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UTC time link calibration report

-- *MEasurement of TOtal DElay for UTC Time Link Calibration*
Phase XIII/2016: Measurements at and between **NIM** and PTB

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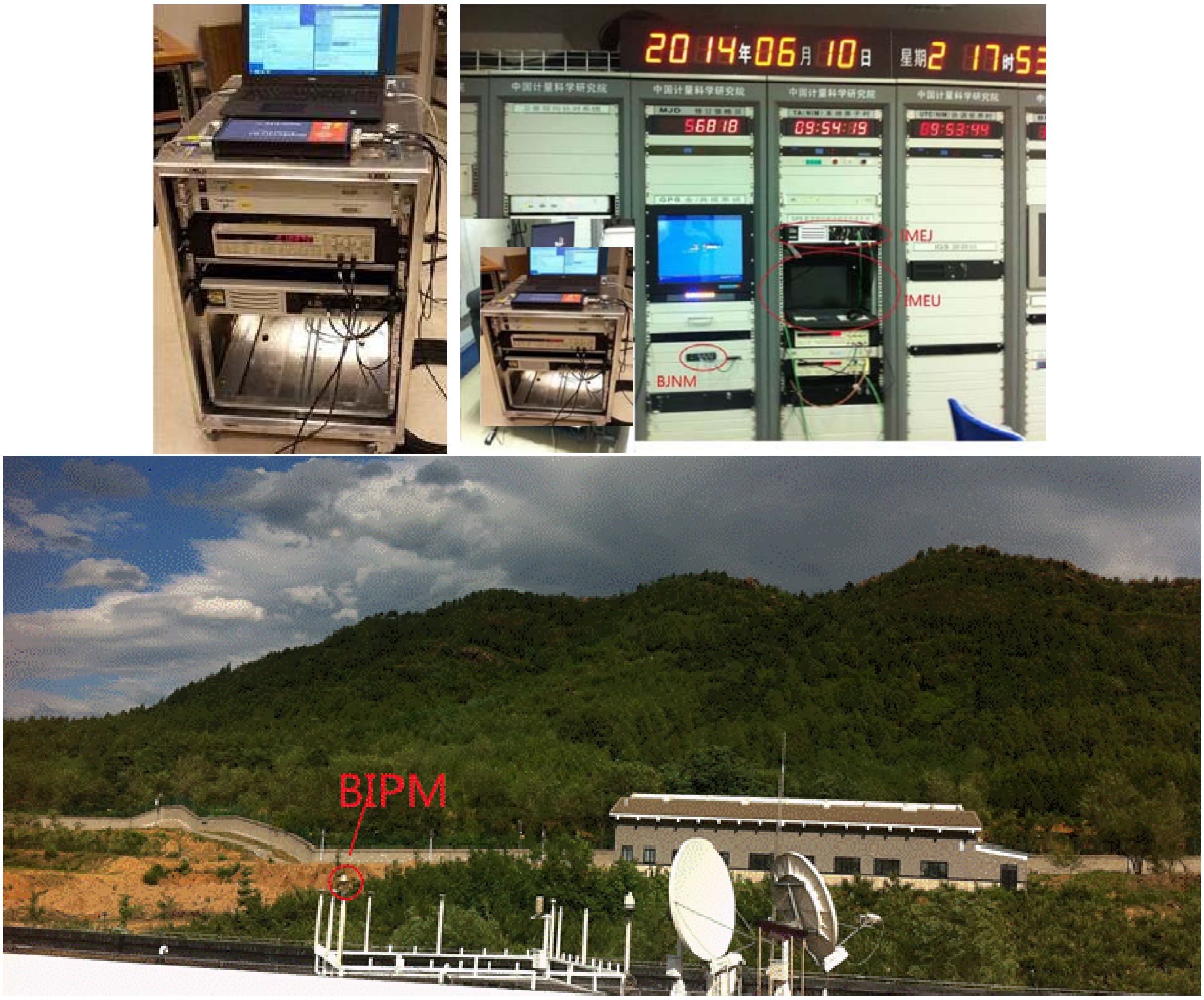
Abstract

During the 6 and 13 July 2016, the BIPM GPS calibrator (Std$_{\mathbf{B}}$*) re-visited NIM, National Institute of Metrology, Beijing, China, to calibrate the UTC TWSTFT link NIM-PTB and the backup time links [1,4]. The first visit was in June 2014 [2].*



The BIPM calibrator setups at NIM (photo 2014)

Notation

UTCp: the UTC(*k*) point at Lab(*k*). Here after the k stands for NIST, the laboratory to be calibrated

Link: a time link is a clock comparison result using a particular technique, e.g., a link of GPS C/A, P3, PPP or GLONASS or TWSTFT or TWOTFT. A UTC link at present is the one between Lab(*k*) and PTB

Std$_B$: the BIPM standard traveling calibration station (calibrator) consisting of N (≥2) GNSS receivers+antennas+cables +pps/frequency-distributors. It is a pre-cabled black box calibrator with unknown but constant total delay during a calibration tour

Total Delay: The total electrical delay from the antenna phase center to the UTCp including all the devices/cables that the satellite and clock signals pass through. It equals numerically the sum of all the sub-delays. It is the total delay that really affects the UTC time transfer uncertainty

METODE: MEasurement of TOtal DElay, the BIPM calibration scheme composed of related methods and equipment (Std$_B$) for the generation of UTC-UTC(*k*) in Circular T [1]

C$_M$: The METODE total delay correction. It should be *subtracted* from the GPS data, e.g. RefGPS-C$_M$ in CGGTTS, -C$_M$ in Clb_GNSS.Lst file; and the CALR of the ITU TWSTFT data of the Lab(*k*) side. Because the PTB is taken as the reference of the calibration, the time link correction is equal to the classic GNSS equipment calibration correction [8]

u$_A$, u$_B$: type A and type B uncertainties (1-σ)

u$_M$: Total uncertainty of the total delay correction **C$_M$**;

CCD: common clock difference

DCD: double clock difference

Tour: a calibration *tour* is a go-back or start-closure calibration travel. It may include several laboratories

1 Summary

1.1 General

The last BIPM calibration was made in the frame of the BIPM Pilot Project, namely METODE aiming at unifying the UTC time link calibrations with a calibration uncertainty u$_B$ of 1.5 ns [1-4], during 11-19 June 2014, MJD 56818-56827, the same calibrator (Std$_B$) was installed at the NIM.

During 6-14 July 2016, MJD 57575-57583, the BIPM Standard travelling calibrator (Std$_B$) re-visited the Changping time and frequency laboratory of NIM, National Institute of Metrology, Beijing, China. The goal is to calibrate the UTC TWSTFT (TW for short) link NIM-PTB and the backup time links [1,4].

As given by the TWSTFT calibration guideline [7], the reference point of the UTC TWSTFT network is PTB. The visits to PTB before and after the calibration tour allow the Std$_B$ transferring the calibration of the PTB equipment to the Lab(*k*). Cf. the Sect. 6 on the start and closure measurements at PTB and BIPM.

This report includes the calibration results (Table 1.2): 1) the main result is the CALR for the TWSTFT link NIM-PTB (Sect. 4); 2) for reference, we give also the result of the GPS master receiver (Sect. 5)

The NIM time laboratory, together with its TWSTFT and GNSS time/frequency transfer facilities, located in the new campus (the Base II) in Changping, about 40 km in the north of Beijing. The master receiver is a GTR50 IMEJ. The backup receivers are IMEU and BJNM, both the Sept. Polarx4. See Table 3.1.

The requirements for the setup and computations can be found in the BIPM METODE Notice [6] or the Guideline [3]. Taking into account of the starting and closure measurements at the BIPM, we compute the calibration corrections for the UTC TWSTFT link of NIM-PTB. For reference, we compute also the total delay calibration correction for the NIM GPS master receiver, which however, is not used for the TW link calibration.

It should be pointed out that the TW link and GPS receiver calibrations are independent performed according to two different guidelines for TW time *link* calibration (using TW mobile station or *GPSPPP* link [7]) and the GNSS *receiver* (using *GPS P codes* [8]). The first supplies officially the UTC time link calibration scale through the combination of TW and GPS PPP. The fact that, the local GPS master receiver at Lab(*k*) is not at all involved in the TW link calibration, the calibrated TW and GPS links may be slightly different within the u$_A$. For the PPP and P3, the u$_A$ are 0.3 ns and 0.7 ns respectively.

The GPS PPP solutions are used for METODE link calibration [1,3,4,7].

Hereafter in the expression, we have always *k*=NIM in the term Lab(*k*).

1.2 The main result

The calibration result is the time link corrections (C_M), which should be used for all the GNSS (PPP, C/AL1C, P3) links and the TWSTFT links on the baseline Lab(*k*)-PTB. The UTC GPS/TWSTFT results are given in Table 1.2a. Cf. the Section 4. Because the PTB is taken as the reference of the calibration and its correction is set zero [1,4], the time link correction C_M is equal to the GNSS equipment calibration correction and can be converted to the classic equipment calibration result [4], termly INTDLY(P1/P2) in Table 1.2b.

The calibration correction for the IMEJ is -0.7 ns largely inferior to the calibration uncertainty u_M (1.5 ns). Applying this correction is not very meaningful. In fact, introducing this jump causes the instability in the time scale UTC(NIM). It is therefore not suggested to implement the correction in the GPS receiver.

Table 1.2a The total delay correction for the UTC GPS and TW time links/Receivers

Labo	Time Rcv/Link	CalR/C_M/ns	u_M	CLBID	ITU CI
NIM	TWSTFT: NIM-PTB	**2319.7**	1.5 ns	A3 2 PP 48 05 16	**417**
NIM	GTR50/IMEJ	**-0.7**	1.5 ns	A3 1 PP 48 05 16	-

Table 1.2b The total delay correction converted to the classic equipment calibration result

Labo	Time Rcv/Link	INTDLY(P1/P2) /ns	u_M
NIM	GTR50/IMEJ	0/0	~3 ns

1.3 Uncertainty

The *total uncertainty* (U_M) of the C_M is composed of [3,4,7]:

- Measurement uncertainty (u_A): about (0.1~0.3) ns (u_A of PPP link);
- Calibration uncertainty of the calibrator Std_B: (0.5~1.0) ns;
- Instability of the reference and traveling receivers: (0.5~0.8) ns;
- Uncertainty relating to the measurements of UTCp-CLBp: (0.2~0.5) ns;
- Others (0.3~0.6) ns (unexpected)

The U_M is hence (0.8~1.5) ns (1σ). The conventional uncertainty of 1.5 ns is assigned for this calibration.

The internal delays INTDLY(L1/L2) is obtained by subtracting all the sub-delays from the directly observed 'total delay'. This may produce a few ns uncertainty [4,5]. Ignoring the L1/L2 delay difference going through the antenna cable produces at least 3 ns error [5]. The total uncertainty of INTDLYs is no less than 3 ns, as given in the Table 1.2b.

2 Setups of the Std_B

By the definition of the METODE UTC time link calibration correction [1,3,4,6], we have the following steps:

- We start from BIPM
- We set the PTB's master GPS receiver (PTBB) as the reference of the calibration and its calibration correction to be zero;
- We align the $Std_\mathbf{B}$ to PTBB, i.e. the BP0U and BP1C in $Std_\mathbf{B}$ are to be corrected -4.7 ns and 2.3 ns, cf. Tab. 6.1.2 in Section 6.1;
- The $Std_\mathbf{B}$ goes to the Lab(*k*), and makes measurements side by side with the master receiver of Lab(*k*), both of the $Std_\mathbf{B}$ and the master receiver use the same reference signals of UTC(*k*);
- The closure measurement at the starting point. For short tours, the starting-closure point is BIPM;
- We compute the double clock difference:

$$C_M = DCD = [UTC(k)_{rcv(k)} - UTC(PTB)] - [UTC(k)_{StdB} - UTC(PTB)] \qquad (2.1)$$

The no-zero DCD is the calibration correction to the master GNSS receiver of Lab(*k*).

For GPSPPP, the difference between 'link' and 'equipment' solutions is negligible. The (2.1) can be simplified:

$$C_M = DCD \approx CCD = UTC(k)_{rcv(k)} - UTC(k)_{StdB} \qquad (2.1a)$$

And the correction of the backup links:

$$C_M = [UTC(k)_{backup} - UTC(PTB)] - [UTC(k)_{calibrated} - UTC(PTB)] \qquad (2.2)$$

The setup of the $Std_\mathbf{B}$ is shown in the Figure 2.1. The cable C166 was directly connected to the UTC(*k*).

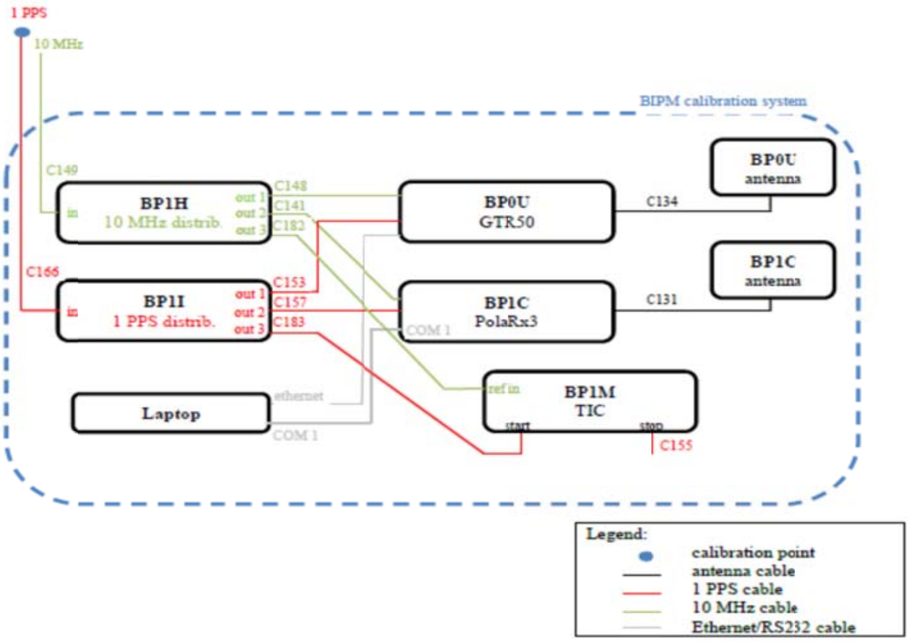


Figure 2.1 The Std$_B$ setups at the BIPM and Lab(*k*)

3 Setups of the Lab(k) equipment and the StdB

The experiment setup at NIM is illustrated in the Figure 3.1. See also the Figures on the cover page.

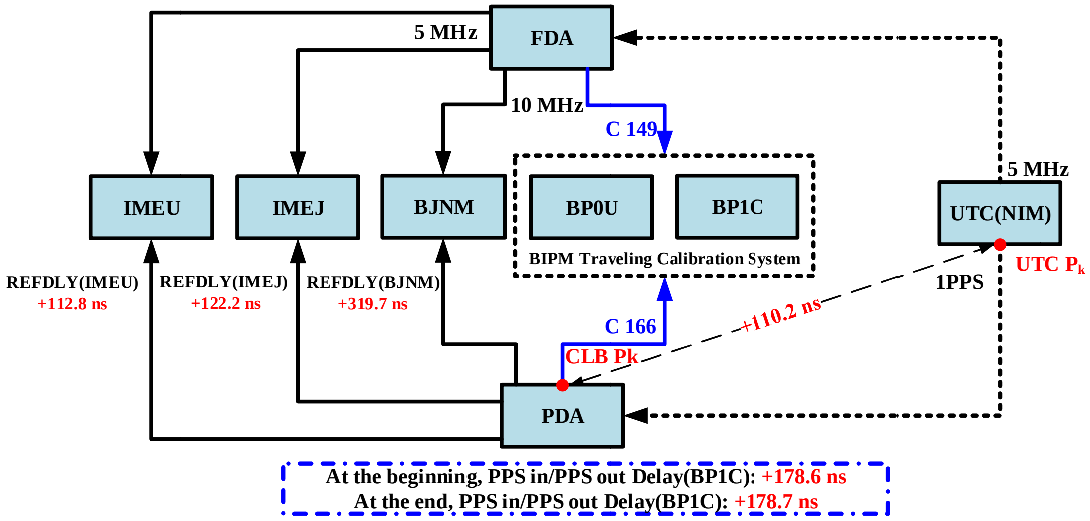


Figure 3.1 Setup of the Std$_B$ and the UTC devices in the NIM T/F laboratory

The Table 3.1 gives the antenna information used in the PPP data processing.

Table 3.1 The antenna information

No.	Receiver	Antenna	Antenna code	Note
1	BP0U	NOV702GG	NAE07190046	
2	BP1C	ASH701945E_M	2000785	
3	PTBB	ASH700936E SNOW	CR15930	
4	IMEJ	NOV702	NAE10220060	
5	IMEU	JNSMARANT_GGD NONE	0155	backup
6	BJNM	NOV702GG NONE	NAE09190046	backup

4 *The calibrations of the UTC TWSTFT links between NIM-PTB*

At present, the official UTC link is that of the combination of TWSTFT and GPSPPP. According to the TW link calibration guideline [7] and by METODE link calibration technique [1,3], we use directly the BIPM calibrator to calibrate the UTC TW link NIM-PTB.

4.1 The calibration of the TWSTFT link

Figure 4.1.1 is the UTC TW time links of NIM-PTB before (*left*) and after (*right*) the calibration correction CALR=2319.7 ns to be applied, cf. the Figure 4.1.2 below.

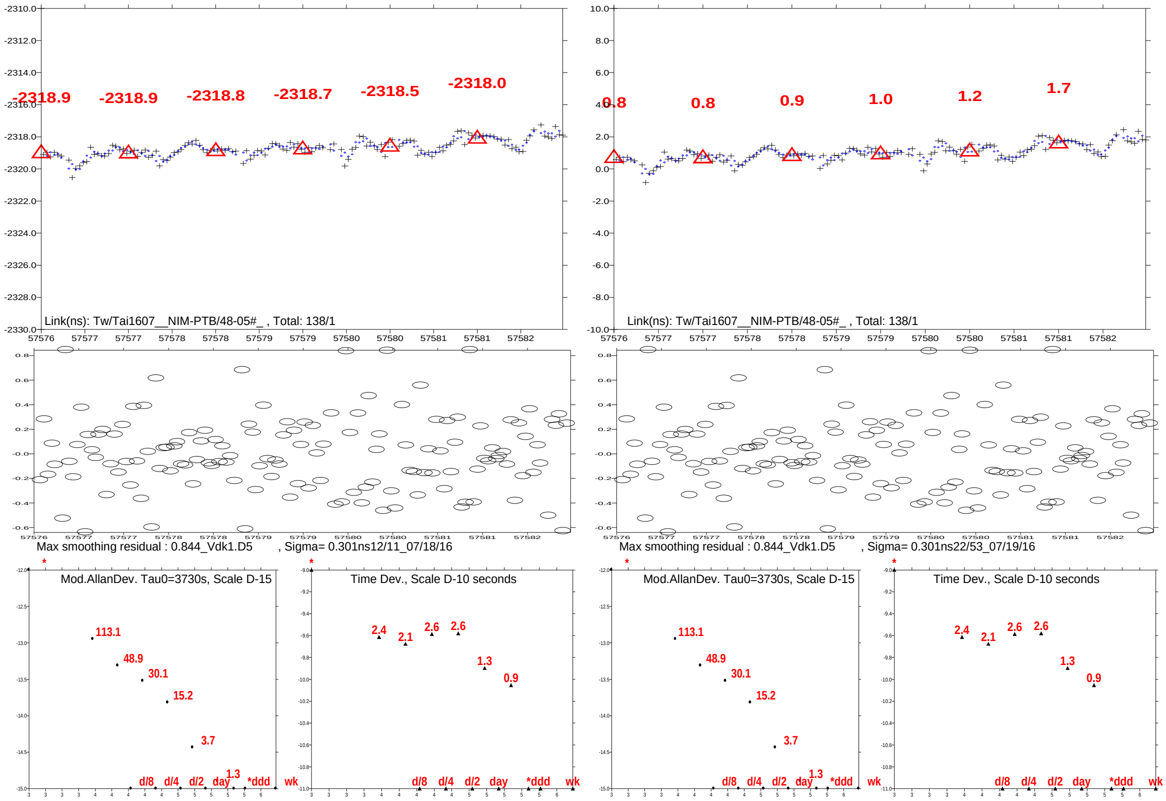


Figure 4.1.1 The TW links NIM-PTB before (*left*) and after (*right*) the calibration correction CALR=2319.7 ns

Figure 4.1.2 is the double clock difference DCD of the TW and GPSPPP links respectively for the GPS calibrators BP0U (*left*) and BP1C (*right*): -2320.169±0.484 ns and -2319.267±0.491 ns. The mean on average of the two calibrators is C_M=-2319.7±0.49 ns.

This correction C_M should be *subtracted* from the old CALR of the ITU TWSTFT data format file of the NIM side but *added* to that of PTB side, that is, new_CALR(NIM)=old_CLAR-C_M=0-(-2319.7)=2319.7 ns for the NIM side in the ITU data files corresponding to ESDVAR=0. The Job of the Tsoft Menu Y20 for this calibration correction (active Calib) is:

```
Calib. ______ ______: S=1 CALR= 00000.000 ESDVAR= 00000.000   ! CLB correction:-2319.7±0.49 ns
Calib.  PTB03  NIM01: S=1 CALR= -2319.7   ESDVAR= 00000.000   ! PTBmj.ddd ITU file
Calib.  NIM01  PTB03: S=1 CALR= +2319.7   ESDVAR= 00000.000   ! NIMmj.ddd ITU file
```

Note here that, as usual the ESDVAR has to be set zero after the calibration. Figure 4.1.3 shows the DCD of TW-GPSPPP links after the new CALR to be used.

Provisional application of the calibration correction

The BIPM computes the DCD of the TW-GPSPPP links which is indispensable for the study of the long-term stability of the UTC links. When the calibration correction is too big, the nanosecond level variation is not easy to be observed and the computation is sometimes blocked. Moreover, rigorously speaking, the final CALR should be computed after the closure measurement at PTB, with still several months' delay. And it should be implemented meanwhile on both sides with an official CI code issued by BIPM. Therefore a temporary measure may be used to introduce the CALR in the ESDVAR, i.e. by the relation ESDVAR (Labk)=2*CALR(Labk).

The Job of the Tsoft Menu Y20 for this operation (active Calib) is:

```
Calib. ______ ______: S=0 CALR= 00000.000 ESDVAR= 00000.000   ! ESDVAR(NIM)=CalR*2=2319.7*2
Calib.  PTB03  NIM01: S=0 CALR=  0000.0    ESDVAR= 00000.000   ! subtracted from ITU PTBmj.ddd
Calib.  NIM01  PTB03: S=0 CALR=  0000.0    ESDVAR= 04639.400   ! added to ITU NIMmj.ddd files
```

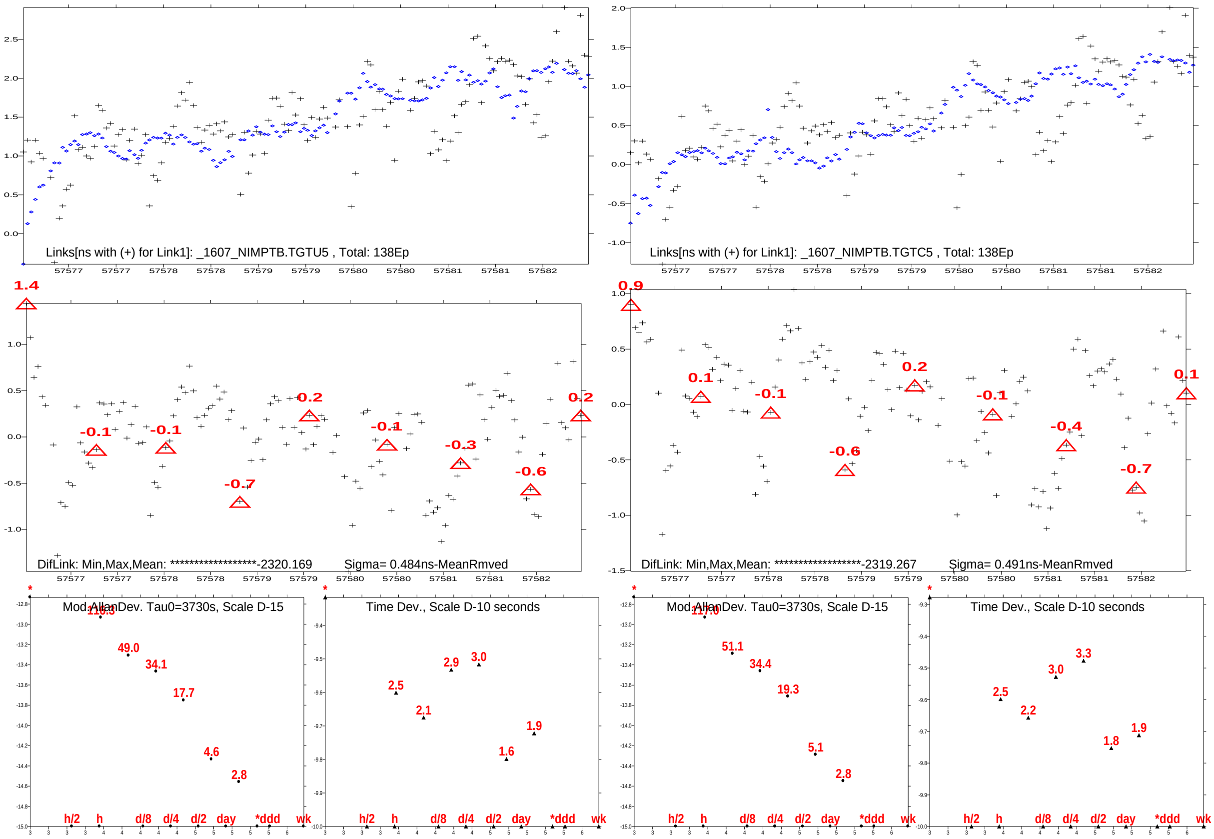


Figure 4.1.2 DCD of TW and GPSPPP links respectively to the calibrators BP0U (*left*) and BP1C (*right*): -2320.169 ±0.484 ns and -2319.267±0.491 ns, and -2319.7±0.5 ns on average

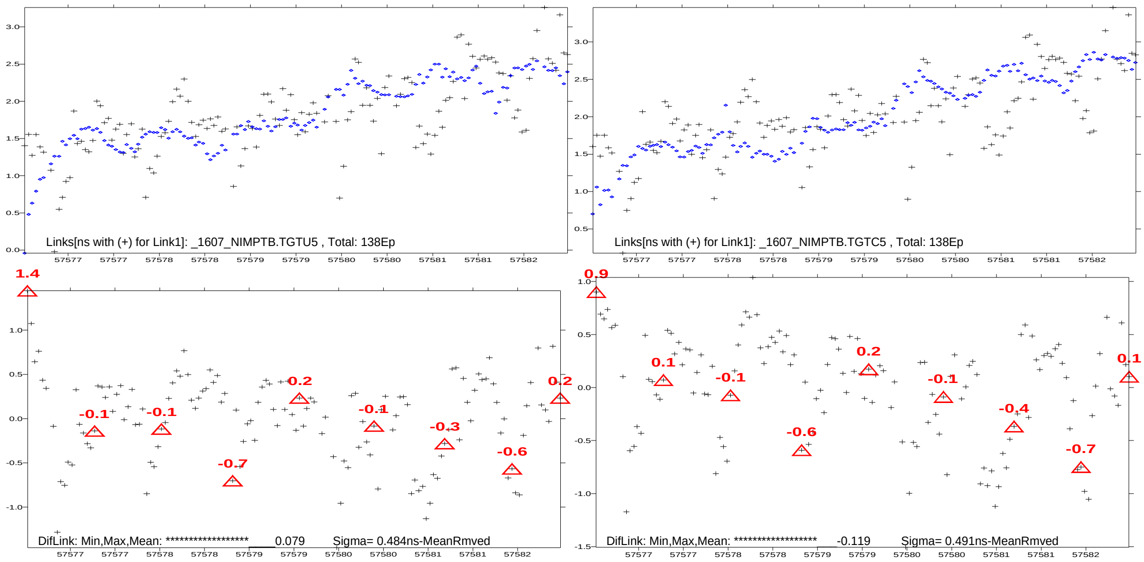


Figure 4.1.3 DCD of TW and GPSPPP links respectively to the calibrators BP0U (*left*) and BP1C (*right*): after the new CALR=2319.7±0.5 ns to be applied

4.2 Discussion on the long-term stability of the DCD of the TW-GPS links

As can be seen in the Figure 4.2.1, there seems a slop about 1.5 ns/month exists in the 1606 comparison of the TW and the PPP links. We do not know the cause for this moment. Further investigation is needed.

The mean of the differences between TW and GPS links of the month 1606 is -2320.97±0.62 ns. Comparing with that of 1602, -2320.15±0.32 ns [9], the difference is 0.8 ns, not big with respect to the uncertainty 1.5 ns. Meanwhile the GPS link calibration is only -0.8 ns, cf. Table 5.2.1. The calibration used the 1607 data set. When this report is prepared, the monthly data set 1607 are not available.

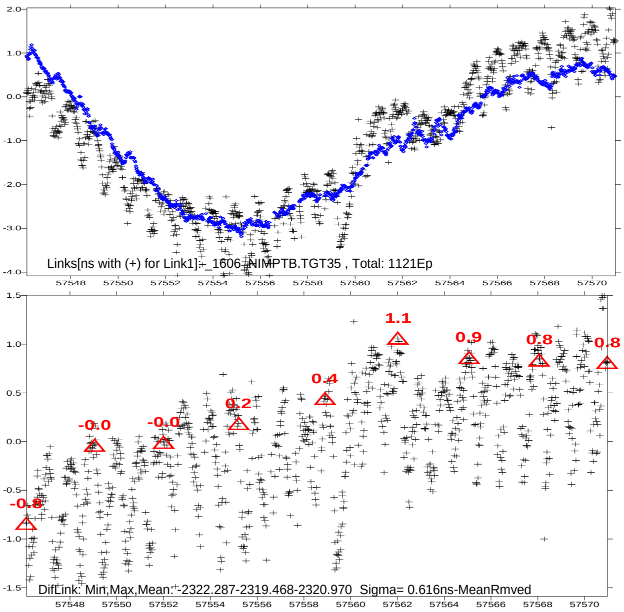


Figure 4.2.1 One monthly (1606) DCD of the NIM-PTB TW and GPSPPP links. A slop about 1.5 ns/month seems present. The DCD on average is -2320.970±0.616 ns.

5 GPS Data processing

We first compute the METODE total delay calibration correction C_M through GPSPPP [1,3,4] and then convert it to the classic equipment calibration result, the internal delays: INTDLY(P1/P2), cf. [3] for details.

5.1 The GPSPPP solution

Table 5.1.1 gives the calibration values for the StdB, the master GPS receivers of PTB and Lab(*k*).

6 days data are selected: DOY 189-195 of 2016. The Rinex files are cleaned and composed by using Teqc, then compressed and submitted to the online CSRS-PPP service, cf. Section 9 of [3].

Table 5.1.1 Computation of the UTC(*k*)-GPST by GPSPPP (6-day NRCan solution/DOY 189-195 of 2016)

RevSys	Doy1	Doy2	ClkPh/ns	Drift	ClkPh0/ns	RMS/ns
BP0U	189	195	-124,14	0,36	-123,06	0,9
BP1C	189	195	-64,76	0,40	-63,56	0,93
IMEJ	189	195	2,32	0,40	3,52	0,9
PTBB	189	195	509,22	0,11	509,55	0,97

5.2 The Total delay and the total delay corrections

Table 5.2.1 gives the total delay and the total delay correction for the GPS receivers of the Lab(*k*). The CCDu and CCDc are the calibration correction given by BP0U and BP1C of the StdB. When the Internal Delays IntD(L1)= IntD(L2)= IntD(L3)=0, the calibration corrections are the calibrated internal delay of L3. LkGps and LkTw are the mean values of the related links. Note, here computed the C_M for TW link is approximated value. The final value is given in the computation of Section 4.1, Cf. Figure 4.1.2. However, from the rigorous computation (Fig. 4.1.2) and the approximated value in Table 5.2.1, we have exactly the same result 2319.7 ns. In fact, when there are not data missing in TW/GPS, the two approaches should give the same result.

Table 5.2.1 Total Delay and Total Delay Correction (C_M/L3) /DOY189-195)

Rcv	IntD$_{L1}$	IntD$_{L2}$	L_1-L_2	IntD$_{L3}$	CabD	RefD	C_0	C_1	C_2	C_3	TotDly	ClkP	m-l	CCD$_u$	CCD$_c$	C_M/CalR
	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
a	b	c	d	e	f	g	h	i	j	k	l	m	ns	o	p	q
BPOU				0,0		-110,2	-20,8	**4,7**			-126,3	-123,1	3,24			
BP1C				0,0		-110,2	225,2	**-2,3**	-178,6	0,0	-65,9	-63,6	2,34			
IMEJ*	0,0	0,0	0,0	0,0	0,0	0,0					0,0	3,5	3,52	-0,28	-1,18	**-0,7**
PTBB	303,9	319,3	-15,4	280,1	301,7	-74,0					507,8	509,6	1,74	1,50	0,59	1,0
LkGps													1,04			
LkTw												-2318,7				**2319,7**

* The total delay has been preset in the GTR50/IMEJ by Dicom and in Rinex file. So here zero is used

6. Start and closure measurements at PTB and BIPM

6.1 At PTB

The last visit of the StdB to PTB was in June 2015 and was make a side by side setup with the PTBB and an alignment measurement to determine or to check the stability of the StdB and re-compute the corrections for the StdB [10]. A *receiver* total delay calibration result was made [11]. Because the calibration result of [11] has been implemented in Aug. 2015, after the StdB visit to PTB, the total delay of the PTB master receiver PTBB has been changed for 0.9 ns, cf. PTBBold and PTBBnew in Table 6.1.2. Hens, the StdB calibration or alignment has to be re-computed using the both the 2015 raw data [10] and the new calibration results [11].

Tables 6.1.1 and 6.1.2 give the computation details.

6 days Rinex data are selected: DOY 189-195 of 2015. The Rinex files are cleaned and composed by using Teqc, then compressed and submitted to CSRS-PPP, cf. Section 9 of [3]. The sub-delays are given from [4,10,11].

Table 6.1.1 Computation of the UTC(*k*)-GPST by GPSPPP (6-day NRCan solution/DOY 160-165 of 2015)

RevSys	Doy1	Doy2	ClkPh/ns	Drift	ClkPh0/ns	RMS/ns
BP0U	160	165	-51,57	0,16	-51,17	0,12
BP1C	160	165	-5,61	0,22	-5,06	0,12
PTBB	160	165	507,57	0,12	507,87	0,12

The Total delay and the total delay corrections

Table 6.1.2 gives the total delay and the total delay correction for the GPS receivers of the Lab(*k*). The CCDu and CCDc are the calibration correction given by BP0U and BP1C of the StdB. The calibration or alignment corrections for BP0U and BP1C are 4.67 ns and -2.32 ns respectively, see columns '*n*' in the table. The old corrections are 5.2 ns and 3.6 ns. Remove the 0.9 ns implemented in PTBB in Aug. 2015, we have the BP0U correction 5.2-0.9=4.3 ns, which is 0.4 ns smaller than the new value (4.67 ns). For BP1C, we have similar equation 3.6-0.9-6.5=-3.8 ns, 1.5 ns smaller than the new value (-2.32 ns). Here the 6.5 ns was caused by firmware upgrade. This 1.5 ns, much bigger than the PPP measurement uncertainty (uA=0.3 ns), would come probably from the PPS in/out for the Sept. Polarx receivers.

Table 6.1.2 Total Delay and Total Delay Correction (C_M/L3) /DOY160-165 OF 2015)

Rcv	IntD$_{L1}$	IntD$_{L2}$	L_1-L_2	IntD$_{L3}$	CabD	RefD	C_0	C_1	C_2	C_3	TotDly	ClkP	m-l	CCD$_u$	CCD$_c$	C_M
	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q
BPOU				0,0		-35,1	-20,8	0,0			-55,9	-51,2	4,73			
BP1C				0,0		-35,1	225,2	0,0	-192,9	0,0	-2,8	-5,1	-2,26			
PTBB$_{new}$	303,9	319,3	-15,4	280,1	301,7	-74,0					507,8	507,9	0,06	**4,67**	**-2,32**	1,18
PTBB$_{old}$	304,5	318,9	-14,4	282,3	301,7	-75,3					508,7	509,6	0,90	3,83	-3,16	0,34

6.2 At BIPM

The final calibration should be made after the closure measurement which controls the stability of the StdB. The PPP closures at BIPM before and after the visits to NIM/BSNC vs. the BIPM fixed reference receivers are within 0.5 ns.

Table 6.1 3 months PPP closures at BIPM before and after the visits to NIM vs. the GTR50 BP0T

Period	BP0U – BP0T/ns	BP1C – BP0T/ns	BP1C – BP0U/ns	Mean/ns
56685-56690	-124.8±0.1	-126.8±0.1	2.0±0.1	-125.8±0.1
56762-56764	-124.7±0.1	-125.7±0.1	1.0±0.1	-125.2±0.1
56864-56865	-124.5±0.1	-125.5±0.1	1.0±0.1	-125.0±0.1
Old-New closure	0.2	0.2	1	0.2

Acknowledgement

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Reference

[1] Jiang Z., Arias F., Lewandowski W., Petit G. (2011) BIPM Calibration Scheme for UTC Time Links, Proc. EFTF 2011, pp 1064-1069

[2] Liang K et al. (2014) BIPM TM234, METODE Experiments 2013-VII, at and between BIPM and NIM, July. 2014

[3] BIPM TM228 (2014), BIPM guideline for UTC time link calibration V2.2 draft 2/2014

[4] Jiang Z. (2016) Final report of the BIPM Pilot Study on UTC time link calibration, Proc. PTTI, Dec. 2016, Monetary, CA, USA

[5] Lin S. Y. (2014) A Modification of Z12T Metronome Time Transfer System, IN. Proc. EFTF2014

[6] BIPM (2014) Notice for the BIPM calibration scheme METODE *MEasurement of TOtal Delay* Draft 0.9 (06/06/2014)

[7] BIPM and CCTF WG on TWSTFT (2015) TWSTFT Calibration Guidelines for UTC Time Links (v3.0) (2015)

[8] BIPM GNSS receiver calibration guidelines (2015)

[9] Jiang Z, Piester D, Yang Z, Zhang H, Wu W and Li H (2016), BIPM TM259, TWSTFT Europe-Asia and Asia-Asia links via AM22

[10] PTB (2015) Relative calibration of PTBB and PTBG internal delays by means of BIPM traveling systme B3TS-June 2015

[11] Petit G (2015) TM243, Determination of reference GPS “INTDLY” values of Group 1 geodetic receivers in the initial Group 1 trip (Cal_Id = 1001-2014)