High Accuracy Time Synchronization over SpaceWire Networks

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Overview

▼ Definitions

▼ Time message over SpaceWire
  – Time formats
  – Protocol formats

▼ Time synchronization over SpaceWire
  – SpaceWire Time-Codes and Interrupts
  – Accuracy of SpaceWire Time-Codes
  – Improved accuracy of Time-Codes
### Definitions

- **Source:** Distributes time to destinations
- **Destination:** Receives time from a source
- **Time message:** Carries time value
- **Time synchronization:** Qualifies time value
Time message over SpaceWire – time code

▼ 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
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)

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
Time message over SpaceWire - time code

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

<table>
<thead>
<tr>
<th>P-Field</th>
<th>T-Field</th>
</tr>
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<tbody>
<tr>
<td>1st</td>
<td>Coarse Time</td>
</tr>
<tr>
<td>2nd</td>
<td>$2^{31}$</td>
</tr>
<tr>
<td></td>
<td>$2^{24}$</td>
</tr>
<tr>
<td></td>
<td>$2^{23}$</td>
</tr>
<tr>
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<td>$2^{16}$</td>
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<td>$2^{15}$</td>
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<td></td>
<td>$2^{8}$</td>
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<td></td>
<td>$2^{7}$</td>
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<tr>
<td></td>
<td>$2^{0}$</td>
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<td>8 bits</td>
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</tbody>
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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?
Protocol structure:

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

- 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)
Proposal:

- Add a first control byte to enable future extensions (can be integrated in RMAP address)
- Investigate the need for bi-dir communication, if so select RMAP (-like) protocol
- Possible system settings:
  - Time-Code rate, e.g. 10 ms
  - Source for Synchronization, e.g. 63 to 0 wrap, or Interrupt #0
- Possible destination setup:
  - Latency (i.e. distance from) wrt source
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…
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  – There might be hope…
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…
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