UTC link calibration report

-- MEasurement of TOtal DElay for UTC Time Link Calibration
Phase X: **NIST**

B. Patla[1], S. Romisch[1], V. Zhang[1], W Wu[2], L. Tisserand[2], G. Petit[2], F Arias[2] and Z Jiang[2*]

1 NIST: National Institute of Standards and Technology, 325 Broadway, Boulder, CO80305, US
2 BIPM: Bureau International des Poids et Mesures
* Corresponding person, *zjiang@bipm.org*

Abstract

This report includes the calibration results of NIST and closure measurement of the tour BIPM-NIST-USNO-BIPM. During 22 Jan.-5 Feb., 2015 (57044-57058), the BIPM Standard travelling calibration station (Std_B) visited NIST. The goal is: 1) to calibrate the UTC and the backup time links of NIST-PTB; 2) to calibrate the NIST's travelling GPS timing receiver to fulfil the G1 responsibility. This work and this report are realized according to the BIPM UTC time link calibration guideline [8].

The METODE calibration equipment at NIST

Content

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 *added* to 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

G1/G2=group1/ group2, the UTC laboratories are grouped into G1 and G2 calibration groups

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

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1 Summary

1.1 General

This report includes the calibration results of NIST and closure measurement of the tour BIPM-NIST-USNO-BIPM. During 22 Jan.-5 Feb., 2015 (57044-57058), the BIPM Standard travelling calibration station (Std_B) visited NIST. The goal is: 1) to calibrate the UTC and the backup time links of NIST-PTB; 2) to calibrate the NIST's travelling GPS timing receiver to fulfil the G1 responsibility. This work and this report are realized according to the BIPM UTC time link calibration guideline [8].

During 24 to 31 Jan. 2015 , MJD 57046-57053, the Std_B was installed at NIST, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA. Since 2013, in the frame of the BIPM Pilot Project, namely METODE aiming at unifying the UTC time link calibrations with a calibration uncertainty $u_B \leq 2$ ns [1,11,13,14 shorten the reference as the guideline Annex II], the Std_B has visited the UTC labs: OP, PTB, PL, AOS, TL, NMIJ, NICT, NIM (BSNC), ROA; experiments were made also at the BIPM, NIST and USNO [2-8]. The two visits to PTB in June 2013 and Aug. 2014 allow the Std_B transferring the calibration of the PTB master receiver to the Lab(*k*). The difference of the two visits is 0.03 ns [TM235]. This and the closure measurements at BIPM prove the long-term stability of the Std_B.

The requirements for the setup and computations can be found in the BIPM guideline [8]. Taking into account of the starting and closure measurements at the BIPM, we compute the calibration corrections for the UTC master receiver, the backup GPS receivers of NIST and the TWSTFT time links between NIST-PTB. The NIST-PTB TWSTFT supplies officially the UTC time link calibration through the combination of TWSTFT and GPS PPP.

The GPS PPP solutions are used for this calibration. Hereafter in the expression UTC(*k*) or Lab(*k*), we have always *k*=NIST.

The report serves also as the calculation sheet. Major calculations are made using the Excel tables hereafter. Some intermediate results in these tables are very useful for the computation and the verifications but boring. Readers may skip them.

1.2 The main result$_{(k)}$

The calibration result are the GPS and the TWSTFT time link corrections (C_M) on the baseline Lab(*k*)-PTB. The UTC GPS/TWSTFT results are given in Table 1.2a. Tables 1.2b/c gives the backup GPS link corrections. Because the PTB is taken as the reference of the calibration and its correction is set zero, the time link correction C_M is equal to the GPS equipment calibration correction and can be converted to the classic equipment calibration result, termed INTDLY(P1/P2) in Table 1.3, assuming that that CAB DLY and REF DLY are known. For the NovaTel receiver, the P1 should be replaced by C1.

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

Lab	Time Rcv/Link	C_M/ns	u_M	CLBID	ITU CI	S
NIST	GNSS Novatel/NIST (L3)	-7.5*	≤ 2 ns	A1 1 PP 02 05 15		
NIST	TWSTFT: NIST-PTB	-3.7**	≤ 2 ns	A1 2 TP 02 05 15	393	1

* The bias C1-P1 was corrected

** The new CALR= -203.3 ns (ESDVAR=0) in ITU file, e.g. TWNIST57.048, cf. Section 5.

Table 1.2b The total delay correction for the *backup* GPS time receiver/link

Lab	Time Rcv/Link	C_M/ns	u_M	CLBID	Note
NIST	GNSS Novatel/NB01 (L3)	11.2	≤ 2 ns	A1 3 pP 02 05 15	
NIST	GNSS Novatel/NB02 (L3)	9.2	≤ 2 ns	A1 4 pP 02 05 15	

Table 1.2c The total delay correction (old INTDLY-C_M) converted to the classic equipment calibration result

Rcv	Time Rcv	INTDLY(L3) /ns	INTDLY(L1/L2) /ns	u_M
NIST	GNSS Novatel/NIST	-37.2	To be filled up latter	3 ns
NIST	GNSS Novatel/NB01	11.2		3 ns
NIST	GNSS Novatel/NB02	9.2		3 ns

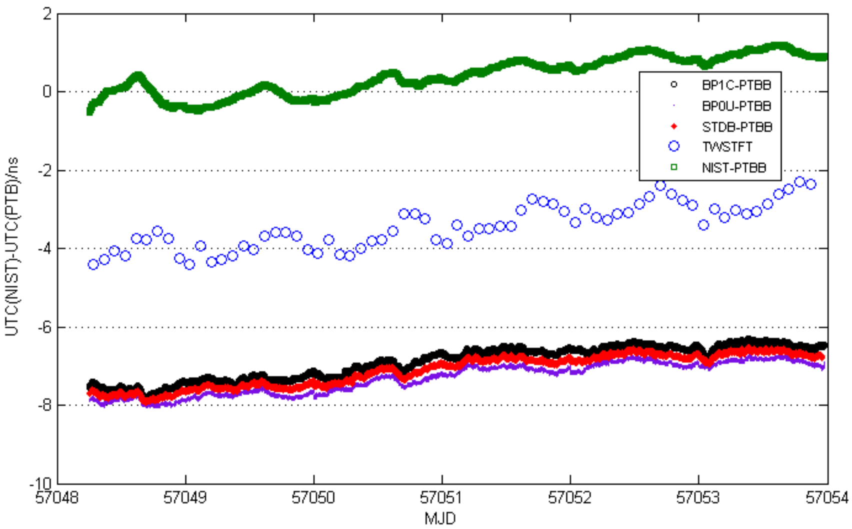
Tables 1.3a/b/c give the code solutions (to be updated).

Table 1.3a The total delay correction for the **UTC** GPS **Code** and TW time links/Receivers

Table 1.3b The total delay correction for the *backup* GPS time receiver/link

Table 1.3c The total delay correction (old INTDLY-C_M) converted to the classic equipment calibration result

Figure 1.2 shows the time links on the UTC baseline NIST-PTB during the calibration period 26-31 Jan. 2015 (MJD 57048-57054). Here Std_B stands for the mean value of the BP0U and BP1C installed in the BIPM Std_B. Taking the link Std_B-PTB as reference, the TWSTFT and GPSPPP links are higher respectively 3.6±0.3 ns and 7.5±0.3 ns than that of the Std_B.



Green: PPP NIST-PTB; **Blue**: TWSTFT NIST-PTB; **Red:** PPP StdB-PTBB (StdB is mean of BP0U/**violet** and BP1C/**black**)

Figure 1.2 The time links on the UTC baseline NIST-PTB during the calibration period 26-31 Jan. 2015

1.3 Uncertainty

The *total uncertainty* (U_M) of the C_M is composed of [11,13,18]:

- 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 ≤ 2 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 [11]. Ignoring the L1/L2 delay difference going through the antenna cable produces at least 3 ns error [12]. The total uncertainty of INTDLYs is no less than 3 ns, as given in the Table 1.2c.

2 Setups of the Std$_B$

2.1 The standard setup

By the definition of the METODE UTC time link calibration correction [1,11], 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$_B$ to PTBB, i.e. the BP0U and BP1C in Std$_B$ are to be corrected -5.2 ns and -3.6 ns;
- The Std$_B$ goes to the Lab(k), and makes measurements side by side with the master receiver of Lab(k), both of the Std$_B$ and the master receiver use the same reference signals of UTC(k);
- The closure measurement at the starting point;
- We compute the double clock difference:

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

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:

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

And the correction of the backup links:

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

The setup of the Std$_B$ is shown in the Figure 2.1. The cable C166 was directly connected to the UTC(k).

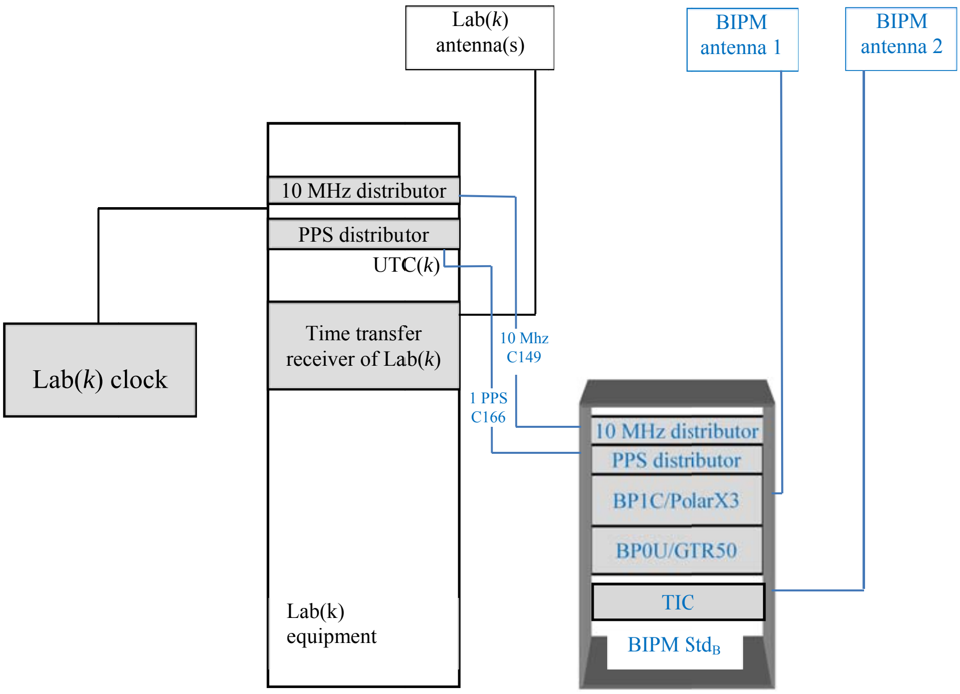


Figure 2.1 The Std$_B$ setups at the BIPM and Lab(k)
(the BIPM devices including cables are shown in blue. That of Lab(k) in black)

2.2 The setup change in BP1C due to a firmware upgrading

Required by the manufacture, the firmware of the BP1C (Sept. PolarX3) was upgraded on the 16 Sept. 2014 (56916). This produced an unexpected jump. By comparing the CCDs of the BP1C against other three independent GPS receivers BP0R (PolarX2), BP0T (GTR50) and BP0U (GTR50, one of the traveling calibration system), we can find the jump.

Using the GPS PPP solutions, we compared the data of three days before and after the firmware upgrading on 56916, as shown in the Excel Tables 2.2.1 and 2.2.2. Here the definitions of the terms, ClkPh, Drift, ClhPh0 and TotDly, are given in [8]. These tables, serve as the calculation sheet as same as bellow, give automatic procedure for the calibration computation. The values there are rather intermediate results of the procedure and Readers may skip them. Our main interests are the CCD values in the tables.

Table 2.2.1 CCD of BP1C vs. 3 other receivers 3 days *before* the BP1C firmware upgrade on 56916/259

Rev	Doy1	Doy2	ClkPh	Drift	ClkPh0	TotDly	ClkPh0-TotDly	CCD	Note
			ns	ns	ns	ns	ns	ns	
BP1C	256	259	-153,65	-1,58	-156,02	0,00	-156,02		
BP0R	256	259	-95,85	-1,53	-98,15	0,00	-98,15	-57,88	
BP0T	256	259	-181,10	-1,43	-183,25	0,00	-183,25	27,23	
BP0U	256	259	-194,25	-1,54	-196,56	0,00	-196,56	40,54	

Table 2.2.2 CCD of BP1C vs. 3 other receivers 3 days *after* the BP1C firmware upgrade on 56916/259

Rev	Doy1	Doy2	ClkPh	Drift	ClkPh0	TotDly	ClkPh0-TotDly	CCD	Note
			ns	ns	ns	ns	ns	ns	
BP1C	260	263	-161,48	-1,58	-163,85	0,00	-163,85		
BP0R	260	263	-97,25	-1,53	-99,55	0,00	-99,55	-64,31	
BP0T	260	263	-182,30	-1,43	-184,45	0,00	-184,45	20,60	
BP0U	260	263	-195,68	-1,54	-197,99	0,00	-197,99	34,14	

Table 2.2.3 CCD jumps due to the BP1C firmware upgrade on MJD 56916/DOY 259

CCD/Rcv	Doy 256-259	Doy 260-263	dCCD	u
	ns	ns	ns	ns
BP1C-BP0R	-57,88	-64,31	6,43	
BP1C-BP0T	27,23	20,60	6,63	
BP1C-BP0U	40,54	34,14	6,40	
Mean			**6,49**	0.24

The Table 2.2.3 gives the mean value +6.5 ns (±0.4 ns). Taking the u_A= 0.3 ns of the PPP solution (Section 6 of Circular T), the uncertainty of a dCCD is $\sqrt{2}\times0.3$ ns and that of the mean of the three values becomes $\sqrt{2}\times0.3/\sqrt{3}$ ns =0.24 ns. This suggests, a constant of 6.49 ns should be removed from all the measurements of the BP1C.

3 Setups of the Lab(k) equipment

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

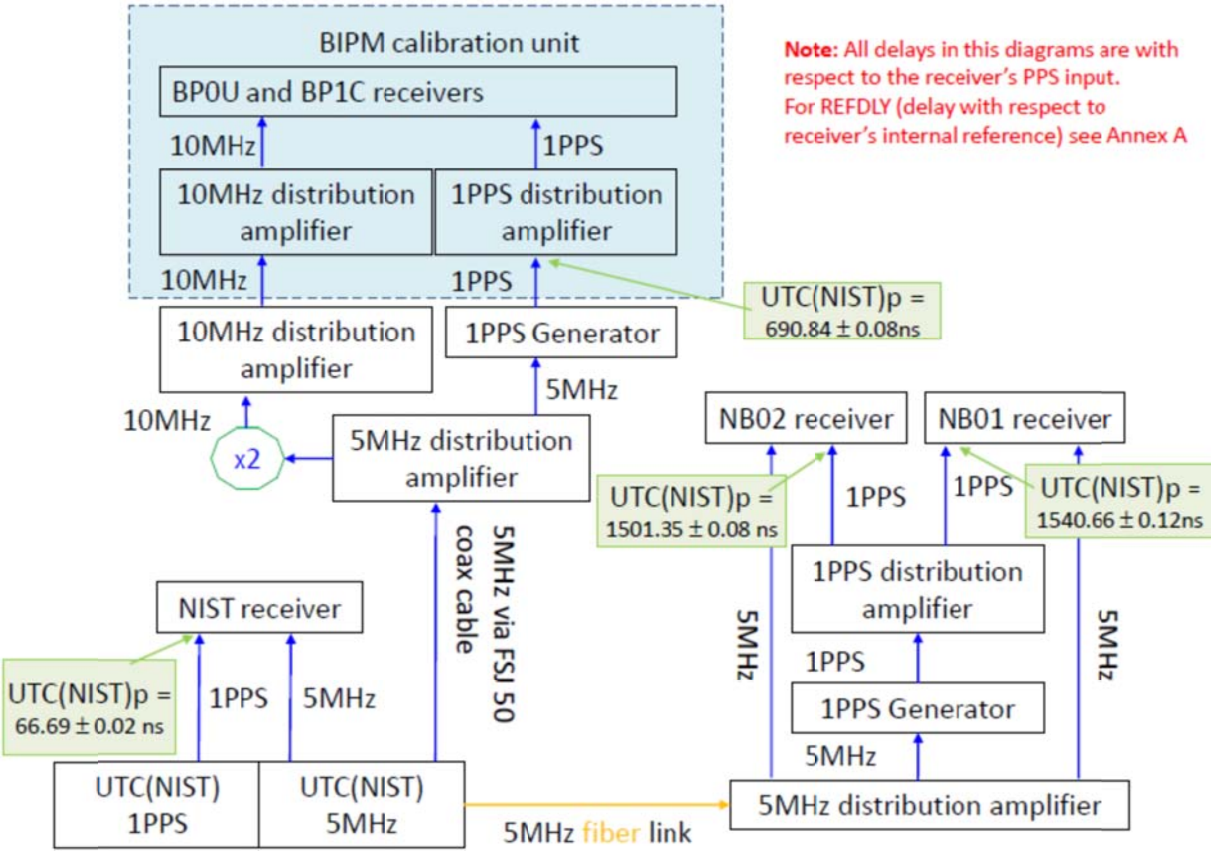


Figure 3.1 Setup of the Std_B and the receivers to be calibrated in the NIST T/F laboratory

Table 3.1 is a summary of the Annex A giving the receiver and the antenna information directly used in the calibration data processing. Table 3.2 lists the present sub-delays before the calibration. They will be used as the starting values in the Table 4.2.1 for the calibration computation.

Table 3.1 The receiver and antenna information

No.	Receiver	Type	Antenna	Antenna code	Note
1	BP0U	GTR50	NOV702GG	NAE07190046	
2	BP1C	Sept. Polarx3	ASH701945E_M	2000785	
3	PTBB	Ashtech Z12T	ASH700936E SNOW	CR15930	
4	NIST	Novatel	NOV702	04230007	Master
5	NB01	Novate	NOV703GGG.R2	NEG10500001	backup
6	NB02	Novate	NOV703GGG.R2	NEG10390004	backup

Table 3.2 The present calibration information (in CGGTTS header) /ns

No.	Receiver system	IntDly(L1)	IntDly(L2)	IntDly(L3)	CabDly	RefDly	Co*	C1*	C2*	C3*	TotalDly	Note
1	BP0U					-690.84	-20.8	5.2			-706.5	
2	BP1C					-690.84	225.2	3.6	-195.7	-6.5	-664.3	
3	PTBB	304.5	318.9	282.252	301.7	75.3					508.7	
4	NIST	-44.7	-44.7	-44.7	275.5	114.5					116.3	
5	NB01	0	0	0	298.5	1545.77					-1247.3	
6	NB02	0	0	0	298.0	1516.49					-1218.4	

* *Co, C1, C2, C3 are the sub-delays/corrections, such as the jump of the 6.49 ns in BP1C, cf. Section 2.2*

4 Data processing

We first compute the METODE total delay calibration correction C_M through PPP (Tables 1.2) [10] and then convert it to the classic equipment calibration result, the internal delays (Table 1.2c): INTDLY(L1/L2), cf. [9] for details.

4.1 GPSPPP solution

7 days data are selected: DOY 24-31 of 2015.

Figures 4.1.1 and 4.1.2 show the GPSPPP solutions for the calibrations and the time link comparison over the UTC(NIST)-UTC(PTB) baseline. Here StdB stands for the mean value of the BP0U and BP1C. Tables 4.1.1a and 1b give the UTC(*k*)-GPST value using the GPSPPP solutions. ClkPh0 is the mean value obtained by the linear regression corresponding to the mid-point of the measurement duration. Here, CCDu and CCDc are corresponding respectively to the receiver systems BP0U and BP1C. Readers may skip these Excel tables.

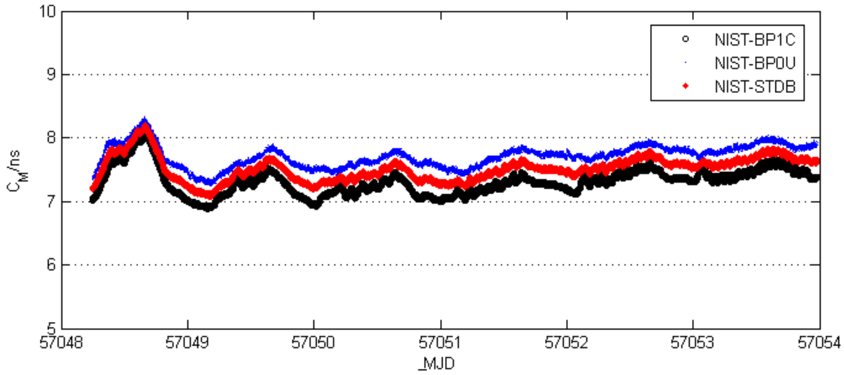


Figure 4.1.1 The PPP CCD at NIST (Av. NIST-StdB = 7.5 ns)

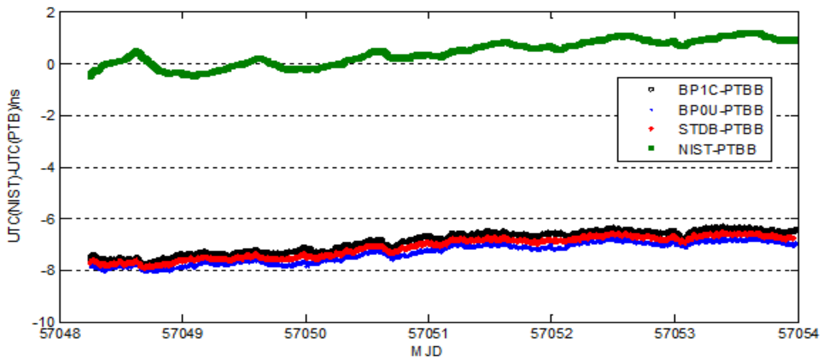


Figure 4.1.2 The PPP time links over the baseline NIST-PTB (Av. DCD = 7.51±0.19 ns)

Table 4.1.1 Computation of the UTC(*k*)-GPST by GPSPPP (6-day NRCan online solution/DOY 24-29)

RevSys	Doy1	Doy2	ClkPh/ns	Drift	ClkPh0/ns	RMS/ns
BP0U	26	32	-710,12	0,10	-709,82	0,32
BP1C	26	32	-667,56	0,11	-667,23	0,29
NIST	26	32	120,15	0,16	120,63	0,26
NB01	26	32	-1238,99	-0,11	-1239,32	0,46
NB02	26	32	-1212,36	0,03	-1212,27	0,32
PTBB	26	32	513,03	-0,13	512,64	0,29

4.2 The Total delay and the total delay corrections

Table 4.2.1 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. When the Internal Delays IntD(L1)= IntD(L2)= IntD(L3)=0, the calibration corrections are the calibrated internal delay of L3. For NIST receiver, the new IntDly(L3)=-44.7+7.5=-37.2 ns.

Table 4.2.1 Total Delay and Total Delay Calibration Correction (C_M/L3) (6-day NRCan online solution/DOY24-29)

Rcv	IntD/L1	IntD/L2	L1-L2	IntD/L3	CabD	RefD	Co	C1	C2	C3	TotDly	ClkP	m-l	CCDu	CCDc	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	ns	o	p	q
BPOU				0,0		-690,8	-20,8	5,2			-706,4	-709,8	-3,4			
BP1C				0,0		-690,8	225,2	3,6	-195,7	-6,5	-664,2	-667,2	-3,0			
NIST	-44,7	-44,7	0,0	-44,7	275,5	-114,5					116,3	120,6	4,3	-7,7	-7,3	-7,5
NB01	0,0	0,0	0,0	0,0	298,5	-1545,8					-1247,3	-1239,3	8,0	-11,3	-10,9	-11,1
NB02	0,0	0,0	0,0	0,0	298,0	-1516,5					-1218,5	-1212,3	6,2	-9,6	-9,2	-9,4
PTBB	304,5	318,9	-14,4	282,3	301,7	-75,3					508,7	512,6	4,0	-7,4	-7,0	-7,2

5 The other link calibrations

Hereafter is the calibration computation for the official UTC link of NIST-PTB TWSTFT. The raw data of the GPS and TWSTFT between MJD 57048-57054 were used.

5.1 The calibration of the TWSTFT link

Figure 5.1.1 gives the TWSTFT and GPSPPP links over the baseline NIST-PTB. Here StdB stands for the mean value of the BP0U and BP1C. Figure 5.1.2 shows the double clock differences (DCD) of the two links: TWSTFT link minus the GPSPPP link. The mean value is -3.69±0.34 ns, which is the TWSTFT link calibration correction and should be added to the CALR in the ITU file on the NIST side.

The old CALR= -199.617 ns with ESDVAR=7.282±0.5 ns in the ITU file TWNIST57.048. We have then the METODE calibrated CALR= -199.617+(-3.69)=-203.3 ns.

This correction should be *subtracted* from the ITU TWSTFT data format file of the PTB side. The Job of the Tsoft Menu Y20 for this calibration correction (active Calib) is:

```
Calib. ______ ______: S=1 CALR= 00000.000 ESDVAR= 00000.000 !CALR=-203.3=-199.6-3.7/ITU CI=393
Calib.  PTB01 NIST01: S=1 CALR= +203.3    ESDVAR= 01035.000 !subtracted from ITU TWPTBmj.ddd
Calib. NIST01  PTB01: S=1 CALR= -203.3    ESDVAR= 00007.282 !added to ITU TWNISTmj.ddd files
```

The present ESDVAR values kept unchanged in both sides of PTB and NIST. Please note here that, usually the ESDVAR should be set to 999999 or zero after the calibrations.

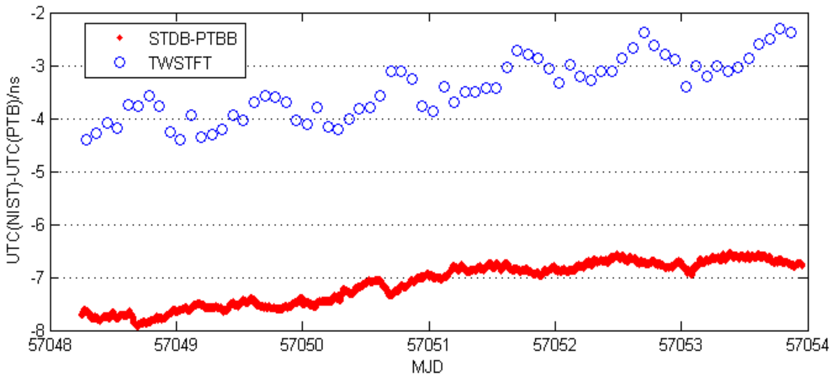


Figure 5.1.1 The TWSTFT and PPP (StdB-PTBB) time links over the baseline NIST-PTB

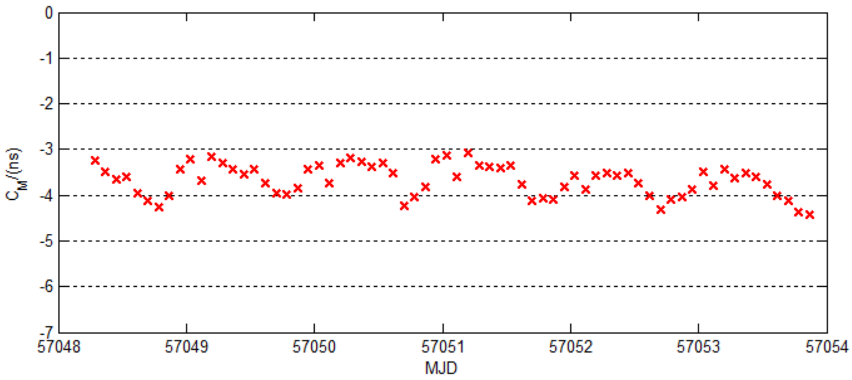


Figure 5.1.2 The difference of the TWSTFT and the GPSPPP time links (DCD), Mean=3.69±0.34 ns

5.2 The TWSTFT and GPSPPP links after the calibrations

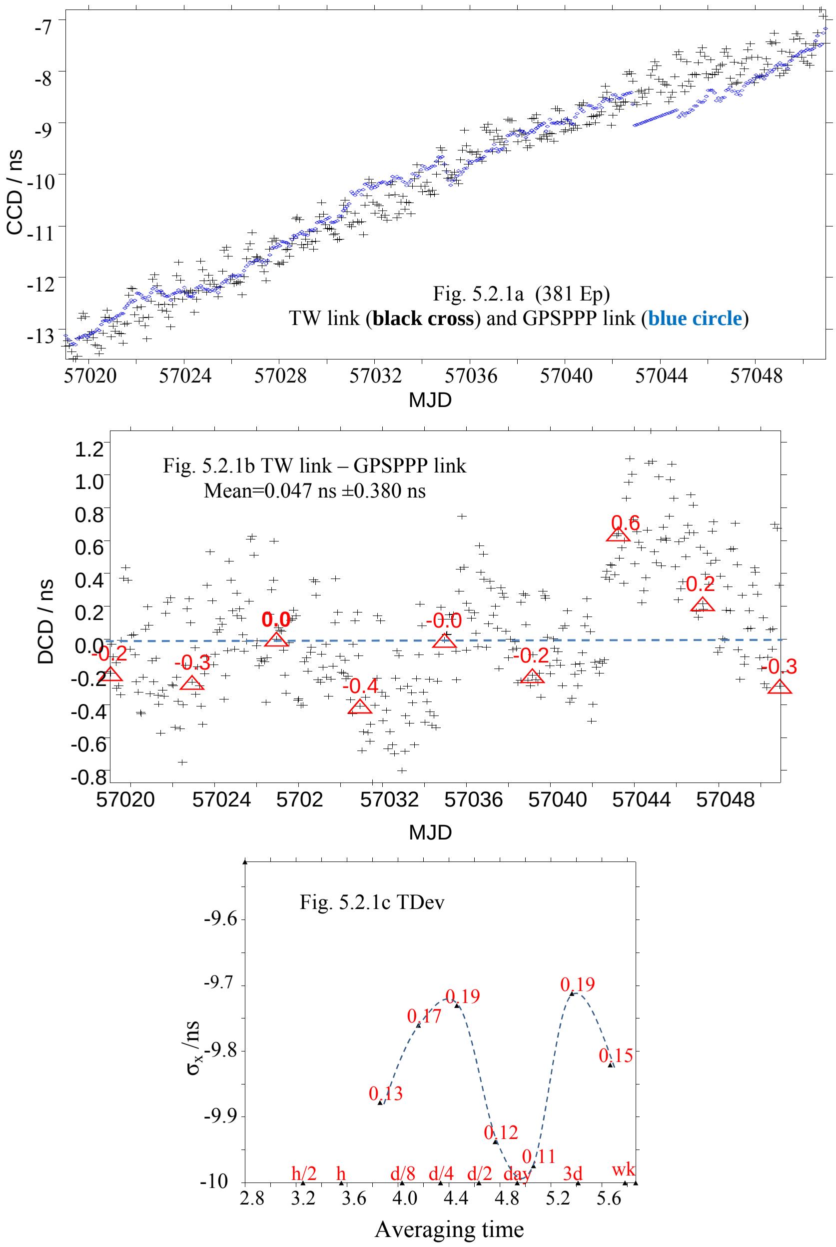


Figure 5.2.1 NIST-PTB link comparison. Both TW and PPP are calibrated (cf. Table 1.2a)

Figures 5.2.1a/b/c show the TW and GPSPPP links after that the new CALR(NIST)= 203.3 ns (S=1, ITU

CI=393) and the new INTDLY(L3) = -37.2 ns (for the GPS receiver NIST) are applied, cf. Table 1.2a. The mean of the differences is 0.047 ns ±0.380 ns. Here the data set of the month Jan 2015 is used. Significant diurnal presents as shown the TDev (Figure 5.2.1c) in the link differences (Figure 5.2.1b) which comes probably from the TWSTFT data.

From the Figure 5.2.1a, the PPP link is disturbed after the MJD 57042 due to a 2-day gap in the NIST receiver data.

6 Stability of Std_B and closure at BIPM-PTB before-after the US tours

The final calibration should be made after the closure measurement which controls the stability of the Std_B. The Tables 6.1, 6.2 and 6.3 give the PPP closures at BIPM before and after the visits to NIST and USNO vs. the BIPM stationary reference receivers: Sept BP0R and GTR50 BP0T. The closure of the Std_B is 0.6 ns and 0.4 ns for BP1C and BP0U vs. BP0R. On average, the closure of the Std_B is 0.5 ns. The maximum difference between the two travailing receivers in the Std_B is 0.3 ns. The Std_B is stable during the calibration tour.

The Std_B re-visited PTB during 9-16 Aug Doy 221-228 2014 and visited NIST-USNO during 22 Jan-30 March Doy 22-90 2015. It is important to underline that the tables give the instability by the statistic data since the end of last July, covering the closures and discrepancies between BP0U and since the second visit of Std_B to PTB. The first visit was in the end of June 2013. The difference of the two visits was only 0.03 ns.

Based on above analysis, we conclude that the instability of the Std_B is within 0.5 ns during the NIST-USNO calibration tours. In fact, this 0.5 ns includes also the instability of the fixed reference receivers BP0R and BP0T at PTB and BIPM. In fact, the travelling Std_B suffered serious transport shocks and the BIPM fixed reference receivers suffered a clock, therefore the RefDly, changes as shown in Table 6.4.

Table 6.1 CCDs of BP1C vs. BP0R and BP0T in July, Sept., Dec 2014 and April 2015

The StdB re-visited the PTB during 9-16 Aug Doy 221-228 2014 and to NIST-USNO during 22 Jan-30 March Doy 22-90 2015

The correction of 6.6 ns is added to BO1C, see Table 2.2.3. The same for Tables 6.2 and 6.3

dCCD/Rcv	Doy 206-208	Doy 256-262	Doy 344-348/2014 bf US	Doy 106-109/2015 af US	Dif. bf-af
	ns	ns	ns	ns	ns
BP1C-BP0T	21,0	20,8			
BP1C-BP0R	-64,3	-64,2	-64,8	-64,2	**0.6**
Mean					

Table 6.2 CCDs of BP0U vs. BP0R and BP0T in July, Sept., Dec 2014 and April 2015

dCCD/Rcv	Doy 206-208	Doy 256-262	Doy 344-348/2014 bf US	Doy 106-109/2015 af US	Dif. bf-af
	ns	ns	ns	ns	ns
BP0U-BP0T	-13,3	-13,2	-13,2		
BP0U-BP0R	-98,4	-98,4	-98,7	-98,3	**0.4**
Mean	-55,8	-55,8	-56,0		

Table 6.3 CCDs between BP0U BP1C in July, Sept., Dec 2014 and April 2015

dCCD/Rcv	Doy 206-208	Doy 256-262	Doy 344-348/2014 bf US	Doy 106-109/2015 af US	max change
	ns	ns	ns	ns	ns
BP1C-BP0U	34,1	34,2	33,9	34,0	**0,30**

Table 6.4 Sub-delay changes due to the BIPM master clock changed during the US tour

receivers	period	INT DLY*	CAB DEY	REF DEY	TotDly	Dif. $_{\text{Before-after}}$
BP0U	Before US		182.00	52.60	129.40	0.00
	After US		182.00	52.60	129.40	
BP1C	Before US		235.70	257.90	-22.20	**3.14**
	After US		235.70	261.04	-25.34	
BP0R	Before US		133.40	270.30	-136.90	**3.39**
	After US		133.40	273.69	-140.29	
BP0T	Before US		176.90	42.60	134.30	0.00
	After US		176.90	42.60	134.30	

* Note: the TotDly is INT DLY+CAB DEY-REFDLY, the INT DLY is set to 0 here.

Acknowledgement

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Reference

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Annex A: Setup information at NIST

Annex A - Information Sheet

(to be repeated for each calibrated system)

Laboratory:	NIST
Date and hour of the beginning of measurements:	01/24/2015 00.00 UTC
Date and hour of the end of measurements:	02/01/2015 24.00 UTC

Information on the system

	Local:	Travelling:
4-character BIPM code	NB01	BPIC, BP0U
• Receiver maker and type: Receiver serial number:	Novatel OEM5 NAP10500009	
1 PPS trigger level /V:	0.5	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Andrew LDF2-50 N	
Length outside the building /m:	5.0	
• Antenna maker and type: Antenna serial number:	Novatel 703 NEG10500001	
Temperature (if stabilised) /°C		

Measured delays /ns

(if needed fill box "Additional Information" below)

	Local:	Travelling:
• Delay from local UTC to receiver 1 PPS-in:	1540.66 ± 0.12	690.84 ± 0.08
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	5.12 ± 0.06	
• Antenna cable delay:	298.5 ± 0.25	(1)
Splitter delay (if any):	N/A	(1)
Additional cable delay (if any):	N/A	(1)

Data used for the generation of CGGTTS files

• INT DLY (GPS) /ns:	
• INT DLY (GLONASS) /ns:	
• CAB DLY /ns:	298.5 ± 0.25
• REF DLY /ns:	1545.77 ± 0.1
• Coordinates reference frame:	WGS84
X /m:	-1288547.087
Y /m:	-4721701.103
Z /m	4078586.498

General information

• Rise time of the local UTC pulse:	3 ns
• Is the laboratory air conditioned:	yes
Set temperature value and uncertainty:	21.2 ± 0.5 °C
Set humidity value and uncertainty:	

Laboratory:	NIST
Date and hour of the beginning of measurements:	01/24/2015 00.00 UTC
Date and hour of the end of measurements:	02/01/2015 24.00 UTC

Information on the system

	Local:	Travelling:
4-character BIPM code	NB02	BPIC, BP0U
• Receiver maker and type: Receiver serial number:	Novatel OEM5 NAP10500008	
1 PPS trigger level /V:	0.5	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Andrew LDF2-50 N	
Length outside the building /m:	7.5	
• Antenna maker and type: Antenna serial number:	Novatel 703 NEG10390004	
Temperature (if stabilised) /°C		

Measured delays /ns

(if needed fill box "Additional Information" below)

	Local:	Travelling:
• Delay from local UTC to receiver 1 PPS-in:	1501.35 ± 0.08	690.84 ± 0.08
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	15.14 ± 0.07	
• Antenna cable delay:	298.0 ± 0.3	(1)
Splitter delay (if any):	N/A	(1)
Additional cable delay (if any):	N/A	(1)

Data used for the generation of CGGTTS files

• INT DLY (GPS) /ns:	
• INT DLY (GLONASS) /ns:	
• CAB DLY /ns:	298.0 ± 0.3
• REF DLY /ns:	1516.49 ± 0.11
• Coordinates reference frame:	WGS84
X /m:	-1288550.036
Y /m:	-4721698.460
Z /m	4078588.617

General information

• Rise time of the local UTC pulse:	3 ns
• Is the laboratory air conditioned:	yes
Set temperature value and uncertainty:	21.2 ± 0.5 °C
Set humidity value and uncertainty:	

Laboratory:	NIST
Date and hour of the beginning of measurements:	01/24/2015 00.00 UTC
Date and hour of the end of measurements:	02/01/2015 24.00 UTC

Information on the system

	Local:	Travelling:
4-character BIPM code	NIST	BPIC, BP0U
• Receiver maker and type: Receiver serial number:	Novatel OEM4-G2 NVH04230007	
1 PPS trigger level /V:	1.0	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Andrew FSJ1-50A N	
Length outside the building /m:	65.0	
• Antenna maker and type: Antenna serial number:	Novatel 702	
Temperature (if stabilised) /°C		

Measured delays /ns

(if needed fill box "Additional Information" below)

	Local:	Travelling:
• Delay from local UTC to receiver 1 PPS-in:	66.69 ± 0.02	690.84 ± 0.08
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	13.3 ± 0.1	
• Antenna cable delay:	275.5	(1)
Splitter delay (if any):	N/A	(1)
Additional cable delay (if any):	N/A	(1)

Data used for the generation of CGGTTS files

(VALUES USED PRIOR TO THIS CALIBRATION)

• INT DLY (GPS) /ns:	-44.7
• INT DLY (GLONASS) /ns:	
• CAB DLY /ns:	275.5
• REF DLY /ns:	114.5
• Coordinates reference frame:	WGS84
X /m:	-1288398.360
Y /m:	-4721697.040
Z /m	4078625.500

General information

• Rise time of the local UTC pulse:	3 ns
• Is the laboratory air conditioned:	yes
Set temperature value and uncertainty:	25.2 ± 0.7 °C
Set humidity value and uncertainty:	

Annex B: Calibration information at NIST

B1. General

From the late 1980s to July of 2006, NIST used a single frequency, single channel TTR-5 receiver (*NBS10*) as the primary timing receiver. The *NBS10*'s receiver delay ($INTDLY_{L1}$) was calibrated several times against absolutely calibrated receivers during that period. The *NBS10*'s receiver delay was also calibrated periodically by the BIPM's travelling receivers. The last BIPM calibration of *NBS10* was performed in December of 2005 [1]. The BIPM calibrations were using OP as the reference point. All of the receiver delay calibration results fell in the 5ns uncertainty margin and therefore no receiver delay adjustment has ever been applied.

The *NBS10* receiver was replaced by a Novatel OEM4 dual-frequency, multi-channel receiver (acronym *NIST*) in July of 2006 as the NIST primary timing receiver. The *NIST*'s receiver delay for the L1 measurements ($INTDLY_{L1}$) was obtained from the common-clock, common-view difference between the *NIST* receiver and the *NBS10* receiver. The *NIST*'s receiver delay on L2 measurements ($INTDLY_{L2}$) has never been calibrated. The *NIST* receiver has never been calibrated by the BIPM travelling receivers. Several calibration attempts have been made by NIST, USNO, NRL and OP to have the *NIST* receiver calibrated. However, the calibrations produced inconsistent results. The NB01 and NB02, both Novatel, were relatively calibrated vs. the *NIST*.

The NIST/PTB TWSTFT link became NIST's primary link to TAI/UTC in 2002. The link's delay was originally estimated from the NIST/PTB single frequency, single channel GPS common-view difference. After each of the changes of equipment, reference signal, satellite and frequency, the link delay change was estimated and corrected. The last one was in 2011 cf. [2].

Reference

[1] BIPM C/A code calibration: http://www.bipm.org/jsp/en/TimeCalibrations.jsp
[2] Jiang Z, Lewandowski W, Harmegnies A, Piester D and Zhang V (2011) TM198, Restoration the TWSTFT link calibration using GPSPPP bridging after the satellite change on Mjd 55769/27 July 2011

B2. Setup information

February 5, 2015

CALIBRATION WITH BIPM TRAVELLING SYSTEM - SUMMARY FROM NIST

The BIPM travelling system B3TS was delivered at NIST on January 21st 2015 and was setup the next day.

The antenna cable C131 was found with a "kink" that apparently was not there when the system was measured at BIPM.

The Time Interval Counter (TIC) that is part of the travelling system (SRS SR620) was found not working.

The initial delay measurements were done as required with TIC HP53131A (TIC #1, S/N….) on January 23rd, 2015:

Tare: 13.7 $\pm$ 0.15 ns (averaged over 300s, TIC#1)
Delay: 210.2 $\pm$ 0.22 ns (averaged over 300s, TIC#1))

PolaRx PPSin-PPSout = Delay-Tare = 196.5 $\pm$ 0.27 ns

Following the first upload of data from the travelling system, a possible discrepancy between the two receivers BP1C and BP0U was highlighted.

BIPM asked us to redo the delay measurements for the PolaRx (BP1C) and to measure some of the cables that were last measured at BIPM, to compare the values.

The new measurements were done with a different HP53131A (TIC#2, S/N KR91201378) and the results are shown below:

	C155 [ns]	C157 [ns]	C166 [ns]	C183 [ns]	tare [ns]	C131 (antenna cable) [ns]
NIST (TIC#2)	15±0.45	9.9±0.42	25.2±0.37	9.8±0.3	15.0±0.46	235.4 ± 0.36
BIPM	15.1ns	10.1ns	25.2ns	N/A	15.5ns	235.7ns

The above measurements (done with TIC#2) have been compared to the measurements from a HP5370B TIC and from a GT200 TIC. The measurements from the three TICs agreed to each other within 100ps. So we feel confident the TIC#2's measurements are correct.

The new measurements for the PolaRx delays are:

Tare: 15.0 $\pm$ 0.46 ns (averaged over 300s, TIC#2)
Delay: 210.7 $\pm$ 0.45 ns (averaged over 300s, TIC#2)

PolaRx PPSin-PPSout = Delay-Tare = 195.7 $\pm$ 0.64 ns

The antenna cable C131 was also characterized using a network Analyzer and the following values for the scattering parameters were measured, to verify the possible damage (impedance mismatch) produced by the "kink". The numbers in the table below suggest a non-significant impact of the "kink", as indicated also by the delay measurements that doesn't significantly differ from the value measured at BIPM in December.

	@ L1 [dB]	@ L2 [dB]
S11 (reflection coefficient)	-30	-25
S22 (reflection coefficient)	-27	-27
S21 transmission losses	-36	-39
S12 transmission losses	-36	-39

Nonetheless, it is strongly recommended for the future the use of higher quality cables (i.e. Andrew LDF2-50 or FSJ050A) between the antennas and the receiver, for better mechanical protection as well as significantly lower losses (-8dB for LDF2-50 and -10 dB for FSJ-50A), lower temperature sensitivity and better electromagnetic shielding.

A re-processing by Gerard Petit of the data uploaded by NIST by BIPM showed agreement between the two receivers BP1C and BP0U within 1 ns (see Gerard Petit), seemingly consistent with the only difference found between the initial tare measurement and the one repeated with TIC#2, which caused the PolaRx PPSin-PPSout value to change from 196.5 $\pm$ 0.27 ns (wrong value) to 195.7 $\pm$ 0.64 ns (right value).

<u>Note:</u> NIST REFDLY has changed.
A new cable was used to provide the PPS signal from UTC(NIST) to the input of the NIST receiver, so that the REFDLY is now difference from the value used so far.
The Annex A - Information Sheet for NIST reports the present values in the section titled "Measured Delays", but reports the old numbers in the section titled "Data used for the generation of CGGTTS files".

The position of the antenna hasn't changed.