Brief Overview of IEEE 1588 Test Results – Concept and Practical Examples and Lessons Learned

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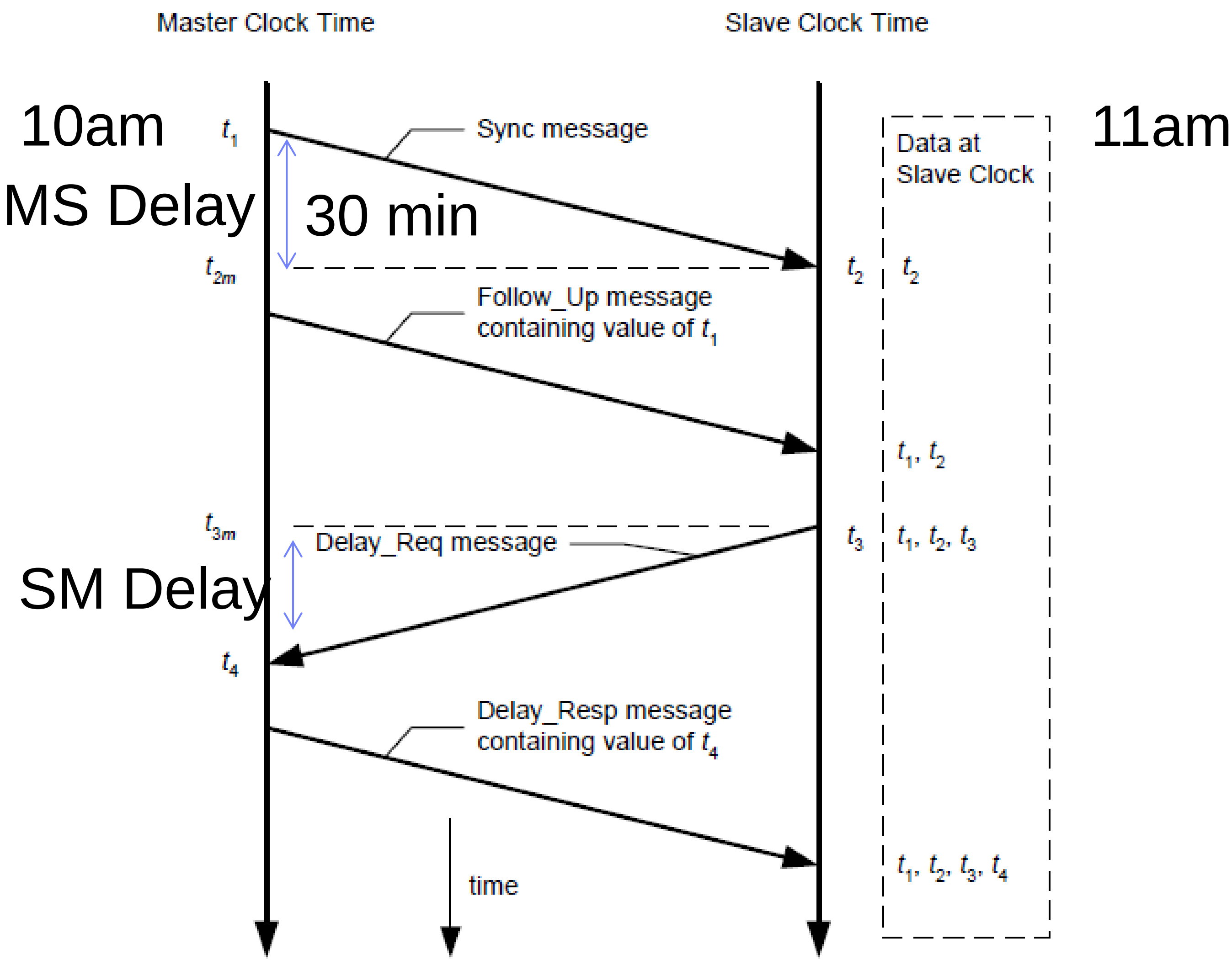
imagination at work

QUANTA TECHNOLOGY

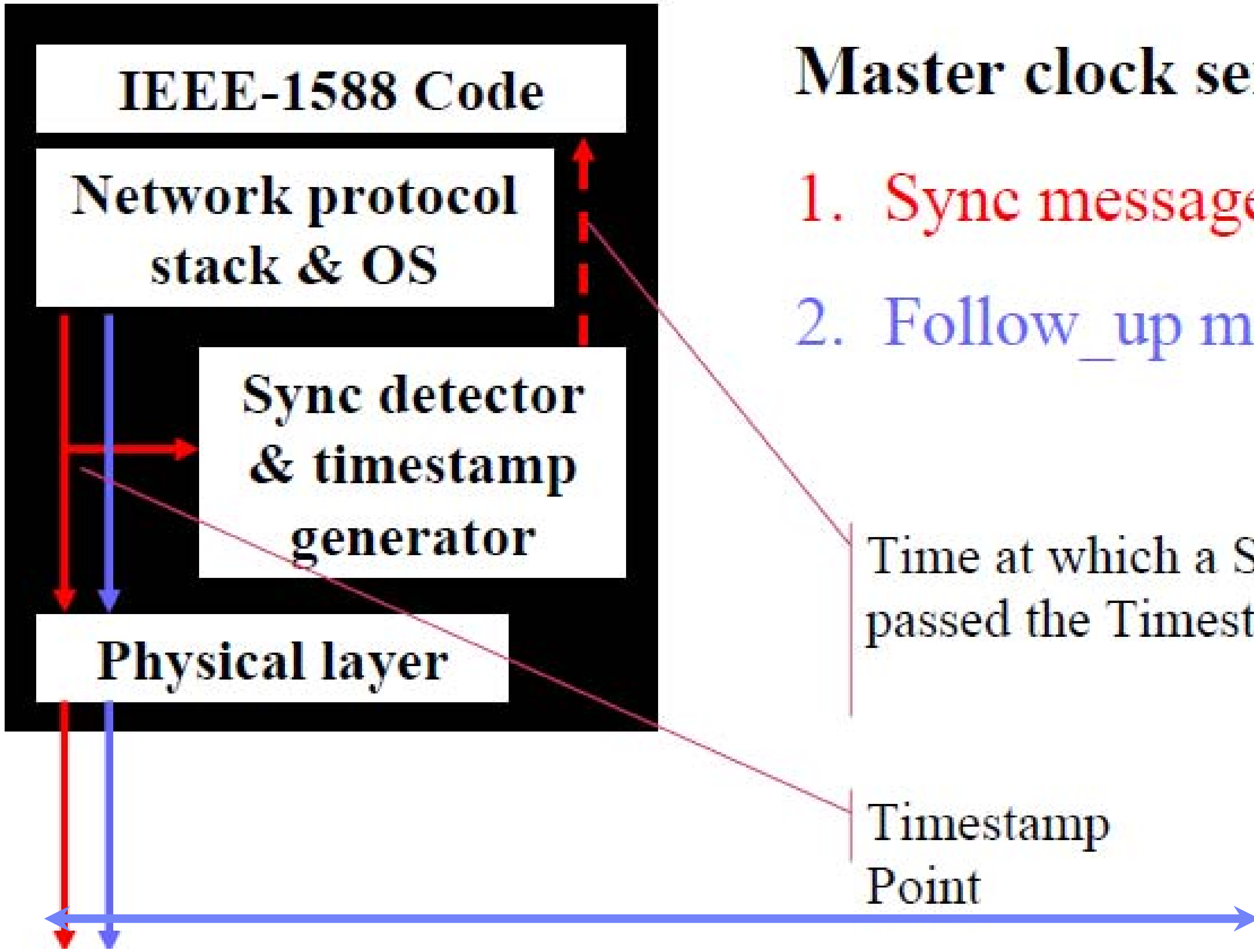
IEEE 1588 – Precision Time Protocol (PTP) over Ethernet

- Capable of sub-microsecond time sync
- Provides a messaging system to identify the various clock performances
- Operates through messages in the Ethernet data frame

1588 Basic Operation (1-step, 2-step)



Synchronization Details (clauses 6 & 7)



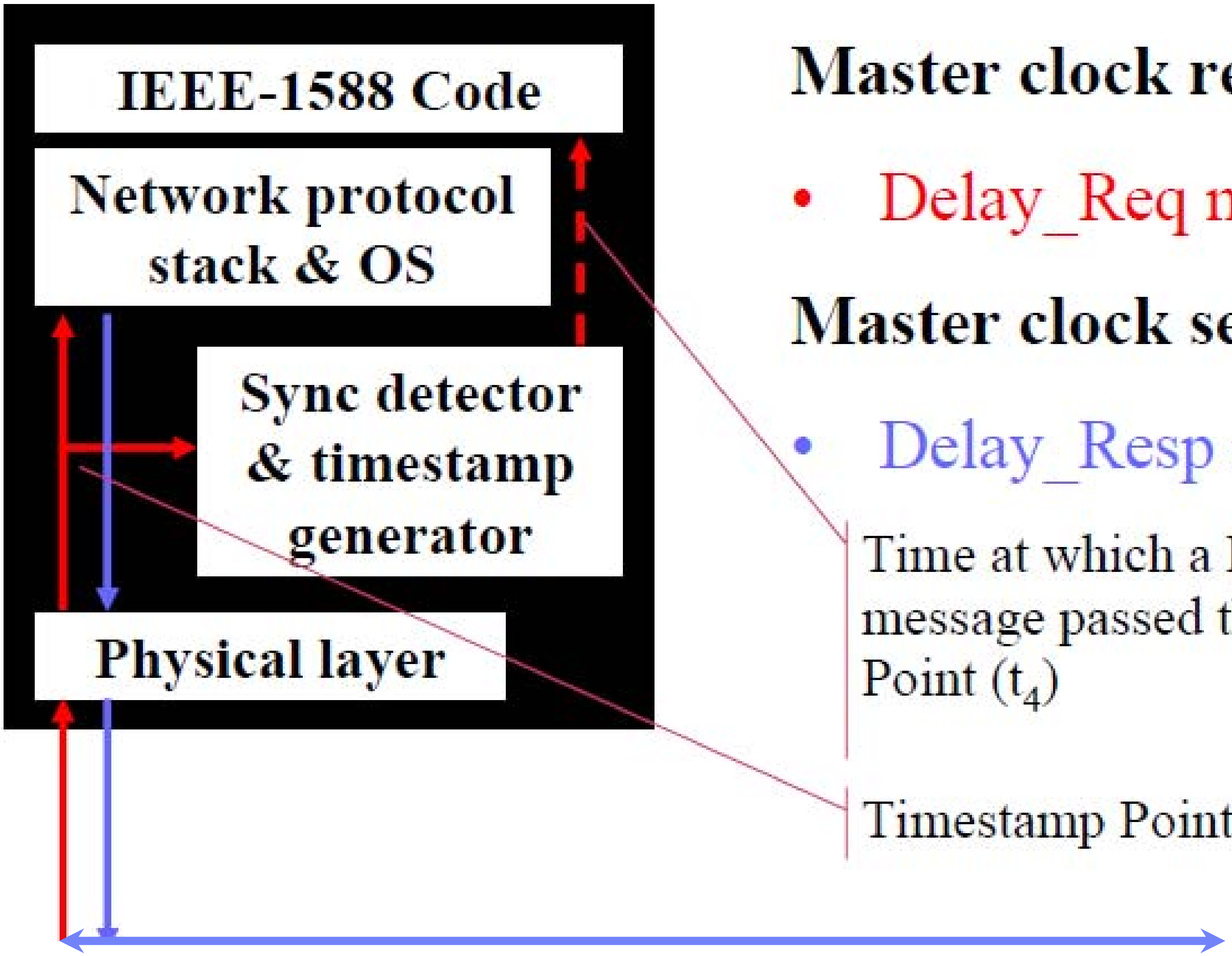
Master clock sends:

1. Sync message
2. Follow_up message

Time at which a Sync message passed the Timestamp Point (t_1)

Timestamp Point

Synchronization Details (continued)



Master clock receives:

- Delay_Req message

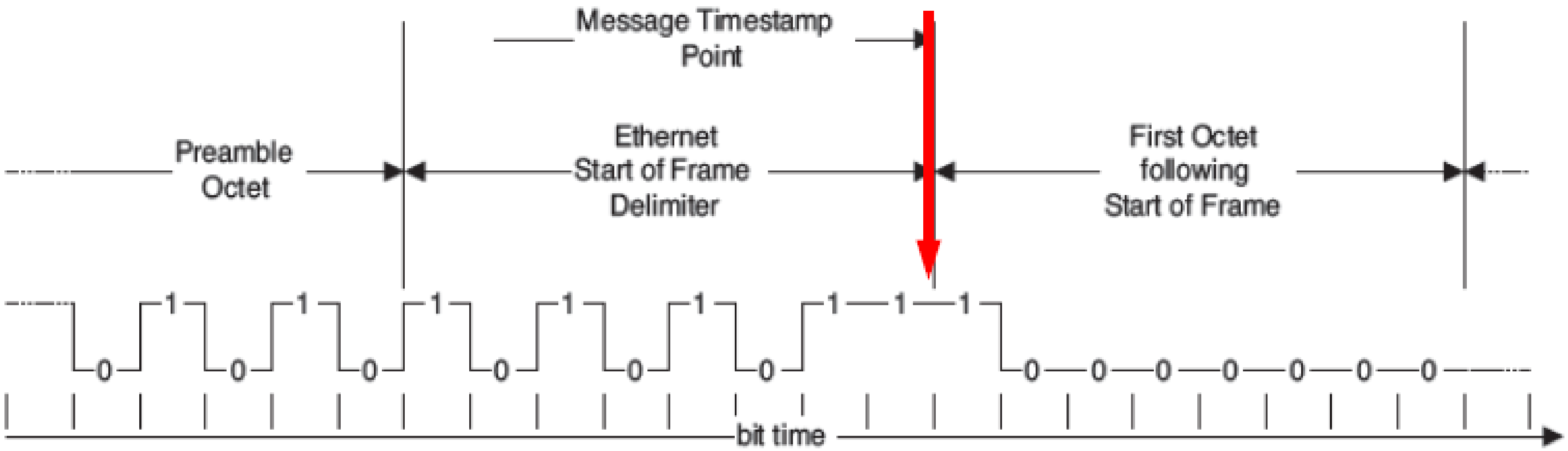
Master clock sends:

- Delay_Resp message

Time at which a Delay_Req message passed the Timestamp Point (t_4)

Timestamp Point

Ethernet Message Time Stamping



Hardware-based Time Stamp is applied based on the Rising Edge of the First Bit after the Start of Frame Delimiter

Time Sync Calculations

MS_difference = offset + MS_delay = t2-t1
= 11:30 – 10:00 = 90 min

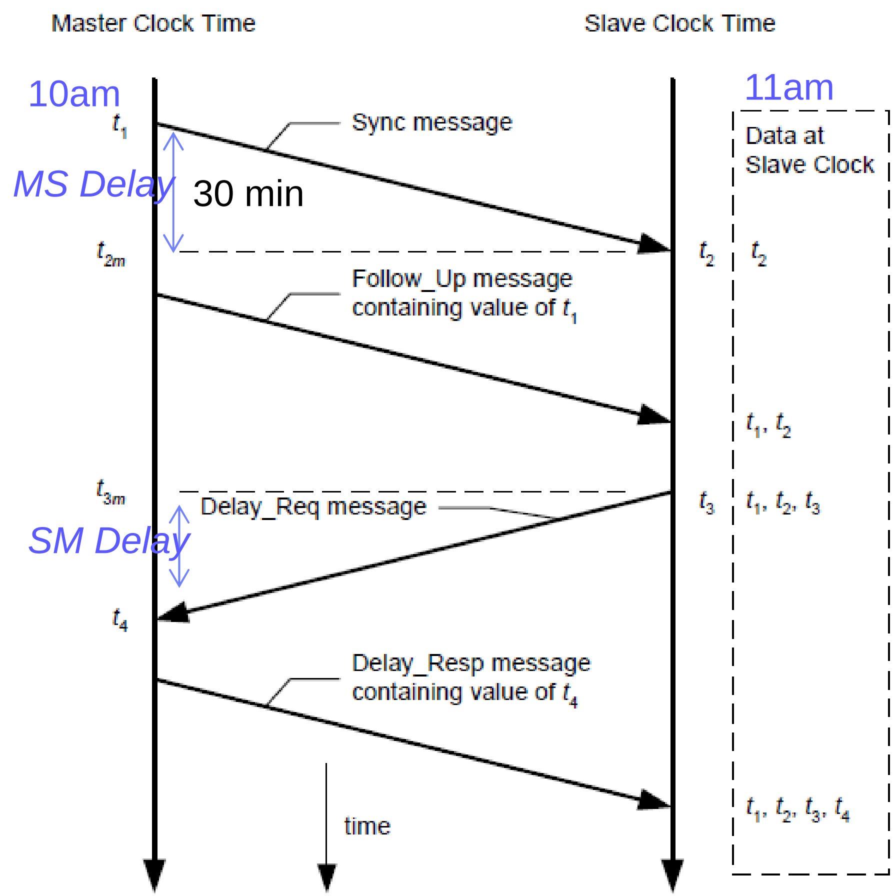
SM_difference = -offset + SM_delay = t4-t3
= 11:30 – 10:30 = -30 min

Assuming that MS_delay=SM_delay then:

Offset and Delay Calculations

Offset = (MS_difference – SM_difference)/2
= (90 – (-30)) / 2 = 60 Min

One_Way_Delay = (MS_Difference + SM_difference)/2
= (90 + (-30)) / 2 = 30 min



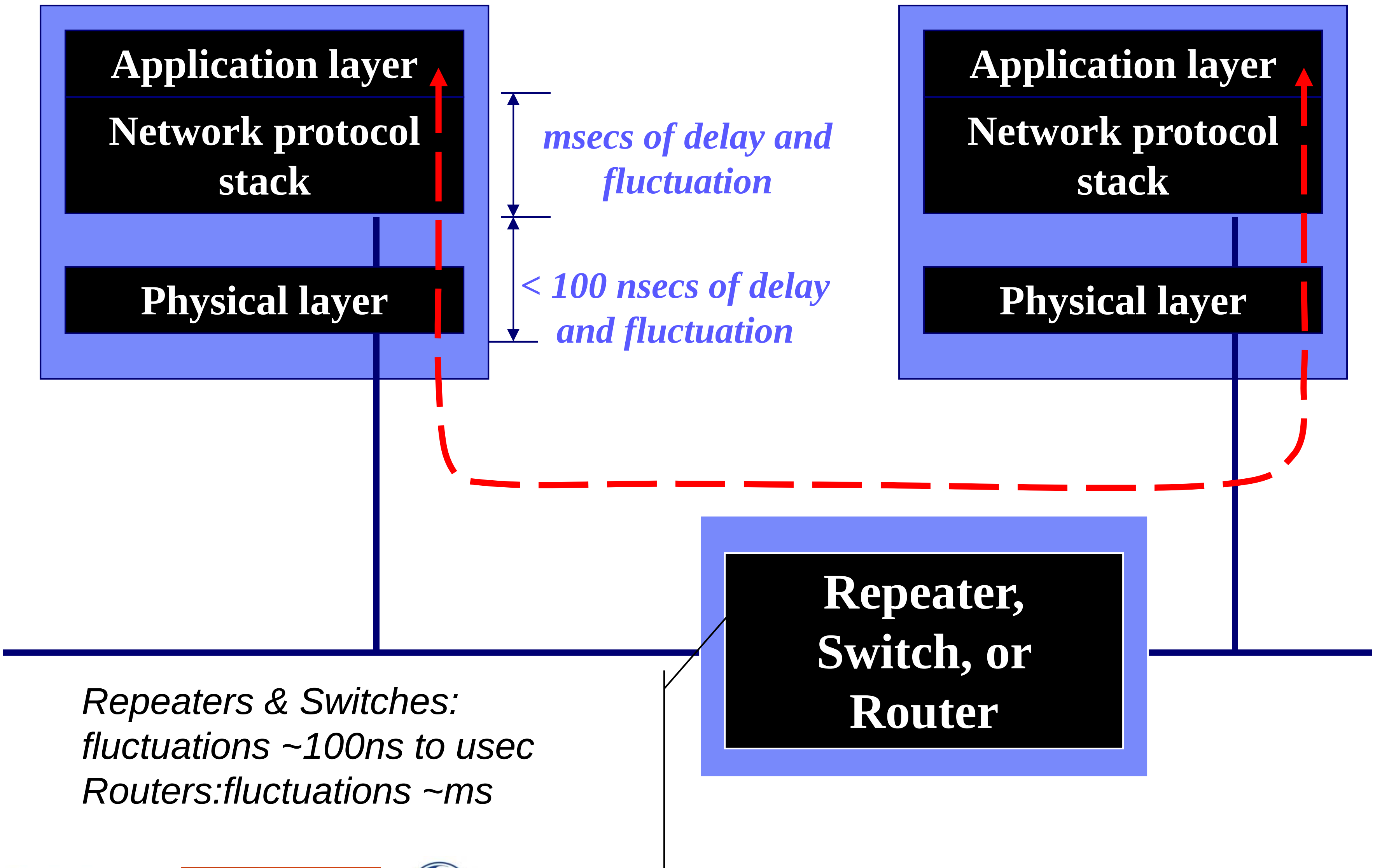
Announce Message:

- Clock ID
- Grand Master Clock Accuracy
- Grand Master Variance
- Origin Time Stamp (Sec and nsec)
- UTC Offset
- Grand Master Time Source (e.g. – GPS)

Included in the Sync Message:

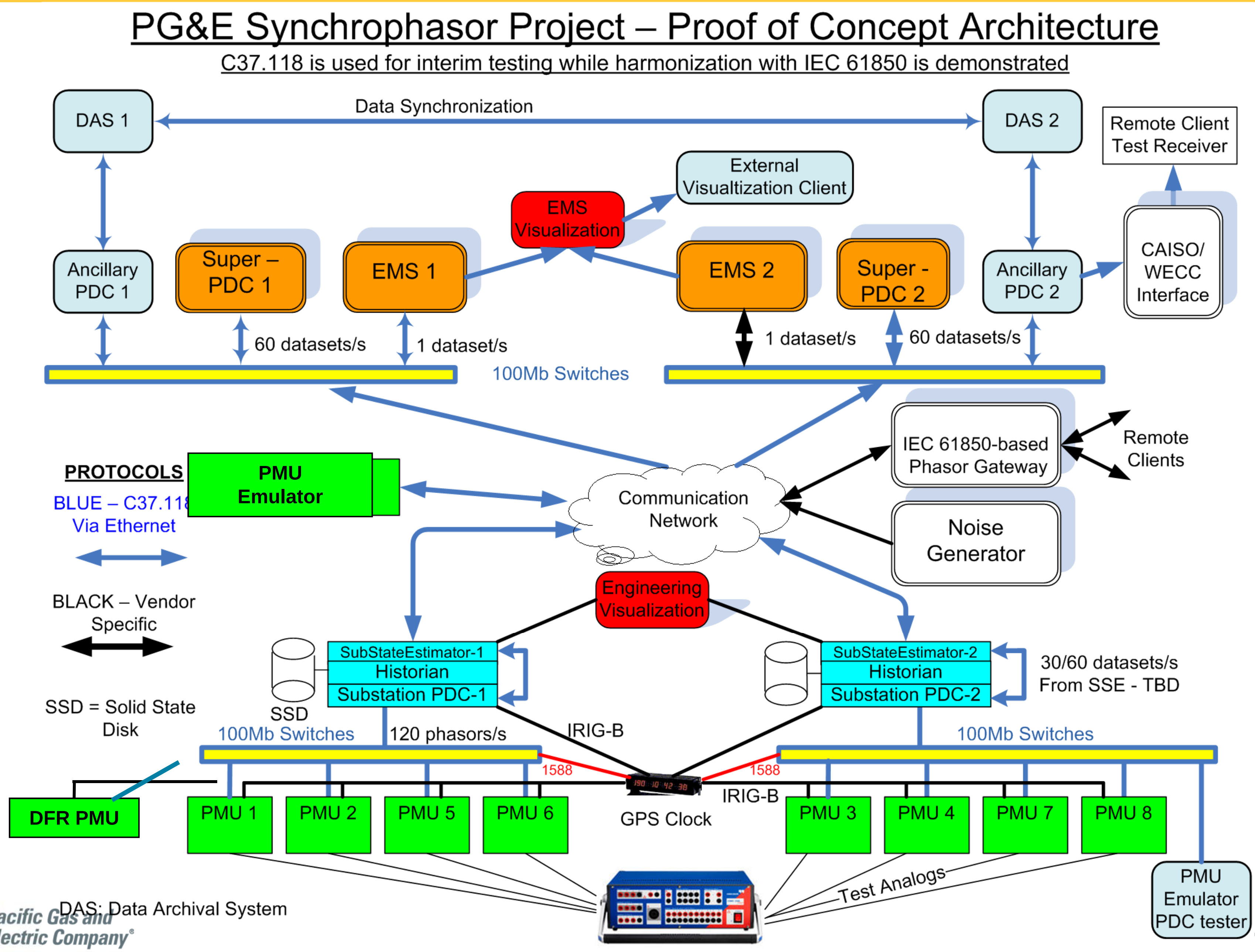
- Message ID (e.g. – Sync, Follow-up, delay request
- PTP Version Number
- Message Length (2 bytes)
- Subdomain Number (1 byte)
- PTP Flags (16)
- Correction (nsec)
- Clock Identity (8 bytes)
- Source Port (2 bytes)
- Origin Time Stamp (Seconds & Nanoseconds)

Timing Latency & Fluctuation



Repeaters & Switches:
fluctuations ~100ns to usec
Routers:fluctuations ~ms

Proof of Concept Testing - Architecture



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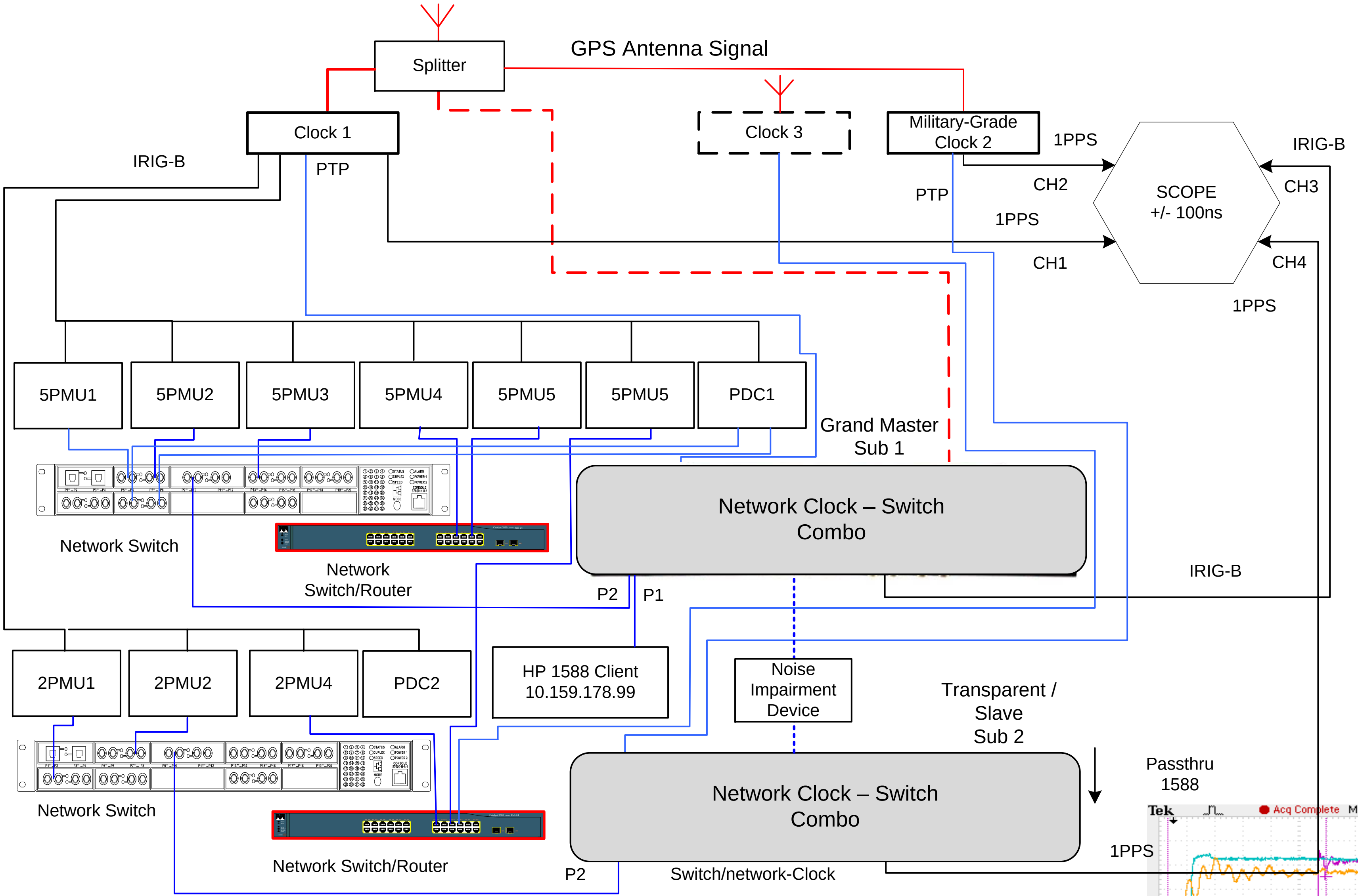
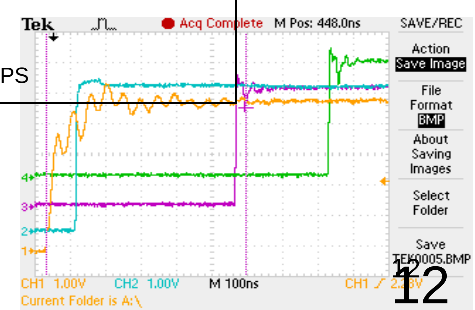
Observations – Timing functions (GPS, IRIG-B, and IEEE 1588)





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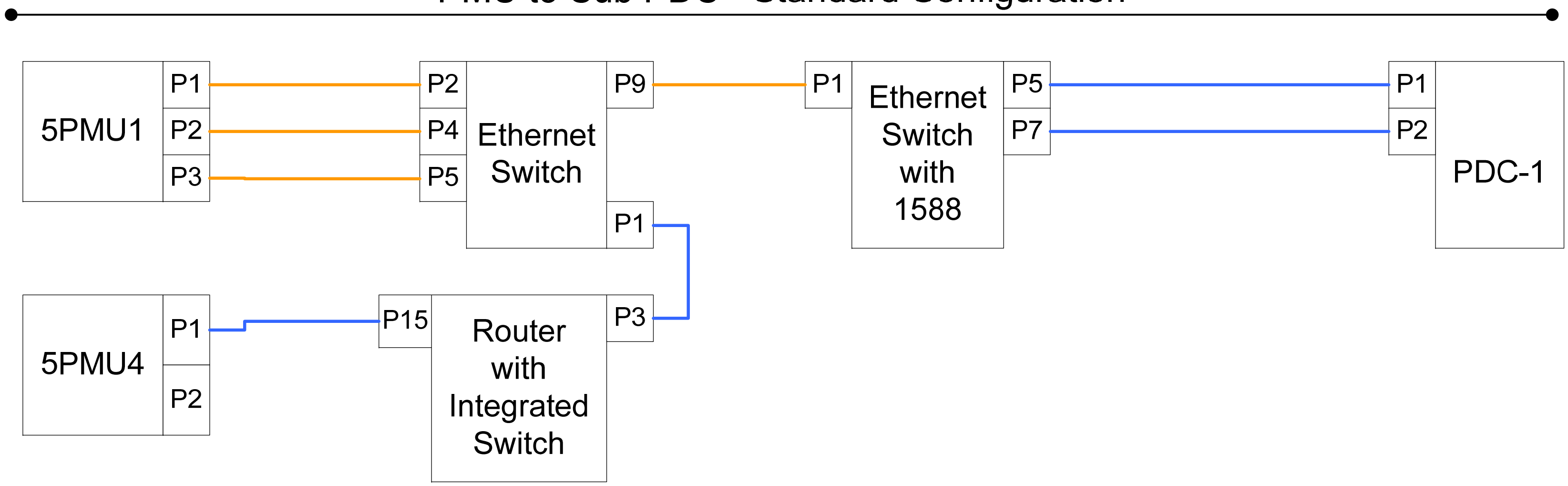
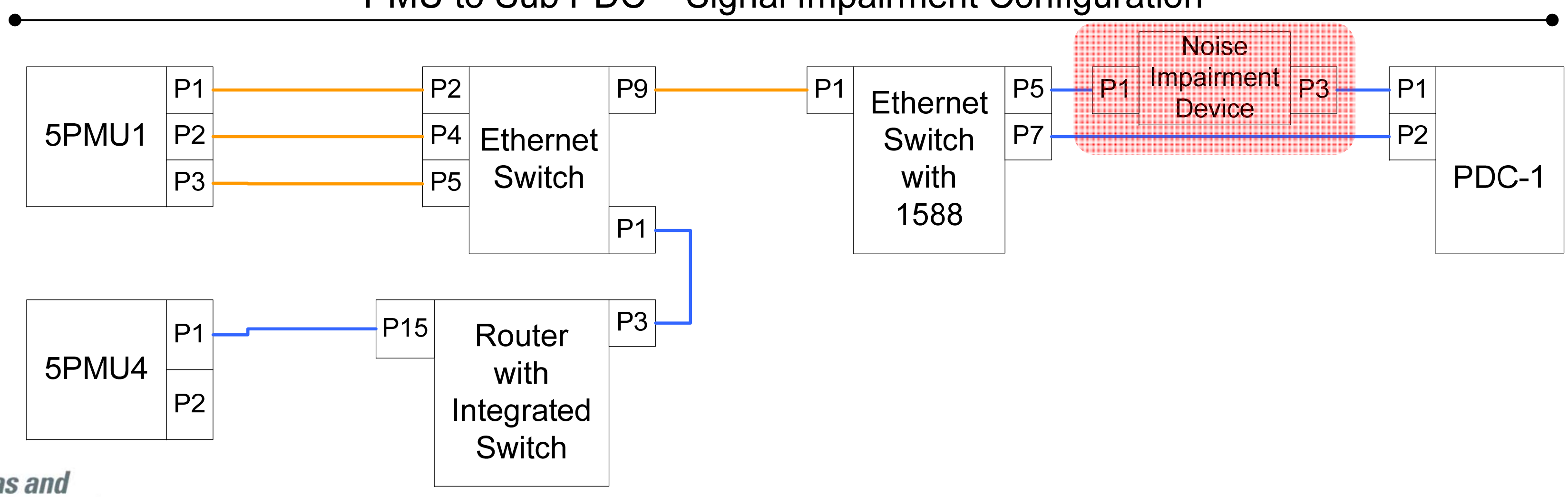
Noise Impairment Tests

- Noise Injection / IP Packet interference

PMU to Sub PDC - Standard Configuration



PMU to Sub PDC – Signal Impairment Configuration



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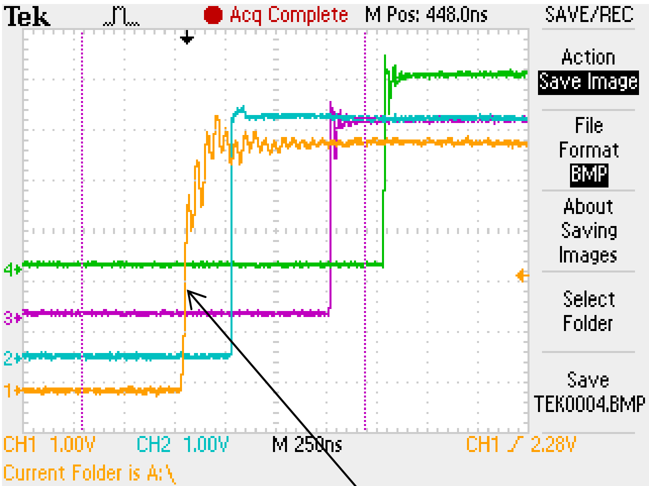
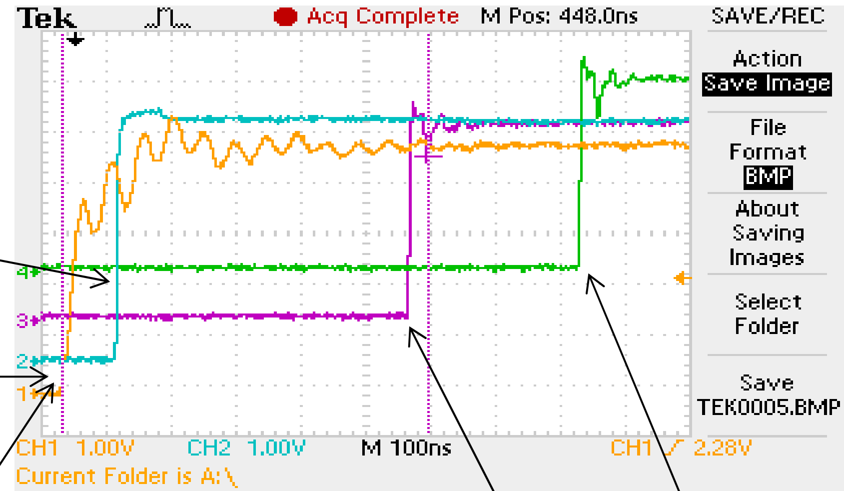
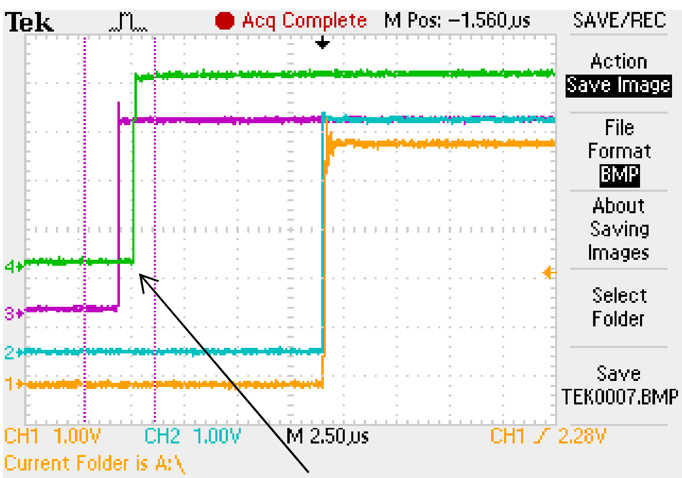


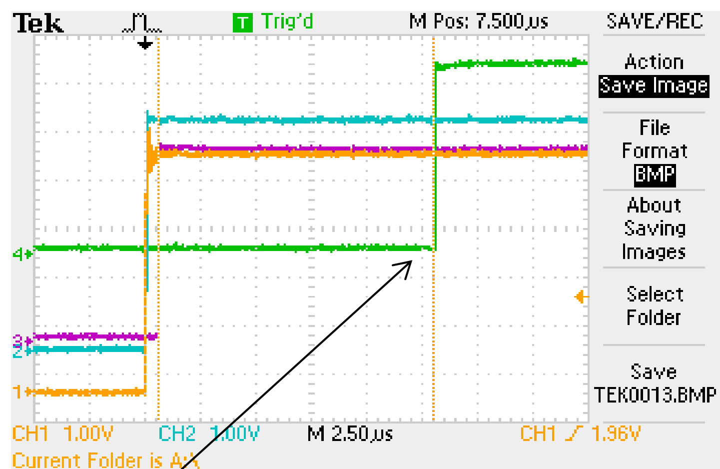
Before calibration (-0.25 µs)



After calibration (0.1µs) Compensating for GPS Antenna cable length



~15 minutes after GPS Antenna removal from Grandmaster(10 µs)



10 µs delay injected in 1588 path between grandmaster and transparent clock

Observations – Timing functions (GPS, IRIG-B, and IEEE 1588)

- Several GPS-synchronized clocks providing timing accuracy better than 1 us (mostly on the order of 0.1 us)
- Some clocks did not update time-quality bits in IRIG-B timing data after loss of GPS input. Similarly, for IEEE 1588 PTP.
- In the absence of GPS input, clock drifts on the order of 10^{-7} to 10^{-9} were observed from different clocks.
  - Typical commercial products
    - 10^{-9} is a drift of 4 us in about an hour
    - 10^{-7} is a drift of 26 us in about 4 minutes (Bad Time)
      - Synchrophasor permissible TVE of 1% ~ 26.5 us
- Other 1588 PTP (precision time protocol) test results
  - Typical accuracy of 0.1 to 0.5 us has been observed.
  - Any delay in network communication can translate to delay in Transparent Clock when not compensated.
  - Some Slave clocks assume transmission delay is the same in both directions (usually OK, but not always)

Tests – Summary of the Findings

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IEC61850 Levels of Time Synchronization

LN – STIM identified to set time and provide time synchronization in a substation

Class	Accuracy	Function/phase error
T1	± 1 ms	Event timing
T2	± 0.1 ms	Zero Crossing / Sync Check
T3	± 25 μs	32’ at 60Hz / 27’ at 50 Hz
T4	± 4 μs	5’ at 60Hz / 4’ at 50 Hz
T5	± 1 μs	1’ - Synchrophasors
T6	± 0.1 μs	Available, but not defined yet

C37.118 4 Bit Time Quality Indicator Code

BINARY	HEX	VALUE (worst case accuracy)
1111	F	Fault--Clock failure, time not reliable
1011	B	10 seconds
1010	A	1 second
1001	9	100 milliseconds (time within 0.1 sec)
1000	8	10 milliseconds (time within 0.01 sec)
0111	7	1 millisecond (time within 0.001 sec)
0110	6	100 microseconds (time within 10^{-4}sec)
0101	5	10 microseconds (time within 10^{-5}sec)
0100	4	1 microsecond (time within 10-^{6} sec)
0011	3	100 nanoseconds (time within 10-^{7} sec)
0010	2	10 nanoseconds (time within 10-^{8} sec)
0001	1	1 nanosecond (time within 10-^{9} sec)
0000	0	Normal operation, clock locked