GNSS CALIBRATION REPORT

G1G2_1013_2020

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

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

Authorized by: BIPM

Project:	PTB_G1G2_ESTEC
Code:	1013_2020
Version:	1.1
Safe date:	24.08.2020 15:17

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

REFERENCES

REFERENCES	
RD01	**BIPM report 2018 Group 1 GPS calibration trip 1001-2018_GPSP3C1_Group1-trip_V2**
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**
RD08	**BIPM / Gerard Petit / TM266 V2.5 19 June 2020, "Continuity of GNSS "INTDLY" values of Group 1 geodetic receivers in successive Group 1 trips", Section C.6**

ACRONYMS

ACRONYMS	
BIPM	**Bureau International de Poids et Mesures, Sèvres, France**
CGGTTS	**CCTF Generic GNSS Time Transfer Standard**
ESA	**European Space Agency**
ESTEC	**European Space Technology Centre**
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 G1 laboratories, PTB conducted a relative calibration of the GNSS equipment of ESTEC (ESA, the Netherlands) with respect to the calibration of PTB receiver PT13, which currently serves as the reference receiver in all GNSS dual-frequency time links to PTB in the context of realization of TAI. The PT13 signal delays for GPS and Galileo were determined with respect to receiver PT09 which in turn got its last calibration from BIPM as reported with Cal_Id=1001-2018 [RD01]. PTB provided its receiver PTBM 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 1013_2020. Primary 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)). With the same method, the signal delays for Galileo E1 and E5a which are relevant for the use of Galileo signals in a ionosphere-free linear combination were determined, although this is currently beyond the scope of the BIPM Guide [2]. Delays have been determined with reference to the selected BIPM receiver that were passed down to PT13 via PT09.

The final results are included in Table 9-1 and Table 9-2. The internal delays of the six receivers involved were determined with an uncertainty of slightly below 1 ns for single frequency observations. The uncertainty for time transfer links to PTB evaluated in a ionosphere-free linear combination is less than 1.1 ns in all cases.

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

PTB quality management responsibles gave the advice to stress in this report 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 the BIPM Time and Frequency Group by EURAMET G1 laboratories, PTB conducted a relative calibration of the GNSS equipment of ESTEC (ESA, the Netherlands) with respect to the calibration of PTB receiver PT13, which currently serves as the reference receiver in all GNSS dual-frequency time links to PTB in the context of realization of TAI. The PT13 signal delays for GPS and Galileo were determined with respect to receiver PT09 which in turn got its last calibration from BIPM as reported with Cal_Id=1001-2018 [RD01]. PTB provided its receiver PTBM 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, PTBM, was compared to the "golden" receiver, PT13, and the offset between the actual and the assumed PTBM delay values were determined.

After that, the receiver was installed at the visited sites and the internal delay values of the devices under test and their statistical properties were determined with respect to PTBM.

Finally, the stability of the PTBM delays 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 were 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 ESTEC. The final results and the uncertainty discussion close the report. In the Annex the BIPM information tables are reproduced.

1.1. CHANGE LOG

Version	Date	Changes
0	07.07.2020	Version 0, all new
0.2	05.08.2020	Version with completed entries and info from ESTEC
1.0	06.08.2020	Complete version
1.1	24.08.2020	Replies from ESTEC and BIPM received and corrections made

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
ESTEC	Cédric Plantard T +31 71 565 41 87	Keplerlaan 1 2200 AG Noordwijk, The Netherlands

Table 2-2: Schedule of the campaign

Date	Institute	Action	Remarks
2020-06- 26 until 2020-07-02	PTB	First common-clock comparison between PTBTM and PT13	7 days used for determination of delays, MJD 59026 – 59032
2020-07-18 until 2020-07-27	ESTEC	Operation of PTBM in parallel with 5 receivers	8 days used for determination of delays ;JD 59048 – 59055
2020-07-30 Until 2020-08-04	PTB	Operation of PTBM after return	6 days used for determination of delays, MJD 59060 - 59065

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

3. CALIBRATION PROCEDURE

3.1. GENERAL DESCRIPTION

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 a software routine written by Egle Staliuniene 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, PT13 (named PTBB when referred to as IGS station) serves as the reference receiver G. Its delays were determined with respect to receiver PT09 which in turn got its last calibration from BIPM as reported with Cal_Id=1001-2018 [RD01]. PTBM 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, f1 and f2.

INT DLY(f1) and INT DLY(f2) of receiver V are the basic quantities that are determined during the relative calibration. For calculating ionosphere—free observation data, INT DLY(f3) is calculated as 2.54×INT DLY(f1) - 1.54×INT DLY(f2) for GPS and as 2.26×INT DLY(f1) - 1.26×INT DLY(f2) for Galileo, respectively. In figures and results tables we use the designation P1, P2 for GPS, and E1, E5a for Galileo, instead of f1, f2.

The following terms are considered frequency independent, i. e. no distinction is made for f1 and f2.

(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 Septentrio PolaRx4: The 1 PPS-out, no further correction
- For Septentrio PolaRx5TR: optionally X0 is determined autonomously by the receiver or it can be determined alike to the PolaRx4.
- For DICOM GTR50 and GTR51: The 1PPS-in, i.e. $X_O = 0$,
- 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.

PT13 (PolaRx5TR) had been installed in April 2019, and the auto-calibration option was disabled. PTBM (PolaRx5TR) makes use of the auto-calibration option.

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 (f3) data (including correct, accurate antenna coordinates) are needed. As a reminder,

$$REFSYS(k) = [REFSYS_{RAW}(k) – CAB\ DLY_F – INT\ DLY(f3) + REF\ DLY_F], \quad (1)$$

where REFSYS(k) is reported in column 10 of the standard CGGTTS files, $REFSYS_{RAW}$ designates the uncorrected measurement values, INT DLY(f3) is calculated as explained before, and the values designated as "Q_F" are reported in the CGGTTS file header.

The ionospheric delay for a signal at frequency *f* is proportional to $1/f^2$. According to [RD07], the column MDIO in CGGTTS V2E files contains the measured ionospheric delay for the higher of the two combined frequencies. The delay for the other frequency is thus MDIO × $(f_1/f_2)^2$. The software in calibration mode thus calculates:

$$REFSYS_{f1}(j) = REFSYS(j) + MDIO(j) \quad (2a)$$
$$REFSYS_{f2}(j) = REFSYS(j) + (f_1/f_2)^2 \times MDIO(j), \quad (2b)$$

where $(f_1/f_2)^2 = 1.647$ for GPS and 1.793 for Galileo, respectively, for each satellite observation j and REFSYS(j) and MDIO(j) are from the line in the CGGTTS file that reports the observation j.

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

$$\Delta IDi(T,G): = REFSYS_{fi}(T) – REFSYS_{fi}(G) \quad (3)$$

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

The software provides the median value of all individual observations ΔIDi for f1 and f2, and the number of data points used. In addition, a file that contains observation epoch (MJD.frakt) and the average ΔIDi of all satellite observations at that epoch (duration 13 minutes) is generated. Such values are plotted throughout the report in the various figures.

The calculation of the INT DLY values comprises two steps:

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

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

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

where <ΔIDi(T,G)> 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.

3.2. DETERMINATION OF DELAYS OF GALILEO SIGNALS

In the current campaign, for the first time, Galileo delays of visited receivers are calculated with reference to the values determined by BIPM in campaign 1001.2018 in retrospect [RD08]. The CCTF working group on GNSS, at its meeting held June 3, 2020, decided that the Galileo reference for Group 1 calibrations would be realized through the absolute calibration of the BIPM receiver BP21 performed by ESTEC in 2019. In order to provide in retrospect Galileo INTDLY values for 1001-2018 whenever possible, i.e. for Galileo-capable receivers visited by a Galileo-capable traveling receiver (in the EURAMET and SIM legs), BP21 has been added to the set of 1001-2018 receivers. In doing so, the Galileo absolute calibration was transferred from BP21 to the 1001-2018 reference BP1J, then to all possible receivers. In case of PTB, receiver delays for PT09 were determined [RD08]. These were transferred to PT13 after publication of [RD08] in June 2020.

4. CHARACTERIZATION OF PTB EQUIPMENT

Due to the Covid-19 pandemia, PTBM was operated for one month in PTB before the start of the campaign. The stability of PTBM in comparison with the reference PT13 during this period can be inferred from Figure 4-1.

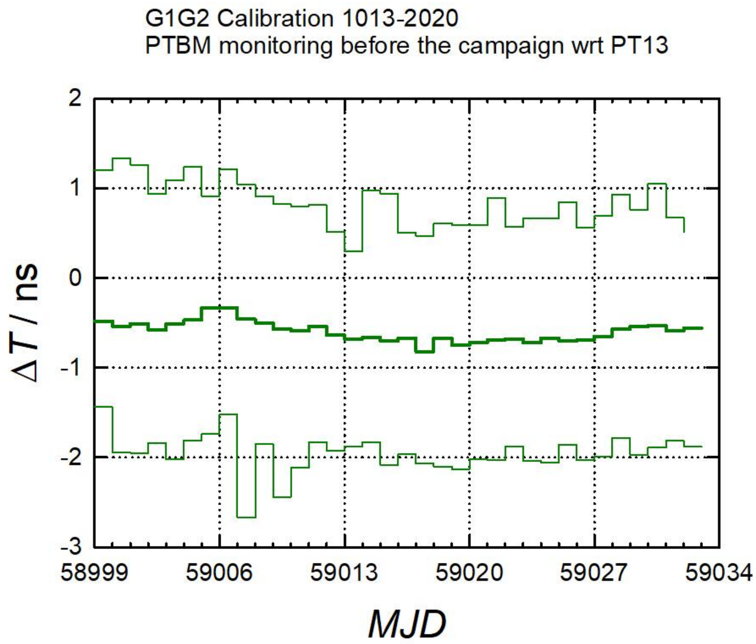

Figure 4-1: Common-clock common-view GPS comparison between PTBM and PT13 in a period preceding the current campaign; thick lines: daily mean values, thin lines: maximum and minimum value (13-min average) during the respective day.

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 PT03 receiver was supplied with 20 MHz from a times 4 multiplier, but was decommissioned before the start of the current campaign.

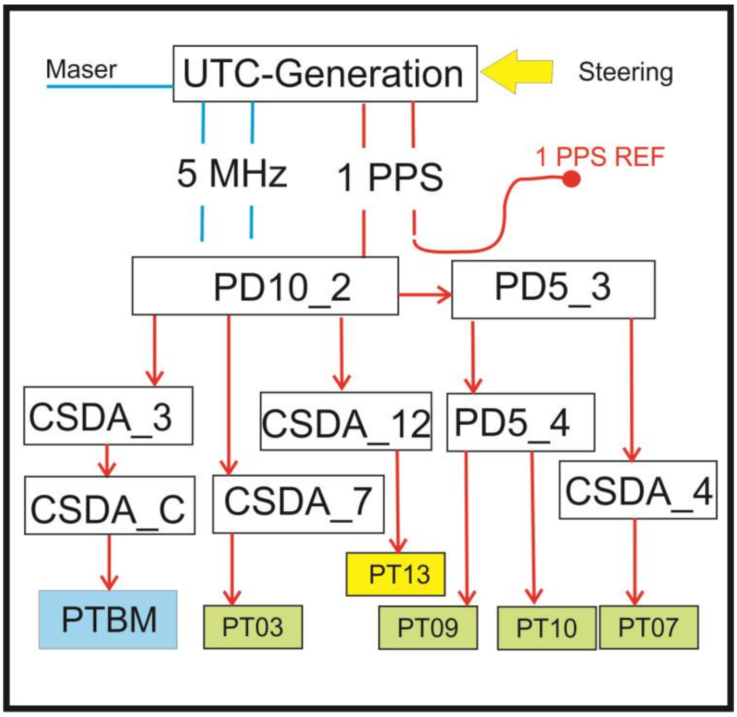

Figure 4-2: UTC(PTB) reference point and 1 PPS signal distribution to PT13, PTBM, and other receivers; PD10 stands for pulse distributor, CSDA stands for clock signal distribution amplifier

A clarification may be helpful regarding the 1 PPS REF point. When measuring with a TIC the time difference between Port A = UTC(PTB), and 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.

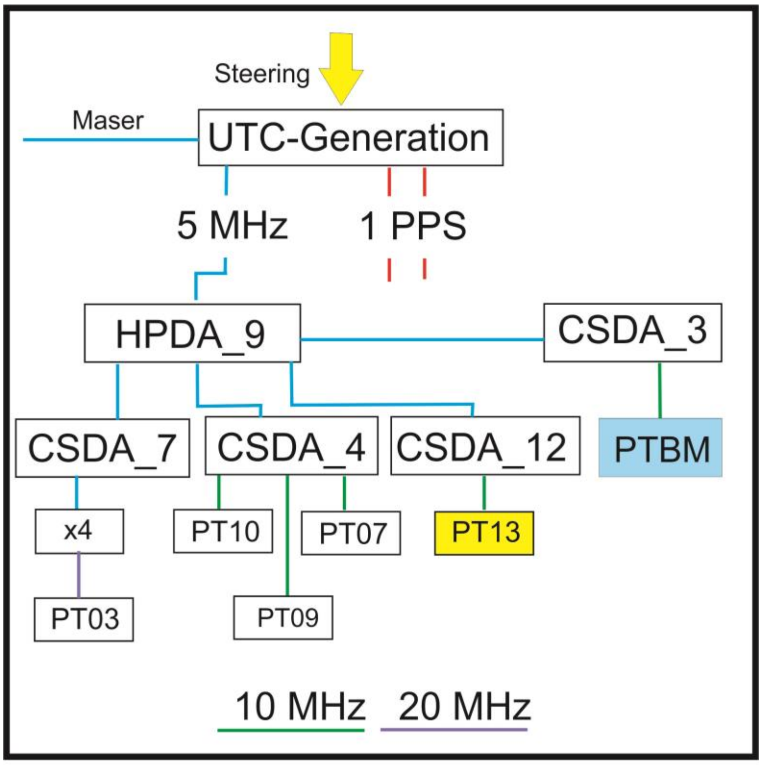

Figure 4-3: UTC(PTB) signal distribution (5 MHz, 10 MHz, 20 MHz) to PT13, PTBM, and other receivers

HPDA stands for High-precision distribution amplifier (for rf frequencies)

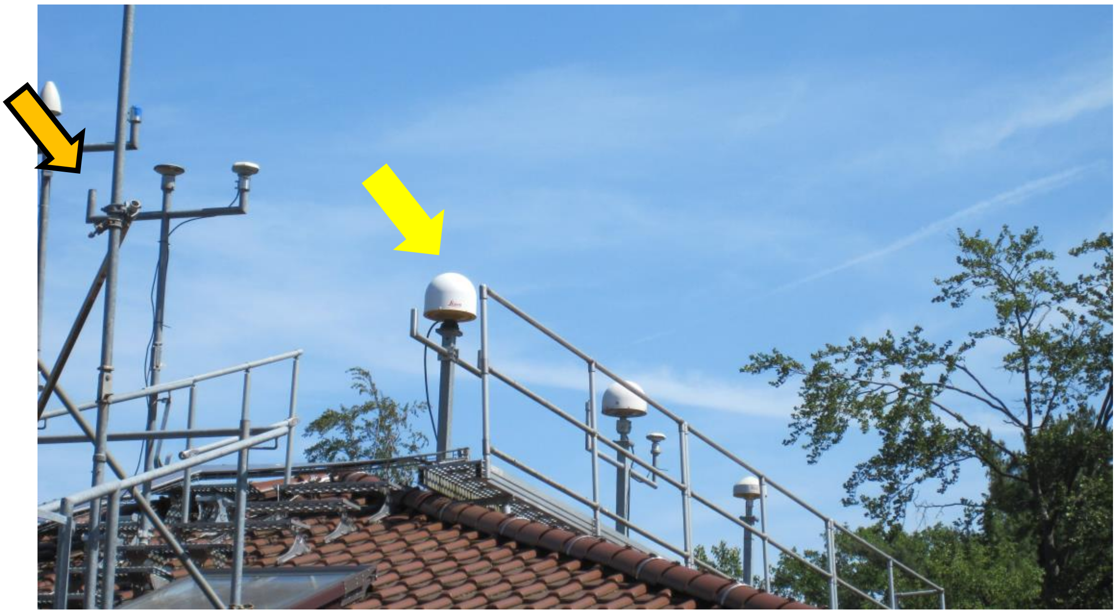

Figure 4-4: Installation of GNSS antennas at PTB, PT13 antenna (yellow) and PTBM antenna position during CC1 and C2 indicated (orange)

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

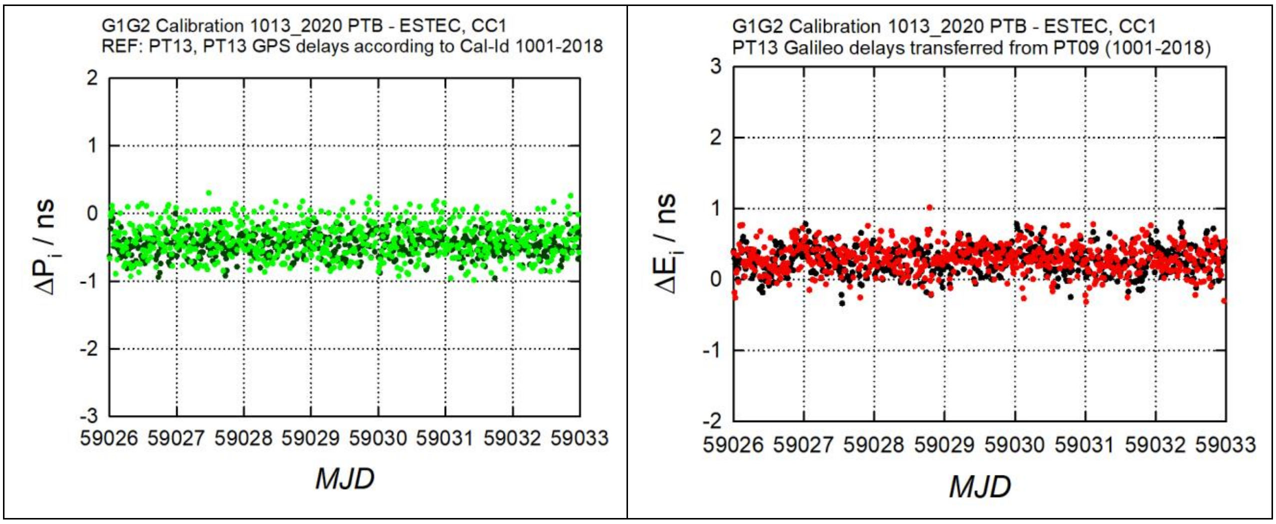

Figure 5-1: Left: Corrections to GPS delay in PTBM during CC1, ∆P1 (dark green) and ∆P2 (light green) Right: Corrections to Galileo delays in PTBM during CC1, ∆E1 (black) and ∆E5a (red).

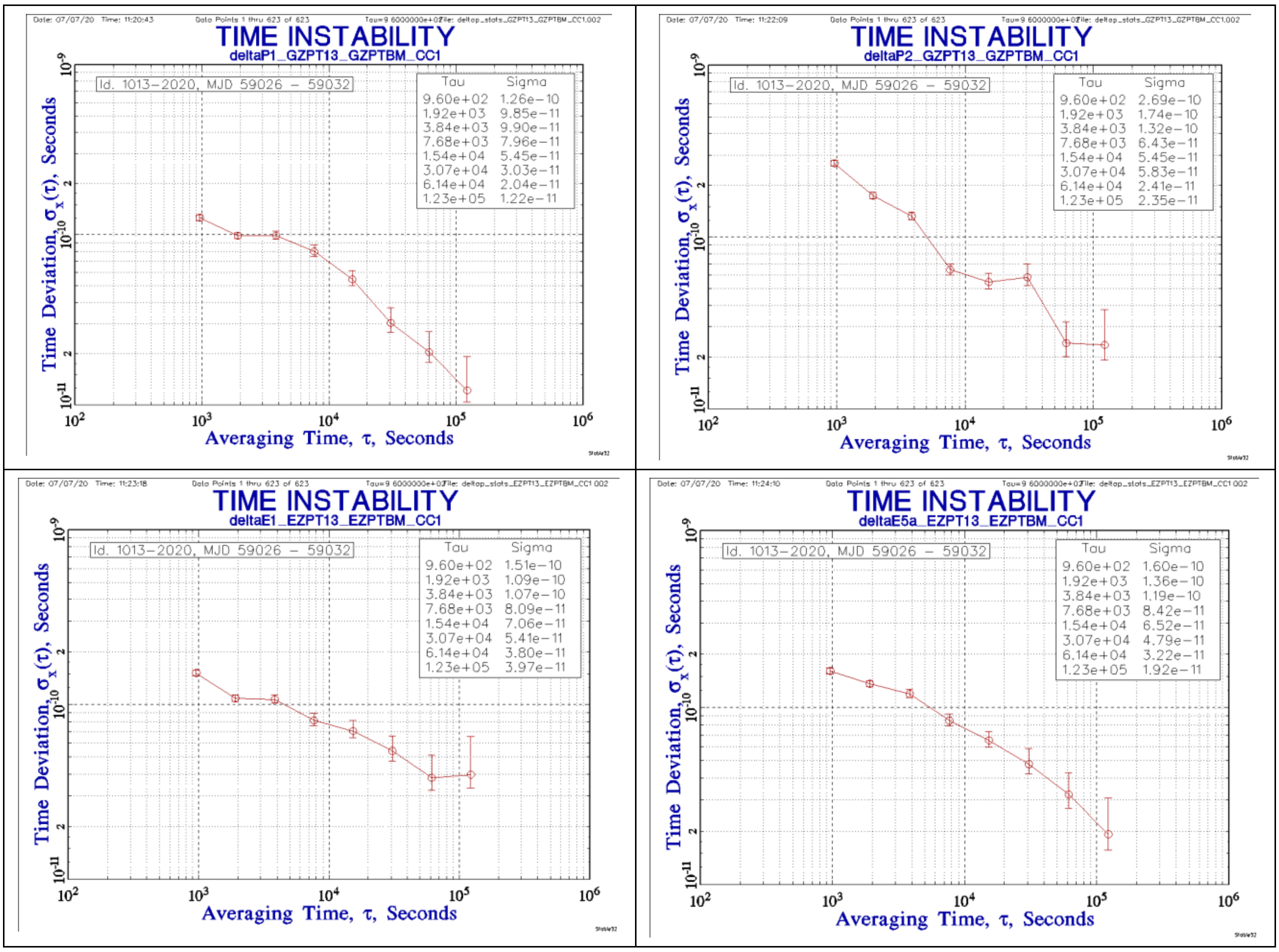

Figure 5-2: TDEV obtained for the four data sets shown in Figure 5-1, GPS (upper row), Galileo (lower row).

The period 59026 to 59032 (7 days) was chosen to determine the initial PTBT INT DLY values (CC1). The result of comparison with PT13 as the reference are shown in Figure 5-1 illustrating in total 623 values obtained for each GNSS frequency 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.

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 PTBM AT ESTEC

PTBM was operated at ESTEC during week 30, 2020. Eight days were used as the data base for the delay determination of the receivers ES03, ES04, ES07, ES07, ES09 (6 days only), and eso7. The results are presented below. Details on the receivers and their installation are given in the Annex. The antenna positions were determined from analysis of RINEX data using the NRCan PPP software for all receivers. The CGGTTS files from PTBM and ESTEC receivers were reprocessed using r2cggtts V 8.1.

The signal distribution to receivers PTBM, and ESTEC receivers is illustrated in Figure 6-1. The mounting position of the antennas is shown in Figure 6-2.

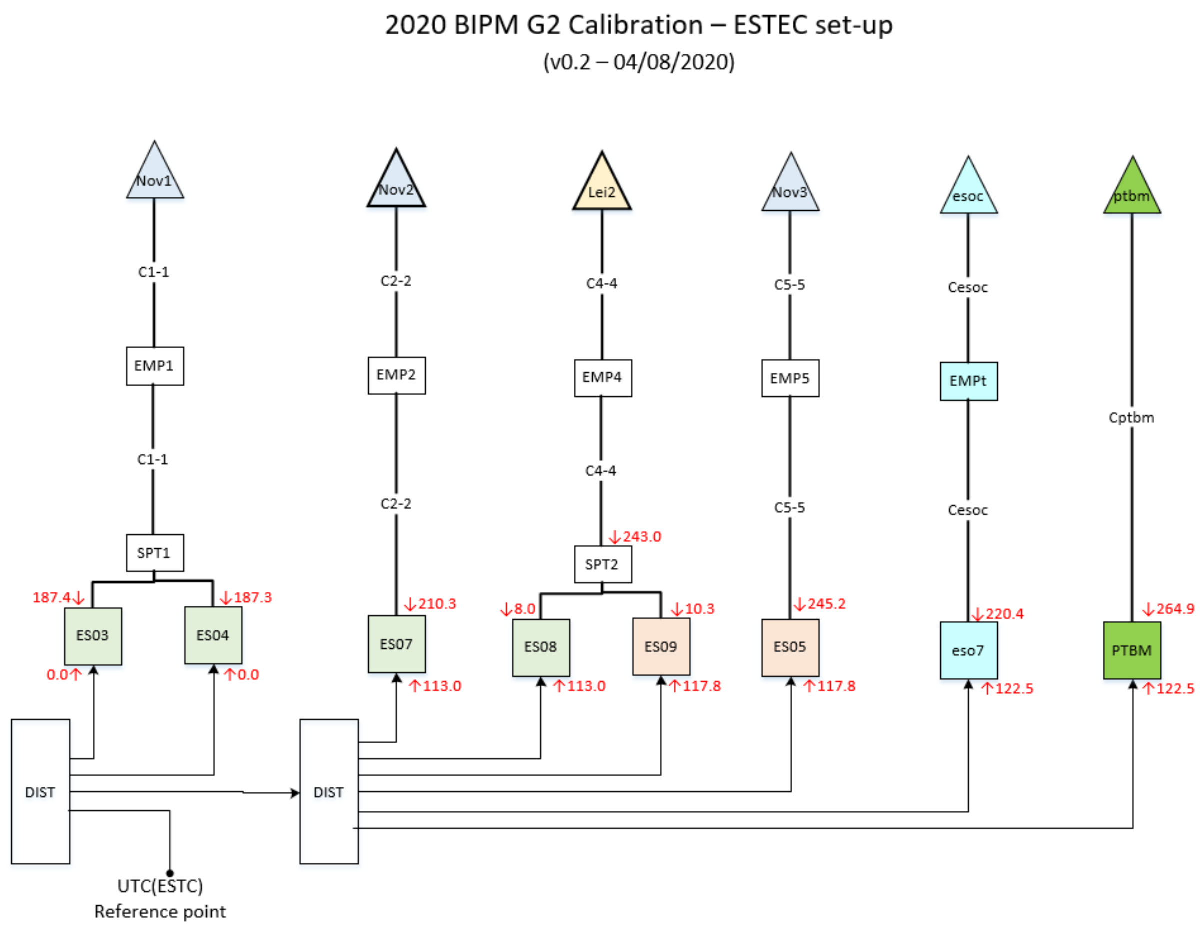

Figure 6-1 Signal distribution at ESTEC to the receivers

Figure 6-2: GNSS antennas on the rooftop of a building at ESTEC hosting the time laboratory

6.1. CALIBRATION OF RECEIVERS ES03 AND ES04

Receivers ES03 and ES04 had been calibrated in a previous campaign (1019-2016) so that the exercise possibly verifies the stability of installation and internal delays. Both receivers are connected to the same antenna. ES03 does not track Galileo.

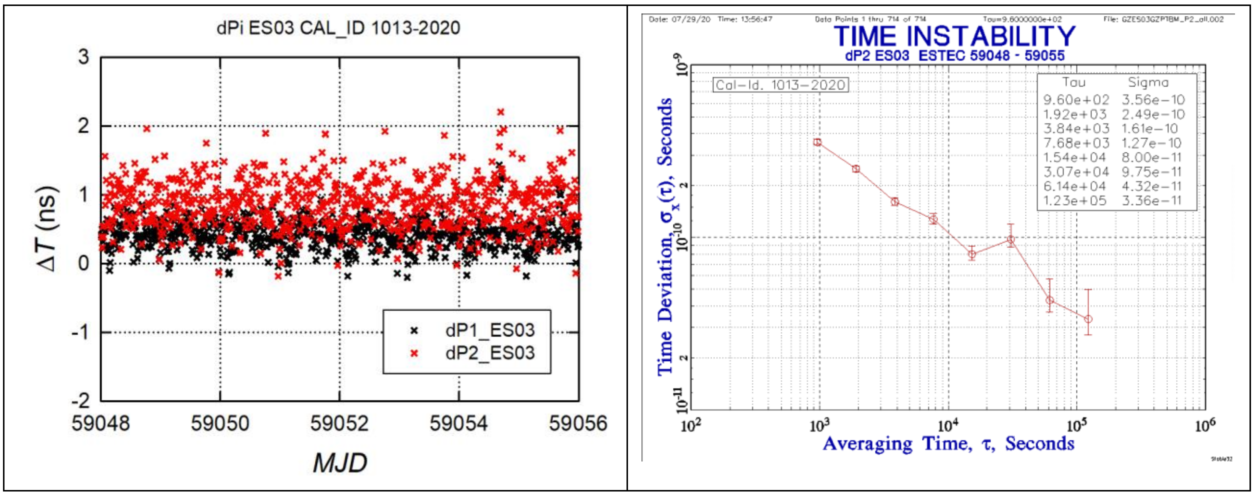

Figure 6-3. Left: Corrections to GPS INT DLY in ES03, reference PTBM; GPS ΔP1 (black) and ΔP2 (red), right: TDEV calculated from the dP2 values shown in the left panel.

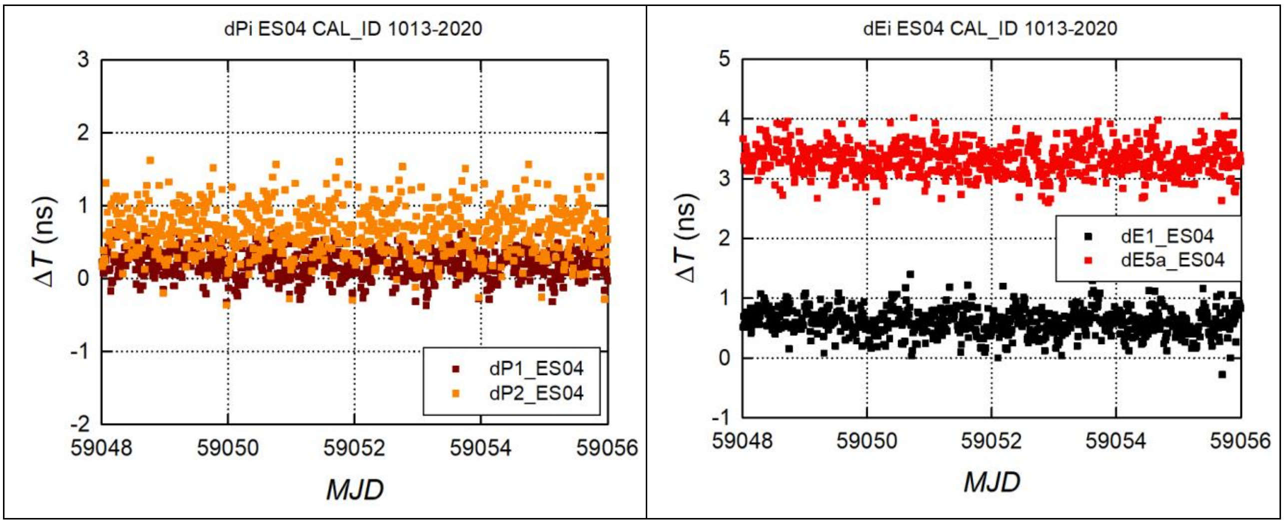

Figure 6-4 Left: Corrections to INT DLY in ES04, reference PTBM; left: GPS ΔP1 (brown) and ΔP2 (oranget), right: Galileo, ΔE1 (black) and ΔE5a (red).

In Figure 6-3 and Figure 6-4, the ΔIDi (3) derived from the raw data are depicted. The results regarding all receivers are tabulated in Table 6-1 which contains the mean and the median value, the standard deviation of individual data points and an estimate for the statistical uncertainty which is derived from TDEV at = 50 000 s. The default value of 0.1 ns is chosen if the measured TDEV is less than 0.1 ns. As seen in Table 6-1, the dP2 values are the most noisy ones in all cases. TDEV of all receivers and signals were found similar to those shown in Figure 6-3 right and are thus not reproduced here.

6.2. CALIBRATION OF ES07 AND ES08

The receivers ES07 and ES08 came without delay values previously determined. The values reported are thus the delays to be used furtheron.

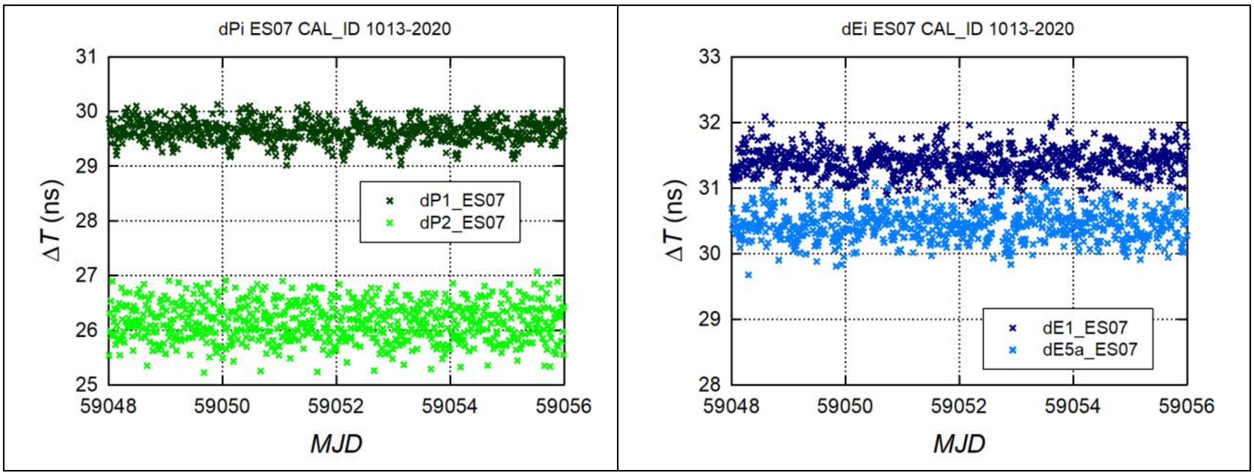

Figure 6-5. Left: INT DLY of ES07, reference PTBM; left: GPS ΔP1 (dark) and ΔP2 (light), right: Galileo, ΔE1 (dark) and ΔE5a (light).

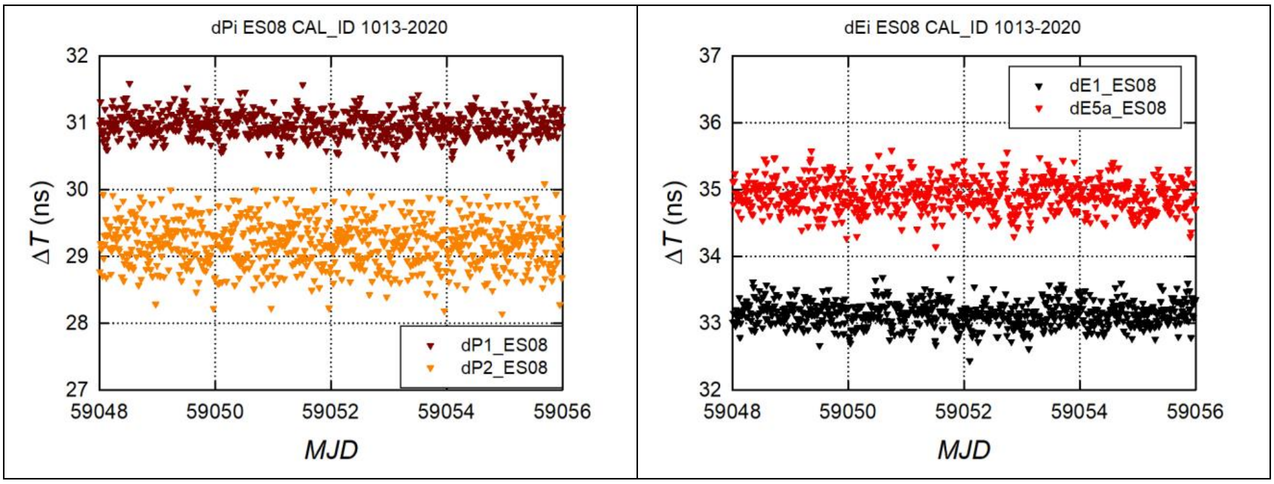

Figure 6-6. INT DLY of ES08, reference PTBM; left: GPS ΔP1 (brown) and ΔP2 (orange), right: Galileo, ΔE1 (black) and ΔE5a (red).

6.3. CALIBRATION OF RECEIVER ES09

Receiver ES09 is the only MESIT GTR51 receiver, an instrument which usually is delivered with a factory calibration. Values shown are thus again the corrections to delay values known beforehand. ES09 data were available only for 6 days only.

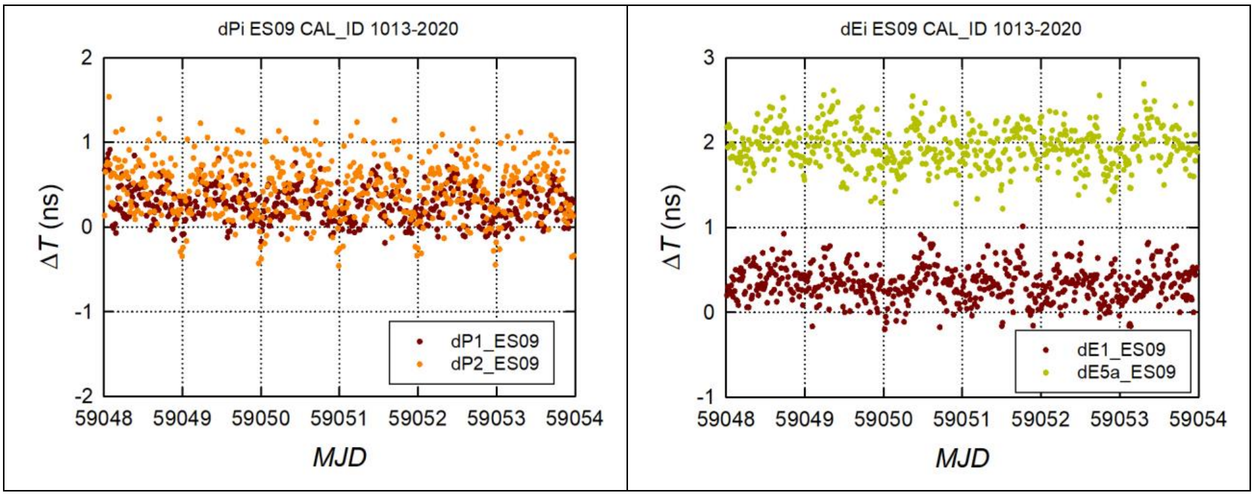

Figure 6-7. Corrections to INT DLY of ES09, reference PTBM; left: GPS ΔP1 (brown) and ΔP2 (orange), right: Galileo, ΔE1 (brown) and ΔE5a (green).

6.4. CALIBRATION OF RECEIVER ESO7

Please note the receiver designation is eso7, not ES_zero_7.

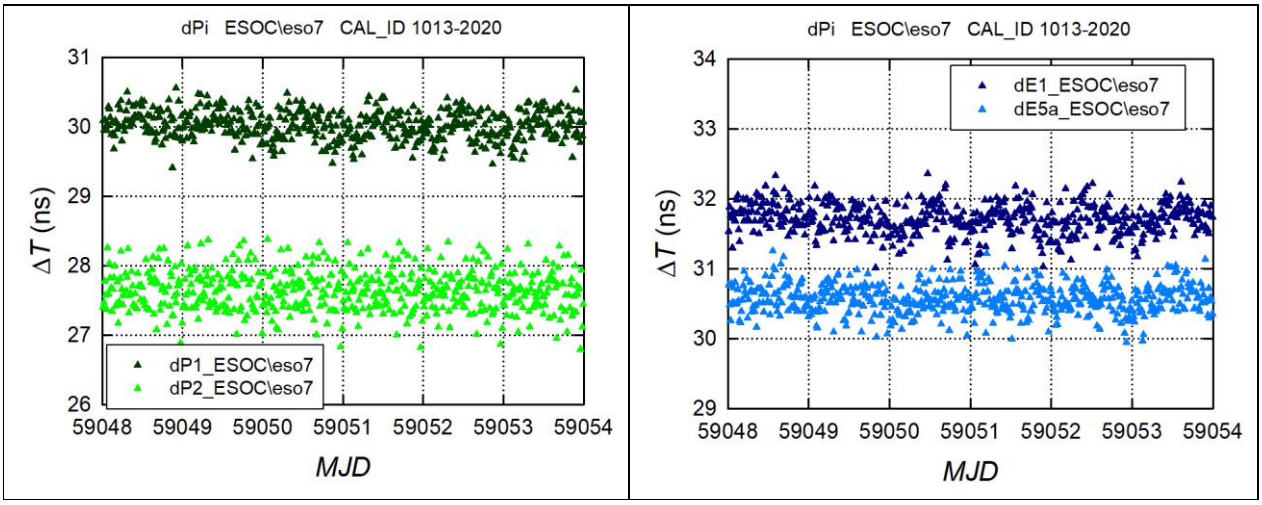

Figure 6-8 INT DLY of eso7, reference PTBM; left: GPS ΔP1 (dark) and ΔP2 (light), right: Galileo, ΔE1 (dark) and ΔE5a (light).

6.5. SUMMARY OF RESULTS OBTAINED AT ESTEC

Table 6-1 ΔINT DLY(fi) values and statistical properties (in ns) obtained initially.

ΔINT DLY (fi) for receiver at ESTEC	Mean (ns)	Median (ns)	Std. Dev. (ns)	TDEV (ns)	Number of 16-min epochs
ES03					
ΔP1	0.42	0.42	0.20	0.1	714
ΔP2	0.87	0.88	0.35	0.1	714
ES04					
ΔP1	0.20	0.21	0.21	0.1	714
ΔP2	0.66	0.66	0.32	0.1	714
ΔE1	0.60	0.60	0.22	0.1	713
ΔE5a	3.32	3.31	0.25	0.1	713
ES07					
ΔP1	29.64	29.63	0.20	0.1	714
ΔP2	26.14	26.13	0.35	0.1	714
ΔE1	31.39	31.38	0.21	0.1	713
ΔE5a	30.44	30.44	0.23	0.1	713
ES08					
ΔP1	30.97	30.95	0.19	0.1	714

ΔP2	29.18	29.19	0.35	0.1	714
ΔE1	33.14	33.14	0.18	0.1	713
ΔE5a	34.91	34.92	0.23	0.1	713
ES09					
ΔP1	0.28	0.27	0.21	0.1	530
ΔP2	0.46	0.47	0.34	0.1	530
ΔE1	0.34	0.33	0.221	0.1	529
ΔE5a	1.95	1.93	0.25	0.1	529
Eso7					
ΔP1	30.03	30.02	0.20	0.1	714
ΔP2	27.64	27.64	0.30	0.1	714
ΔE1	31.71	31.71	0.22	0.1	713
ΔE5a	30.35	30.35	0.21	0.1	713

7. OPERATION OF PTBT AT PTB: SECOND PERIOD

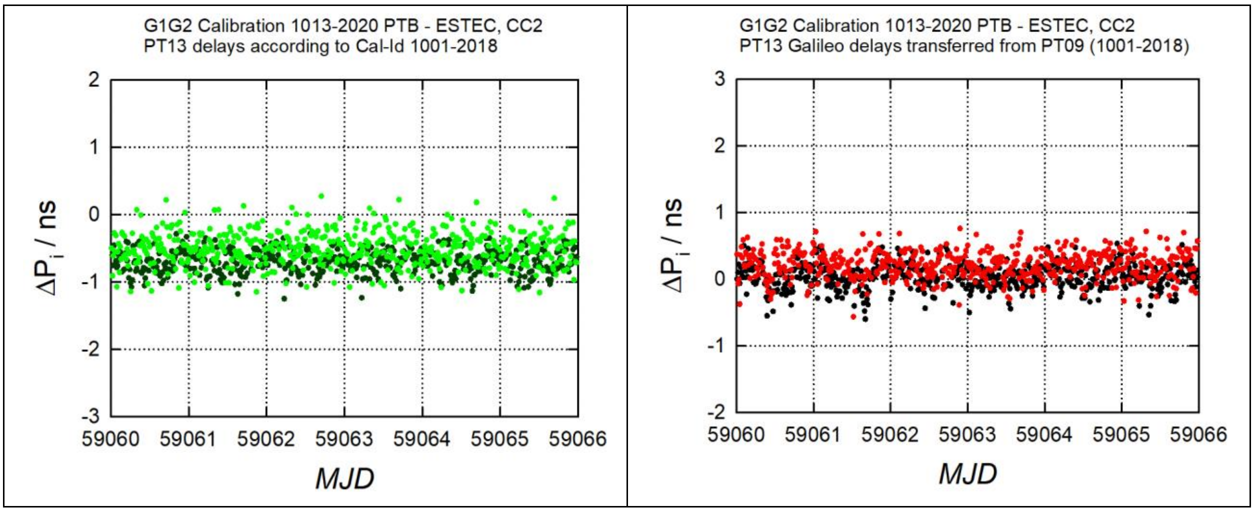

Figure 7-1. Left: Corrections to GPS delay in PTBM during CC2, ∆P1 (dark green) and ∆P2 (light green) Right: Corrections to Galileo delays in PTBM during CC2, ∆E1 (black) and ∆E5a (red).

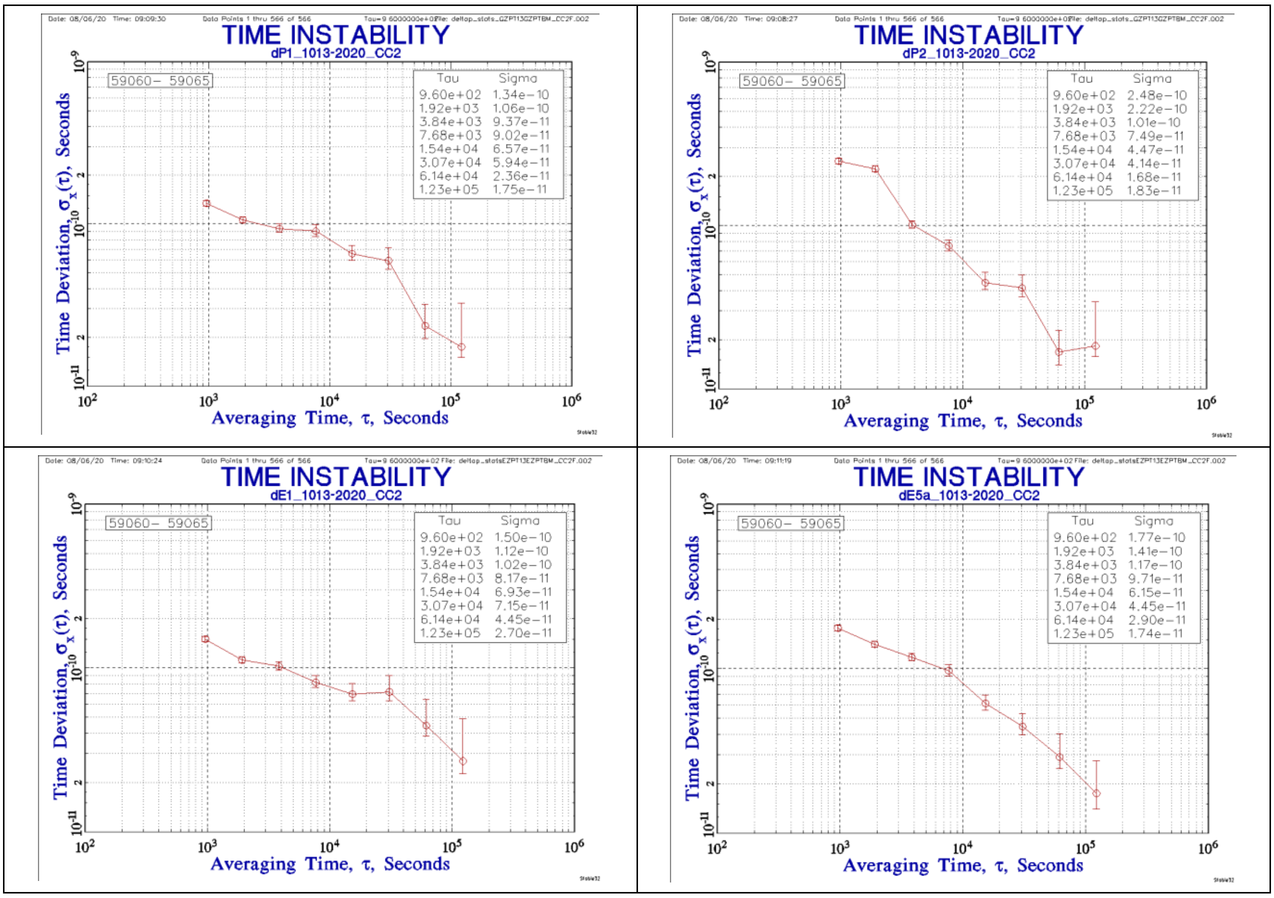

Figure 7-2. TDEV obtained for the four data sets shown in Figure 7-1, GPS (upper row) and Galileo (lower row).

The period 59060 to 59065 (6 days) was chosen to determine PTBM INT DLY values during the common clock period CC2. The results of comparison with PT13 as the reference are shown in Figure 7-1 illustrating in total 533 ΔIDi values obtained as mean values over all common view observations at a given epoch. The time instability (TDEV) plots for the data sets follow as Figure 7-2.

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 0.41 ns for ΔE3. For the evaluation of the delays of the visited receivers the mean values 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)	-0.47	0.16	< 0.1
ΔP2 (CC1)	-0.38	0.26	< 0.1
ΔP3 (CC1)	-0.60		
ΔE1 (CC1)	+0.27	0.19	< 0.1
ΔE5a (CC1)	+0.30	0.20	< 0.1
ΔE3 (CC1)	+0.23		
ΔP1 (CC2)	-0.69	0.17	0.1
ΔP2 (CC2)	-0.50	0.26	0.1
ΔP3 (CC2)	-0.98		
ΔE1 (CC2)	0.05	0.19	0.1
ΔE5a (CC2)	0.23	0.20	0.1
ΔE3 (CC2)	-0.18		
Mean values used for evaluation of visited receivers' internal delays			
ΔP1	-0.58		
ΔP2	-0.44		
ΔE1	0.16		
ΔE5a	0.26		

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 ORB 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) = $\sqrt{\{u(P1)^2 + (1.54 \times u(P1-P2))^2\}}$. Uncertainties for the Galileo delays are calculated according to $\sqrt{\{u(E1)^2 + (1.26 \times u(E1-E5a))^2\}}$.

Note that the uncertainty of the INT DLY values of PTB's fixed receiver PT13 (G) which served as the reference is not included.

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

	Uncertainty	Value f1 (ns)	Value f2 (ns)	Value f1-f2 (ns)	Value f3 (ns)	Description
1	u_a (PTB)	0.1	0.1	0.14	0.23	CC measurement uncertainty at PTB, TDEV max. of the two CC campaigns
2	u_a(ESTEC)	0.1	0.1	0.14	0.23	CC measurement uncertainty, for all six ESTEC receivers
Result of closure measurement at PTB						
3a	$u_{b,1}$ (GPS)	0.32	0.12		0.38	Misclosure, see Table 7-1
3b	$u_{b,1}$ (Galileo)	0.22	0.23		0.41	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	$u_{b,12}$(ESTEC)	0.1	0.1	0.14	0.28	Position error at ESTEC
6	$u_{b,13}$	0.2	0.2	0.0	0.2	Multipath at PTB
7	$u_{b,14}$	0.2	0.2	0.0	0.2	Multipath at ESTEC
Installation of PTBT and visited receivers						
8	$u_{b,21}$	0.2	0.2	0	0.2	Connection of PTBM to UTC(PTB) (REF DLY)
9	$u_{b,22}$	0.2	0.2	0	0.2	Connection of PTBM to UTC(ESTEC) (REF DLY)
10	$u_{b,23}$	0.2	0.2	0	0.2	Connection of receivers at ESTEC to UTC(ESTEC) (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 ESTEC
Antenna cable delay						
13	$u_{b,31}$(PTB)	0.5	0.5	0	0.5	Uncertainty estimate for the PTBM CAB DLY when installed at PTB
14	$u_{b,32}$(ESTEC)	0.0	0.0	0	0.0	Uncertainty estimate for the PTBM CAB DLY when installed at ESTEC
15	$u_{b,33}$(ESTEC)	0.5	0.5	0	0.5	Uncertainty estimate for ESTEC CAB DLY values

As demonstrated in Table 6-1, the six receivers at ESTEC show almost the same time instability. The TDEV plots (not reproduced in this Report) show marginal differences, and the value of 0.1 ns is a conservative estimate anyway. Thus, a single uncertainty budget can cover all other contributions.

The uncertainty contribution $u_{b,1}$ is based on the difference between the two common clock campaigns in the following way. The respective differences hardly exceed the statistical measurement uncertainty. So either the difference itself or the statistical measurement uncertainty is considered as measure for the uncertainty, whatever is the larger quantity.

For the generation of the CGGTTS data the PTBM antenna position is manually entered into the processing software in ITRF coordinates before the CC evaluation at both sites. 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 f1 and f2 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 f1-f2 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 ($u_{b,21}$, $u_{b,22}$, $u_{b,23}$) has been estimated as 0.2 ns for PTBM at both locations and as 0.2 ns for the internal set-up at ESTEC.

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 10 MHz using cables of different lengths, 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 PTBM cable was employed in CC1, CC2 and at ESTEC. CAB DLY values were 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 as long as the same PPS signal source was used, but differed by up to 0.5 ns when the slew rate of the pulse was significantly different. Thus we retain a uncertainty contribution $u_{b,31}$ of 0.5 ns. For the stationary antenna cables at ESTEC we conservatively assume the same 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 institute. If the stated CAB DLY for the visited fixed receiver(s) 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_1013_2020 are summarized in Table 9-1 and Table 9-2. It contains the designation of the visited receiver, the INT DLY values hitherto used, the offsets ΔIDi(V,T) and ΔIDi(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 L3P (E1, E5a and L3E), 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_1013_2020: GPS delays, 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}, L3P
ES03	48.9	46.8	0.42	0.88	-0.58	-0.44	48.74	0.92	47.24	0.89	1.06
ES04	57.4	54.9	0.21	0.66	-0.58	-0.44	57.03	0.92	55.12	0.89	1.06
ES07	0	0	29.63	26.13	-0.58	-0.44	29.05	0.92	25.69	0.89	1.06
ES08	0	0	30.95	29.19	-0.58	-0.44	30.37	0.92	28.75	0.89	1.06
ES09	21.0	17.5	0.27	0.47	-0.58	-0.44	20.69	0.92	17.53	0.89	1.06
eso7	0	0	30.02	27.64	-0.58	-0.44	29.44	0.92	27.2o	0.89	1.06

Table 9-2. Results of the Calibration Campaign G1G2_1013_2020: Galileo delays, all values in ns

Receiver	INT DLY(E1), old	INT DLY(E5a); old	ΔE1 (V,T)	ΔE5a (V,T)	ΔE1 (T,G)	Δ(E5a) (T,G)	INT DLY(1), new	u_{cal}, E1	INT DLY(E5a), new	u_{cal}, E5a	u_{cal}, L3E
ES04	57.4	61.50	0.60	3.31	0.16	0.26	58.16	0.87	65.07	0.96	1.07
ES07	0	0	31.38	30.44	0.16	0.26	31.54	0.87	30.70	0.96	1.07
ES08	0	0	33.14	34.92	0.16	0.26	33.30	0.87	35.18	0.96	1.07
ES09	20.9	21.4	0.33	1.93	0.16	0.26	21.39	0.87	23.59	0.96	1.07
eso7	0	0	31.71	30.35	0.16	0.26	31.87	0.87	30.61	0.96	1.07

ANNEX: BIPM CALIBRATION INFORMATION SHEETS

First common clock measurement at PTB

Laboratory:	**PTB**			
Date and hour of the beginning of	2020-06-26 0:00 UTC (MJD 59026)			
Date and hour of the end of measurements:	2020-07-02 24:00 UTC (MJD 59032)			
Information on the system				
	Local:		**Travelling:**	
4-character BIPM code	**PT13**		**PTBM**	
Receiver maker and type: Receiver serial number:	PolaRx5TR (5.2.0) S/N 470 1292		PolaRx5TR (5.3.0) S/N 3048338	
1 PPS trigger level /V:	1		1	
Antenna cable maker and type: Phase stabilised cable (Y/N):	ECOFLEX15		LMR-400 (N)	
Length outside the building /m:	approx. 25		25	
Antenna maker and type: Antenna serial number:	LEICA AR25 726333, Calib Geo++ 18.08.2015		Navexperience 3G+C REFERENCE S/N RE 0560	
Temperature (if stabilised) /°C				
Measured delays /ns				
	Local:		**Travelling:**	
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	9.33 ± 0.1 (#)		43.3 +/- 0.2	
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	45.0 ± 0.1 (#)		Determined automatically by receiver software	
Antenna cable delay: (X_C) / ns	205.7 ± 0.1		264.9 ± 0.5	
Splitter delay (if any):	N/A			
Data used for the generation of CGGTTS files				
	LOCAL:		Travelling	
☐ INT DLY (or X_R+X_S) (GPS) /ns:	29.7 (P1), 27.2 (P2), 31.7 (C1) (*) 31.0 (E1), 30.5 (E5a) (**)		18.9 (P1) 17.1 (P2) (****) 20.8 (E1), 17.9 (E5a) (****)	
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:				
☐ CAB DLY (or X_C) /ns:	205.7		264.9	
☐ REF DLY (or X_P+X_O) /ns:	54.3		43.3+unknown	
☐ Coordinates reference frame:	ITRF (***)		ITRF (****)	
X /m:	+3844059.86 (***)	Mast P10	+3844062.13 ($)	Mast P9
Y /m:	+709661.56 (***)		+709658.71 ($)	
Z /m	+5023129.87 (***)		+5023128.30 ($)	
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 0.5° C

Notes valid for CC1 and CC2:

(#) values determined at installation of PT13 in March 2019, local measurements not repeated

($) Coordinates of mast P9 (APC) were determined on 26.05.2020 using NRCan PPP

(*) values based on G1 calib 1001-2018, transferred from receiver PT09

(**) vales based on calib 1001-2018, transferred from receiver PT09 [RD08]
(***) values provided by BIPM via Mail 2019-08-07
(****) PTBT INT DLY were adjusted so that PTBM – PT13 for GPS and Galileo were close to zero for convenience.

Names of files to be used in processing for site PTB
Travelling receiver GZPTBTMJ.DDD, EZPTBMMJ.DDD
Reference receiverGZPT13MJ.DDD, EZPT13MJ.DDD

PTBM operation at ESTEC: Receiver ES03

Laboratory:	ESTEC
Date and hour of the beginning of measurements:	2020-07-18 00:00 GPS, MJD 59048, 2020
Date and hour of the end of measurements:	2020-07-25 23:59 GPS, MJD 59055, 2020

Information on the system

	Local:	**Travelling:**
4-character BIPM code	ES03	PTBM
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx3eTR Pro S/N 2001059	Septentrio PolaRx5TR (5.3.0) 3048338
1 PPS trigger level /V:	1.0 V	1.0 V
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Sucofeed ½", N-connectors N	LMR-400, N-connectors N
Length outside the building /m:	Approx. 30 m	Approx. 30 m
• Antenna maker and type: Antenna serial number:	NOV750.R4 1019003	Navexperience 3G+C S/N RE 0560
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:	$X_P + X_O$ = 195.0 ns X_P = 0.0 ns X_O = 195.0 ns	122.5 ns (delay from UTC(ESTEC) to the box)
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		Determined automatically by receiver software
• Antenna cable delay:	187.4 ns	264.9 ns
Splitter delay (if any):	N/A	
Additional cable delay (if any):	N/A	

Data used for the generation of CGGTTS files ES03
Reference : 1019-2016

• INT DLY (GPS) /ns:	48.9 ns (P1) / 46.8 (P2)
• CAB DLY /ns:	187.4
• REF DLY /ns:	195.0
• Coordinates reference frame:	ITRF
Latitude or X /m:	3904171.67
Longitude or Y /m:	301744.55

Height or Z /m:	5017777.72
Data used for the generation of CGGTTS files PTBM RINEX files collected, r2cgggtts V8.1 for generation of cggtts files	
• INT DLY (GPS) /ns:	18.9 (P1) 17.1 (P2) 21.2 (C1)
• INT DLY (Galileo) /ns:	20.8 (E1), 17.9 (E5a)
• CAB DLY /ns:	264.9 ns
• REF DLY /ns:	122.5 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	3904169.47
Longitude or Y /m:	301745.81
Height or Z /m:	5017779.16
• Rise time of the local UTC pulse:	
• Is the laboratory air conditioned:	yes
Set temperature value and uncertainty:	
Set humidity value and uncertainty:	

All coordinates (APC) determined using NRCCan PPP for day 201/2020. CAB DLY values represent te signal delay between output socket of the antenna and input socket of the receiver, including all cables and splitter (if applicable). This applies to all receivers.

PTBM operation at ESTEC: Receiver ES04

Laboratory:	ESTEC
Date and hour of the beginning of measurements:	2020-07-18 00:00 GPS, MJD 59048, 2020
Date and hour of the end of measurements:	2020-07-25 23:59 GPS, MJD 59055, 2020

Information on the system

	Local:	**Travelling:**
4-character BIPM code	ES04	PTBM
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx4TR S/N 3001286	Septentrio PolaRx5TR (5.3.0) 3048338
1 PPS trigger level /V:	1.0 V	1.0 V
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Sucofeed ½”, N-connectors N	LMR-400, N-connectors N
Length outside the building /m:	approx. 30 m	approx. 30 m
• Antenna maker and type: Antenna serial number:	Nov750.R4 1019003	Navexperience 3G+C S/N RE 0560
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:	$X_P + X_O$ = 136.1 ns X_P = 0.0 ns X_O = 136.1 ns	122.5 ns (delay from UTC(ESTEC) to the box)
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		Determined automatically by receiver software
• Antenna cable delay:	187.3ns	264.9 ns
Splitter delay (if any):	N/A	
Additional cable delay (if any):	N/A	

Data used for the generation of CGGTTS files ES04
Reference : 1019-2016

• INT DLY (GPS) /ns:	57.4 ns (P1) / 54.9 (P2)
• INT DLY (Galileo) /ns:	57.4 (E1) / 61.5 (E5a)
• CAB DLY /ns:	187.3
• REF DLY /ns:	136.1
• Coordinates reference frame:	ITRF

Latitude or X /m:	3904171.67
Longitude or Y /m:	301744.55
Height or Z /m:	5017777.72

Data used for the generation of CGGTTS files PTBM RINEX files collected, r2cgggtts V8.1 for generation of cggtts files	
• INT DLY (GPS) /ns:	18.9 (P1) 17.1 (P2) 21.2 (C1)
• INT DLY (Galileo) /ns:	20.8 (E1), 17.9 (E5a)
• CAB DLY /ns:	264.9 ns
• REF DLY /ns:	122.5 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	3904169.47
Longitude or Y /m:	301745.81
Height or Z /m:	5017779.16
• Rise time of the local UTC pulse:	
• Is the laboratory air conditioned:	yes
Set temperature value and uncertainty:	
Set humidity value and uncertainty:	

PTBM operation at ESTEC: Receiver ES07

Laboratory:	ESTEC
Date and hour of the beginning of measurements:	2020-07-18 00:00 GPS, MJD 59048, 2020
Date and hour of the end of measurements:	2020-07-25 23:59 GPS, MJD 59055, 2020

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	ES07	PTBM
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx5TR S/N 3018491	Septentrio PolaRx5TR 3048338
1 PPS trigger level /V:	1.0 V	1.0 V
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Sucofeed ½", N-connectors N	LMR-400, N-connectors N
Length outside the building /m:	Approx. 30 m	Approx. 30 m
• Antenna maker and type: Antenna serial number:	Nov750.R4 1018874	Navexperience 3G+C S/N RE 0560
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:	$X_P + X_O$ = 113.0 ns X_P = 113.0 ns X_O = 0.0 ns (auto compensation on)	122.5 ns (delay from UTC(ESTEC) to the box)
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		Determined automatically by receiver software
• Antenna cable delay:	210.3ns	264.9 ns
Splitter delay (if any):	N/A	
Additional cable delay (if any):	N/A	

Data used for the generation of CGGTTS files ES07	
• INT DLY (GPS) /ns:	0 (P1) / 0 (P2)
• INT DLY (Galileo) /ns:	0 (E1) / 0 (E5a)
• CAB DLY /ns:	210.3
• REF DLY /ns:	113.0
• Coordinates reference frame:	ITRF

Latitude or X /m:	3904170.62
Longitude or Y /m:	301745.19
Height or Z /m:	5017778.49

Data used for the generation of CGGTTS files PTBM RINEX files collected, r2cgggtts V8.1 for generation of cggtts files	
• INT DLY (GPS) /ns:	18.9 (P1) 17.1 (P2) 21.2 (C1)
• INT DLY (Galileo) /ns:	20.8 (E1), 17.9 (E5a)
• CAB DLY /ns:	264.9 ns
• REF DLY /ns:	122.5 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	3904169.47
Longitude or Y /m:	301745.81
Height or Z /m:	5017779.16
• Rise time of the local UTC pulse:	
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	
Set humidity value and uncertainty:	

PTBM operation at ESTEC: Receiver ES08

Laboratory:	ESTEC	
Date and hour of the beginning of measurements:	2020-07-18 00:00 GPS, MJD 59048, 2020	
Date and hour of the end of measurements:	2020-07-25 23:59 GPS, MJD 59055, 2020	
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	ES08	PTBM
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx5TR S/N 3022405	Septentrio PolaRx5TR 3048338
1 PPS trigger level /V:	1.0 V	1.0 V
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Sucofeed ½", N-connectors N	LMR-400, N-connectors N
Length outside the building /m:	Approx. 30 m	Approx. 30 m
• Antenna maker and type: Antenna serial number:	LEIAR20 124509	Navexperience 3G+C S/N RE 0560
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:	$X_P + X_O$ = 113.0 ns X_P = 113.0 ns X_O = 0.0 ns (auto compensation on)	122.5 ns (delay from UTC(ESTEC) to the box)
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		Determined automatically by receiver software
• Antenna cable delay:	251.0ns	264.9 ns
Splitter delay (if any):	N/A	
Additional cable delay (if any):	N/A	

Data used for the generation of CGGTTS files ES08	
• INT DLY (GPS) /ns:	0 (P1) / 0 (P2)
• INT DLY (Galileo) /ns:	0 (E1) / 0 (E5a)
• CAB DLY /ns:	251.0
• REF DLY /ns:	113.0
• Coordinates reference frame:	ITRF
Latitude or X /m:	3904168.16

Longitude or Y /m:	301750.81
Height or Z /m:	5017779.89

Data used for the generation of CGGTTS files PTBM RINEX files collected, r2cgggtts V8.1 for generation of cggtts files	
• INT DLY (GPS) /ns:	18.9 (P1) 17.1 (P2) 21.2 (C1)
• INT DLY (Galileo) /ns:	20.8 (E1), 17.9 (E5a)
• CAB DLY /ns:	264.9 ns
• REF DLY /ns:	122.5 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	3904169.47
Longitude or Y /m:	301745.81
Height or Z /m:	5017779.16
• Rise time of the local UTC pulse:	
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	
Set humidity value and uncertainty:	

PTBM operation at ESTEC: Receiver ES09

Laboratory:	ESTEC
Date and hour of the beginning of measurements:	2020-07-18 00:00 GPS, MJD 59048, 2020
Date and hour of the end of measurements:	2020-07-23 23:59 GPS, MJD 59053, 2020

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	ES09	PTBM
• Receiver maker and type: Receiver serial number:	MESIT GTR55/ JAVAD TRE_3 S/N 1808067	Septentrio PolaRx5TR 3048338
1 PPS trigger level /V:	1.0 V	1.0 V
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Sucofeed ½", N-connectors N	LMR-400, N-connectors N
Length outside the building /m:	Approx. 30 m	Approx. 30 m
• Antenna maker and type: Antenna serial number:	LEIAR20 124509	Navexperience 3G+C S/N RE 0560
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:	$X_P + X_O$ = 117.8 ns	122.5 ns (delay from UTC(ESTEC) to the box)
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		Determined automatically by receiver software
• Antenna cable delay:	253.3 ns	264.9 ns
Splitter delay (if any):	N/A	
Additional cable delay (if any):	N/A	

Data used for the generation of CGGTTS files ES09	
• INT DLY (GPS) /ns:	21.0 (P1) / 17.5 (P2)
• INT DLY (Galileo) /ns:	20.9 (E1) / 21.4 (E5a)
• CAB DLY /ns:	253.3
• REF DLY /ns:	117.8
• Coordinates reference frame:	ITRF
Latitude or X /m:	3904168.16

Longitude or Y /m:	301750.81
Height or Z /m:	5017779.89

Data used for the generation of CGGTTS files PTBM RINEX files collected, r2cgggtts V8.1 for generation of cggtts files	
• INT DLY (GPS) /ns:	18.9 (P1) 17.1 (P2) 21.2 (C1)
• INT DLY (Galileo) /ns:	20.8 (E1), 17.9 (E5a)
• CAB DLY /ns:	264.9 ns
• REF DLY /ns:	122.5 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	3904169.47
Longitude or Y /m:	301745.81
Height or Z /m:	5017779.16
• Rise time of the local UTC pulse:	
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	
Set humidity value and uncertainty:	

PTBM operation at ESTEC: Receiver eso7

Laboratory:	ESTEC
Date and hour of the beginning of measurements:	2020-07-18 00:00 GPS, MJD 59048, 2020
Date and hour of the end of measurements:	2020-07-25 23:59 GPS, MJD 59055, 2020

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	eso7	PTBM
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx5TR S/N 4701369	Septentrio PolaRx5TR 3048338
1 PPS trigger level /V:	1.0 V	1.0 V
• Antenna cable maker and type: Phase stabilised cable (Y/N):	LMR-600, N-connectors N	LMR-400, N-connectors N
Length outside the building /m:	Approx. 30 m	Approx.. 30 m
• Antenna maker and type: Antenna serial number:	SEPCHOKE_B3E6 SPKE 5578	Navexperience 3G+C S/N RE 0560
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:	$X_P + X_O$ = 122.5 ns X_P = 122.5 ns X_O = 0.0 ns (auto compensation on)	122.5 ns (delay from UTC(ESTEC) to the box)
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		Determined automatically by receiver software
• Antenna cable delay:	220.4 ns	264.9 ns
Splitter delay (if any):	N/A	
Additional cable delay (if any):	N/A	

Data used for the generation of CGGTTS files eso7	
• INT DLY (GPS) /ns:	0 (P1) / 0 (P2)
• INT DLY (Galileo) /ns:	0 (E1) / 0 (E5a)
• CAB DLY /ns:	220.4
• REF DLY /ns:	122.5
• Coordinates reference frame:	ITRF
Latitude or X /m:	39041686.19

Longitude or Y /m:	301748.83
Height or Z /m:	5017781.55

Data used for the generation of CGGTTS files PTBM RINEX files collected, r2cgggtts V8.1 for generation of cggtts files	
• INT DLY (GPS) /ns:	18.9 (P1) 17.1 (P2) 21.2 (C1)
• INT DLY (Galileo) /ns:	20.8 (E1), 17.9 (E5a)
• CAB DLY /ns:	264.9 ns
• REF DLY /ns:	122.5 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	3904169.47
Longitude or Y /m:	301745.81
Height or Z /m:	5017779.16
• Rise time of the local UTC pulse:	
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	
Set humidity value and uncertainty:	

Second common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of	2020-07-30 0:00 UTC (MJD 59060)
Date and hour of the end of measurements:	2020-08-04 24:00 UTC (MJD 59065)

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	**PT13**	**PTBM**
Receiver maker and type: Receiver serial number:	PolaRx5TR (5.2.0) S/N 470 1292	PolaRx5TR (5.3.0) S/N 3048338
1 PPS trigger level /V:	1	1
Antenna cable maker and type: Phase stabilised cable (Y/N):	ECOFLEX15	LMR-400 (N)
Length outside the building /m:	approx. 25	25
Antenna maker and type: Antenna serial number:	LEICA AR25 726333, Calib Geo++ 18.08.2015	Navexperience 3G+C REFERENCE S/N RE 0560
Temperature (if stabilised) /°C		

Measured delays /ns		
	Local:	**Travelling:**
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	9.33 ± 0.1 (#)	49.1 +/- 0.2
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	45.0 ± 0.1 (#)	Determined automatically by receiver software
Antenna cable delay: (X_C) / ns	205.7 ± 0.1	264.9 ± 0.5
Splitter delay (if any):	N/A	

Data used for the generation of CGGTTS files				
	LOCAL:		Travelling	
☐ INT DLY (or X_R+X_S) (GPS) /ns:	29.7 (P1), 27.2 (P2), 31.7 (C1) (*) 31.0 (E1), 30.5 (E5a) (**)		18.9 (P1) 17.1 (P2) (****) 21.2 (C1) 20.8 (E1), 17.9 (E5a) (****)	
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:				
☐ CAB DLY (or X_C) /ns:	205.7		264.9	
☐ REF DLY (or X_P+X_O) /ns:	54.3		49.1+unknown	
☐ Coordinates reference frame:	ITRF (***)		ITRF (****)	
X /m:	+3844059.86 (***)	Mast P10	+3844062.13 (****)	Mast P9
Y /m:	+709661.56 (***)		+709658.71 (****)	
Z /m	+5023129.87 (***)		+5023128.30 (****)	

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

END of DOCUMENT