Comparative Evaluation of IEEE-1588 Precision Time Protocol for the Synchronized Operation of Tokamak Device

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Background

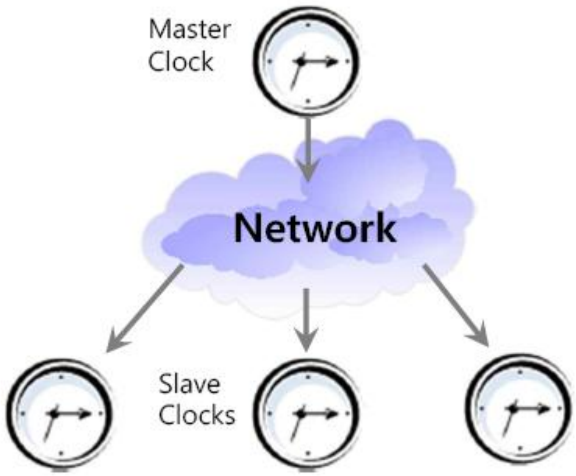
- This work was initiated for the validation of Time Communication Network using IEEE1588-2008 of ITER. So, some documents of ITER were referenced and the drivers for IEEE1588 boards were used for the test.
- However, it is at an early stage and much progress has not achieved, yet.

- Outlines –
  - Introduction of IEEE1588 Precision Time Protocol
  - Application in fusion devices
  - Comparison with other protocols
  - Conclusions

What is Precision Time Protocol ?

IEEE1588 Standard

- IEEE1588 : Precision Time Protocol (PTP)
- It is a standard for a Precision Clock Synchronization Protocol for networked measurements and control systems using Ethernet communication network
- Two versions released :
  - version 1 : IEEE1588-2002
  - version 1 : IEEE1588-2008
- It is possible to synchronize distributed clocks with an accuracy of less than 1 μsec
- It uses UDP packet communication based on TCP/IP protocol stack
- It works inside LAN (PTP Domain)



What is Precision Time Protocol ?

IEEE1588 Standard - Features

- Master-Slave Hierarchy
- Best Master Clock Selection Algorithm
- Fault tolerance
- Hardware time-stamping
- Low cost to implement
- Limitation in v.1 vs. Improvement in v.2 :

  - Slow Sync message rate : 2sec

    ⇨ Higher Sync message rate : less than 100ms

  -Traffic congestion : non-optimized message size

    ⇨ 'Shorter Sync Message'

  - Non-linear effect on jitter : cascaded boundary clock

    ⇨ introducing 'Transparency Clock'

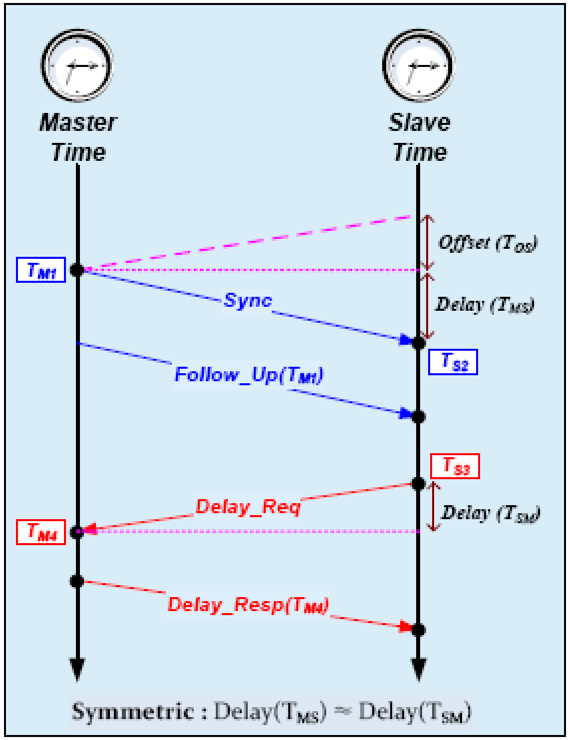
  - No correction for asymmetry error : network asymmetry

    ⇨ Introducing 'Correction Mechanism'

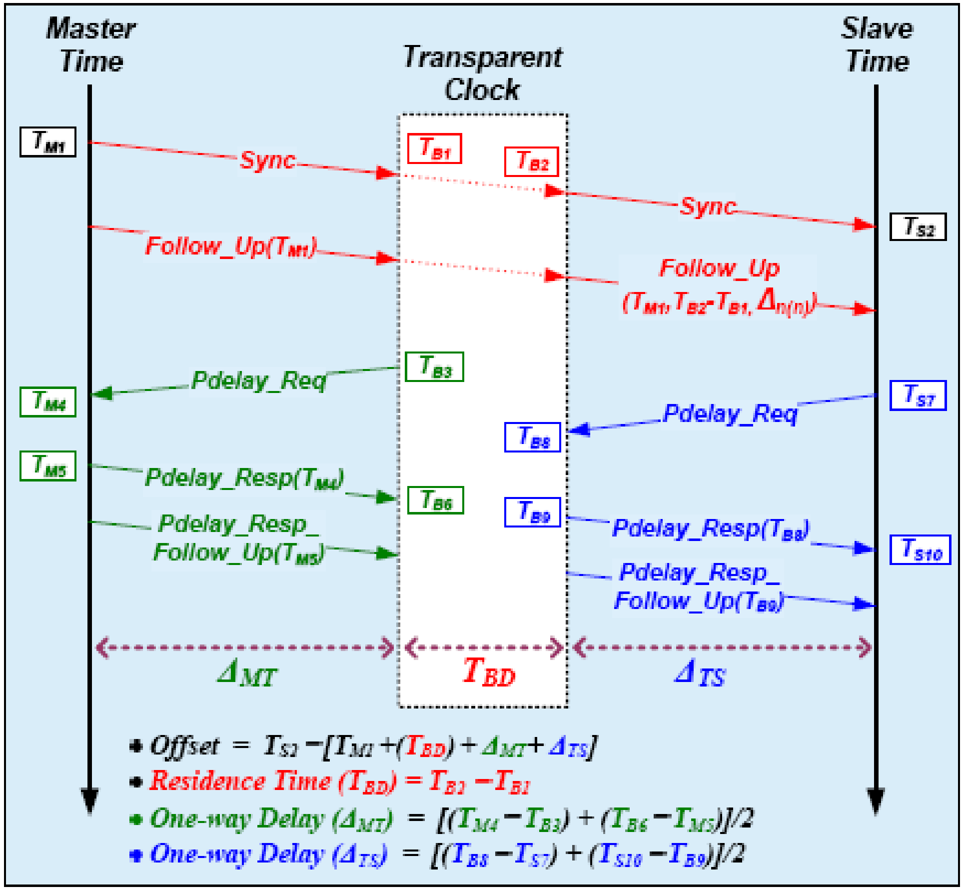
What is Precision Time Protocol ?

Basic Synchronization – Message-based Two Way Transfer

- **Version 1**



- **Version 2**



- **Step 1 : Propagation delay measurement**

  $T_{LD} = ((T_{S2} - T_{M1}) - (T_{M4} - T_{S3}))/2$,

  if $T_{LD} = T_{MS} = T_{SM}$, symmetric link)

- **Step 2 : Offset measurement**

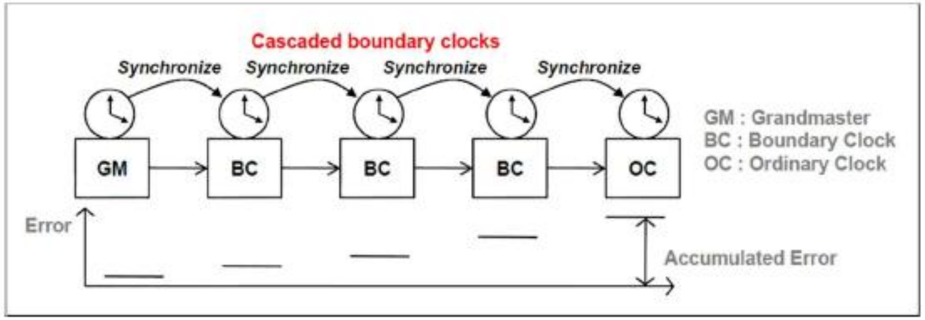
  $T_{OS} = T_{S2} - T_{M1} - T_{LD}$

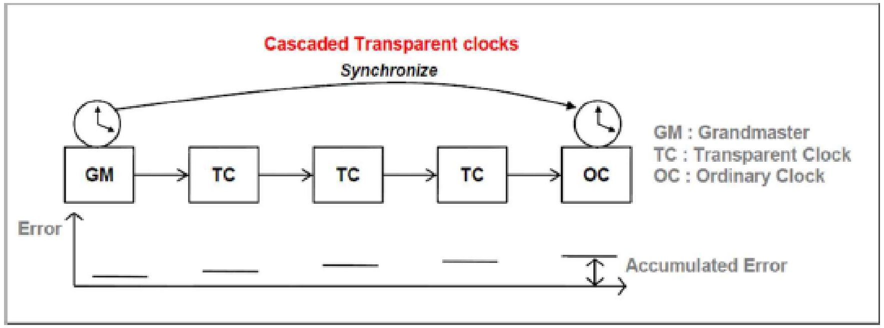
What is Precision Time Protocol ?

Best Master Clock Selection Algorithm

- State Decision Algorithm : to produce a recommended state by comparing all relevant data sets
- Data Set Comparison Algorithm : to select clock from better

Transparent Clock





- Correction Field in TC
  - Original Timestamp : 48bits in sec + 32bits in ns
  - Correction Field : 48bits in ns + 16bits in scaled fractional ns
    - . Sub-ns accuracy
    - . Transparent correction + asymmetry correction

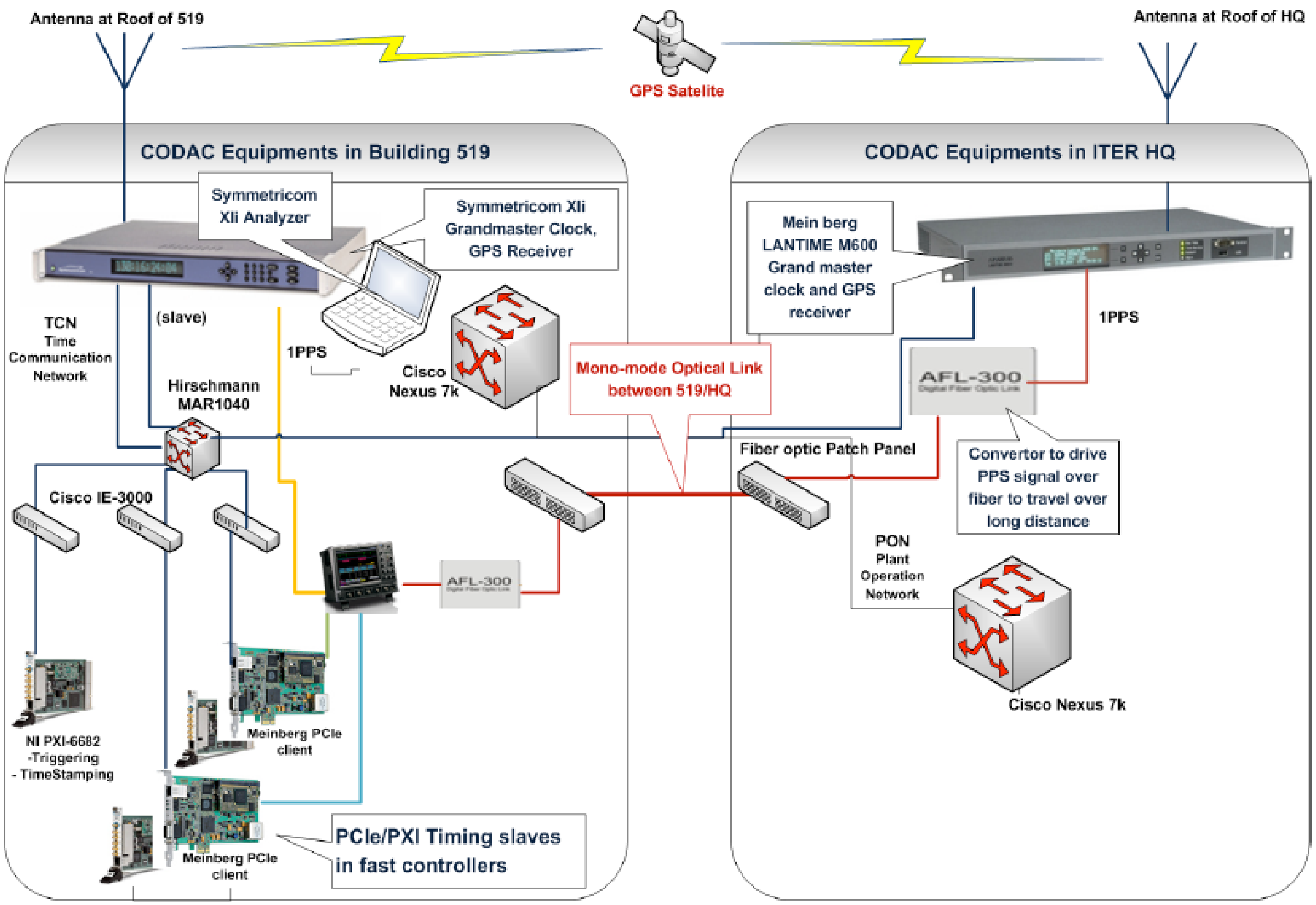
Application for Tokamak Operation

Use case in ITER

- ITER is the biggest project in the world to construct a superconducting experimental reactor in cooperation with 7 states
- ITER control system, CODAC, aims at standardization by using the latest, but performance-proven technologies
- They decided IEEE 1588-2008 as a standard for TCN to synchronize time
- Also, they performed evaluation test using several COTS products
- And, they got results as follows :
  - Confirm basic functions
  - Time jitter less than 50ns,rms
- Acronyms :
  - ITER : International Thermonuclear Experimental Reactor
  - CODAC : Control, Data Access, and Communication
  - TCN : Time Communication Network

Application for Tokamak Operation

● Use case in ITER



TCN Test Bed Setup for ITER

Application for Tokamak Operation

● Use case in ITER _ Test Results

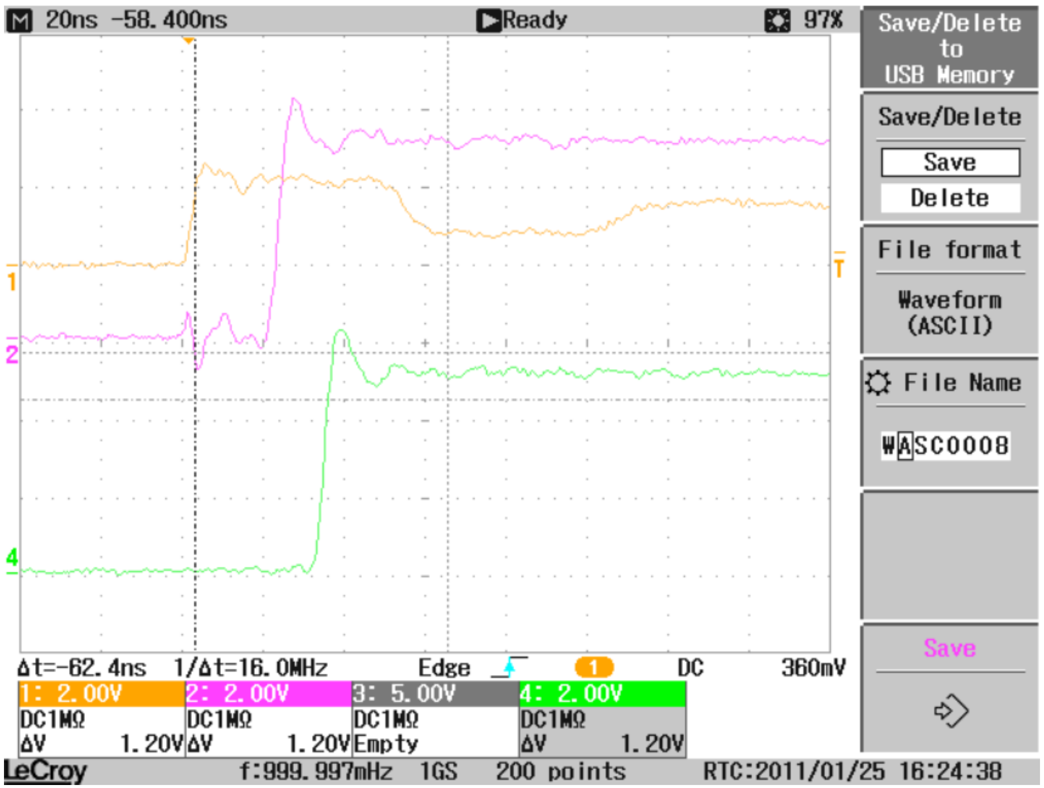
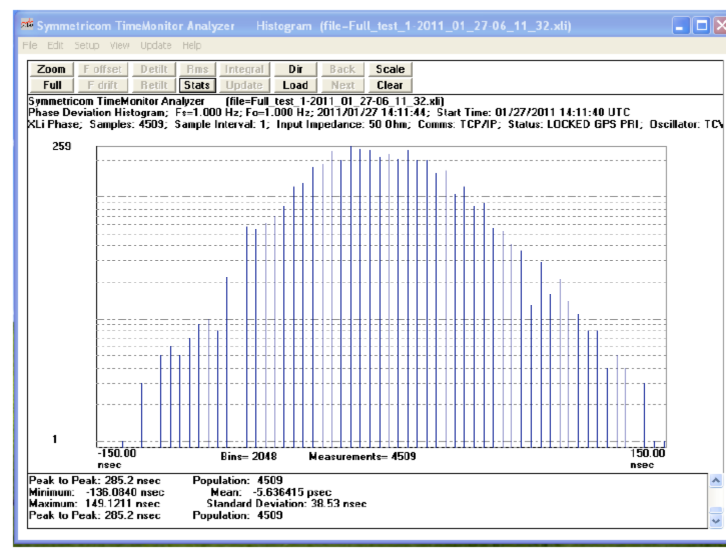


Figure 3. Oscilloscope output of the IEEE 1588-2008 compatibility testing where Channel 1 (yellow) represents the 1PPS signal output from the Grandmaster, Channel 2 (magenta) represents the 1PPS output of the 1st PPT slave, and Channel 4 (green) represents the 2nd PTP slave.

Jitter measurement	Δ time
average	-5.6ps
maximum	149ns
minimum	-136ns
peak-to-peak maximum	285ns
RMS	38.53 ns

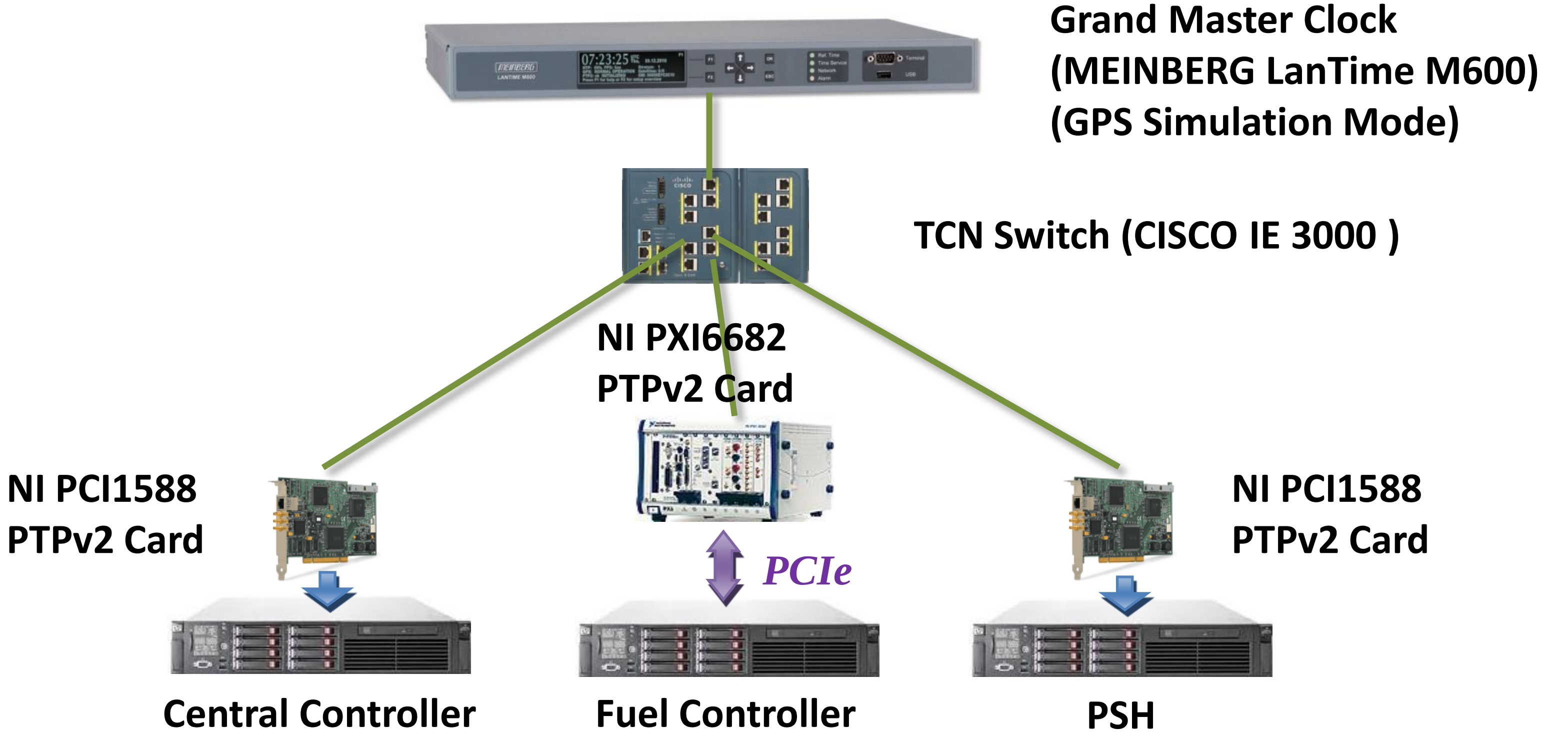


Histogram of Phase Deviation

Application for Tokamak Operation

Evaluation Test in KSTAR

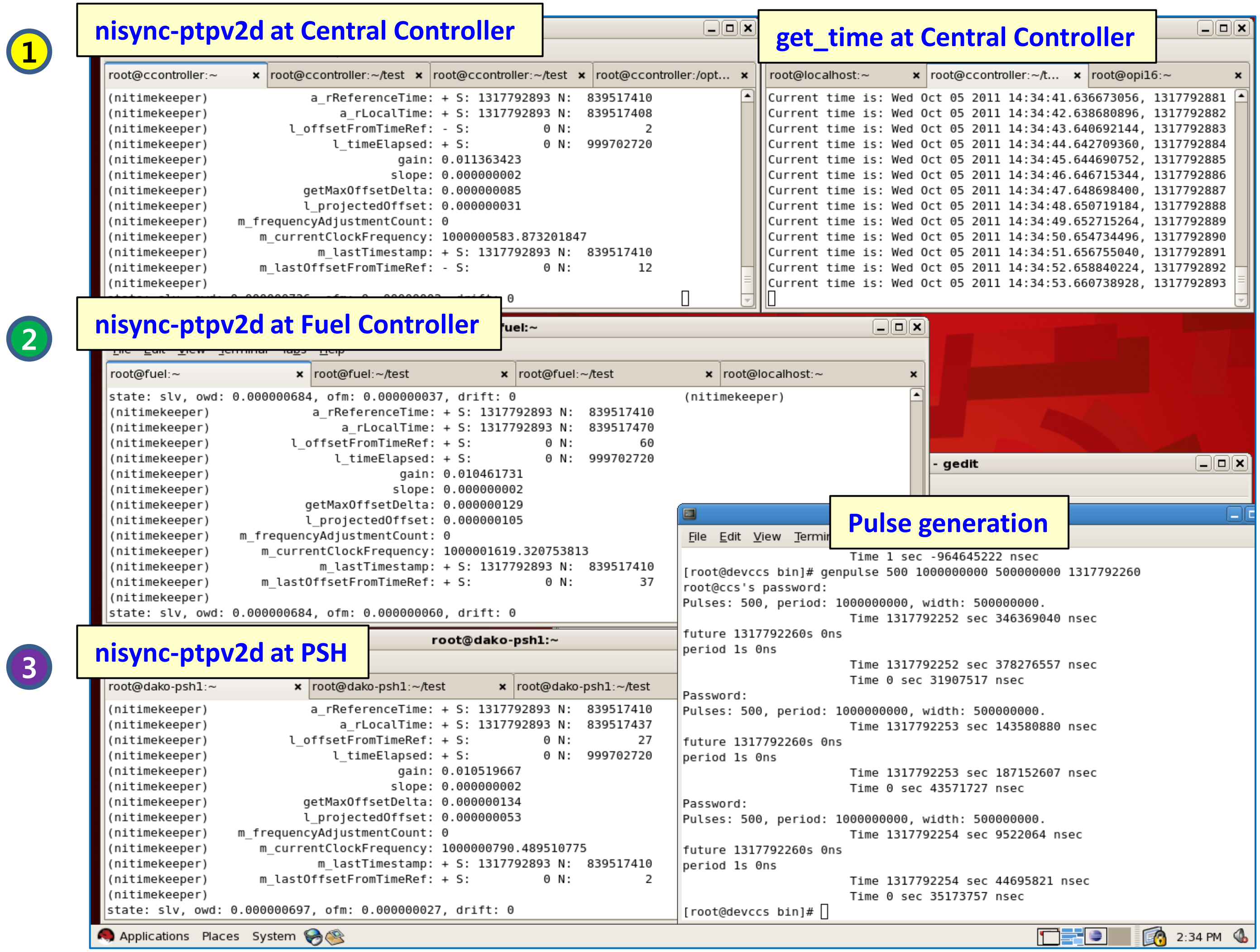
- To verify the basic functions of IEEE 1588 (PTPv2) :
  - Time synchronization
  - Time Accuracy and Jitter
- Setup : a Grandmaster + 3 Slaves



Application for Tokamak Operation

● Evaluation Test in KSTAR

Confirm time synchronization using PTPv2

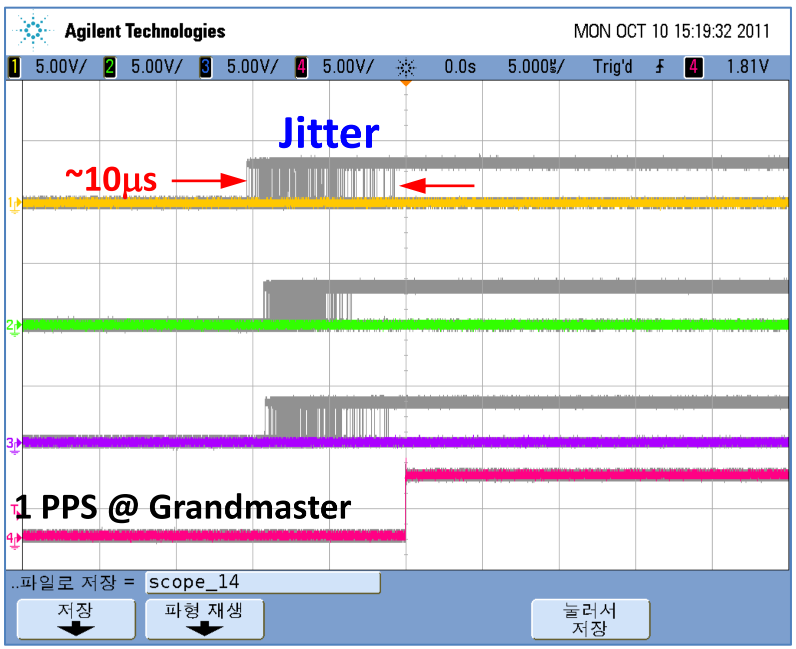


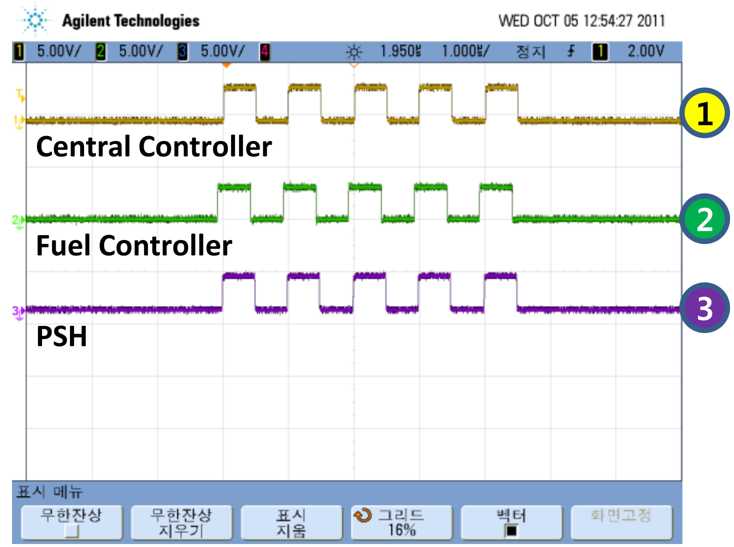
Application for Tokamak Operation

Evaluation Test in KSTAR

- Measure 1PPS of a Grandmaster and 3 Slave boards
- Measure time differences between slave cards

(5 Pulses, Period 1us, Width 100ns (repeat 5 times)



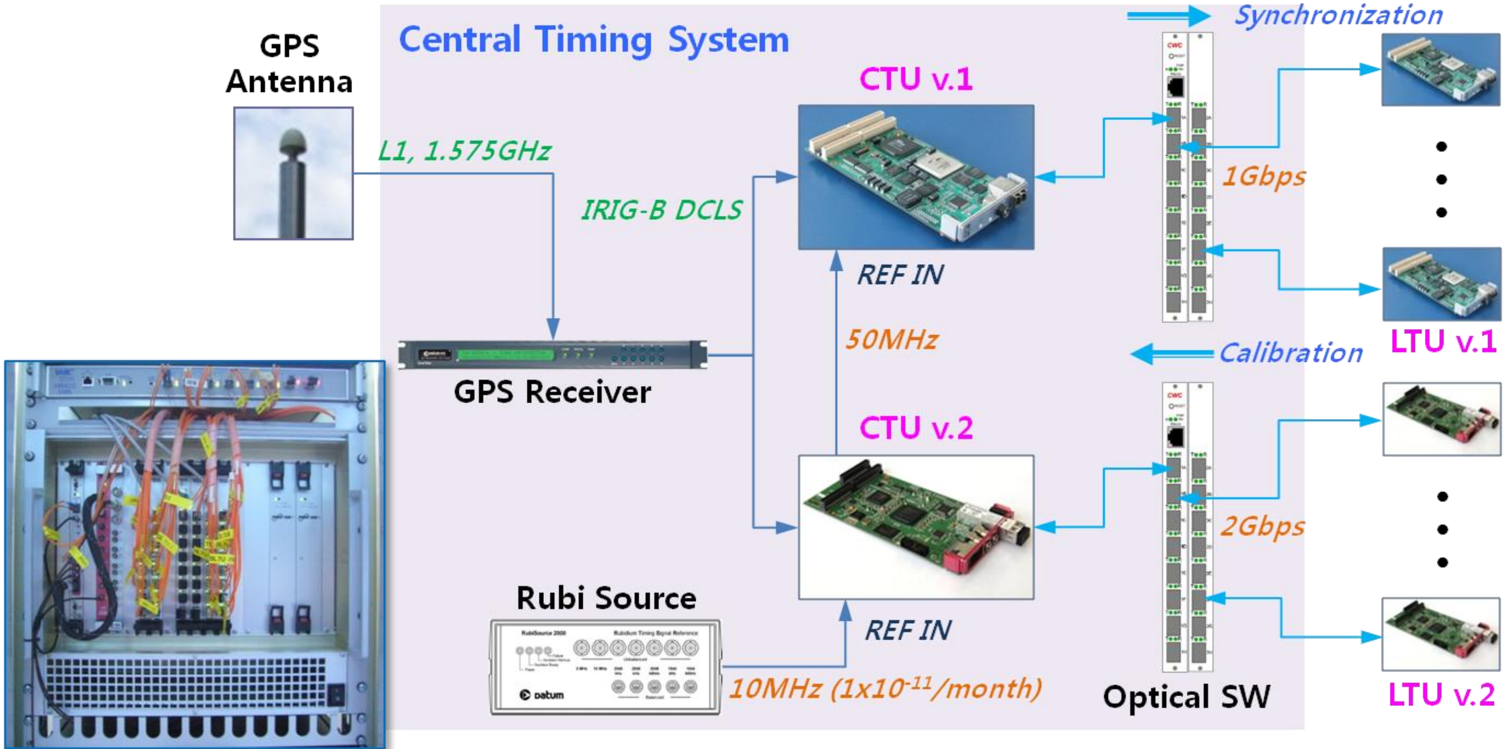


Trial	1	2	3
1	-	-90ns	-10ns
2	-	-100ns	-10ns
3	-	-80ns	-10ns
4	-	-5ns	-90ns
5	-	-5ns	-10ns

Comparison with Other Timing Systems

Customized Protocol – e.g. KSTAR Timing Protocol

- Providing 'Synchronized Time' and 'Synchronized Events'
- Using home-made timing protocol
- Master time reference to GPS time
- Dedicated optical timing network using Star-topology

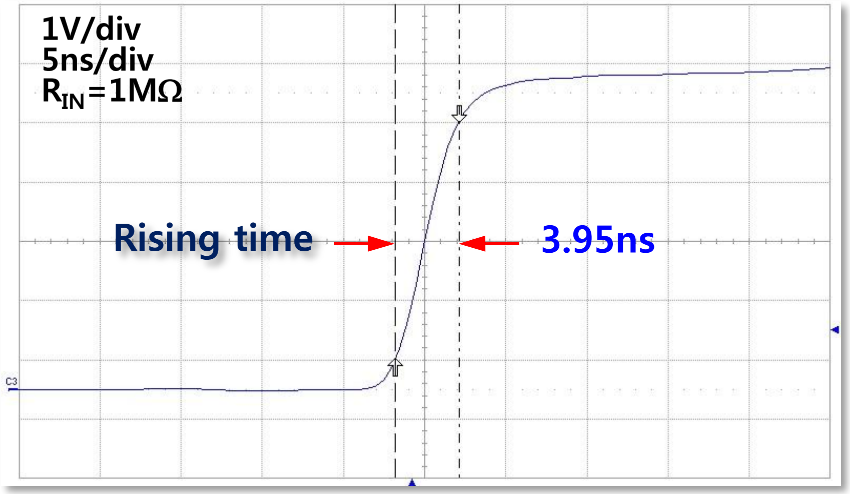


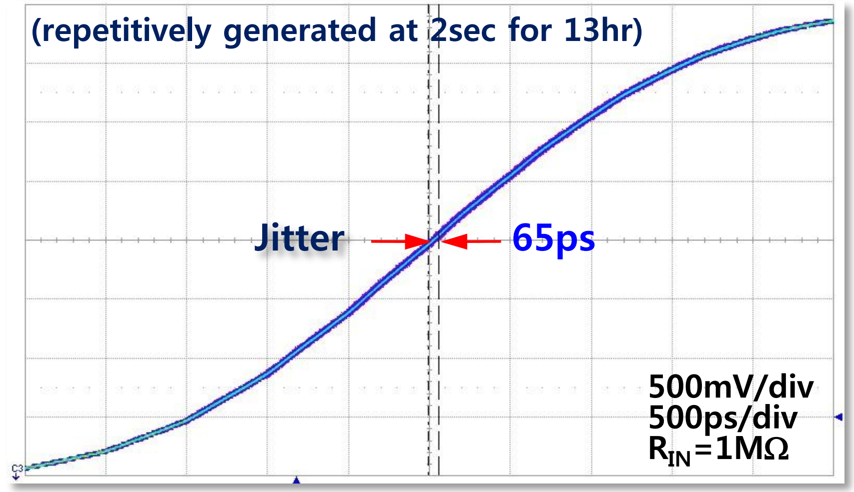
※ CTU : Central Timing Unit
LTU : Local Timing Unit

F/O : 850nm, Multi-mode

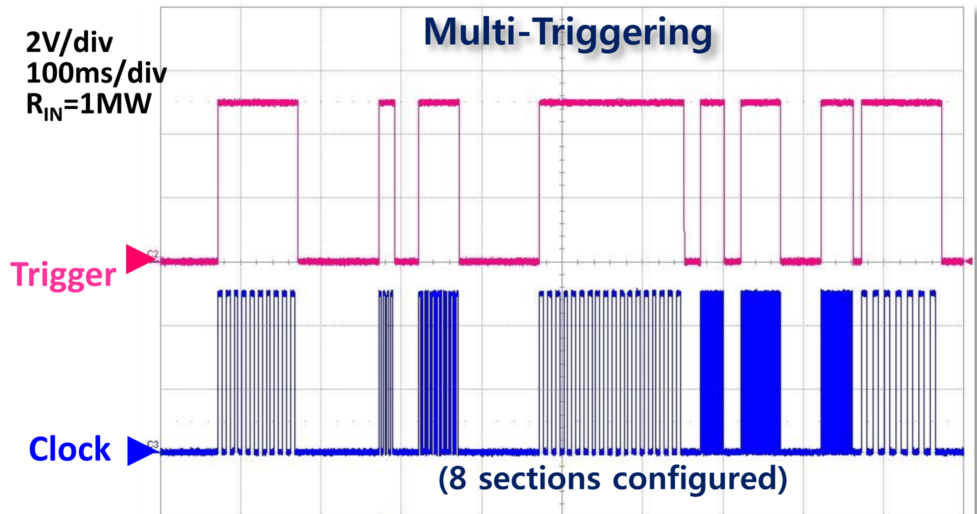
Comparison with Other Timing Systems

● Customized Protocol – e.g. KSTAR Timing Protocol





Specification	V.2
Timing accuracy	max. 5ns (1 tick)
Timing Jitter	<100ps,max
Output clock	1Hz ~ 100MHz
Trigger/Clock output	8, configurable
Multi triggering sections	8, configurable
Optical communication speed	2 Gbps
FPGA	Spartan-6 (150K logic cells)
IRIG-B GPS time decoding	O
PMC Form-factor, PCI/PCI-x	32/64-bit, 33/66MHz
EPICS device driver in	Vxworks, Linux 2.4x/2.6x



Comparison with Other Timing Systems

WHITERABBIT

- To provide precise timing and events distribution for high-end real-time system
  - Sun-nanosecond timing accuracy (using compensation of signal propagation delay)
  - Packet loss : 10^{-12} (forward error correction and introduction of QoS)
- WR timing network : a deterministic field bus based on synchronous giga-bit Ethernet and Precision Time Protocol
- It operates with completely open license on hardware and software
- It is a growing future protocol and currently working prototype is released

Conclusions

Pros and Cons

Generally Spoken Advantages

- Easier and Cheaper implementation
- Suitable for widely distributed facilities
- Non-time critical applications
- Commonly proven technology
- Guaranteed long time

Weaknesses for Tokamak Operation

- Lack of event synchronization
  - Need extra cost to provide synchronized events
  - Synchronized sampling clock signals are also necessary for data acquisition
- Somewhat, insufficient timing accuracy
  - to support high-speed DAQ systems

References

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