

Validation Methods and Test Results from Mobile Calibration Station (TIM02)



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W. SCHÄFER, S. Liu, A. Balu

TimeTech GmbH, Stuttgart, Germany

Prepared by shuo.liu@timetech.de

Outline



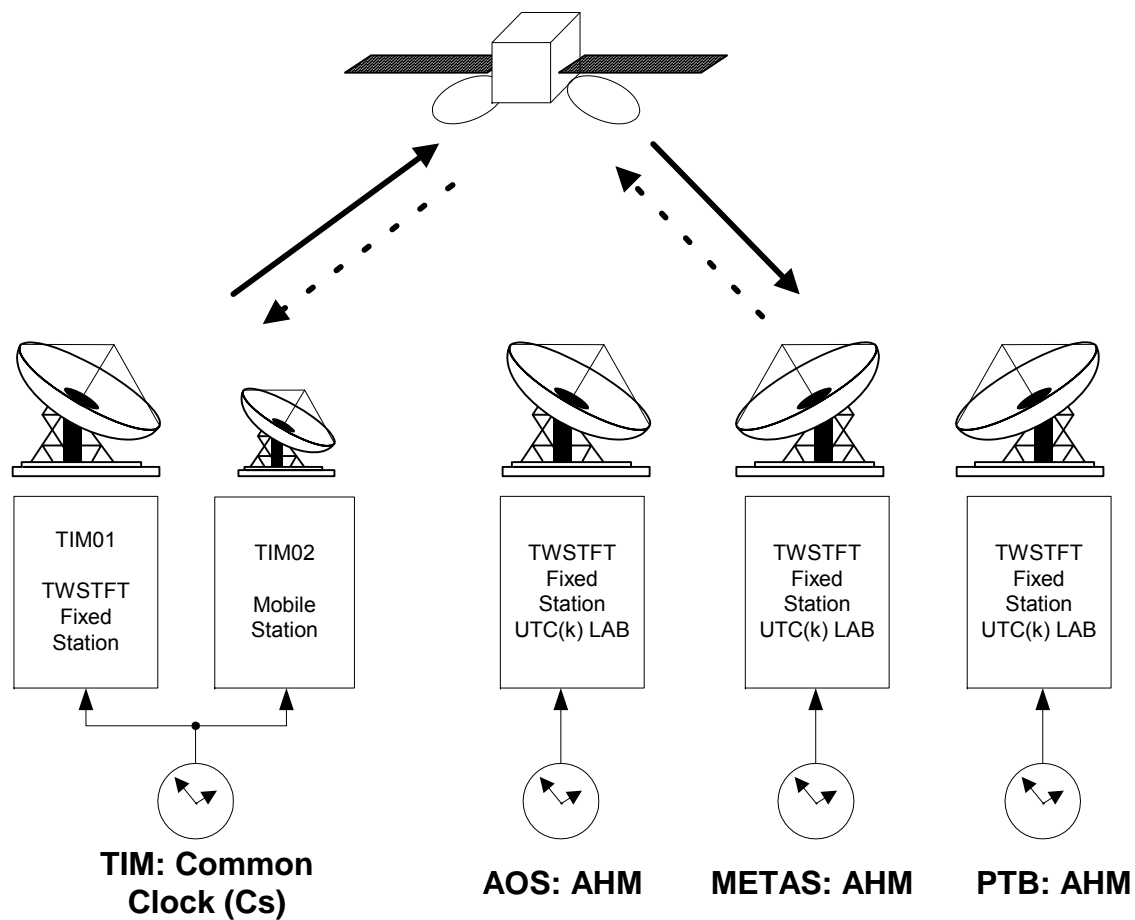
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- Overview
 - Preparation
 - Frequency Assignments
 - Participating Stations
 - Schedule
 - Validation Test
 - Common Clock Test
 - OFF-ON Sequence Test
 - SATSIM Test
 - Tools
 - Test Results
 - Signal Flow Chart and Complete Calibration Formula
 - Status and Outlook

Objectives

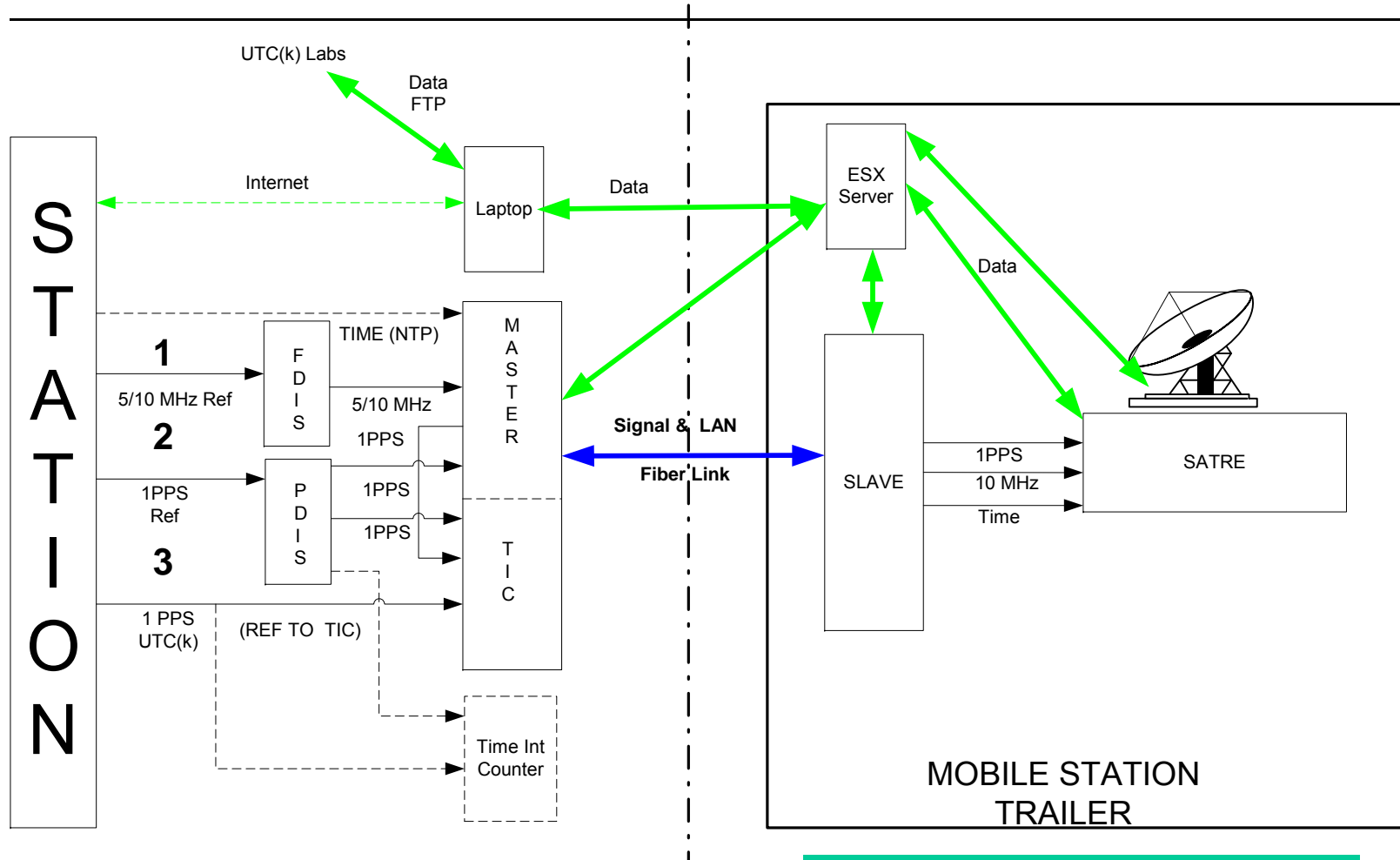


- Verify readiness of calibration station (TIM02)
- Remain at TIM: what can be done without travel?
- Performance of TIM01 (fixed) and TIM02 (mobile)
- Verify QA measures (start & end of a visit)
- Verify the calibration status on stand-alone mode
- Station interfaces: signals & data
- (Near) realtime data processing
- Check configuration control
- Qualify TimeTech (TIM01) as start & end points of a calibration trip

Verification setup



Calibration Station Concept



Multimode fiber of length 500m

Oplink performance
5ps @ 10s
2ps @ 300 s

TIM01 and TIM02 Frequency Assignments



Mobile Station (TIM02) Settings

Description	Assignment
Station Name	TIM02
Clean Carrier Freq offset	-70 kHz
PN Code	31
PN Frequency offset	-31.304 kHz

TIM Fixed station (TIM01) settings

Description	Assignment
Station Name	TIM01
Clean Carrier Freq offset	-30 kHz
PN Code	14
PN Frequency offset	-13.416 kHz

Station Identifier Assignments



Station	Station ID	Description
PTB	PTB 01	PTB Even Hour 2min
	PTB 11	PTB Odd Hour 2min Session
	PTB 21	PTB Odd Hour 4min Session
CH	CH 01	CH Even Hour 2min
	CH 11	CH Odd Hour 2min Session
	CH 21	CH Odd Hour 4min Session
AOS	AOS 01	AOS Even Hour 2min
	AOS 11	AOS Odd Hour 2min Session
	AOS 21	AOS Odd Hour 4min Session
TIM	TIM 01	TIM Fixed Station Even Hour 2min
	TIM 11	TIM Fixed Station Odd Hour 2min Session
	TIM 21	TIM Fixed Station Odd Hour 4min Session
	TIM 02	TIM Mobile Station Even Hour 2min
	TIM 12	TIM Mobile Station Odd Hour 2min Session
	TIM 22	TIM Mobile Station Odd Hour 4min Session

Participating Stations & Schedule



Start	End	Length	PTB01	CH01	AOS01	TIM01	TIM02
file char			e	n	q	t	v
Tx code			4	9	11	14	31
00:04:00	00:06:59	120					Ranging
00:09:00	00:11:59	120		TIM02			CH01
00:15:00	00:17:59	120			TIM02		AOS01
00:18:00	00:20:59	120				TIM02	TIM01
00:33:00	00:35:59	120	TIM02				PTB01
01:16:00	01:18:59	120	PTB11	TIM11		CH11	PTB11
01:19:00	01:21:59	120		TIM12	TIM11	AOS11	CH11
01:22:00	01:24:59	120	CH11	PTB11	TIM12		AOS11
01:25:00	01:27:59	120	AOS11		PTB11	TIM12	TIM11
01:28:00	01:30:59	120	TIM11	AOS11	CH11	PTB11	Ranging
01:31:00	01:35:59	240	TIM22	TIM21		CH21	PTB21
01:36:00	01:40:59	240		TIM22	TIM21	AOS21	CH21
01:41:00	01:45:59	240	CH21	PTB11	TIM22		AOS21
01:46:00	01:50:59	240	AOS21		PTB21	TIM22	TIM21
01:51:00	01:55:59	240	TIM21	AOS21	CH21	PTB21	Ranging

✓The purpose of even and odd hour sessions is to compare the hourly effects on the TW measurements.

✓The 4 min sessions are to compare the effect of increased sample points on the precision of the measurements.

Common Clock Test with (PTB, AOS, CH)



- ✓ Test period – 3 days
- ✓ Data Types used
 1. Real Time – SATRE solution
 2. Inputs from ITU-format files exchanged by ftp server
 3. Inputs from 1s files exchanged by ftp server
 - $TW (Labi - Labj)$, namely $\frac{1}{2} [TW (Labi) - TW (Labj)]$
 - $TW (Labi)$ refers to the output in ITU output, “TW” column
 - The TW result time-tag formula Time tagged as

Floor ((Stop time – Start time + 1s) / 2) + Correct factor

(The *Correct Factor* for the SATRE modem is -0.5s)

OFF-ON Sequence Test



- ✓ Verify the stability after “transportation” of Mobile Station
- ✓ Operations:
 - Operate for > 5 days
 - Switch OFF Master Oplink and Complete Mobile Station 6 hrs
 - Switch ON
 - Operate the station for 5 days and compare the TW results
 - Repeat the switch OFF and ON and verify the TW results

Tools – System M&C



Two way measurements via SATRE500 Modem v2.6

Operation View Functions Display Help

System Status H2Unit Status Settings Add-ons Filtering of raw data Receive statistics Station Statistics Operations & Events

SATRE TWSTFT Modem 500

Module	Rx1	Rx2	Rx3	Tx
Config	SP01	SP01	TIM01	TIM01
PN Code	1MChip PN 3	1MChip PN 3	1MChip PN 14	1MChip PN 1
Frequency [Hz]	70133349.093	70133349.092	<empty>	-12
Power [dBm]	-53.7	-53.5	<empty>	70136584.000
C/No [dBHz]	50.5	49.7	<empty>	
Jitter [ns]	1.349	1.458	<empty>	
Lock Status	Code & Carrier	Code & Carrier	idle	
Status	●	●	●	
Samples	39	29	0	

Modem Control

- unused
- unlocked
- locked
- format error

Date & Time
Date 2012/09/02 MJD 56172 UTC 20:37:40 (SATRE)

Environment
Temperature (Outdoor) 37.3°C Temperature (IDU)
Tpps ref. OK Time ref. OK
Frequency ref. OK GPS Receiver OK

Transceiver ComTech Status
Uplink Freq **14260.0MHz** Uplink Att **18dB** Humidity [16.0%]
Downlink Freq **10960.0MHz** Downlink Att **15.0dB** [SAT Ranging]
 RF Status **ON** RF Power **31dBm**

Telnet Start Stop

Scheduler

Start Time	Sys. Action	Rx1 Measurement [ns]				Rx2 Measurement [ns]				Rx3 Measurement [ns]			
		Action	Round Trip	Clock Diff	Clock Drift	Action	Round Trip	Clock Diff	Clock Drift	Action	Round Trip	Clock Diff	Clock Drift
20:21:15		LOCK[CH01]	264008767.607	0.000	0.0000	LOCK[CH01]	264008750.363	0.000	0.0000				
20:22:00		MEAS[120s]	264009488.577	-1896.925	0.0114	MEAS[120s]	264009488.814	0.000	0.0000				
20:24:05		Rx[IDLE]				Rx[IDLE]							
20:24:15		LOCK[IPQ01]	259287322.940	0.000	0.0000	LOCK[IPQ01]	259287323.961	0.000	0.0000				
20:25:00		MEAS[120s]	259288045.817	-1867.712	-0.0010	MEAS[120s]	259288045.853	0.000	0.0000				
20:27:05		Rx[IDLE]				Rx[IDLE]							
20:27:15		LOCK[AOS01]	266903992.499	0.000	0.0000	LOCK[AOS01]	266903991.233	0.000	0.0000				
20:28:00		MEAS[120s]	266904701.468	-1949.123	-0.0242	MEAS[120s]	266904701.729	0.000	0.0000				
20:30:05		Rx[IDLE]				Rx[IDLE]							
20:33:15		LOCK[VSL01]				LOCK[VSL01]	264570810.916	0.000	0.0000				
20:34:00		MEAS[120s]	264571534.442	-2256.355	0.0152	MEAS[120s]	264571534.911	0.000	0.0000				
20:36:05		Rx[IDLE]				Rx[IDLE]							
20:36:15		LOCK[SP01]				LOCK[SP01]							
20:37:00		MEAS[120s]	267216182.175	-1841.833	-0.0266	MEAS[120s]	267216182.635	0.000	0.0000				
20:39:05		Rx[IDLE]				Rx[IDLE]							
20:41:15		LOCK[PC01]				LOCK[PC01]							

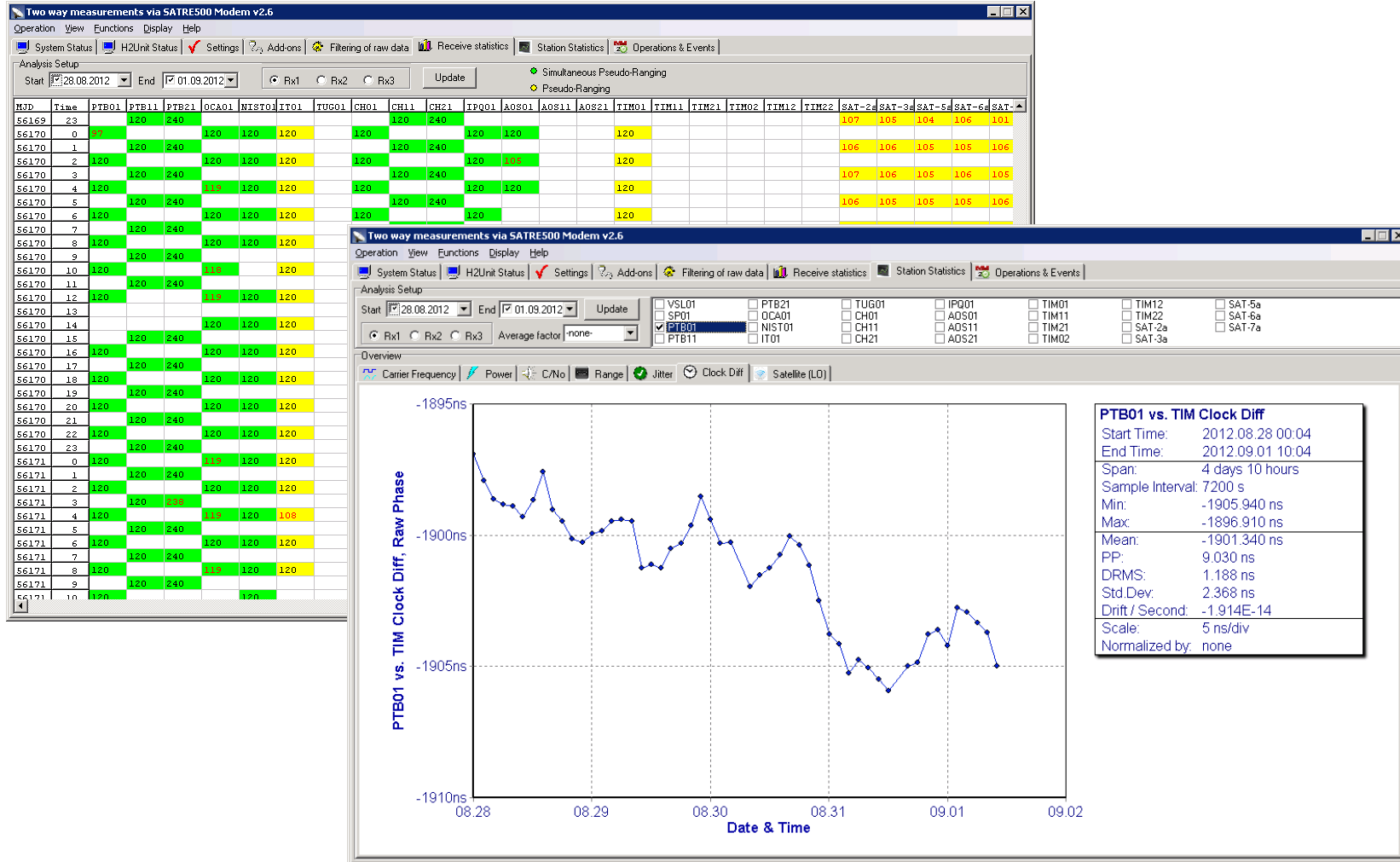
- **Monitor & Control of**

- ✓ 1x SATRE Modem
- ✓ 1x Transceiver
ComTech, AnaCom, CrossTech...
- ✓ 1 set SATSIM ODU/IDU
- ✓ TimeTech H2Unit

- **Real-time Outputs**

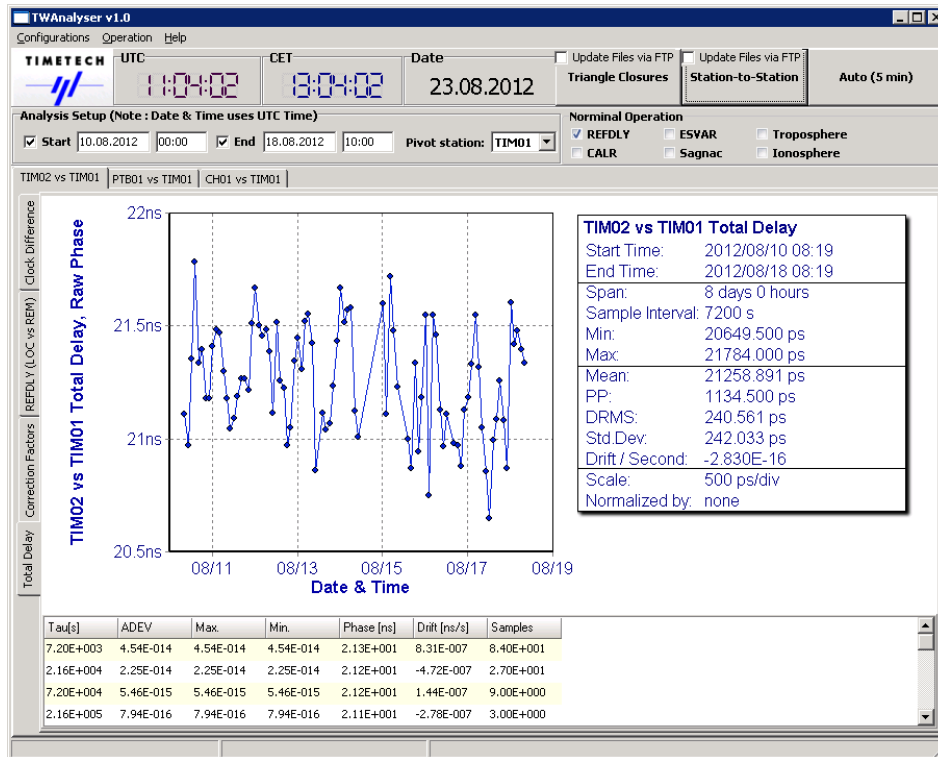
- ✓ ITU Files
- ✓ Raw Data
- ✓ Log, Statistics, User-Defined Files...

Tools – System M&C (contd.)



Session lock details (left) and real time observation of the clock difference

Tools – TW Analyser



- Download of 1s Files or ITU Files over FTP with auto-update feature
- Computation and Analysis of raw clock difference, i.e. $\frac{1}{2} [TW (Lab_i) - TW (Lab_j)]$
- Computation of differential RefDly, i.e. $REFDELAY (Lab_i) - REFDELAY (Lab_j)$
- Computation and Analysis of Sagnac Effect with/without TLE
- Computation and Analysis of Troposphere Effect with/without TLE
- Computation and Analysis of Total Delay with selectable corrective parameters
- Computation and Analysis of 3-Corner-Hat Closure (TCC)

Common Clock Test with (PTB, AOS, CH)



- Objective - *Validation*
- Participating labs PTB, AOS, CH, TIM (Fixed & Mobile)
- Performance comparison odd and even hours in TW (Labi – Labj) without REFDLY
- Performance comparison 120s vs 240s in TW (Labi – Labj) without REFDLY
- Performance of IIOTIC reporting REFDLY
- Performance of Optical Link

Performance Comparison Hour Effect and NTL Effect in TW (Labi – Labj) without REFDLY



$$TW (Labi - Labj) = \frac{1}{2} [TW (Labi) - TW (Labj)] \text{ (Data from ITU)}$$

Link ID	Even Hour		Odd Hour			
	120		120		240	
Statistics	Peak to Peak [ns]	Std. Dev [ns]	Peak to Peak	Std. Dev	Peak to Peak	Std. Dev
TW(TIM01, TIM02)	1,9435	0,441213	1,237	0,291386	1,0555	0,238218
TW(TIM01, PTB01)	24,158	7,046	24,365	7,229	24,627	7,263
TW(TIM01, CH01)	24,793	7,334	24,514	7,266	24,41	7,026
TW(TIM02, PTB01)	24,254	7,119	23,792	7,17	24,337	7,204
TW(TIM02, CH01)	24,939	7,008	23,925	7,191	24,422	7,018

Link ID	HOUR (Even vs Odd)		Normal Track length (2min vs 4min)	
	NTL (2 min, each)		ODD Hour	
Statistics	Peak to Peak [ns]	Std. Dev [ns]	Peak to Peak [ns]	Std. Dev [ns]
TW(TIM01, TIM02)	1,57	1,51	1,17	1,22
TW(TIM01, PTB01)	0,99	0,97	0,99	1,00
TW(TIM01, CH01)	1,01	1,01	1,00	1,03
TW(TIM02, PTB01)	1,02	0,99	0,98	1,00
TW(TIM02, CH01)	1,04	0,97	0,98	1,02
AVG	1,02	0,99	0,99	1,01

- Performance in ODD VS EVEN hours (CCD)
 - 1.5 times better in Peak-to-Peak & Std.Dev
- Performance with 240s VS 120s (CCD)
 - 1.2 times better in Peak-to-Peak & Std.Dev
- Performance in ODD VS EVEN hours (TW)
 - Equivalent in Peak-to-Peak & Std.Dev
- Performance with 240s VS 120s (TW)
 - Equivalent in Peak-to-Peak & Std.Dev

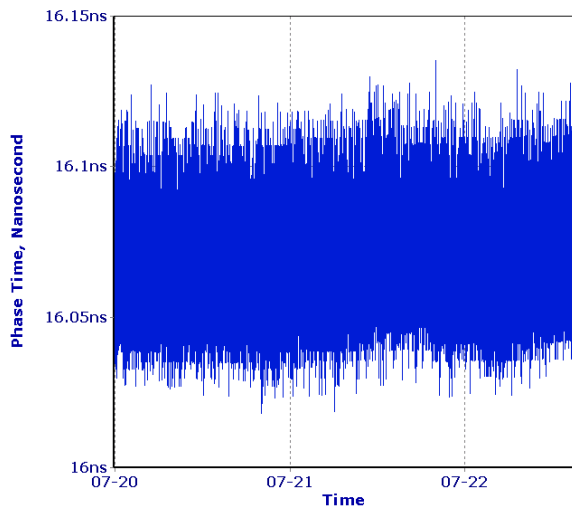
Performance of IIOTIC Reporting REFDLY Performance of Oplink



$$\text{REFDLY (Labi)} = \text{UTC(Labi)} - 1\text{PPSIN} + \text{Avg}\langle 1\text{PPSIN} - 1\text{PPSTX} \rangle \text{ (From IIOTIC)}$$

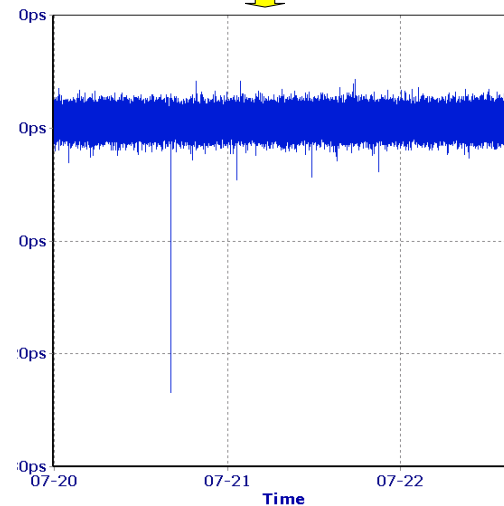
Link ID	Even Hour		Odd Hour			
	120		120		240	
NPL (s)						
Statistics	Peak to Peak [ns]	Std. Dev [ns]	Peak to Peak	Std. Dev	Peak to Peak	Std. Dev
TIM01 (REFDLY)	0,088	0,02	0,085	0,02	0,085	0,02
TIM02 (REFDLY)	0,063	0,013	0,058	0,011	0,058	0,011

$$\text{OPLINK (Labi)} = \text{Master Delay (From Ext.TIC)} + \text{Oplink Delay (From Slave)} + \text{CALR}$$



Phase vs. Time	
2012/07/20 00:00 - 07/22 15:00	
Instrument:	Mobile_Oplink-M
Source:	refgen8_TIC1@Par3
Remarks:	no comment
No Averaging	
Averaged Samples: None	
Sample Interval:	1 s
Min Value:	16018.095 ps
Max Value:	16135.224 ps
Average:	16067.015 ps
Std.Dev:	10.773 ps
Data Length:	226800 s
Peak-To-Peak:	117.129 ps
2-Sigma:	21.547 ps
Residuals(RMS):	10.663 ps
Scale:	50 ps/div
Data Gaps:	220

Peak to Peak 117ps, Std.Dev 10ps



Phase vs. Time	
2012/07/20 00:00 - 07/22 15:59	
Instrument:	Mobile_Oplink-M
Source:	refgen8_OPLK@Par2
Remarks:	no comment
No Averaging	
Averaged Samples: None	
Sample Interval:	1 s
Min Value:	-23.440 ps
Max Value:	7.800 ps
Average:	0.531 ps
Std.Dev:	0.692 ps
Data Length:	230399 s
Peak-To-Peak:	31.240 ps
2-Sigma:	1.385 ps
Residuals(RMS):	0.692 ps
Scale:	10 ps/div
Data Gaps:	235

Peak to Peak 31ps, Std.Dev 0.7ps

CCD and Three-Corner-Hat Round-Trip Closure (TCC)



$$\text{CCD} = \text{TW}(\text{Labi} - \text{Labj}) + \text{REFDLY}(\text{Labi}) - \text{REFDLY}(\text{Labj})$$

Link ID	Even Hour		Odd Hour			
	120		120		240	
Statistics	Peak to Peak [ns]	Std. Dev [ns]	Peak to Peak	Std. Dev	Peak to Peak	Std. Dev
CCD	1,955	0,442	1,099	0,265	0,841	0,203

$$\text{Closure analysis (stability): } [\text{TW}(1) - \text{TW}(2)] + [\text{TW}(2) - \text{TW}(3)] + [\text{TW}(3) - \text{TW}(1)] = 0$$

Link ID	Even Hour		Odd Hour			
	120		120		240	
Statistics	Mean [ns]	Std. Dev [ns]	Mean	Std. Dev	Mean	Std. Dev
[TIM01-TIM02-PTB01]	-0,477	0,734	0,352	0,374	0,261	0,407
[TIM01-TIM02-CH01]	0,621	0,425	-0,666	0,24	-0,677	0,266

Observations:

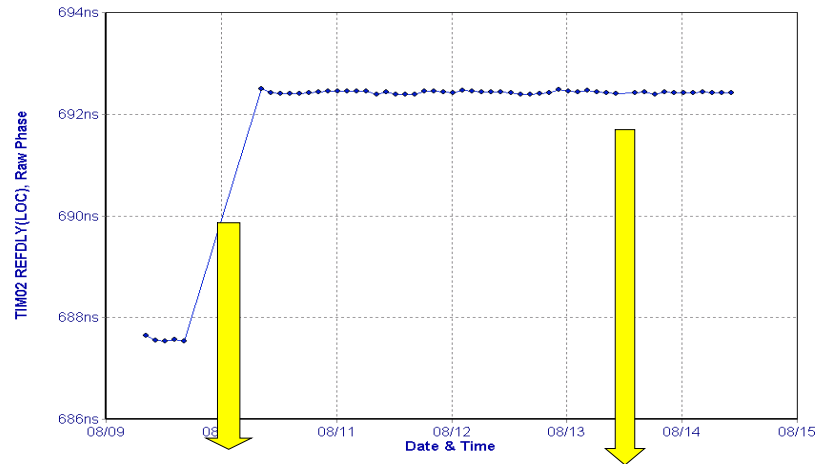
- Improved stability in Odd hour on both CCD and TCC
- Improved stability in CCD by increase in track length

OFF-ON Sequence Test



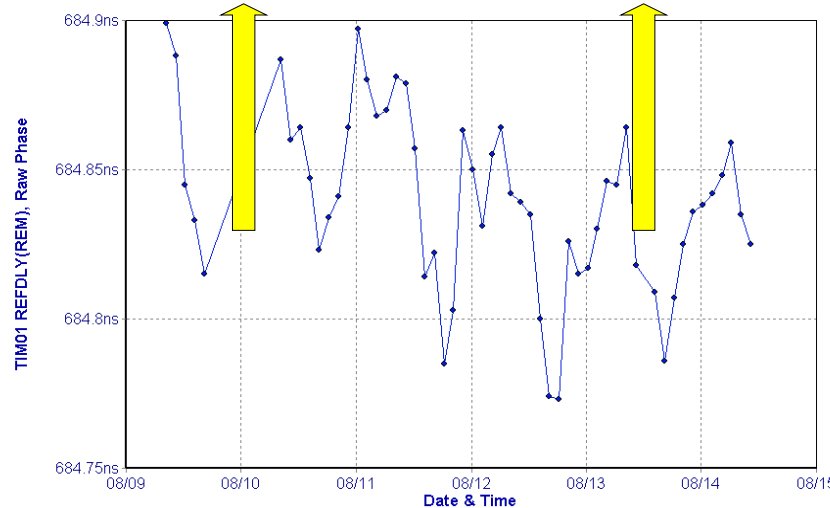
- Objective – Verifying repeatability of performance
- Participating labs PTB, AOS, CH, TIM (Fixed & Mobile)
- Performance of IOTIC reporting REFDLY
- Performance of Optical Link
- CCD Validation

OFF-ON Sequence Test – REFDLY (Fixed & Mobile)



TIM02 REFDLY(LOC)	
Start Time:	2012/08/09 08:19
End Time:	2012/08/14 10:19
Span:	5 days 2 hours
Sample Interval:	7200 s
Min:	687.528 ns
Max:	692.490 ns
Mean:	691.976 ns
PP:	4.962 ns
DRMS:	0.995 ns
Std.Dev:	1.410 ns
Drift / Second:	6.288E-15
Scale:	2 ns/div
Normalized by:	none

OFF- ON Sequence (Master/Slave Oplink + SATRE)



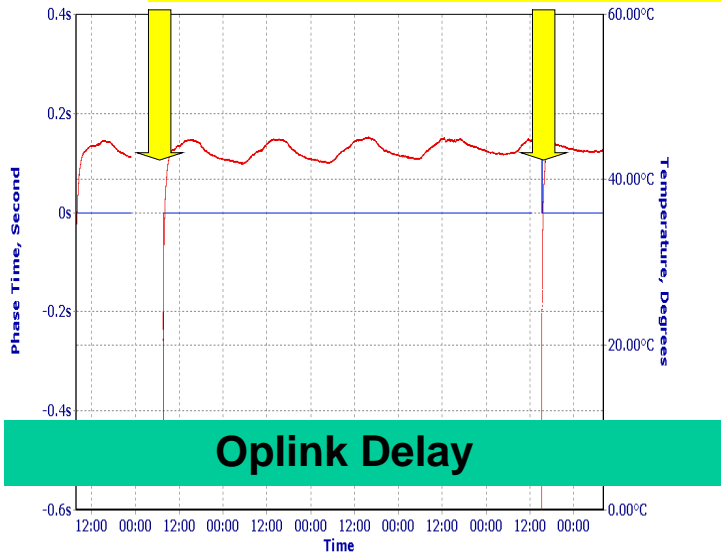
TIM01 REFDLY(REM)	
Start Time:	2012/08/09 08:19
End Time:	2012/08/14 10:19
Span:	5 days 2 hours
Sample Interval:	7200 s
Min:	684773.000 ps
Max:	684899.000 ps
Mean:	684839.870 ps
PP:	126.000 ps
DRMS:	26.627 ps
Std.Dev:	29.340 ps
Drift / Second:	-1.096E-16
Scale:	50 ps/div
Normalized by:	none

- Oplink shows instability of 5ns (Under Investigation)
- IIOTIC REFDLY [20ps @1day, 30ps @3day]

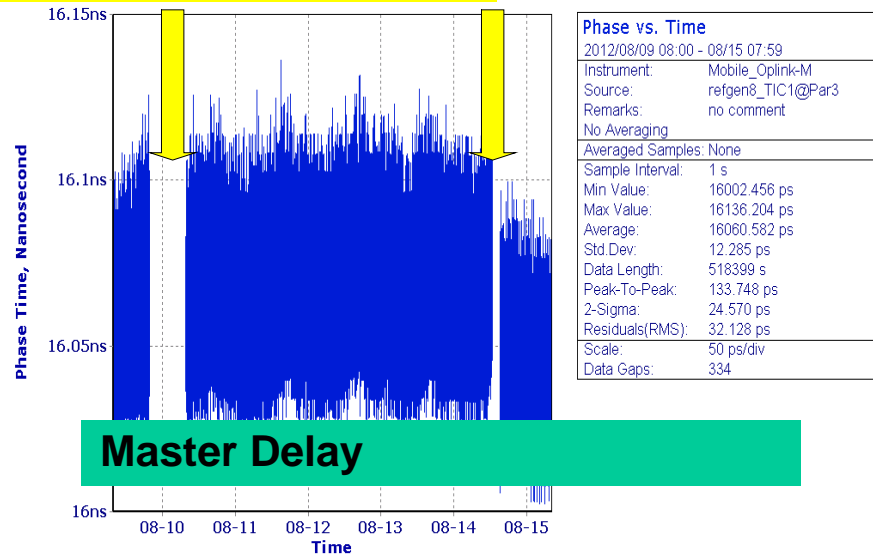
OFF-ON Sequence Test – OPLINK



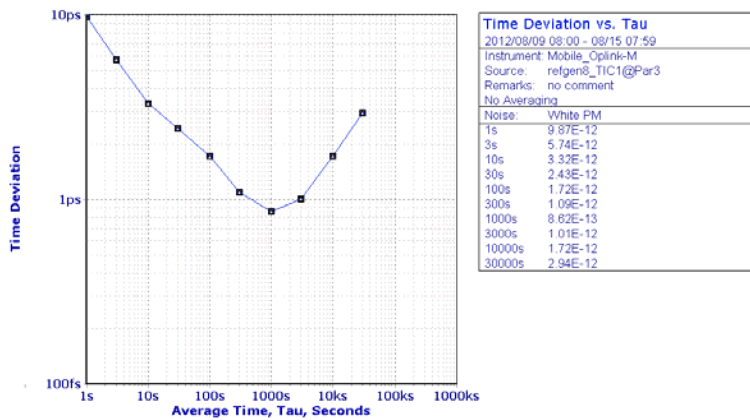
OFF- ON Sequence (Master/Slave Oplink + SATRE)



TimeTech DataAnalyzer v2.4 © TimeTech GmbH 2012



TimeTech DataAnalyzer v2.4 © TimeTech GmbH 2012



TimeTech DataAnalyzer v2.4 © TimeTech GmbH 2012

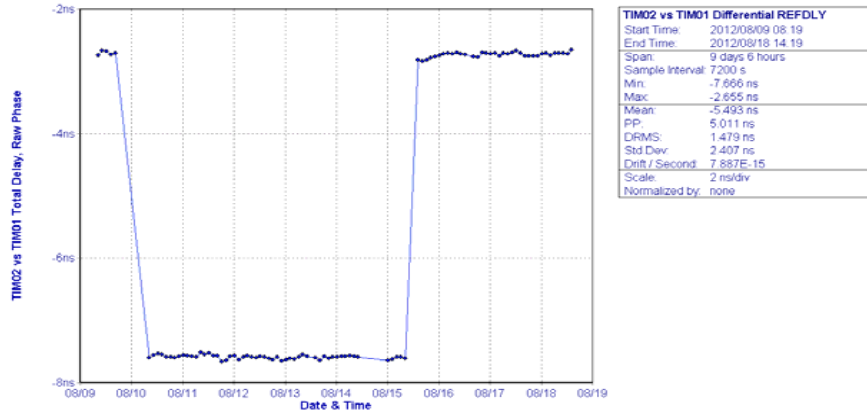
Oplink Not used in CCD computation
Even and Odd hours data combined together

TDEV: 2ps @ 1day -> As required!

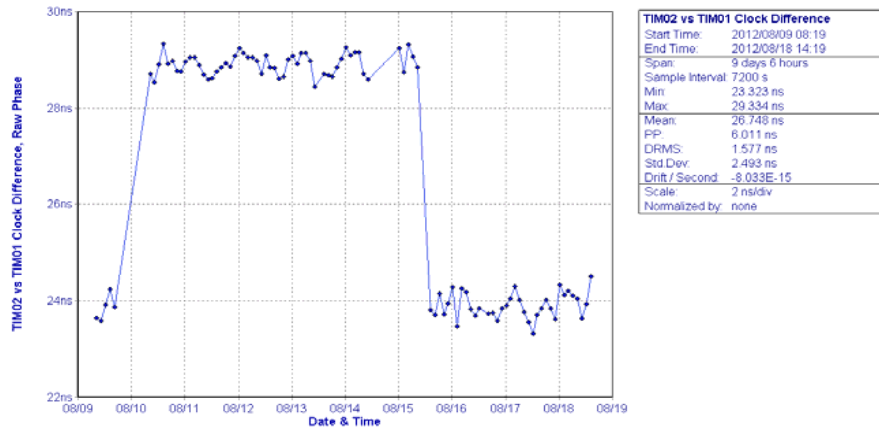
OFF-ON Sequence Test – CCD



Differential REFDLY (TIM02 vs TIM01)



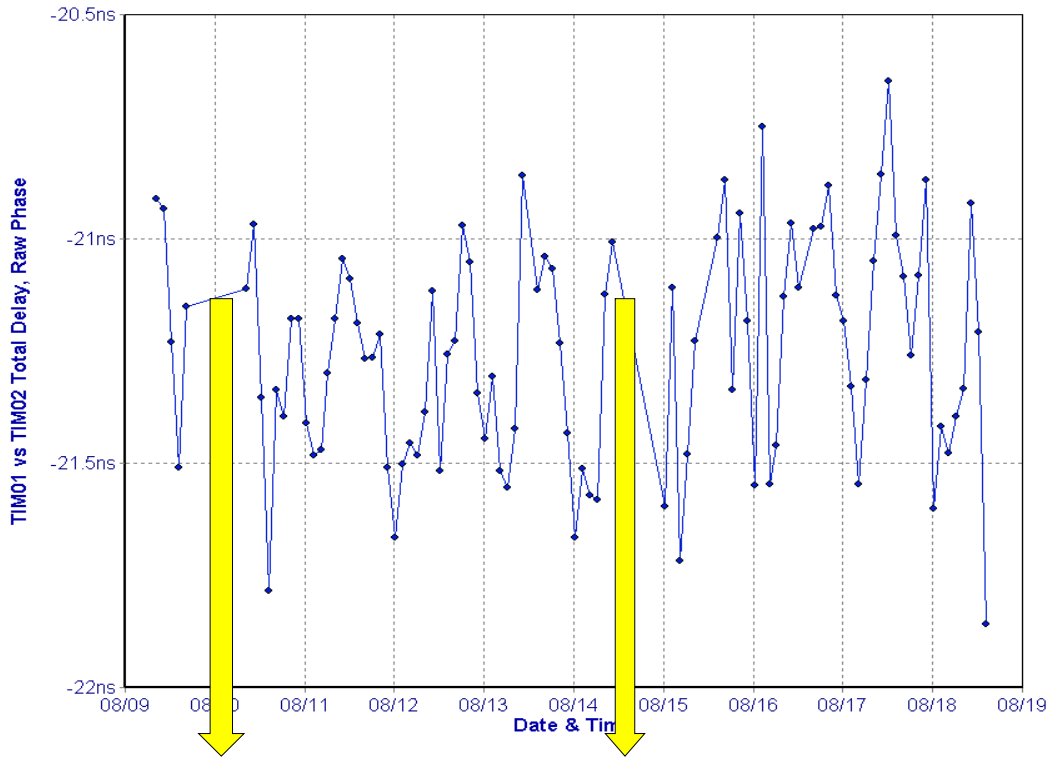
Differential TW (TIM02 vs TIM01)



Differential TW
 + Differential REFDLY

 = CCD (TIM01, TIM02)

OFF-ON Sequence Test – CCD



TIM01 vs TIM02 Total Delay	
Start Time:	2012/08/09 08:19
End Time:	2012/08/18 14:19
Span:	9 days 6 hours
Sample Interval:	7200 s
Min:	-21860.000 ps
Max:	-20649.500 ps
Mean:	-21255.226 ps
PP:	1210.500 ps
DRMS:	250.423 ps
Std.Dev:	248.724 ps
Drift / Second:	1.456E-16
Scale:	500 ps/div
Normalized by:	none

OFF- ON Sequence (Master/Slave Oplink + SATRE)

Note : 5ns PPS instability compensated with TW

OFF-ON Sequence Test – (CCD, TCC) Validation



$$\text{CCD} = \text{TW} (\text{Labi} - \text{Labj}) + \text{REFDLY} (\text{Labi}) - \text{REFDLY}(\text{Labj})$$

Link ID	Even Hour			Odd Hour		
NPL (s)	120			240		
Statistics	Peak to Peak [ns]	Std. Dev [ns]		Peak to Peak	Std. Dev	Peak to Peak
CCD (Total)	0,924	0,221		0,819	0,185	0,688

		CCD(Start)	SD[CCD(Start)]	CCD(End)	SD[CCD(End)]	CCD(Start - End)	CSD
Even Hour	120	23,854	0,219	23,87	0,166	0,016	0,385
Odd Hour	120	23,661	0,127	23,656	0,188	0,005	0,315
	240	23,708	0,04	23,869	0,126	0,161	0,166

Closure analysis (stability): $[\text{TW}(1) - \text{TW}(2)] + [\text{TW}(2) - \text{TW}(3)] + [\text{TW}(3) - \text{TW}(1)] = 0$

Link ID	Even Hour			Odd Hour		
NPL (s)	120			240		
Statistics	Mean [ns]	Std. Dev [ns]		Mean	Std. Dev	Mean
[TIM01-TIM02-PTB01]	-0,394	0,681		0,3	0,381	0,399
[TIM01-TIM02-CH01]	-0,152	0,44		-0,475	0,191	-0,154

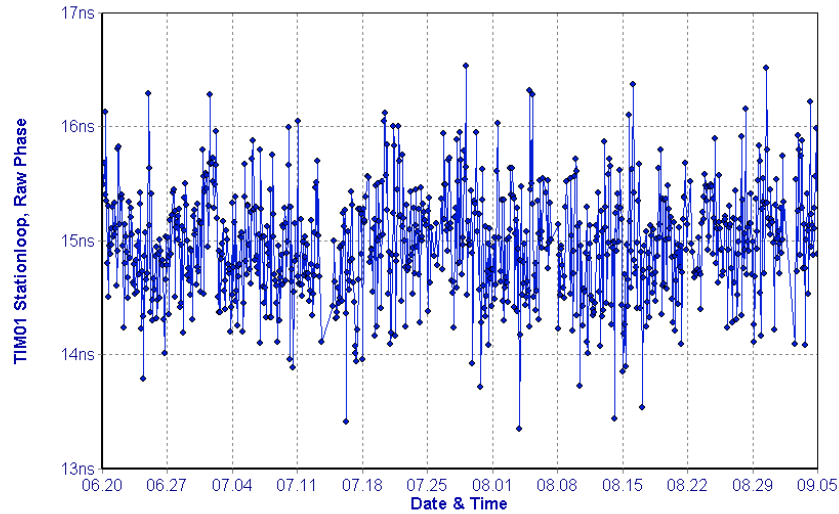
Results from former campaign

Campaign	CCD ₁	SD ₁	CCD ₂	SD ₂	CCD ₁ - CCD ₂	CSD
E1	4.146	0.148	4.304	0.261	0.158	0.300
E2	-278.024	0.196	-277.547	0.335	0.477	0.388
E2	694.683	0.034	694.135	0.624	0.548	0.625
E3	7.400	0.183	7.011	0.282	0.389	0.336
E4	41.025	0.306	41.116	0.597	0.091	0.671
E5	-20.102	0.157	-20.103	0.111	0.001	0.192

No.	Year	Participating institutes
E1	1997	TUG, DTAG, PTB
T1	2002	USNO, PTB
T2	2003	USNO, PTB
E2	2003	INRIM, PTB
E3	2004	PTB, VSL, OP, NPL
T3	2004	USNO, PTB
T4	2004	USNO, PTB
T5	2005	USNO, PTB
E4	2005	PTB, SP, VSL, NPL, OP, INRIM
T6	2006	USNO, PTB
E5	2006	TUG, PTB, METAS
T7	2007	USNO, PTB
T8	2007	USNO, PTB

Excellent match with earlier campaigns!!

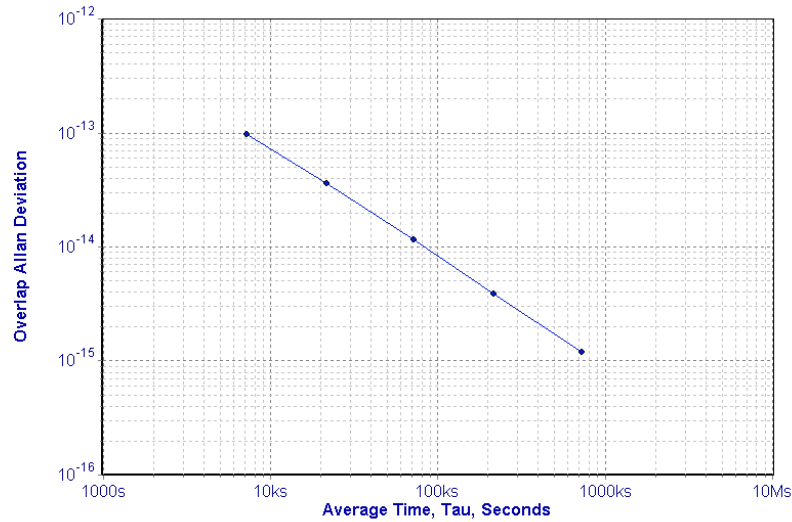
SATSIM Test (Stationloop of TIM01, fixed)



TIM01 Stationloop	
Start Time:	2012.06.20 01:00
End Time:	2012.09.04 23:00
Span:	76 days 22 hours
Sample Interval:	7200 s
Min:	13.347 ns
Max:	16.538 ns
Mean:	14.968 ns
PP:	3.191 ns
DRMS:	0.474 ns
Std.Dev:	0.476 ns
Drift / Second:	1.486E-17
Scale:	1 ns/div
Normalized by:	none

Station loop Delay = Tx Delay – Rx Delay

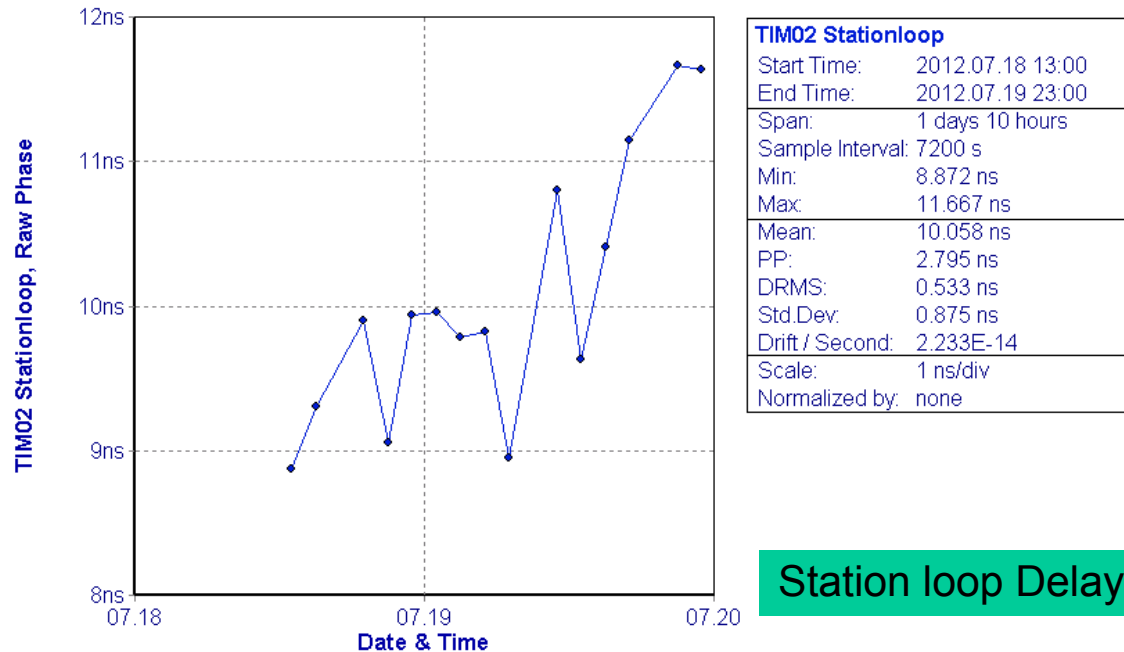
Peak-to-Peak 3ns, Std.Dev 0.476ns



Overlap Allan Deviation vs. Tau	
Start Time:	2012.06.20 01:00
End Time:	2012.09.04 23:00
Span:	76 days 22 hours
Noise:	White PM
7200s	9.72E-14
21600s	3.63E-14
72000s	1.16E-14
216000s	3.83E-15
720000s	1.18E-15

Not used in CCD computation
 Even and Odd hours data combined together
 No correction on Temperature Effect

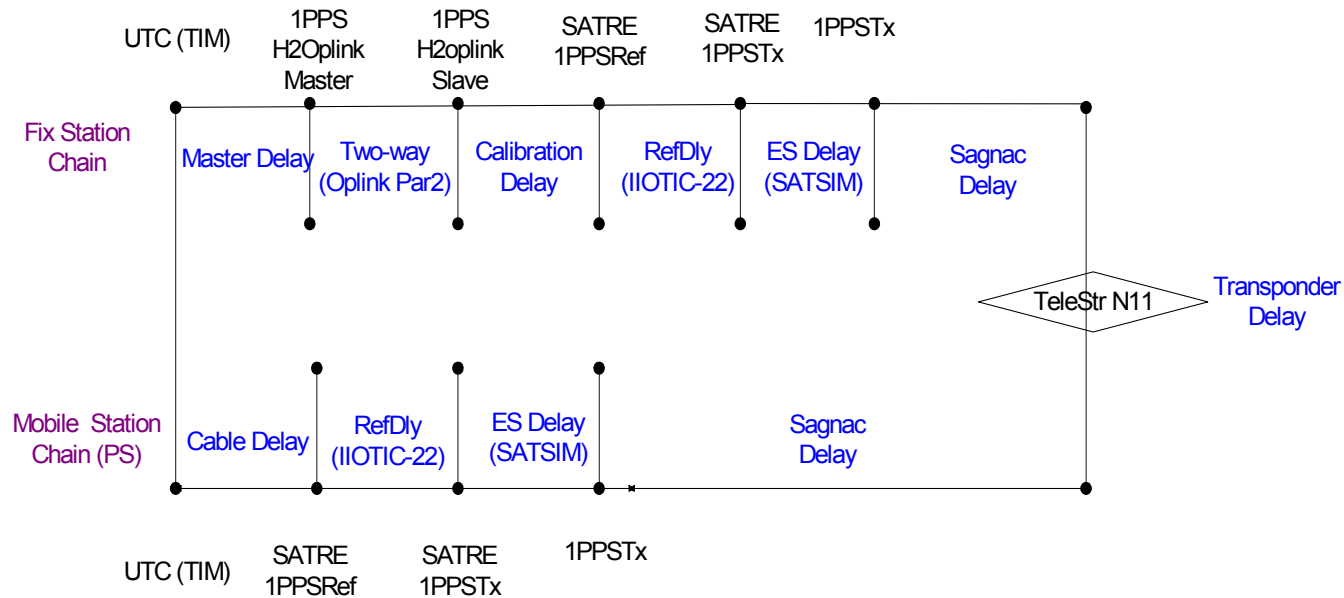
SATSIM Test (Stationloop of TIM 02, mobile)



Station loop Delay = Tx Delay – Rx Delay

High impact of temperature due to unstable air conditioner
Repeat SATSIM tests for Mobile station after solving the air conditioner issue

Signal Flow Chart & Complete Calibration Formula



$$\Delta VAR = [OPLINKVAR(2, 1) + ESVAR(2, 1)]$$

$$CCD(i, PS) = 0.5 * (TW(i) - TW(PS)) + REFDELAY(i) - REFDELAY(PS)$$

$$[UTC(1) - UTC(2)]_{Link} = 0.5 * (TW(i) - TW(PS@2)) + CCD(1, PS) + SCD(2) - SCD(1) - \Delta VAR$$

$$OPLINK(i) = Master Delay(From Ext.TIC) + Oplink Delay (From Slave) + CALR$$

$$CAL_{SITE}(1,2) = CCD(2, PS) - CCD(1, PS) + SCD(2) - SCD(1) - \Delta VAR$$

$$CAL_{Link}(1,2) = [UTC(1) - UTC(2)]_{Link} - 0.5 * (TW(1) - TW(2))$$

Leasons Learnt



- CCD can be improved by having odd hour sessions with long track period TW
- Adaptation of the AOS data format where the %22 message (REFDLY) is concacnated with the Rx output messages
- Inputs for analysis from all labs need to based on equivalent TW algorithim i.e. The quadratic fit algorithm without filtering
- Calibration Method proposed is LINK + SITE
- Temperature inside mobile station requires better stabilization

Further work



Solve Oplink 5ns Instability (offline, not affecting availability)

Install new air conditioning equipment (unavailable for 1 week)

Code vs Carrier phase Common Clock analysis

Some software improvements

Refine configuration control

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Commercial information



- Station ready by Oct. 1st
- Cost €6000 / participant
- 1 formal order from METAS (thanks!)
- Document „Site preparation“ available
- Calibration includes:
 - Pre-test verification (on-site), 4 hrs max
 - Installation & setup, 4 hrs max
 - 3 days measurements, automatic operation
 - Real-time data quality assessment
 - Post test verification (on site), 4 hrs max
 - Dismounting / packing (on site), 4 hrs max
 - All test data in text format
 - Calibration Protocol (on-site), signed by Lab and TIM
 - Calibration Report (after the trip)
- Support by 1 person of the lab is required

Summary & Conclusions



- The Mobile Calibration Station successfully achieved test objectives
- Common clock test results compatible with earlier results
- Appropriate analysis tools are available
- A dedicated calibration schedule has been established
- 3 day calibration duration has been found optimum
- Configuration control implemented
- Station ready for starting campaign in Europe