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AP1615410

XC2000

SENT Decoder for XC2000

Microcontrollers

Never stop thinking

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AP99007

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Page	Subjects (major changes since last revision)

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1 Scope

Single Edge Nibble Transmission (SENT) is a promising low-cost solution for communication between off-ECU sensors and a microcontroller. This Application Note describes the decoding of a SENT signal using the CAPCOM 6 module.

This document will give you step by step instruction in order to install and operate the receiver, but also described in detail the configuration needed to realize such a function on example of XC2287 using an Easy Kit XC2287.

The following features are supported by the receiver:

- Reception and decoding of SENT compliant frames.
- Configurable SAE SENT or Infineon specific SENT protocol receiver
- Configurable number of data nibbles per frame.
- Serial data decoding.
- Error detection: signal loss, synchronization loss, clock drift, invalid CRC, invalid data nibble, serial data error.
- Full source code and DAvE configuration file available.

Note: Single Edge Nibble Transmission (SENT) refers to the SAE standard J2716. For more information, please visit www.sae.org.

Note: The receiver decodes logical SENT frames. Electrical characteristics as defined by the standard are not covered.

Note: The code delivered with this application note is aimed at development and demonstration purpose only. Neither is its quality nor its robustness guaranteed.

2 Preconditions

The following HW and SW are used:

- XC2287 Easy Kit (evaluation board) with connected sensor with SENT interface (e.g. TLE 4948)
- DAvE r2.1 and DIP file for XC2287
- Tasking toolset v8.7r1
- The SENT receiver source code and executable (AP1615410.exe).

The receiver software delivered with this application note is made of:

- C and Header files for the receiver.
- Executable files (.out and .hex)
- A Tasking project files for the toolchain v8.7r1

To download the executable to the Easy Kit you can use the integrated CrossViewPro debugger or any other debugger supporting XC2287.

3 SENT Implementation on XC2287

3.1 SENT receiver-channel state machine

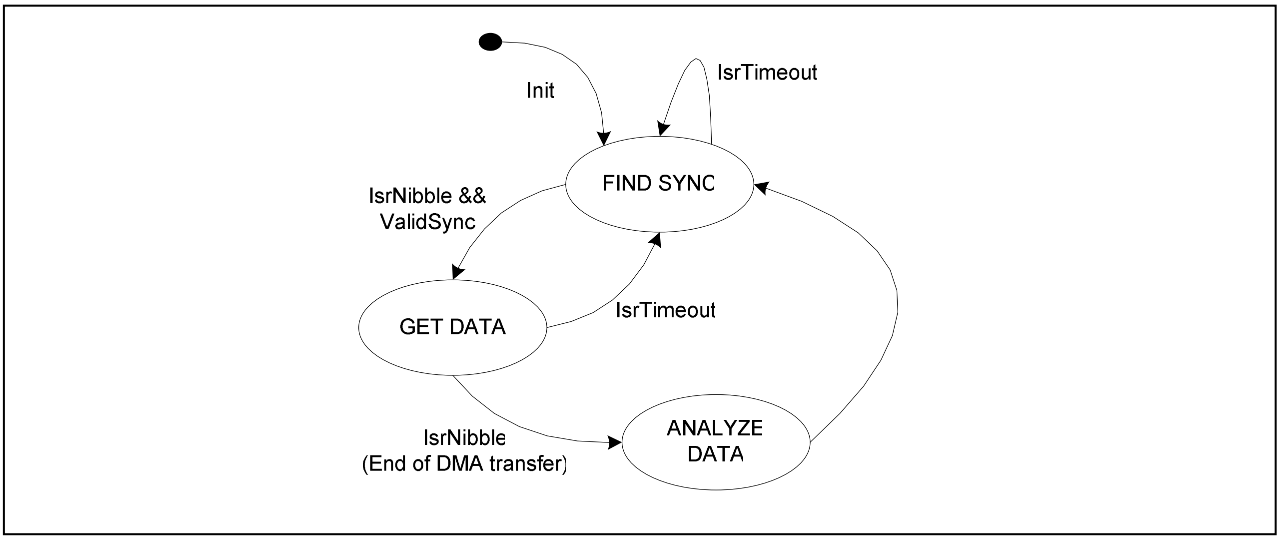
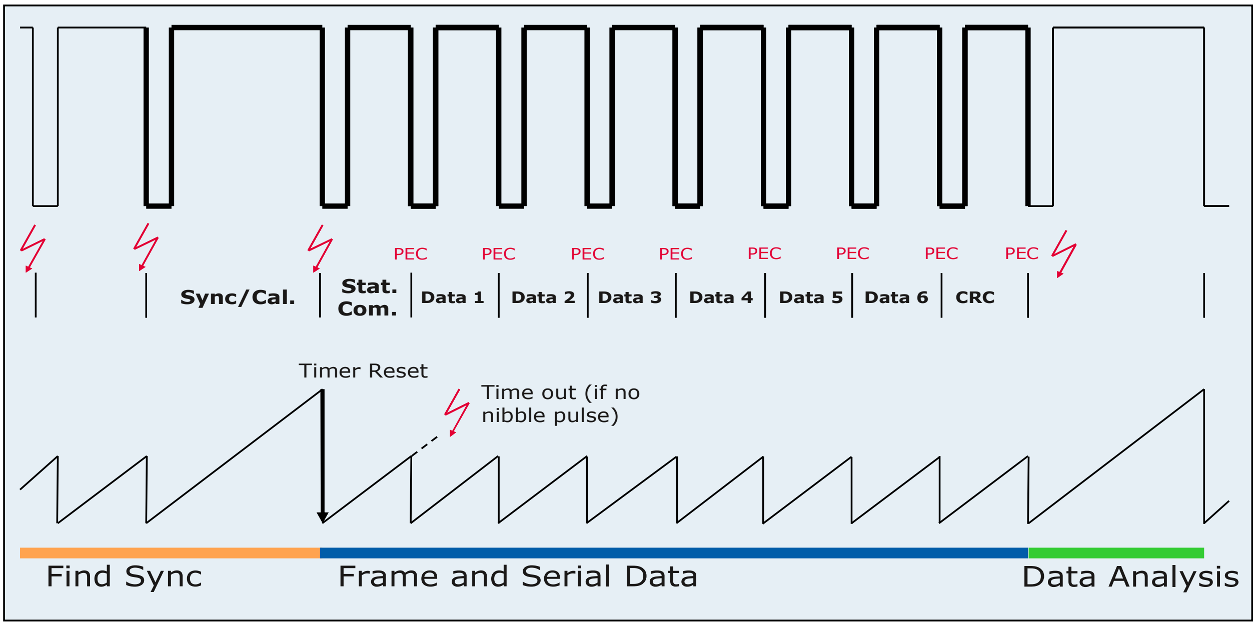


Figure 1 SENT receiver channel state machine

After initialization, the channel will be in the “FIND SYNC” state. Any falling-edge event at the input pin will trigger an interrupt request “IsrNibble”. If valid synchronization (or calibration) signal has been received, it will switch to “GET DATA” state and turn-on the DMA unit to collect several nibbles (status, data and CRC) from the next incoming pulses. When all nibbles have been collected, the DMA will generate an interrupt request and the data can be analyzed. Note that on XC2287, at the end of PEC transfer interrupt is generated using the same interrupt frame as the **normal** one, i.e. “IsrNibble”.



If there is no received pulse after specific timeout (larger than the maximum calibration pulse length[1]), interrupt request will be generated and the channel switches back into "FIND SYNC" state. If it was from "GET DATA" state, DMA transfer will be stopped.

3.2 Single-channel requirement

Each SENT receiver channel requires the following resources:

- One self-reset timer per channel, timer directly gives pulse period when captured on falling-edge.
- One capture register per channel for input falling edge event
- One compare register per channel for timeout event
- One DMA/PEC channel for transferring captured timer into a temporary buffer
- Falling-edge event interrupt, or end-of-DMA transfer interrupt
- Timeout event interrupt

3.3 Resource usage

Resource	Channel 0
Peripheral	CCU60
SENT input pin	P9.7 (pull-up)
Timer register	CCU60_T12R
Capture register	CCU60_CC60R
Compare register	CCU60_T12PR
DMA / PEC Channel[2]	0

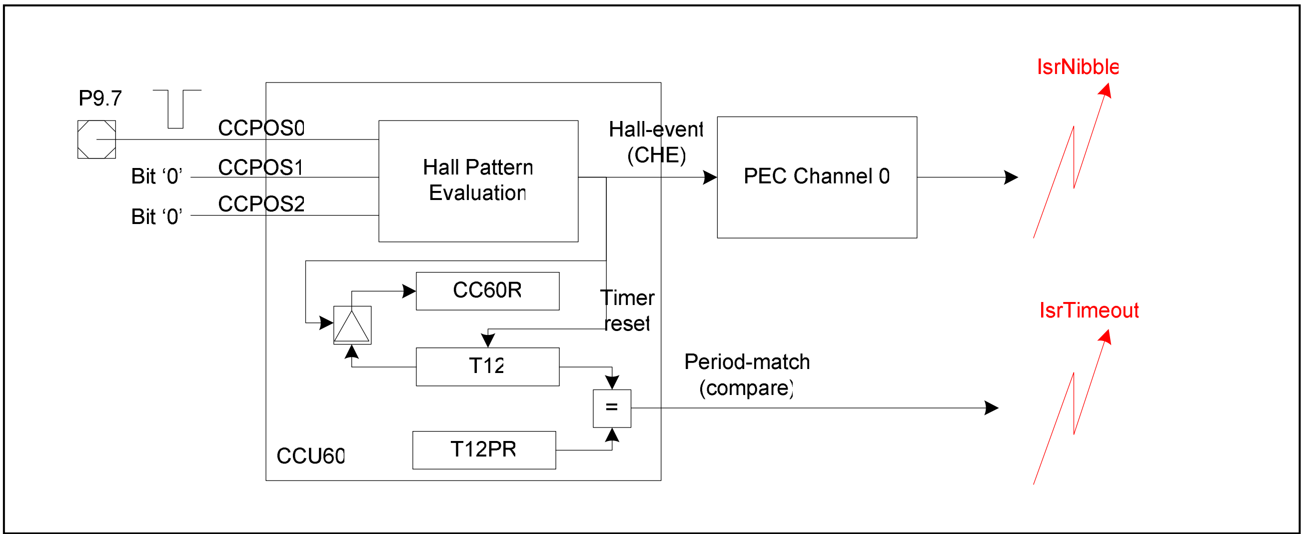


Figure 2 SENT receiver channel 0 resource usage

[1] Nominal calibration pulse length is 56 x 3us = 168us. Maximum calibration pulse is nominal +25%, i.e. 210us.
[2] DMA/PEC Channel number to use is configurable, see section 5.2.2 "DMA/PEC Channel Configuration"

3.4 Falling-edge detection

In order to detect falling-edge input on CCPOS0, CCU6x shall be set to “Hall-sensor mode” and the pattern is:

CURRS = ‘001’

EXPHS = ‘000’

Therefore, in file sent_ccu6x.h some registers are configured.

For channel 0, used in *CCU60_vInit()*

```
#define VAL_PISELL(ist12hr, ispos2, ispos1, ispos0, istrp, iscc62, iscc61, iscc60) \
  ((iscc60 << 0) | (iscc61 << 2)  | (iscc62 << 4)  | (istrp << 6) |    (ispos0 << 8) \
 | (ispos1 << 10) | (ispos2 << 12) | (ist12hr << 14))

_inline void Sent_CCU6x_Init_0(void)
{
    Sent_PEC_Init_0();
    Sent_TimeoutDisable_0();

    ...

    /* Load CCU60 Port Input Selection register to select only CCPOSA(P9.7)
       and others to input zero */
    CCU60_PISELL = VAL_PISELL(0, 2, 2, 1, 3, 2, 2, 2);

    CCU60_MCMOUTS = 0x8800; // CURHS = '001', EXPHS = '000'
}
```

3.5 Interrupt service routines

The interrupt service routines API are called from corresponding interrupt vector/frame. These routines mainly evaluate channel state and performs necessary operations.

Sent_IsrNibble

```
void Sent_IsrNibble(TSentChannel* Channel)
{
    if (Channel->ui_Rx_SENT_Status==SENT_STATE_FIND_SYNCH)
    {
        if (Sent_CheckCalibrationPulse(Channel)==TRUE)
        {
            Channel->ui_Rx_SENT_Status = SENT_STATE_GET_DATA;
        }
    }
    else if (Channel->ui_Rx_SENT_Status==SENT_STATE_GET_DATA)
    {
        ...
        // future state after exiting this interrupt context
        Channel->ui_Rx_SENT_Status=SENT_STATE_FIND_SYNCH;
        ...
        Sent_AnalyzeNibbles(Channel);
        ...
        if (Channel->cbDataReady)
            Channel->cbDataReady(Channel->ub_ChannelNr);
        ...
     }
}
```

Sent_IsrTimeout

```
void Sent_IsrTimeout(TSentChannel* Channel)
{
        ...
    if (Channel->ui_Rx_SENT_Status==SENT_STATE_GET_DATA)
        Sent_StopDMA(Channel);

    Sent_RaiseError(Channel, SENT_ERR_TIMEOUT);
    Channel->ui_Rx_SENT_Status = SENT_STATE_FIND_SYNCH;
        ...
}
```

3.6 Validation of calibration pulse (on falling-edge interrupt, "FIND SYNC" state)

Validation of calibration pulse is done by using both of these two criteria:

- Pulse-length is within expected nominal length (i.e. 168us) +/- 25%
- Difference (jitter) between successive calibration pulses is not above 1.5625% (1/64 time).

When valid calibration pulse is detected, the channel will store:

- the actual calibration pulse length for future jitter validation
- the ratio between captured and expected tick, example: ratio = CCU60_CC60R / 56

Sent_CheckCalibrationPulse

```
bool Sent_CheckCalibrationPulse(TSentChannel* Channel)
{
    uword ui_SCapture = (*Channel->CAPREG);
        ...
    uword ui_PulseLength = ui_SCapture;
    uword ActualTime = 0;
        ...

    if (Sent_IsValidCalibrationPulse(ui_PulseLength) == FALSE)
    {
        Sent_RaiseError(Channel, SENT_ERR_INVALID_CALIBRATION_PULSE);
        return FALSE;
    }
    else if ((Channel->Synchronized==TRUE)
          && (Sent_IsValidCalibrationJitter(Channel, ui_PulseLength)==FALSE))
    {
        Sent_RaiseError(Channel, SENT_ERR_INVALID_CALIBRATION_PULSE);
```

```
        return FALSE;
    }
    else
    {
        Sent_StartDMA(Channel);
        ...
        Channel->MaxCalibrationJitter = Sent_CalcCalibrationPulseJitter(ui_PulseLength);
        Channel->Synchronized = TRUE;
        ...
        Channel->ui_TickRatio = SENT_TICK_RATIO_CALC(ui_PulseLength);
        Channel->LastCalibrationPulse = (sword)ui_PulseLength;
        return TRUE;
    };
}
```

3.7 Buffering the nibbles ("GET DATA" state)

In order to offload the CPU that decodes the SENT frame, the nibbles are buffered by the PEC engine until a complete frame has been received. Then the PEC raise an interrupt to the processor using the same interrupt frame as the synchronization/calibration pulse interrupt (for example, see interrupt frame *CCU60_viNodeI0* which then calls *Sent_IsrNibble*).

The PEC transfers the pulse length (in timer tick) from the capture register (e.g. CCU60_CC60R) into array-variable *ui_Capture* of *TSentChannel* structure.

```
typedef struct {
        ......
        ubyte ub_NumNibbles;                // number of data nibbles of this channel
        ......
        uword ui_Capture[SENT_NIBBLES_MAX];  // nibble values, calculated
        ......
} TSentChannel;
```

The *Sent_StartDMA* and `Sent_StopDMA` code are used to start and stop accordingly the required DMA/PEC channel for this purpose.

3.8 Analyze Data (on end of DMA/PEC transfer)

At the end of PEC transfer interrupt request is generated using the same interrupt frame as the **normal** one, i.e. "IsrNibble". Therefore, inside Sent_IsrNibble the state variable is checked, then if it was in "GET DATA" state:

- Every pulse length representing value of status, all data, and CRC are decoded and validated
- CRC is calculated and compared with the received CRC
- Channel's status flag is updated, in case of error or new data.

Pulse decoding is done by using 16-bit fixed-point math operation.

```
#define ROUND_MASK (0x1 << (SENT_CONVERSION_Q-SENT_TICK_RATIO_Q-1))
```

```
ubyte Sent_DecodePulse(TSentChannel* Channel, uword ui_PulseLength)
{
    uword Value = (ui_PulseLength << SENT_CONVERSION_Q) / Channel->ui_TickRatio;
  #if SENT_CONVERSION_Q != 0
    Value += ((Value & ROUND_MASK) << 1);  // round-up if needed
  #endif
    Value = Value >> (SENT_CONVERSION_Q-SENT_TICK_RATIO_Q);

    if (!(Value >= 12 && Value <= 27))
        Sent_RaiseError(Channel, SENT_ERR_INVALID_NIBBLE);

    return (ubyte)(Value - 12); /* return nibble value represented by pulse length  */
}
```

For example in sent_ccu6x.h:

```
#define SENT_CONVERSION_Q  3
#define SENT_TICK_RATIO_Q  0
```

when ui_PulseLength = 1141 (decimal) and pre-calculated Channel->ui_TickRatio = 60,

initial value	00000**10001110101**	(binary)
left shift (Q):	00**10001110101**000	(binary)
divide (bold bit is the masked bit for rounding):	0000000010011**0**00	(binary)
add:	0000000010011000	(binary)
right-shift (Q - TICK_RATIO_Q) :	0000000000010011	(binary)
end value	19	(decimal)
decoded value (subtract by 12)	9	(decimal)

In comparison to floating point operation, 1141 / 60 = 19.02 => 19 (rounded).

4 Execution times

On normal operation and serial frame decoding is disabled, for each channel the receiver gives following figures:

4.1.1 SENT Decoder (CPU@80MHz)

	Frame time (us)	**Execution time without callback function**
Find sync		2.4us
Analyze/decoding data		9.8us
Total time		**12.2us**
Average case[3]	**642.0**	**1.9%**
Worst case[4]	364.8	3.3%
Best case[5]	993.6	1.3%

[3] Having a nominal frame tick of 3us, average frame length 214 ticks
[4] Having a nominal frame tick of 3us - 20% = 2.4us, min frame length 152 ticks
[5] Having a nominal frame tick of 3us + 20% = 3.6us, max frame length 276 ticks

5 Configuration

5.1 Configurable parameters in sent_cfg.h

The settings that can be modified by the user are “defines” located in the file “sent_cfg.h”. After a parameter has been modified, the program should be recompiled.

sent_cfg.h

Name	Description	Default
`SENT_IFX_CRC`	1: use IFX CRC 0: use original SENT CRC	`0`
`SENT_SERIAL_DATA_ENABLED`	1: enable serial data decoding 0: disable serial data decoding	`0`
`SENT_CHKSUM_STATUS`	1: enable code to include status nibble in CRC calculation 0: disable feature	`0`
`SENT_SERIAL_FRAME_LENGTH`	Number of bit in the serial frame (). Only used if *SENT_SERIAL_DATA_ENABLED != 0*	`16`
`SENT_DEVELOPMENT_DEBUG`	If defined, debug information is given	(defined)
`OPTIMIZE_INLINE_SENT`	If set to `_inline` the driver is optimized using inline function else should be defined empty	`_inline`
`SENT_CALLBACK_ENABLED`	1: enable callback function 0: disable callback function	`1`
`SENT_PERIPHERAL`	In this implementation, always `USE_CCU6`	`USE_CCU6`
`SENT_CHANNELS_MAX`	1 or 2 channels receiver will be implemented. 1 channels implementation only uses CCU60. 2 channels implementation uses CCU60 and CCU62	`2`
`SENT_NIBBLES_MAX`	Maximum nibbles to handle: status, data, and CRC equiv.: number of data nibbles + two	`8`
`SENT_SPC_PERIOD_SYNCH`	Only valid for `SENT_PROTOCOL_SPC != 0` Period of synchronization signal in **microsecond**. Minimum period is FRAME_TICK x 3us x 125% where: *FRAME_TICK =* *56 // tick of calibration pulse* *+ (27 x SENT_NIBBLES_MAX) // status,data,crc* *+ 57 // idle nibble* with SENT_NIBBLES_MAX = 8, minimum is 1326us	`1500`

SENT_SPC_LOW_TIME	Only valid for SENT_PROTOCOL_SPC != 0 Time in microsecond when the SPC line will be driven low. By default, as per SENT protocol, 5 ticks => 15 us By default, as per SPC protocol, it can be lower, i.e. 3 ticks => 9us	15

Other settings can be done during the driver initialization with the Sent_ChannelInit() function.

5.2 Configurable parameters in DAvE

The DAvE will regenerate CCU60.c. Depend on how far the changes in the DAvE, sent_cfg.c will need to be modified too.

5.2.1 sent_cfg.c

By default, this file implements *TSentChannelConfig SentChannelsConfig[SENT_CHANNELS_MAX]*

in sent.h

```
typedef struct {
  void (*cbDataReady)(ubyte Channel); // callback function upon data ready
  uword ub_NumNibbles;             // number of data nibbles, upto SENT_NIBBLES_MAX-2
  ubyte ub_PEC_Nr;                     // DMA/PEC channel Nr.
  uword* CAPREG_Ptr;                   // address of signal capture register
} TSentChannelConfig;
```

Example configuration:

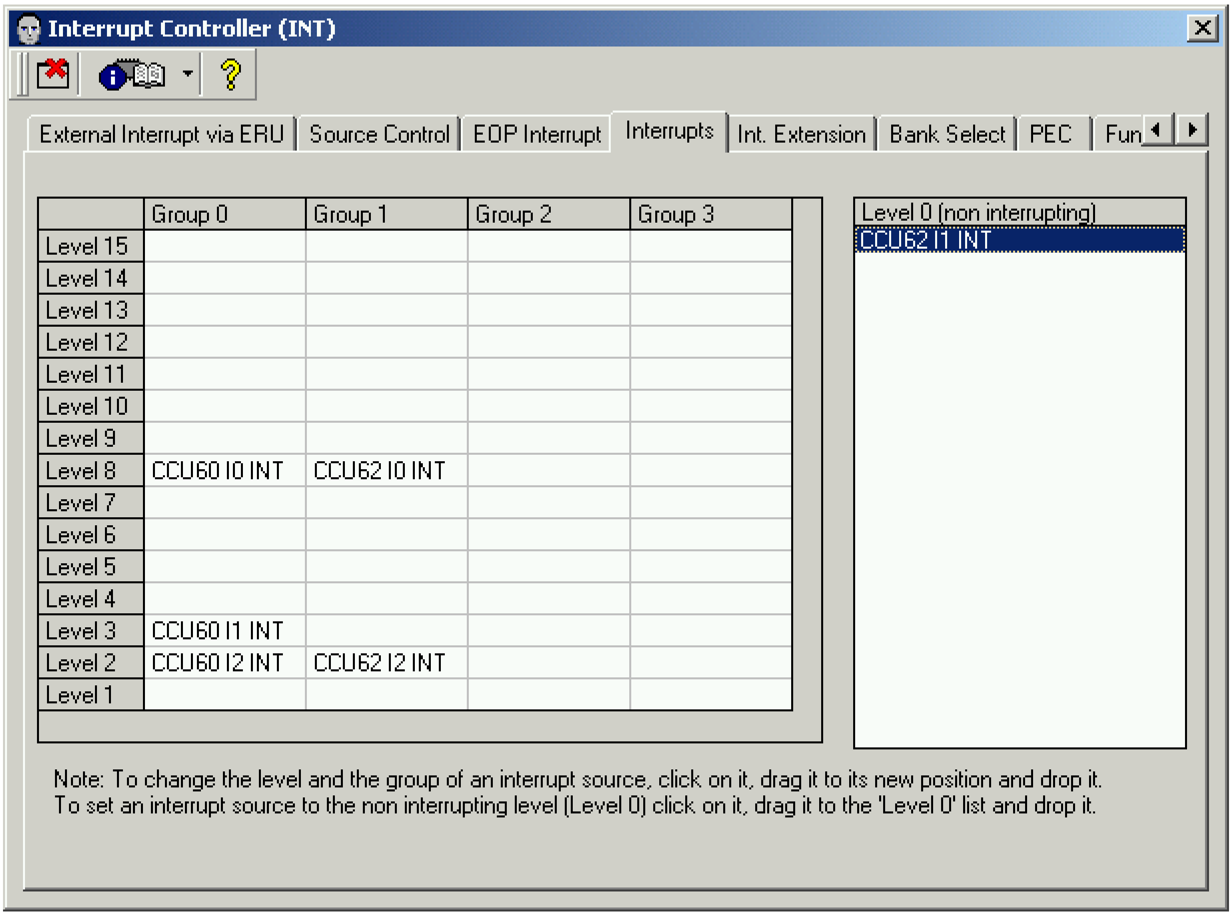
```
extern void cbSent0_DataReady(ubyte Channel); // in MAIN.c

TSentChannelConfig SentChannelsConfig[SENT_CHANNELS_MAX] =
{ /* cbDataReady        ub_NumDataNibbles   ub_PEC_Nr   CAPREG_Ptr          */
  {  cbSent0_DataReady, 6,                  0,          (uword*)&CCU60_CC60R},
  {  0,                 6,                  1,          (uword*)&CCU62_CC60R},
};
```

The configuration of PEC channel number might be changed as described in the section 5.2.2 "DMA/PEC Channel Configuration".

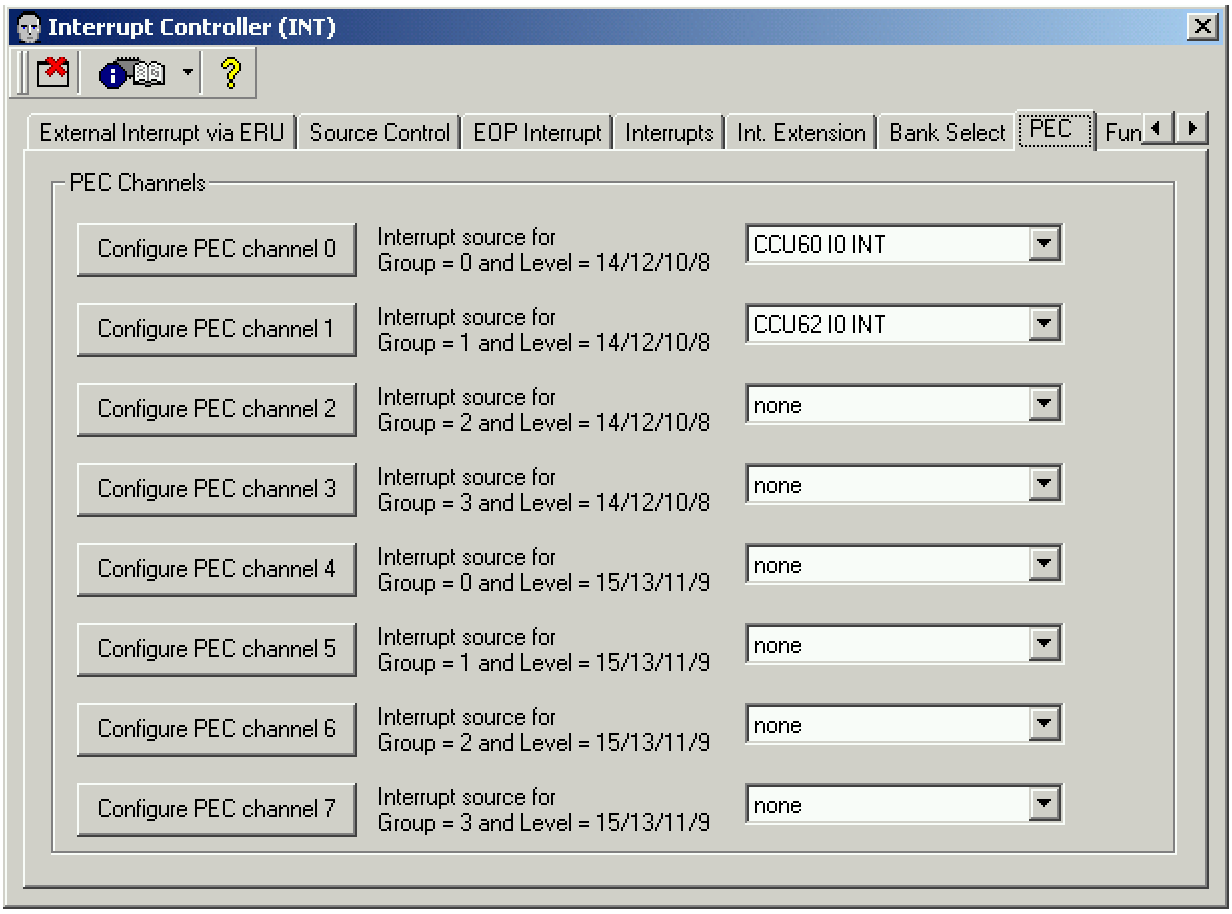
5.2.2 DMA/PEC Channel Configuration

By default, CCU6x interrupts are organized as shown in the following picture. Interrupt nodes CCU60_I0_INT is handled by PEC channel 0 during the “GET DATA” state.

Interrupt configuration:



PEC channel assignment:



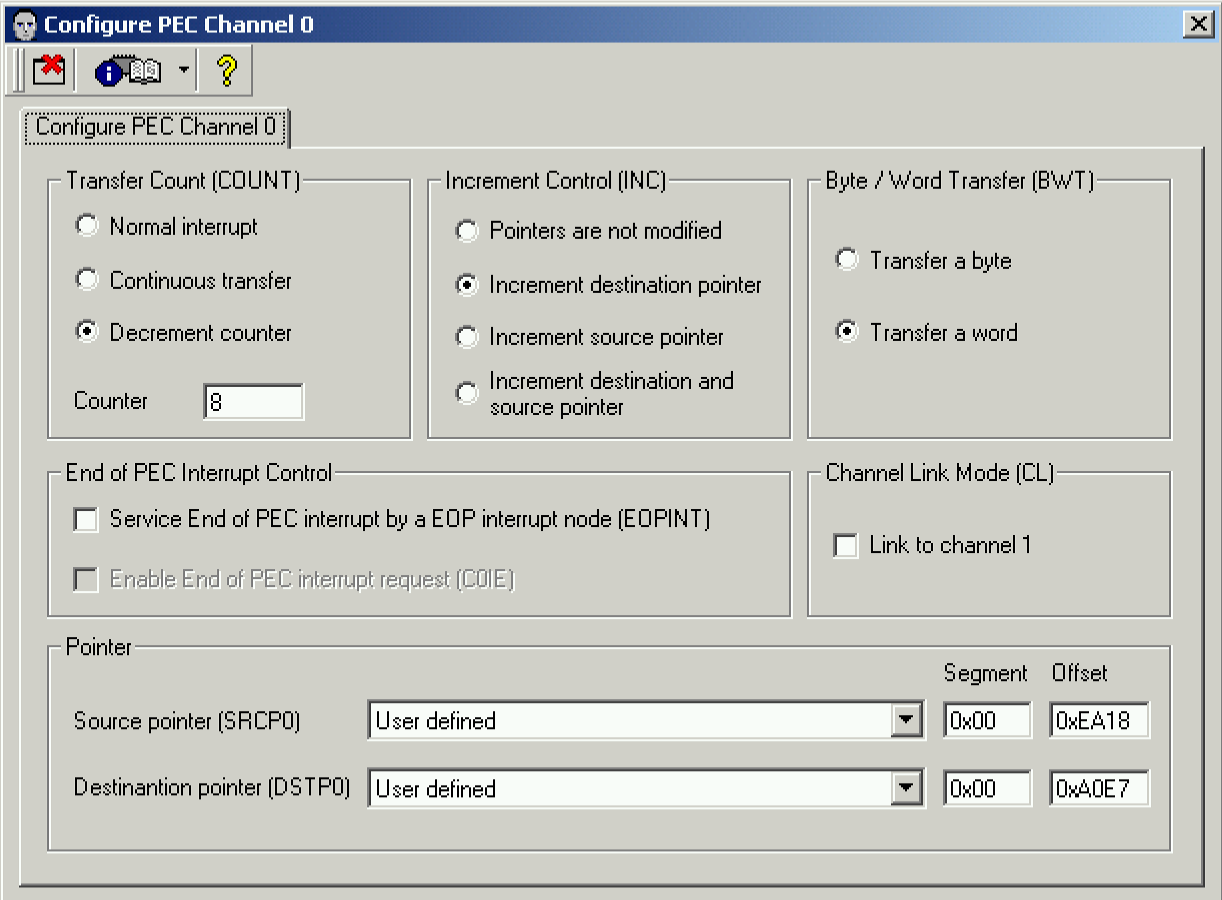
Single PEC channel X configuration:

It is important and necessary to keep to these settings:

- "Decremented COUNT"
- "Increment destination pointer"
- "Transfer a word"
- SRCPx Segment = 0x00

Other settings will be filled by the driver:

- SRCPx Offset
- DSTPx Segment and Offset



6 Driver's API

For the user (upper-layer), the driver provides following API:

6.1 Global channels variable

Definition in sent.h

```
typedef struct {
       /* processing results */
       volatile ubyte ui_Result[SENT_NIBBLES_MAX];  // received result nibbles:
                 //    [0]=>Status    and    Comm,    [1..NumNibbles-1]=>Data,
[NumNibles]=>CRC
       volatile uword RSerialData;                  // received serial data
       uword RDataCounter;                          // received data counter

       /* information */
       volatile uword ui_StatusFlags;                  // driver status (sticky
flag)
       uword ui_Error;                              // error counter
       ...
} TSentChannel;

extern TSentChannel SentChannels[SENT_CHANNELS_MAX]; // implemented in sent.c
```

6.2 Bit mask of ui_StatusFlags

These are defined as follows in sent.h, which can be used as mask to test the bit field.

```
#define SENT_ERR_UNEXPECTED_CALIBRATION_PULSE           (0x0001)
#define SENT_ERR_INVALID_CALIBRATION_PULSE              (0x0002)
#define SENT_ERR_FRAME_TIMEOUT                          (0x0004)
#define SENT_ERR_INVALID_NIBBLE                         (0x0008)
#define SENT_ERR_DATA_CRC                               (0x0010)
#define SENT_ERR_UNEXPEXTED_START_BIT                   (0x0020)
#define SENT_ERR_SERIAL_DATA_CRC                        (0x0040)
#define SENT_ERR_TIMEOUT                                (0x0080)
#define SENT_NEW_DATA                                   (0x0100)
#define SENT_ERR_FRAME_MISSING_CALIBRATION_PULSE        (0x0200)
#define SENT_NEW_SERIAL_DATA                            (0x0400)
#define SENT_NEW_ERROR                                  (0x0800)
#define SENT_RAISE_INTERRUPT                            (0x1000)
#define SENT_ERR_MISSING_START_BIT                      (0x2000)
```

6.3 Functions prototypes in sent.h

6.3.1 Sent_ChannelInit

Note:

This function shall be called before initialization of CCU6x (calling to `vCCU60_Init()`)

Purpose:

Initialization of channel variables.

Copying values from driver's global configuration `SentChannelConfig.`

Prototype:

```
void Sent_ChannelInit(ubyte ChannelNr);
```

Parameters:

ChannelNr Channel number to initialize

6.3.2 Sent_CopyData

Purpose :

To copy all the latest data nibbles. If in between the copy process there's a new data, the copy data will be repeated.

Prototype:

```
void Sent_CopyData(ubyte ChannelNr, ubyte* DestinationPtr);
```

Parameters:

ChannelNr	Channel number
DestinationPtr	Location the data nibbles will be copied into

6.4 Functions prototypes in CCU60.h

Purpose:

Initialization of the CCU6x peripherals

Prototype:

```
void CCU60_vInit(void);
```

7 Outlook

This AppNote describes an implementation with one channel. In many applications two or more SENT interfaces are used. By using another CCU peripheral as well more channels can be implemented in parallel. We recommend to use CCU62 for the second channel.

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