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.

Draft standard: Time-stamping and latency

- 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

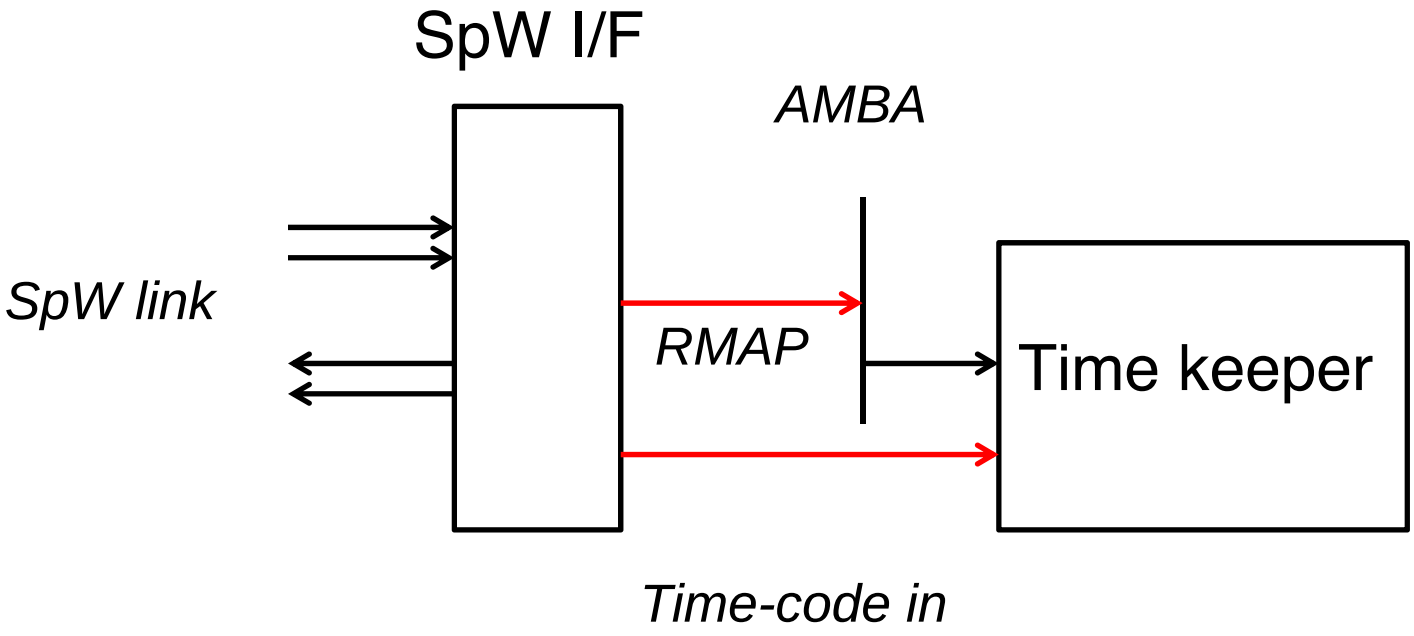
Draft standard: formats (3 of 3)

- **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

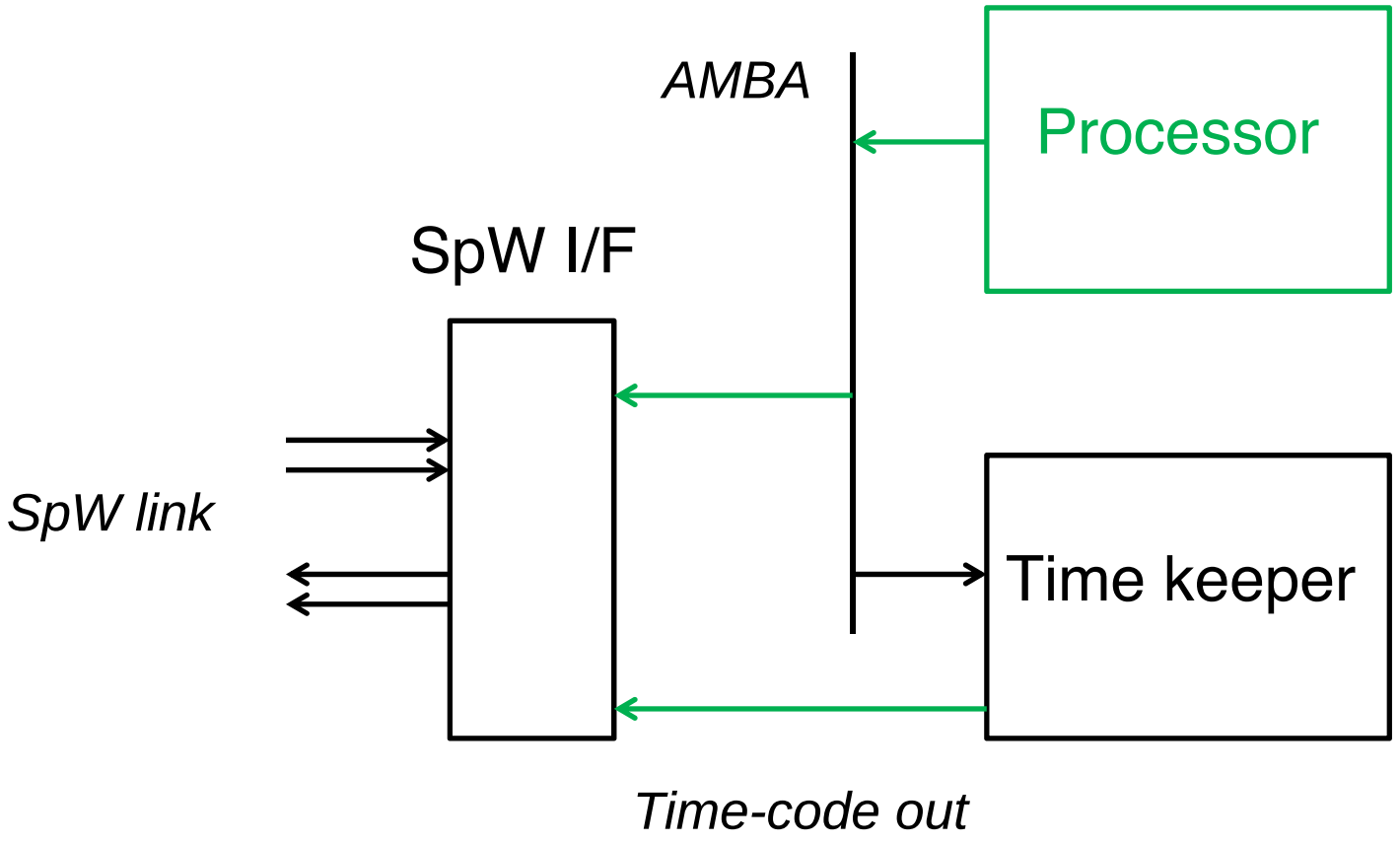
Draft standard: addressing

- 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

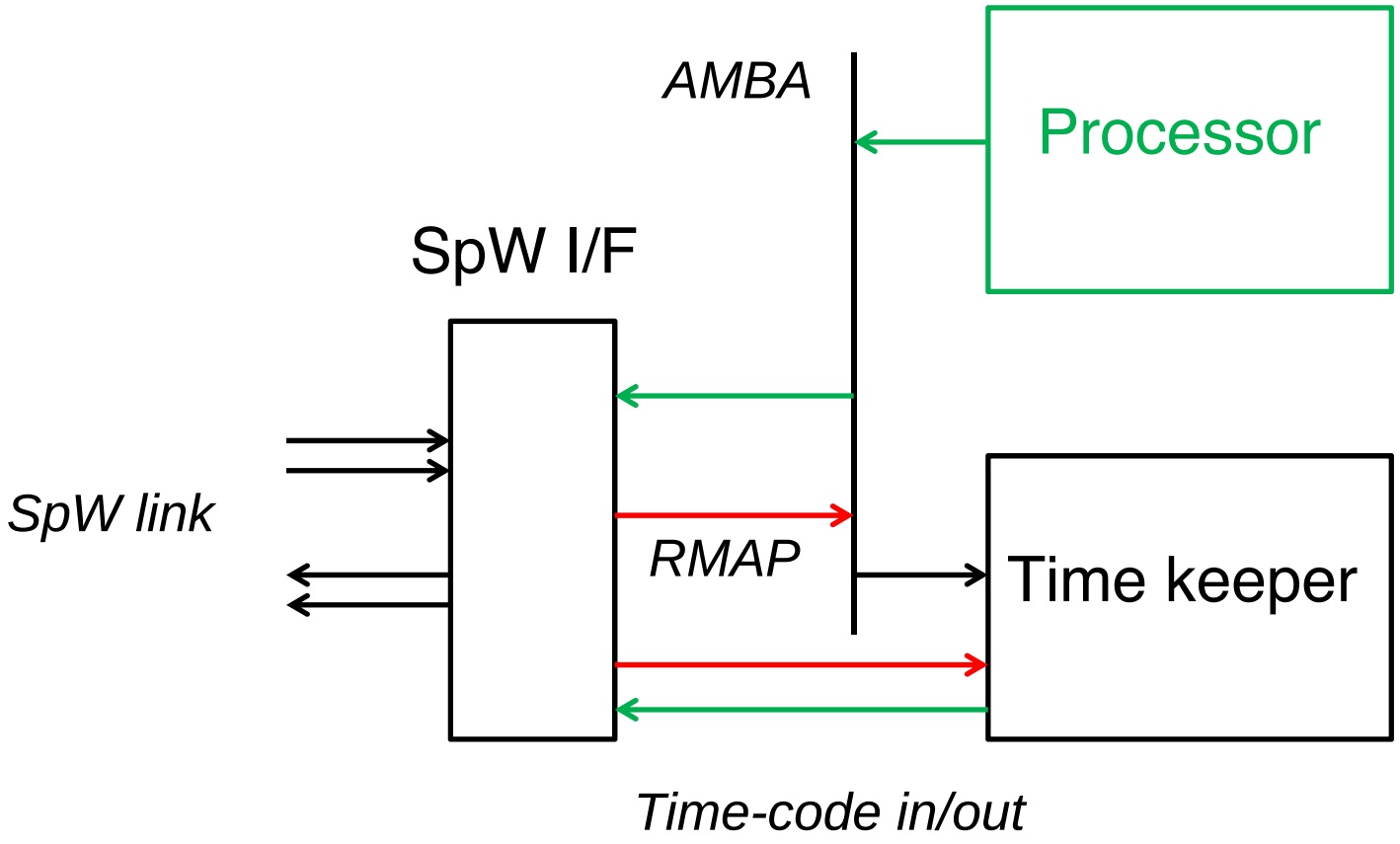
Draft standard: target implementation



Draft standard: initiator implementation



Draft standard: complete implementation



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**

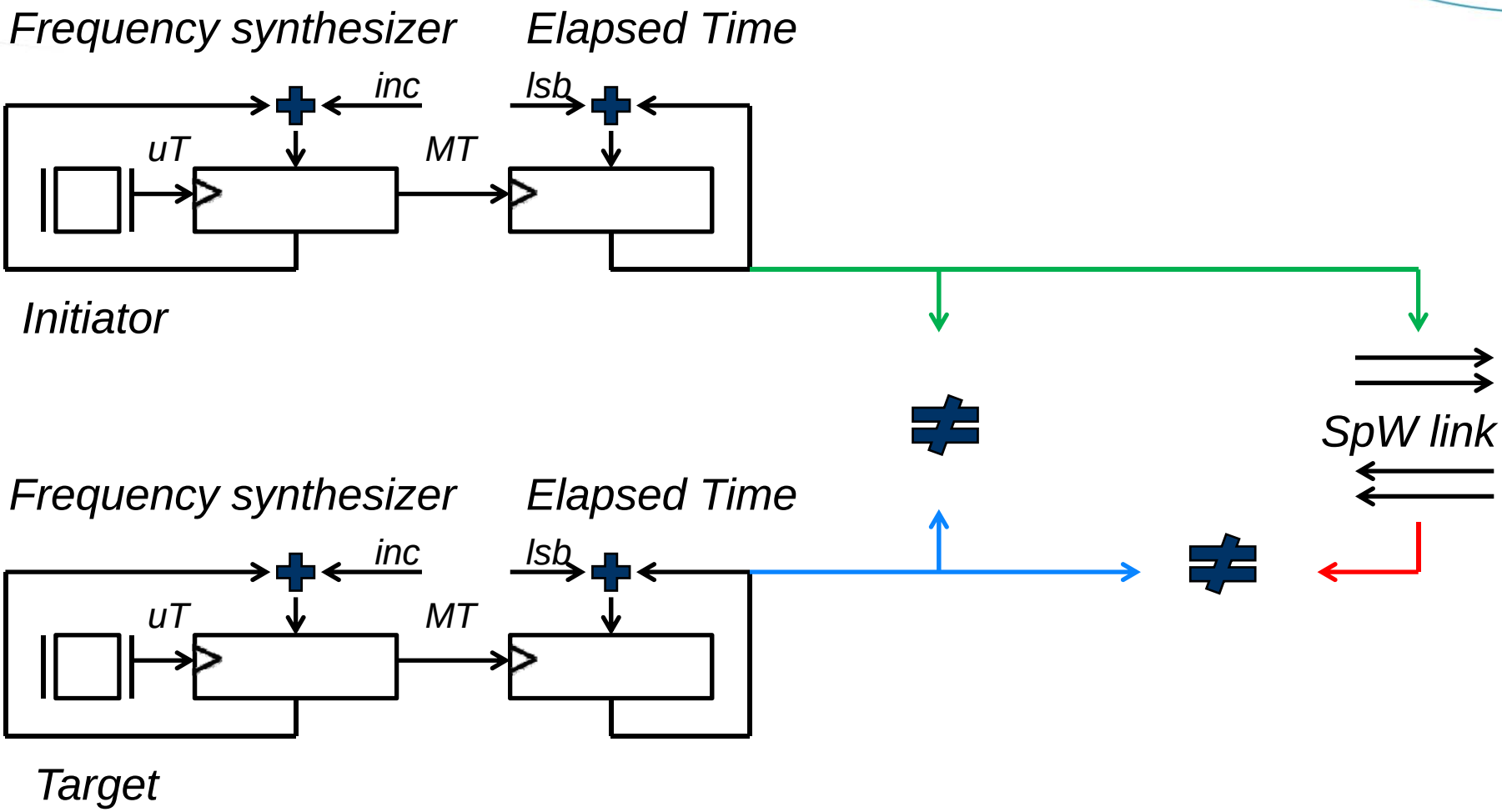
Time synchronization – accuracy

- **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…

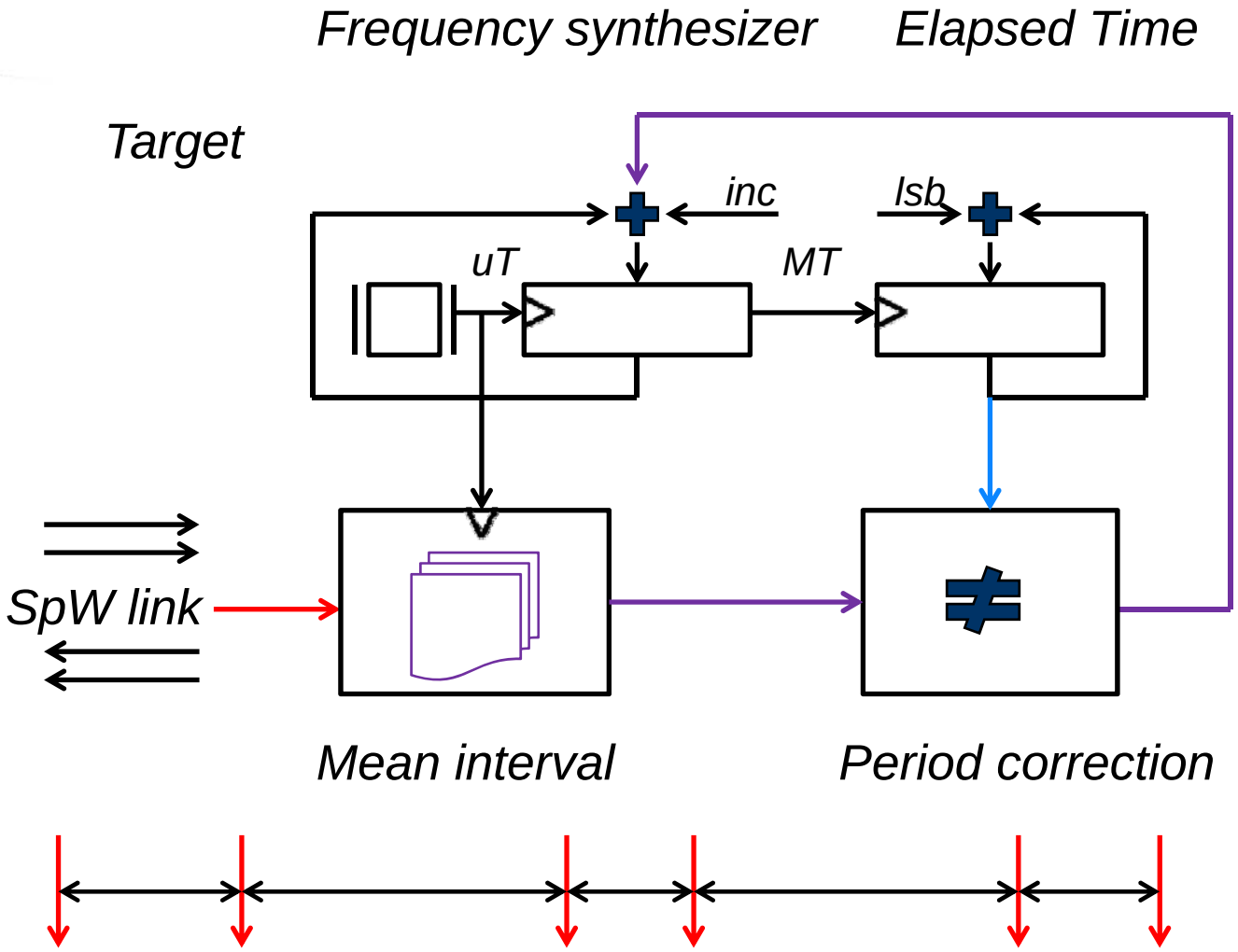
Time synchronization – improvement

- **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!**

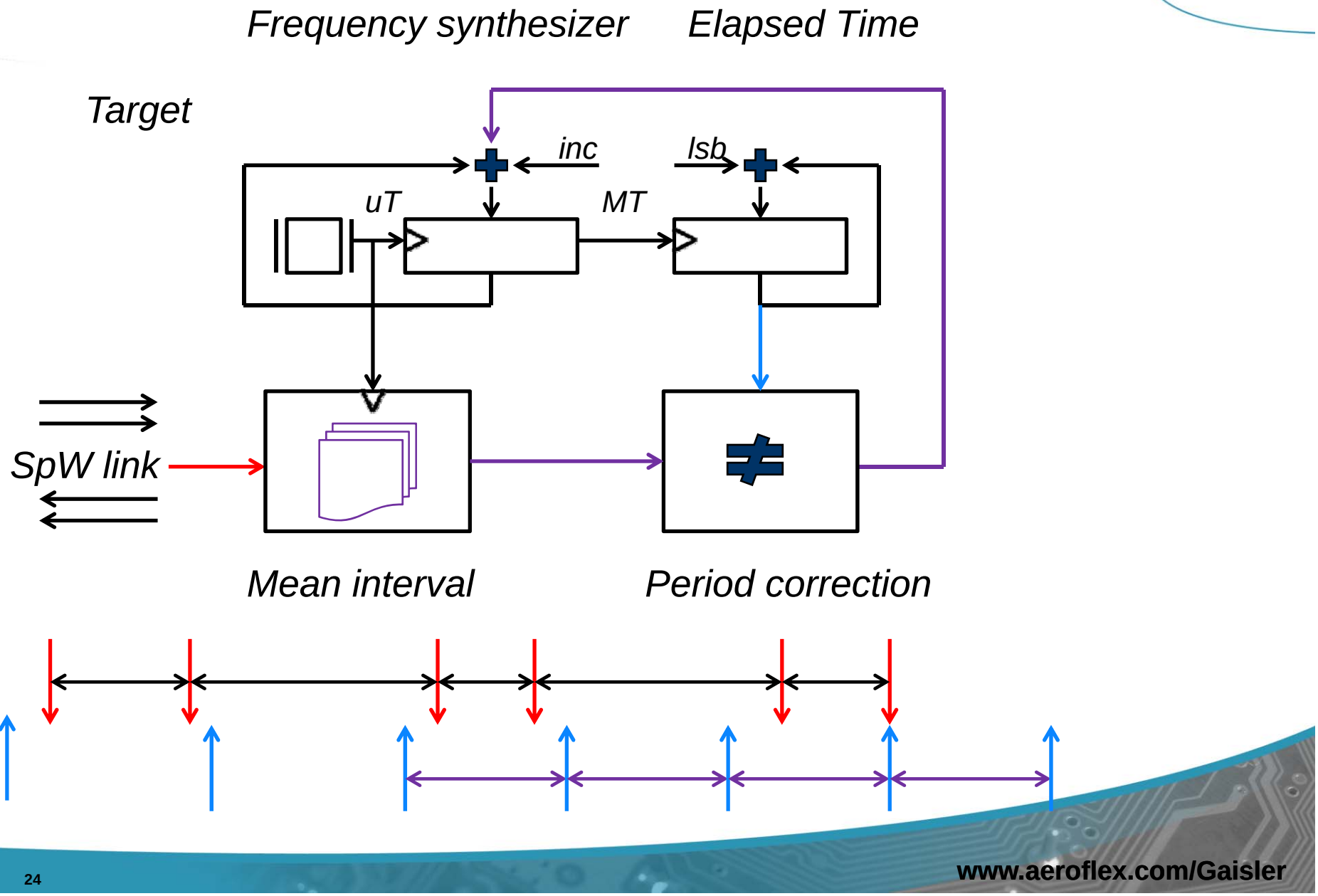
Problem formulation



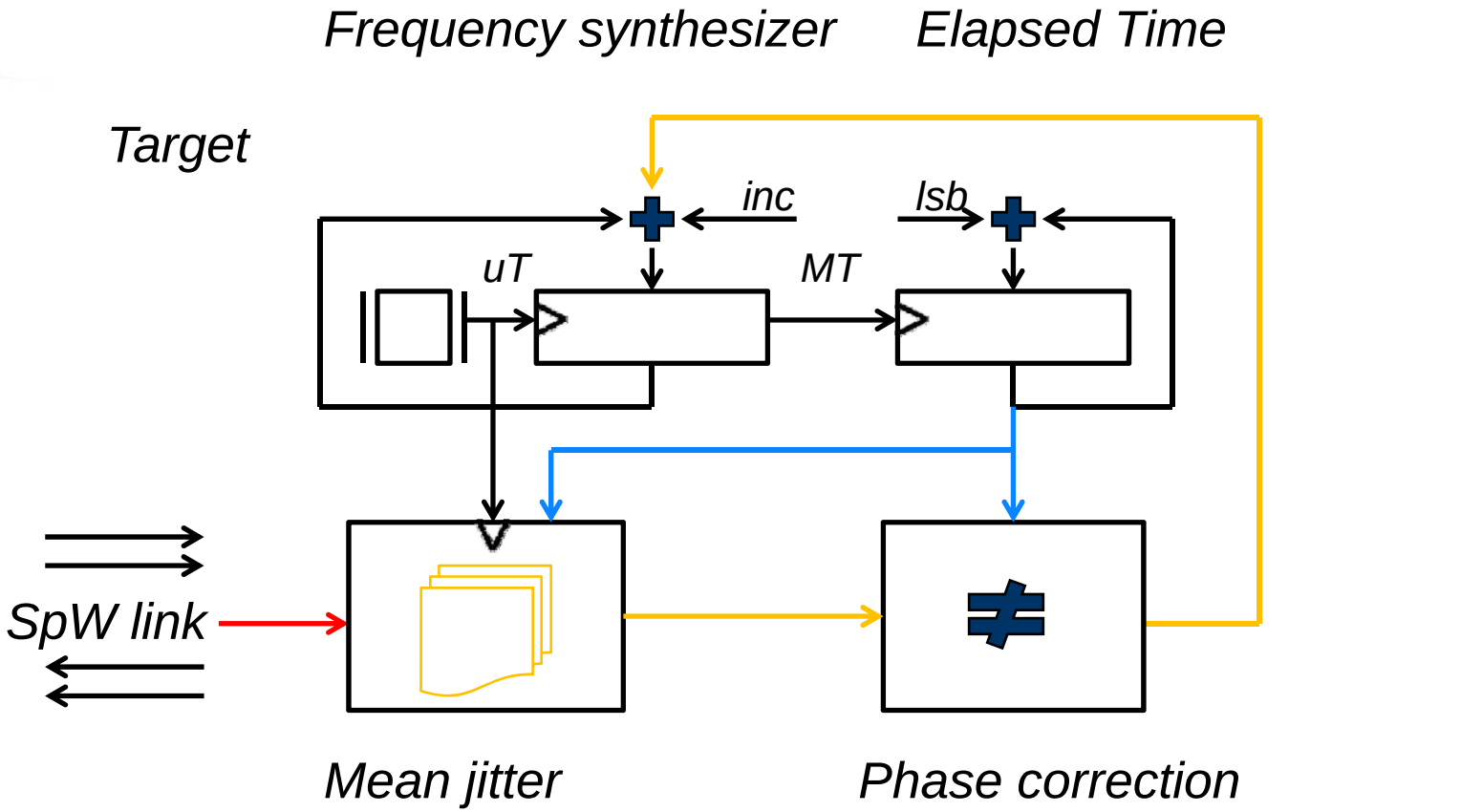
Measure mean interval, correct period

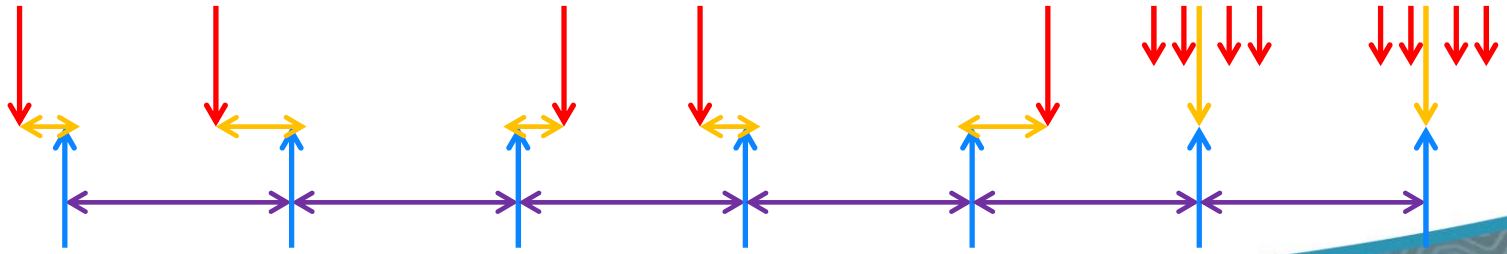


Measure mean interval, correct period

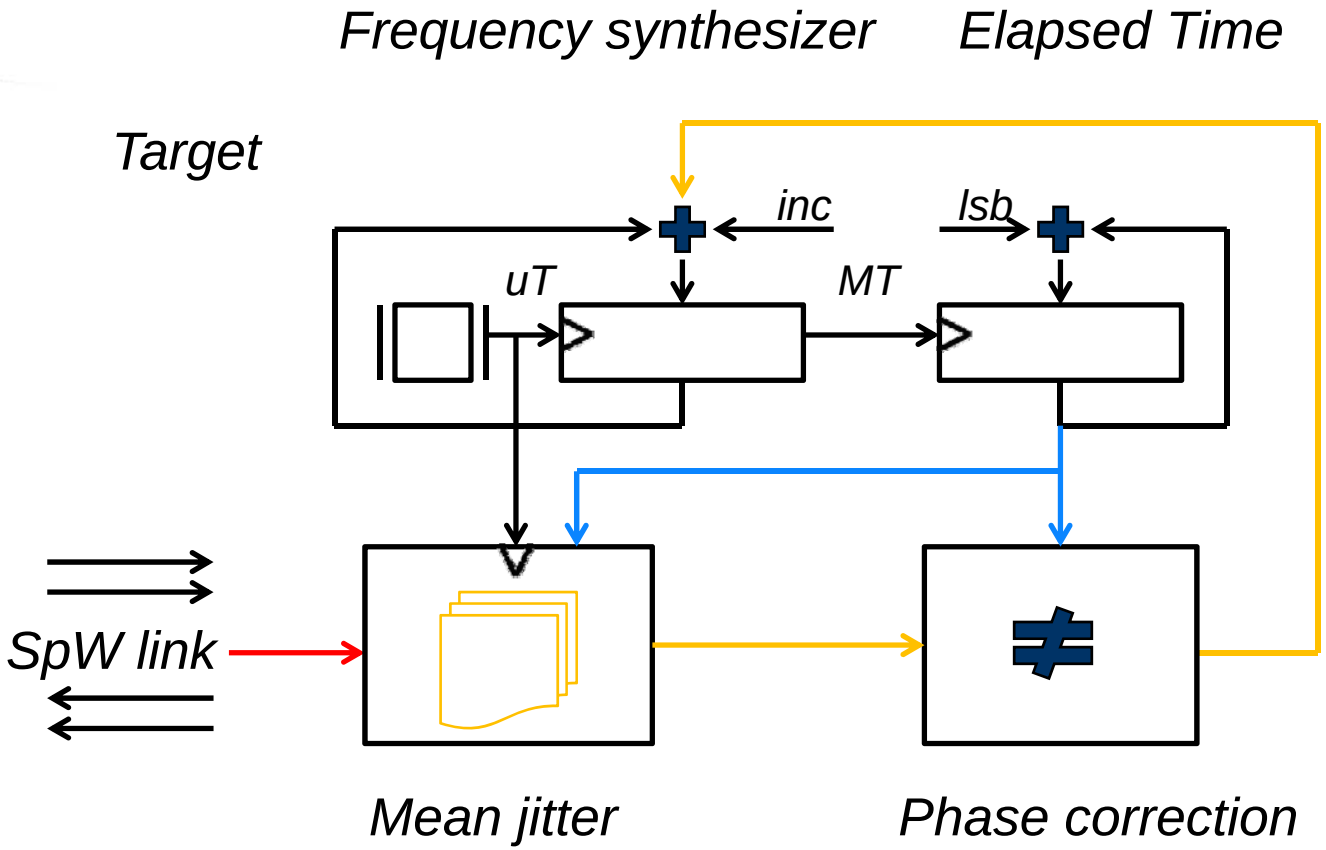


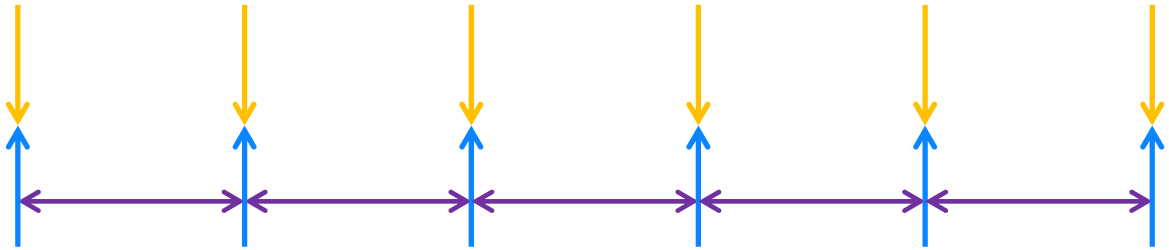
Measure mean jitter, correct phase



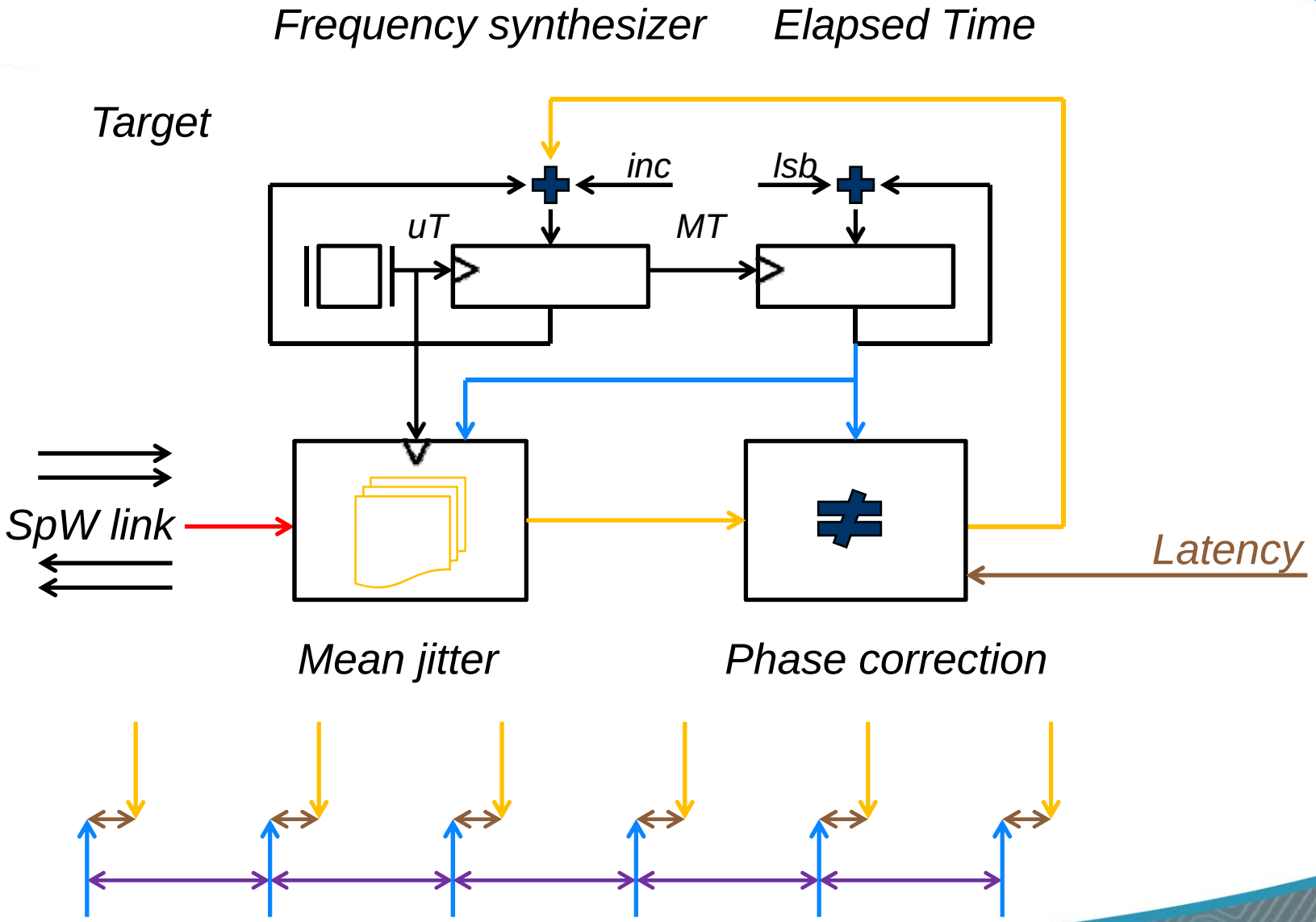


Measure mean jitter, correct phase & latency

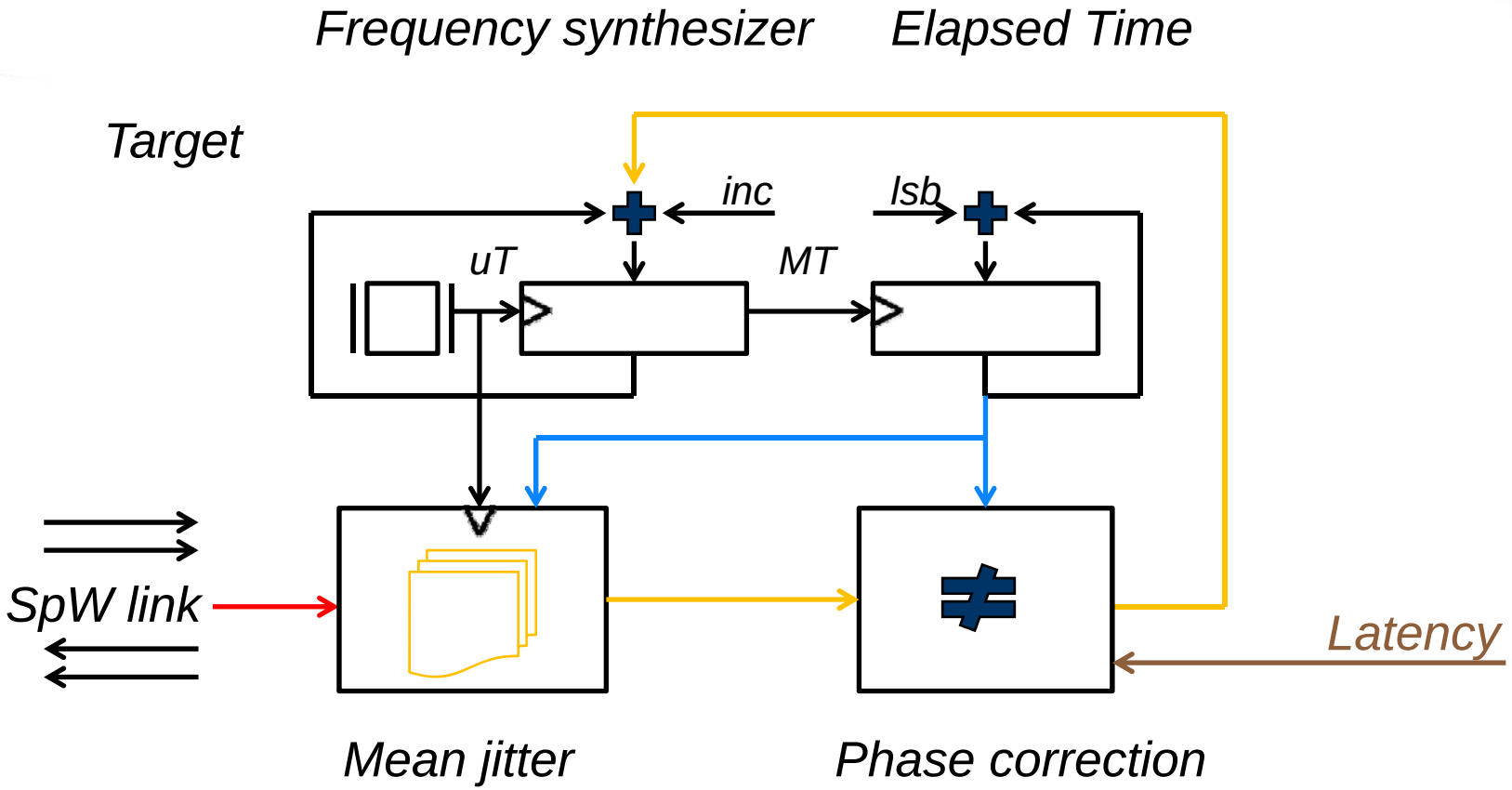




Measure mean jitter, correct phase & latency



Measure mean jitter, correct phase & latency



Contact information

- **IP cores information:**

  http://www.Aeroflex.com/Gaisler

- **Board information:**

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