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

F. Meynadier

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 : MJD 58729 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.

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

CISCALRAOSO1CHO1518132.400AOSO1NPLO25191-700.200AOSO1PTB05520131.700AOSO1TIM01528169.400AOSO1VSLO15211306.600

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 ADS01 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 NPLO2 AOSO1 519 1 700.200 NPLO2 CHO1 522 1 732.600 NPLO2 PTBO5 525 1 731.900 NPLO2 TIMO1 530 1 769.600 NPLO2 VSLO1 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
 AOSO1
 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 TIMO1 AOSO1 528 1 -69.400 TIMO1 CHO1 529 1 -37.000 TIMO1 NPLO2 530 1 -769.600 TIMO1 PTB05 531 1 -37.700 TIMO1 VSLO1 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 AOSO1 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
Туре	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	2		
	1.1	1 Scope of the document	2		
	1.2	2 Reference documents	3		
	1.3	3 Acronyms and abbreviations	1		
2		Background of this TWSTFT calibration campaign	5		
	2.1	1 Operation status in the transatlantic region	5		
	2.2	2 Motivation and structure of this calibration campaign	5		
3		Organization of the TWSTFT calibration campaign	3		
	3.1	1 General Information	3		
	3.2	2 Participants and Contacts	3		
	3.3	3 TWSTFT Station Information	7		
4		Operational Information	7		
	4.′	1 Technical parameters of the satellite as of August-October 2019	7		
	4.2	2 Measurement schedules	3		
5		TWSTFT calibration background10)		
	5.′	1 General description of TWSTFT measurements10)		
	5.2	2 Details of the applied calibration method1	I		
	5.3	3 Role of the mobile TWSTFT station	2		
	5.4	4 Connecting TWSTFT stations to time scales with REFDLY	2		
	5.5	5 Reporting of TWSTFT station changes during time using ESDVAR	2		
6		Description of the mobile TWSTFT station	3		
	6.1	1 Mobile TWSTFT station and interface	3		
7		Measurement data	5		
	7.′	1 Site location related data	5		
	7.2	2 Measured CCD using the site-mode method15	5		
		7.2.1 Averaged CCD	3		
		7.2.2 Stability of the mobile TWSTFT station	7		
8		Calibration results	7		
9	Comparison with previous calibration data19				
10) Summary of the calibration campaign21				
11		Annex 1, Graphs of CCDs using the site-mode method22	2		
12	2	Annex 2, application of CALR values in TWSTFT "ITU" files	5		
13	}	List of tables and figures27			

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.

Ref.	Title	Code	Version	Issue
RD01	The operational use of two-way satellite time	Recommendation ITU-R	4	08/2015
	and frequency transfer employing	TF.1153-4, Geneva,		
	pseudorandom noise codes	Switzerland		
RD02	European TWSTFT Calibration Campaign 2014	2014-summer_European		2015
		_Calibration_for_BIPM		
		_final_report.pdf		
RD03	Summary for the GSOP 2019 TWSTFT	0489-2019_tw_	V1.0	2019
	calibration report	roa_v1-0-1.pdf		
RD04	MODELSR620 Universal Time Interval		2.7	2006
	Counter, Stanford Research Systems, Revision			
	2.7 (2006)			
RD05	J. Achkar; D. Rovera; I. Sesia; P. Tavella,	DOI:10.1109/	2.7	2016
	"Determination of differential delays of earth	EFTF.2016.7477800		
	stations in Paris and Torino from the			
	calibrated OP-IT TWSTFT link", in Proceedings			
	of 2016 European Frequency and Time Forum			
	(EFTF)			
RD06	Linking document for the TWSTFT calibration	0295-2015_tw_vsl_	29 Oct.	2015
	campaigns of October/November 2012 and	ori.pdf	2015	
	April/May 2013			
RD07	Application of CALR values from calibration	0284-2012_tw_ch_	7 Jan.	2016
	report CAL-TIM-RP-0001	ori.pdf	2016	
RD08	Results of the BIPM 2017 TWSTFT SATRE	0450-2017_tw_	2a	2017
	calibrations for UTC and Non-UTC links	npl_ori.pdf		
		TM270_Tw-Satre_TCC-		
		BIPM_Calib2017Sumary.docx		
		TM268V2a		
RD09	Results of the BIPM 2017 TWSTFT SATRE	0449-2017_tw_	2a	2017
	calibrations for UTC and Non-UTC links	aos_ori.pdf		
		TM270_Tw-Satre_TCC-		
		BIPM_Calib2017Sumary.docx		
		TM268V2a		
RD10	Results of the BIPM 2017 TWSTFT calibrations	0450-2017_TW_	2	2017
	for UTC and Non-UTC links	NPL_v2-0.pdf		
		TM270.V2		
RD11	Site Preparation Document for Two-Way	MOB-TIM-L1-002	2/6	2019
	Calibration Campaign			

Table 1-1: Reference documents

1.3 Acronyms and abbreviations

Table 1-2: List of acronyms and abbreviations

Acronym	Definition
AGS	Americom Governement Services
AOS	Astrogeodynamical Observatory, Poland
СН	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
РТВ	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.
МОВ	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.
	Keceived 1PPS signal from the partner IWSIFI station.
PPSTX(i)	I ransmitted 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	TTU-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

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

Table 3-1: Participants and contacts

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**

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
РТВ	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
СН	Bern CH	CH01	CH11	LA: N 46° 55' 25.386" LO: E 7° 27' 51.002" HT: 612.82 m
МОВ	Stuttgart DE	MOB02	MOB12	Mobile

Table 3-2: TWSTFT station information

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.

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
СН	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

Table 4-1: Measurement schedule





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.

TWSTFT S	Schedule Euro	ope <-> E	urope	+ Europe <-> USA	Starting at hh: UTC:	00h 02h 04h etc., each even hour
First	Last Ac	ction	Length	OP01 NPL01 VSL0	01 SP01	PTBUS OCANI ITO2 ROANI WISTOI USNOOI MOBO2 CHOI PONI AOSOI PTFIOI PTF201 TIMO1 LTFB01 Lab
11	1					
hhmmss	hhmmss		5	20 0 20	-40	40 60 50 100 80 50 -70 10 10 30 50 50 30 70 offset
UTC	UTC			0 1 2	3	4 5 6 7 31 9 10 11 12 13 14 15 TX core
	UIC OF COLOR	D link		EUR EUR EUR EUR	<mark>r Eur Eur Eur</mark>	EUR
00:00:00	00:00:59 Pr	rep.time	60			
00:03:00	00:02:59 Pr	en time	60	0 0 1 1 2	2 3 12	
00:04:00	00:05:59 CA	AL	120	0 0 1 1 2	2 3 12	4 14 5 5 6 6 7 7 6 6 7 7 9 9 10 10 11 11 12 3 14 4 15 15
00:06:00	00:06:59 Pr	rep.time	60	0 0 1 1 2	2 3 3	4 4 5 5 6 6 7 7 6 6 7 7 31 31 9 9 10 10 11 11 12 12 13 13 14 14
00:07:00	00:08:59 Ra	anging	120	0 0 1 1 2	2 3 3	4 4 5 5 6 6 7 7 6 6 7 7 31 31 9 9 10 10 11 11 12 12 13 13 14 14
00-09-00	00-09-59 Pr	0 link	60	O 1 1 0 2	R EUR EUR EUR	EUR
00:10:00	00:11:59 M	easure	120	0 1 1 0 2	3 3 2	
11	un	D link		EUR EUR EUR EUR	R EUR EUR EUR	EUR EUR EUR EUR EUR EUR EUR EUR TRA TRA TRA TRA TRA EUR
00:12:00	00:12:59 Pr	rep.time	60	0 2 1 3 2	0 3 1	4 6 5 7 6 4 7 5 6 7 12 9 11 10 11 9 12 7
00:13:00	00:14:59 M	easure	120			
00:16:00	00:17:59 M	easure	120	0 3 1 2 2	1 3 0	
11	ur	D link		EUR EUR EUR EUR	R EUR EUR EUR	EUR EUR EUR EUR EUR EUR EUR TRA TRA TRA EUR EUR TRA TRA TRA TRA EUR EUR EUR EUR EUR EUR
00:18:00	00:18:59 Pr	rep.time	60	0 4 1 5 2	6 3 7	4 0 5 1 6 2 7 3 6 10 7 11 31 14 9 10 6 11 7 14 31
00:19:00	00:20:59 M	easure	120	0 4 1 5 2	6 3 7	4 0 5 1 6 2 7 3 6 10 7 11 31 14 9 10 6 11 7 14 31
00:21:00	00:23:59 M	easure	120		7 3 6	
	ur	D link			R EUR EUR EUR	EUR EUR EUR EUR EUR EUR EUR EUR TRA TRA TRA TRA TRA TRA EUR EUR EUR EUR EUR EUR
00:24:00	00:24:59 Pr	rep.time	60	0 6 1 7 2	4 3 5	4 2 5 3 6 0 7 1 6 7 9 9 7 10 11
00:25:00	00:26:59 M	easure	120	0 6 1 7 2	4 3 5	
00:27:00	00:27:59 Pr	rep.time	120		5 3 4	
	UI	D link			A TRA TRA TRA	TRA
00:30:00	00:30:59 Pr	rep.time	60	CC CC CC	CC	D2 D2 <thd2< th=""> D2 D2 D2<!--</td--></thd2<>
00:31:00	00:32:59 C0	C	120	CC CC CC	CC CC	33 33<
00.22.00	00.22.50	D link		TRA TRA TRA EUR	R EUR TRA TRA	EUR
00:34:00	00:35:59 M	easure	120	0 7 2		
	ur	D link		TRA TRA TRA TRA TRA	A TRA EUR EUR	EUR EUR EUR EUR EUR EUR EUR EUR TRA TRA TRA EUR
00:36:00	00:36:59 Pr	rep.time	60	0 6 1 7 2	3 14	4 9 5 6 11 7 10 6 0 7 1 9 4 10 7 11 6 14 3
00:37:00	00:38:59 M	easure	120	0 6 1 7 2	3 14	
00-29-00	00-29-59 Pr	D link	60	EUR EUR TRA TRA TRA	7 2 42	EUR
00:40:00	00:41:59 M	easure	120	0 12 1 6 2	7 3 13	
	un	D link		TRA TRA EUR EUR TRA	A TRA TRA TRA	EUR
00:42:00	00:42:59 Pr	rep.time	60	0 13 1 31 2	6 3 7	4 11 5 10 6 9 6 2 7 3 31 1 9 6 10 5 11 4 13 0
00:43:00	00:44:59 M	easure	120	0 13 1 31 2	6 3 7	
00:45:00	00:45:59 Pr	rep.time	60	0 15 1 11 2	10 3 9	
00:46:00	00:47:59 M	easure	120	0 15 1 11 2	10 3 9	4 7 5 6 6 12 7 13 6 5 7 4 9 3 10 2 11 1 12 6 13 7 15 0
00:48:00	00:48:59 Pr	rep.time	60	0 9 1 2	11 3 10	4 5 5 7 6 13 7 12 6 4 7 5 9 0 10 3 11 2 12 7 13 6
00:49:00	00:50:59 M	easure	120	0 9 1 2	11 3 10	4 6 5 7 6 13 7 12 6 4 7 5 9 0 10 13 11 2 12 7 13 6
00:51:00	00-51-59 0	o ink	60	0 31 1 9 2	31 3 44	
00:52:00	00:53:59 M	easure	120	0 31 1 9 2	31 3 11	
00:54:00	00:54:59 Pr	rep.time	60	0 11 1 10 2	9	4 13 5 6 7 7 6 6 7 7 6 9 2 10 1 11 0 13 4
00:55:00	00:56:59 M	easure	120	0 11 1 10 2	9	4 13 5 6 7 7 6 9 2 10 1 11 0 13 4
00-57-04	00-57-50 0-	D link	60	EUR EUR EUR EUR	R EUR EUR EUR	EUR EUR EUR EUR EUR EUR EUR EUR UTA UTA UTA UTA UTA EUR
00:58:00	00:59:59 C/	AL	120	0 0 1 1 2	2 3 3	
CC:	Clean Carrier			EUR: european up/down links	frequencies	TRA: transatlantic up/down links frequencies
CAL:	Calibration			USA: american up/down links	frequencies	

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

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



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.



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

$$TW(2) = TS(2) - TS(1) + TX(1) + SP(1) + RX(2) + SCD(2) - SCD(1).$$
(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 Tl(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

(4)

(5)

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:

 $\mathsf{DLD}(\mathsf{i}) = \mathsf{TX}(\mathsf{i}) - \mathsf{RX}(\mathsf{i}).$

SP(1) = SP(2)

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

 $TS(1) - TS(2) = 0.5 * [TW(1) - TW(2)] + \{0.5 * [DLD(1) - DLD(2)] - [SCD(1) - SCD(2)]\}.$ (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)]. (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: $0 = 0.5 * [TW(k) - TW(MOB@k)] + \{0.5 * [DLD(k) - DLD(MOB)]\}.$ (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)]. (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:

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

Combining Eq. (10) and Eq. (7) leads to: CALR(1,2) = CCD(MOB@1) - CCD(MOB@2) - [SCD(1) - SCD(2)]. (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	Connectors	Connector
				diameter		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).





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:

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.

Location of MOB	REFDLY(MOB@k)	uREFDLY(MOB@k)	REFDLY(UTC(k))	uREFDLY(UTC(k))
	/ ns	/ ns	/ ns	/ 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
СН	19.64	0.02	785.10	0.05
TIM_stop	111.46	0.03	705.15	0.01

Table 7-2: REFDLY measured at each location

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.

Location	Session	CCD_eh(k) or CCD_oh(k)	TDev_CCD(k)	StDev_CCD(k)	N
of MOB	hour	/ ns	/ ns	/ ns	
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				
СН	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

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

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:

$$CCD_site(k) = 0.5 * [CCD_eh(k) + CCD_oh(k)].$$

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

 $CCD_diff(k) = CCD_eh(k) - CCD_oh(k).$

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)

(14)

(15)

Location of MOB	CCD_site(k)	uCCD_site(k)	CCD_diff(k)
	/ 115	/ 115	/ 113
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	
СН	-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:

 $CALR = CCD_site(1) - CCD_site(2) - SCD(1) + SCD(2).$

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.

(17)

Group	Sub	Source	Contribution	Tot
	group		/ ns	/ ns
ub, l		Mobile station and related equipment		0.36
	ub, 1	0.192		
	ub, 2	Uncertainty due to other contributions related to the	0.035	
		mobile station		
	ub, 3	Instability of the mobile station	0.301	
		(CCD_site_stop – CCD_site_start)		
ub, ll		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	0.020	
		stations		
ub, III(i)		Interface between mobile station and local UTC(k)		0.25
		realization		to
				0.26
	ub, 6(i)	Contribution to the CCD measurements associated with	0.039 to	
		the REFDLY uncertainties, the uREFDLY values.	0.089	
	ub, 7	Uncertainty due to contributions of laboratory signal	0.200	
		distribution equipment [RD04, RD05]		
	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	0.150	
		Tx power, C/NO 0.150 ns		
	ub, 11	Atmosphere	0.105	
		Ionosphere 0.030 ns		
		Troposphere 0.001 ns		
		Temp. var. on ground stations 0.100 ns		
		Humidity changes 0.010 ns		
	ub, 12	Satellite motion	0.251	
		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		
	ub, 13	Even and odd hours measurements as possible interfe-	0.300	
		rences between PRN codes		

Table	8-1:	Overview	of the	tvpe	В	uncertainties
1 0010	U 11	010111011		.,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	-	an 1001 tail 1100

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.

Liı	nk	CALR	uCALR	ua1	ua2	ub, l	ub, ll	ub, 6(i)	ub, III	ub, IV
Lab(j)	Lab(k)	/ ns	/ ns	/ ns	/ ns	/ ns	/ ns	/ ns	/ ns	/ 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

Table 8-2: Calibration results with their respective uncertainties

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) v	with uncertainties	and corrected	(interim) values
----------------------------------	--------------------	---------------	------------------

Li	nk	Data	CALR_old	uCALR_old	ESDVAR(j)	ESIG(j)	ESDVAR(k)	ESIG(k)	CALR	uCALR
Lab(j)	Lab(k)	source	/ ns	/ ns	/ ns	/ ns	/ ns	/ ns	Interim	interim
		for							/ns	/ns
		CALR_old								
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.

Li	nk	CALR	uCALR	CALR interim	uCALR interim	CALR deviation	uCALR devia-
Lab(1)	Lab(2)	/ ns	/ ns	/ ns	/ ns	/ ns	tion / ns
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

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

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 11-7: Common-clock measurements MOB at CH





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 * CAL * CAL * CAL * CAL	518 TYPE 519 TYPE 520 TYPE 528 TYPE 521 TYPE	E: PORI E: PORI E: PORI E: PORI E: PORI	' ES REL ' ES REL ' ES REL ' ES REL ' ES REL	MJD: MJD: MJD: MJD: MJD:	59305 59305 59305 59305 59305 59305	EST. EST. EST. EST. EST.	UNCERT .: UNCERT .: UNCERT .: UNCERT .: UNCERT .:	1.100 ns 1.200 ns 1.100 ns 1.000 ns 1.000 ns
AOS 01 AOS 01 AOS 01 AOS 01 AOS 01	CH01 5 NPL02 5 PTB05 5 TIM01 5 VSL01 5	CI S 518 1 519 1 520 1 528 1 521 1	CALR 32.400 -700.200 31.700 69.400 306.600					

CH01

*	CAL	518	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	1	.100	ns
*	CAL	522	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	1	.000	ns
*	CAL	523	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	C).900	ns
*	CAL	529	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	C	.800	ns
*	CAL	524	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	C	.800	ns
			CI	ΓS	CA	ALR							
	CH01	AOSC)1 518	31	-32	2.400							
	01101	NTD T C		1	7 2 2								

CHUI	AUSUI	219	\perp	-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	ΕS	REL	MJD:	59305	EST.	UNCERT.:	1.200	ns
*	CAL	522	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	1.000	ns
*	CAL	525	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.900	ns
*	CAL	530	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.900	ns
*	CAL	526	TYPE:	PORT	ΕS	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	ΕS	REL	MJD:	59305	EST.	UNCERT.:	1.100	ns
*	CAL	523	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.900	ns
*	CAL	525	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.900	ns
*	CAL	531	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.800	ns
*	CAL	527	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.800	ns

			CI	S	CALR
Ρ	TB05	AOS01	520	1	-31.700
Ρ	TB05	CH01	523	1	0.700
Ρ	TB05	NPL02	525	1	-731.900
Ρ	TB05	TIM01	531	1	37.700
Ρ	TB05	VSL01	527	1	274.900

TIM01

*	CAL	528	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	1.000	ns
*	CAL	529	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.800	ns
*	CAL	530	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.900	ns
*	CAL	531	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.800	ns
*	CAL	532	TYPE:	PORT	ΕS	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	ΕS	REL	MJD:	59305	EST.	UNCERT.:	1.000	ns
*	CAL	524	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.800	ns
*	CAL	526	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.900	ns
*	CAL	527	TYPE:	PORT	ΕS	REL	MJD:	59305	EST.	UNCERT.:	0.800	ns
*	CAL	532	TYPE:	PORT	ΕS	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

Table 1-1: Reference documents	3
Table 1-2: List of acronyms and abbreviations	4
Table 3-1: Participants and contacts	6
Table 3-2: TWSTFT station information	7
Table 4-1: Measurement schedule	8
Table 6-1: List of cables provided with the mobile TWSTFT station	13
Table 7-1: Sagnac corrections	15
Table 7-2: REFDLY measured at each location	15
Table 7-3: CCD values measured at even and odd hours	16
Table 7-4: Results of CCD site-mode measurements	17
Table 8-1: Overview of the type B uncertainties	18
Table 8-2: Calibration results with their respective uncertainties	19
Table 9-1: Previous CALR (old) with uncertainties and corrected (interim) values	19
Table 9-2: New CALR and comparisons with previous values	20
Figure 4-1: Road map for the calibration campaign	8
Figure 4-2: TWSTFT calibration scheduler for even hour measurement sessions	9
Figure 4-3: TWSTFT calibration scheduler for odd hour measurement sessions	9
Figure 5-1: Schematics of a TWSTFT setup [RD01]	10
Figure 6-1: Block diagram of the mobile TWSTFT station and connection with the participating laboratory	13
Figure 6-2: Changes of MOB signal connections at TIM between 2012 and 2019	14
Figure 9-1: Deviation between old and new calibration constants of TAI contributors	20
Figure 9-2: Deviation between old and new calibration constants of TimeTech links	21
Figure 11-1: Common-clock measurements MOB at TimeTech at the beginning of the cal. campaign	22
Figure 11-2: Common-clock measurements MOB at TimeTech at the end of the cal. campaign	22
Figure 11-3: Common-clock measurements MOB at NPL	22
Figure 11-4: Common-clock measurements MOB at VSL	23
Figure 11-5: Common-clock measurements MOB at PTB	23
Figure 11-6: Common-clock measurements MOB at AOS	23
Figure 11-7: Common-clock measurements MOB at CH	24
Figure 11-8: TDEV computations of the CCD for even hours	24
Figure 11-9: TDEV computations of the CCD for odd hours	24