Report

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Doc. No:	CAL-TIM-RP-0002		
Prepared by:	(TIM) A. Balu		Date: 3 Dec 2013
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Iss. / Rev. Date	Page	Chapter	Description of Change	Release
1/0	All	All	Initial release	A. Balu
1/1	7,9,24,26,41	7,9,18	Corrected TIC representation in the mobile station, typos, interface to the station	A. Balu

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1 Introduction

From 26 April 2013 to 22 May 2013 a calibration campaign using a mobile calibration trailer was carried out between VSL, AOS and TimeTech to measure the differential delays between the on-time reference points, by collocating the mobile trailer with the reference stations

The Mobile Station was operated by Arvind Balu.

1.1 Participants

Following are the list of participants in the calibration campaign:

Abbreviation	Full Name & Contact	Address
TIM	TimeTech GmbH Shuo Liu Arvind Balu	Curiestrasse 2 D-70563 Stuttgart Germany Phone: +49-711-678080
VSL	VSL, Dutch Metrology Institute Erik Dierikx	Thijsseweg 11, 2629 JA, DELFT, The Netherlands Phone: +31 15 269 16 88
AOS	AOS, Astrogeodynamical Observatory, Borowiec near Poznan. Dr Jerzy Nawrocki	Space Research Centre P. A. S. PL 62-035 KORNIK, Poland Phone: +48-61-8-170-187 Fax: +48-61- 8-170-219,

2 Documents, Abbreviations

2.1 Documents

2.1.1 Applicable Documents

REF	Doc Number	Iss/Rev	Title
[AD1]			
[AD2]			
[AD3]			
[AD4]			

2.1.2 Reference Documents

REF	Title	Author
[RD1]	Directive for operational use and data handling in two-way satellite time and frequency transfer (TWSTFT)	A. Bauch et al
[RD2]	Calibration of Six European TWSTFT Earth Stations Using a Portable Station	D.Piester et al
[RD3]	Calibration of TWSTFT links through the triangle closure condition	Z.Jiang et al
[RD4]	Time Transfer with nanosecond accuracy for realization of International Atomic Time	D.Piester et al

2.2 Abbreviations

CALR	Calibration value
CC	Clean Carrier
CCD	Common Clock difference
FDIS	Frequency Distribution Amplifier
hh	Hour
IIOTIC	Intelligent In/Out & Time Interval Counter
kHz	kilohertz
LAN	Local Area Network
MHz	Megahertz
MJD	Modified Julian Date
mm	Minute
ns	nanosecond
OF	Optic Fiber
PDIS	Pulse Distribution Amplifier
PN	Pseudo-random Noise
PPS	Pulse per second
ps	picosecond
Ref	Reference
Rx	Receiver
Sqrt	Square root
ss	Second
TIC	Time Interval Counter
TWSTFT	Two Way satellite time and frequency transfer
Tx	Transmitter
UTC	Coordinated Universal Time
UTC(Cal)	UTC point assigned for calibration campaign
WAN	Wide Area Network
WLAN	Wireless Local Area Network

Table 2-1

2.3 Acronyms

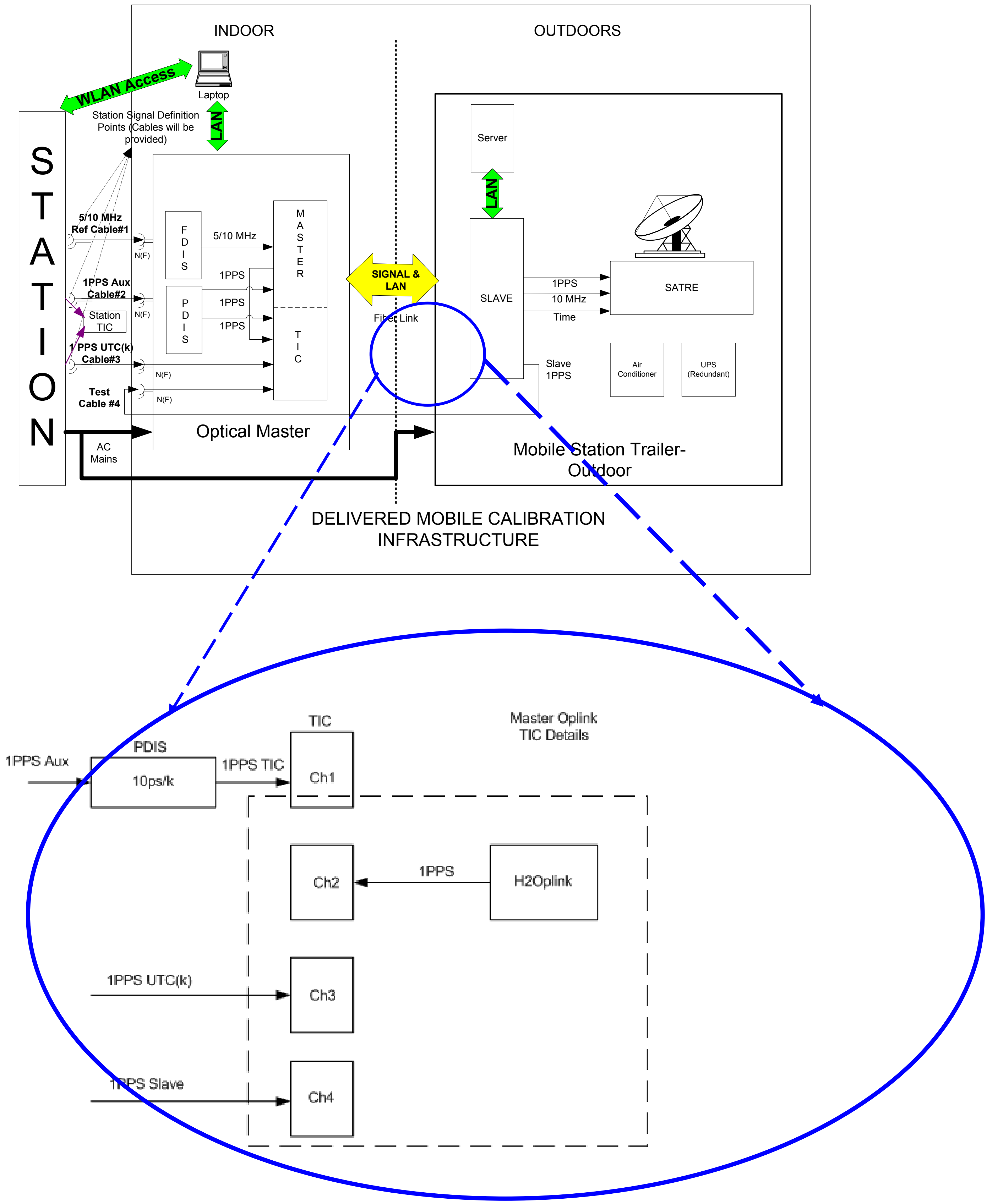
CAL(i,k)	Calibration value, which has to be added to the raw TWSTFT measurement result between stations i, k to yield the true time difference between the clocks at stations i and k.
CCD(I,k)	Common clock difference, TWSTFT measurement result between two TWSTFT setups (i,k) at one site, connected to the same clock.
DLD(i)	Difference of signal propagation delay through the transmit and receive path of station i, Tx(i) – Rx(i).
EDV	Earth station delay variation, used to report known changes in the setup of a TWSTFT ground station.
GEO	Geostationary satellite.
PS	Portable station, short form for a transportable TWSTFT ground station used in calibration experiments.
REFDELAY	Reference delay, time difference between the local time scale and the modem 1PPS output synchronous with the Tx signal.
Rx(i)	Signal delay in the receive path of TWSTFT station i.
SCD(i)	Sagnac delay for a signal propagating from the GEO satellite to station i.
SCU(i)	Sagnac delay for a signal propagating from the station i to GEO satellite.
SP(i)	Complete signal path delay from station i to station k through station k through the GDO, SPU(k) + SPT(k) + SPD(i)
TD	Total Delay
TIC	Time interval counter
TW(i)	Counter reading in TWSTFT station i.
TX(i)	Signal delay in the transmit path of the TWSTFT station i.

Table 2-2

3 Station Signal Interface

3.1 Scheme

Station Signal Interface



3.2 Interface Cable description

The following cables are the common interface to the Master Blue box of the oplink. The Cable #2 and Cable #3 also have N(M) to BNC adapters connected.

Cable #	Signal type	Cable Length	Cable Type	Connectors
Cable #1	5/10 MHz Ref	7.5m	RG223	N(M) - N(M)
Cable #2	1PPS(Aux)	7.5m	RG223	N(M) - N(M)
Cable #3	1PPS UTC(k)	7.5m	RG223	N(M) - N(M)

Table 3-1

3.3 Trigger levels

Lab	UTC	1PPS(Aux)	1PPS Tx
VSL	+ slope @ 1.0 V	+ slope @ 1.0 V	+ slope @ 1.0 V
AOS	+ slope @ 1.0 V	+ slope @ 1.0 V	+ slope @ 1.0 V
TIM (Fixed)	+ slope @ 1.0 V	+ slope @ 1.0 V	+ slope @ 0.6 V
TIM (Mobile)	Not applicable	+ slope @ 1.0 V	+ slope @ 0.5 V

Table 3-2

The trigger level of 1PPS Tx in the TIM (Mobile) is set to ~ 50% of the 1PPS level and these levels remain unchanged throughout the calibration and after. The signal load is 50 Ohms.

The 1PPS Tx signal is the one from the SATRE Tx module to the IIOTIC in the case of TIM, VSL and AOS.

3.4 Mobile Station REFDELAY Signal Path at Stations

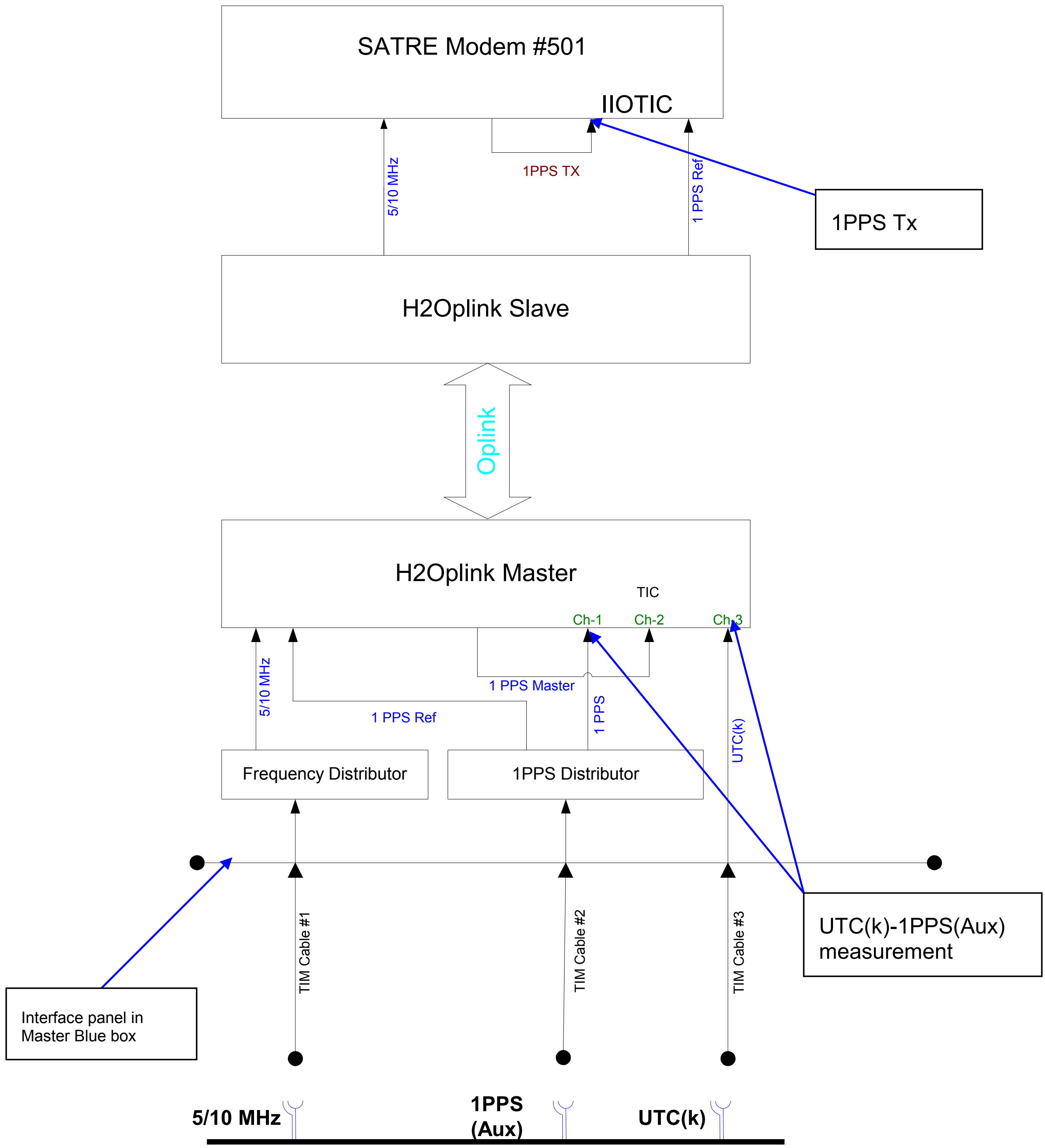


Figure 3-1: Station Interface with depiction of the 1PPS trigger points

3.5 Principle of operation of the Oplink

The optical link in mobile station refers all measurements to 1PPS(Aux) input, independent of the phase of the reference frequency. The operation of the optical link has the additional effect, that it presents coherent and phase stable 10 MHz & 1pps signals to the SATRE Modem in the mobile station, hence the frequency input to that SATRE follows the phase of the local 1PPS(Aux) signal. The IIOTIC in SATRE-Mobile shall read always the same value and does not need to be applied as a correction.

Hence, the 1PPS(Aux) signal from the station corresponds to the 1PPS TX to the calibration station SATRE in terms of phase and absolute delay stability.

This is in contrast to normal SATRE operation, where the measurements are referred to the reference frequency. The difference to local 1pps is measured with the built-in IIOTIC, which has to be applied to all measurements.

Please note, that this difference in operations might show as inconsistencies between a fixed station and the mobile station, in particular if the fixed station is not corrected for REFDLY / IIOTIC values.

4 Work flow

The differential earth station delays between the TWSTFT stations VSL01, AOS01 and TIM01 with respect to the calibrating station TIM02 co-located at each site had to be determined. The first measurements at TimeTech at the beginning of the campaign were verified by a second series of measurements at TimeTech at the end of the campaign.

4.1 Schedule

Day	DoW	Date	MJD	From	To	Activity
1	Fri	26.04.2013	56408			Start TIM
6	Tue	01.05.2013	56413	TIM	VSL	Travel to VSL
7	Wed	02.05.2013	56414			Start VSL
15	Fri	10.05.2013	56422	VSL	AOS	Travel to AOS
16	Sat	11.05.2013	56423			Start AOS
20	Tue	15.05.2013	56427	AOS	TIM	Travel to TIM
21	Wed	16.05.2013	56428	TIM		Start TIM
27	Tue	22.05.2013	56434			End of campaign

Table 4-1

4.2 TWSTFT Station Identifier of the Participating Laboratories

Station	Station ID	Description
TIM	TIM01	Even hour 2min Session
	TIM11	Odd hour 2min Session
	TIM02	Even hour 2min Session
	TIM12	Odd hour 2min Session
VSL	VSL01	Even hour 2min Session
	VSL11	Odd hour 2min Session
AOS	AOS01	Even hour 2min Session
	AOS11	Odd hour 2min Session

Table 4-2

4.3 Satellite: TELSTAR 11N

Satellite Name	Position	Uplink Frequency	Downlink Frequency
TELSTAR 11N	37.5 ° W	14260.150MHz	10960.150MHz

Table 4-3

Longitude 37° 30’
Beacon: 11699.5 MHz vertical Polarisation
11198.25 MHz horizontal Polarisation

4.4 TWSTFT Earth stations' Geographical Positions and Pointing Data

4.4.1 Pointing of Mobile Calibration trailer antenna while at TIM

TELSTAR 11N at 37.5° W	Pointing on site of TIM		
	deg	Min	Sec
Longitude Earth Station	09	06	45.106
Latitude Earth Station	48	44	16.272
Earth Station Elevation nominal	18.5°		
Earth Station Azimuth nominal	234.6°		
Antenna Azimuth set / Course displayed	10°/227.5°		
Antenna elevation set	18.5°		
Polarisation set	121°		

Table 4-4

4.4.2 Pointing of Mobile Calibration trailer antenna while at VSL

TELSTAR 11N at 37.5° W	Pointing on site of VSL		
	deg	Min	Sec
Longitude Earth Station	4	23	16.94
Latitude Earth Station	51	59	7.82
Earth Station Elevation nominal	19.1°		
Earth Station Azimuth nominal	228.7°		
Antenna Azimuth set / Course displayed	340.995°/227°		
Antenna elevation set	21.99°		
Polarisation set	121°		

Table 4-5

4.4.3 Pointing of Mobile Calibration trailer antenna while at AOS

TELSTAR 11N at 37.5° W	Pointing on site of AOS		
	deg	Min	Sec
Longitude Earth Station	17	04	32.784
Latitude Earth Station	52	16	31.421
Earth Station Elevation nominal	13°		
Earth Station Azimuth nominal	238°		
Antenna Azimuth set / Course displayed	118°/237.9°		
Antenna elevation set	13.49°		
Polarisation set	121°		

Table 4-6

Note: The longitude and latitude of the earth stations are recorded from the standard TWSTFT ITU files [RD1]. The 'Earth Station Elevation' and the 'Earth Station Azimuth' are the values obtained as the predicted Az and El for the given coordinates of the earth station. Antenna Azimuth set is the azimuth with respect to the trailer position and the Course displayed is the true Azimuth. The antenna control unit has a GPS receiver and an Az/El compass that steers the antenna to the desired coordinates.

4.4.4 Assigned Codes and Clean Carrier Offsets

Following are the code and clean carrier offsets of the Participating Two-way Laboratories and the mobile calibration station

TWSTFT Station ID	PNCode	Clean Carrier [kHz]	Carrier Offset [kHz] (i.e. CC /sqrt(5))
TIM	14	-30	-13.416
VSL	2	+20	+8.944
AOS	11	+30	+13.416
TIM02	31	-70	-31.305

Table 4-7

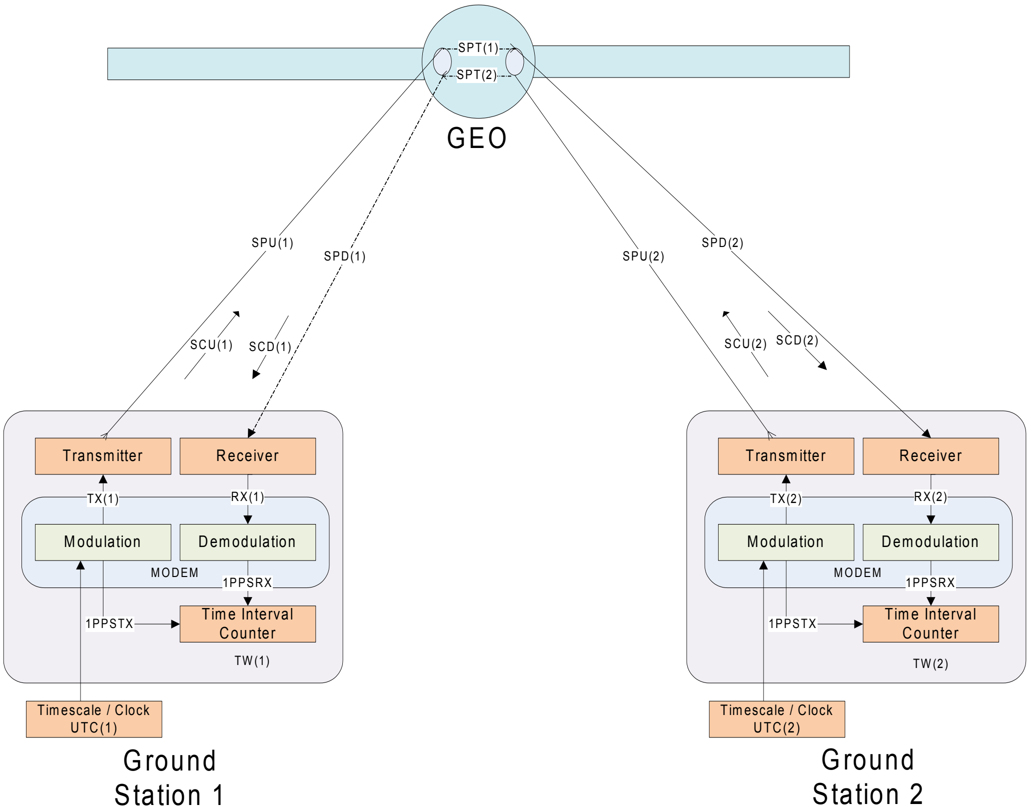
4.4.5 Basic Time Table for the Two-way Measurements

During the campaign, all the participating stations had the transmission ON, in the odd hours from 04:00 to 22:00 minutes. The even hour measurements were as per the regular Two-way sessions. The schedule for receive is per the table below.

Start	End	Action	Length	VSL11		PTB11		CH11		AOS11		TIM11		TIM12		
			s	c		e		n		q		t		v		File Char
hhmmss	hhmmss			20		40		10		30		-30		-70		Offset kHz
				2		4		9		11		14		31		Tx code
				Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	
01:04:00	01:04:59	Prep.time	60	2	2	4	4	9	9	11	11	14	14	31	31	
01:05:00	01:06:59	Measure	120	2	2	4	4	9	9	11	11	14	14	31	31	
01:07:00	01:07:59	Prep.time	60	2	4	4	2	9	11	11	9	14	31	31	14	
01:08:00	01:09:59	Measure	120	2	4	4	2	9	11	11	9	14	31	31	14	
01:10:00	01:10:59	Prep.time	60	2	14	4	11	9	31	11	4	14	2	31	9	
01:11:00	01:12:59	Measure	120	2	14	4	11	9	31	11	4	14	2	31	9	
01:13:00	01:13:59	Prep.time	60	2	31	4	9	9	4	11	14	14	11	31	2	
01:14:00	01:15:59	Measure	120	2	31	4	9	9	4	11	14	14	11	31	2	
01:16:00	01:16:59	Prep.time	60	2	9	4	14	9	2	11	31	14	4	31	11	
01:17:00	01:18:59	Measure	120	2	9	4	14	9	2	11	31	14	4	31	11	
01:19:00	01:19:59	Prep.time	60	2	11	4	31	9	14	11	2	14	9	31	4	
01:20:00	01:21:59	Measure	120	2	11	4	31	9	14	11	2	14	9	31	4	
				VSL01		PTB01		CH01		AOS01		TIM01		TIM02		Station
00:09:00	00:09:59	Prep.time	60	2		4		9	31	11		14		31	9	
00:10:00	00:11:59	Measure	120	2		4		9	31	11		14		31	9	
00:15:00	00:15:59	Prep.time	60	2		4		9		11	31	14		31	11	
00:16:00	00:17:59	Measure	120	2		4		9		11	31	14		31	11	
00:18:00	00:18:59	Prep.time	60	2		4		9		11		14	31	31	14	
00:19:00	00:20:59	Measure	120	2		4		9		11		14	31	31	14	
00:33:00	00:33:59	Prep.time	60	2		4	31	9		11		14		31	4	
00:34:00	00:35:59	Measure	120	2		4	31	9		11		14		31	4	
00:51:00	00:51:59	Prep.time	60	2	31	4		9		11		14		31	2	
00:52:00	00:53:59	Measure	120	2	31	4		9		11		14		31	2	

Table 4-8: Scheduler for the campaign

5 Calculation of the CALR Value from the Two-way Equation



The following two equations are derived from the above scheme (abbreviations described in 2.3),

TW(1) = UTC(1) – UTC(2) + TX(2) + SP(2) + RX(1) + SCD(1) – SCD(2) + REFDELAY(1) – REFDELAY(2) (1)

TW(2) = UTC(2) – UTC(1) + TX(1) + SP(1) + RX(2) + SCD(2) – SCD(1) + REFDELAY(2) – REFDELAY(1) (2)

Assuming a complete reciprocity of the signal path: SP(1) = SP(2). The signal path consists of three components, SPU, SPT and SPD. The time-scale difference can be computed by subtraction of (2) from (1) and combined with laboratory UTC:

UTC(1) – UTC(2) = 0.5 * [TW(1) – TW(2)] + [REFDELAY(1) – REFDELAY(2)]

+{0.5 * [DLD(1) – DLD(2)] + [SCD(2) – SCD(1)]} (3)

Here, DLD(i) is the signal-delay difference between the transmitter and the receiver part of station i, and REFDELAY(i) is the signal-delay between the UTC(i) and 1PPSTX(i). i.e.

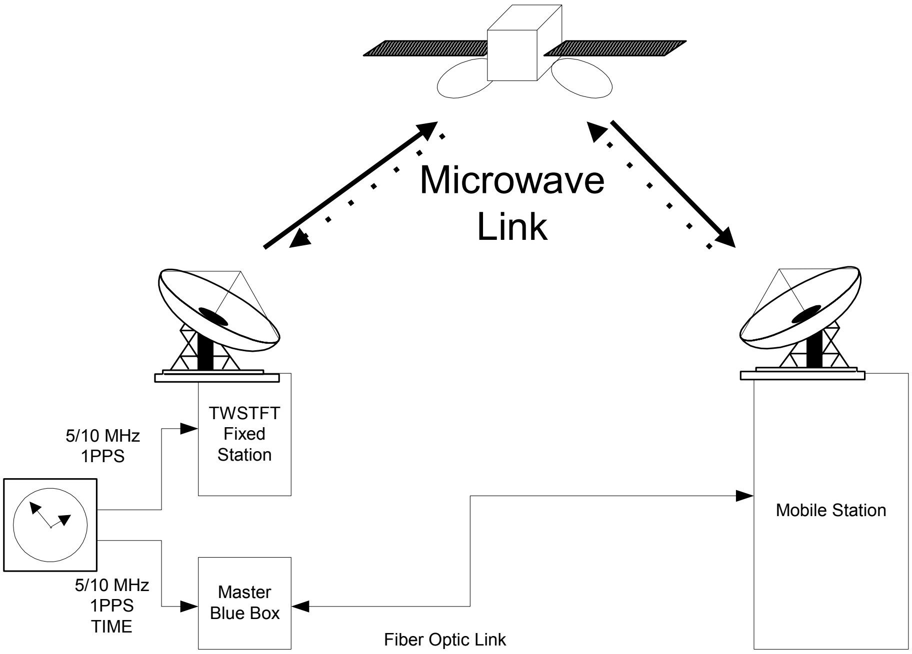
REFDELAY(i) = UTC(i) – 1PPSTX(i)

DLD(i) = TX(i) − RX(i)

The calibration value between sites 1 and 2 is defined as CALR(1,2), which contains the terms in curly brackets in equation (3)

$$\mathrm{CALR}(1, 2) = 0.5 * [\mathrm{DLD}(1) - \mathrm{DLD}(2)] + [\mathrm{SCD}(2) - \mathrm{SCD}(1)] \qquad (4)$$

For its determination, two different approaches, LINK and SITE methods, are applicable. In this calibration report, the calibration values for participating stations are calculated by SITE method as illustrated in the following:
For the description of the interfaces and the reference points please refer to the scheme in section 1.2.



First, the mobile station (TIM02) is operated in parallel to station 1 as shown in above figure connected to a common clock via optical link. Equation (3) is, thus simplified to

$$0 = 0.5 * [\mathrm{TW}(1) - \mathrm{TW}(\mathrm{TIM02})] + \mathrm{REFDELAY}(1) - \mathrm{REFDELAY}(2) + 0.5 * [\mathrm{DLD}(1) - \mathrm{DLD}(\mathrm{TIM02})]$$

5.1 The common-clock difference

CCD(1, TIM02) is defined as – 0.5 * [DLD(1) – DLD(TIM02)] and is determined from a TWSTFT measurement between Station 1 and TIM02 as:

$$\mathrm{CCD}(1, \mathrm{TIM02}) = 0.5 * [\mathrm{TW}(1) - \mathrm{TW}(\mathrm{TIM02})] + \mathrm{REFDELAY}(1) - \mathrm{REFDELAY}(\mathrm{TIM02}) \qquad (5)$$

The similar equation can be obtained when the mobile station is operated with station 2, i.e.

$$\mathrm{CCD}(2, \mathrm{TIM02}) = 0.5 * [\mathrm{TW}(2) - \mathrm{TW}(\mathrm{TIM02})] + \mathrm{REFDELAY}(2) - \mathrm{REFDELAY}(\mathrm{TIM02}) \qquad (6)$$

Then Subtracting (5) from (6) gives

$$\mathrm{CCD}(2, \mathrm{TIM02}) - \mathrm{CCD}(1, \mathrm{TIM02}) = 0.5 * [\mathrm{DLD}(1) - \mathrm{DLD}(\mathrm{TIM02})] - 0.5 * [\mathrm{DLD}(2) - \mathrm{DLD}(\mathrm{TIM02})]$$

$$= 0.5 * [\mathrm{DLD}(1) - \mathrm{DLD}(2)] \qquad (7)$$

Combined (7) with (4), the final equation is

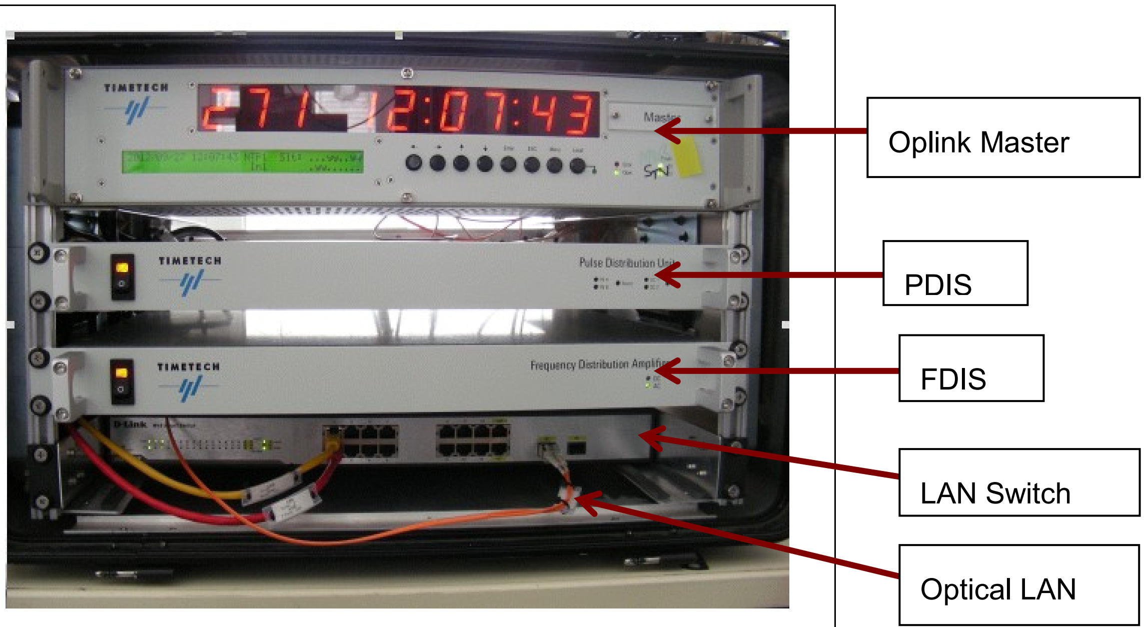
$$\mathrm{CALR}\ (1, 2) = \mathrm{CCD}(2, \mathrm{TIM02}) - \mathrm{CCD}(1, \mathrm{TIM02}) + [\mathrm{SCD}(2) - \mathrm{SCD}(1)]$$

6 Elements of the Mobile Calibration Station

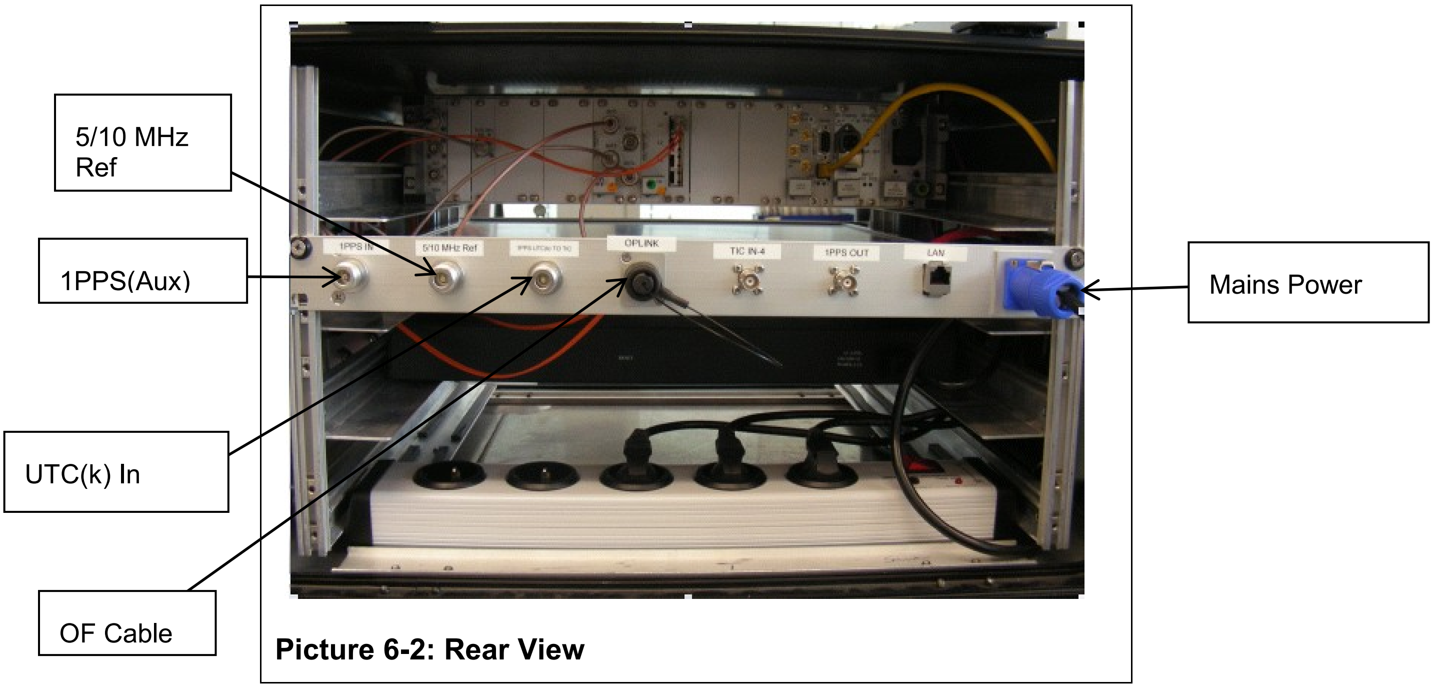
6.1 Optical Link Master

The Oplink master (in the blue box) is the Interface to the Station references namely 1PPS(Aux), 5/10 MHz reference and the 1PPS UTC(Cal) signals. The optic fiber (OF) cable from the Blue box is connected to the trailer.

The Blue Box consists of the Master Oplink, Pulse Distribution Unit (PDIS), Frequency Distribution unit (FDIS) and the LAN Switch.



Picture 6-1: Front View



Picture 6-2: Rear View

6.2 Fiber optic cable

Fiber optic cable drum with 500m cable

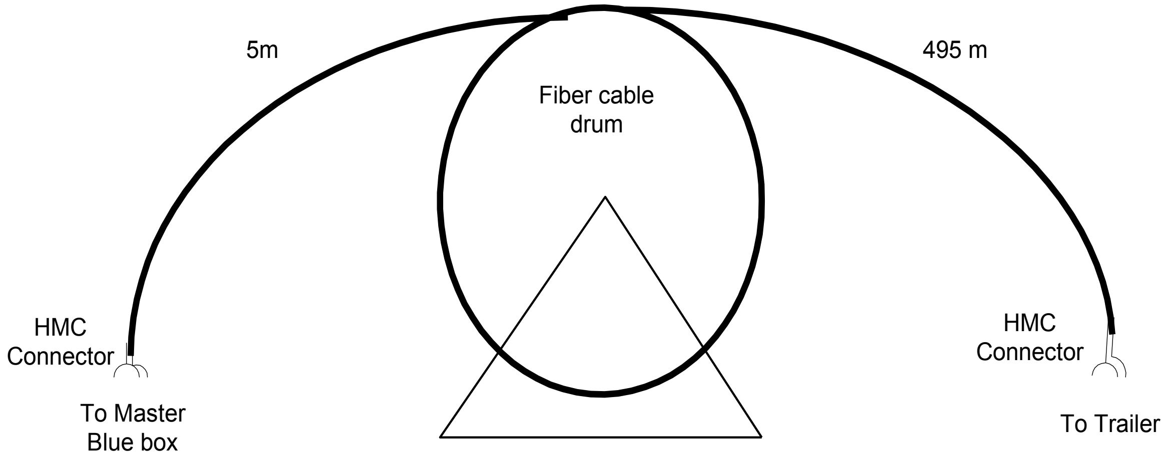
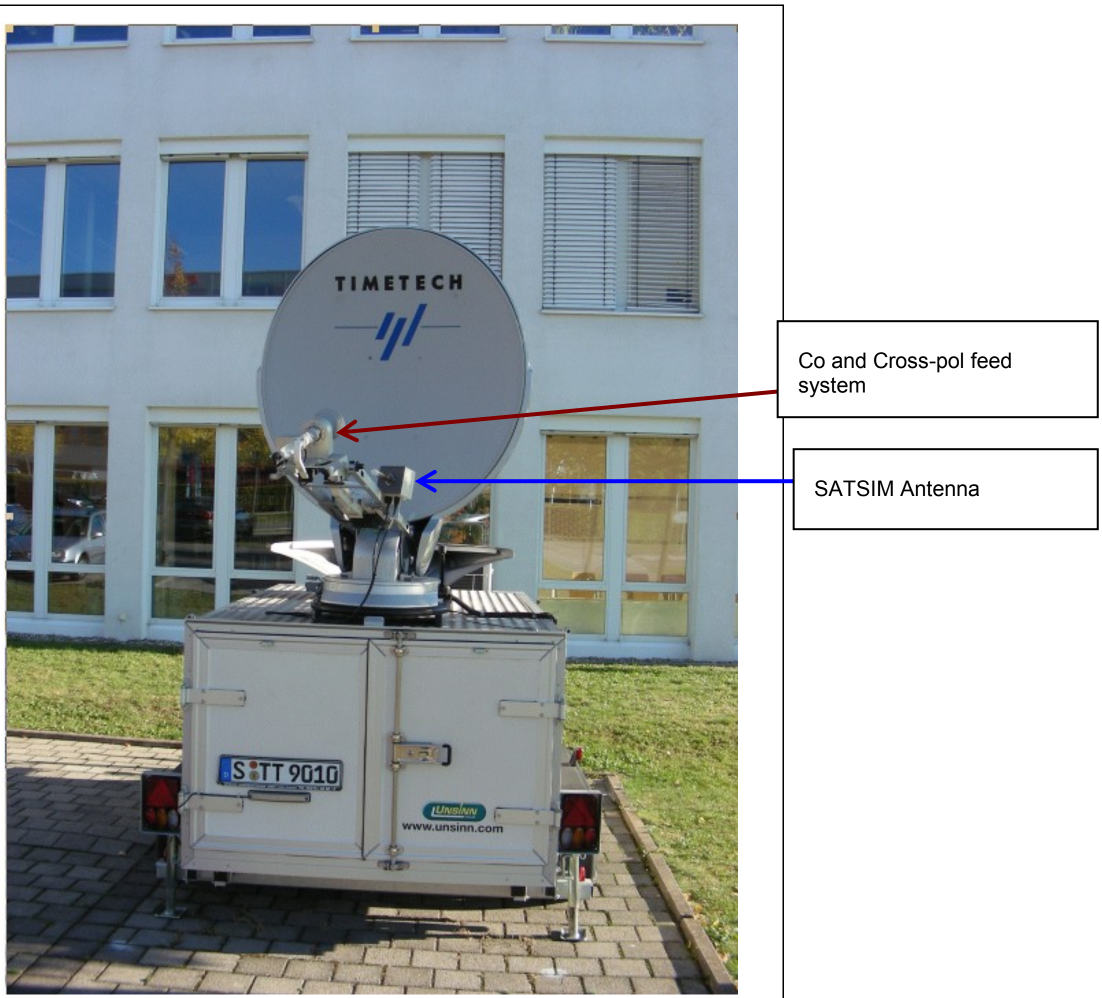


Figure 6-1: Depiction of the cable drum

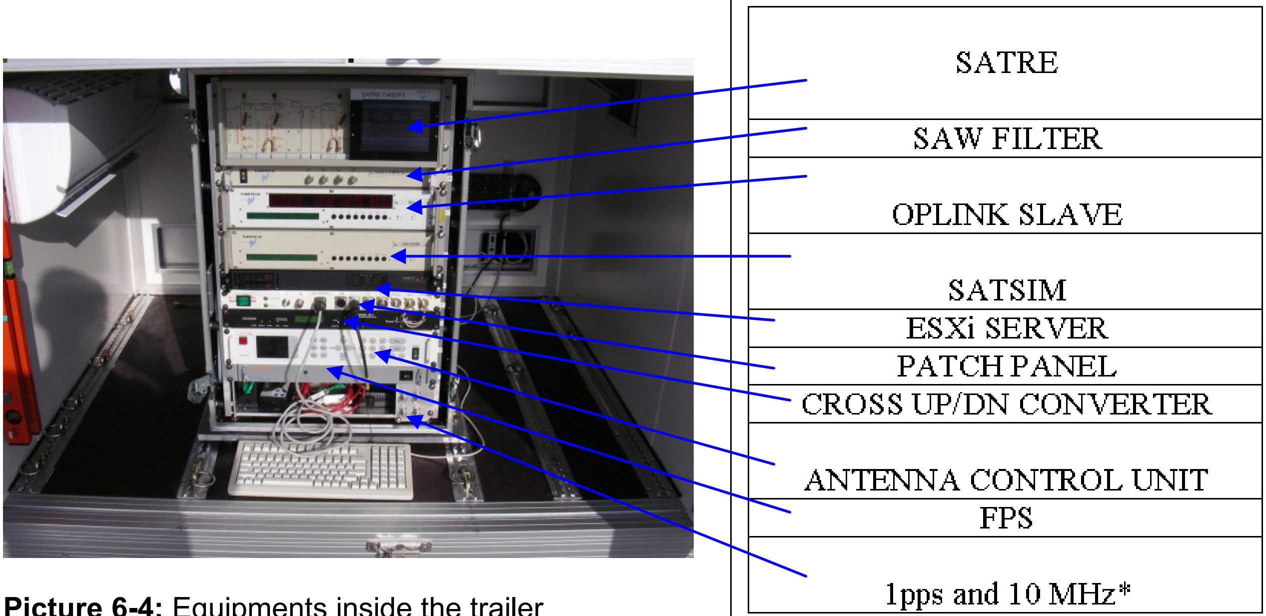
The fiber optic cable is the transmission medium for the references (Frequency and 1PPS) from the two-way room of the laboratories to the trailer during the calibration campaign. The cable drum is placed in the TW room with one of the designated end of the cable connected to the blue box in the TW Laboratory and the other designated end is connected to the optical interface in the trailer.

6.3 The Trailer

The mobile calibration trailer includes a temperature controlled climatic chamber and an uninterruptible power supply (UPS). This trailer houses the SATRE, SATSIM, SAW Filter, Slave Oplink, Antenna Control Unit (ACU), Ku Band Up/Down converter and the Control computer and ESXi Server.



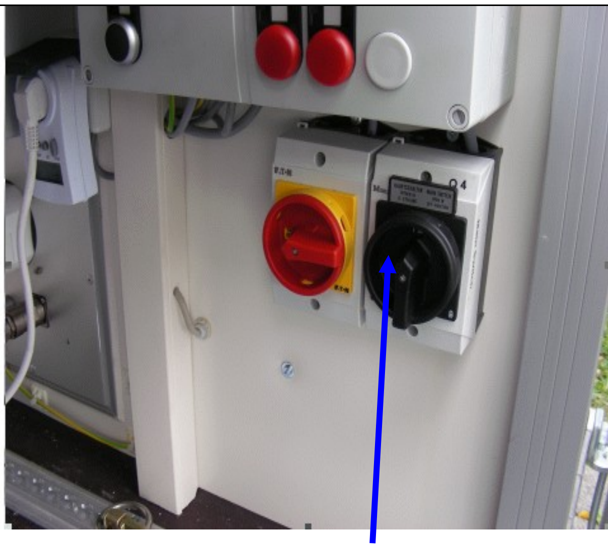
Picture 6-3: The trailer with the antenna unstowed and pointing to the satellite



Picture 6-4: Equipments inside the trailer

*1 pps and 10 MHz (2 each) are the test outputs from the Oplink Slave.
The patch panel has the mains power switch, Block up converter (BUC) control interface, Optical interface to the Slave, Antenna Polarisation (Cross or co-pol) and the reference signal.
The FPS is the interface between the L- Band Up/Down converter and the LNA/HPA unit mounted on the antenna boom.
The external interfaces to the trailer are the power supply and the fiber optic cable (HMC connector), which are connected on the rear side of the trailer.

Picture 6-5: UPS and Batteries



Picture 6-6: Mains Switch

7 UTC signal points from the stations:

The stations provided the representative UTC 1PPS signals at the connector that was the end of a specific cable or as a connector from a distribution panel. In the case of TIM the UTC 1PPS was the actual UTC(k) points whereas for VSL and AOS these signals were not at the UTC(k) points and these representative UTC signals are referred to as UTC(Cal) points.

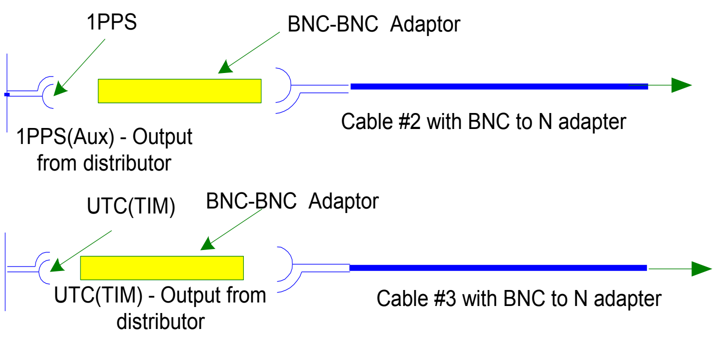
For this reason, there is discrimination in the nomenclature of the UTC signals as UTC (K) – for TIM and as UTC (Cal) – for VSL and AOS.

Note that the calibration referenced to the UTC points at VSL, AOS and TIM.

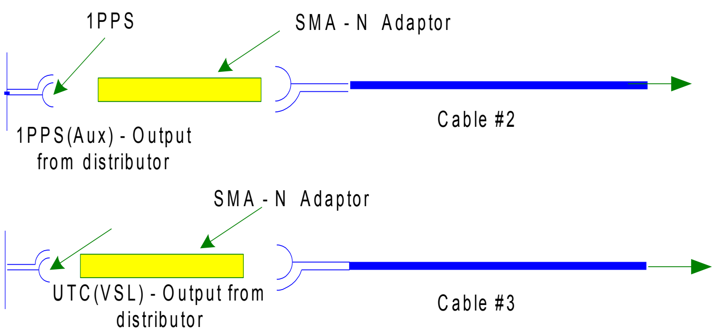
The same cable, marked at TIM cable, was used in all the stations and the difference between the UTC 1PPS and the 1PPS(Aux) were measured using the Time interval counter in the Master Oplink (Figure 3-1: Station Interface with depiction of the 1PPS trigger points). This difference in the UTC 1PPS and the 1PPS(Aux) was verified at the stations using a local TIC measurement device.

The references from the different stations are shown below. The TIM cables are marked Cable #2 and Cable #3 described in section 3.2. These cables have N(M) connectors at both ends. Since the common interface for 1PPS in the laboratories is BNC, there is a BNC-N adapter connected and this is interfacing with the stations.

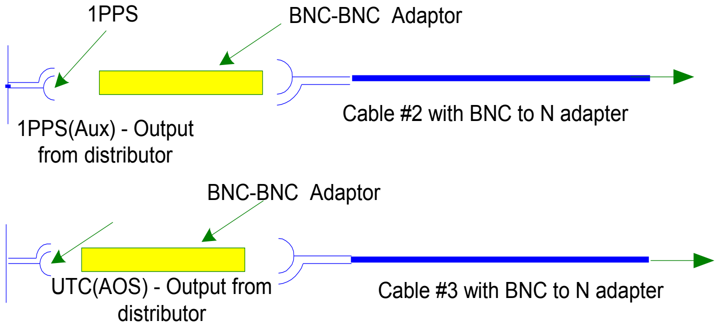
7.1 UTC (k) vs 1PPS(Aux) at TIM



7.2 UTC (Cal) vs 1PPS(Aux) at VSL



7.3 UTC (Cal) vs 1PPS(Aux) at AOS



8 REFDELAY

The REFDELAY values for the fixed stations are as provided by the stations and given in the TWSTFT ITU files [RD1] – sample ITU file annexed in 21.1.

The mobile station REFDELAY comprises of UTC(k) – 1PPS(Tx). As explained in the section 3.5, 1PPS(Tx) corresponds to 1PPS(Aux). Hence the REFDELAY is measured directly at the H2Oplink Master input panel and can be expressed as UTC(k)-1PPS(Aux).

UTC(k) – 1PPS(Aux) is a measurement value from the TIC in the Master oplink and comprises the signal delay difference between the station connection points to the inputs of TIC.

9 The Common Clock Difference

The common clock difference (CCD) which is relevant for time transfer is calculated as follows:
- 0.5 *CALR1 = + 0.5 (TW1) + REFDELAY1 – (0.5 (TW2) + REFDELAY2)

CCD(1, TIM02) = 0.5 * [TW(1) – TW(TIM02)] + REFDELAY(1) – REFDELAY(TIM02)

The CCD illustration in this report uses the TWSTFT ITU files [RD1] from the laboratories. The computation table for the CCD is shown in the excel sheet separately submitted.

10 Participating stations configuration

10.1 TIM

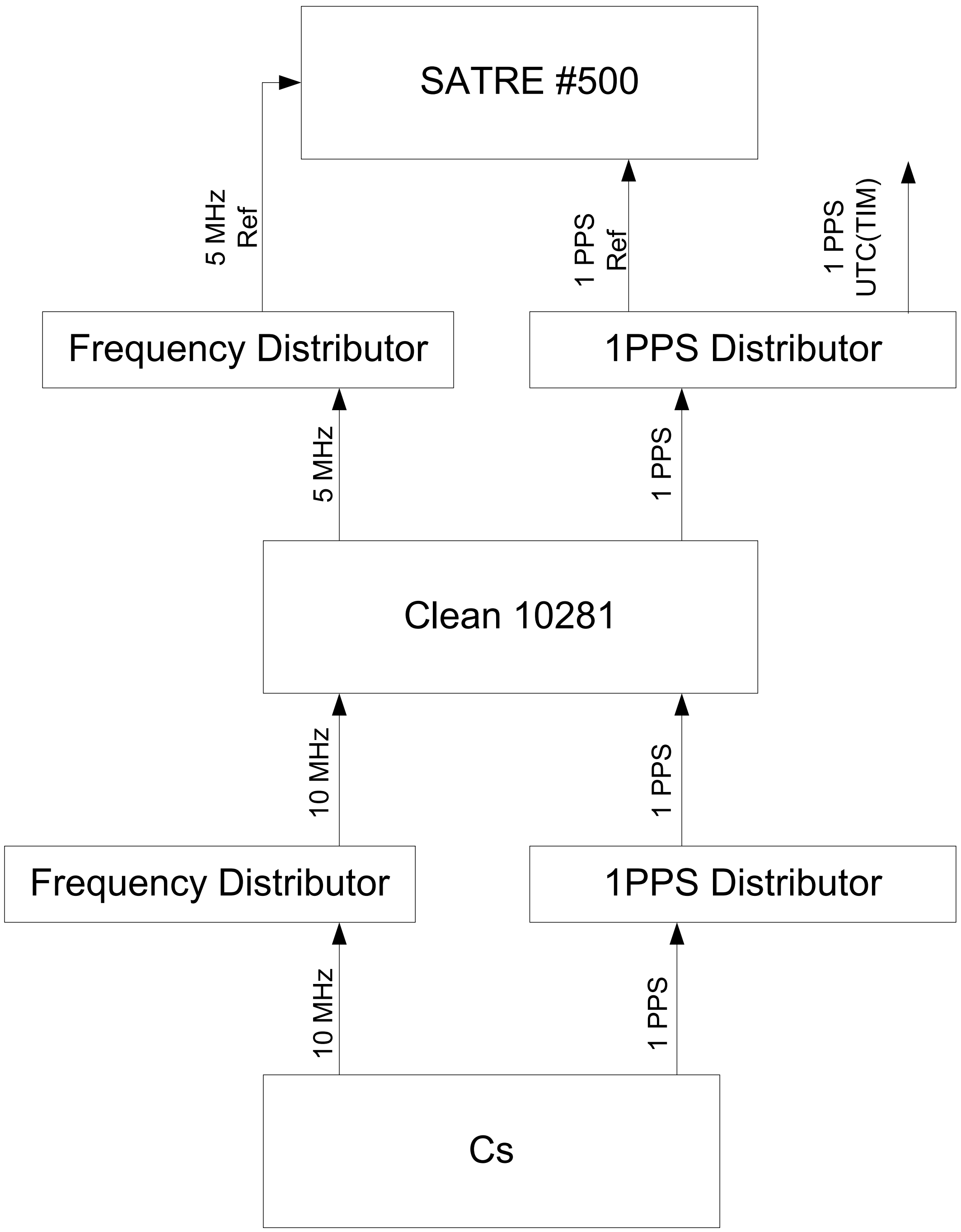


Figure 10-1

10.2 VSL

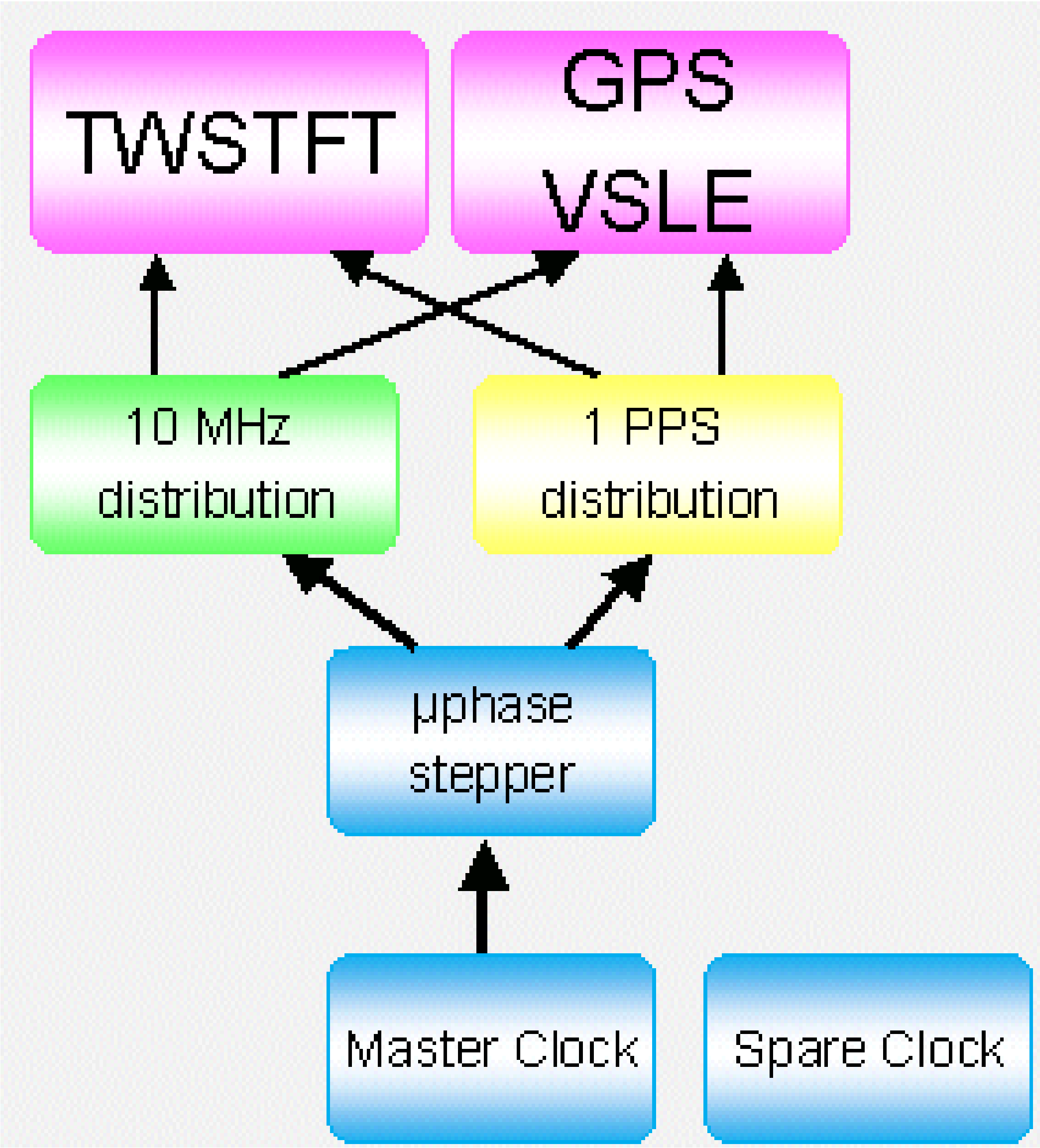


Figure 10-2

10.3 AOS

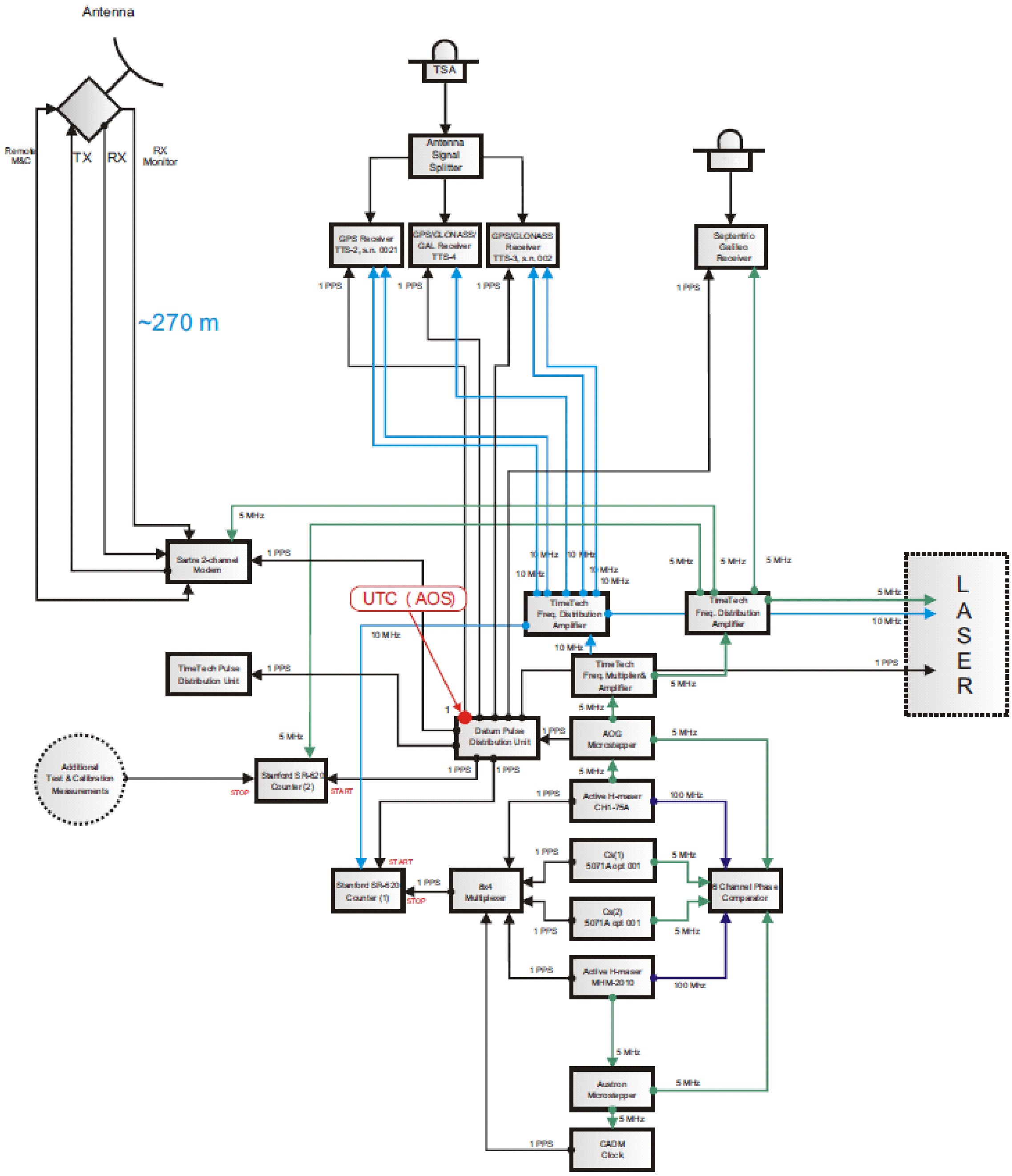


Figure 10-3

11 Software versions of the elements in the mobile station

Instrument	Software version
SATRE	5.1.23g
SATSIM	2.0
Master Oplink H2PC firmware Oplink firmware H2Pulse firmware	 4.2.3.28 2.17 1.38
Slave Oplink H2PC firmware Oplink firmware H2OSC firmware	 4.2.3.28 2.17 2.24
Antenna Control Unit Image Version App Version	 3.0.9 1.1.0
Up/Dn Converter (Model)	2017.02
ESXi	5.0.0
TWSI software	2.6
TW Analyser	1.1
Data Analyser	2.3
Data recorder	1.5

Table 11-1

12 Calibration of TIM (MJD 56408 to 56413 & MJD 56428 to 56433)

12.1 Set-up at TIM

The Master blue box is setup in the TIM TW room with references 5 MHz, 1PPS(Aux) and 1PPS UTC (TIM) in the signal patch panel. This is connected to the Master Blue box at the interface panel. The optical cable is routed outdoors to the trailer. The fiber cable was drawn from the TIM Clock room to the Trailer at the parking lot.
The trailer was placed in the parking lot with a clear view to the satellite.
The station was setup in approximately 4 hours. The antenna pointing and optimization was performed and the station was ready at about UTC 1530. From UTC 1600 the station was operational with the scheduler and was performing nominal measurements. The measurements were carried out from the MJD56408 to MJD56413 in the start of the campaign and from MJD56428 to MJD56433 at the end of the campaign.

Picture 12-1: Placement of the trailer at TIM during the campaign

12.2 REFDELAY at TIM (Description of REFDELAY in chapter 8)

12.2.1 UTC(TIM) – 1PPS(Aux)

MJD 56408 to 56413(Begin)

UTC(TIM) – 1PPS(Aux)	Jitter
8.847 ns	0.011ns

Table 12-1

MJD 56428 to 56433(End)

UTC(TIM) – 1PPS(Aux)	Jitter
8.873 ns	0.010ns

Table 12-2

12.3 CCD

Illustration of the CCD between TIM01 and TIM02 (without REFDELAY)

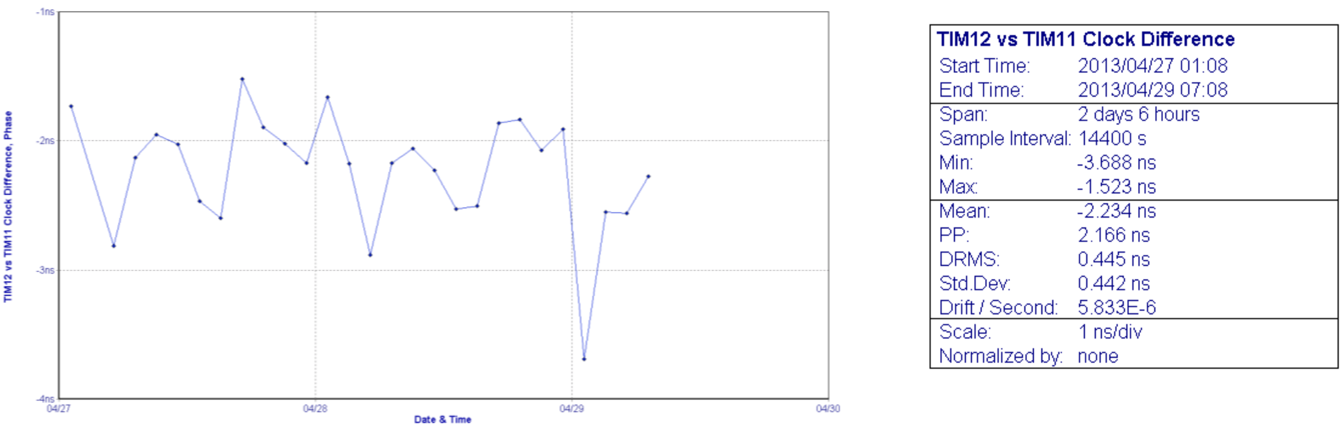


Figure 12-1: CCD TIM12-TIM11 during Beginning of campaign at TIM

MJD 56408 to 56413 – Before the trip to metrology labs

CCD Mean	CCD Peak to Peak	CCD Std Dev
-2.234 ns	2.166 ns	0.442 ns

Table 12-3

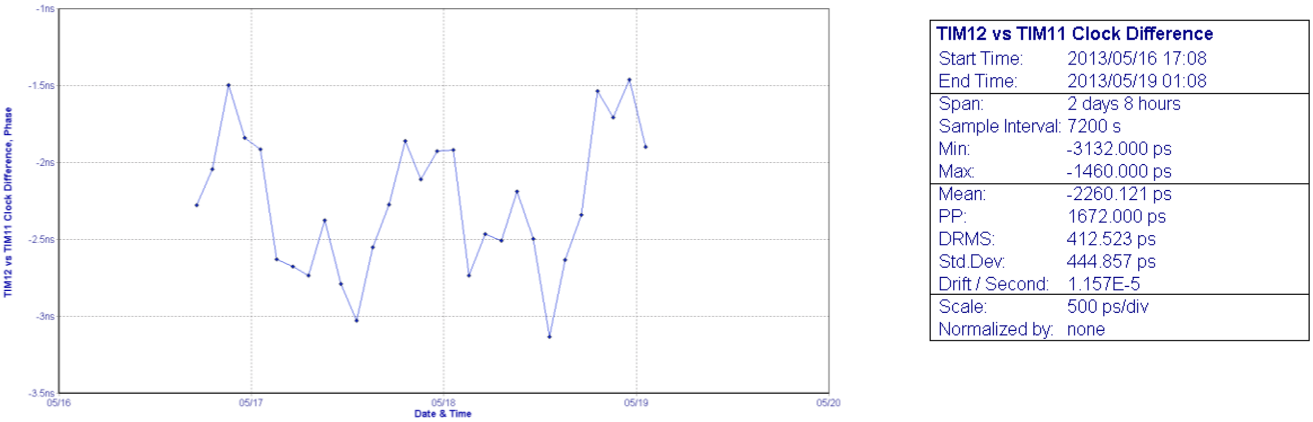


Figure 12-2: CCD TIM12-TIM11 during end of campaign at TIM

MJD 56261 to 56264 – After station return to TIM

CCD Mean	CCD Peak to Peak	CCD Std Dev
-2.260ns	1.672	0.444 ns

Table 12-4

13 Calibration of VSL(MJD 56414 to 56418)

13.1 Set-up at VSL

The Master blue box is setup in the VSL TW room with reference 1PPS and UTC (Cal-VSL) in a BNC connector at the end of a cable. This is connected to the Master Blue box at the interface panel. The optical cable is routed outdoors to the trailer.

The trailer was lifted and placed in the parapet (5m) from ground and the fiber cable was routed from the 6th floor of the building where the clock room is situated to the trailer.

The antenna pointing and optimization was performed and the station was ready and operational with the scheduler and was performing nominal measurements from the MJD56414 to MJD56418.

Picture 13-1: Placement of the trailer at VSL during the campaign

13.2 REFDELAY at VSL

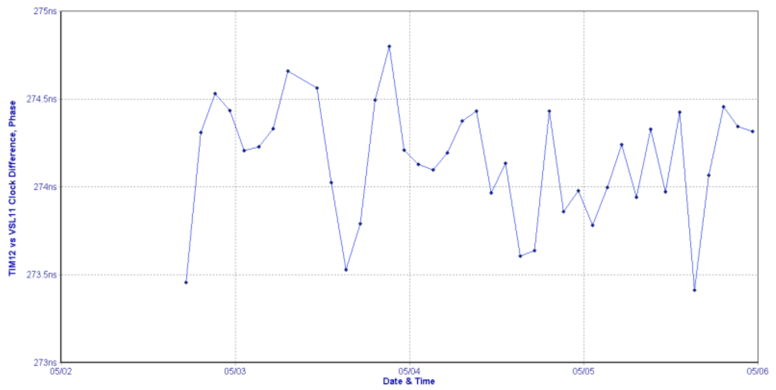
13.2.1 UTC(VSL) – 1PPS(Aux)

UTC(VSL) – 1PPS(Aux)	Jitter
38.122ns	0.026 ns

Table 13-1

13.3 CCD

Illustration of the CCD between TIM12 and VSL11 (without REFDELAY)



TIM12 vs VSL11 Clock Difference	
Start Time:	2013/05/02 17:14
End Time:	2013/05/05 23:14
Span:	3 days 6 hours
Sample Interval:	7200 s
Min:	273413.000 ps
Max:	274800.500 ps
Mean:	274145.744 ps
PP:	1387.500 ps
DRMS:	338.920 ps
Std.Dev:	330.507 ps
Drift / Second:	1.186E-5
Scale:	500 ps/div
Normalized by:	none

Figure 13-1: CCD TIM12-VSL11 at VSL

MJD 56414 to 56418

CCD Mean	CCD Peak to Peak	CCD Std Dev
274.145ns	1.387 ns	0.330 ns

Table 13-2

14 Calibration of AOS(MJD 56423 to 56427)

14.1 Set-up at AOS

The Master blue box is setup in the AOS TW room with reference 1PPS and UTC (AOS) in a BNC connector in a distribution amplifier. This is connected to the Master Blue box at the interface panel. The optical cable is routed outdoors to the trailer.

The fiber cable was laid from the AOS Two-way room and the trailer by routing the cable from the basement. The trailer was placed on firm grounds, with a clear view to the satellite. (Picture below). A spirit level was used to check and monitor the level thru the period of the campaign. The TW receive power and the ranging power was also monitored to check for any misalignment of the antenna.
The antenna pointing and optimization was performed and the station was operational with the scheduler and was performing nominal measurements from the MJD56423 to MJD56427.

Picture 14-1: Placement of the trailer at AOS during the campaign

14.2 REFDELAY at AOS

14.2.1 UTC(AOS) – 1PPS(Aux)

UTC(AOS) – 1PPS(Aux)	Jitter
36.902 ns	0.026 ns

Table 14-1

14.3 CCD

Illustration of the CCD between TIM12 and AOS11 (without REFDELAY)

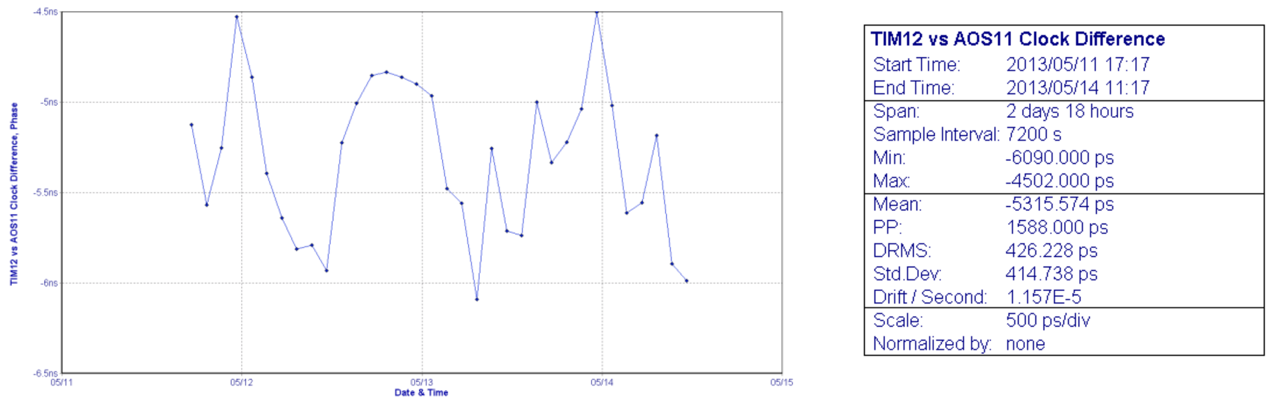


Figure 14-1: CCD TIM12-AOS11 at AOS

CCD Mean	CCD Peak to Peak	CCD Std Dev
-5.315 ns	1.588 ns	0.414 ns

Table 14-2

15 Summary of CCD

The CCD values in the table below are computed per the formula in Section 9.

Period / Location	CCD Mean	CCD Std Dev
MJD 56408 to 56413 / TIM	651.24 ns	0.711 ns
MJD 56428 to 56431 / TIM	651.39 ns	0.801 ns
MJD 56414 to 56418 / VSL	964.24 ns	0.332 ns
MJD 56423 to 56427 / AOS	638.54 ns	0.416 ns

Table 15-1

15.1 Difference in the CCD results at TIM

The change in the CCD mean value at TIM from the beginning and end of the campaign is 0.310 ns.

The difference of CCD Mean values is lower than the CCD Std Dev, which is indicative of the calibration station's stability.

16 Number of samples considered

The samples used for the plots are all from the TWSTFT ITU files [RD1].

TIM-1	VSL	AOS	TIM-2
28	39	32	28

Table 16-1

17 CALR Values

The calibration campaign of Calibration Period was successfully completed. The CALR values for the calibrated TWSTFT stations are as follows:

Link k-l	CALR (k,l) [ns]	Ua,k[ns]	Ua,l[ns]	Ub,1[ns]	Ub,2[ns]	Ub,3[ns]	U [ns]
TIM01-VSL01	297.943	0.44	0.33	0.31	0.50	0.42	0.91
TIM01-AOS01	-8.651	0.44	0.41	0.31	0.50	0.42	0.94
VSL01-AOS01	-306.595	0.33	0.41	0.50	0.50	0.42	0.98

Table 17-1

17.1 Description of Uncertainties

- Statistical uncertainty: $U_a = \sqrt{{u_{a,K}}^2 + {u_{a,L}}^2}$

$U_{a,K}$, $U_{a,K}$: Jitter of the common-clock (CCD) measurements at Lab K and L. The jitter of fixed SATRE and fixed ground station, as well as the jitter of the travelling two-way equipment, and the jitter of optical link are included.

- Systematic uncertainty: $U_b = \sqrt{\sum_j u_{b,j}}$

Includes all contributions, which affect the CCD measurements at each station the same way.

- Combined Uncertainty: $U = \sqrt{{U_a}^2 + {U_b}^2}$

The uncertainties accounted for are:

- Ua,k – Stability of CCD at station K
- Ua,l – Stability of CCD at station L
- Ub,1 – Stability of portable station
- Ub,2 – From Station Measurement (PN, Power) [RD4]
- Ub,3 – Instability of connection to the local UTC [RD4]
- U – Combined uncertainty

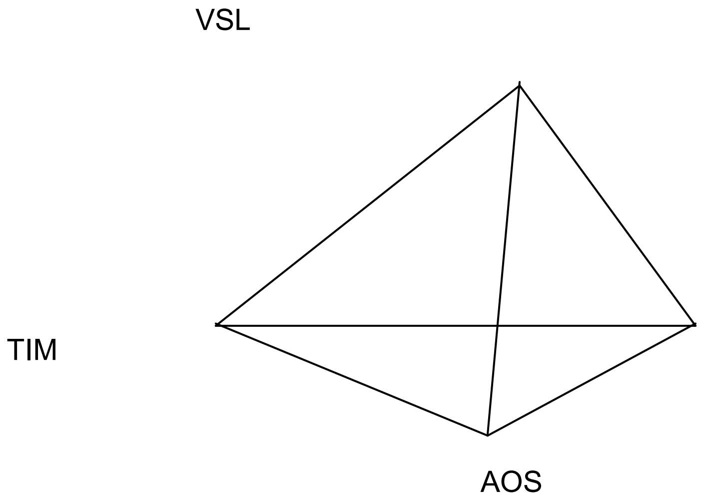
18 Triangle Closure

The Triangle closure is based on the principle that for calibrated stations, if the link measurement errors and the noises are neglected then the time scale UTC (lab) i.e. clocks are cancelled and the sum of the 3 vectors, for eg. [(TIM-VSL) + (VSL-AOS) + (AOS-TIM)] is 0 (zero).

Equation: [UTC (Labi) – UTC (VSL)] − [UTC (Labj) – UTC (VSL)] +

[UTC (Labj) – UTC (Labi)] = Closure -> 0

The inputs to the computation of the triangle closures are the TWSTFT ITU [RD1] files after replacing with the new CALR values computed from as a outcome of this calibration campaign.



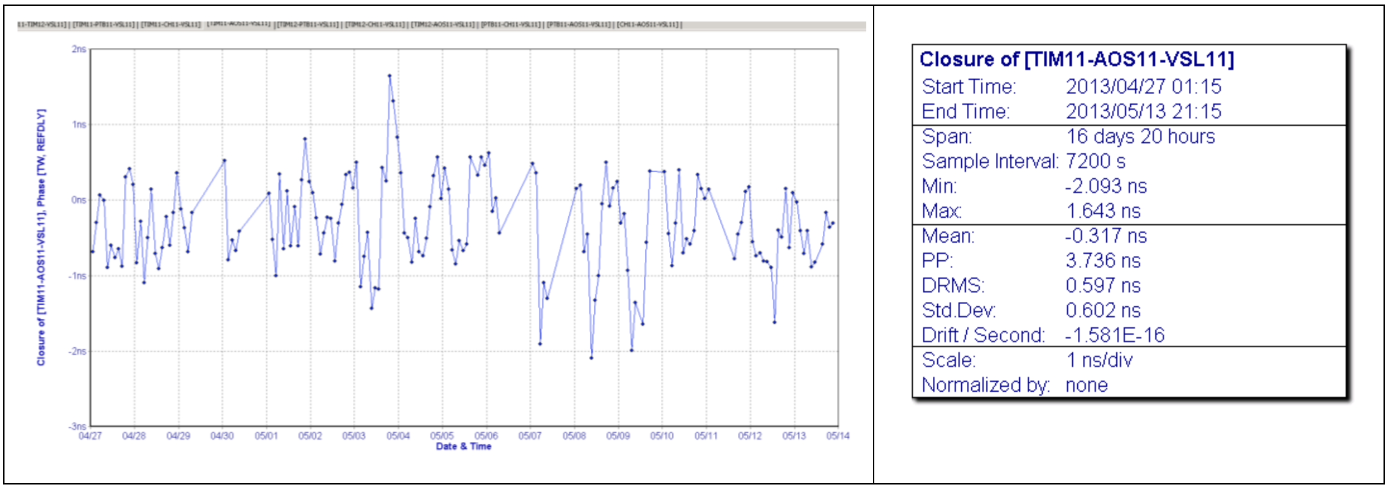


Figure 18-1: Triangle closure plots

Laboratory	Min (ns)	Max (ns)	Mean (ns)	Std Dev(ns)
TIM-AOS-VSL	-2.093	1.643	-0.317	0.690

Table 18-1

In the case of the 3 stations participating there is one triangle closure possible that is illustrated above. The mean values are smaller than the Std Dev and mean values is converging to zero.

19 Calibration Deviation

If the station stability, concerning delay offsets, was maintained optimal since the last TWSTFT calibration with a portable earth station in July 2009 (where the ESDVARs have been set to zero), the following equation, which indicates a calibration deviation, should show no difference.

$$CALR\_dev_{Lab1\text{-}Lab2} = CALR_{tt2012} - [0.5*(ESDVAR_{Lab1} - ESDVAR_{Lab2}) + CALR_{TM198}] = 0$$

$$uCALR\_dev_{Lab1-Lab2} = \sqrt{uCALR_{tt2012}^{\,2} + \left(\frac{ESIG_{Lab1}}{2}\right)^2 + \left(\frac{ESIG_{Lab2}}{2}\right)^2 + uCALR_{TM198}^{\,2}}$$

$CALR_{tt2012}$ Calibration constant according to the calibration in 2012

$CALR_{TM198}$ Calibration constant according to the BIPM bridging calibration (ID no TM198) due to the frequency change on satellite T-11N on MJD 55769.

$ESDVAR_{Lab1}$ Earth station delay variation (since the calibration with the portable earth station in July 2009) of link laboratory no 1 to the time of the calibration in 2012.

$ESDVAR_{Lab2}$ Earth station delay variation (since the calibration with the portable earth station in July 2009) of link laboratory no 2 to the time of the calibration in 2012.

$ESIG_{Lab1}$ Standard measurement uncertainty of $ESDVAR_{Lab1}$.

$ESIG_{Lab2}$ Standard measurement uncertainty of $ESDVAR_{Lab2}$.

$Link_{Lab1\text{-}Lab2}$	$CALR_{tt2012}$	$ESDVAR_{Lab1}$	$ESDVAR_{Lab2}$	$CALR_{TM198}$	$CALR\_dev_{Lab1\text{-}Lab2}$
VSL-AOS	-306.60±0.9	0	0	-307.77	1.17

All values in ns, uncertainties (1σ)

20 Summary

The calibration campaign shows good agreement in triangle closure and in the calibration deviation table.

21 Annex

21.1 Sample ITU File

```
* twptb56.242
* FORMAT    01
* LAB       PTB
* REV DATE  2011-08-03
* ES  PTB01 LA: N  52 17 49.787      LO: E  10 27 37.966   HT:   143.41 m
* REF-FRAME WGS84
* LINK   14 SAT: TELSTAR 11N         NLO: E 322 30 00.000  XPNDR: 999999999 ns
*           SAT-NTX: 10960.1500 MHz  SAT-NRX: 14260.1500 MHz  BW:   1.7 MHz
* LINK   16 SAT: TELSTAR 11N         NLO: E 322 30 00.000  XPNDR: 999999999 ns
*           SAT-NTX: 11489.0600 MHz  SAT-NRX: 14046.5900 MHz  BW:   1.6 MHz
* CAL   211 TYPE: CAL 139 BRIDGED    MJD: 55769  EST. UNCERT.:    1.200 ns
* CAL   214 TYPE: CAL 141 BRIDGED    MJD: 55769  EST. UNCERT.:    5.000 ns
* CAL   213 TYPE: CAL 142 BRIDGED    MJD: 55769  EST. UNCERT.:    1.300 ns
* CAL   216 TYPE: CAL 142 BRIDGED    MJD: 55769  EST. UNCERT.:    1.200 ns
* CAL   217 TYPE: CAL 144 BRIDGED    MJD: 55769  EST. UNCERT.:    5.000 ns
* CAL   218 TYPE: CAL 145 BRIDGED    MJD: 55769  EST. UNCERT.:    1.200 ns
* CAL   220 TYPE: CAL 146 BRIDGED    MJD: 55769  EST. UNCERT.:    1.300 ns
* CAL   210 TYPE: CAL 171 BRIDGED    MJD: 55769  EST. UNCERT.:    7.000 ns
* CAL   212 TYPE: CAL 172 BRIDGED    MJD: 55769  EST. UNCERT.:    7.000 ns
* CAL   215 TYPE: CAL 173 BRIDGED    MJD: 55769  EST. UNCERT.:    7.000 ns
* CAL   219 TYPE: CAL 174 BRIDGED    MJD: 55769  EST. UNCERT.:    3.000 ns
* CAL   273 TYPE: GPS                MJD: 56044  EST. UNCERT.:    5.000 ns
* LOC-MON   NO
* MODEM     SATRE 037
* COMMENTS
*
* EARTH-STAT  LI  MJD  STTIME NTL        TW         DRMS SMP ATL     REFDELAY     RSIG  CI S    CALR      ESDVAR    ESIG TMP HUM PRES
* LOC    REM               hhmmss  s          s           ns       s          s          ns            ns         ns       ns degC  %  mbar
 PTB01  TIM01 14 56242 000400 119  0.265714984623 1.834 120 119  0.000000040870 0.020 999 9 999999999  1035.000 2.800   9  98  992
 PTB01  PTB01 14 56242 000700 119  0.266693424998 2.333 120 119  0.000000040870 0.020 999 9 999999999  1035.000 2.800   9  98  992
 PTB01  OCA01 14 56242 001000 119  0.264287114307 2.367 108 119  0.000000040870 0.020 999 9 999999999  1035.000 2.800   9  98  992
 PTB01   IT02 14 56242 001300 119  0.264677798129 1.741 120 119  0.000000040870 0.020 213 1   479.209  1035.000 2.800   9  98  992
 PTB01  ROA01 14 56242 001600 119  0.260314610472 1.318 120 119  0.000000040870 0.020 217 1   298.673  1035.000 2.800   9  98  992
 PTB01   OP01 14 56242 001900 119  0.264528175745 1.443 120 119  0.000000040870 0.020 216 1  7300.704  1035.000 2.800   9  98  992
 PTB01  NPL01 14 56242 002200 119  0.264721339285 2.490 120 119  0.000000040870 0.020 215 1  -490.373  1035.000 2.800   9  98  992
 PTB01  VSL01 14 56242 002500 119  0.265589976699 2.557 110 109  0.000000040870 0.020 220 1   471.935  1035.000 2.800   9  98  992
 PTB01   SP01 14 56242 002800 119  0.268234509620 1.279 119 118  0.000000040870 0.020 218 1   194.939  1035.000 2.800   9  98  992
 PTB01  TIM02 14 56242 003400 119  0.265720039069 1.055 120 119  0.000000040870 0.020 999 9 999999999  1035.000 2.800   9  98  992
 PTB01   CH01 14 56242 003700 119  0.265034460491 1.333 120 119  0.000000040870 0.020 211 1   209.877  1035.000 2.800   9  98  992
 PTB01  AOS01 14 56242 004300 119  0.267928675674 1.878 120 119  0.000000040870 0.020 210 1   164.141  1035.000 2.800   9  98  992
 PTB01 USNO01 16 56242 004600 119  0.262347943688 0.776 120 119  0.000000040870 0.020 219 1  -212.129  1035.000 2.800  10  98  992
 PTB01 NIST01 16 56242 004900 119  0.269350786822 0.466 120 119  0.000000040870 0.020 214 1   199.617  1035.000 2.800  10  98  992
 PTB01 PTF101 14 56242 005200 119  0.265417016539 1.394 120 119  0.000000040870 0.020 273 1  -462.000  1035.000 2.800  10  98  992
 PTB11   CH11 14 56242 010400 119  0.265038977827 1.286 120 119  0.000000040870 0.020 211 1   209.877  1035.000 2.800   9  98  992
 PTB11   OP11 14 56242 010700 119  0.264536197908 1.113 120 119  0.000000040870 0.020 216 1  7300.704  1035.000 2.800   9  98  992
 PTB11  TIM11 14 56242 011000 119  0.265726144854 1.168 120 119  0.000000040870 0.020 999 9 999999999  1035.000 2.800   9  98  992
```

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23 Distribution List

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24 Document Information

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Annex

Linking document for the TWSTFT calibration campaigns of October/November 2012 and April/May 2013

version 29 October 2015

Erik Dierikx
VSL

This document links the TWSTFT calibration campaign of April/May 2013 to the campaign of October/November 2012, with the objective of computing CALR values for the TW-links involved in both campaigns.

The data used for the computations in this document are obtained from [1] and [2].

The computations are based on the equations of ITU-R TF.1153-4 [3]. Name conventions of parameters used in this document are kept in close agreement with those used in [3].

In both of these campaigns, the calibration was performed with the mobile TWSTFT station from TimeTech. Furthermore, in both of these campaigns, a start and end measurement (also referred to as closure measurement) was performed at the fixed station of TimeTech. These measurements consist of common clock difference (CCD) measurements between the mobile station (MOB) and the fixed station (TIM). The results of these closure measurements are shown in table 1 and figure 1.
From the four individual measurement series performed at TIM, an overall mean $\overline{CCD}$ has been computed, together with the combined standard deviation $u_A\left(\overline{CCD}\right)$ of the four measurement series.

$$u_A\left(\overline{CCD}\right) = \sqrt{\left(\sigma\left(CCD_i\right)\right)^2 + \sum_i^{n=4}\left(\frac{u_A\left(CCD_i\right)}{n}\right)^2}$$

Table 2. CCD measurements performed at TIM

MJD start	MJD end	CCD_i	$u_A(CCD_i)$
		[ns]	[ns]
56239	56243	651.55	0.31
56261	56264	651.24	0.71
56408	56413	651.24	0.71
56428	56431	651.39	0.80
		$\overline{CCD}$	$u_A\left(\overline{CCD}\right)$
		651.35	0.36

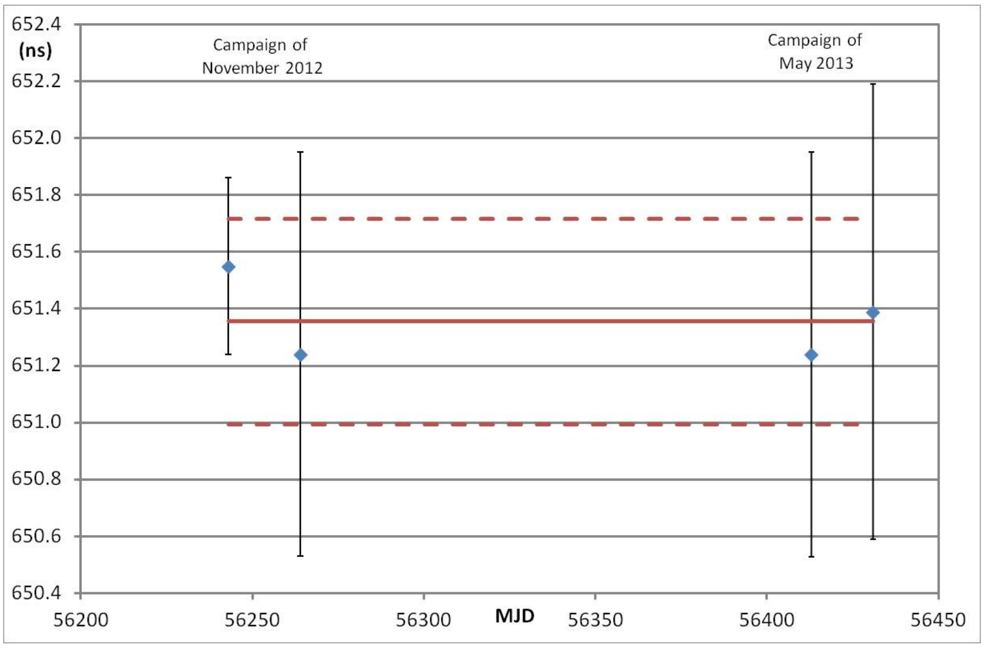

Figure 1. CCD measurements between the fixed station TIM and the mobile station. The red line indicates the average of all measurements; the dashed red lines indicate the combined standard deviation in the measurements.

From the results shown in figure 1, it is safe to assume that these results are within the same statistical distribution and therefore, we can assume that the mobile station has not changed between the campaign of November 2012 and the campaign of May 2013.
Based on this assumption, this document provides the computation of CALR value of the TW links between AOS and VSL and the laboratories involved in the campaign of November 2012: PTB, OP and CH.
The main equations for these computations are given in section 5.1 of [1], and are repeated here:

CALR(k, l) = CCD(l, MOB) - CCD(k, MOB) + SCD(l) - SCD(k)

where

CCD(l, MOB) = 0.5*(TW(l) - TW(MOB)) + REFDLY(l) - REFDLY(MOB)
CCD(k, MOB) = 0.5*(TW(k) - TW(MOB)) + REFDLY(k) - REFDLY(MOB)

l and k represent the fixed stations involved in the link to be calibrated
MOB represents the mobile TWSTFT station
TW(*i*) is the result of the quadratic fit of raw TW measurements performed by lab k, l or the mobile station
REFDLY(i) is the delay of the reference 1PPS signal from the UTC(k) definition point to SATRE modem's reference point of station k, l or the mobile station

The measurements involved in these computations were performed in the periods indicated in Table 2

Table 3. Dates of measurements of the mobile station at the participating stations

Station	MJD start	MJD end
TIM01(1)	56239	56243
PTB01	56244	56247
OP01	56250	56253
CH01	56256	56260
TIM01(2)	56261	56264
TIM01(3)	56408	56413
VSL01	56414	56418
AOS01	56423	56427
TIM01(4)	56428	56431

At each of the participating stations, for the CCD measurements, the reference delay (REFDLY) and its uncertainty *u*(REFDLY) were determined for both the fixed station and the mobile station. The difference of reference delay d_{REFDLY} between the fixed and mobile station, together with the corresponding uncertainty $u(d_{REFDLY})$, have been calculated and are also given in Table 3.

Table 4. 1PPS Reference delays and the REFDLY differences between the fixed and mobile station

Station	REFDLY Fixed station	*u*(REFDLY) Fixed station	REFDLY Mobile station	*u*(REFDLY) Mobile station	d_{REFDLY} (Fix - Mob)	$u(d_{REFDLY})$
	[ns]	[ns]	[ns]	[ns]	[ns]	[ns]
TIM01(1)	662.14	0.01	8.89	0.02	653.25	0.03
PTB01	40.87	0.00	72.19	0.50	-31.32	0.50
OP01	687.60	0.00	-46.56	0.14	734.12	0.14
CH01	753.03	0.02	-2.04	0.01	755.07	0.04
TIM01(2)	662.27	0.03	8.85	0.03	653.42	0.05
TIM01(3)	662.14	0.02	8.85	0.01	653.25	0.03
VSL01	728.22	0.03	38.12	0.03	690.10	0.04
AOS01	680.76	0.04	36.90	0.03	643.86	0.04
TIM01(4)	662.27	0.04	8.87	0.01	653.42	0.04
TIM01_avg	662.21	0.04	8.87	0.03	653.33	0.05

The mean common clock differences (CCD) between the fixed stations and the mobile station are given in Table 4 together with the standard deviation in these measurements.

Table 5. Common clock differences

Station	**CCD mean**	**CCD std dev**
	[ns]	**[ns]**
TIM01(1)	651.55	0.31
PTB01	-31.48	0.30
OP01	7791.39	0.23
CH01	675.67	0.59
TIM01(2)	651.24	0.71
TIM01(3)	651.24	0.71
VSL01	964.24	0.33
AOS01	638.54	0.42
TIM01(4)	651.39	0.80
TIM01_avg	651.36	0.36

To determine the new CALR values for the links between the stations, corrections have to be applied for the Sagnac effect. Table 5 gives the correction value of the Sagnac effect for the path from the station to the satellite. The effect for the path from the satellite to the station has the same value, but the opposite sign.

Table 6. Sagnac corrections

Station	**SCD**	***u*(SCD)**
	[ns]	**[ns]**
TIM01	104.59	0.10
PTB01	99.11	0.10
OP01	92.00	0.10
CH01	105.32	0.10
VSL01	89.68	0.10
AOS01	108.79	0.10

Finally, from the CCD values and the Sagnac corrections, the CALR values can be computed. The values are given in Table 6, and the corresponding uncertainties are given in Table 7.

Table 7. New link calibration values CALR

Link(k - l)		CALR(k, l)
k	**l**	**[ns]**
TIM01	PTB01	-688.31
TIM01	OP01	7127.45
TIM01	CH01	25.05
TIM01	VSL01	297.98
TIM01	AOS01	-8.61
AOS01	PTB01	-679.70
AOS01	OP01	7136.06
AOS01	CH01	33.66
AOS01	VSL01	306.59
VSL01	PTB01	-986.30
VSL01	OP01	6829.47
VSL01	CH01	-272.93
VSL01	AOS01	-306.59

The uncertainties of the CALR results have been re-evaluated following the example of Annex I of TWSTFT Calibration Guidelines for UTC Time Links (V3.0) [4].

Two kinds of statistical uncertainty components were identified:
$u_a(i)$ reflects the instability of the common-clock difference (CCD) measurements at site *i*. These include the contributions of the fixed TWSTFT installation, the travelling two-way equipment, and the jitter of the optical link.

Other types of uncertainty determined by type "b" evaluations were identified as follows:
$u_{b,1}$ – instability of the portable station (from closure measurement, Table 1)

$u_{b,2}(i)$ – uncertainty of the connection of the fixed stations to the local time scales.
This contribution is the uncertainty of the so called REFDELAY measurement, derived from the use of high-performance counters for time interval measurements. $u_{b,2}(i)$ could in principle be reduced by using the identical counter unit for all measurement purposes. This would require touching the fixed installations at each site which is preferably avoided. On the other hand, any error made in the determination of the fixed-station REFDELAY will be absorbed in the result of the calibration (CALR value).

$u_{b,3}(i)$ – uncertainty of the connection of the mobile station to the local time scales.
This contribution comprises the uncertainty of the phase relation between 1 PPS(Aux) and 1 PPS provided to the SATRE modem in the trailer.

The contributions $u_{b,2}(i)$ and $u_{b,3}(i)$, derived from the use of high-performance counters for time interval measurements, additionally include the instability of the connection to UTC(*k*), TIC trigger level timing error, and nonlinearities in the TIC in conjunction with the external reference frequency used.

$u_{b,4}$ – uncertainty of the Sagnac corrections
The station coordinates are sufficiently well known to assure an uncertainty $u_{b,4} < 0.1$ ns.

$u_{b,5}$ – All other suspected possible contributions that are not included in the statistical evaluation. These effects are, for example, the use of different PRN codes compared with the operational modes during the calibration campaign, or variations of transmission and receiving power. The overall contributions were estimated to be 0.4 ns.

The combined uncertainty u_{tot} is estimated as the square-root of the sum of squares of all contributions.

The expanded uncertainty U_{exp} corresponding to a probability interval of about 95 % is given by:

$U_{exp} = 2 \times u_{tot}$

All uncertainty contributions are summarized in Table 7.

Table 8. Uncertainty evaluation of the CALR values

CALR(k,l)		$u_{a,k}$	$u_{a,l}$	$u_{b,1}$	$u_{b,2}$(k)	$u_{b,2}$(l)	$u_{b,3}$(k)	$u_{b,3}$(l)	$u_{b,4}$	$u_{b,5}$	u_{tot}	U_{exp}
k	**l**	**[ns]**	**[ns]**	**[ns]**	**[ns]**	**[ns]**	**[ns]**	**[ns]**	**[ns]**	**[ns]**	**[ns]**	**[ns]**
TIM01	PTB01	0.36	0.30	0.36	0.05	0.00	0.03	0.50	0.10	0.40	0.88	1.76
TIM01	OP01	0.36	0.23	0.36	0.05	0.00	0.03	0.14	0.10	0.40	0.71	1.43
TIM01	CH01	0.36	0.59	0.36	0.05	0.02	0.03	0.01	0.10	0.40	0.89	1.77
TIM01	VSL01	0.36	0.33	0.36	0.05	0.03	0.03	0.03	0.10	0.40	0.74	1.48
TIM01	AOS01	0.36	0.41	0.36	0.05	0.04	0.03	0.03	0.10	0.40	0.78	1.56
AOS01	PTB01	0.41	0.30	0.36	0.04	0.00	0.03	0.50	0.10	0.40	0.90	1.80
AOS01	OP01	0.41	0.23	0.36	0.04	0.00	0.03	0.14	0.10	0.40	0.74	1.48
AOS01	CH01	0.41	0.59	0.36	0.04	0.02	0.03	0.01	0.10	0.40	0.91	1.81
AOS01	VSL01	0.41	0.33	0.36	0.04	0.03	0.03	0.03	0.10	0.40	0.76	1.53
VSL01	PTB01	0.33	0.30	0.36	0.03	0.00	0.03	0.50	0.10	0.40	0.87	1.73
VSL01	OP01	0.33	0.23	0.36	0.03	0.00	0.03	0.14	0.10	0.40	0.70	1.39
VSL01	CH01	0.33	0.59	0.36	0.03	0.02	0.03	0.01	0.10	0.40	0.87	1.74
VSL01	AOS01	0.33	0.41	0.36	0.03	0.04	0.03	0.03	0.10	0.40	0.76	1.53

References

[1] A. Balu, E. Dierikx, J. Nawrocky, "Calibration Report CAL-TIM-RP-0002", TimeTech report, 3 December 2013.

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[3] ITU-R TF.1153-4, "The operational use of two-way satellite time and frequency transfer employing pseudorandom noise codes", (08/2015), (www.itu.int/rec/r-rec-tf.1153/en).

[4] CCTF WG TWSTFT, "TWSTFT Calibration Guidelines for UTC Time Links (V3.0)", approved September 2015.