High Accuracy Time Synchronization over SpaceWire Networks - an update

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Overview

▼ Concept (repeat)
  – Time synchronization
  – Time message
  – RMAP & PnP

▼ Draft standard (new)
  – Concept
  – Services
  – Formats

▼ Time synchronization (update)
  – (Lack of ) accuracy
  – Improvements
Concept

▼ 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 (PnP or unique PID considered)

▼ Time synchronization:
  – Qualifies time value
  – Carried in Time-Codes (or Distributed Interrupt)
  – Time-Codes are pre-qualified by the Time message
Time message – CCSDS 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
Time synchronization – SpW Time-Code

▪ **Qualify each Time-Code:**
  - Specify what Time-Code value is used as trigger
  - Also allows Distributed Interrupts

▪ **Use Time-Codes “as is”**
  - no jitter mitigation required
RMAP or Plug & Play

- Defined RMAP address space:
  - Message
    - CUC P-Field and T-Field
    - Time-Code qualifier
  - Settings (informative)
    - Time-Code rate, e.g. 10 ms
    - E.g. CCSDS Time Code format
  - Status (informative)
    - E.g. in lock, freewheeling
    - E.g. local range and precision
    - E.g. system frequency, stability
Draft standard: CCSDS Time Codes

- The Time Distribution Protocol provides the capability to transfer CCSDS Time Codes between onboard users of a SpaceWire network.

- The CCSDS Time Codes may be of variable length or fixed size at the discretion of the user and may be submitted for transmission at variable time intervals, providing a communication service.
Draft standard: Synchronization

- The Time Distribution Protocol provides the capability to synchronize nodes in a SpaceWire network by using SpaceWire time control codes (Time-Codes), providing a timing service.

- Note: (Time-Code) could also be interpreted as the Distributed Interrupts currently being defined for ECSS-E-ST-50-12C Rev.1.
Draft standard: Initiator and target

- An Initiator is a SpaceWire node distributing CCSDS Time Codes and SpaceWire time-control codes (Time-Code). It is also an RMAP initiator, capable of transmitting RMAP commands and receiving RMAP replies. There is only one active initiator in a SpaceWire network during a mission phase.

- A Target is a SpaceWire node receiving CCSDS Time Codes and SpaceWire time-control codes (Time-Codes). A target is also an RMAP target, capable of receiving RMAP commands and transmitting RMAP replies. There can be one or more targets in a SpaceWire network.
The protocol provides means for time-stamping of incoming and outgoing SpaceWire time-control codes (Time-Code) in the Target, make this information accessible to an Initiator by means of RMAP accesses.

(Time-Code) should be interpreted as the Distributed Interrupts currently being defined for ECSS-E-ST-50-12C Rev.1.

The protocol provides means for transferring latency correction information from an Initiator to a Target by means of RMAP accesses.
Draft standard: Services

- Configuration
- Status
- Command (CCSDS Time Code)
- Datation
- Timing (Initialisation/Synchronization)
- Time-Stamp {of SpaceWire time-control codes (Time-Codes)}.
- Latency
Draft standard: formats  (1 of 3)

▼ Configuration field
   – 128-bit composite field
   – Not defined at this stage

▼ Status field
   – 128-bit composite field
   – Not defined at this stage
Draft standard: formats (2 of 3)

▼ Command field
  - Control field - 8-bit
    - New field
    - Initialise field (initialize / synchronize)
  - SpaceWire Time-Code field - 8-bit
  - CCSDS Time Code fields
    - CCSDS Unsegmented Time Code (CUC) – mandatory
    - CCSDS Calendar Segmented Time Code (CCS) – optional
    - CCSDS Day Segmented Time Code (CDS) – optional

▼ Datation field
  - CCSDS Time Code fields
    - CCSDS Unsegmented Time Code (CUC) – mandatory
    - CCSDS Calendar Segmented Time Code (CCS) – optional
    - CCSDS Day Segmented Time Code (CDS) – optional
Draft standard: formats (3 of 3)

▼ Time-Stamp field
- SpaceWire Time-Code field - 8-bit
- CCSDS Time Code fields - received
  - CCSDS Unsegmented Time Code (CUC) – mandatory
  - CCSDS Calendar Segmented Time Code (CCS) – optional
  - CCSDS Day Segmented Time Code (CDS) – optional
- CCSDS Time Code fields - transmitted
  - CCSDS Unsegmented Time Code (CUC) – mandatory
  - CCSDS Calendar Segmented Time Code (CCS) – optional
  - CCSDS Day Segmented Time Code (CDS) – optional

▼ Latency field
- CCSDS Time Code fields
  - CCSDS Unsegmented Time Code (CUC) – mandatory
  - CCSDS Calendar Segmented Time Code (CCS) – optional
  - CCSDS Day Segmented Time Code (CDS) – optional
Draft standard: addressing

- **0x00 – 0x0F** Configuration field
- **0x10 – 0x1F** Status field
- **0x20 – 0x3F** Command field
  - **0x20** Control field - 8-bit
  - **0x21** SpaceWire Time-Code field - 8-bit
  - **0x22-0x3F** CCSDS Time Code fields
- **0x40 – 0x5F** Datation field
  - **0x40-0x41** {unused}
  - **0x42-0x5F** CCSDS Time Code fields
- **0x60 – 0x9F** Time-Stamp field
  - **0x60** {unused}
  - **0x61** SpaceWire Time-Code field - 8-bit
  - **0x62-0x7F** CCSDS Time Code fields – received
  - **0x80-0x81** {unused}
  - **0x82-0x9F** CCSDS Time Code fields - transmitted
- **0xA0 – 0xBF** Latency field
  - **0xA0-0xA1** {unused}
  - **0xA2-0xBF** CCSDS Time Code fields
Draft standard: target implementation

SpW I/F

AMBA

SpW link

Time code in

Time keeper

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Draft standard: initiator implementation

- AMBA
- Processor
- SpW I/F
- SpW link
- Time keeper
- Time-code out

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Draft standard: complete implementation

AMBA

Processor

SpW I/F

SpW link

RMAP

Time keeper

Time-code in/out
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
  – Varies with system frequency, transmitter/receiver frequency and actual bit rate

▼ Jitter, empirical:
  – Add two bit periods for quantatization effects

▼ For extremely high requirement applications:
  – Use a separate synchronization signal!

▼ For high requirement applications:
  – There might be hope...
Time synchronization – improvement

▼ Jitter reduction techniques based on statistical methods under investigation:

– Measure the delta between ideal (w.r.t. 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 ... come to the conference to hear more!
Problem formulation

Frequency synthesizer

Elapsed Time

Initiator

Frequency synthesizer

Elapsed Time

Target
Measure mean interval, correct period

Frequency synthesizer  Elapsed Time

Target

Mean interval  Period correction

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Measure mean interval, correct period

Frequency synthesizer   Elapsed Time

Target

SpW link

Mean interval   Period correction
Measure mean jitter, correct phase

Frequency synthesizer  Elapsed Time

Target

Mean jitter  Phase correction

SpW link
Measure mean jitter, correct phase & latency

Frequency synthesizer  Elapsed Time

Target

Mean jitter  Phase correction

SpW link

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Measure mean jitter, correct phase & latency

Frequency synthesizer  
Elapsed Time

Target

Mean jitter  
Phase correction

SpW link  
Latency

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Measure mean jitter, correct phase & latency

Frequency synthesizer  Elapsed Time

Target

Mean jitter  Phase correction

SpW link

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