GNSS CALIBRATION REPORT

G1G2_1018_2018

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

REFERENCES

REFERENCES	
RD01	**BIPM report 1001-2016, 2016 Group 1 GPS calibration trip BV 1.1 2017-01-18**
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**
EURAMET	**The European Association of National Metrology Institutes**
IGS	**International GNSS Service**
GNSS	**Global Navigation Satellite System**
NMISA	**National Metrology Institute of South Africa**
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 G1 laboratories, PTB conducted a relative calibration of the GNSS equipment of NMISA, Pretoria, South Africa, with respect to the calibration of PTB receiver PT02, whose last calibration was reported with Cal_Id=1001-2016 [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 1018_2018. Results provided are the visited receiver’s 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 the receiver was 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 NMISA, Pretoria, South Africa, with respect to the calibration of receiver PT02, whose last calibration was reported with Cal_Id=1001-2016 [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 receiver 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, PT02, and the offset between the actual and the assumed PTBT delay values is determined.

After that, the receiver is installed at NMISA and the internal delay values of the device under test and their statistical properties are determined with respect to PTBT.

Finally, the stability of the PTBT delay is 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 NMISA. 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
NMISA	Chris Matthee Tel +27 12 841 2245 cmatthee@nmisa.org	NMISA CSIR campus building 5 Meiring Naude Road Pretoria, South Africa

Table 2-2: Schedule of the campaign

Date	Institute	Action	Remarks
2018-09-02 until 2018-09-09	PTB	First common-clock comparison between PTBT and PT02	8 days used for evaluation, MJD 58363 – 58370 (incl.)
2018-10-18 Until 2018-10-29	NMISA	Operation of PTBT and one GNSS receiver in sequence	10 days used for evaluation, MJD 58411 – 58420 (incl.)
2018-12-14 until 2018-12-19	PTB	Operation of PTBT after return	6 days used for evaluation, MJD 58466 – 58471 (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, PT02 (named PTBB when referred to as IGS station) serves as the reference receiver G, its internal delays were determined by BIPM in the second G1 campaign with the identifier Cal_Id=1001-2016. 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.

Details of the measurement procedures for the Ashtech Z12-T are given in the BIPM calibration guideline [RD02], but the parameters of PT02 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,

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

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:

$$\text{REFGPS}_{P1}(j) = \text{REFGPS}(j) + \text{MDIO}(j) \qquad (2a)$$

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

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

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

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

where the last summand >_F < is the value reported in the CGGTTS file.

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

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

where $\langle\Delta Pi(T,G)\rangle$ is the mean value obtained during CC1 and CC2. Another option would have been to adjust the INT DLY of receiver T after CC1, but this was not done.

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 during campaign G1G2_1014_2018 which ended with its second CC data taking between MJD 58359 and 58366. The CC1 period of the current campaign partially overlaps with CC2 from the previous one. For the current campaign, new antenna coordinates for the golden receiver PT02 have been used as provided in TM.281 by BIPM. The stability of PT02 during the current campaign can be inferred from Figure 4-1 in which common-clock commonview comparisons o two other receivers are documented, PT07, a MESI GTR50, and PT09, a Septentrio PolaRx4TR. We see a change by about 0.5 ns that must be attributed to PT02. The installation of the receivers in PTB is depicted in Figure 4-2 for 1 PPS signals and in Figure 4-3 for 5 MHz signals. The PT02 and PT03 receivers are supplied with 20 MHz from a times 4 multiplier.

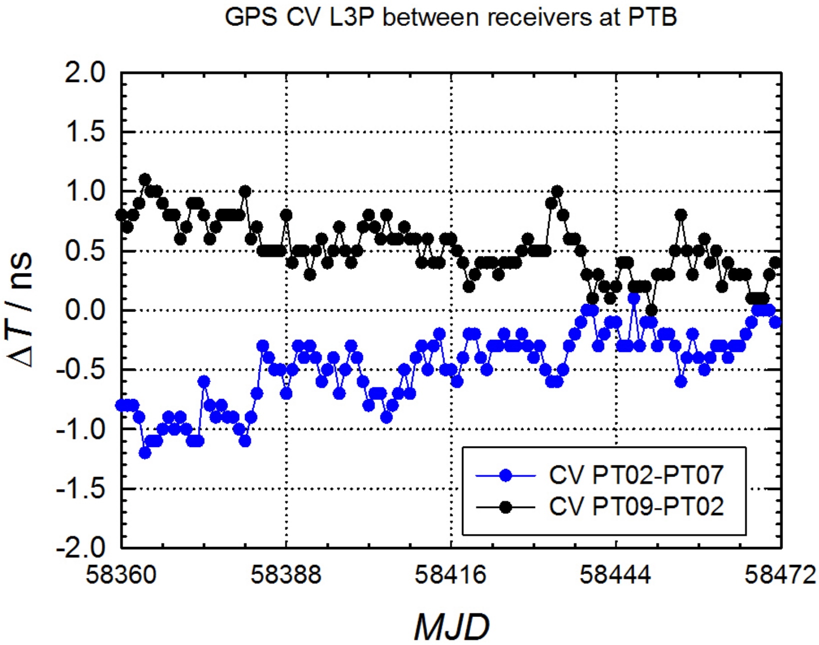

Figure 4-1: Common-clock common-view comparison between PT02 and two other receivers at PTB during campaign 1018-2018

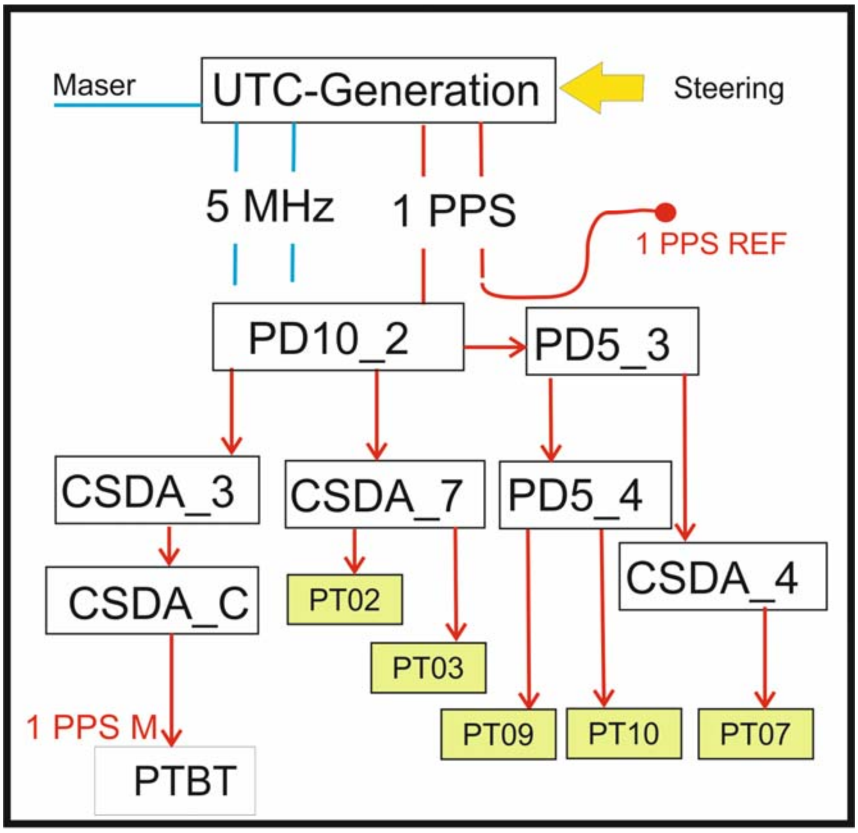

Figure 4-2: UTC(PTB) reference point and 1 PPS signal distribution to PT02, PT07, PT09 and PTBT; PD10 stands for pulse distributor, CSDA stands for clock signal distribution amplifier

A clarification may be helpful regarding the 1 PPS REF point. The 1 PPS signal connected to the 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 4-4 illustrates the installation of GNSS antennas on the roof of the PTB time laboratory (clock hall) during CC1. The two Ashtech SNOW antennas (with dome) belong to PT02 (background) and PT03 (foreground). The PTBT CC1 is seen as the most right antenna in the foreground.

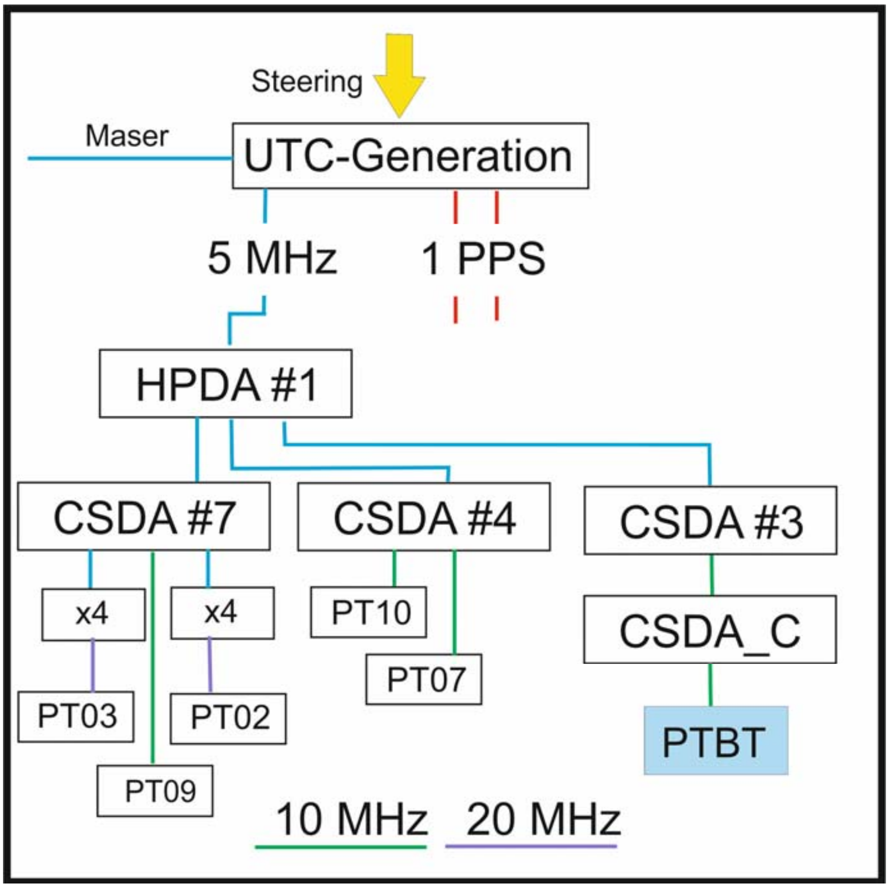

Figure 4-3: UTC(PTB) signal distribution (5 MHz, 10 MHz, 20 MHz) to PT02, PT07, PT09 and PTBT, HPDA stands for High-precision distribution amplifier (for rf frequencies)

Figure 4-4: Installation of GNSS antennas at PTB

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

The period 58363 to 58370 (8 days) was chosen to determine the initial PTBT INT DLY values (CC1). The result of comparison with PT02 as the reference are shown in Figure 5-1 illustrating in total 708 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 5-2. The numerical results are given in the Summary sub-section at the end of the report on CC2 in PTB.

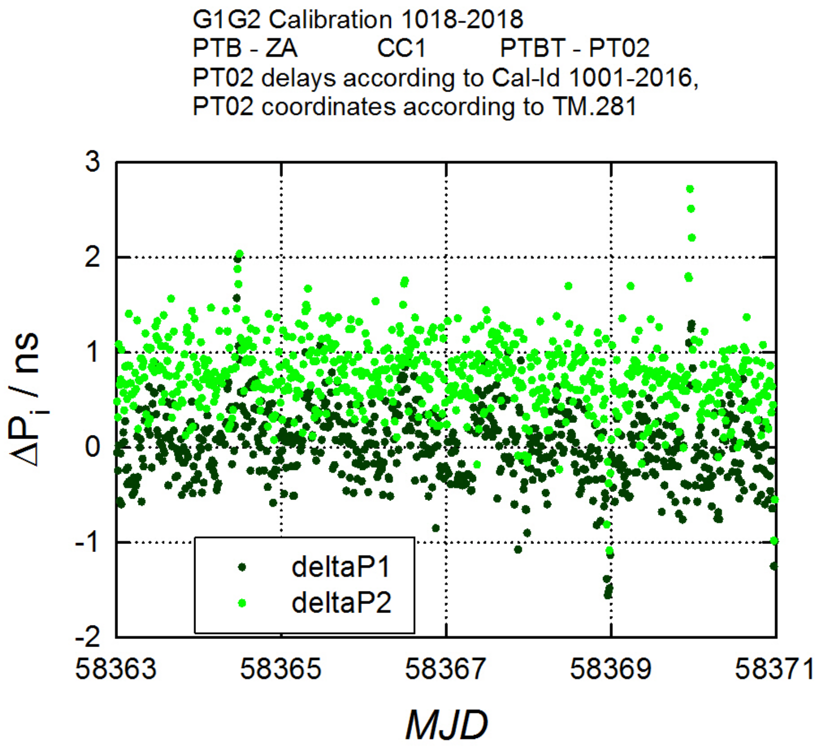

Figure 5-1: ΔP1 (dark green) and ΔP2 (light green) values obtained during the first common-clock set-up in PTB.

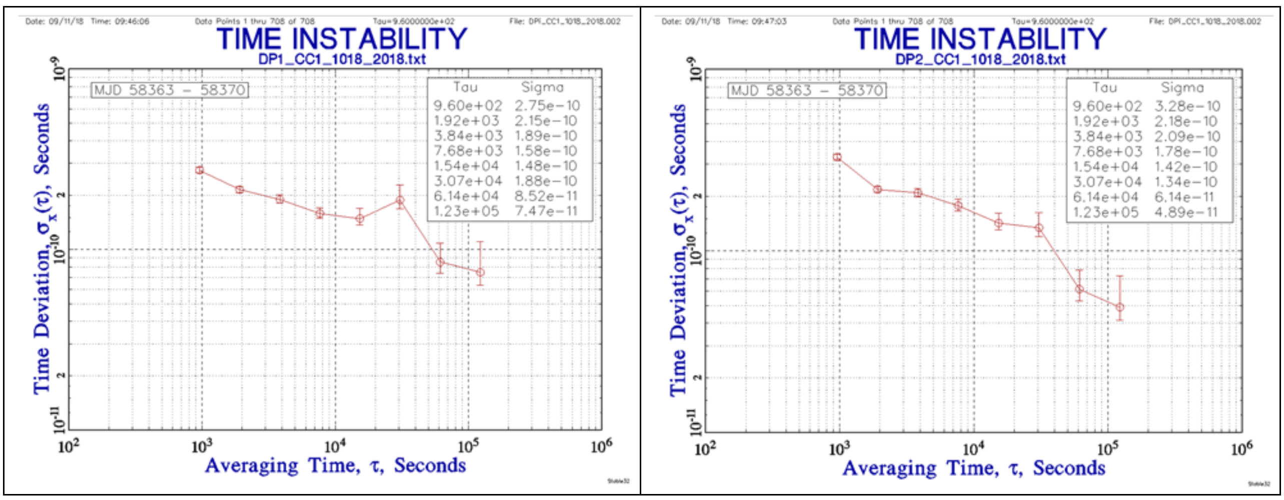

Figure 5-2: TDEV obtained for the two data sets shown in, ΔP1 left, ΔP2 right.

The INT DLY(Pi) of PTBT have not been corrected for the offsets shown in Figure 5-1 before shipment. Instead, the individual value found for the visited receivers will be corrected for the mean value obtained after the second common-clock set-up (see eq. 5)).

6. OPERATION OF PTBT AT NMISA

PTBT was operated at NMISA for an extended period. The results are presented below.

6.1. CALIBRATION OF RECEIVER ZA02

10 days between MJD 58411 and 58420 (2018-10-20 and 2018-10-29, both dates inclusive) were used for the data analysis of receiver ZA02. RINEX data of this receiver are designated as za02ddd0.yyo with CGGTTS data designated as MZZA02MJ.DDD. Details on the receiver and its installation are given in the Annex. The antenna position of ZA02 was determined from analysis of RINEX data using the NRCan PPP software. The PTBT antenna coordinates were initially estimated from a known position. New coordinates were obtained doing PPP analysis based on two days of observations of PTBT at the NMISA site. PTBT CGGTTS files were then reprocessed using r2cggtts V 5.3 and given file names GZPTBU to distinguish from the files generated on site by the receiver software. The y-coordinates differed by 0.3 m, and the z-coordinated by 0.5 m. The values used are reported in the Annex.

The signal distribution to receivers PTBT and ZA02 at NMISA is illustrated in Figure 6-1. The mounting position of the antennas is shown in Figure 6-2.

In the diagrams, receiver ZA is also shown, but was not used in this exercise.

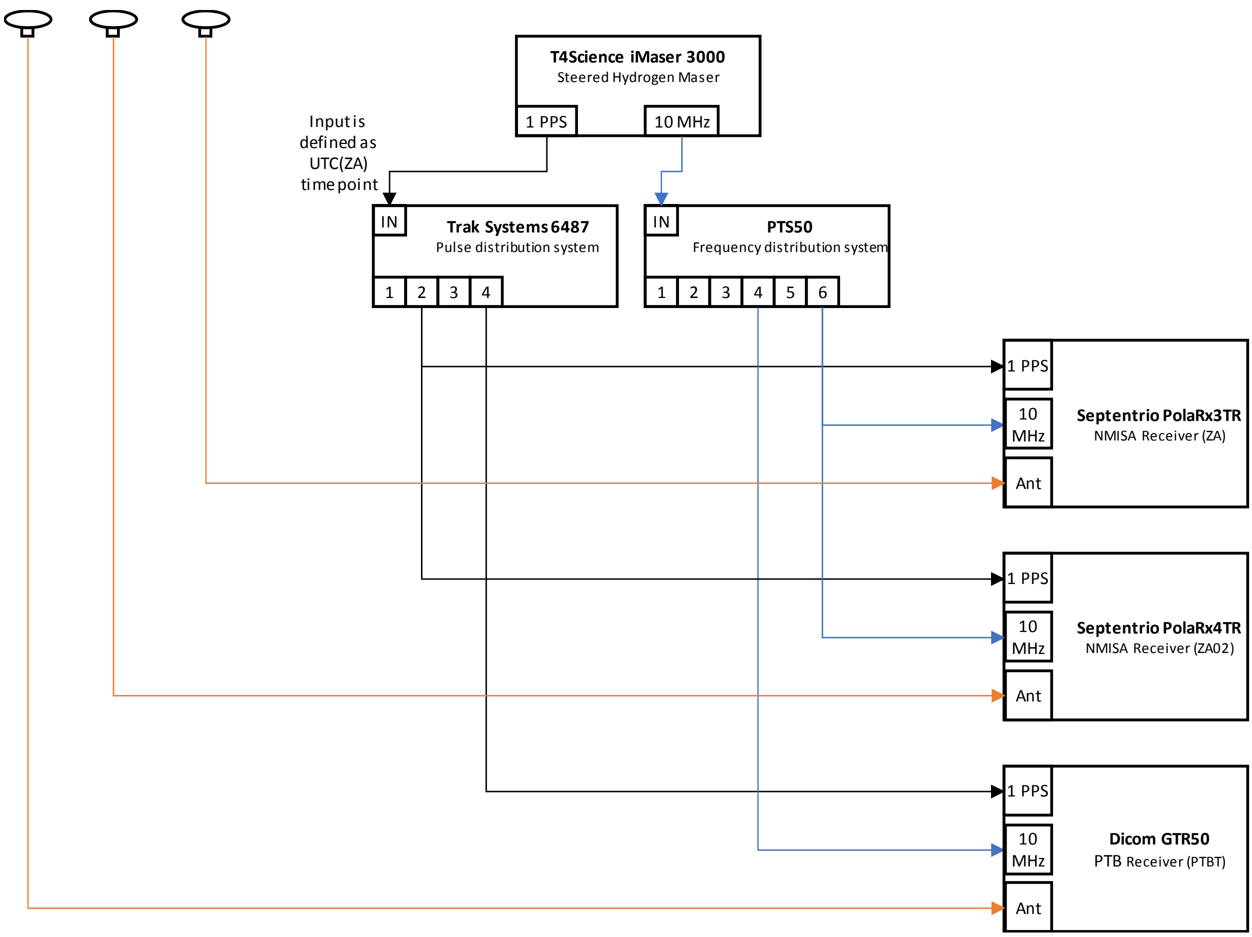

Figure 6-1 Signal distribution at NMISA to the receivers

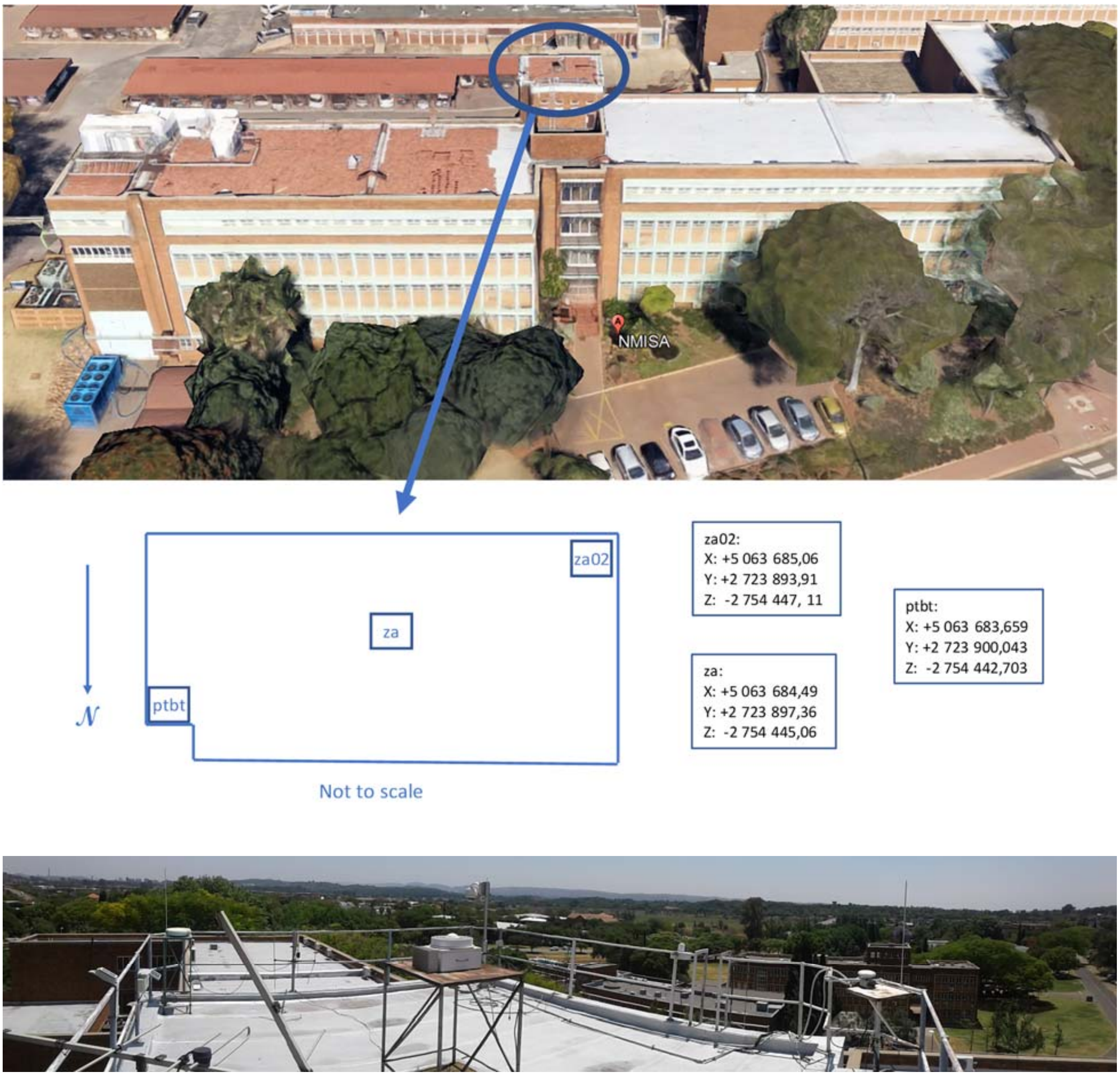

Figure 6-2: Antenna position on the rooftop of the NMISA building and panoramic view of the antenna installations (lower image)

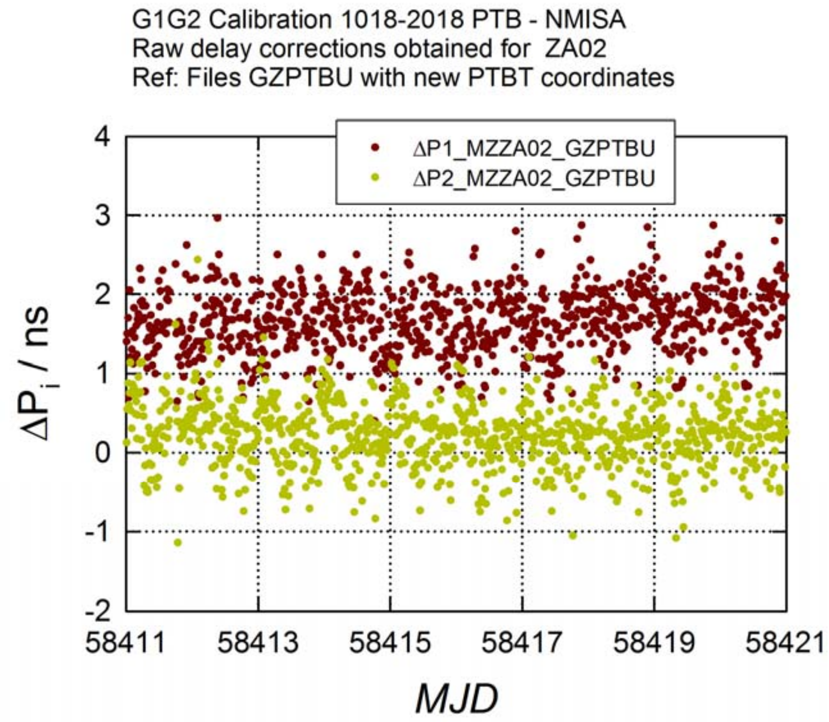

Figure 6-3 ΔP1 (dark red) and ΔP2 (olive) values obtained comparing receiver ZA02 (file name MZZA02MJ.DDD) and PTBT.

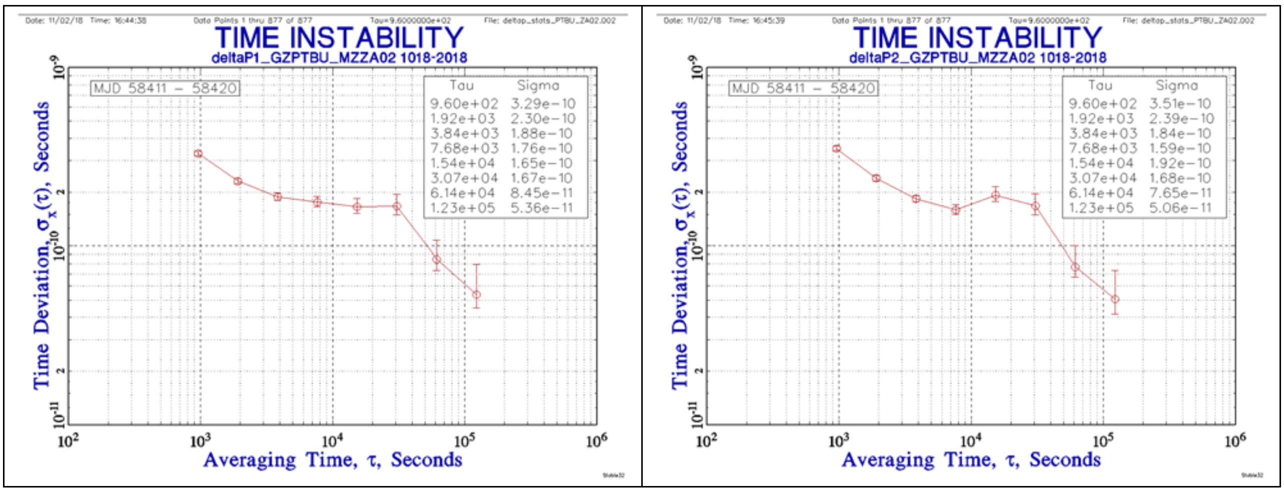

Figure 6-4: TDEV obtained for the two data sets shown in Figure 6-3, ΔP1 left, ΔP2 right.

In Figure 6-3 the ΔPi (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 in Figure 6-4. As a statistical measurement uncertainty the value of TDEV at τ equal to about one tenth of the total measurement time (about 80 000 s) is chosen, cum grano salis, to be not too optimistic.

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

∆INT DLY (Pi) for receivers at NMISA	Mean (ns)	Median (ns)	Std. Dev. (ns)	TDEV (ns)	Number of 16-min epochs
ZA02 ∆P1	1.672	1.668	0.40	0.1	877
ZA02 ∆P2	0.221	0.244	0.41	0.1	877

7. OPERATION OF PTBT AT PTB: SECOND PERIOD

The period 58466 to 58471 (6 days) was chosen to determine PTBT INT DLY values during the common clock period CC2. The results of comparison with PT02 as the reference are shown in Figure 7-1 illustrating in total 530 ΔPi (see eq. 3) values obtained as mean values over all common view observations at a given epoch. The time instability (TDEV) plots for the two data sets follow as Figure 7-2.

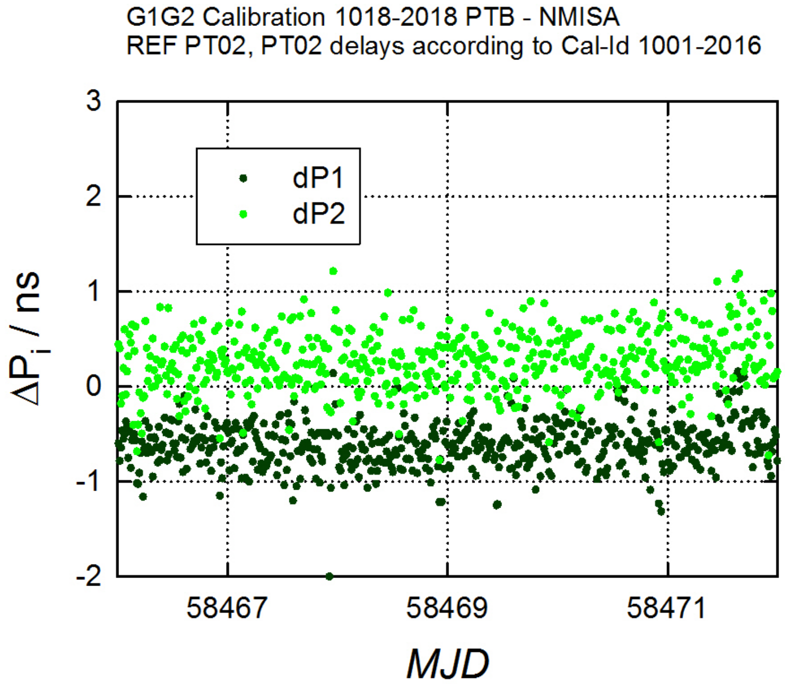

Figure 7-1. ΔPi values obtained during the second common-clock set-up in PTB.

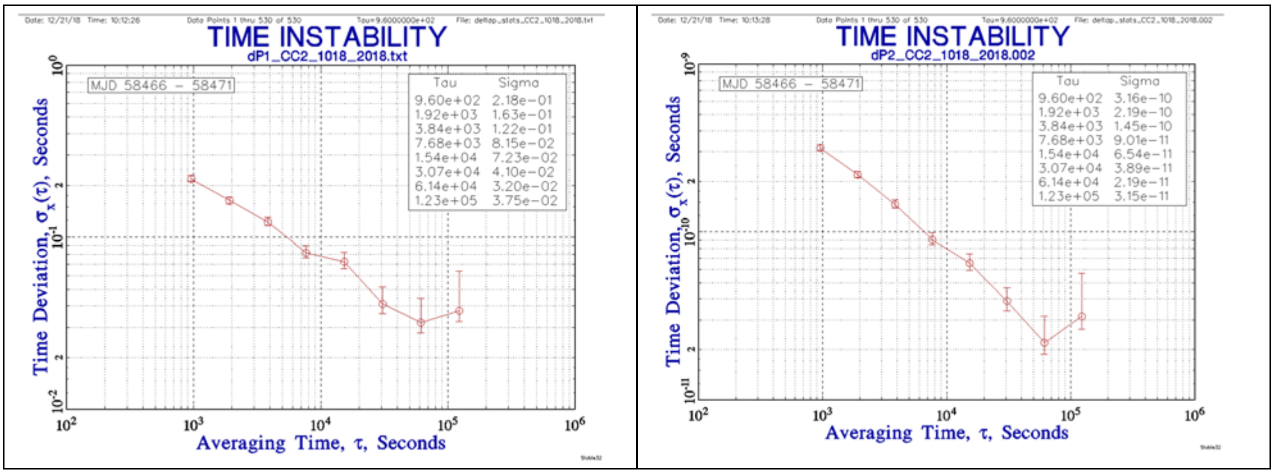

Figure 7-2. TDEV obtained for the two data sets shown in, ΔP1 left, ΔP2 right.

7.1. SUMMARY

The numerical results of the two common-clock campaigns at PTB are given in Table 7-1. The largest change noted between CC1 and CC2 amounts to 0.63 ns for ΔP1. For the evaluation of the delays of the visited receivers the mean values for ΔP1, ΔP2 are used. 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)	0.03	0.39	0.15
ΔP2 (CC1)	0.76	0.39	0.15
ΔP3 (CC1)	-1.09		
ΔP1 (CC2)	-0.60	0.27	0.10
ΔP2 (CC2)	0.26	0.31	0.10
ΔP3 (CC2)	-1.92		
Mean values used for evaluation of ZA02 internal delays			
ΔP1	-0.28		
ΔP2	0.51		

8. INT DLY UNCERTAINTY EVALUATION

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

$$\mathrm{u_{CAL}} = \sqrt{\mathrm{u_a^2} + \mathrm{u_b^2}}\,, \tag{6}$$

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 NMISA and PTB, respectively. The systematic uncertainty is given by

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

The contributions to the sum (7) are listed and explained subsequently.

Values in column P3 are calculated according to $u(P3) = \sqrt{\{u(P1)^2 + (1.54 \times u(P1\text{-}P2))^2\}}$.

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)	0.15	0.15	0.21	0.35	CC measurement uncertainty at PTB, TDEV max. of the two CC campaigns
2a	u_a(NMISA)	0.1	0.1	0.14	0.23	CC measurement uncertainty, receiver ZA02
Result of closure measurement at PTB						
3	$u_{b,1}$	0.63	0.5		0.83	Misclosure, see Table 7-1
Systematic components due to antenna installation						
4	$u_{b,11}$	0.1	0.1	0.14	0.28	Position error at PTB
5a	$u_{b,12}$(NMISA)	0.1	0.1	0.14	0.28	Position error at NMISA
6	$u_{b,13}$	0.1	0.1	0.14	0.28	Multipath at PTB
7	$u_{b,14}$	0.1	0.1	0.14	0.28	Multipath at NMISA
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	$u_{b,22}$	0.5	0.5	0	0.5	Connection of PTBT to UTC(ZA) (REF DLY)
10	$u_{b,23}$	0.2	0.2	0	0.2	Connection of receivers at NMISA to UTC(ZA) (REF DEL)
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 NMISA
Antenna cable delay						
13	$u_{b,31}$(PTB)	0.0	0.0	0	0.0	Uncertainty estimate for the PTBT CAB DLY when installed at PTB
14	$u_{b,32}$(NMISA)	0.2	0.2	0	0.2	Uncertainty estimate for the PTBT CAB DLY when installed at NMISA
15	$u_{b,33}$(NMISA)	0.5	0.5	0	0.5	Uncertainty estimate provided by NMISA for the ZA02 CAB DLY

The uncertainty contribution $u_{b,1}$ is estimated as the difference between the results of the two common clock campaigns, as reported in Table 7-1.

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 it was confirmed that the antenna coordinates were determined for all masts 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 0.1 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 REFDLY 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 (called 1 PPS REF in Figure 4-2) is repeatedly controlled and has been used in many calibration exercises. NMISA 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 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 $u_{b,33}$. During the current campaign the same PTBT cable was employed in both CC and at NMISA. The CAB DLY was measured at PTB in previous campaigns, with the cable rolled out and also with the cable on the spool. Each measurement was made with a differential method so that the TIC-internal error should be small anyway. All results agreed within 0.1 ns. Therefore no uncertainty contribution arises a priori from the PTBT antenna cable delay. The contribution $u_{b,32}$ reflects the potential change of the CAB DLY due to the higher temperatures encountered during the installation at NMISA. For the stationary antenna cables at NMISA we conservatively assume 0.5 ns for the uncertainty of the delay value.

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 stated CAB DLY for the NMISA 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_1018_2018 are summarized in Table 9-1. It contains the designation of the 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_1018_2018, 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
NMISA, ZA02	47.0	51.0	1.67	0.24	-0.28	0.51	48.39	1.05	51.75	0.98	1.35

ANNEX: BIPM CALIBRATION INFORMATION SHEETS

First common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of	2018-09-02 0:00 UTC (MJD 58363)
Date and hour of the end of measurements:	2018-09-09 24:00 UTC (MJD 58370)

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	**PTBB**	**PTBT**
Receiver maker and type: Receiver serial number:	ASHTECH Z-XII3T (S/N RT820013901)	Dicom GTR50 0708522 1.7.7
1 PPS trigger level /V:	1	1
Antenna cable maker and type: Phase stabilised cable (Y/N):	Nokia RG214	Andrews FSJ-1 (N)
Length outside the building /m:	approx. 25	25
Antenna maker and type: Antenna serial number:	Ashtech ASH700936 SNOW (S/N CR15930)	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	19.9 ± 0.1 (**)	2.7 +/- 0,1 (to port 1 PPS REF)
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	38.2 ± 0.1 (**) + 15.8	N/A
Antenna cable delay: (X_C) / ns	301.7	209.0 ± 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:	304.5 (P1), 319.8 (P2) (**)		-42.6 (P1) -49.1 (P2) (***)	
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:				
☐ CAB DLY (or X_C) /ns:	301.7		209.0	
☐ REF DLY (or X_P+X_O) /ns:	73.9 (**)		59.6	
☐ Coordinates reference frame:	ITRF (*)		ITRF (***)	
X /m:	+3844059.82 (*)	Mast P10	+3844063.48 (***)	Mast P4
Y /m:	+709661.55 (*)		+709658.72 (***)	
Z /m	+5023129.78 (*)		+5023127.31 (***)	

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 by BIPM Cal_Id 1001-2016 / local measurements not repeated
(***) BIPM campaign 1001-2014 provided new 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 P4 (APC) were determined before campaign 1014-2018 using NRCan PPP.

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

Local receiver: GZPT02MJ.DDD. Files were generated using r2cggtts V5.1 in order to implement the TM.281 coordinates

Travelling receiver GZPTBTMJ.DDD

PTBT operation at NMISA: Receiver ZA02

Laboratory:	**NMISA**
Date and hour of the beginning of measurements:	2018-10–20 00:00:00 UTC (58411)
Date and hour of the end of measurements:	2018-10–29 24:00:00 UTC (58420)

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	**ZA02**	**PTBT**
Receiver maker and type: Receiver serial number:	Septentrio PolaRx4TR PRO 3102318	Dicom GTR50 0708522 1.7.4
1 PPS trigger level /V:	1.0	1.0
Antenna cable maker and type: Phase stabilised cable (Y/N):	TNC Not phase stabilised	N-type, LMR400
Length outside the building /m:	25	12
Antenna maker and type: Antenna serial number:	Topcon RegAnt 2-3 RRA00111	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	178.2	36.4
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	N/A (included above)	N/A
Antenna cable delay: (X_C) / ns	152.6	209.0
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:	47.0 (P1) , 51.0 (P2)	-42.6 (P1) -49.1 (P2)
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:	N/A	N/A
☐ CAB DLY (or X_C) /ns:	152.6	209,0
☐ REF DLY (or X_P+X_O) /ns:	178.2	36.4
☐ Coordinates reference frame:	ITRF	ITRF
X /m:	5 063 685.06	5 063 683.76
Y /m:	2 723 893.91	2 723 900.30
Z /m	-2 754 447.11	-2 754 443.20

General information	
☐ Rise time of the local UTC pulse:	2 ns
☐ Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	22,0 °C ± 1,0 °C

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

Local receiver: za02ddd0.yyo / MZZA02MJ.DDD
Travelling receiver GZPTBTMJ.DDD (files generated after the fact using r2cggtts V 5.1)

Notes:
All coordinates determined consistently using NRCan PPP immediately before (ZA02) and after (PTBT) the period of data taking

Second common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of measurements:	2018-12-14 (MJD 58466)
Date and hour of the end of measurements:	2018-12-19 (MJD 58471)

Information on the system

	Local:	**Travelling:**
4-character BIPM code	**PTBB**	**PTBT**
Receiver maker and type: Receiver serial number:	ASHTECH Z-XII3T (S/N RT820013901)	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):	Nokia RG214	Andrews FSJ-1 (N)
Length outside the building /m:	approx. 25 m	25 m
Antenna maker and type: Antenna serial number:	Ashtech ASH700936 SNOW (S/N CR15930)	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	19.9 ± 0.1 (**)	2.7 ns ± 0.1
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	38.2 ± 0.1 (**) + 15.8	N/A
Antenna cable delay: (X_C) / ns	301.7	209.0 ± 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:	304.5 (P1), 319.8 (P2) (**)		-42.6 (P1) -49.1 (P2) (***)	
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:				
☐ CAB DLY (or X_C) /ns:	301.7		209.0	
☐ REF DLY (or X_P+X_O) /ns:	73.9 (**)		59.9	
☐ Coordinates reference frame:	ITRF (*)		ITRF (***)	
X /m:	+3844059.82 (*)	Mast P10	+3844062.56(***)	Mast P7
Y /m:	+709661.55 (*)		+709659.49 (***)	
Z /m	+5023129.78 (*)		+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 (TM.281)

(**) values provided by BIPM Cal_Id 1001-2016 / local measurements not repeated
(***) BIPM campaign 1001-2014 provided new 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 (APC) were determined using PTBT data collected during the period CC2 and using NRCan PPP.

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

Local receiver: GZPT02MJ.DDD

Travelling receiver GZPTBTMJ.DDD

END of DOCUMENT