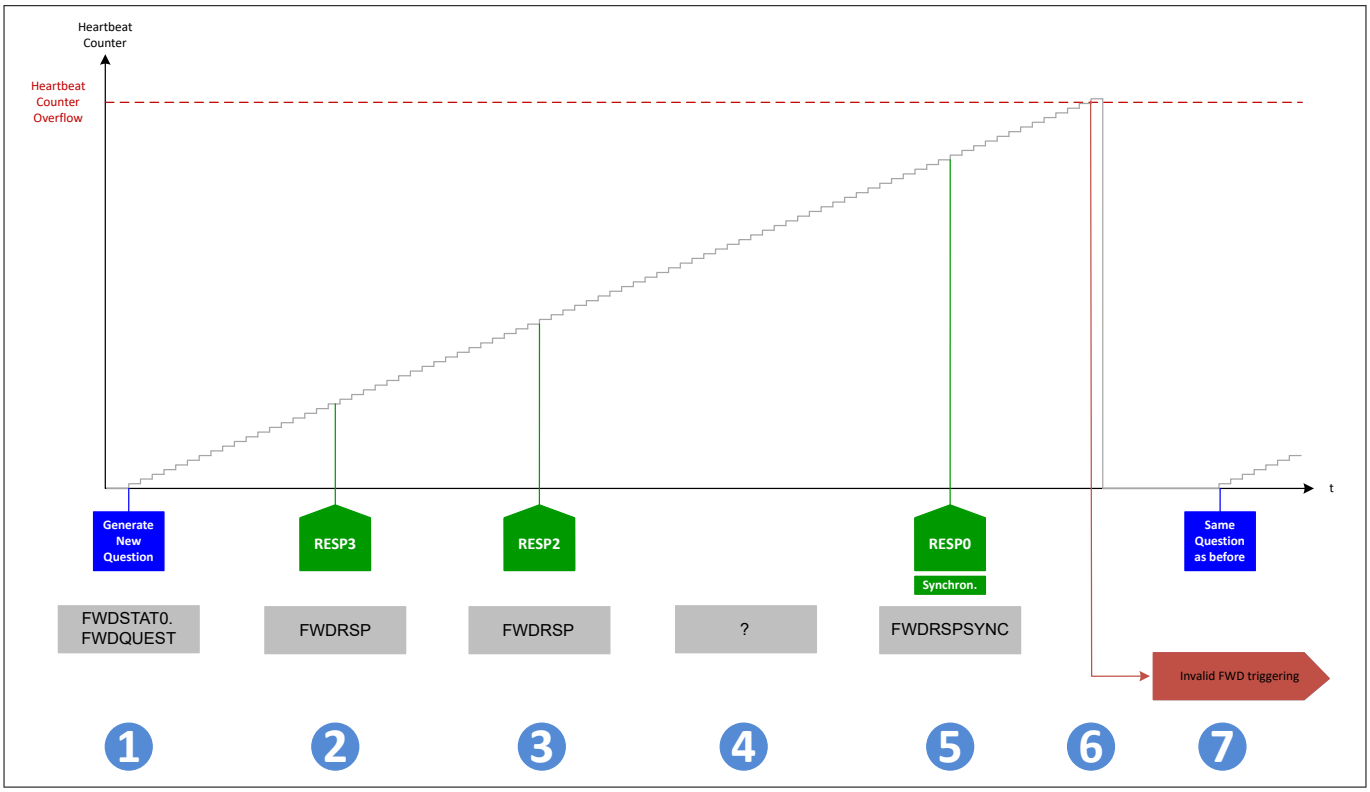


Figure 89 Fault operation: answer is not complete

1. A new question is generated, in parallel the heartbeat counter starts counting up (It is assumed, that a "Valid FWD triggering" has happened before).
2. A correct response is received (RESP3)
3. A correct response is received (RESP2)
4. A response is missing (RESP1)
5. A correct response is received (RESP0). So the last response is not the last response but the second last due to the missing response (in this example RESP1). The functional watchdog waits for all four responses to be written, while the heartbeat counter keeps on counting. There is no fixed time for all four responses, but they must be sent in correct order before the heartbeat counter expires.
6. The complete answer is not correct due to missing response RESP1. Although the last response is synchronized, the heartbeat counter is not reset and continue counting up until an overflow occurs. This is regarded as "Invalid FWD triggering". The functional watchdog error counter ΣFWO is incremented by 2. The heartbeat counter is reset.
7. No new question is generated and the heartbeat counter starts counting up.

15 Application information

The following figure describes how the IC is used in its environment.

***Note**: The following information is given as an example for the implementation of the device only and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device.*

- Please contact us for additional supportive documentation.
- For further information you may contact http://www.infineon.com/

***Note**: This figure is a simplified example of an application circuit. The function must be verified in the application.*

15 Application information

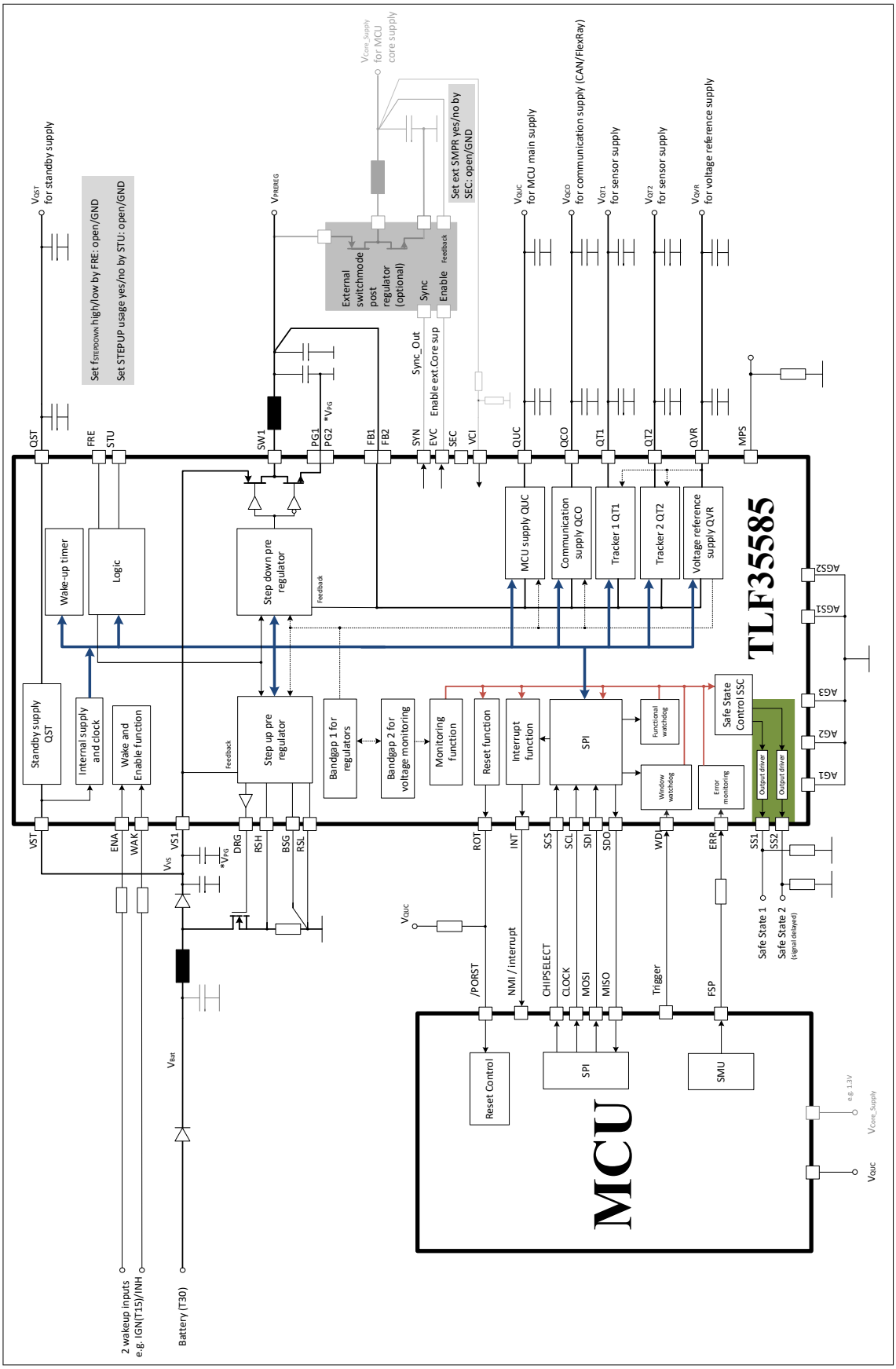


Figure 90 Application diagram

16 Package information

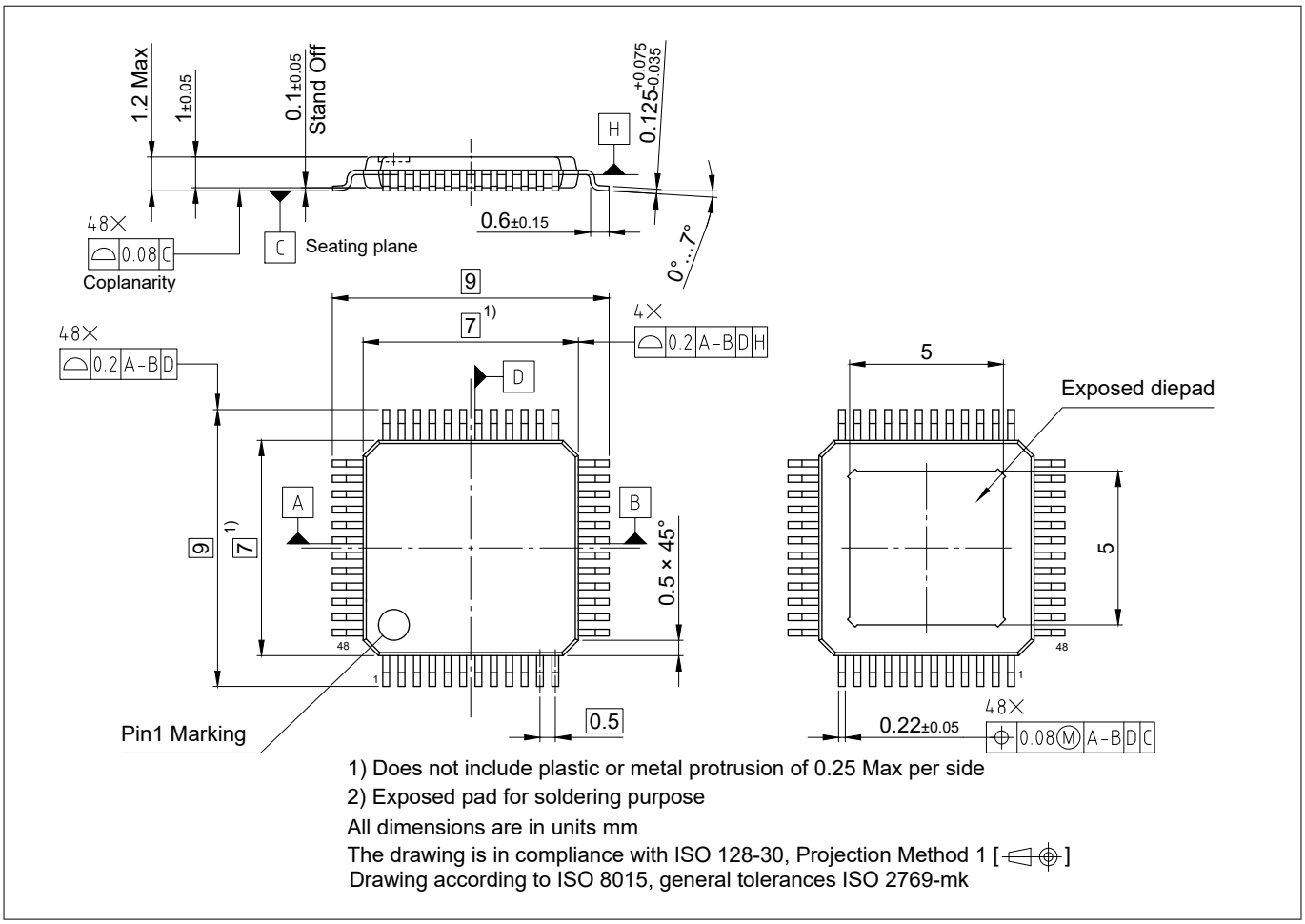


Figure 91 PG-TQFP-48-10

Green Product (RoHS compliant)

To meet the world-wide customer requirements for environmentally friendly products and to be compliant with government regulations the device is available as a Green Product. Green Products are RoHS compliant (Pb-free finish on leads and suitable for Pb-free soldering according to IPC/JEDEC J-STD-020).

Information on alternative packages

Please visit www.infineon.com/packages.

Revision history

Revision	Date	Changes
2.01	2024-09-23	• Chapter 3.4, modified conditions in P_4.4.8, P_4.4.9 and P_4.4.10 • Chapter 12.4.1.5: restored DISOFFSET bit description from Rev. 1.0 • Editorial changes
2.0	2024-08-07	• Electrical characteristic table (all): removed V_S < 20 V limit exception/condition • Description: modified marking, Line2 • Chapter 5.3.1: modified buck converter functional description in SLEEP mode • Chapter 5.3.2: added note to P_6.3.2.10, not applicable in SLEEP state • Chapter 6.5.2: removed P_7.5.2.9 and modified P_7.5.2.1 condition to cover full temperature range • Chapter 7.3: added description related to ROT behavior in case of loose of internal supplies • Chapter 8.1.1: removed QST overload detection functionality • Chapter 9.1: modified WKTIMCFGx registers readback value management • Chapter 10.1: modified FSM chart to include new SLEEP to WAKE triggering event and removal of QST OC Stay in current state interrupt event generator • Chapter 10.2.5 - Table 22: added new SLEEP to WAKE triggering event in PreReg SLEEP-state settings • Chapter 10.2.6: modified WAKE-state description including new SLEEP to WAKE triggering event • Chapter 10.3.3.2: added SLEEP to WAKE triggering event • Chapter 10.4.1: removed QST OC as contributor of Stay in current state Interrupt event generator • Chapter 10.6.1: added note referring to DISOFFSET handling during full-path ABIST on QUC and QST • Chapter 10.7.1: removed chapter • Chapter 12.4.1.5: modified DISOFFSET bit description • Chapter 12.4.1.12: modified DISOFFSET bit description • Chapter 12.4.1.19: modified TIMVALL description including 30 µs lowest configuration value • Chapter 12.4.1.31: modified WKSF.CMON description • Chapter 12.4.1.38: removed OTWRNSF.STBY bit • Chapter 12.4.1.50: BCK_FREQ_CHANGE.BCK_DRV_STAGE – added note referring to SLEEP state • Chapter 12.4.1.54: added DEVINFO.CHIPSTEP value for B30-step • Chapter 13: removed QST OC as contributor of interrupt event generator
1.0	2023-02-03	Datasheet created

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