High Accuracy Time Synchronization over SpaceWire Networks - update

Aeroflex Gaisler AB

Kungsgatan 12, SE-41119 Göteborg, Sweden

sales@gaisler.com

+46 31 775 86 50

www.Aeroflex.com/Gaisler

Overview

- Standard
- Time synchronization
- Time message
- RMAP

Standard

- **Initiator:** Distributes time to targets
- **Target:** Receives time from an initiator
- **Time message:**
  - Carries time value
  - CCSDS Time Code Formats (any could be supported)
  - CCSDS Unsegmented Code (CUC) (baseline)
  - All ranges and precisions allowed (defined by P-Field)
  - Carried in RMAP commands (unique PID considered)
- **Time synchronization:**
  - Qualifies time value
  - Carried in Time-Codes
  - Time-Codes are pre-qualified by the time message

Time synchronization

- **Time-Codes with T7:T6=00**
- **Qualify each Time-Code:**
  - **Specify what Time-Code value is used as trigger**
- **Use Time-Codes “as is”**
  - **no jitter mitigation required**

Time message – P-Field

- CCSDS Recommendation for Time Code Formats, CCSDS 301.0-B-4
  - Preamble Field (P-Field)
    - Bit 0: Extension flag
    - Bit 1-3: Time code identification
    - Bit 4:7 Detail bits for information on the code
    - Note that the P-Field can be extended by an octet, bit 0 always being the Extension flag for the next octet.
  - Time Field (T-Field)
    - One or more octets

Time message – T-Field

- CCSDS UNSEGMENTED TIME CODE (CUC)
- Octet 1 (mandatory if P-Field is used)
  - Bit 0 = P-Field Extension (‘zero’: no extension; ‘one’: field is extended)
  - Bit 1 - 3 = Time code identification
    - 001 — 1958 January 1 epoch (Level 1 Time Code)
    - 010 — Agency-defined epoch (Level 2 Time Code)
  - Bit 4 - 5 = Number of octets of the basic time unit minus one
  - Bit 6 - 7 = Number of octets of the fractional time unit
- Octet 2 (optional—presence is signaled in Octet 1)
  - Bit 0 = P-Field Extension (‘zero’: no extension; ‘one’: field is extended)
  - Bits 1-2 = Number of additional octets of the basic time added to that specified in Octet 1
  - Bits 3-5 = Number of additional octets of the fractional time added to that specified in Octet 1
  - Bits 6-7 = Reserved for mission definition

RMAP

- **Define RMAP address space:**
  - **Message**
    - **CUC P-Field and T-Field**
    - **Time-Code qualifier**
  - **Settings (informative)**
    - **Time-Code rate, e.g. 10 ms**
    - **Source for synchronization, e.g. Time-Code, Irq**
    - **Latency & jitter**
    - **E.g. CCSDS Time Code format**
  - **Status (informative)**
    - **E.g. in lock, freewheeling**
    - **E.g. local range and precision**
    - **E.g. system frequency, stability**

Contact information

- **IP cores information:**

  http://www.Aeroflex.com/Gaisler

- **Board information:**

  http://www.Aeroflex.com/Gaisler

- **Software and tools information:**

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- **Contact:**

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Time synchronization – Time-Codes

- **SpaceWire Time-Codes - general**
  - 2 bits used for status flags, but to be changed to identifier bits instead (T7:T6)
- **SpaceWire Time-Codes with T7:76 = 00**
  - 6 bits used for counter (with values 0 to 63)
  - Legacy operation called time-codes hereafter
- **SpaceWire Time-Codes with T7:76 = ??**
  - 5 bit used for interrupt number
  - 1 bit used for interrupt/acknowledgement selection
  - New operation called interrupts hereafter

Time synchronization – Time-Codes

- **SpaceWire Time-Codes with T7:76 = 00**
  - Proposed to be used in SpaceWire-D as time-slot delimiters, being sent every 10-100 ms (approximately)
  - Could be used for synchronization, but might be difficult to align 64 codes with e.g. 1 second boundary
- **SpaceWire Time-Codes with T7:76 = ??**
  - If priority is specified e.g. Interrupt #0, then short latency could be obtained (as goods as for time-codes)
  - Interrupt acknowledge #0 (from a destination) could be used for measuring round-trip delays (i.e. latency*2)
  - Separated from time-code usage in SpaceWire-D

Time synchronization – Accuracy

- **Time-Code distribution suffers from:**
  - **Latency:**

    time it takes to transfer a time-code from source to destination
  - **Jitter:**

    variation of the above time
- **Latency, theoretical:**
  - **Best case 14 bit periods**
  - **Worst case 14 bit periods + synchronization**
- **Jitter, theoretical:**
  - **Best case 10 bit periods**
  - **Worst case 12 bit periods + synchronization**

Time synchronization – Accuracy

- **Latency, empirical:**
  - **Design dependent:**
    - **E.g. highly pipelined SpaceWire codec supporting 200 Mbits in an anti-fuse FPGA has high latency due to intermediate buffer stages**
  - **Varies with system frequency, transmitter/receiver frequency and actual bit rate:**
    - **Need to characterize at several frequencies and bit rates**
- **Jitter, empirical:**
  - **Add two bit periods for quantatization effects**

Time synchronization – improvements

- **Jitter reduction techniques have been proposed:**
  - **Stretch the clock period (up to 12.5 Mbps)**
  - **Add fixed time to latency that can compensate jitter, requires that the jitter for each time-code is distributed with the time code. Requires a change to SpaceWire standard.**
- **For extremely high requirement applications:**
  - **Use a separate synchronization signal!**
- **For high requirement applications:**
  - **There might be hope…**

Time synchronization – improvements

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- **For high requirement applications:**
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Time synchronization – improvements

- **Jitter reduction techniques based on statistical methods under investigation:**
  - **Measure the delta between ideal (wrt local time-keeper) and actual occurrence of a time-code arrival**
  - **Store delta with sign and build statistics**
  - **Calculate appropriate correction**
  - **Correct ideal time for next expected occurrence of time-code arrival**
- **Method also corrects drift (or frequency wander)**
- **Does not affect standardization**
- **Work in progress…**

Time message over SpaceWire - time code

- **CCSDS Recommendation for Time Code Formats, CCSDS 301.0-B-4**
  - CCSDS UNSEGMENTED TIME CODE (CUC)
    - TAI based, no leap second correction
  - CCSDS DAY SEGMENTED TIME CODE (CDS)
    - UTC based, leap second corrections
  - CCSDS CALENDAR SEGMENTED TIME CODE (CCS)
    - UTC based, leap second corrections
  - CCSDS ASCII CALENDAR SEGMENTED TIME CODE (ASCII)
    - UTC based, leap second corrections
  - AGENCY-DEFINED CODES
    - COORDINATED UNIVERSAL TIME (UTC)
    - INTERNATIONAL ATOMIC TIME (TAI)
    - GREENWICH MEAN TIME (GMT)

Time message over SpaceWire - time code

- **CCSDS UNSEGMENTED TIME CODE (CUC)**

CCSDS Unsegmented Code											
P-Field		T-Field									
1st	2nd	Coarse Time						Fine Time			
		2^{31} 2^{24}	2^{23} 2^{16}	2^{15} 2^{8}	2^{7} 2^{0}	2^{-1} 2^{-8}	2^{-9} 2^{-16}	2^{-17} 2^{-24}			
0 7	8 15	0 7	8 15	16 23	24 31	32 39	40 47	48 55			
8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits			

Time message over SpaceWire - time code

- **Proposal:**
  - **Overall time message format and protocol not to be limited to one time format, it should instead support all CCSDS time formats**
  - **CUC to be the baseline (most commonly used)**
  - **Each recipient of the time message to accept all CUC sizes (as currently defined) as input, not only a limited subset, even if only a subset is implemented by the recipient**

Time message over SpaceWire - protocol

- Time message protocols are traditionally unidirectional, e.g. Mil-Std-1553B, GPS, CAN
- Time message protocols traditionally only carry time information, possibly status from source
- Questions:
  - Is there a need for bi-directional communication?

    E.g. to read out status of a destination.
  - Is there a need for other information than just time?

    E.g. to communicate system settings.

    E.g. to setup destination remotely?

Time message over SpaceWire - protocol

- **Protocol structure:**
  - **Simple unidirectional, e.g. CCSDS Unsegmented Code Transfer Protocol (CUCTP)**

Destination Logical Address	Protocol Identifier	CCSDS Unsegmented Code											CRC	EOP
		P-Field		T-Field										
		Default	Extended	Coarse Time						Fine Time				
				2^{31} 2^{24}	2^{23} 2^{16}	2^{15} 2^{8}	2^{7} 2^{0}	2^{-1} 2^{-8}	2^{-9} 2^{-16}	2^{-17} 2^{-24}				*weight*
		0 7	8 15	0 7	8 15	16 23	24 31	32 39	40 47	48 55				*index*
8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits			8 bits	*no. of bits*

  - **Remote Memory Access Protocol (RMAP)**
    - **Supports write (uni-dir) and read (bi-dir)**
  - **Custom protocol based on RMAP**
    - **Subset of RMAP for time distribution only**
    - **New Protocol ID (PID)**