21NRM02 Digital-IT - Metrology for digital substation instrumentation: Timing activities

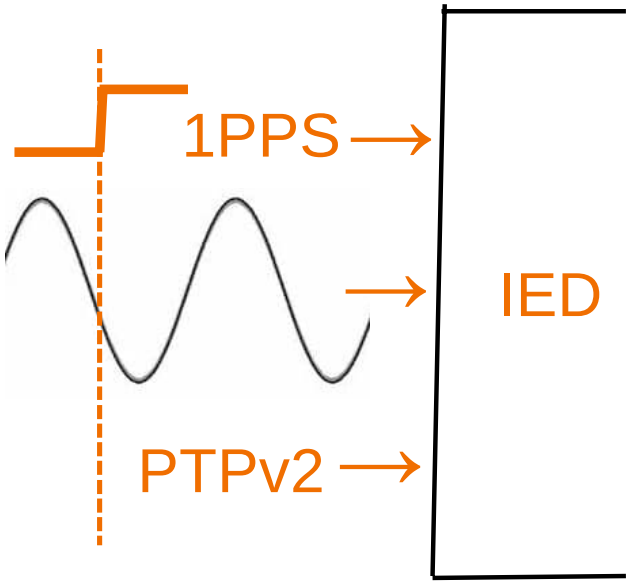
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TCEM SC P&E Meeting 2024, Delft

21NRM02 Digital-IT – Work packages

- WP1: Calibration setups for Sampled Values instrumentation
- WP2: Software for data analysis
- WP3: Networks and timing
  - Setting up communication networks for reliable SV and PTPv2 data
  - PTP: ”Golden calibrator pair” method (VSL, RISE)
  - PTP: Physical layer probing (VTT)
  - Synchronization on a live substation (JV, Statnett)

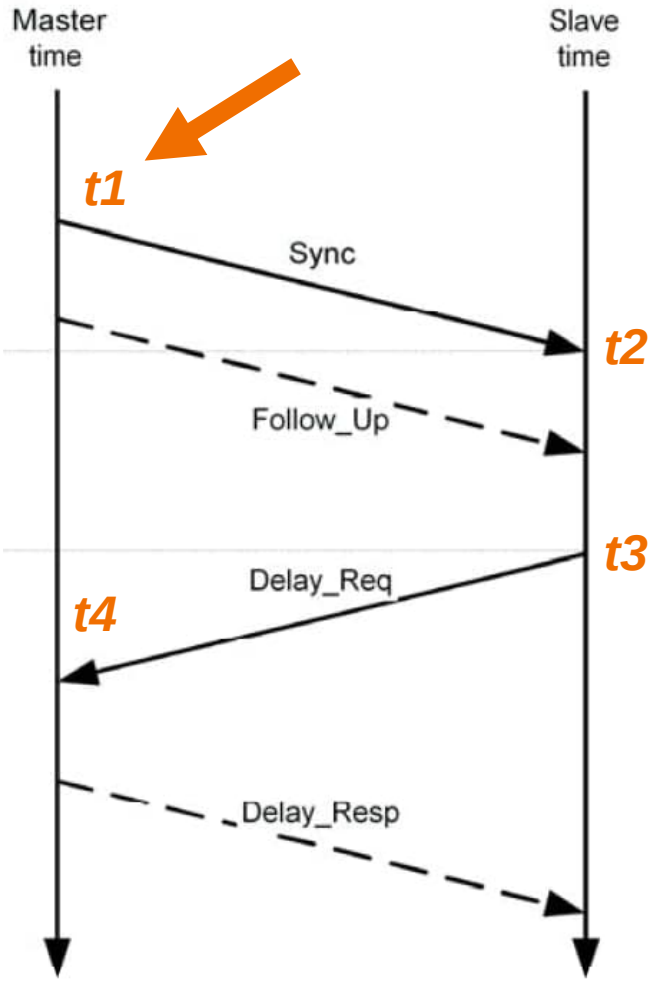
Using 1PPS and PTPv2 in IED calibration

- WAMS: signal phase related to common time source
  - Phasor measurement units: phase angle related to UTC
  - IEC 61850-9-2 Sampled Values: All samples time-tagged
- Time synchronicity using 1-pulse-per-second (1PPS)
  - 1PPS rising edge used as a reference point
  - Compensate various delays in the measurement chain
- IEEE 1588-2008 Precision time protocol (PTPv2)
  - Time sync over communications network (process bus)
  - Preferred synchronization source for measurement instruments in IEC 61869-9 (digital output)
  - IEC 61869-13 Class 0.05 SAMU: 2.5’ @ 50 Hz = 2.3 µs
  - How do we determine IED timing during calibration?



IEEE 1588 Precision Time Protocol

- **Two-step Sync** message from master (***t1***, ***t2***)
  - **Sync** packet is sent and master notes the time when it leaves its ethernet port
  - **Follow_Up** packet containing the time when Sync was sent follows right after Sync (*preciseOriginTimestamp*)
- Different delay mechanisms are implemented to account for network delays (**t3**, **t4**)
- **Sync** message is an ”event” message in the protocol = **time-critical**
  - Let’s take a closer look at how to calibrate ***t1***



IEEE-1588 event message timestamping

- Excerpt from IEEE 1588-2008:

7.3.4.1 Event message timestamp point

Unless otherwise specified in a transport-specific annex to this standard, the message timestamp point for an event message shall be the beginning of the first symbol after the Start of Frame (SOF) delimiter.

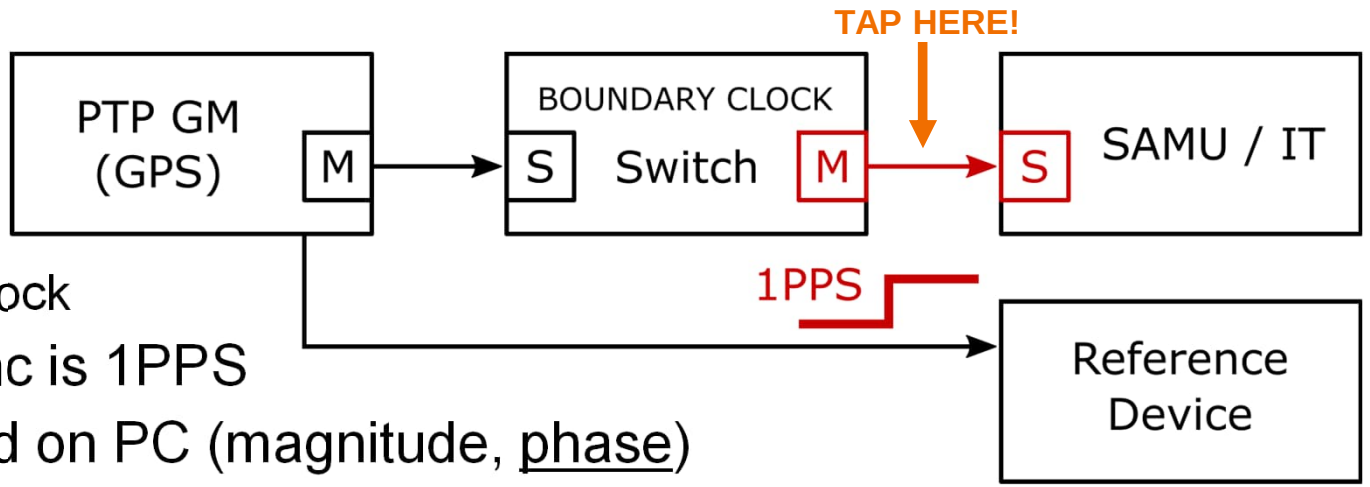
- Layer 1 ethernet frame (from Wikipedia):

802.3 Ethernet packet and frame structure

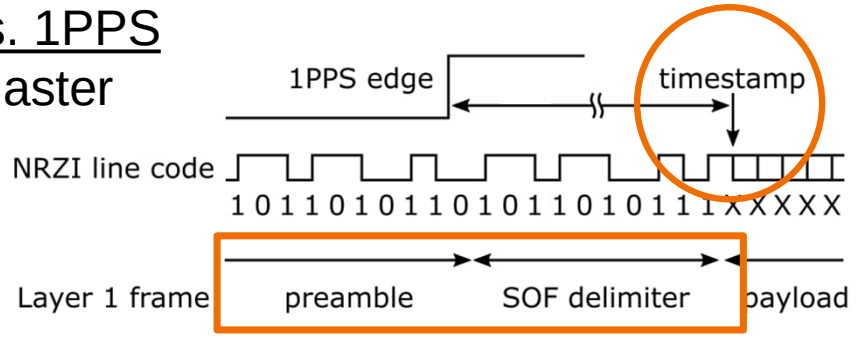
Layer	Preamble	Start frame delimiter	MAC destination	MAC source	802.1Q tag (optional)	Ethertype (Ethernet II) or length (IEEE 802.3)	Payload	Frame check sequence (32-bit CRC)	Interpacket gap
Layer 1	7 octets	1 octet	6 octets	6 octets	(4 octets)	2 octets	46-1500 octets	4 octets	12 octets
Layer 2 Ethernet frame			← 64–1522 octets →						

TIMESTAMP LOCATION

SAMU / IT calibration setup timing (PTPv2)



- Simple PTPv2 setup
  - Grandmaster (GM)
  - Switch as boundary clock
- Reference device sync is 1PPS
- SV streams compared on PC (magnitude, phase)
- We need to know two parameters:
  - Switch master port Sync message timing vs. 1PPS
  - SAMU / IT slave port timing vs. upstream master
- Search for PTPv2 frames on the wire
  - Traffic access point (TAP) required
  - Record also 1PPS rising edge time

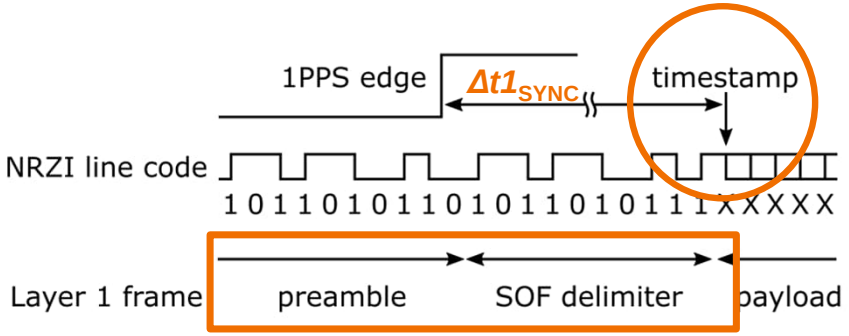


100Base-TX probing: Tools and definitions

- Capture at 625 MHz using oscilloscope
- Search for layer 1 frames (python)
- **Sync** message: Parameter $\Delta t1_{SYNC}$
- **Follow_Up** message: Parameter $t1_{FU}$
- Error $\varepsilon_{t1} = t1_{FU} - \Delta t1_{Sync}$

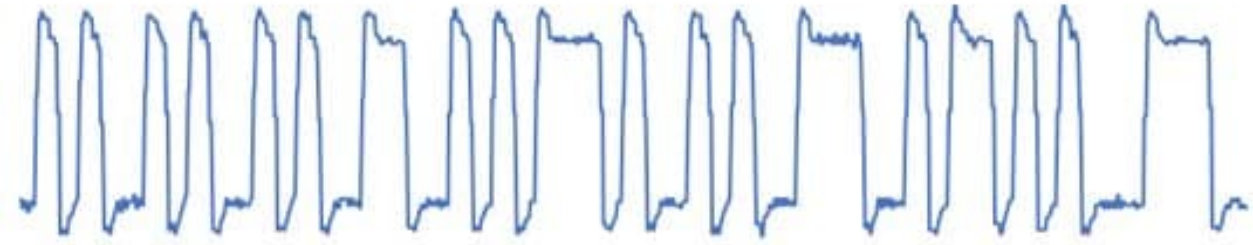




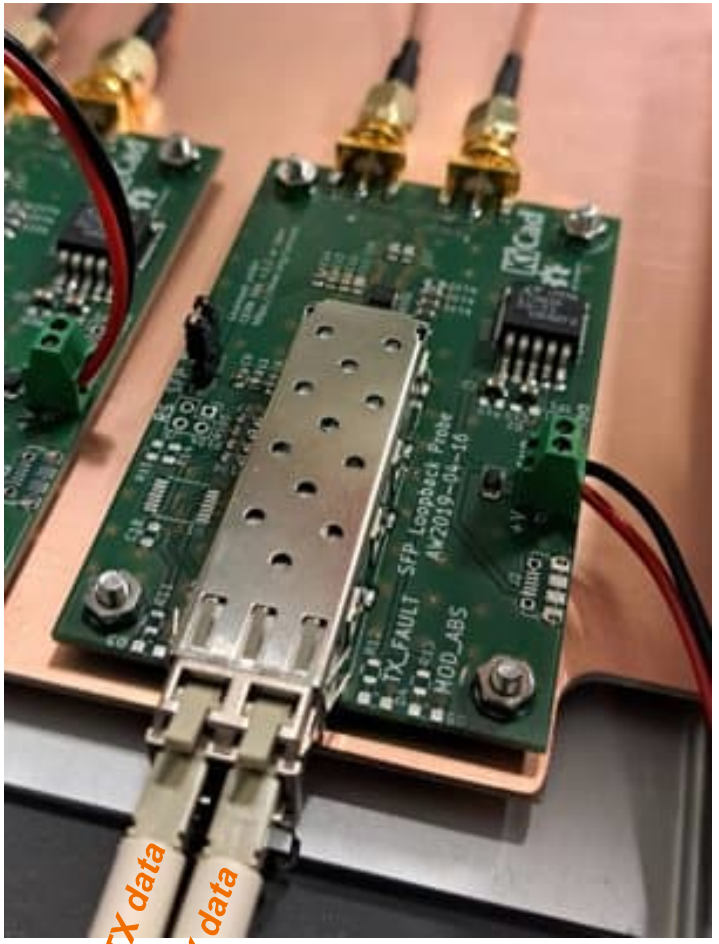


100Base-FX probing: Tools

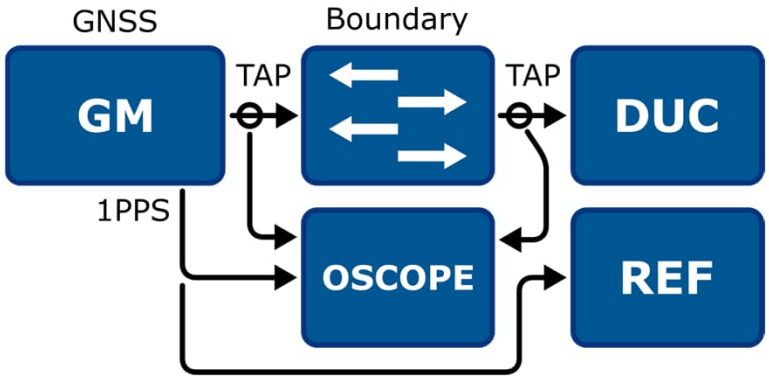
- Optical fiber links often used in a substation
- Optical to electrical signal TAP (17IND14 WRITE)
  - Extract Rx/Tx signals from a 100Base-FX link
  - Single SFP module Rx to Tx loopback
  - Signal is tapped at electrical loopback point
- Decoding significantly faster than 100Base-TX



ELECTRICAL



Measurement results: Boundary clock (FX)

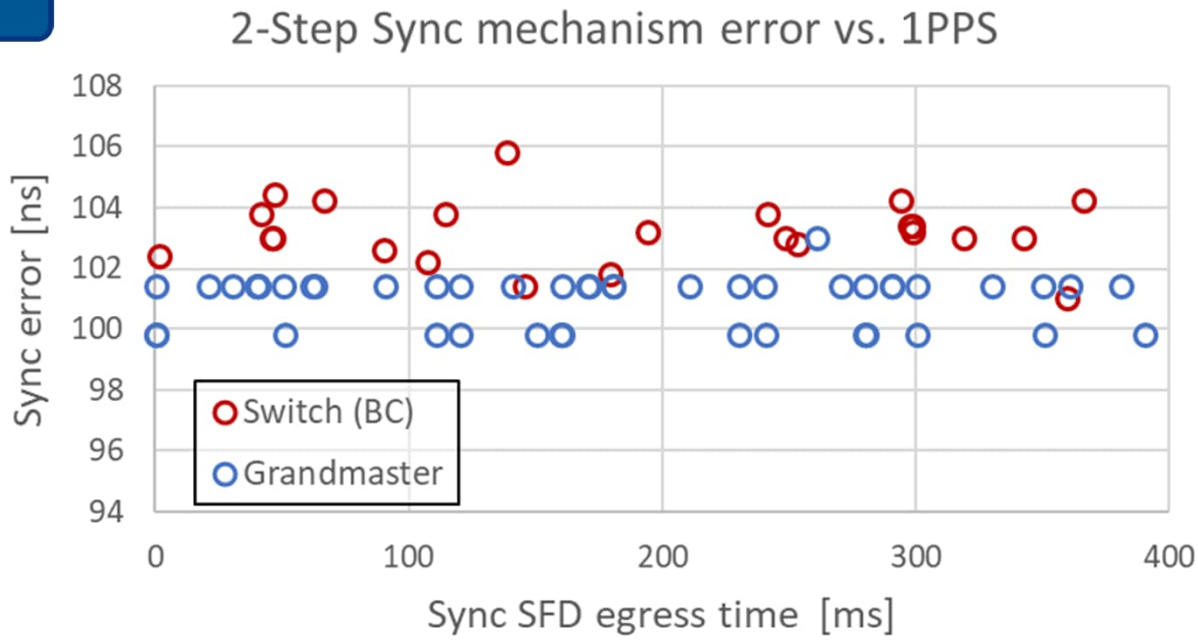




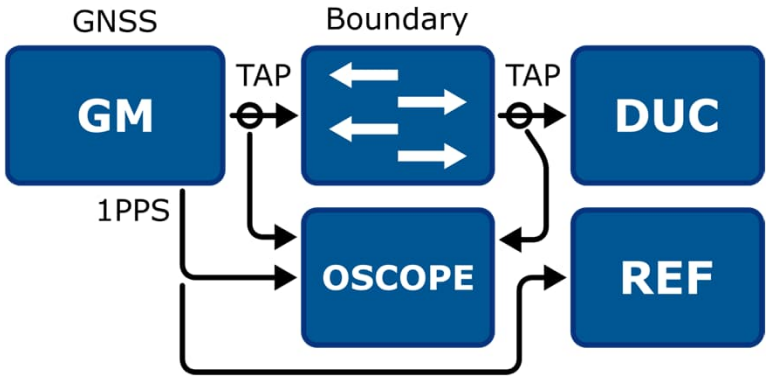
Optical TAP

Oscilloscope

- Grandmaster Sync msg
  - 2-step, 8 Syncs/sec
  - Difference (101 ± 4) ns
  - Quantized to 1.6 ns
- Boundary clock Sync
  - Difference (103 ± 6) ns
  - Limited by optical TAP



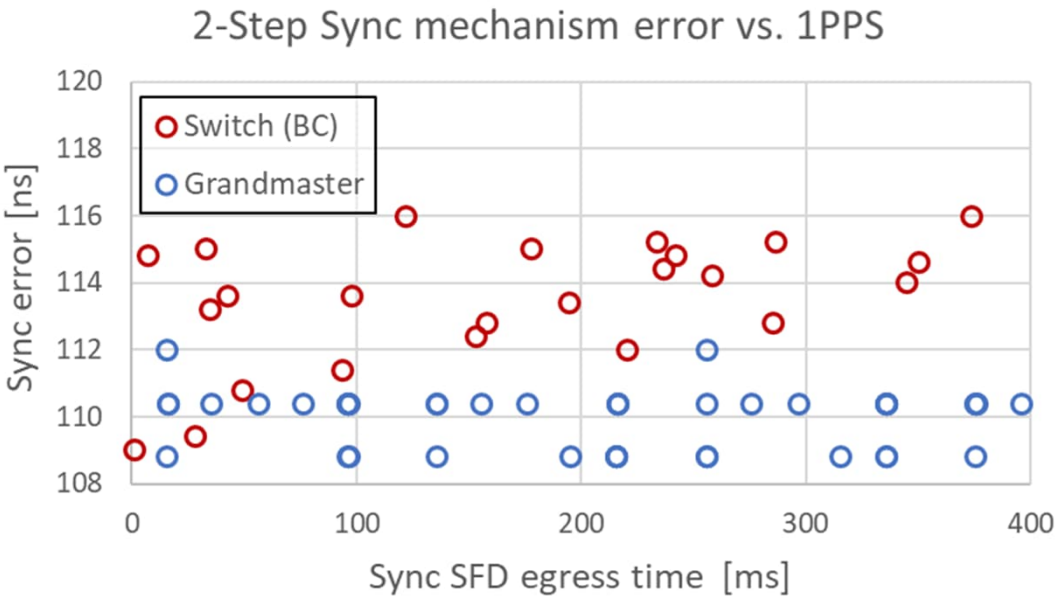
Measurement results: Boundary clock (TX)



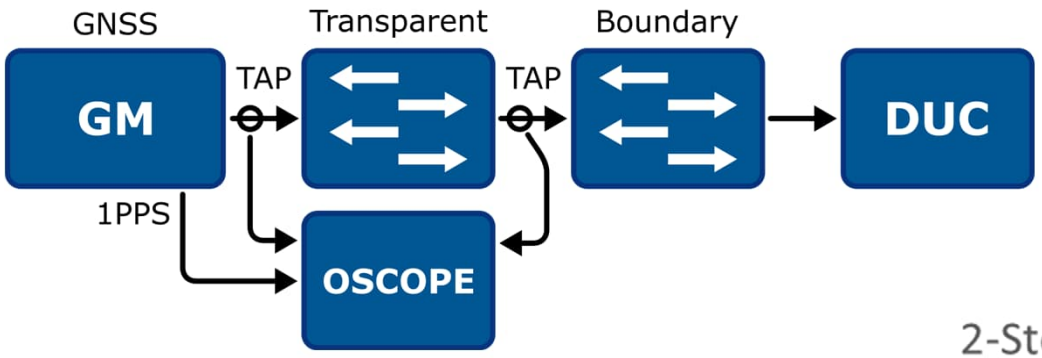


Electrical TAP

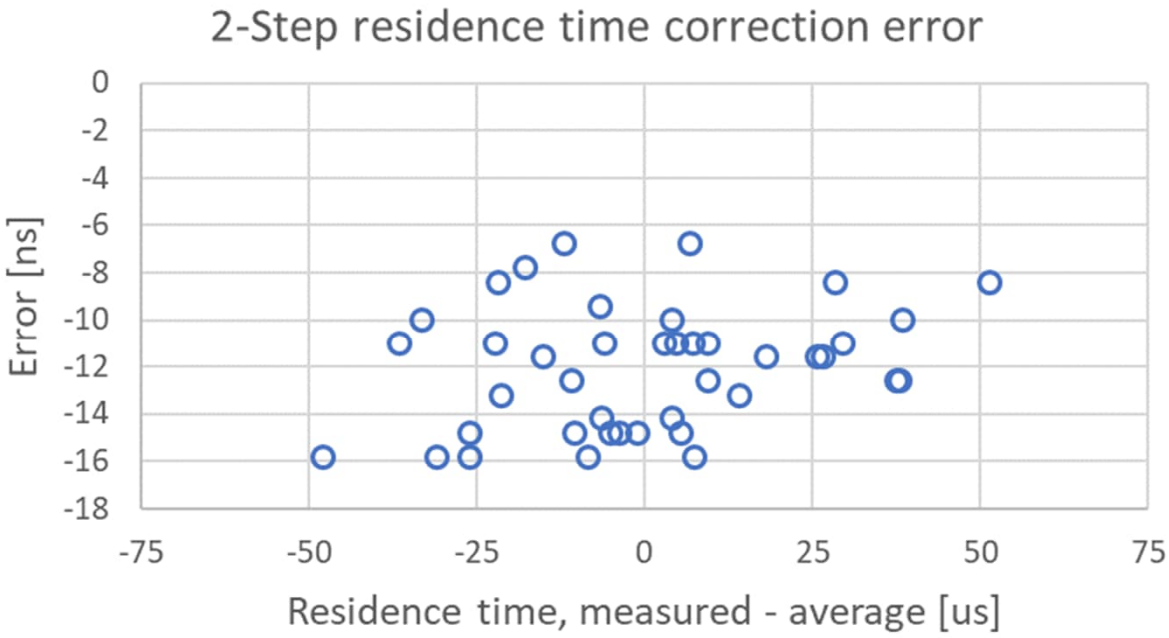
- Grandmaster Sync msg
  - Difference (110 ± 4) ns
  - Quantized to 1.6 ns
  - t_{SFD} - t_{1PPS}=2n*10ms + offset
- Boundary clock Sync msg
  - Error (114 ± 4) ns



Measurement results: Transparent clock



- Residence time correction
  - No other traffic in switch
- Measured residence time
  - Average 1 ms
  - ± 50 µs min-max deviation
- Error (-12 ± 4) ns
  - Data from Follow_Up msg



beyond

the obvious

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