Summary for the 2021 TWSTFT AOS, CH, NPL, PTB, VSL calibration report

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This document summarizes the report of the 2021 calibration of the TW link between AOS, CH, NPL, PTB and VSL stations, using the TimeTech mobile station, and coordinated by METAS.

Author of the report :	C. Schlunegger (METAS)
Version :	2
Date :	2021-03-16

Date of calibration : 26 Aug. 2019 to 11 Oct. 2019, central date : 18 Sep. 2019 / MJD 58744
Date of implementation : 1 Apr. 2021 / MJD 59305

Results

The following tables reproduce the final pages of the report containing the CALR values and CI to be used for each calibrated link, as well as the lines to be inserted in the ITU format files.

The complete report is appended to this summary as an appendix.

Note that it has been agreed from now on to allocate CI to mobile station TIM01 in order to ease the monitoring of its own calibration constants.

Also, due to changes in PTB05 setup between the calibration trip and the implementation date, ESDVAR and ESIG values in PTB05 data files of the corresponding links will be 12.32 ns and 0.20 ns, respectively.

AOS01

```
* CAL 518 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.100 ns
* CAL 519 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.200 ns
* CAL 520 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.100 ns
* CAL 528 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.000 ns
* CAL 521 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.000 ns

             CI S  CALR
AOS01  CH01 518 1  32.400
AOS01 NPL02 519 1 -700.200
AOS01 PTB05 520 1  31.700
AOS01 TIM01 528 1  69.400
AOS01 VSL01 521 1  306.600
```

CH01

```
* CAL 518 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.100 ns
* CAL 522 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.000 ns
* CAL 523 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.900 ns
* CAL 529 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns
* CAL 524 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns

            CI S  CALR
CH01 AOS01 518 1 -32.400
CH01 NPL02 522 1 -732.600
CH01 PTB05 523 1 -0.700
CH01 TIM01 529 1  37.000
CH01 VSL01 524 1  274.200
```

NPL02

```
* CAL 519 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.200 ns
* CAL 522 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.000 ns
* CAL 525 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.900 ns
* CAL 530 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.900 ns
* CAL 526 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.900 ns

             CI S  CALR
NPL02 AOS01 519 1  700.200
NPL02  CH01 522 1  732.600
NPL02 PTB05 525 1  731.900
NPL02 TIM01 530 1  769.600
NPL02 VSL01 526 1  1006.800
```

PTB05

```
* CAL 520 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.100 ns
* CAL 523 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.900 ns
* CAL 525 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.900 ns
* CAL 531 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns
* CAL 527 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns

             CI S  CALR     ESDVAR  ESIG
PTB05 AOS01 520 1 -31.700   12.320  0.200
PTB05  CH01 523 1  0.700    12.320  0.200
PTB05 NPL02 525 1 -731.900  12.320  0.200
PTB05 TIM01 531 1  37.700   12.320  0.200
PTB05 VSL01 527 1  274.900  12.320  0.200
```

TIM01

```
* CAL 528 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.000 ns
* CAL 529 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns
* CAL 530 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.900 ns
* CAL 531 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns
* CAL 532 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns

             CI S  CALR
TIM01 AOS01 528 1 -69.400
TIM01  CH01 529 1 -37.000
TIM01 NPL02 530 1 -769.600
TIM01 PTB05 531 1 -37.700
TIM01 VSL01 532 1  237.200
```

VSL01

```
* CAL 521 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 1.000 ns
* CAL 524 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns
* CAL 526 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.900 ns
* CAL 527 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns
* CAL 532 TYPE: PORT ES REL MJD: 59305 EST. UNCERT.: 0.800 ns

             CI S  CALR
VSL01 AOS01 521 1 -306.600
VSL01  CH01 524 1 -274.200
VSL01 NPL02 526 1 -1006.800
VSL01 PTB05 527 1 -274.900
VSL01 TIM01 532 1 -237.200
```

Results of the 2019 TWSTFT Calibration Campaign involving five European Stations

Identification	2nd_2019_TW-EU-Calibration
Participating Stations	AOS, CH, NPL, PTB, VSL
Coordinator	METAS / Christian Schlunegger
Purpose	TWSTFT Calibration for UTC Time Links
Type	Calibration using a TWSTFT mobile station
Mobile station provider	TimeTech
Period of measurements	From 26 August 2019 to 11 October 2019
Version	2
Date	16/03/2021

Contents

1 Introduction

1.1 Scope of the document

This document describes the TWSTFT calibration campaign, which was carried out in autumn 2019 in Europe with AOS, CH, NPL, PTB, VSL and support of TIM, and presents the achieved calibration results.

These calibration activities are necessary for time and frequency laboratories equipped with TWSTFT stations in order to have calibrated time links between each contributing laboratory, and finally to connect their local timescales via the pivot PTB to UTC.

The TWSTFT calibration method using a mobile earth station was used, since this approach allows achieving the lowest possible level of measurement uncertainty.

1.2 Reference documents

This report refers to the following documents of previous similar campaigns and of TWSTFT operational reports.

Table 1-1: Reference documents

Ref.	Title	Code	Version	Issue
RD01	The operational use of two-way satellite time and frequency transfer employing pseudorandom noise codes	Recommendation ITU-R TF.1153-4, Geneva, Switzerland	4	08/2015
RD02	European TWSTFT Calibration Campaign 2014	2014-summer_European _Calibration_for_BIPM _final_report.pdf		2015
RD03	Summary for the GSOP 2019 TWSTFT calibration report	0489-2019_tw_ roa_v1-0-1.pdf	V1.0	2019
RD04	MODEL SR620 Universal Time Interval Counter, Stanford Research Systems, Revision 2.7 (2006)		2.7	2006
RD05	J. Achkar; D. Rovera; I. Sesia; P. Tavella, "Determination of differential delays of earth stations in Paris and Torino from the calibrated OP-IT TWSTFT link", in Proceedings of 2016 European Frequency and Time Forum (EFTF)	DOI:10.1109/ EFTF.2016.7477800	2.7	2016
RD06	Linking document for the TWSTFT calibration campaigns of October/November 2012 and April/May 2013	0295-2015_tw_vsl_ ori.pdf	29 Oct. 2015	2015
RD07	Application of CALR values from calibration report CAL-TIM-RP-0001	0284-2012_tw_ch_ ori.pdf	7 Jan. 2016	2016
RD08	Results of the BIPM 2017 TWSTFT SATRE calibrations for UTC and Non-UTC links	0450-2017_tw_ npl_ori.pdf TM270_Tw-Satre_TCC-BIPM_Calib2017Sumary.docx TM268V2a	2a	2017
RD09	Results of the BIPM 2017 TWSTFT SATRE calibrations for UTC and Non-UTC links	0449-2017_tw_ aos_ori.pdf TM270_Tw-Satre_TCC-BIPM_Calib2017Sumary.docx TM268V2a	2a	2017
RD10	Results of the BIPM 2017 TWSTFT calibrations for UTC and Non-UTC links	0450-2017_TW_ NPL_v2-0.pdf TM270.V2	2	2017
RD11	Site Preparation Document for Two-Way Calibration Campaign	MOB-TIM-L1-002	2 / 6	2019

1.3 Acronyms and abbreviations

Table 1-2: List of acronyms and abbreviations

Acronym	Definition
AGS	Americom Governement Services
AOS	Astrogeodynamical Observatory, Poland
CH	Federal Institute of Metrology METAS, Switzerland
EPS	European Participating Stations (in TWSTFT)
ITU	International Telecommunication Union
NPL	National Physical Laboratory, United Kingdom
PDIS	Pulse distribution amplifier
PPS	Signal with one pulse per second
PTB	Physikalisch-Technische Bundesanstalt, Germany
PTF	Precise Timing Facility
RiteNet, MD	Telecommunication provider, hosted in Maryland
TDEV	Time Deviation is a measure of time stability based on the modified Allan variance
TELESAT	Global satellite operator
TIC	Time Interval Counter
TimeTech, TIM	TimeTech GmbH, Germany
TVF	Timing Validation Facility
TWSTFT	Two-Way Satellite Time and Frequency Transfer
UTC	Coordinated Universal Time
UTC(k)	Version of UTC realized at each of the contributing NMI(k)s
VSL	Van Swinden Laboratory, Netherlands
	TWSTFT specific acronyms
ADUO	Additional diurnal of unknown origin.
CALR(i, k)/CALR	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 time scale maintained at stations i and k.
CALR_interim	Calibration situation on a new epoch, based on a reference calibration value by considering the TWSTFT earth station delay changes since the reference calibration.
CCD(i, k)	Common-clock difference, TWSTFT measurement result between two TWSTFT setups (i, k) at one site, connected to the same clock.
CI	Calibration Identification.
DLD(i)	Difference of signal propagation delay through the transmit and receive path of station i, Tx(i) - Rx(i).
ESDVAR(i)	Earth station delay variation, with respect to the Earth station delay at the time of calibration.
ESIG(i)	ITU-file parameter, which is the uncertainty of the ESDVAR(i).
IIOTIC	Intelligent In/Out and Time Interval Counter.
MOB	Mobile station, short form for a mobile TWSTFT ground station used in calibration experiments.
OPLINK	Optical connection of the mobile TWSTFT station between the Indoor Blue Box and the Outdoor Trailer.
PPS AUX	Auxiliary PPS connection.
PPSRX(i)	Received 1PPS signal from the partner TWSTFT station.
PPSTX(i)	Transmitted 1PPS signal from the own to the partner TWSTFT station.
REFDELAY(i)	Reference delay, time difference between the local time scale and the modem 1PPS output synchronous with the TX signal. This abbreviation is used in the ITU-files.
REFDLY(i)	Shorter abbreviation for REFDELAY, used in this report.
RSIG	ITU-file parameter, which is the uncertainty of the REFDELAY(k).
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 the GEO satellite.
SP(i)	Complete signal path delay from station i to station k, SPU(k) + SPT(k) + SPD(i).
SPD(i)	Signal path downlink delay.
SPT(i)	Signal path delay through the transponder from station i to station k.
SPU(i)	Signal path uplink delay.
$TDev_{Half\_TWDiff(k)}$	Time deviation of the half difference of the measured TI(i)s of both TWSTFT stations.
TI(i)	Time interval counter measurement result, here of a TWSTFT station between PPSTX(i)-PPSRX(i).
Time scale/clock(i)	Reference signal for a TWSTFT station, either from a time scale or a reference clock.
TS(i)	Local time scale, physically represented by the 1PPSTX signal generated by the modem, i being 1 for station 1 and 2 for station 2.
TW(i)	Counter reading in TWSTFT station i.
TX(i)	Signal delay in the transmit path of the TWSTFT station i.
UTC CAL	Derivation of local realization to UTC(k). Used for practical reasons.

2 Background of this TWSTFT calibration campaign

2.1 Operation status in the transatlantic region

TWSTFT comparisons are used worldwide and are structured by regions. This calibration campaign was held in Europe, within the transatlantic region, covered since summer 2009 by the Telesat satellite T-11N.
The access to the satellite was initially managed by Americom Government Services (AGS). Thirteen institutes - 2 in the US, and 11 in Europe, including TimeTech GmbH, Stuttgart, Germany (in short TimeTech) as industrial partner - agreed on the contract with AGS. The two Galileo PTFs were integrated into the network at a later stage. The European participating stations (EPS), among them the TVF partners, signed an agreement with PTB dealing with the cost sharing, the practice of invoicing, and other administrative issues. Since July 2011 the lease agent for the transponder capacity on the same satellite was changed to RiteNet, MD.

2.2 Motivation and structure of this calibration campaign

As mentioned before, TWSTFT calibration activities are necessary to get absolute time calibrated links between the local time scales of the participating stations. Normally these local time scales are the official national time scales of the countries that are hosting the corresponding laboratory. To ensure a successful calibration campaign, all stations need to be operated in a very reliable way, which demands a high effort in work force and in equipment. This is the reason why such campaigns are not organized very often and are carried out only with a limited number of participants. AOS and VSL together with PTB were last calibrated in 2013 and CH with PTB in 2012. NPL has never been calibrated with a mobile earth station since the NPL stations were brought into operation in their present locations in March 2016.

3 Organization of the TWSTFT calibration campaign

The herein reported calibration campaign was initiated by METAS, together with AOS, NPL, PTB and VSL. TimeTech was commissioned to perform measurements with their mobile TWSTFT station. Based on their large expertise in this domain, TimeTech brought a highly appreciated and efficient support to this campaign.

3.1 General Information

Identification:	2nd_2019_TW-EU-Calibration
Purpose:	TWSTFT Calibration for UTC Time Links
Coordinator:	METAS / Christian Schlunegger
Type:	Calibration using a TWSTFT mobile station
Provider of the mobile station:	TimeTech
Station for the closure measurement:	TimeTech

3.2 Participants and Contacts

Table 3-1: Participants and contacts

TIM Dr Thorsten Feldmann thorsten.feldmann@timetech.de TimeTech GmbH Curiestrasse 2 D-70563 Stuttgart, Germany	**NPL** Dr Peter Whibberley peter.whibberley@npl.co.uk National Physical Laboratory Hampton Road, Teddington Middlesex TW11 0LW, United Kingdom
VSL Dr Erik Dierikx edierikx@vsl.nl Van Swinden Laboratory Thijsseweg 11 2629 JA, Delft, The Netherlands	**PTB** Dr Dirk Piester dirk.piester@ptb.de Physikalisch-Technische Bundesanstalt Bundesallee 100 38116 Braunschweig, Germany
AOS Dr Jerzy Nawrocki nawrocki@cbk.poznan.pl Astrogeodynamical Observatory Space Research Centre Borowiec near Poznan, ul. Drapalka 4 62-035 KORNIK, Poland	**CH** Christian Schlunegger christian.schlunegger@metas.ch Federal Institute of Metrology METAS Lindenweg 50 CH-3003 Bern-Wabern, Switzerland

This table lists the participating laboratories, including the station for the closure measurement and the station of the European pivot, which is PTB.

3.3 TWSTFT Station Information

Table 3-2: TWSTFT station information

Laboratory	Location	TWSTFT station code for even hour	TWSTFT station code for odd hour	Antenna Position
TIM	Stuttgart DE	TIM01	TIM11	LA: N 48° 44' 16.272" LO: E 9° 06' 45.106" HT: 529.00 m
NPL	Teddington UK	NPL02	NPL12	LA: N 51° 25' 32.800" LO: E 359° 39' 23.300" HT: 68.00 m
VSL	Delft NL	VSL01	VSL11	LA: N 51° 59' 07.820" LO: E 4° 23' 16.950" HT: 76.80 m
PTB	Braunschweig DE	PTB05	PTB15	LA: N 52° 17' 49.787" LO: E 10° 27' 37.966" HT: 143.41 m
AOS	Borowiec PL	AOS01	AOS11	LA: N 52° 16' 31.421" LO: E 17° 04' 32.784" HT: 120.00 m
CH	Bern CH	CH01	CH11	LA: N 46° 55' 25.386" LO: E 7° 27' 51.002" HT: 612.82 m
MOB	Stuttgart DE	MOB02	MOB12	Mobile

This table gives information about the participating laboratories, together with their geographic locations.

4 Operational Information

For this calibration campaign transponder with carrier ID 112677 was used out of the total three transponders of T-11N involved in the transatlantic TWSTFT region. The details of the transponders are shown in the next section.

4.1 Technical parameters of the satellite as of August-October 2019

Used satellite:	Satellite T-11N at 37.5° W, owned by Telesat Satellite access managed by RiteNet, MD Beacon frequency, 11699.5 MHz
For the Europe to Europe link:	Carrier ID, 112677 Uplink, 14260.150 MHz, horizontal polarization Downlink, 10960.150 MHz, vertical polarization
For the transatlantic link:	In Europe: Carrier ID, 112673 Uplink, 14046.5900 MHz, horizontal polarization Downlink, 11489.060 MHz, vertical polarization In USA: Carrier ID, 112701 Uplink, 14289.060 MHz, horizontal polarization Downlink, 11746.590 MHz, vertical polarization.

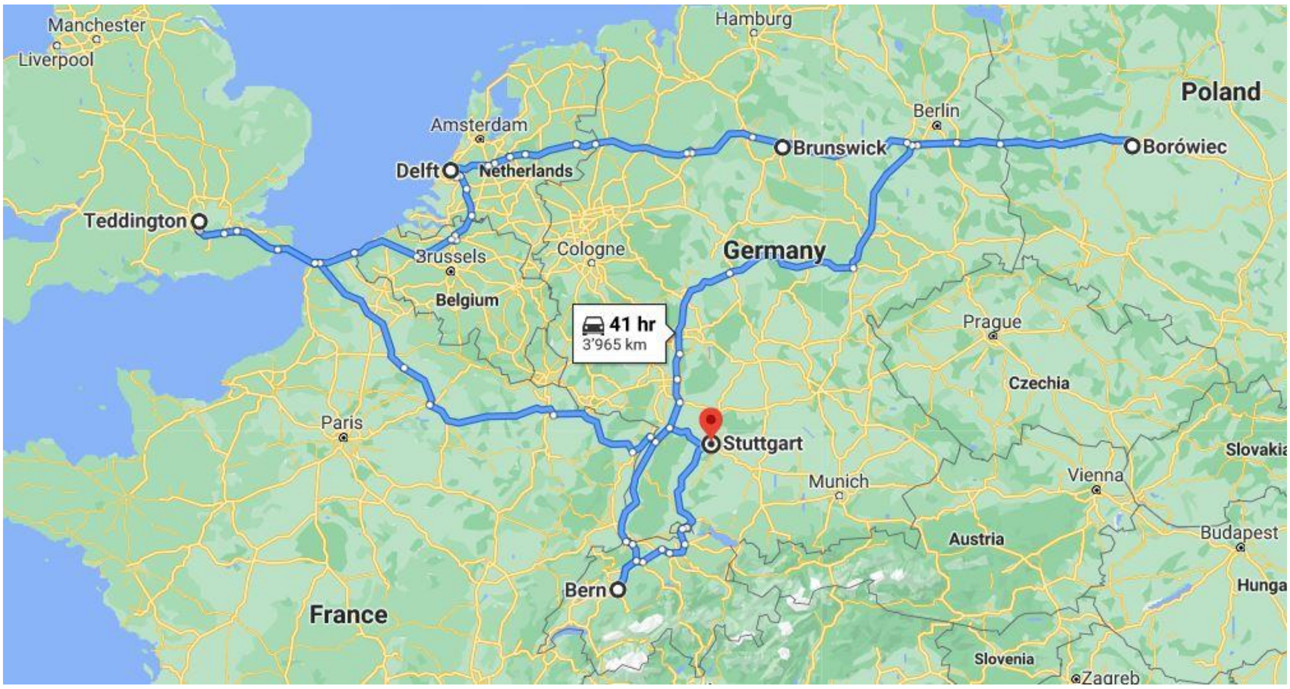
4.2 Measurement schedules

The transport of the mobile TWSTFT station to each participant and the onsite measurement campaigns were organized according to the schedule and to the road map as shown in Table 4-1 and in Figure 4-1.

Table 4-1: Measurement schedule

MOB at	Week #	From Date		To Date		MJD
TIM	35	Mon, 26 Aug 2019	21:00	Thu, 29 Aug 2019	12:00	58722 - 58725
NPL	36	Mon, 2 Sep 2019	13:00	Fri, 6 Sep 2019	14:00	58728 - 58732
VSL	37	Mon, 9 Sep 2019	13:00	Fri, 13 Sep 2019	05:00	58735 – 58739
PTB	38	Mon, 16 Sep 2019	09:00	Thu, 19 Sep 2019	20:00	58742 - 58745
AOS	39	Tue, 24 Sep 2019	18:00	Fri, 27 Sep 2019	05:00	58749 – 58753
CH	40	Mon, 30 Sep 2019	10:00	Fri, 4 Oct 2019	06:00	58756 - 58760
TIM	41	Mon, 7 Oct 2019	13:00	Fri, 11 Oct 2019	10:00	58763 - 58767

Figure 4-1: Road map for the calibration campaign



The total travel distance was of about 4000 km.

The even hour TWSTFT measurements needed for this calibration campaign were added into the transatlantic measurement plan as shown in Figure 4-2.

Additional measurements were also performed during the odd hours, according to the TWSTFT calibration schedule as shown in Figure 4-3.

Figure 4-2: TWSTFT calibration scheduler for even hour measurement sessions

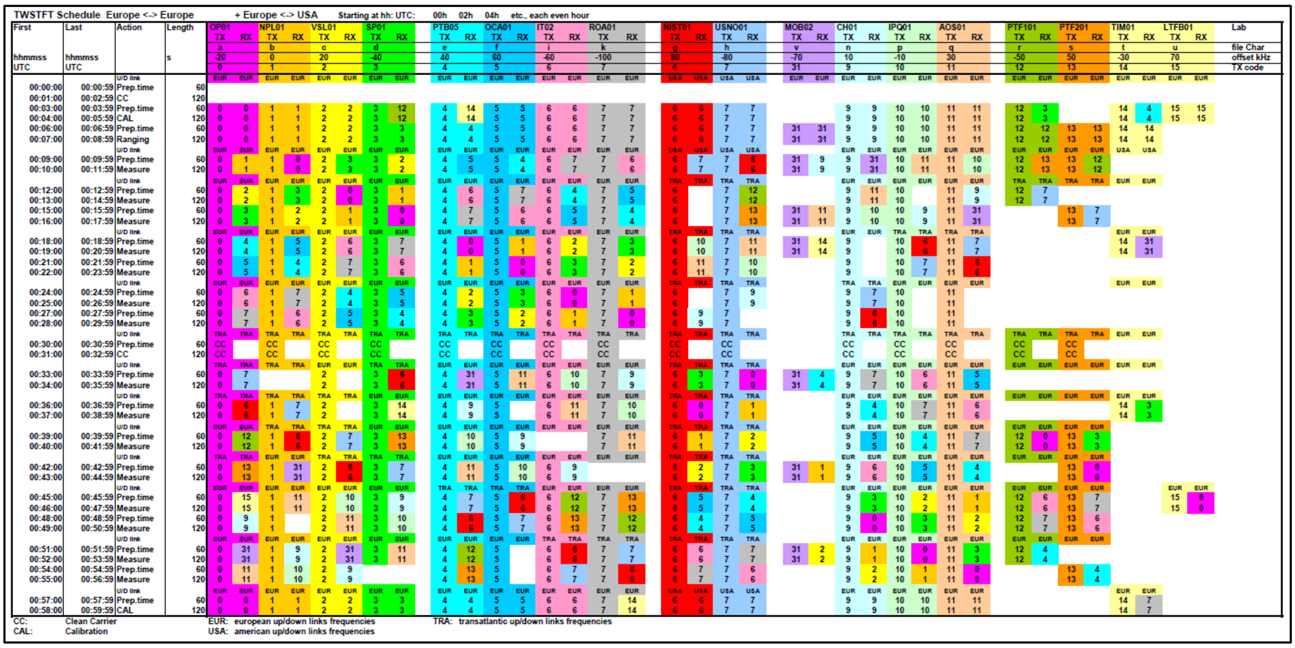


Figure 4-3: TWSTFT calibration scheduler for odd hour measurement sessions

TWSTFT Schedule Europe <-> Europe + Europe <-> USA Starting at hh: UTC: 01h

First	Last	Action	Length	NPL11 TX	NPL11 RX	VSL11 TX	VSL11 RX	PTB15 TX	PTB15 RX	CH11 TX	CH11 RX	AOS11 TX	AOS11 RX	TIM11 TX	TIM11 RX	MOB12 TX	MOB12 RX	Lab
				b		c		e		n		q		t		v		file Char
hhmmss	hhmmss		s	0		20		40		10		30		-30		-70		offset kHz
UTC	UTC			1		2		4		9		11		14		31		TX code
		U/D link		EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	
01:00:00	01:00:59	Prep.time	60															
01:01:00	01:02:59	CC	120															
01:03:00	01:03:59	Prep.time	60	1	1	2		4	31	9	14	11	11	14	9	31	4	
01:04:00	01:05:59	Ranging	120	1	1	2		4	31	9	14	11	11	14	9	31	4	
01:06:00	01:06:59	Prep.time	60	1	2	2	1	4		9	31	11	14	14	11	31	9	
01:07:00	01:08:59	Measure	120	1	2	2	1	4		9	31	11	14	14	11	31	9	
01:09:00	01:09:59	Prep.time	60	1	4	2	2	4	1	9		11	31	14	14	31	11	
01:10:00	01:11:59	Measure	120	1	4	2	2	4	1	9		11	31	14	14	31	11	
01:12:00	01:12:59	Prep.time	60	1	9	2	4	4	2	9	1	11		14	31	31	14	
01:13:00	01:14:59	Measure	120	1	9	2	4	4	2	9	1	11		14	31	31	14	
01:15:00	01:15:59	Prep.time	60	1	11	2	9	4	4	9	2	11	1	14		31	31	
01:16:00	01:17:59	Measure	120	1	11	2	9	4	4	9	2	11	1	14		31	31	
01:18:00	01:18:59	Prep.time	60	1	14	2	11	4	9	9	4	11	2	14	1	31		
01:19:00	01:20:59	Measure	120	1	14	2	11	4	9	9	4	11	2	14	1	31		
01:21:00	01:21:59	Prep.time	60	1	31	2	14	4	11	9	9	11	4	14	2	31	1	
01:22:00	01:23:59	Measure	120	1	31	2	14	4	11	9	9	11	4	14	2	31	1	
01:24:00	01:24:59	Prep.time	60	1		2	31	4	14	9	11	11	9	14	4	31	2	
01:25:00	01:26:59	Measure	120	1		2	31	4	14	9	11	11	9	14	4	31	2	
01:27:00	01:27:59	Prep.time	60															
01:28:00	01:29:59	Measure	120															
		U/D link		EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	
01:30:00	01:30:59	Prep.time	60															
01:31:00	01:32:59	CC	120															
01:33:00	01:33:59	Prep.time	60	1	1	2		4	31	9	14	11	11	14	9	31	4	
01:34:00	01:35:59	Measure	120	1	1	2		4	31	9	14	11	11	14	9	31	4	
01:36:00	01:36:59	Prep.time	60	1	2	2	1	4		9	31	11	14	14	11	31	9	
01:37:00	01:38:59	Measure	120	1	2	2	1	4		9	31	11	14	14	11	31	9	
01:39:00	01:39:59	Prep.time	60	1	4	2	2	4	1	9		11	31	14	14	31	11	
01:40:00	01:41:59	Measure	120	1	4	2	2	4	1	9		11	31	14	14	31	11	
01:42:00	01:42:59	Prep.time	60	1	9	2	4	4	2	9	1	11		14	31	31	14	
01:43:00	01:44:59	Measure	120	1	9	2	4	4	2	9	1	11		14	31	31	14	
01:45:00	01:45:59	Prep.time	60	1	11	2	9	4	4	9	2	11	1	14		31	31	
01:46:00	01:47:59	Measure	120	1	11	2	9	4	4	9	2	11	1	14		31	31	
01:48:00	01:48:59	Prep.time	60	1	14	2	11	4	9	9	4	11	2	14	1	31		
01:49:00	01:50:59	Measure	120	1	14	2	11	4	9	9	4	11	2	14	1	31		
01:51:00	01:51:59	Prep.time	60	1	31	2	14	4	11	9	9	11	4	14	2	31	1	
01:52:00	01:53:59	Measure	120	1	31	2	14	4	11	9	9	11	4	14	2	31	1	
01:54:00	01:54:59	Prep.time	60	1		2	31	4	14	9	11	11	9	14	4	31	2	
01:55:00	01:56:59	Measure	120	1		2	31	4	14	9	11	11	9	14	4	31	2	
01:57:00	01:57:59	Prep.time	60															
01:58:00	01:59:59	CAL	120															

CC: Clean Carrier
CAL: Calibration
EUR: european up/down links frequencies
USA: american up/down links frequencies
TRA: transatlantic up/down links frequencies

5 TWSTFT calibration background

This section describes the method and calculation used for this TWSTFT calibration. They are based on the theory and equations elaborated for the 2019 Galileo calibration campaign [RD03] and follow the definitions of the ITU-R Recommendation TF.1153-4 [RD01].

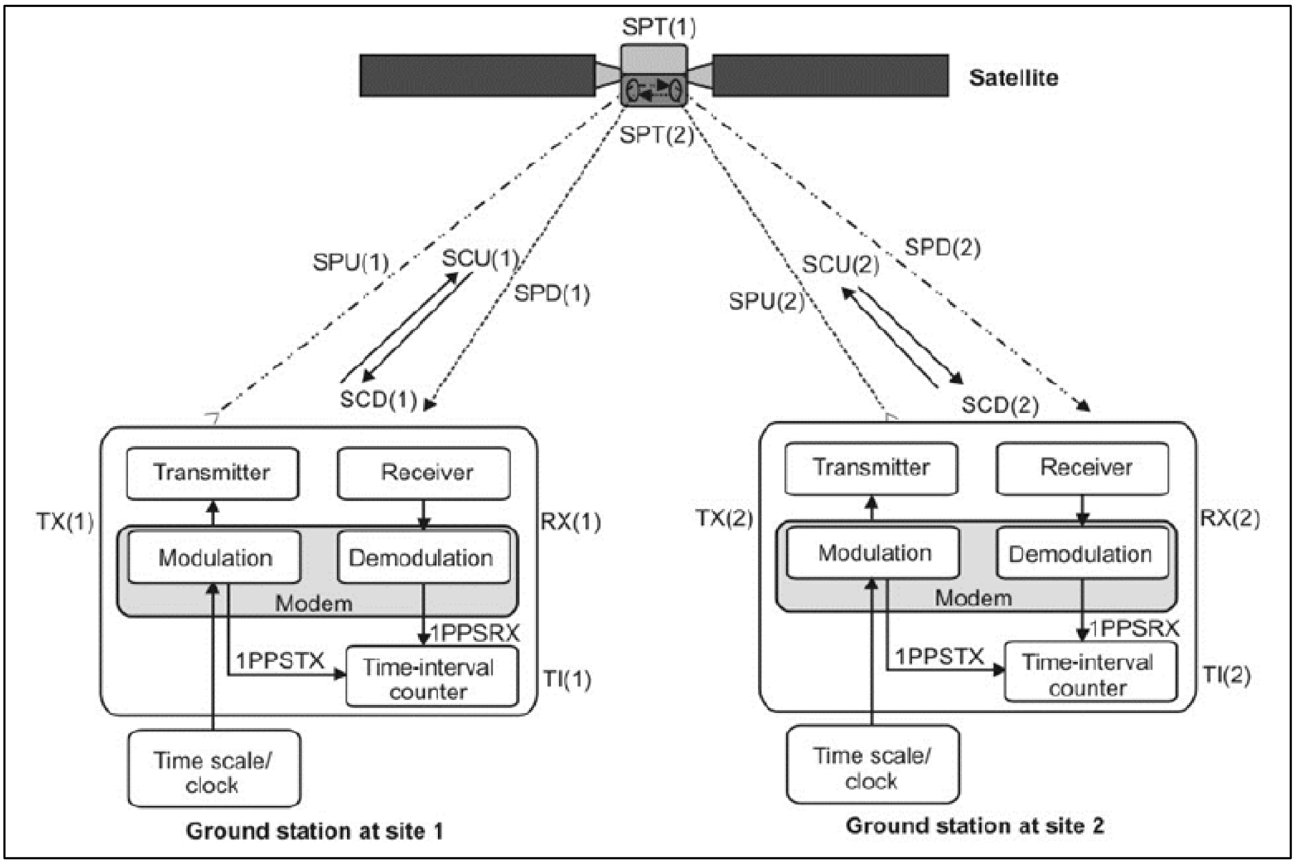
5.1 General description of TWSTFT measurements

The objective is to compare two remote time scales to determine their time difference.

Both involved stations (ground station at site i) simultaneously send to the partner laboratory a 1PPSTX(i) signal originating from their local time scale using a geostationary satellite (SPT) link. At both stations, each incoming 1PPSRX(i) time signal is then compared to the local PPS time signal using a time interval counter to determine the time differences TI(i) = 1PPSTX(i) – 1PPSRX(i).

Figure 5-1 illustrates the situation.

Figure 5-1: Schematics of a TWSTFT setup [RD01]



Each time signal on the way from one ground station to the other is affected by various time delays. The signal paths expressed with their individual delays are as follows:

$$SP(i) = SPU(i) + SPT(i) + SPD(i) \quad (1)$$

$$TW(1) = TS(1) - TS(2) + TX(2) + SP(2) + RX(1) + SCD(1) - SCD(2) \quad (2)$$

$$TW(2) = TS(2) - TS(1) + TX(1) + SP(1) + RX(2) + SCD(2) - SCD(1). \quad (3)$$

SP(i) is the sum of all delays arising outside the ground stations, namely, the uplink signal delay SPU(i), the satellite transition signal delay SPT(i) and the downlink signal delay SPD(i).

TW(i) are the reading values of the time interval counters named TI(i) in the scheme of figure 5-1. TS(i) are the time scale PPS events, TX(i) are the transmit path signal delays inside the ground stations, RX(i) are the receive signal delays inside the ground stations and SCD(i) are the non-reciprocity corrections due to the Sagnac effect. The Sagnac effect is detailed in [RD01].

The reciprocity of both complete path delays, namely

$$SP(1) = SP(2) \quad (4)$$

is usually assumed, which is in reality not absolutely correct and will be taken into account by considering an appropriate uncertainty contribution, as shown in Table 8-1 as uncertainty group "ub, IV".

The differences of the signal propagation delays through the transmit and receive path of station i, Tx(i) - Rx(i) are defined as:

$$DLD(i) = TX(i) – RX(i). \quad (5)$$

The time scale difference is then obtained by subtracting Eq. (3) from Eq. (2) and by using Eqs. (4) and (5). This yields:

$$TS(1) – TS(2) = 0.5 * [TW(1) – TW(2)] + \{0.5 * [DLD(1) – DLD(2)] – [SCD(1) – SCD(2)]\}. \quad (6)$$

The asymmetries of the ground station delays and the Sagnac correction delays define the calibration value CALR(1,2), which corresponds to the terms in curly brackets of eq. (6), namely:

$$CALR(1,2) = 0.5 * [DLD(1) – DLD(2)] – [SCD(1) – SCD(2)]. \quad (7)$$

5.2 Details of the applied calibration method

For the determination of CALR(1,2) two different approaches are possible, namely, the site-mode and the baseline-mode methods.
Both methods make use of an additional mobile TWSTFT station (MOB).

For this calibration campaign the site-mode approach was used, in which the mobile station located at site k is used to perform TWSTFT measurements with the same site station k; the site and the mobile station being connected to the same time scale. In this case, Eq. (6) simplifies to:

$$0 = 0.5 * [TW(k) – TW(MOB@k)] + \{0.5 * [DLD(k) – DLD(MOB)]\}. \quad (8)$$

In this common-clock measurement the delay difference due to Sagnac effect cancels out, because both TWSTFT stations are located at the same site.

We define the common-clock difference CCD(MOB@k) as the second term in Eq. (8), namely:

$$CCD(MOB@k) = 0.5 * [DLD(k) – DLD(MOB)]. \quad (9)$$

Eq. (9) can be used to express the difference between the differential earth station delays of the TWSTFT stations at sites 1 and 2. This yields:

$$CCD(MOB@1) - CCD(MOB@2) = 0.5 * [DLD(1) – DLD(2)]. \quad (10)$$

Combining Eq. (10) and Eq. (7) leads to:

$$CALR(1,2) = CCD(MOB@1) - CCD(MOB@2) – [SCD(1) – SCD(2)]. \quad (11)$$

Equation (11) gives the calibration value using the site-mode method.

The CCD values can be determined by combining Eq. (8) and Eq. (9):

CCD(MOB@k) = 0.5 * [TW(MOB@k) – TW(k)]. (12)

5.3 Role of the mobile TWSTFT station

In the TWSTFT calibration process, the mobile station serves as a differential transfer device. It is therefore mandatory to keep the signal paths delays in the mobile station constant during the whole calibration campaign.

5.4 Connecting TWSTFT stations to time scales with REFDLY

Equation (8) assumes that the mobile station and the fixed site station at site k are connected to the same time scale. In reality this connection is done from the modem of the appropriate TWSTFT station to the time scale connection point with a cable, whose delay needs to be calibrated. All TWSTFT stations report their delays in the published ITU-files with the parameter REFDELAY and with its uncertainty parameter RSIG, also published in the same file [RD01].

The CCDs with REFDLY are defined, for even (eh) and for odd hours (oh) measurements as follows:

CCD_eh/oh(k) = CCD(MOB@k) + REFDLY(MOB@k) – REFDLY(k) (13)

5.5 Reporting of TWSTFT station changes during time using ESDVAR

Possible changes in the calibrated delays, due, for example, to hardware modification in the station, are taken into account by adjusting the ESDVAR (Earth Station Delay Variation) parameter, jointly with its uncertainty ESIG and are reported in the corresponding file. The ESDVAR parameter should be set to zero after each new calibration campaign [RD01].

6 Description of the mobile TWSTFT station

The mobile TWSTFT station has not changed since the last European calibration campaign [RD03]. Most of the descriptions in this chapter follow the documentation of [RD03] and the site preparation document of TimeTech [RD11].

6.1 Mobile TWSTFT station and interface

Figure 6-1 shows a simplified block diagram of the mobile TWSTFT station and the interface between the local laboratory and the mobile station. UTC(k) designates the reference time scale of the institute k. If UTC(k) is not directly accessible, the laboratory provides a signal UTC CAL, along with its offset and uncertainty with respect to UTC(k).

A list of the connection cable provided with the TWSTFT Mobile station is given in Table 6-1.

Figure 6-1: Block diagram of the mobile TWSTFT station and connection with the participating laboratory

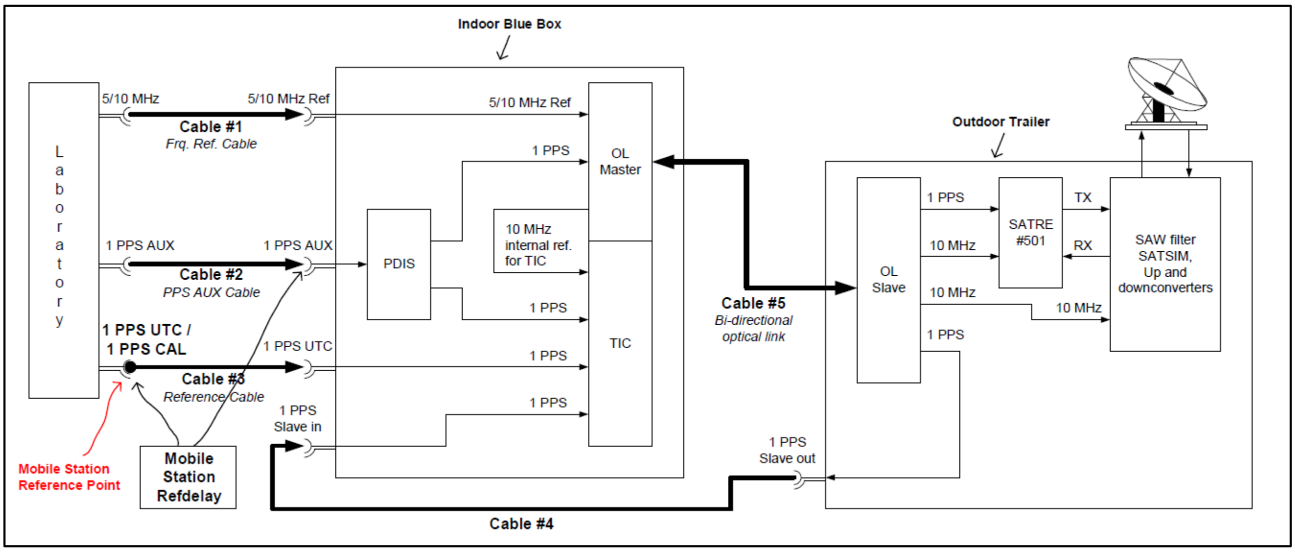


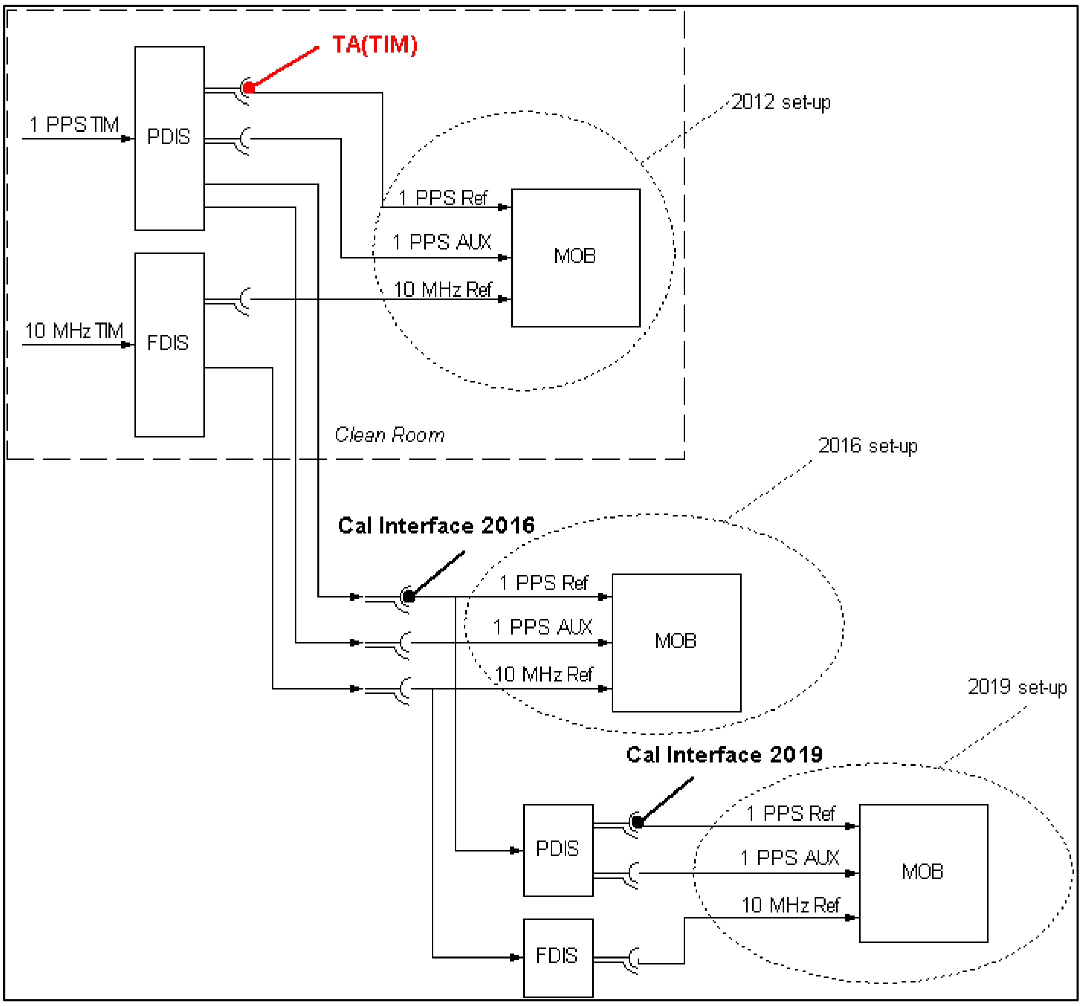
Table 6-1: List of cables provided with the mobile TWSTFT station

Cable #	Signal name	Cable length	Cable type	Cable diameter	Connectors	Connector diameter
Cable #1	5/10 MHz Ref	7.5 m	RG223	5.40 mm	N(M) – N(M)	19 mm
Cable #2	1 PPS AUX	7.5 m	RG223	5.40 mm	N(M) – N(M)	19 mm
Cable #3	1 PPS UTC	7.5 m	Sucotest 18	4.60 mm	N(M) – N(M)	19 mm
Cable #4	Test cable	200 m	Ecoflex 10	6.40 mm	N(M) – N(M)	19 mm
Cable #5	Optical cable	200 m	LWL-4HMC	6.00 mm	HMC - HMC	23 mm

Cable #4 (see Figure 6-1) is a test cable used to verify the 1 PPS of the slave optical link using the TIC inside the Blue Box. The use of the reference cable #3 is mandatory, since the reference point of the mobile station is defined at the endpoint of this cable.

In contrast to the 2012 and 2013 calibration campaigns, the mobile TWSTFT station was not directly connected to the timescale reference point at TIM, TA(TIM). In order to simplify the installation, the place of installation of the indoor blue box was changed in 2016 and the mobile TWSTFT station was referenced to a dedicated Cal Interface. The setup was changed again for the 2019 campaign (see Figure 6-2). Therefore an offset of (81.23 ± 0.03) ns needs to be considered, in order to account for the delay TA(TIM) – Cal Interface 2019. This leads to the total REFDLY of the mobile TWSTFT station at TimeTech of (111.46 ± 0.03) ns (see Table 7-2).

Figure 6-2: Changes of MOB signal connections at TIM between 2012 and 2019



7 Measurement data

This chapter summarises all the data necessary for the calculation of the calibration results, together with their respective measurement uncertainties.

7.1 Site location related data

As detailed in [RD01], the Sagnac corrections depend on the locations of the TWSTFT stations and of the satellite and are also influenced by the earth geometry and its dynamics. For the involved partners the following corrections have been calculated:

Table 7-1: Sagnac corrections

Location of MOB	SCD(k) / ns	uSCD(k) / ns
TIM_start	104.784	0.1
NPL	82.344	0.1
VSL	89.909	0.1
PTB	99.315	0.1
AOS	109.023	0.1
CH	105.507	0.1
TIM_stop	104.784	0.1

The station coordinates are sufficiently well known to assure an uncertainty uSCD < 0.1 ns [RD02].

As mentioned earlier, each TWSTFT station is connected to the local timescale with its individual cable. The following REFDLY values and uncertainties were determined and are summarized in Table 7-2.

Table 7-2: REFDLY measured at each location

Location of MOB	REFDLY(MOB@k) / ns	uREFDLY(MOB@k) / ns	REFDLY(UTC(k)) / ns	uREFDLY(UTC(k)) / ns
TIM_start	111.46	0.03	705.09	0.01
NPL	68.02	0.05	65.70	0.05
VSL	56.39	0.01	728.43	0.05
PTB	63.09	0.01	736.13	0.02
AOS	55.56	0.03	681.30	0.02
CH	19.64	0.02	785.10	0.05
TIM_stop	111.46	0.03	705.15	0.01

7.2 Measured CCD using the site-mode method

The CCD were measured at each visited laboratory by performing TWSTFT measurements between the mobile and the local TWSTFT station.

Onsite measurement times of at least three full days were planned, scheduled on even and on odd hours. This could not be fulfilled with all laboratories due to different reasons. Nevertheless, the measurement results were good enough to determine the CCD properly.

By analysing the evolution of the CCD values, typical diurnal variations were observed.

As measurement uncertainty for the CCD values the time deviations TDEV are used, which were determined from the modified Allan deviations of the CCD traces. In most cases the largest TDEV values were observed with an averaging time of about 10 hours, except for the measurements performed at VSL, where the peak TDEV values were observed for an averaging time of about 5 hours.

For each measured CCD, the maximum time deviation TDev_CCD(k), obtained for an averaging time of maximum 24 hours, and the standard deviation StDev_CCD(k) were determined and are summarized in Table 7-3.

Table 7-3: CCD values measured at even and odd hours

Location of MOB	Session hour	CCD_eh(k) or CCD_oh(k) / ns	TDev_CCD(k) / ns	StDev_CCD(k) / ns	N
TIM_start	even	-691.653	0.201	0.294	24
	odd	-691.799	0.083	0.169	63
NPL	even	55.734	0.548	0.642	42
	odd	55.477	0.414	0.406	77
VSL	even	-943.61	0.263	0.341	44
	odd	-943.639	0.212	0.286	86
PTB	even	-659.316	0.320	0.293	40
	odd	-659.376	0.14	0.179	83
AOS	even	-617.955	0.716	0.644	30
	odd	--	--	--	--
CH	even	-653.505	0.397	0.471	44
	odd	-654.146	0.192	0.261	90
TIM_stop	even	-691.401	0.266	0.213	46
	odd	-691.448	0.116	0.19	92

For AOS no odd hour measurements were available.

Related graphs of CCD and TDEV measurements are shown in Annex 1.

7.2.1 Averaged CCD

It was observed at some sites that the CCD values measured at even and at odd hours showed an offset. The largest difference was measured at CH with a value of about 0.64 ns.

The averaged CCD values (CCD_site(k)) of the even hour (CCD_eh(k)) and of the odd hour CCD (CCD_ oh(k)) measurements were then calculated according to:

CCD_site(k) = 0.5 * [CCD_eh(k) + CCD_ oh(k)]. (14)

The differences between CCD measurements performed during even and odd hours were calculated according to:

CCD_diff(k) = CCD_eh(k) – CCD_oh(k). (15)

A deviation CCD_diff(k) larger than the measurement uncertainty was observed at one location, as shown in Table 7-4. This effect was already observed during previous calibration campaigns [RD03] and was attributed to possible interference effects between the transmitted PRN codes. To take into account for this effect, a supplementary uncertainty contribution (ub, 13) was added and was estimated from the standard deviation of the residuals of all the CCD_diff(k) differences [RD03]. This led to an uncertainty of ub, 13 = 0.25 ns, which was rounded to 0.3 ns.

For the CCD uncertainty, the largest of the even and of the odd hour TDev_CCD(k) was considered:

uCCD_site(k) = Max[TDev_CCD(k)]. (16)

Table 7-4: Results of CCD site-mode measurements

Location of MOB	CCD_site(k) / ns	uCCD_site(k) / ns	CCD_diff(k) / ns
TIM_start	-691.726	0.201	0.146
NPL	55.606	0.548	0.257
VSL	-943.625	0.263	0.029
PTB	-659.346	0.320	0.06
AOS	-617.955	0.716	
CH	-653.826	0.397	0.641
TIM_stop	-691.425	0.266	0.047

For the "ub, 13" of Table 8-1 term the uncertainty uCCD_diff = 0.3 ns was calculated.

7.2.2 Stability of the mobile TWSTFT station

The stability of the mobile station was verified by performing two TWSTFT measurements between the Mobile station and the fixed TWSTFT station of TimeTech in Stuttgart; a first time at the beginning and a second time at the end of the calibration campaign. A difference between both measurements of 0.301 ns values was observed and was used to define the type B uncertainty "ub, 3", as summarized in Table 8-1.

8 Calibration results

The CALR calibration values for each link were calculated using Eq. (11), by considering the averaged CCD values, according to:

CALR = CCD_site(1) – CCD_site(2) – SCD(1) + SCD(2). (17)

The corresponding measurement uncertainties uCALR were evaluated by considering statistical (type A) and systematic (type B) contributions. Type A uncertainty contributions are based on the CCD_site measurements between the mobile and the site TWSTFT stations and are given by the uCCD_site(k) estimate, as given by Eq. (16). They are labelled in Table 8-2 as ua1 and ua2 for measurements at sites 1 and 2.
Type B uncertainties are summarized in Table 8-1, as defined in the report [RD03] of the 2019 Galileo calibration campaign , which defines four groups of contributions (labelled as ub, I, ub, II, ub, III(i) and ub, IV).

The REFDLY uncertainty contributions with the "ub, 6(i)" of Table 8-1 term are different for each link and each is a combination of the four involved REFDLY uncertainties. The individual contributions are included in Table 8-2.

Table 8-1: Overview of the type B uncertainties

Group	Sub group	Source	Contribution / ns	Tot / ns
ub, I		Mobile station and related equipment		0.36
	ub, 1	Uncertainty due to the impact of temperature variations	0.192	
	ub, 2	Uncertainty due to other contributions related to the mobile station	0.035	
	ub, 3	Instability of the mobile station (CCD_site_stop – CCD_site_start)	0.301	
ub, II		Laboratory station and related equipment		0.09
	ub, 4	Uncertainty due to the impact of temperature variations	0.085	
	ub, 5	Uncertainty due to other contributions in laboratory stations	0.020	
ub, III(i)		Interface between mobile station and local UTC(k) realization		0.25 to 0.26
	ub, 6(i)	Contribution to the CCD measurements associated with the REFDLY uncertainties, the uREFDLY values.	0.039 to 0.089	
	ub, 7	Uncertainty due to contributions of laboratory signal distribution equipment [RD04, RD05]	0.200	
	ub, 8	Uncertainty due to TIC resolution [RD04]	negligible	
	ub, 9	Uncertainty due to TIC systematic contributions [RD05]	0.130	
ub, IV		Satellite link and environment		0.44
	ub, 10	Satellite communication Tx power, C/NO 0.150 ns	0.150	
	ub, 11	Atmosphere Ionosphere 0.030 ns Troposphere 0.001 ns Temp. var. on ground stations 0.100 ns Humidity changes 0.010 ns	0.105	
	ub, 12	Satellite motion ADUO (add. diurnal of unknown origin) 0.230 ns Residual Sagnac 0.100 ns Path delay diff. between MOB and fixed TWSTFT station 0.002 ns	0.251	
	ub, 13	Even and odd hours measurements as possible interferences between PRN codes	0.300	

All type B uncertainties were taken from report [RD03], with exception of ub, 3 (instability of the mobile station) which was specifically measured for this calibration campaign, then ub, 6(i) (Contribution to the CCD measurements associated with the REFDLY uncertainties, the uREFDLY values) which represents the different REFDLY situations, also ub, 12 (uncertainty due to residual Sagnac effect), which was estimated according to the values reported in Table 7-1, and ub, 13 (Even and odd hours measurements as possible interferences between PRN codes).

The results of the calibration campaign are summarized in Table 8-2, here below. These values will be reported in the ITU-files, as proposed in Annex 2.

Table 8-2: Calibration results with their respective uncertainties

Link Lab(j)	Link Lab(k)	CALR / ns	uCALR / ns	ua1 / ns	ua2 / ns	ub, I / ns	ub, II / ns	ub, 6(i) / ns	ub, III / ns	ub, IV / ns
NPL02	PTB05	731.923	0.9	0.548	0.320	0.36	0.09	0.075	0.26	0.44
VSL01	PTB05	-274.873	0.8	0.263	0.320	0.36	0.09	0.056	0.25	0.44
AOS01	PTB05	31.683	1.1	0.716	0.320	0.36	0.09	0.043	0.25	0.44
CH01	PTB05	-0.671	0.9	0.397	0.320	0.36	0.09	0.059	0.25	0.44
VSL01	NPL02	-1006.795	0.9	0.263	0.548	0.36	0.09	0.088	0.26	0.44
AOS01	NPL02	-700.240	1.2	0.716	0.548	0.36	0.09	0.080	0.26	0.44
CH01	NPL02	-732.594	1.0	0.397	0.548	0.36	0.09	0.089	0.26	0.44
AOS01	VSL01	306.556	1.0	0.716	0.263	0.36	0.09	0.063	0.25	0.44
CH01	VSL01	274.201	0.8	0.397	0.263	0.36	0.09	0.075	0.26	0.44
CH01	AOS01	-32.354	1.1	0.397	0.716	0.36	0.09	0.065	0.25	0.44
TIM01	PTB05	-37.698	0.8	0.266	0.320	0.36	0.09	0.039	0.25	0.44
TIM01	NPL02	-769.621	0.9	0.266	0.548	0.36	0.09	0.078	0.25	0.44
TIM01	VSL01	237.174	0.8	0.266	0.263	0.36	0.09	0.060	0.25	0.44
TIM01	AOS01	-69.381	1.0	0.266	0.716	0.36	0.09	0.048	0.25	0.44
TIM01	CH01	-37.027	0.8	0.266	0.397	0.36	0.09	0.063	0.25	0.44

All uncertainties are given with a coverage factor of k = 1.

9 Comparison with previous calibration data

Table 9-1 shows the previous CALR factors of the same links, together with their ESDVAR corrections and ESIG uncertainties, whenever applicable. The columns "Data source for CALR_old" gives the link to the reference BIPM documents providing these values. The ESDVAR and ESIG data for the individual links were taken from the published ITU-files and were used to calculate the corrected (interim) CALR values, according to:

CALR interim = CALR_old + 0.5 * [ESDVAR(1) - ESDVAR(2)] (18)

uCALR interim = [uCALR_old^2 + (ESIG(1)/2)^2 + (ESIG(2)/2)^2]^0.5. (19)

Table 9-1: Previous CALR (old) with uncertainties and corrected (interim) values

Link Lab(j)	Link Lab(k)	Data source for CALR_old	CALR_old / ns	uCALR_old / ns	ESDVAR(j) / ns	ESIG(j) / ns	ESDVAR(k) / ns	ESIG(k) / ns	CALR Interim /ns	uCALR interim /ns
NPL02	PTB05	RD08	728.1	7.1	0	0	0	0	728.1	7.100
VSL01	PTB05	RD06	-986.3	0.9	0	0	-1418.58	0.6	-277.01	0.949
AOS01	PTB05	RD08	33.1	2.7	0	0.5	0	0	33.1	2.712
CH01	PTB05	RD07	-713.36	1.0	7.64	1.12	-1418.58	0.6	-0.25	1.185
VSL01	NPL02	RD10	-1005.211	7.1	0	0	0	0	-1005.211	7.100
AOS01	NPL02	RD10	-695.477	7.1	0	0.5	0	0	-695.477	7.104
CH01	NPL02	RD10	-733.262	7.1	20.98	2.31	0	0	-722.772	7.193
AOS01	VSL01	RD10	309.468	3	0	0.5	0	0	309.468	3.010
CH01	VSL01	RD10	271.808	2	7.64	1.12	0	0	275.628	2.077
CH01	AOS01	RD10	-37.59	3	20.98	2.31	0	0.5	-27.1	3.224
TIM01	PTB05	RD07	-688.35	1.1	-126.50	0.08	-383.58	2.87	-559.81	1.809
TIM01	NPL02	--	--	--	-126.50	0.08	--	--	--	--
TIM01	VSL01	RD06	297.98	0.8	-126.50	0.08	--	--	234.73	0.801
TIM01	AOS01	RD06	-8.61	0.8	-126.50	0.08	--	--	-71.86	0.801
TIM01	CH01	RD07	25.01	1.1	-126.50	0.08	7.64	1.12	-42.06	1.235

A comparison between the previous corrected CALR (CALR Interim) and the new CALR values obtained during this calibration campaign is shown in Table 9-2, where the deviations

CALR deviation = CARL – CALR interim (20)

with their uncertanities

uCALR deviation = (uCALR^2 + uCALR interim^2)^0.5 (21)

are reported.

Table 9-2: New CALR and comparisons with previous values

Link		CALR / ns	uCALR / ns	CALR interim / ns	uCALR interim / ns	CALR deviation / ns	uCALR deviation / ns
Lab(1)	Lab(2)						
NPL02	PTB05	731.923	0.9	728.1	7.100	3.823	7.157
VSL01	PTB05	-274.873	0.8	-277.01	0.949	2.137	1.241
AOS01	PTB05	31.683	1.1	33.1	2.712	-1.417	2.927
CH01	PTB05	-0.671	0.9	-0.25	1.185	-0.421	1.488
VSL01	NPL02	-1006.795	0.9	-1005.211	7.100	-1.584	7.157
AOS01	NPL02	-700.240	1.2	-695.477	7.104	-4.763	7.206
CH01	NPL02	-732.594	1.0	-722.772	7.193	-9.822	7.263
AOS01	VSL01	306.556	1.0	309.468	3.010	-2.913	3.173
CH01	VSL01	274.201	0.8	275.628	2.077	-1.427	2.226
CH01	AOS01	-32.354	1.1	-27.1	3.224	-5.254	3.407
TIM01	PTB05	-37.698	0.8	-559.81	1.809	522.112	1.978
TIM01	NPL02	-769.621	0.9	--	--	--	0.900
TIM01	VSL01	237.174	0.8	234.73	0.801	2.444	1.133
TIM01	AOS01	-69.381	1.0	-71.86	0.801	2.479	1.282
TIM01	CH01	-37.027	0.8	-42.06	1.235	5.033	1.472

Figure 9-1 shows the calibration deviations between the laboratories who contribute to TAI, whereas Figure 9-2 illustrates the calibration deviations with TimeTech, which serves as closure TWSTFT station. All indicated error bars are k = 1 uncertainties.

Figure 9-1: Deviation between old and new calibration constants of TAI contributors

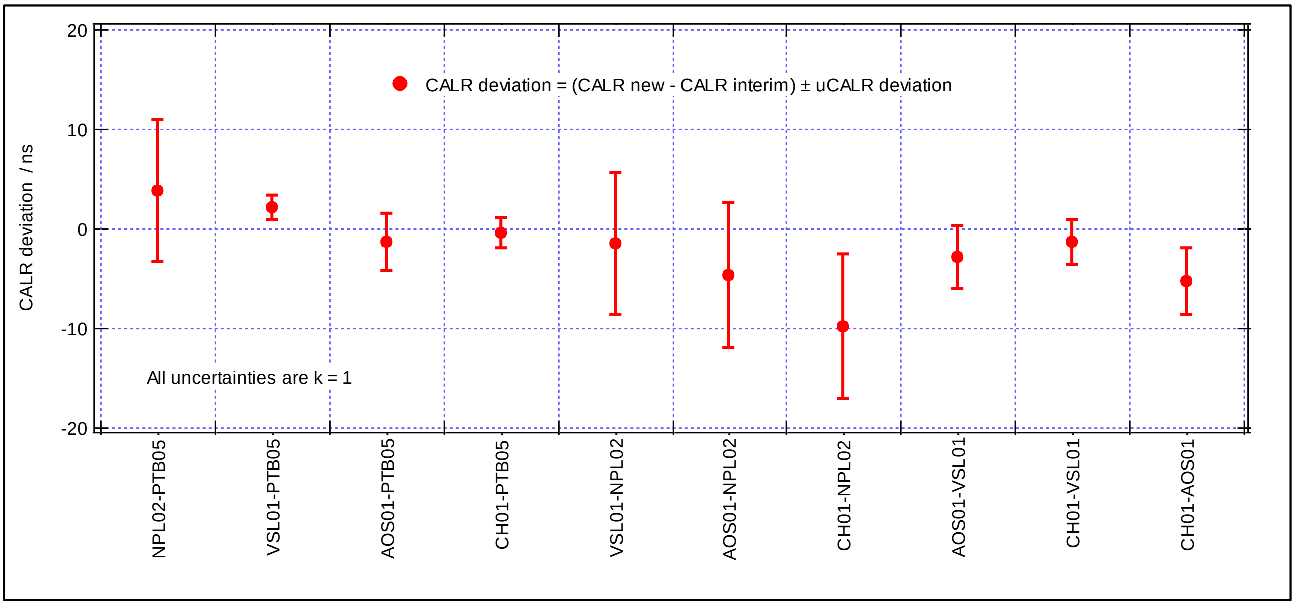
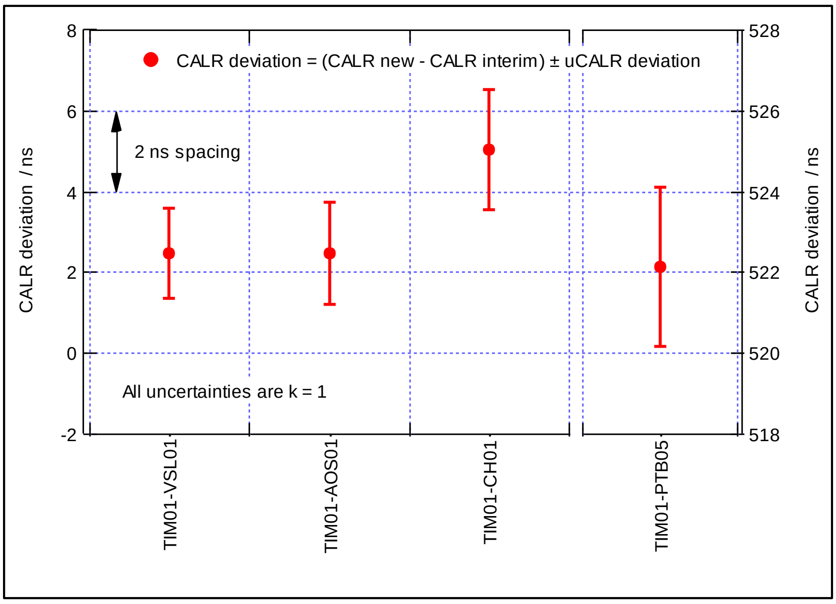


Figure 9-2: Deviation between old and new calibration constants of TimeTech links



The reported deviations with NPL have larger uncertainties than the deviations between other station combinations. The previous calibrations with NPL were done with GPS comparisons, to an epoch where GPS calibrations had uncertainties larger than 5 ns.

Remarkable good agreements between old and new calibration situations can be observed between AOS01-PTB05, CH01-PTB05, AOS01-VSL01 and CH01-VSL01.

In contrast to the other links, the link TIM01-PTB05 shows a remarkable deviation of 522 ns. The reason is that delay changes related to the links involving TIM01 have not been consequently followed up and included in the ITU files in the past, since the time scale at TIM is not used by the BIPM for the generation of TAI and UTC. In the calibration campaigns performed between 2013 and 2019 in the framework of Galileo [RD02, RD03], the CCD measurements at TIM were only used to proof the stability of the mobile TWSTFT station.

10 Summary of the calibration campaign

From August to October of 2019 a TWSTFT calibration campaign could successfully be performed in Europe between NPL, VSL, PTB, AOS and CH with support of TIM. The whole measurement procedures could be realized without noticeable problems. New calibration constants could be evaluated for all links with measurement uncertainties ranging from 0.8 ns to 1.2 ns.

For all participating stations which contribute to TAI the new calibration results are in agreement with the previous calibrations, some of them with remarkable good accordance, despite of the 6 years span between the two campaigns.

It is therefore proposed to apply the new calibration results as listed up in annex 2.

11 Annex 1, Graphs of CCDs using the site-mode method

Figure 11-1: Common-clock measurements MOB at TimeTech at the beginning of the cal. campaign

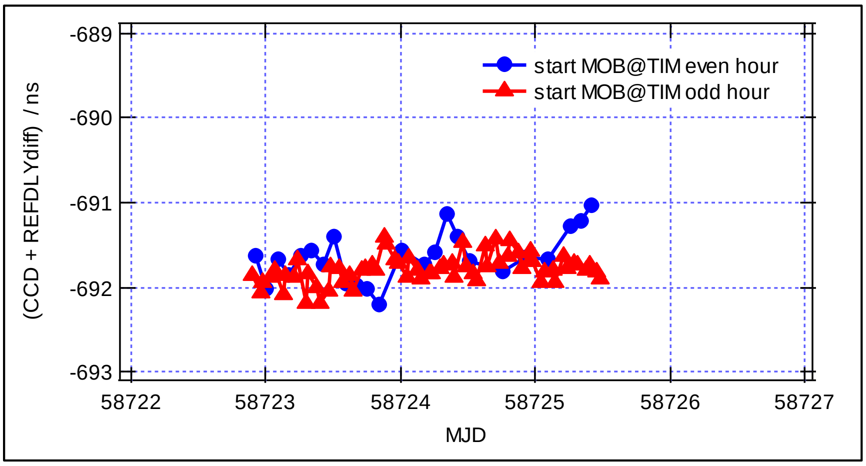


Figure 11-2: Common-clock measurements MOB at TimeTech at the end of the cal. campaign

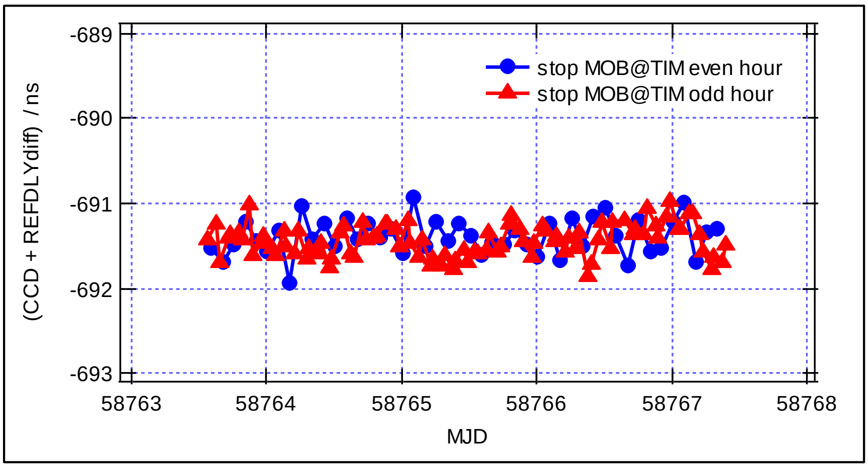


Figure 11-3: Common-clock measurements MOB at NPL

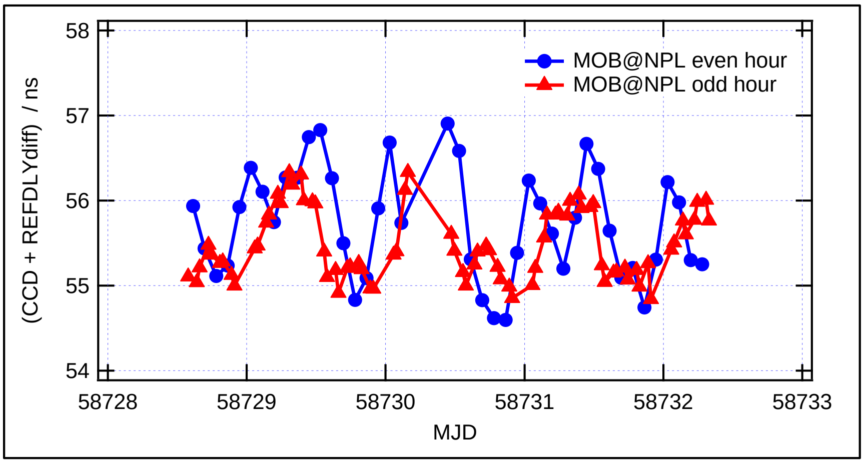


Figure 11-4: Common-clock measurements MOB at VSL

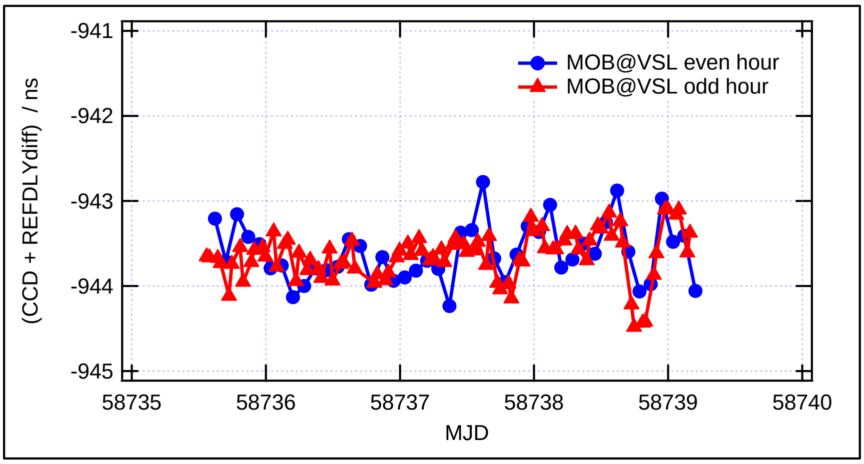


Figure 11-5: Common-clock measurements MOB at PTB

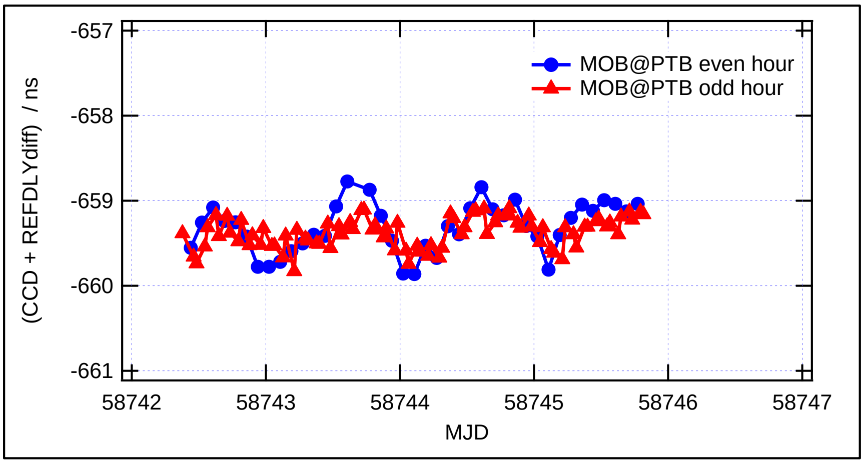


Figure 11-6: Common-clock measurements MOB at AOS

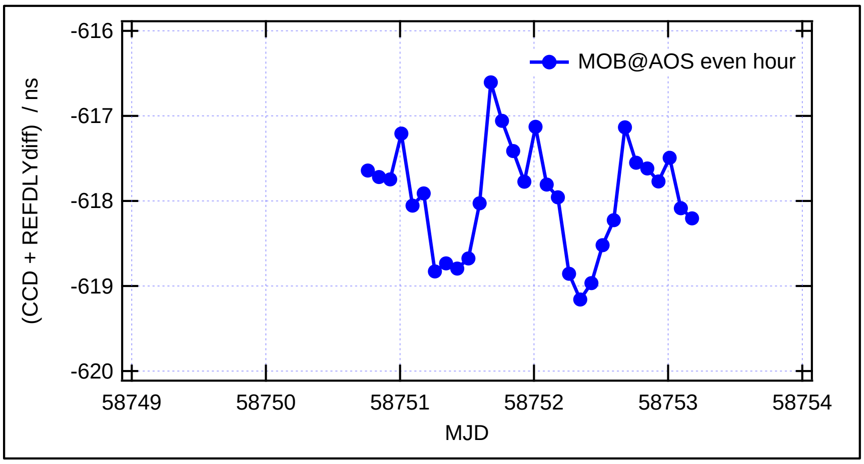


Figure 11-7: Common-clock measurements MOB at CH

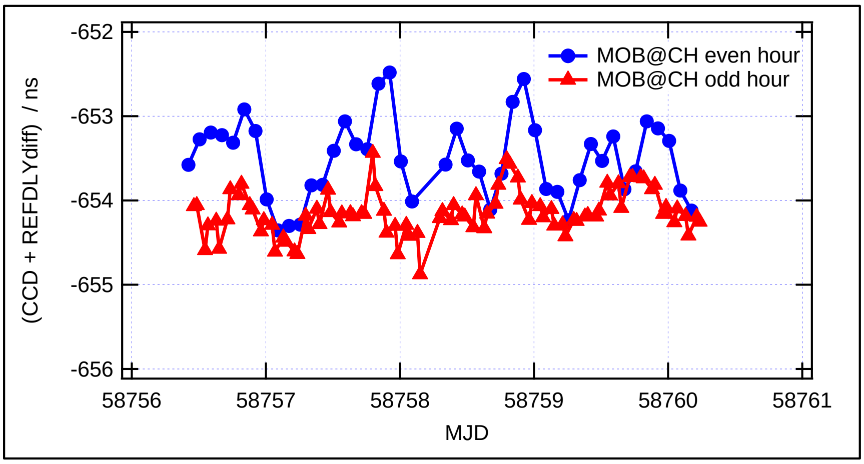


Figure 11-8: TDEV computations of the CCD for even hours

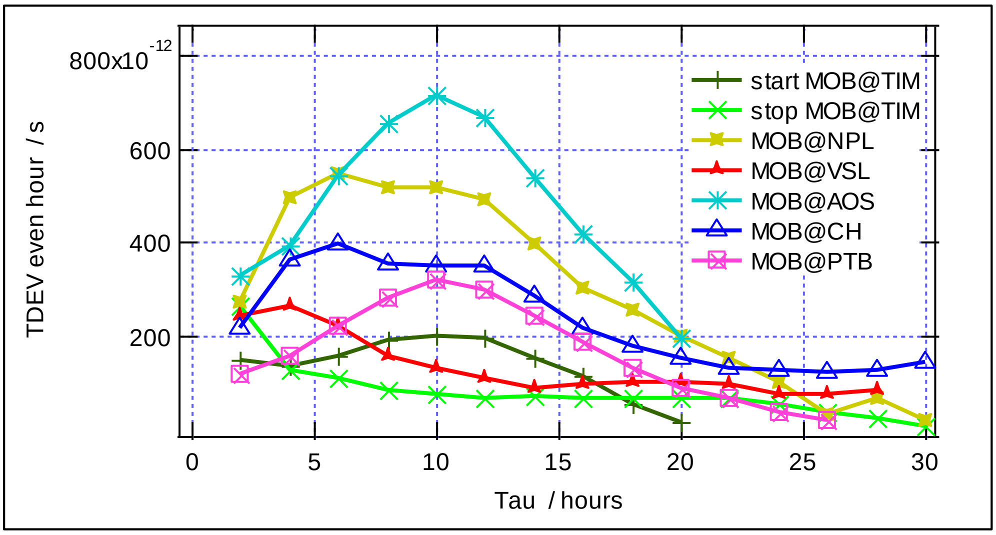
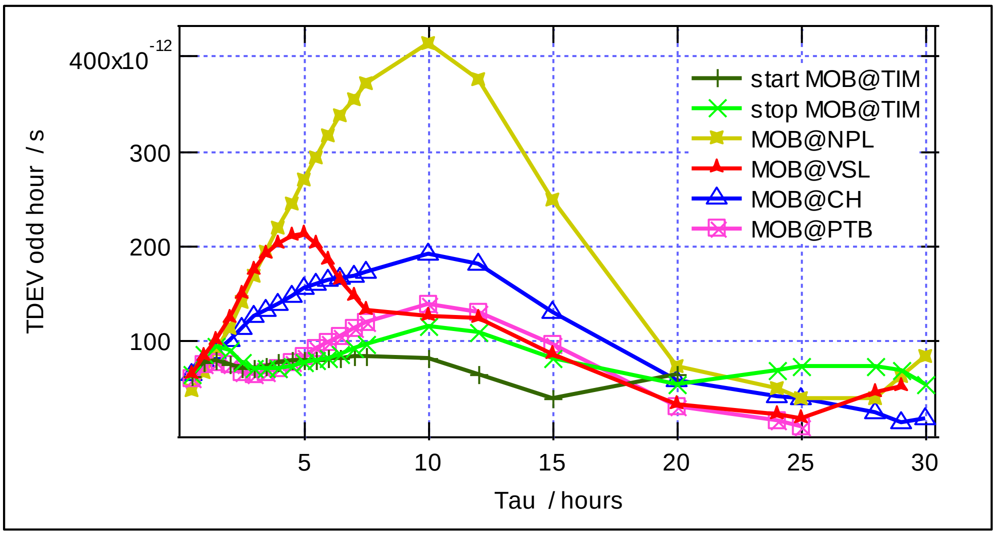


Figure 11-9: TDEV computations of the CCD for odd hours



12 Annex 2, application of CALR values in TWSTFT "ITU" files

In order to be compliant with [RD01], the results of the current TWSTFT calibration need to be introduced into the TWSTFT report files as shown here below. The ESDVAR should be set to zero. The calibration identifiers 518 - 532 were provided by BIPM.

On MJD 58956 (17th April 2020) up- and down-converter units in PTB05 were exchanged. Thus, the ESDVAR values of PTB05 were adjusted by adding 12.32 ns (ESIG 0.20 ns). After the introduction of the CALR values listed in this report, the ESDVAR and ESIG values in PTB05 data files of the corresponding links will be 12.32 ns and 0.20 ns, respectively.

AOS01

```
* CAL   518 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.100 ns
* CAL   519 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.200 ns
* CAL   520 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.100 ns
* CAL   528 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.000 ns
* CAL   521 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.000 ns

                CI S    CALR
 AOS01   CH01  518 1    32.400
 AOS01  NPL02  519 1  -700.200
 AOS01  PTB05  520 1    31.700
 AOS01  TIM01  528 1    69.400
 AOS01  VSL01  521 1   306.600
```

CH01

```
* CAL   518 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.100 ns
* CAL   522 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.000 ns
* CAL   523 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.900 ns
* CAL   529 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns
* CAL   524 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns

                CI S    CALR
  CH01  AOS01  518 1   -32.400
  CH01  NPL02  522 1  -732.600
  CH01  PTB05  523 1    -0.700
  CH01  TIM01  529 1    37.000
  CH01  VSL01  524 1   274.200
```

NPL02

```
* CAL   519 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.200 ns
* CAL   522 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.000 ns
* CAL   525 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.900 ns
* CAL   530 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.900 ns
* CAL   526 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.900 ns

                CI S    CALR
 NPL02  AOS01  519 1   700.200
 NPL02   CH01  522 1   732.600
 NPL02  PTB05  525 1   731.900
 NPL02  TIM01  530 1   769.600
 NPL02  VSL01  526 1  1006.800
```

PTB05

```
* CAL   520 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.100 ns
* CAL   523 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.900 ns
* CAL   525 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.900 ns
* CAL   531 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns
* CAL   527 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns

                CI S    CALR
 PTB05  AOS01  520 1   -31.700
 PTB05   CH01  523 1     0.700
 PTB05  NPL02  525 1  -731.900
 PTB05  TIM01  531 1    37.700
 PTB05  VSL01  527 1   274.900
```

TIM01

```
* CAL   528 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.000 ns
* CAL   529 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns
* CAL   530 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.900 ns
* CAL   531 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns
* CAL   532 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns

                CI S    CALR
 TIM01  AOS01  528 1   -69.400
 TIM01   CH01  529 1   -37.000
 TIM01  NPL02  530 1  -769.600
 TIM01  PTB05  531 1   -37.700
 TIM01  VSL01  532 1   237.200
```

VSL01

```
* CAL   521 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    1.000 ns
* CAL   524 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns
* CAL   526 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.900 ns
* CAL   527 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns
* CAL   532 TYPE: PORT ES REL        MJD: 59305  EST. UNCERT.:    0.800 ns

                CI S    CALR
 VSL01  AOS01  521 1  -306.600
 VSL01   CH01  524 1  -274.200
 VSL01  NPL02  526 1 -1006.800
 VSL01  PTB05  527 1  -274.900
 VSL01  TIM01  532 1  -237.200
```

13 List of tables and figures