GNSS CALIBRATION REPORT

G1G2_1012_2019

Prepared by: Andreas Bauch (PTB)
Head, Time Dissemination
Working Group

Approved by: Jürgen Becker (PTB)
QM-representative of
Time and Frequency
Department of PTB

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REFERENCES

REFERENCES	
RD01	**BIPM report 1001-2018, 1001-2018_GPSP3C1_Group1-trip_V1-5 24.07.2019**
RD02	**BIPM guidelines for GNSS calibration, V3.0, 02/04/2015**
RD03	**BIPM TM.212 (G. Petit), Nov. 2012**
RD04	**J. Kouba, P. Heroux, 2002, *"Precise Point Positioning Using IGS Orbit and Clock Products,"* GPS Solutions, Vol 5, No. 2, 12-28**
RD05	**W. Lewandowski, C. Thomas, 1991, *"GPS Time transfers,"* Proc. IEEE, Vol. 79, No. 7, 991-1000**
RD06	**PTB GNSS calibration report G1G2_1012_2016**
RD07	**P. Defraigne and G. Petit, "CGGTTS-Version 2E: an extended standard for GNSS time transfer, Metrologia 52 (2015) G1**

ACRONYMS

ACRONYMS	
BIPM	**Bureau International de Poids et Mesures, Sèvres, France**
CGGTTS	**CCTF Generic GNSS Time Transfer Standard**
DTAG	**Deutsche Telekom AG**
EURAMET	**The European Association of National Metrology Institutes**
IGS	**International GNSS Service**
GNSS	**Global Navigation Satellite System**
ORB	**Observatoire Royal Belgique**
PPP	**Precise Point Positioning**
PTB	**Physikalisch-Technische Bundesanstalt, Braunschweig, Germany**
RINEX	**Receiver Independent Exchange Format**
R2CGGTTS	**RINEX-to CGGTTS conversion software, provided by ORB / BIPM**
TDEV	**Time deviation**
TIC	**Time interval counter**

EXECUTIVE SUMMARY

As part of the support of the BIPM Time and Frequency Group by EURAMET, PTB conducted a relative calibration of the GNSS equipment of DTAG with respect to the calibration of PTB receiver PT09, whose last calibration was reported with Cal_Id=1001-2018 [RD01]. PTB provided its receiver PTBT for the purpose as travelling equipment.

The current campaign followed as much as possible the BIPM Guide [RD02] and results will be reported using Cal_Id 1012_2019. Results provided are the visited receivers' internal delays for GPS P-code signals on the two frequencies L1 and L2 (INT DLY (P1), and INT DLY(P2)). The delays for the C/A-code signals on L1 and for GLONASS signals were not determined during this campaign.

The final results are included in Table 9-1. The internal delays of 2 receivers were determined with an uncertainty of about 1 ns for P1 and P2, respectively. The uncertainty for P3 time transfer links to PTB is of the order 1.4 ns.

As a reminder: All uncertainty values reported in this document are 1-σ values.

Following instructions from the PTB quality management responsibles, we want to stress that the correctness of all results and of the stated uncertainty values relies partially on the correctness of the entries in the installation report (BIPM information tables) provided by the visited institute.

1. CONTENTS OF THE REPORT

As part of the support of BIPM Time and Frequency Group by EURAMET, PTB conducted a relative calibration of the GNSS equipment of DTAG with respect to the calibration of receiver PT09, whose last calibration was reported with Cal_Id=1001-2018 [RD01]. PTB provided its receiver PTBT for the purpose as travelling equipment. This report documents the installation, data taking and evaluation during the campaign.

The determination of the internal delay values of the receivers at the visited site is a three-step process.

At first (Common-Clock 1, CC1) the travelling receiver, PTBT, is compared to the “golden” receiver, PT09, and the offset between the actual and the assumed PTBT delay values is determined. This time the PTBT internal delays were adjusted before shipment so that L3P data collected with PTBT and PT09, respectively, should agree on average.

After that, the receiver was installed at DTAG and the internal delay values of the devices under test and their statistical properties have been determined.

Finally, the stability of the PTBT delay was assessed by a second Common-Clock measurement (CC2) in PTB. Based thereon, the “final” INT DLY values of the visited receivers and their uncertainty values are calculated.

The structure of this report follows this sequence of work. After presentation of the participants and schedule, a general section follows that contains the (mathematical) calibration procedure, followed by a report of data collection at PTB and DTAG. The final results and the uncertainty discussion close the report. In the Annex the BIPM information tables are reproduced.

2. PARTICIPANTS AND SCHEDULE

Table 2-1: List of participants

Institute	Point of contact	Site address
PTB	Thomas Polewka Tel +49 531 592 4418 Thomas.polewka@ptb.de	PTB, AG 4.42 Bundesallee 100 38116 Braunschweig, Germany
DTAG	Horst Ender Tel: +49 951 885177 Mail: Horst.Ender@telekom.de	Deutsche Telekom Technik GmbH NSO-NTCC Raimundstraße 48-54 60431 Frankfurt am Main

Table 2-2: Schedule of the campaign

Date	Institute	Action	Remarks
2019-06-22 until 2019-06-25	PTB	First common-clock comparison between PTBT and PT09	4 days used for evaluation, MJD 58656 – 58660 (incl.)
2019-08-02 Until 2019-08-08	DTAG	Operation of PTBT and two GNSS receivers in parallel	7 days used for evaluation, MJD 58697–58703 (incl.)
Starting 2019-09-21– 2019-09-26	PTB	Operation of PTBT after return	6 days used for evaluation, MJD 58747 – 58752 (incl.)

Information on the receivers at each site is contained in individual information tables which can be found in the Annex.

3. CALIBRATION PROCEDURE

The calculation of INT DLY values for the receiver to be calibrated follows the description given in BIPM TM.212 [RD03] and has been coded in software routine cv.py written by Julia Leute of PTB. The following text piece that describes its function is generated via copy-paste from [RD03] with small changes of the designation of quantities.

When dealing with G1G2 calibrations, in principal we distinguish receivers V, T, and G: V for visited, T for travelling, and G for golden_reference. G1 labs committed to ship their T to the other sites. In the current campaign, PT09 serves as the reference receiver G, its internal delays were determined by BIPM in the second G1 campaign with the identifier Cal_Id=1001-2018. PTBT served as the travelling receiver T.

Conventionally, the receiver delay D is considered as the sum of different terms that are defined subsequently:

(1) INT DLY

The sum $X_R + X_S$ represents the “INT DLY” field in the CGGTTS header:

X_R represents the receiver hardware delay, between a reference point whose definition depends on the receiver type and the internal time reference of the measurements. X_S represents the antenna delay, between the phase center and the antenna cable connector at the antenna body. We distinguish the two quantities for the two frequencies, 1 and 2.

INT DLY(P1) and INT DLY(P2) of receiver V are the basic quantities that are determined during the relative calibration. For calculating ionosphere—free observation data, INT DLY(P3) is calculated as 2.54×INT DLY(P1) - 1.54×INT DLY(P2).

The following terms are considered frequency independent, i. e. no distinction is made for P1 and P2 and other signal frequencies.

(2) CAB DLY

The sum $X_C + X_D$ represents the “CAB DLY” field in the CGGTTS header.

X_C corresponds to the delay of the long cable from the antenna to the input connector at either the antenna splitter or the receiver body directly. If a splitter is installed, X_D corresponds to the delay of the splitter and the small cable up to the receiver body. For a simple set-up with just an antenna cable, $X_D = 0$.

(3) REF DLY

The sum $X_P + X_O$ represents the “REF DLY” field in the CGGTTS header.

X_P corresponds to the delay of the cable between the laboratory reference point for local UTC and the 1 PPS-in connector of the receiver.

X_O corresponds to the delay between the 1PPS-in connector and the receiver internal reference point, the latter depending on the receiver type:

- For Ashtech Z12-T: The first positive zero crossing of the inverted 20 MHz-in following the 1PPS-in, delayed by 15.8 ns,
- For Septentrio PolaRx2: The 1PPS-out, delayed by 8.7 ns,

- For Septentrio PolaRx3: The 1 PPS-out, no further correction
- For Septentrio PolaRx4: The 1 PPS-out, no further correction
- For DICOM GTR50 and GTR51: The 1PPS-in, i.e. $X_O = 0$,
- For Javad/Topcon: The first positive zero crossing of the 5/10 MHz-in following the 1PPS-in.
- For TTS-4: RD02, Section 2.3.2, and Annex G specify the procedure for TTS-4, which in detail depends on the software version.

The parameters of PT09 had been measured during campaign 1001-2018 in November 2018 and were not determined again on occasion of the current campaign.

The distinction of the individual components of the receiver delay reflects the fact that two of them, 2 and 3, can in principle be measured with standard laboratory equipment. Changes of the receiver installation typically affect cabling and thus such delays.

The quantity to be determined by the relative calibration is INT DLY. INT DLY of the device under test is determined in such a way that the common-clock differences obtained between the device under test and the reference are zero on average. The INT DLY of T may need to be adjusted so that T and G match, but in practice the small correction needed is taken into account only when INT DLY of V is adjusted to G, using T as intermediate for the measurements made at the different sites.

In the process followed by PTB, valid CGGTTS files with dual frequency observation (L3P) data (including correct, accurate antenna coordinates) are needed. As a reminder,

$$\text{REFGPS}(k) = [\text{REFGPS}_{\text{RAW}}(k) - \text{CAB DLY}_F - \text{INT DLY(P3)} + \text{REF DLY}_F], \quad (1)$$

where REFGPS(k) is reported in column 10 of the standard CGGTTS files, $\text{REFGPS}_{\text{RAW}}$ designates the uncorrected measurement values, INT DLY(P3) is calculated as $2.54\times\text{INT DLY(P1)}_F - 1.54\times\text{INT DLY (P2)}_F$, and the values designated as “Q_F” are reported in the CGGTTS file header.

The software cv.py in calibration mode is used to calculate:

$$\text{REFGPS}_{P1}(j) = \text{REFGPS}(j) + \text{MDIO}(j) \quad (2a)$$
$$\text{REFGPS}_{P2}(j) = \text{REFGPS}(j) + \text{MDIO}(j) + (f_1/f_2)^2 \times \text{MDIO}(j), \quad (2b)$$

where $(f_1/f_2)^2 = 1.647$ for GPS for each satellite observation j and REFGPS(j) and MDIO(j) are from the line in the CGGTTS file that reports the observation j. Eq. 2a and 2b build on the rules how CGGTTS L3P data lines are generated.

If the common-view condition is fulfilled for the observations with T and G, the differences

$$\Delta Pi: = \text{REFGPS}_{Pi}(T) - \text{REFGPS}_{Pi}(G) \quad (3)$$

are calculated and represent the difference Pi(new) – Pi(old) for receiver T. The example here involves T and G: Equivalent relations hold for the pair of receivers T and V.

cv.py at the end of the computation edits the median value of all individual observations ΔPi for P1 and P2, and the number of data points used. In addition cv.py generates a file deltap_stats that contains observation epoch (MJD.frakt) and the average ΔP1, ΔP2 of all satellite observations at that epoch. Such values are plotted throughout the report in the various figures.

The calculation of the INT DLY values comprises two steps:

Step 1: $$\text{INT DLY(Pi)\_T\_corr} = \Delta\text{Pi(T,G)} + \text{INT DLY(Pi)\_T\_old}, \qquad (4)$$

where the last summand >_old < is the value reported in the CGGTTS file up to now.

Step 2: The final results for receiver V is to be calculated as

$$\text{INT DLY(Pi)\_V\_new} = \Delta\text{Pi(V,T)} + \langle\Delta\text{Pi(T,G)}\rangle + \text{INT DLY(Pi)\_V\_old}, \qquad (5)$$

where <ΔPi(T,G)> is the mean value obtained during CC1 and CC2. INT DLY of receiver T after CC1 was adjusted such that its result matched PT09.

The third summand in (5) on the right represents the INT DLY value that was reported previously in the CGGTTS file of receiver V. In some cases this value may be reported initially as zero.

4. CHARACTERIZATION OF PTB EQUIPMENT

The receiver PTBT had been used in campaign 1011-2018 and had returned to PTB with a defect in one auxiliary component. The receiver GTR50 and the TIC SR 620 proved to be in perfect shape, but a USB-to-Serial converter connecting both units had failed. In the process of disassembling the device, a mismatch between cabling and practice of report of PTBT INT DLY and PTBT REF DLY was detected and corrected. CC1 (see below) served the purpose to determine the new INT DLY wrt PT09. The installation of the receivers in PTB is depicted in Figure 4-1 for 1 PPS signals and in Figure 4-2 for 5 MHz signals. A clarification may be helpful regarding the 1 PPS REF point. The 1 PPS signal connected to the PTBT port 1 PPS REF is delayed from UTC(PTB) by 2.7 ns. When measuring with a TIC Port A = UTC(PTB), Port B = 1 PPS REF then the result is + 2.7 ns.

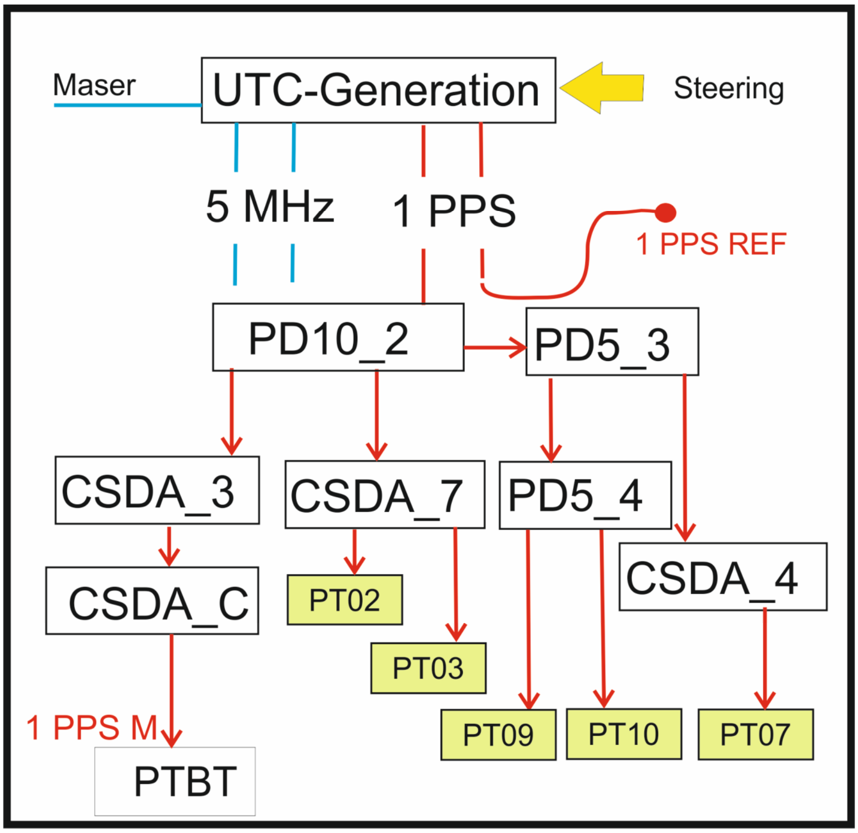


Figure 4-1: UTC(PTB) reference point and 1 PPS signal distribution to PT02, PT07, PT09 and PTBT; PD10 stands for pulse distributor, CSDA stands for clock signal distribution amplifier.

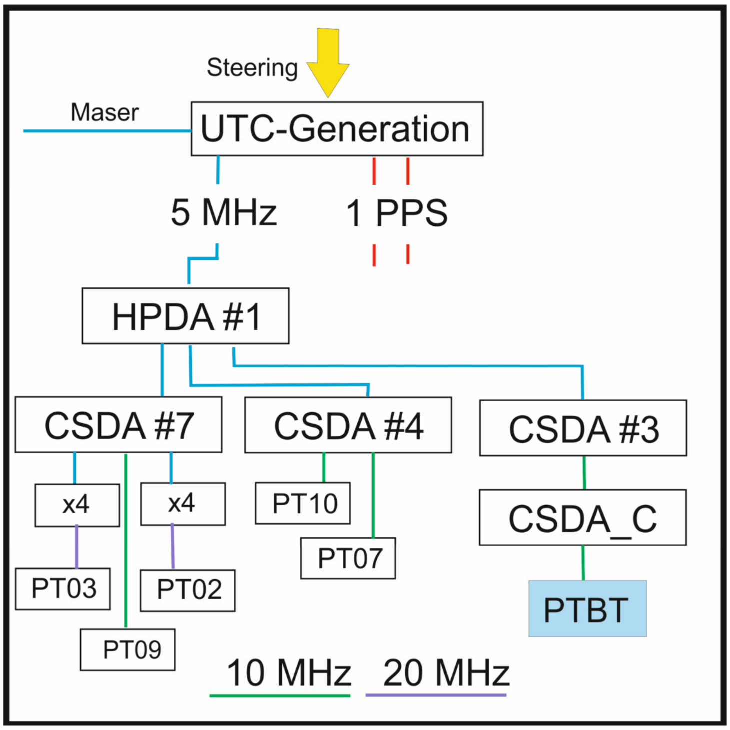


Figure 4-2: UTC(PTB) signal distribution (5 MHz, 10 MHz, 20 MHz) to PT02, PT07, PT09 and PTBT, HPDA stands for High-precision distribution amplifier (for rf frequencies)

Figure 4-3: Installation of GNSS antennas at PTB

Figure 4-3 illustrates the installation of GNSS antennas on the roof of the PTB time laboratory (clock hall). The two Ashtech SNOW antennas (with dome) belong to PT03 (background) and PT02 (middle). The latter was in the meantime replaced by a LEICA AR25 for the new PTBB installation. The PTBT antenna is marked by the yellow arrow, the PT09 antenna is marked by the orange arrow.

The campaign after all lasted about 90 days. In Figure 4-4 the common-view common-clock time differences between PT09 and PT13 during this period are shown. We note a very smooth operation which gives trust in the stable operation of the reference receiver G. PT13 has been chosen as this receiver was recently selected as the pivot receiver for comparisons to PTB by BIPM.

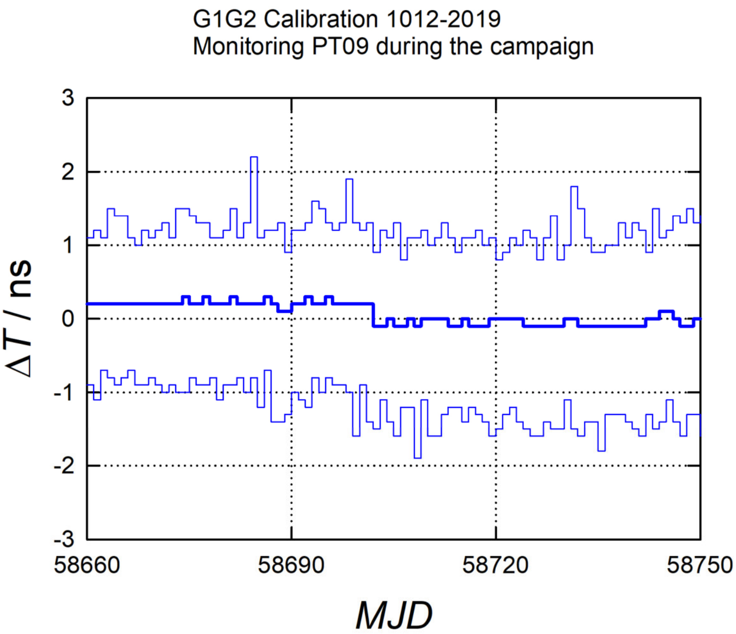


Figure 4-4: Daily mean time difference Δ*T* and daily minimum/ maximum value PT09 – PT13, during the period of the calibration campaign.

5. RESULTS OF COMMON-CLOCK SET-UP IN PTB: PERIOD 1

The current campaign was arranged on short notice and preparations were needed before the start of the summer vacation period. Only 4 days, 58656 to 58659 were chosen to determine the initial PTBT INT DLY values (CC1). The result of comparison with PT09 as the reference are shown in Figure 5-1 illustrating in total 357 ∆Pi (see eq. 3) values obtained as mean over all common view observations at a given epoch. The time instability (TDEV) plots for the two data sets follow as Figure 5-2. The numerical results are given in the Summary sub-section at the end of the report on CC2 in PTB.

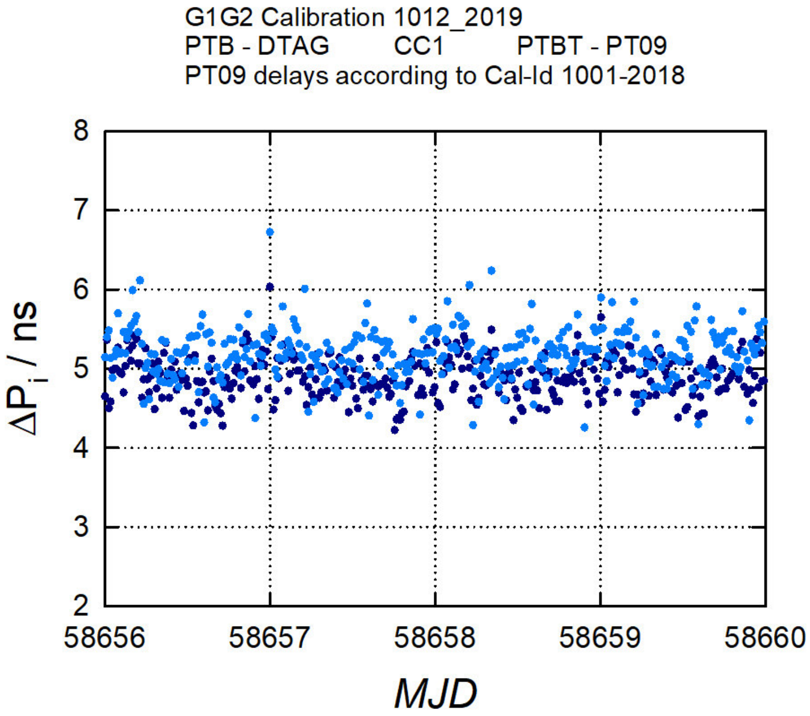


Figure 5-1: ∆P1 (dark blue) and ∆P2 (light blue) values obtained during the first common-clock set-up in PTB.

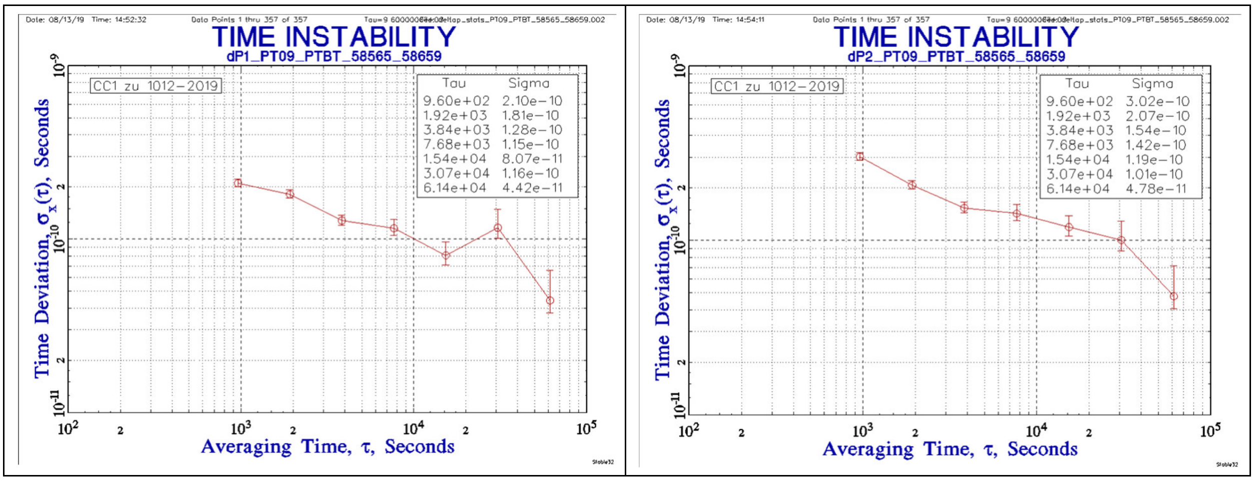


Figure 5-2: TDEV obtained for the two data sets shown in Figure 5-1, ∆P1 left, ∆P2 right.

At variance from prevous campaigns, the INT DLY(Pi) of PTBT were corrected for the offsets shown in Figure 5-1 before shipment. The mean value obtained during the second common-clock set-up (see eq. 5)) agreed with zero within the statistical uncertainty. The difference noted is considered as the misclosure, Table 8-1, line 3.

6. OPERATION OF PTBT AT DTAG, FRANKFURT

PTBT was in the hands of DTAG for several weeks and also used to calibrate delays in receivers operated in another DTAG campus and not reported to BIPM. In parallel, 2 local GNSS receivers of type GTR51 made by MESIT are operated in the Frankfurt premisies of DTAG. There designations are DT04 and DT05, respectively. Firmware upgrades to both receivers had been necessary which caused a large change in apparent internal delays and which made the current campaign necessary. Seven days between MJD 58697 and 58703 (2019-08-02 – 2019-08-08) were used for the data analysis.Details on the receivers and their installation are given in the Annex.

The antenna positions of PTBT, DT04 and DT05, respectively, were determined using NRCan PPP software based on DOYs 217 and 218. In the Annex the final coordinates are given.

The installation of the receivers in the DTAG time laboratory is illustrated in Figure 6-1. The mounting of the antennas is shown in Figure 6-2. A set of fixed LMR400 antenna cables connect the laboratory in the ground floor to the rooftop of the 15-store building. The PTBT was installed using one of these, whose signal delay had been determined previously by the installation company.

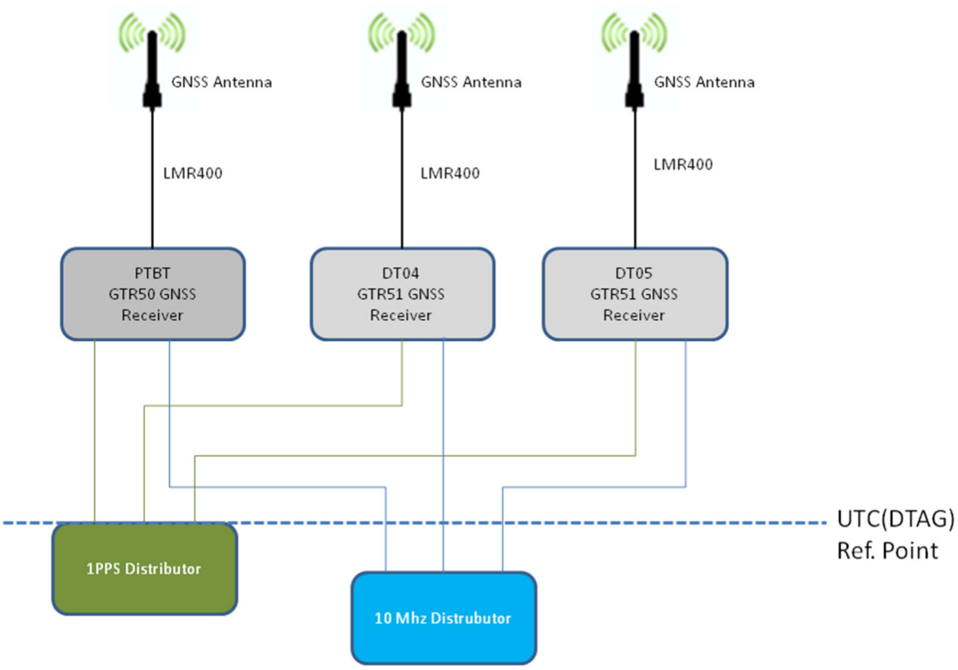
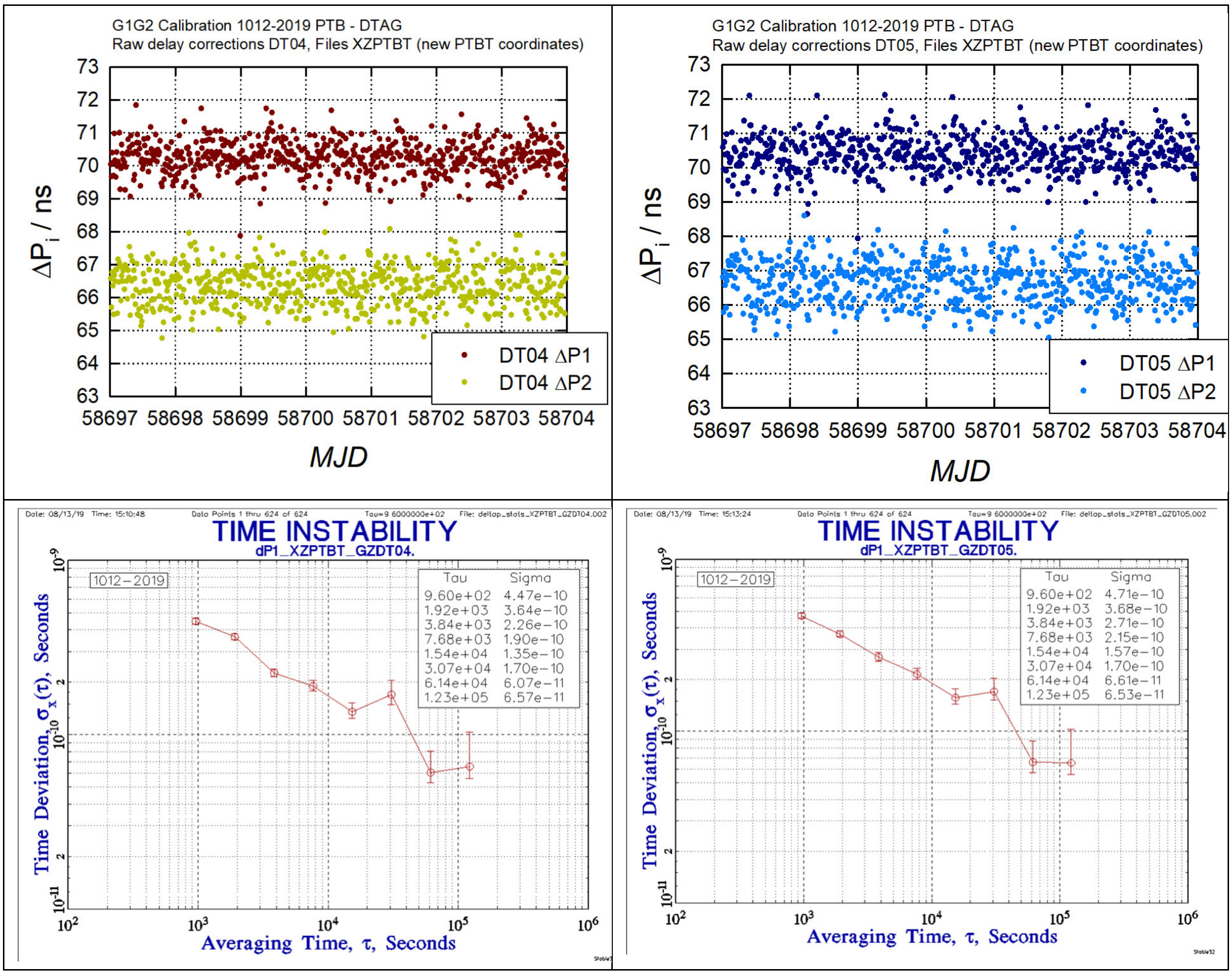


Figure 6-1: Scheme of the installation of the GNSS receivers at DTAG

Figure 6-2: Antenna installation on the rooftop of the DTAG building: left: DT05 antenna (foreground), PTBT antenna (background, small); right: PTBT antenna



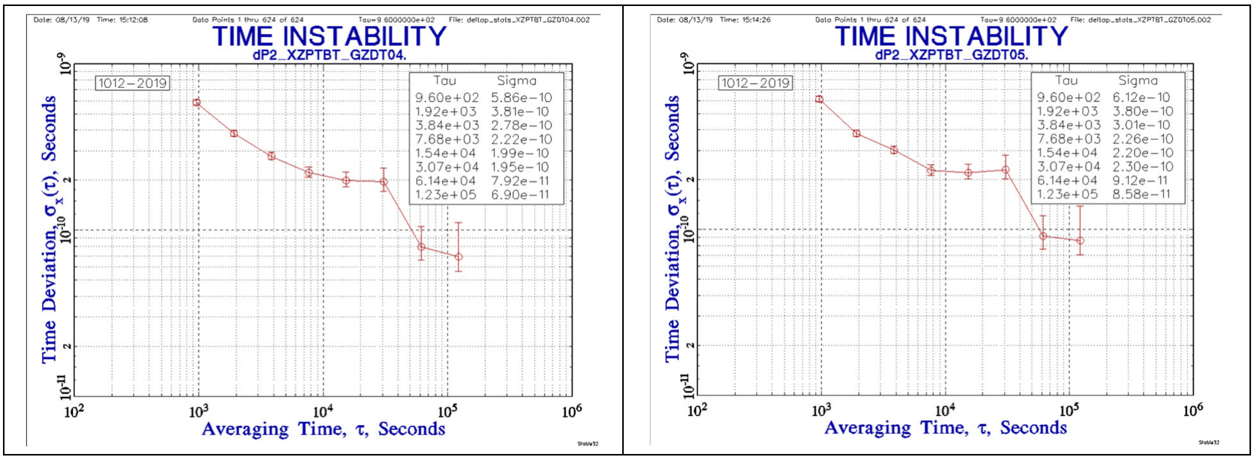


Figure 6-3: Raw ∆Pi-values recorded between PTBT and DT04 and DT05 at DTAG, and TDEV for the four data sets plotted

In Figure 6-3, the ∆Pi (3) derived from the raw data are depicted and the result are summarized in Table 6-1, including their statistical uncertainty. The corresponding TDEV plots are shown under the respective result plots. As a statistical measurement uncertainty the value of TDEV is estimated as 0.2 ns in all cases.

Table 6-1: ∆INT DLY(Pi) values and statistical properties (in ns) obtained initially.

∆INT DLY (Pi) for receivers at DTAG	**Mean / ns**	**Median / ns**	**Std. Dev. / ns**	**TDEV / ns**	**Number of 16-min epochs**
DT04 P1	70.24	70.23	0.49	0.2	624
DT04 P2	66.36	66.39	0.59	0.2	624
DT05 P1	70.38	70.39	0.53	0.2	624
DT05 P2	66.66	66.69	0.63	0.2	624

It turned out that the data collected at DTAG, particularly those of PTBT, are somewhat more noise thatn usual. This may be related to the fact that the GPS-signal attenuation by even one of the best rf-cables, LMR400, at the given length (about 500 ns delay) is substantial, so that the tracking by the receiver might be difficult.

7. OPERATION OF PTBT AT PTB: SECOND PERIOD

The period 58747 to 58752 (6 days) was chosen to determine PTBT INT DLY values during the common clock period CC2. The result of comparison with PT09 as the reference are shown in Figure 7-1 illustrating in total 535 ΔPi (see eq. 3) values obtained as mean over all common view observations at a given epoch. The time instability (TDEV) plots for the two data sets follow as Figure 7-2. The mean values are consistent with zero within the measurement uncertainty.

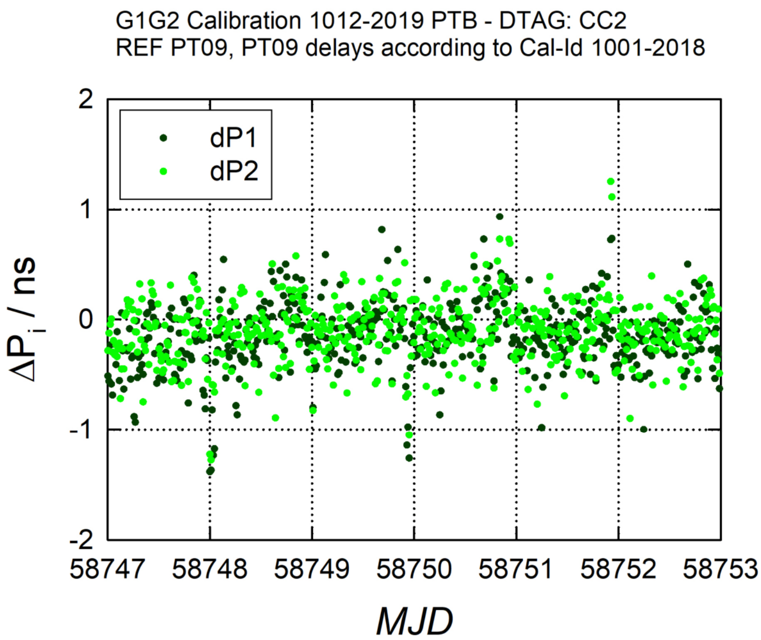


Figure 7-1. ΔPi values obtained during the second common-clock set-up in PTB.

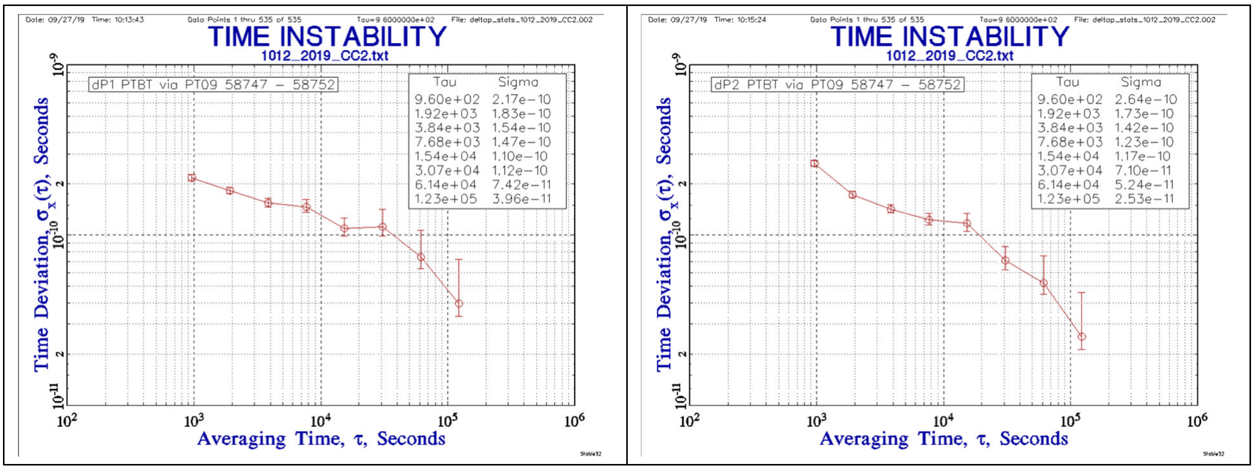


Figure 7-2. TDEV obtained for the two data sets shown in, ΔP1 left, ΔP2 right.

7.1. SUMMARY

The numerical result of the two common-clock campaigns at PTB are given in Table 7-1. The period CC1 was used to determine new delay values for PTBT, and the result of CC2 shows the consistency of the data within the expected calibration uncertainty. So we decided to apply no correction to the dPi values recorded for the receivers DT04 and DT05. The estimate of the uncertainty contribution is given in Section 8.

Table 7-1: Result of common clock measurements at PTB

Quantity	Median (ns)	Sigma (ns)	TDEV (ns)
ΔP1 (CC1)	4.89 ns	0.26 ns	0.1 ns
ΔP2 (CC1)	5.19 ns	0.32 ns	0.1 ns
ΔP3 (CC1)	4.43 ns		
ΔP1 (CC2)	-0.16 ns	0.30 ns	0.1 ns
ΔP2 (CC2)	-0.1 ns	0.29 ns	0.1 ns
δP3 (CC2)	-0.25		
Mean values used for evaluation of DTxx internal delays / total delays			
ΔP1	0 ns		
ΔP2	0 ns		

8. INT DLY UNCERTAINTY EVALUATION

The overall uncertainty of the INT DLY values obtained as a result of the calibration is given by

$$\mathrm{u}_{\mathrm{CAL}} = \sqrt{\mathrm{u}_{\mathrm{a}}^2 + \mathrm{u}_{\mathrm{b}}^2}\,, \tag{6}$$

with the statistical uncertainty u_a and the systematic uncertainty u_b. The statistical uncertainty is related to the instability of the common clock data collected at DTAG and PTB, respectively. The systematic uncertainty is given by

$$\mathrm{u}_{\mathrm{b}} = \sqrt{\sum_n \mathrm{u}_{\mathrm{b},n}}\,. \tag{7}$$

The contributions to the sum (7) are listed and explained subsequently. In the table, extra lines (a, b,) are introduced for the different receivers calibrated at DTAG. Note that the uncertainty of the INT DLY values of PTB's fixed receiver PT02 (G) which served as the reference is not included.

Table 8-1: Uncertainty contributions for the calibration of receiver delays

	Uncertainty	Value P1 (ns)	Value P2 (ns)	Value P1-P2 (ns)	Value P3 (ns)	Description
1	u_a (PTB)	0.10	0.15	0.18	0.29	CC measurement uncertainty at PTB, TDEV at $\tau = 5{\times}10^4$ s, max. of the two CC campaigns
2a	u_a(DTAG)	0.2	0.2	0.28	0.47	CC measurement uncertainty, receiver DT04
2b	u_a(DTAG)	0.2	0.2	0.28	0.47	CC measurement uncertainty, receiver DT05
	Uncertainty	**Value P1 (ns)**	**Value P2 (ns)**	**Value P1-P2 (ns)**	**Value P3 (ns)**	**Description**
Result of closure measurement at PTB						
3	$u_{b,1}$				0.3	Misclosure, conventional value
Systematic components due to antenna installation						
4	$u_{b,11}$	0.1	0.1	0.14	0.28	Position error at PTB
5a	$u_{b,12}$(DTAG)	0.1	0.1	0.14	0.28	Position error at DTAG
6	$u_{b,13}$	0.2	0.2	0.0	0.20	Multipath at PTB
7	$u_{b,14}$	0.2	0.2	0.0	0.20	Multipath at DTAG
Installation of PTBT and visited receivers						
8	$u_{b,21}$	0.2	0.2	0	0.2	Connection of PTBT to UTC(PTB) (REF DLY)
9	$u_{b,22}$	0.2	0.2	0	0.2	Connection of PTBT to UTC(DTAG) (REF DLY)
10	$u_{b,23}$	0.2	0.2	0	0.2	Connection of receivers at DTAG to UTC(DTAG) (REF DEL) (* see explanations below)
11	$u_{b,24}$	0.1	0.1	0	0.1	TIC nonlinearities at PTB
12	$u_{b,25}$	0.1	0.1	0	0.1	TIC nonlinearities at DTAG
Antenna cable delay						
13	$u_{b,31}$(PTB)	0.5	0.5	0	0.5	Uncertainty estimate for the PTBT CAB DLY when installed at PTB
14	$u_{b,32}$(DTAG)	0.5	0.5	0	0.5	Uncertainty estimate provided by DTAG for the PTBT CAB DLY used at DTAG
15	$u_{b,33}$(DTAG)	0.5	0.5	0	0.5	Uncertainty estimate provided by DTAG for the DTxx CAB DLY (*)

For this campaign, the uncertainty contribution $u_{b,1}$ has been estimated as a conventional value of 0.3 ns on suggestion of BIPM. Usually, the uncertainty contribution has been based on the difference between the two common clock campaigns. Te situation is a bit different here as CC1 served as defining the PTBT calibration values.

For the generation of the CGGTTS data the PTBT antenna position is manually entered into the processing software in ITRF coordinates before the CCD measurements. These positions could in principle differ from the "true" positions in a different way in each laboratory. This is taken into account by the contributions $u_{b,11}$ and $u_{b,12}$. In the current campaign, all antenna coordinates were determined for all masts at DTAG involved consistently and the contribution is 0.1 ns at maximum. As a matter of fact, a position error in general could even affect the P1 and P2 delays in a slightly different way, if the distinction between Antenna Reference Point (ARP) and Antenna Phase Centre (APC) is not accurately made. It has been reported that the difference between the two quantities is different for each antenna type but in addition also for the two frequencies received. To be on the safe side, $u_{b,11}$ and $u_{b,12}$ are very conservatively estimated. For other entries, where a frequency dependence can be safely excluded, the entry for P1-P2 is set to zero.

An uncertainty contribution due to potential multipath disturbance is added as $u_{b,13}$ and $u_{b,14}$. If at a given epoch in time the recorded time differences REFSYS would be biased by multipath, this might change with time due to the change in the satellite constellation geometry. [RD05] gives an estimate that has often been referred to. It was agreed at the 2017 meeting of the CCTF WG on GNSS that a 0.2 ns-uncertainty should be attributed to the multipath effect.

The uncertainties of the connection of the receivers to the local time scales ($u_{b,21}$, $u_{b,22}$, $u_{b,23}$) are equal but of different origin. As the same counter is employed for the PTBT REF DLY measurements at all sites, the counter's internal measurement uncertainty for time interval need not be considered. $u_{b,21}$ was estimated by PTB: The cable connecting UTC(PTB) to PTBT is repeatedly controlled and has been used in many calibration exercises. DTAG stated the uncertainty of the connection of PTBT and the local receivers to the local time scale, and this is reflected in $u_{b,22}$, $u_{b,23}$. The term $u_{b,23}$, marked by (*) need not be considered in case that only TOT DLY is stated.

The uncertainty contributions $u_{b,24}$ and $u_{b,25}$ are related to imperfections in the TIC in conjunction with the relationship between the zero-crossings of the external reference frequency and the 1 PPS signals. This "nonlinearity" is probably caused by the internal interpolation process. By connecting the travelling TIC successively to 5 MHz and 10 MHz generated by different clocks (masers, commercial caesium clocks), respectively, the effect was estimated to be at most 0.1 ns if 1 PPS signals with a slew rate of approximately 0.5 V/ns are used.

The measurement of antenna cable delays causes contributions $u_{b,31}$ $u_{b,32}$ and $u_{b,33}$. It is made with different methods in timing laboratories. On PTB side, the same antenna cable(s) were repeatedly measured using 1 PPS signals from different sources – but using the same counter – and an uncertainty of 0.5 ns is estimated. The PTBT antenna cable could not be used at DTAG, and instead a fixed cable was connecting antenna and receiver. All DTAG antenna cable delays were determined using a vector-network-analyser previously by the installation company, and DTAG estimated the uncertainty as 0.5 ns. Nevertheless, the term $u_{b,33}$ need not be considered, the combined uncertainty is enlarged by a conventional value of 0.7 ns by BIPM to reflect the situation that two different antenna cables were used for PTBT in PTB and at DTAG premises, respectively.

Note anyway that this uncertainty contribution $u_{b,33}$ a priori has no impact on the uncertainty of the time transfer link between PTB and the visited institutes. If the started CAB DLY for the DTAG fixed receivers would be erroneous, this would be absorbed in the INT DLY values produced as a result of the campaign.

9. FINAL RESULTS

The results of the calibration campaign G1G2_1012_2019 are summarized in Table 9-1. It contains the designation of visited receiver, the INT DLY values hitherto used, the offsets ΔPi(V,T) and ΔPi(T,G) (see Section 5, (5)), the new INT DLY values to be used with consent by BIPM, and the uncertainty with which the new values were determined. For calculation, the respective entries from Table 8-1, individually for P1, P2, and combined for P3, were used. Intermediate delays and uncertainties are reported here with two decimal points. According to [RD07], in CGGTTS V2E file headers all delays should be reported with one decimal only, so the final results to be reported are rounded to one decimal.

Table 9-1. Results of the Calibration Campaign G1G2_1012_2019, all values in ns

Receiver	INT DLY(P1), old	INT DLY(P2); old	ΔP1 (V,T)	ΔP2 (V,T)	ΔP1 (T,G)	Δ(P2) (T,G)	INT DLY(P1), new	u_{cal}, P1	INT DLY(P2), new	u_{cal}, P2	u_{cal}, P3
DTAG, DT04	-35.6	-34.2	70.23	66.39	0.0	0.0	34.6	1.05	32.2	1.05	1.4
DTAG, DT05	-38.2	-36.1	70.38	66.66	0.0	0.0	32.2	1.05	30.6	1.05	1.4

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ANNEX: BIPM CALIBRATION INFORMATION SHEETS

First common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of	2019-06-22 0:00 UTC (MJD 58656)
Date and hour of the end of measurements:	2019-06-05 24:00 UTC (MJD 58659)

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	**PT09**	**PTBT**
Receiver maker and type: Receiver serial number:	PolaRx4TR (2.9.6), S/N 3001148	Dicom GTR50 0708522 1.7.7
1 PPS trigger level /V:	1	1
Antenna cable maker and type: Phase stabilised cable (Y/N):	ECOFLEX 15plus	Andrews FSJ-1 (N)
Length outside the building /m:	approx. 25	25
Antenna maker and type: Antenna serial number:	NOV750.R4	Navexperience 3G+C NA0164
Temperature (if stabilised) /°C		

Measured delays /ns		
	Local:	**Travelling:**
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	35.19 ± 0.1 (**)	52.1 ± 0.1
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	148.00 ± 0.1 (**)	N/A
Antenna cable delay: (X_C) / ns	198.7	205.0 ± 0.1
Splitter delay (if any):	N/A	
Additional cable delay (if any):	N/A	

Data used for the generation of CGGTTS files				
	LOCAL:		Travelling	
☐ INT DLY (or X_R+X_S) (GPS) /ns:	56.7 (P1), 55.7 (P2) (**)		-42.6 (P1) -49.1 (P2) (***)	
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:				
☐ CAB DLY (or X_C) /ns:	198.7		205.0	
☐ REF DLY (or X_P+X_O) /ns:	183.2 (**)		52.1	
☐ Coordinates reference frame:	ITRF (*)		ITRF (***)	
X /m:	+3844057.34 (*)	Mast P12	+3844062.56 (***)	Mast P7
Y /m:	+709663.82 (*)		+709659.49 (***)	
Z /m	+5023131.76 (*)		+5023127.88 (***)	

General information	
☐ Rise time of the local UTC pulse:	3 ns
☐ Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	23.0 °C, peakt-to-peak variations 0.6 °C

Notes:

(*) values provided by BIPM as part of coordinate alignment 2018 reported in TM.281

(**) values provided for BIPM Cal_Id 1001-2018 / local measurements not repeated
(***) BIPM campaign 1001-2014 provided INT DLY values for PTB receiver PT02. Subsequently PTBT INT DLY were adjusted so that PTBT – PT02 were close to zero for convenience. Coordinates of mast P7 were determined in Dec. 2018 using NRCan PPP.

Names of files to be used in processing for site PTB CC1

Local receiver: GZPT09MJ.DDD

Travelling receiver GZPTBTMJ.DDD

PTBT operation at DTAG: Receiver DT04

Laboratory:	**DTAG**	
Date and hour of the beginning of measurements:	2019-08–02 00:00:00 UTC (58697)	
Date and hour of the end of measurements:	2019-08-08 24:00:00 UTC (58703)	
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	**DT04**	**PTBT**
Receiver maker and type: Receiver serial number:	Mesit GTR51 1609096 1.9.1	Dicom GTR50 0708522 1.7.7
1 PPS trigger level /V:	1.0	1.0
Antenna cable maker and type: Phase stabilised cable (Y/N):	N-Type, LMR400	N-type, LMR400
Length outside the building /m:	5 m	5 m
Antenna maker and type: Antenna serial number:	Leica AR25.4 726132	Navexperience 3G+C NA0164
Temperature (if stabilised) /°C		
Measured delays /ns		
	Local:	**Travelling:**
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	25.3	16.9
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns		N/A
Antenna cable delay: (X_C) / ns	506.1	481.0
Splitter delay (if any):	N/A	N/A
Additional cable delay (if any):	N/A	N/A
Data used for the generation of CGGTTS files		
	LOCAL:	Travelling
☐ INT DLY (or X_R+X_S) (GPS) /ns:	-35.6 (P1), -34.2 (P2)	-37.7 (P1) -43.9 (P2)
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:	N/A	N/A
☐ CAB DLY (or X_C) /ns:	506.1	481.0
☐ REF DLY (or X_P+X_O) /ns:	25.3	16.9
☐ Coordinates reference frame:	ITRF	ITRF
X /m:	+4049235.88	4049236.23
Y /m:	+616569.06	616574.65
Z /m	+4873106.89	4873105.39
General information		
☐ Rise time of the local UTC pulse:	1 ns	
☐ Is the laboratory air conditioned:	Yes	
Set temperature value and uncertainty:		

Names of files to be used in processing for site DTAG:

Local receiver: GZDT04MJ.DDD

Travelling receiver XZPTBTMJ.DDD (with correct coordinates)

Notes:

All coordinates determined and / or checked consistently using NRCan PPP immediately before the period of data taking.

PTBT operation at DTAG: Receiver DT05

Laboratory:	**DTAG**
Date and hour of the beginning of measurements:	2019-08–02 00:00:00 UTC (58697)
Date and hour of the end of measurements:	2019-08-08 24:00:00 UTC (58703)

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	**DT05**	**PTBT**
Receiver maker and type: Receiver serial number:	Mesit GTR51 1510236 1.9.1	Dicom GTR50 0708522 1.7.7
1 PPS trigger level /V:	1.0	1.0
Antenna cable maker and type: Phase stabilised cable (Y/N):	N-Type, LMR400	N-type, LMR400
Length outside the building /m:		
Antenna maker and type: Antenna serial number:	LEICA AR25.4 726130	Navexperience 3G+C NA0164
Temperature (if stabilised) /°C		

Measured delays /ns		
	Local:	**Travelling:**
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	25.3	16.9
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns		N/A
Antenna cable delay: (X_C) / ns	530.7	481.0
Splitter delay (if any):	N/A	N/A
Additional cable delay (if any):	N/A	N/A

Data used for the generation of CGGTTS files		
	LOCAL:	Travelling
☐ INT DLY (or X_R+X_S) (GPS) /ns:	-38.2 (P1) , -36.1 (P2)	-37.7 (P1) -43.9 (P2)
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:	N/A	N/A
☐ CAB DLY (or X_C) /ns:	530.7	481.0
☐ REF DLY (or X_P+X_O) /ns:	25.3	16.9
☐ Coordinates reference frame:	ITRF	ITRF
X /m:	4049232.01	4049236.23
Y /m:	616572.07	616574.65
Z /m	4873109.76	4873105.39

General information	
☐ Rise time of the local UTC pulse:	1 ns
☐ Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	

Names of files to be used in processing for site DTAG

Local receiver: GZDT05MJ.DDD
Travelling receiver XZPTBTMJ.DDD (with correct coordinates)

Notes:
All coordinates determined and / or checked consistently using NRCan PPP immediately before the period of data taking.

Second common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of measurements:	2019-09-21 00:00 UTC (MJD 58747)
Date and hour of the end of measurements:	2019-09-26 23:55 UTC (MJD 58752)

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	**PT09**	**PTBT**
Receiver maker and type: Receiver serial number:	PolaRx4TR (2.9.6), S/N 3001148	Dicom GTR50 0708522 1.7.4
1 PPS trigger level /V:	1 V	1 V
Antenna cable maker and type: Phase stabilised cable (Y/N):	ECOFLEX 15plus	Andrews FSJ-1 (N)
Length outside the building /m:	approx. 25 m	25 m
Antenna maker and type: Antenna serial number:	NOV750.R4	Navexperience 3G+C NA0164
Temperature (if stabilised) /°C		

Measured delays /ns		
	Local:	**Travelling:**
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	35.19 ± 0.1 (**)	44.6 ± 0.1
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	148.0 ± 0.1 (**)	N/A
Antenna cable delay: (X_C) / ns	198.7	205.0 ± 0.1
Splitter delay (if any):	N/A	
Additional cable delay (if any):	N/A	

Data used for the generation of CGGTTS files				
	LOCAL:		Travelling	
☐ INT DLY (or X_R+X_S) (GPS) /ns:	56.7 (P1), 55.7 (P2) (**)		-37.7 (P1) -43.9 (P2) (***)	
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:				
☐ CAB DLY (or X_C) /ns:	198.7		205.0	
☐ REF DLY (or X_P+X_O) /ns:	183.2 (**)		44.6	
☐ Coordinates reference frame:	ITRF (*)		ITRF (***)	
X /m:	+3844057.34 (*)	Mast P12	+3844062.56	Mast P7
Y /m:	+709663.82 (*)		+709659.49 (***)	
Z /m	+5023131.76 (*)		+5023127.88 (***)	

General information	
☐ Rise time of the local UTC pulse:	3 ns
☐ Is the laboratory air conditioned:	yes
Set temperature value and uncertainty:	

Notes:

(*) values provided by BIPM as part of coordinate alignment 2018 reported in TM.281

(**) values provided for BIPM Cal_Id 1001-2018 / local measurements not repeated
(***) New values introduced after CC1, Ref. PT09. Coordinates of mast P7 were determined in Dec. 2018 using NRCan PPP.

Names of files to be used in processing for site PTB CC2

Local receiver: GZPT09MJ.DDD

Travelling receiver GZPTBTMJ.DDD

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