

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

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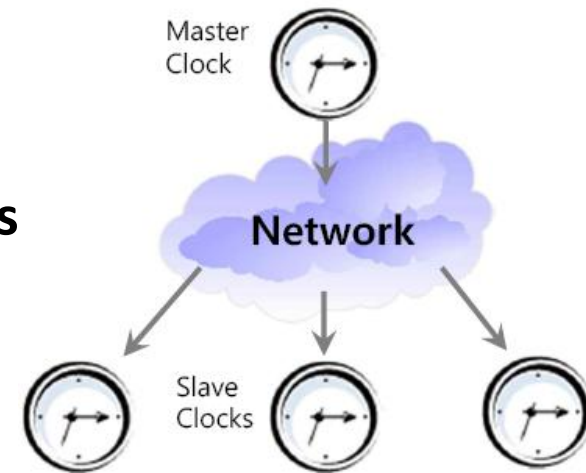
Background

- 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 2 : IEEE1588-2008
- It is possible to synchronize distributed clocks with an accuracy of less than 1 μ sec
- It uses UDP packet communication based on TCP/IP protocol stack
- It works inside LAN (PTP Domain)



What is Precision Time Protocol ?

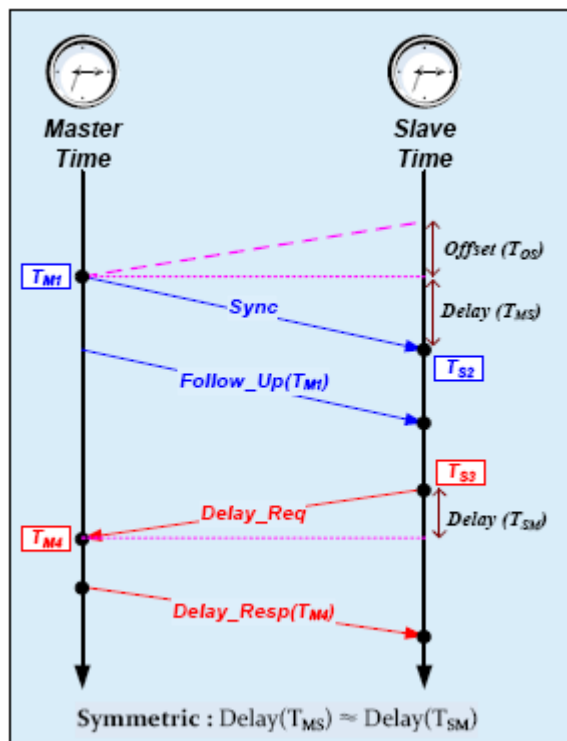
● IEEE1588 Standard - Features

- 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



Step 1 : Propagation delay measurement

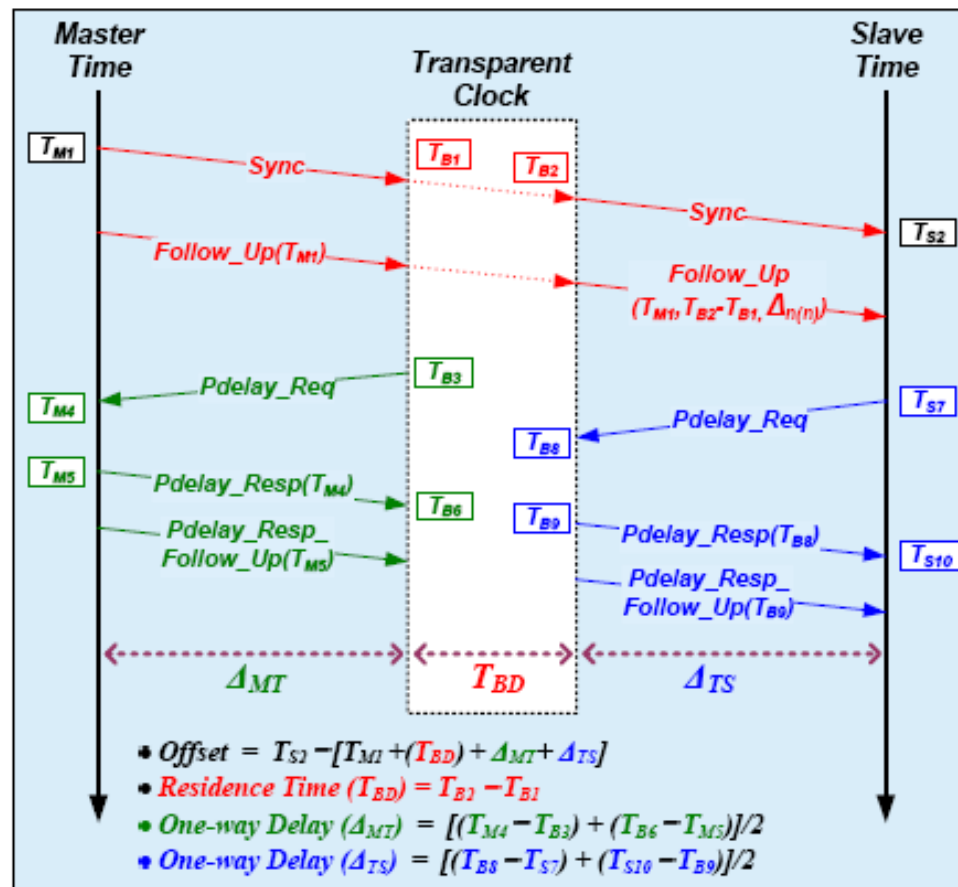
$$T_{LD} = ((T_{S2} - T_{M1}) - (T_{M4} - T_{S3})) / 2,$$

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

Step 2 : Offset measurement

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

Version 2



- $Offset = T_{S2} - [T_{M1} + (T_{BD}) + \Delta_{MT} + \Delta_{TS}]$

- $Residence\ Time\ (T_{BD}) = T_{B2} - T_{B1}$

- $One\text{-}way\ Delay\ (\Delta_{MT}) = [(T_{M4} - T_{B3}) + (T_{B6} - T_{M5})] / 2$

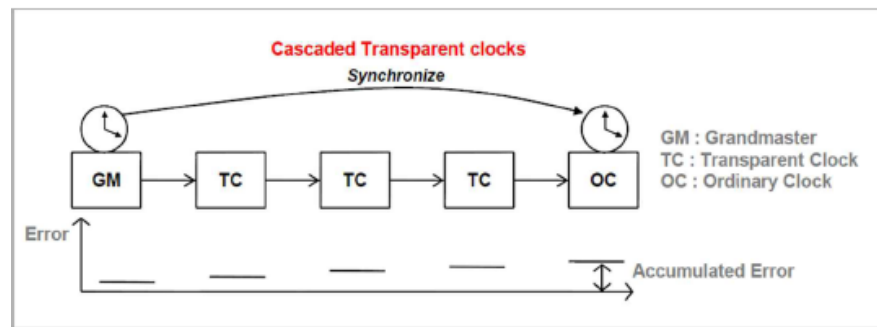
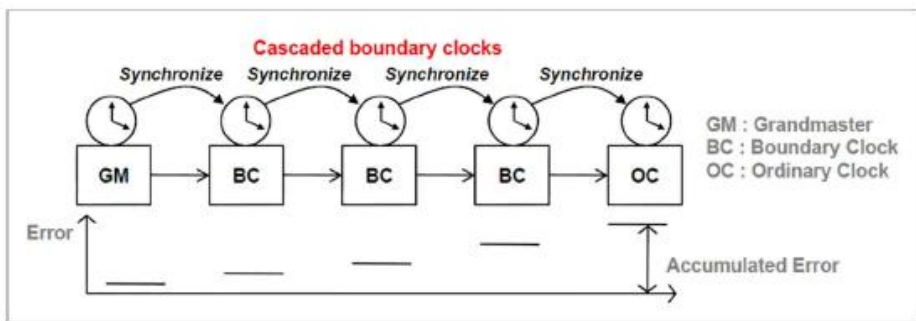
- $One\text{-}way\ Delay\ (\Delta_{TS}) = [(T_{B8} - T_{S7}) + (T_{S10} - T_{B9})] / 2$

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

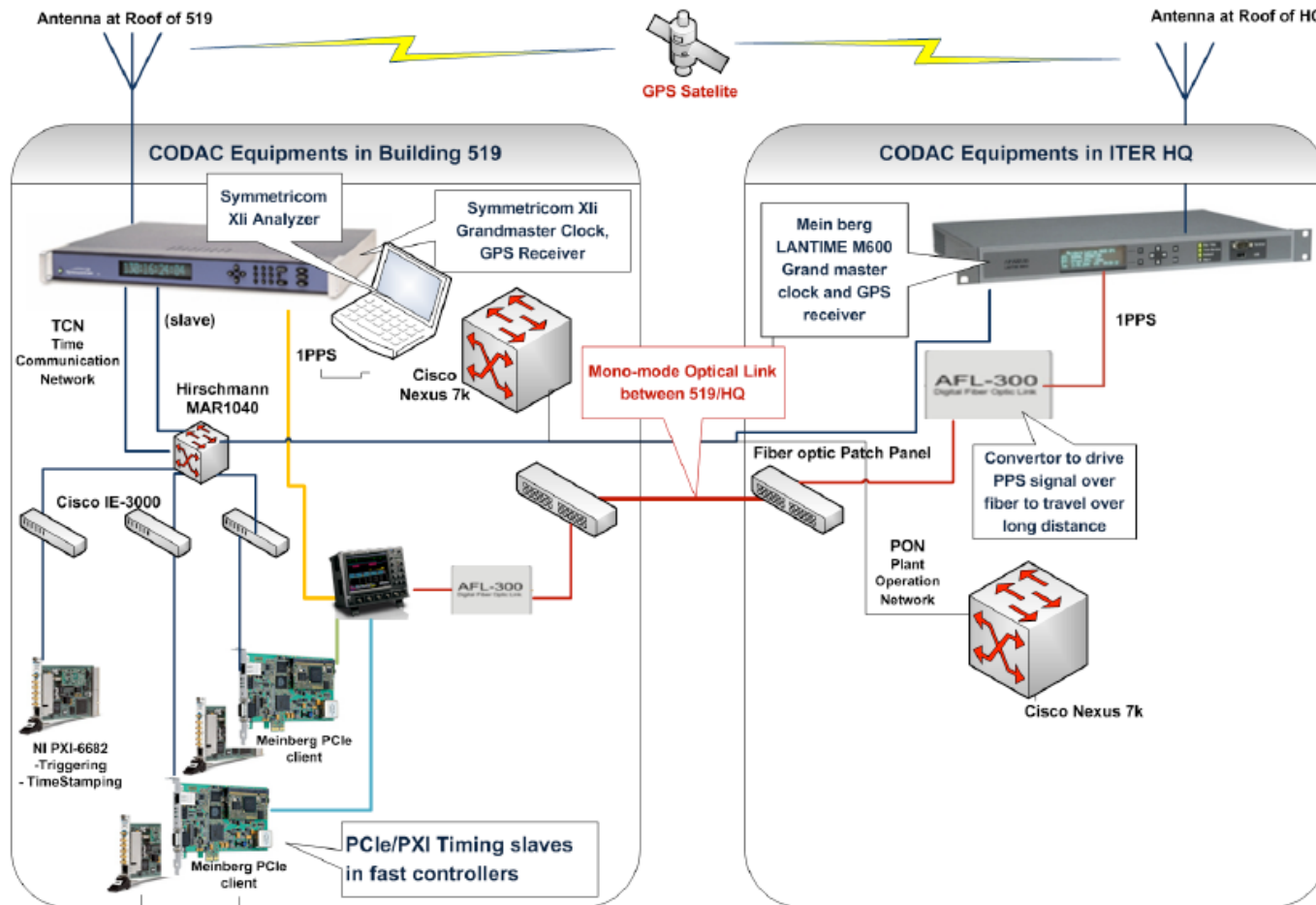
Application for Tokamak Operation

● 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

Legend: — Optical Fiber Link
— Copper Link

Application for Tokamak Operation

● Use case in ITER _ Test Results

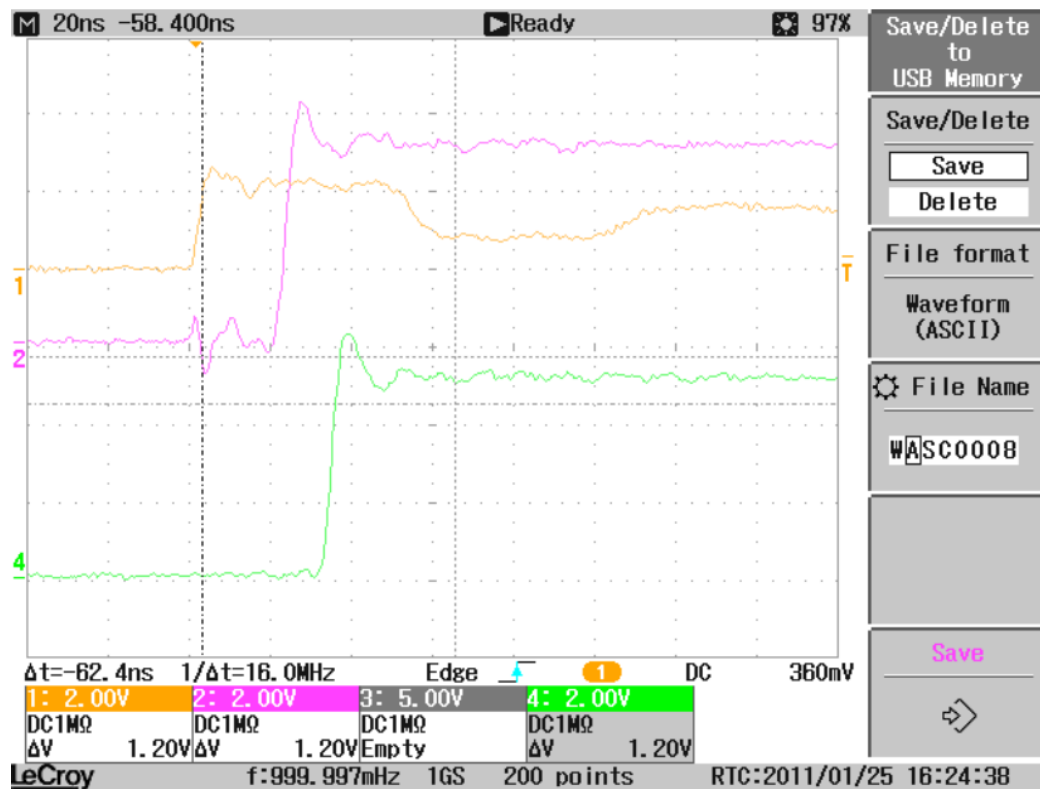
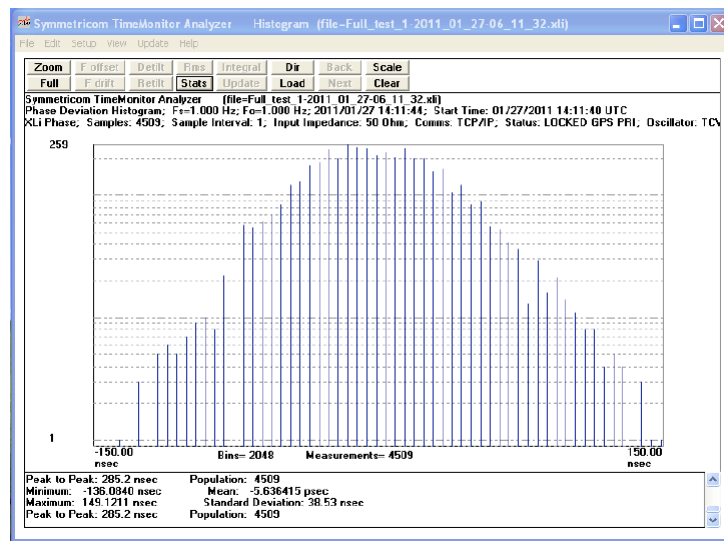


Figure 3. Oscilloscope output of the IEEE 1588-2008 compatibility testing where Channel 1 (yellow) represents the 1PPS signal output from the Grandmaster, Channel 2 (magenta) represents the 1PPS output of the 1st PPT slave, and Channel 4 (green) represents the 2nd PTP slave.

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

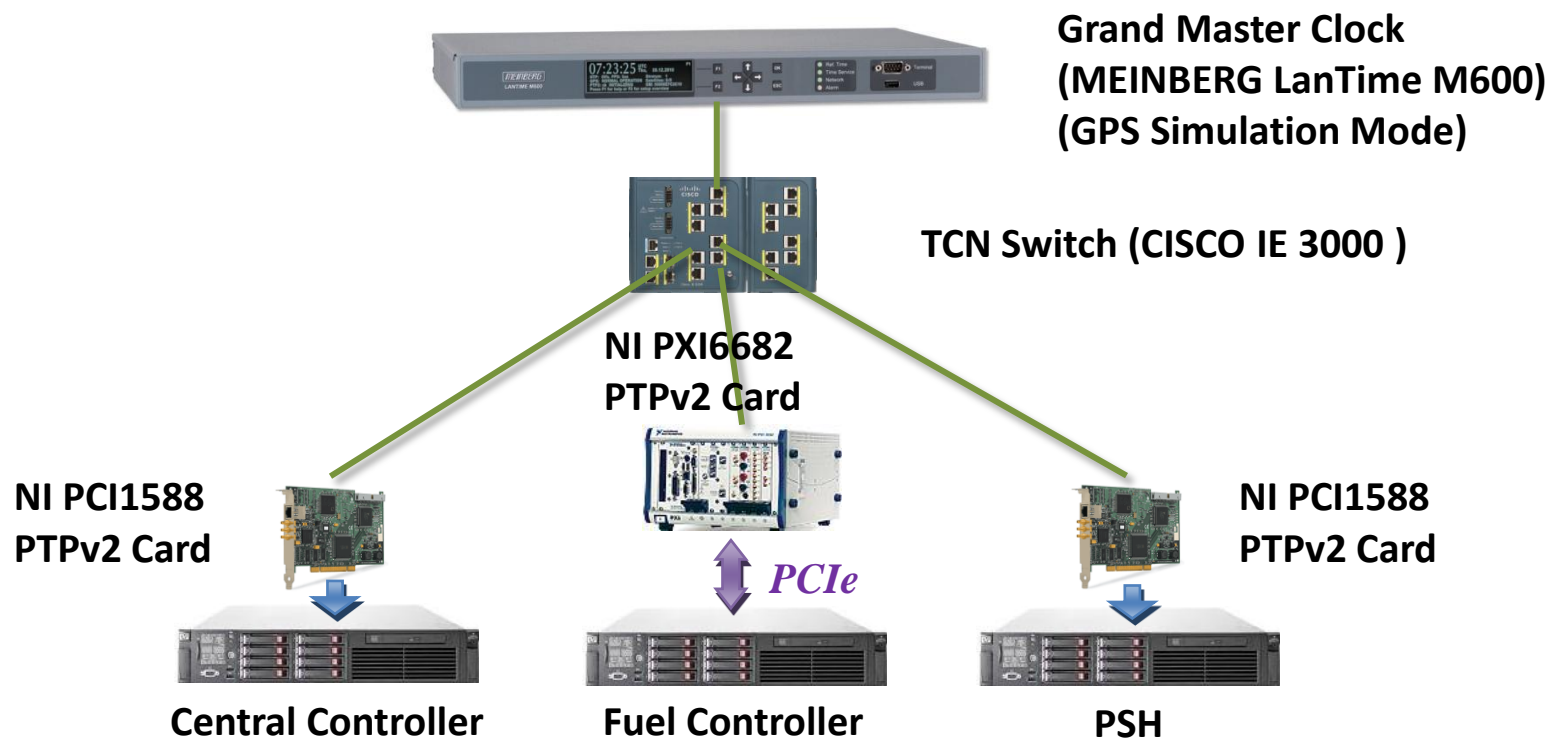


Histogram of Phase Deviation

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

1 **nisync-ptpv2d at Central Controller**

```

root@ccontroller:~
root@ccontroller:~/test
root@ccontroller:~/test
root@ccontroller:/opt...
root@localhost:~
root@ccontroller:~/A...
root@opi16:~

(nitimekeeper) a_rReferenceTime: + S: 1317792893 N: 839517410
(nitimekeeper) a_rLocalTime: + S: 1317792893 N: 839517408
(nitimekeeper) l_offsetFromTimeRef: - S: 0 N: 2
(nitimekeeper) l_timeElapsed: + S: 0 N: 999702720
(nitimekeeper) gain: 0.011363423
(nitimekeeper) slope: 0.000000002
(nitimekeeper) getMaxOffsetDelta: 0.000000085
(nitimekeeper) l_projectedOffset: 0.000000031
(nitimekeeper) m_frequencyAdjustmentCount: 0
(nitimekeeper) m_currentClockFrequency: 1000000583.873201847
(nitimekeeper) m_lastTimestamp: + S: 1317792893 N: 839517410
(nitimekeeper) m_lastOffsetFromTimeRef: - S: 0 N: 12
(nitimekeeper)

```

2 **nisync-ptpv2d at Fuel Controller**

```

root@fuel:~
root@fuel:~/test
root@fuel:~/test
root@localhost:~
(nitimekeeper)
- gedit

state: slv, owd: 0.000000684, ofm: 0.000000037, drift: 0
(nitimekeeper) a_rReferenceTime: + S: 1317792893 N: 839517410
(nitimekeeper) a_rLocalTime: + S: 1317792893 N: 839517470
(nitimekeeper) l_offsetFromTimeRef: + S: 0 N: 60
(nitimekeeper) l_timeElapsed: + S: 0 N: 999702720
(nitimekeeper) gain: 0.010461731
(nitimekeeper) slope: 0.000000002
(nitimekeeper) getMaxOffsetDelta: 0.000000129
(nitimekeeper) l_projectedOffset: 0.000000105
(nitimekeeper) m_frequencyAdjustmentCount: 0
(nitimekeeper) m_currentClockFrequency: 1000001619.320753813
(nitimekeeper) m_lastTimestamp: + S: 1317792893 N: 839517410
(nitimekeeper) m_lastOffsetFromTimeRef: + S: 0 N: 37
(nitimekeeper)
state: slv, owd: 0.000000684, ofm: 0.000000060, drift: 0

```

3 **nisync-ptpv2d at PSH**

```

root@dako-psh1:~
root@dako-psh1:~/test
root@dako-psh1:~/test

(nitimekeeper) a_rReferenceTime: + S: 1317792893 N: 839517410
(nitimekeeper) a_rLocalTime: + S: 1317792893 N: 839517437
(nitimekeeper) l_offsetFromTimeRef: + S: 0 N: 27
(nitimekeeper) l_timeElapsed: + S: 0 N: 999702720
(nitimekeeper) gain: 0.010519667
(nitimekeeper) slope: 0.000000002
(nitimekeeper) getMaxOffsetDelta: 0.000000134
(nitimekeeper) l_projectedOffset: 0.000000053
(nitimekeeper) m_frequencyAdjustmentCount: 0
(nitimekeeper) m_currentClockFrequency: 1000000790.489510775
(nitimekeeper) m_lastTimestamp: + S: 1317792893 N: 839517410
(nitimekeeper) m_lastOffsetFromTimeRef: + S: 0 N: 2
(nitimekeeper)
state: slv, owd: 0.000000697, ofm: 0.000000027, drift: 0

```

Pulse generation

```

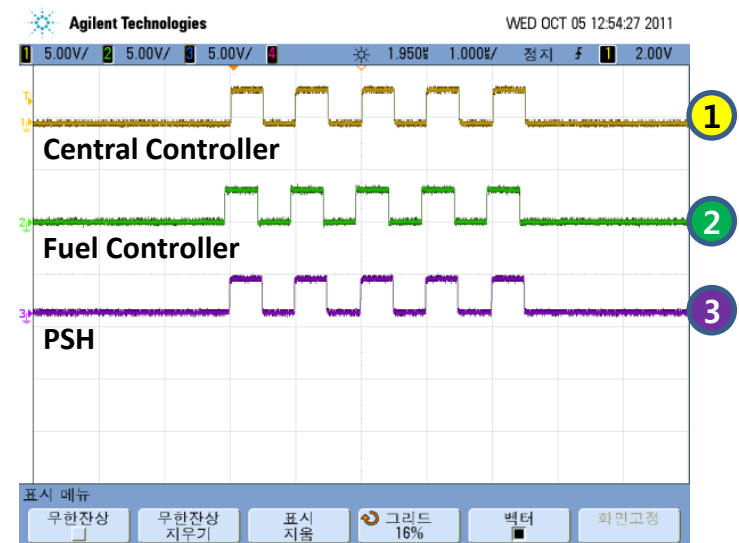
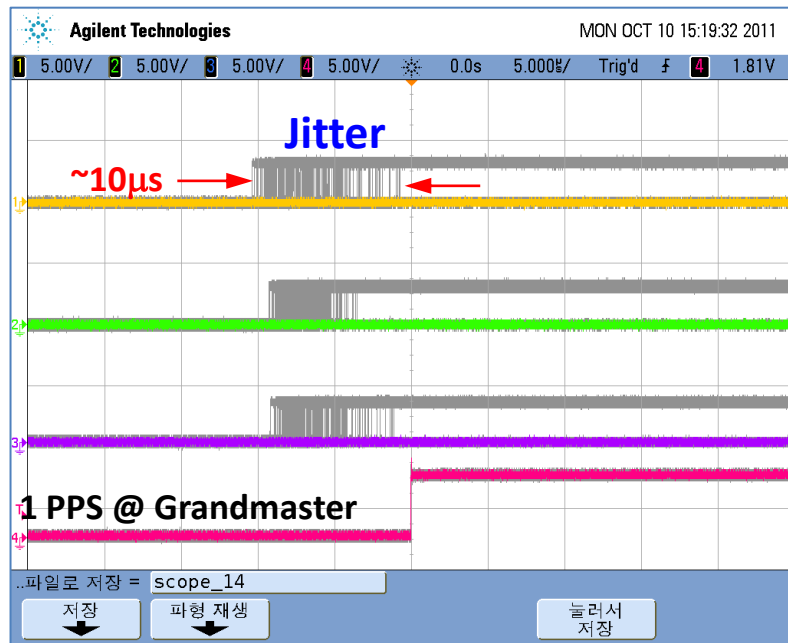
Time 1 sec -964645222 nsec
root@ccs's password:
Pulses: 500, period: 1000000000, width: 500000000.
Time 1317792252 sec 346369040 nsec
future 1317792260s 0ns
period 1s 0ns
Time 1317792252 sec 378276557 nsec
Time 0 sec 31907517 nsec
Password:
Pulses: 500, period: 1000000000, width: 500000000.
Time 1317792253 sec 143580880 nsec
future 1317792260s 0ns
period 1s 0ns
Time 1317792253 sec 187152607 nsec
Time 0 sec 43571727 nsec
Password:
Pulses: 500, period: 1000000000, width: 500000000.
Time 1317792254 sec 9522064 nsec
future 1317792260s 0ns
period 1s 0ns
Time 1317792254 sec 44695821 nsec
Time 0 sec 35173757 nsec
[root@devccs bin]#

```

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))

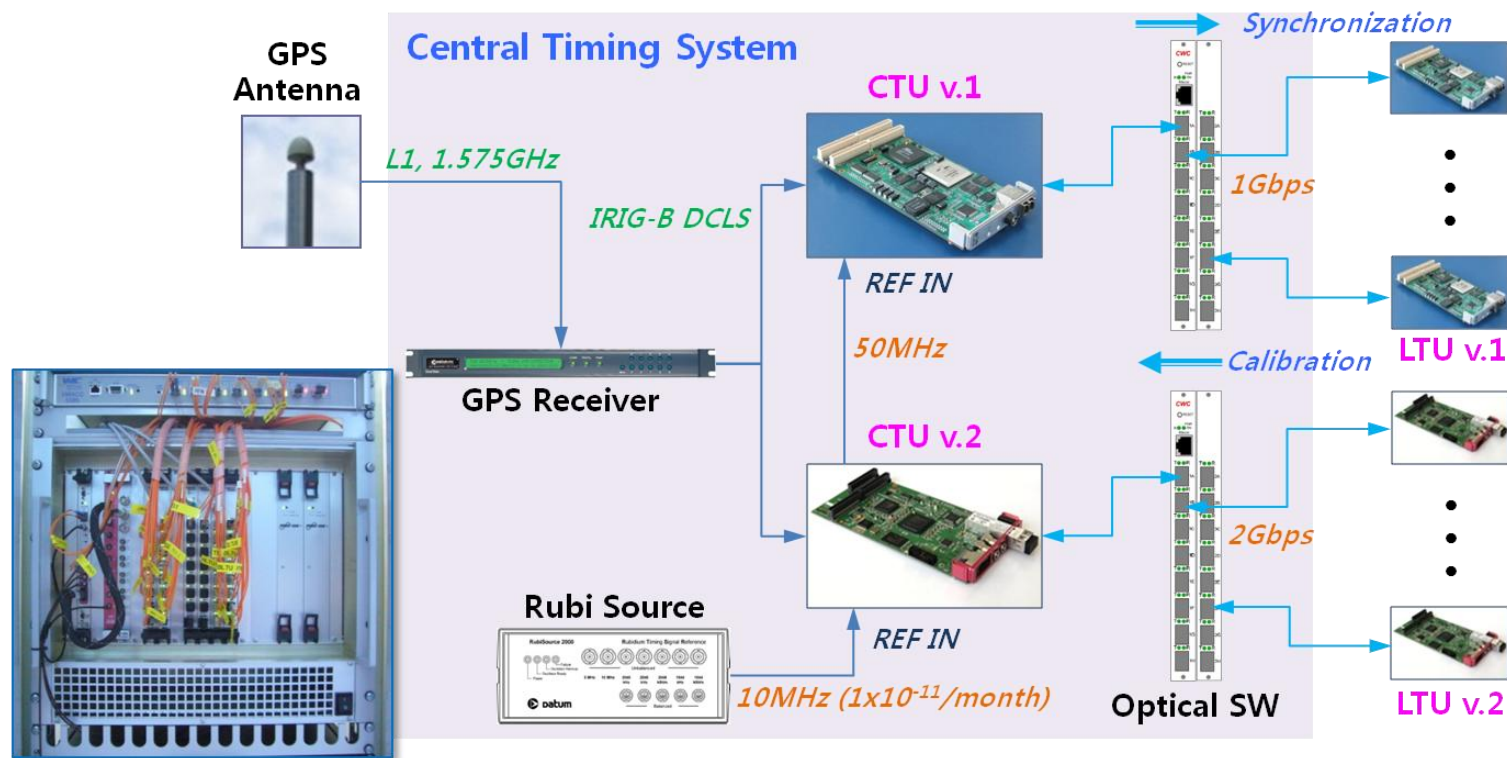


Trial	1	2	3
1	-	-90ns	-10ns
2	-	-100ns	-10ns
3	-	-80ns	-10ns
4	-	-5ns	-90ns
5	-	-5ns	-10ns

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

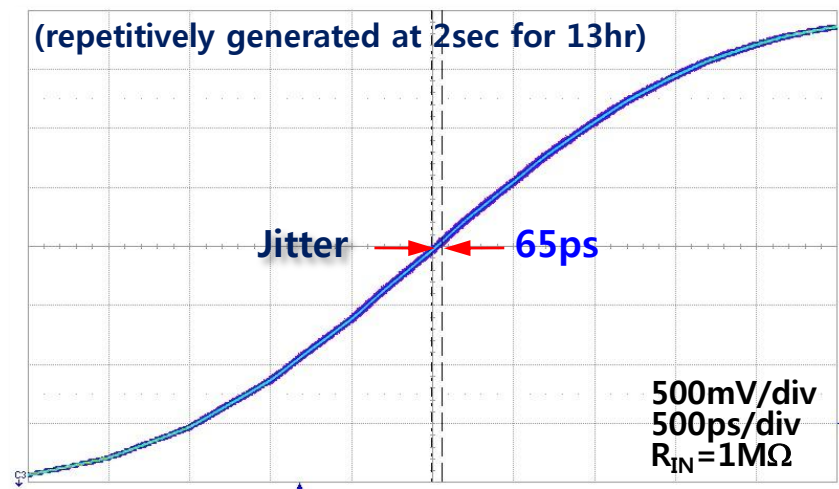
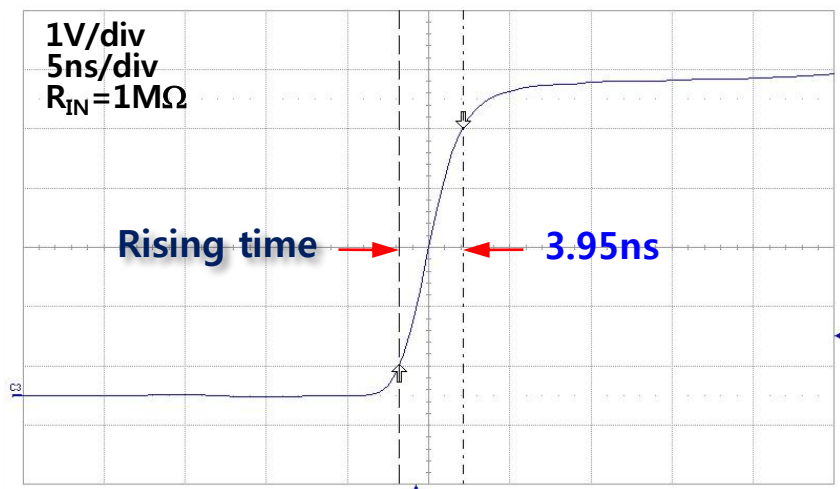


※ CTU : Central Timing Unit
LTU : Local Timing Unit

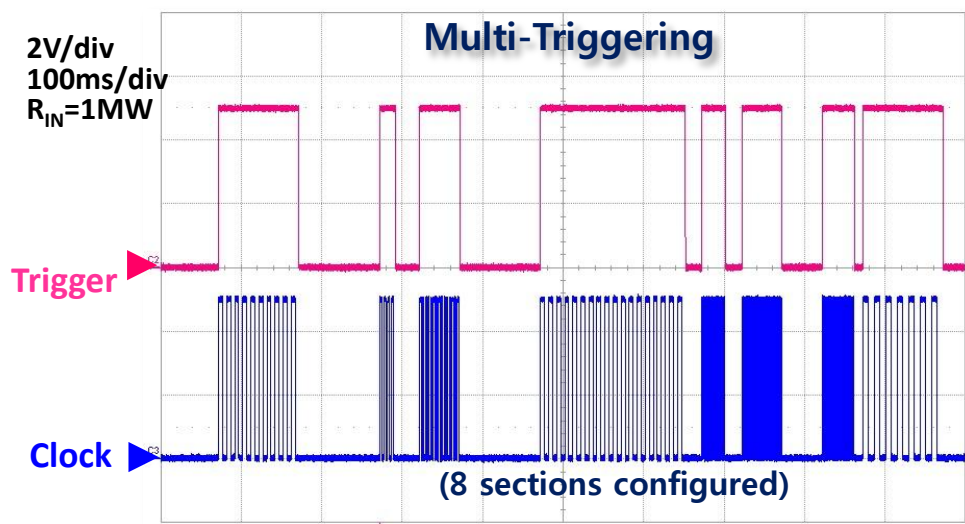
↔ F/O : 850nm, Multi-mode

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	0
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

- <http://www.nist.gov/el/isd/ieee/ieee1588.cfm>
- <http://www.ieee1588.com/index.html>
- <http://fastironex.blogspot.com/2010/02/1588-ecn-asia.html>
- M.Kreider, et.al, “Whiterabbit – A novel, high precision timing system”, Proceeding of PCaPAC2010
- ITER document(ITER_D_4APQYY), “ITER CODAC TCN Infrastructure test Report”
- Mikyung Park and Woongrypl Lee, “The upgrade of KSTAR timing system to support long-pulse operation and high-speed data acquisition”, 2011 IAEA TM