Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

GNSS CALIBRATION REPORT

G1G2_1011_2021

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_INRIM
Code:	1011_2021
Version:	1.2
Safe date:	11.03.2021 10:35

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**
RD09	**PTB Report GNSS CALIBRATION REPORT PT13 VIA 1001-2018, 01 September 2020**
RD10	**Defraigne, P., Aerts, W., Cerretto, G., Cantoni, E., and Sleewaegen, J.-M., "Calibration of Galileo signals for time metrology," IEEE Trans. Ultrason. Ferroelect. Freq. Contr., vol. 61, no. 12, 2014, pp. 1967-1975.**

ACRONYMS

ACRONYMS	
BIPM	**Bureau International de Poids et Mesures, Sèvres, France**
CGGTTS	**CCTF Generic GNSS Time Transfer Standard**
ESA	**European Space Agency**
EURAMET	**The European Association of National Metrology Institutes**
INRIM	**Istituto Nazionale di Ricerca Metrologica, Torino, Italy**
IGS	**International GNSS Service**
GNSS	**Global Navigation Satellite System**
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 GNSS equipment of INRIM 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 had been determined with respect to receiver PT09 in several steps. 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 1011_2021. 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)) and the equivalent for Galileo on frequencies E1 and E5a.

PT13 GPS-signal delays had been provided in [RD01]. Initially, PT13 Galileo delays had been determined with reference to receiver GRCP. With publication of V2 of [RD01] and V2.5 of [RD08] in June 2020, Galileo delay values for the G1 laboratories were published. In case of PTB, values for PT09 were provided. Subsequently, the Galileo delay values of PT13 were aligned using the same method as in 2019 and reported in [RD09].

The final results are included in Table 9-1 and Table 9-2. The internal delays of the two 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 about 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 GNSS equipment of INRIM 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 INRIM. 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	04.01.2021	Version 0, all new
0b	xx.xx.2021	Version incl. Material INRIM / Cerretto
1	01.03.2021	Version 1 complete
1.1	02.03.2021	Version with corrections Tab 6.1, Fig. 6.14,
1.2	11.03.2021	Information on REF DLY at INRIM included in results sheet

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
INRIM	Giancarlo Cerretto Phone: +39 011 3919 239; Fax: +39 011 3919 259	Time and Frequency Group, Quantum Metrology and Nanotechnologies Division (QN) Istituto Nazionale di Ricerca Metrologica (I.N.RI.M.) Strada delle Cacce 91, 10135 Torino, Italy

Table 2-2: Schedule of the campaign

Date	Institute	Action	Remarks
2020-12-27 until 2021-01-02	PTB	First common-clock comparison between PTBTM and PT13	7 days used for determination of delays, MJD 59210 – 59216
2021-01-14 until 2021-01-28	INRIM	Operation of PTBM in parallel with receivers	About 6 days used for determination of delays (in sequence)
2021-02-19 until 2021-02-26	PTB	Operation of PTBM after return	6 days used for determination of delays, MJD 59264 - 59269

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: Xo available at the the 1 PPS-out socket of the receiver
- For Septentrio PolaRx5TR: optionally Xo is determined autonomously by the receiver or it can be determined alike to the PolaRx4.
- For DICOM GTR50, GTR51 and GTR55: $X_O = 0$,
- 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,

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

for reporting results of observation of satellite “j” is valid and 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 $\langle\Delta\text{IDi(T,G)}\rangle$ 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.

3.2. DETERMINATION OF DELAYS OF GALILEO SIGNALS

In the current campaign, 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 [RD09].

4. CHARACTERIZATION OF PTB EQUIPMENT

In the following, we document the stability of PTBM in comparison with the reference PT13 during periods of a few weeks. In Figure 4-1, the performance during the weeks before shipment to INRIM is illustrated. The gap was caused by intentional interruption of the data collection of PTBM.

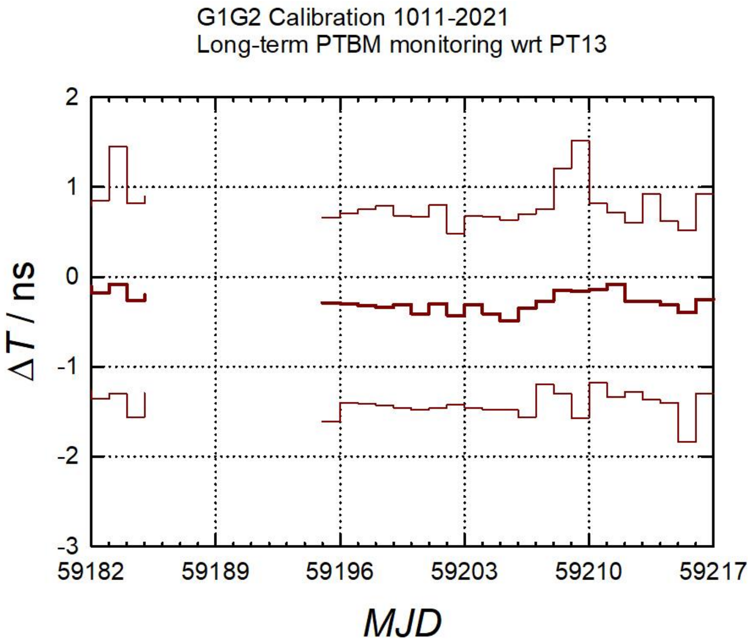

Figure 4-1: Common-clock common-view GPS comparison between PTBM and PT13 in a period preceding campaign 1011-2021; thick lines: daily mean values, thin lines: maximum and minimum value (13-min average) during the respective day.

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.

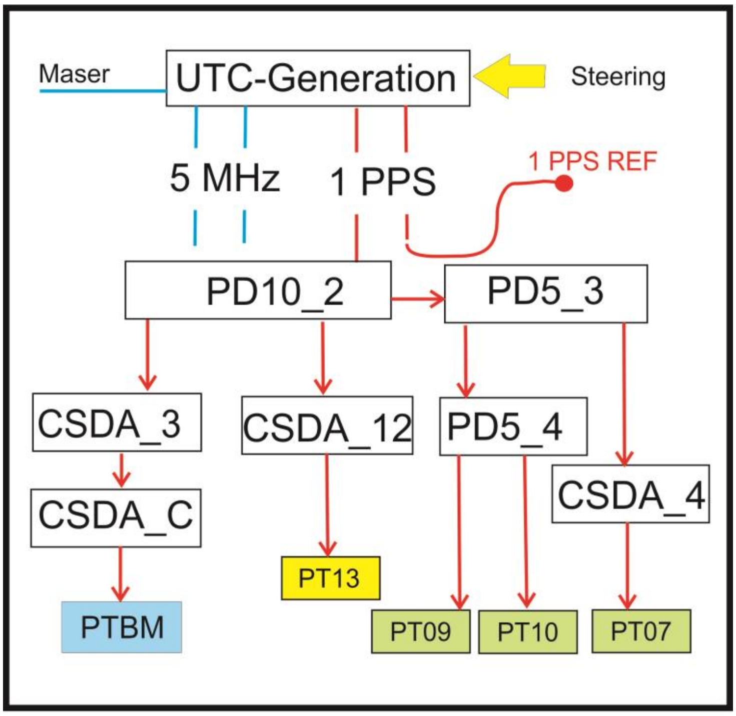

Figure 4-2: UTC(PTB) reference point and 1 PPS signal distribution to PT13, PTBM, and other receivers; PD10 stands for pulse distributor, CSDA stands for clock signal distribution amplifier

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.

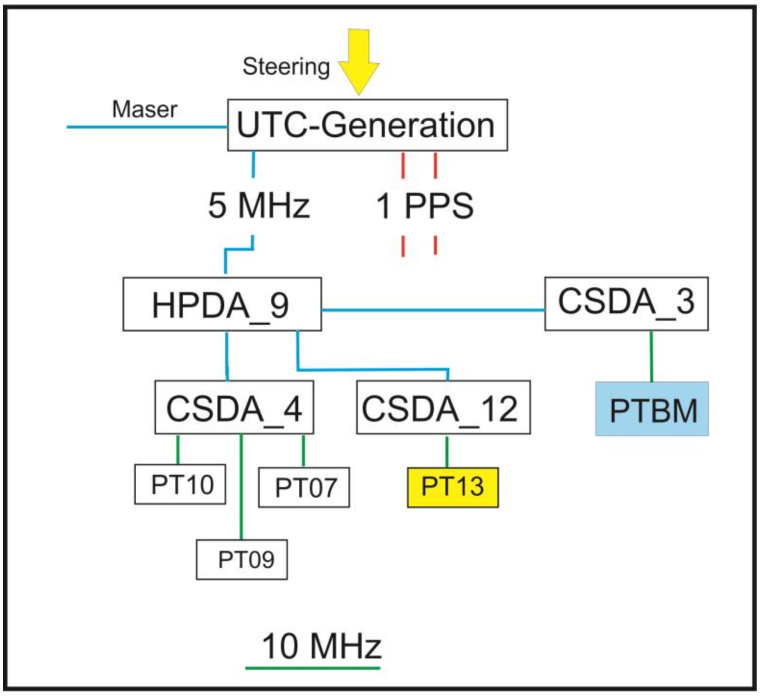

Figure 4-3: UTC(PTB) signal distribution (5 MHz, 10 MHz) to PT13, PTBM, and other receivers

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 during CC1 and CC2 (orange)

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

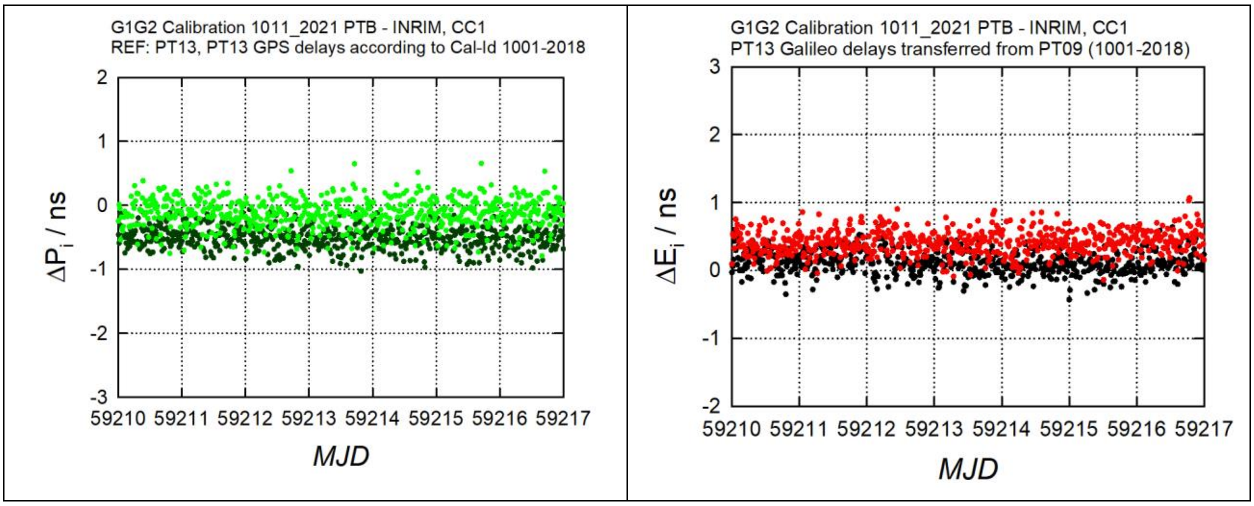

Figure 5-1: Left: Corrections to GPS delay in PTBM during CC1, ΔP1 (dark green) and ΔP2 (light green) Right: Corrections to Galileo delays in PTBM during CC1, ΔE1 (black) and ΔE5a (red).

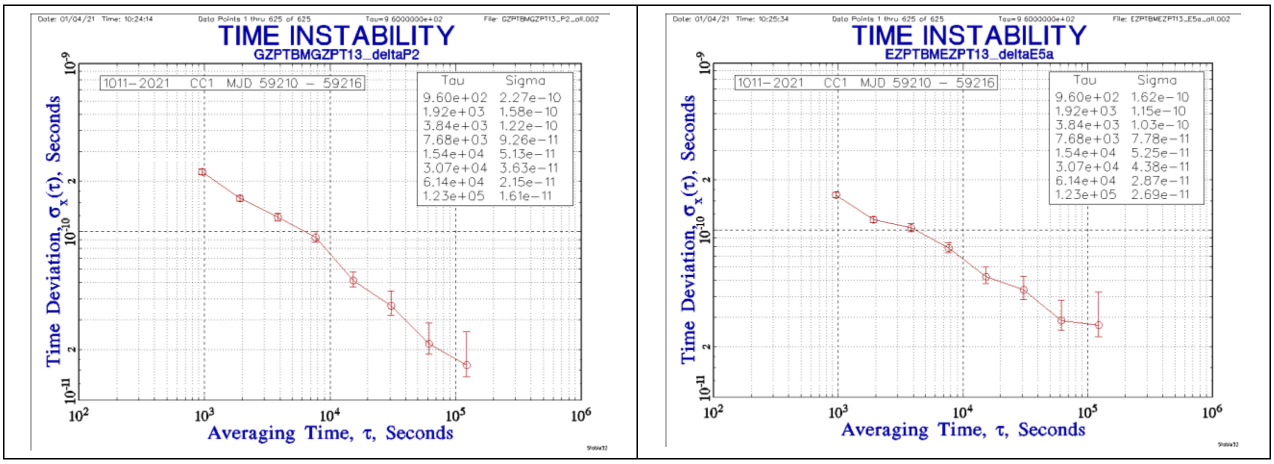

Figure 5-2: TDEV obtained for the two noisier data sets shown in Figure 5-1, GPS dP2 (left), and Galileo dE5a (right).

The period 59210 to 59216 (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 625 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 representing dP2 and dE5a, respectively, follow as Figure 5-2. TDEV for the other data are even lower. 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 INRIM

PTBM was operated at INRIM during weeks 2-4, 2021, in the INRIM time laboratory. INRIM operates a set of receivers whose designations are different when dealing with RINEX and CGGTTS data files, respectively, as illustrated in Table 6-1.

Table 6-1 Designation of INRIM GNSS receivers

Name for reporting to BIPM	IT08	IT09	IT10	IT11	IT12	IT13
INRIM internal designation of the receivers	INR5	INR6	IENG	GR01	GR02	GR03

The signal distribution to receiver PTBM and INRIM receivers is illustrated in Figure 6-1. PTBM was installed in the time lab whereas all INRIM GNSS receivers are operated in the Radio-Navigation Laboratory. Time and Frequency signals are routed between the two locations, and the offset in time between the two UTC(IT) reference points is periodically measured. The actual value is 329.56 ns which is visible in the large values of REFDLY in all CGGTTS files and reported in individual report sheets in the Annex. Repeated REFDLY measurements – one done in the context of this campaign - revealed stable values within 0.1 ns over the last two years.

The main motivation of the current campaign was that the Galileo signal delays in all receivers should be harmonized and aligned to the G1 reference value provided by BIPM in the past as explained above.

During the first period (6 days, ending 2021-01-20) all receivers except IT09 were operated which was operated only in a second period ending 2021-01-28.

The installation of the PTBM antenna is shown as Figure 6-2.

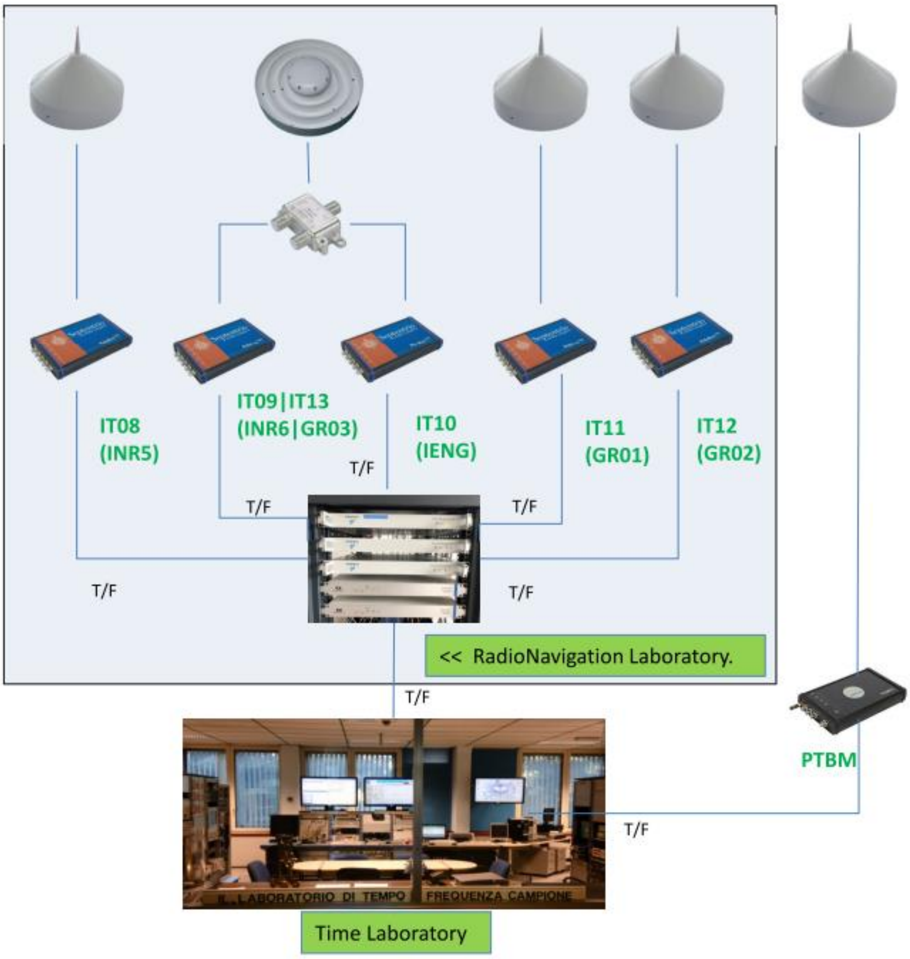

Figure 6-1. Signal distribution at INRIM to the receivers

Figure 6-2. GNSS antennas of PTBM on the INRIM building, view to South

6.1. CALIBRATION OF RECEIVER IT08 (INR5)

Internal delays of receiver IT08 (INR5) had previously been determined in campaign 1014-2019 (GPS) and earlier using the Defraigne method (Galileo) [RD.10].

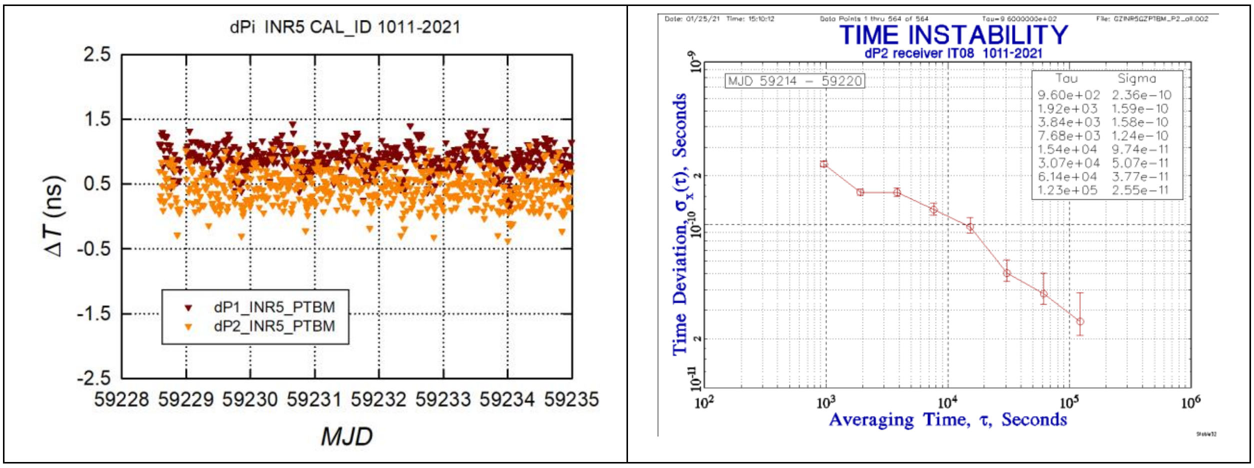

Figure 6-3. Left: Corrections to GPS INT DLY in IT08, reference PTBM; GPS ΔP1 (brown) and ΔP2 (orange), right: TDEV calculated from the dP2 values shown in the left panel.

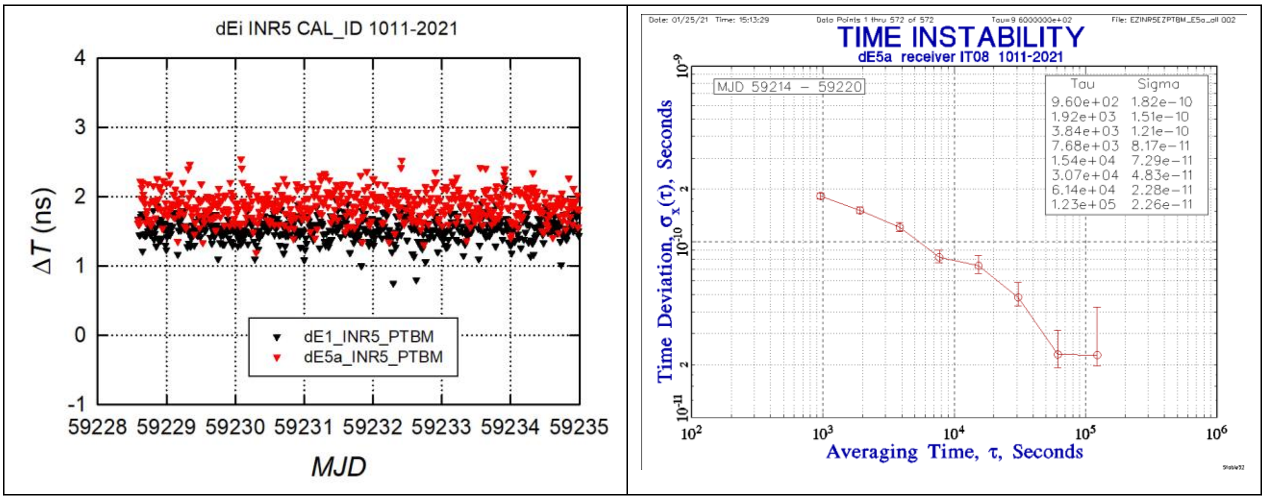

Figure 6-4. Left: Corrections to Galileo INT DLY in IT08, reference PTBM; left: Galileo ΔE1 (black) and ΔE5a (red), right: TDEV calculated from the d5a values shown in the left panel..

In Figure 6-3 and Figure 6-4, the ΔIDi (3) derived from the raw data are depicted. The results are collected in Table 6-2 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 τ = 50 000 s. The default value of 0.1 ns is chosen if the measured TDEV is less than 0.1 ns. In the figures the TDEV-plot for the noisiest data set is shown. These explanataions are valid for all receivers and not repeated each time.

6.2. CALIBRATION OF RECEIVER IT09 (INR6)

The receiver IT09 did not have Galileo delay values previously determined. The values reported are thus the delays to be used furtheron.

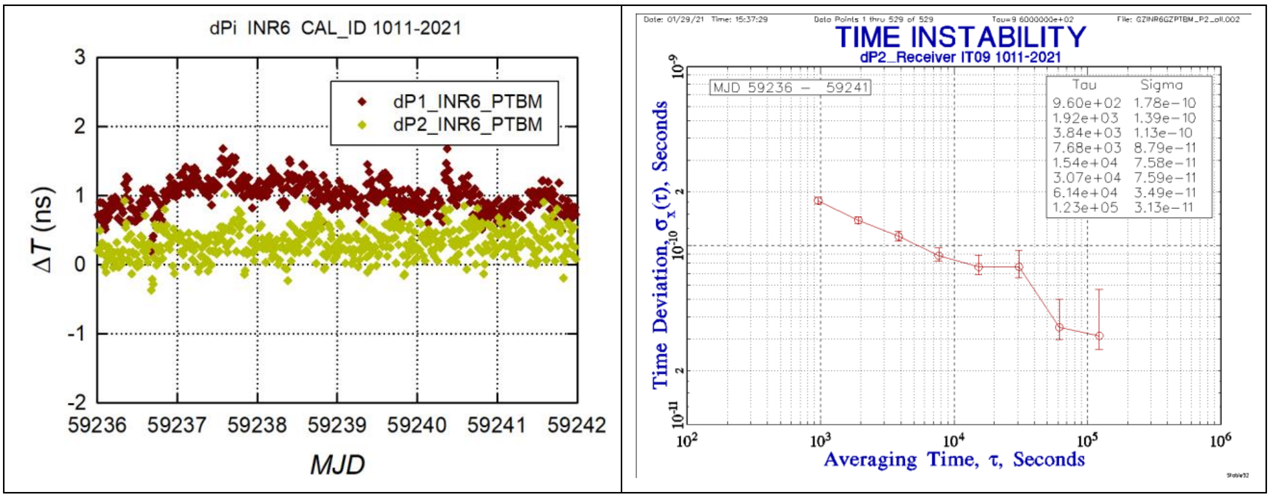

Figure 6-5. Left: INT DLY of IT09, reference PTBM; GPS P1 (brown) and P2 (oliv), right: TDEV calculated from the P2 values shown in the left panel.

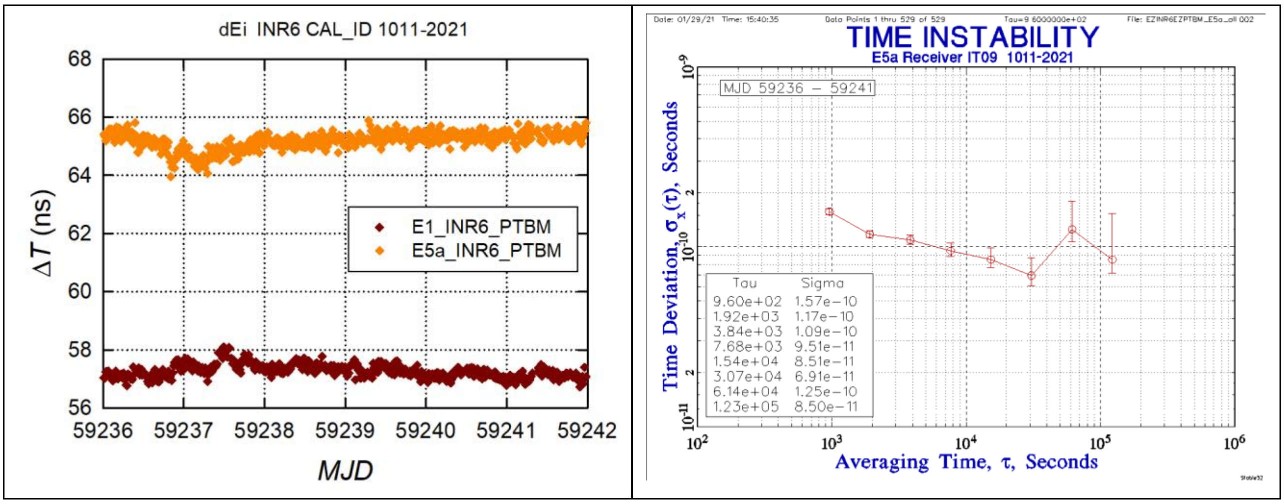

Figure 6-6. INT DLY of IT09, reference PTBM; left: Galileo E1 (brown) and E5a (orange), right: TDEV calculated from the E5a values shown in the left panel.

6.3. CALIBRATION OF RECEIVER IT10 (IENG)

Internal delays of receiver IT11 (GR01G) had previously been determined in campaign 1014-2019 (GPS), but no Galileo delays had been known. The values reported are thus the delays to be used furtheron.

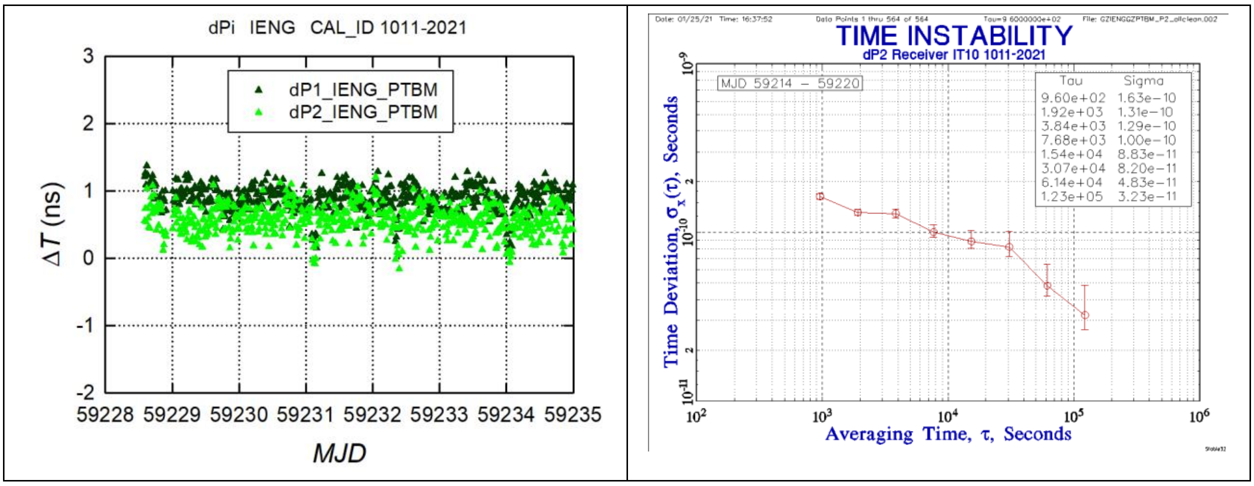

Figure 6-7. Left: Corrections to GPS INT DLY in IT10, reference PTBM; GPS ΔP1 (dark) and ΔP2 (bright), right: TDEV calculated from the dP2 values shown in the left panel.

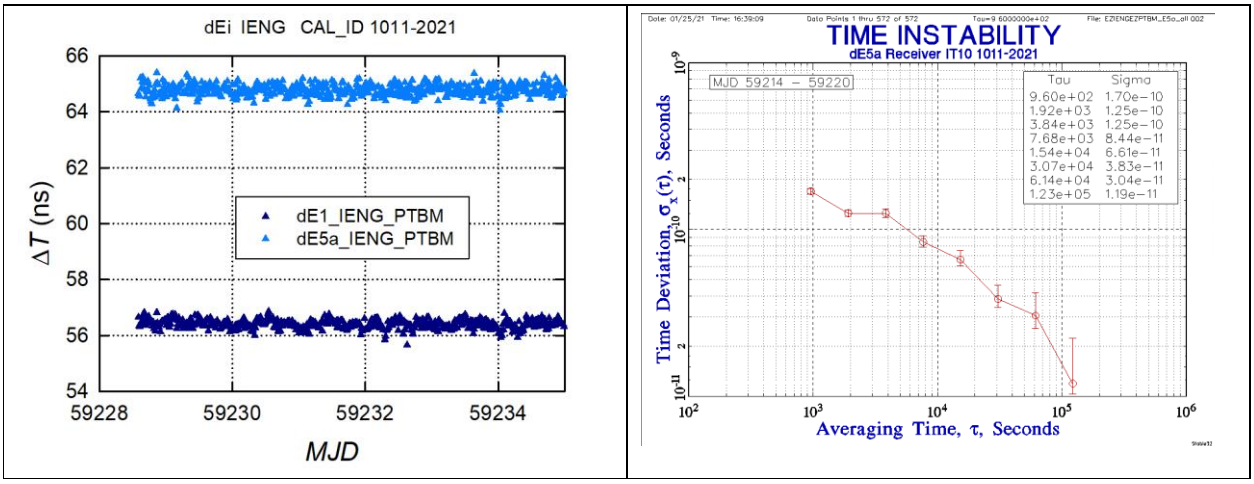

Figure 6-8. Left: Galileo INT DLY in IT10, reference PTBM; left: Galileo ΔE1 (dark) and ΔE5a (bright), right: TDEV calculated from the dE5a values shown in the left panel.

In Figure 6-7 and Figure 6-8, the ΔIDi (3) derived from the raw data are depicted. The results are again collected in Table 6-2.

6.4. CALIBRATION OF RECEIVER IT11 (GR01)

Internal delays of receiver IT11 (GR01) had previously been determined in campaign 1014-2019 (GPS), and Galileo delays had been determined in the frame of the EU DEMETRA project by CNES. In Figure 6-9 and Figure 6-10, the ΔIDi (3) derived from the raw data are depicted. The results are again collected in Table 6-2.

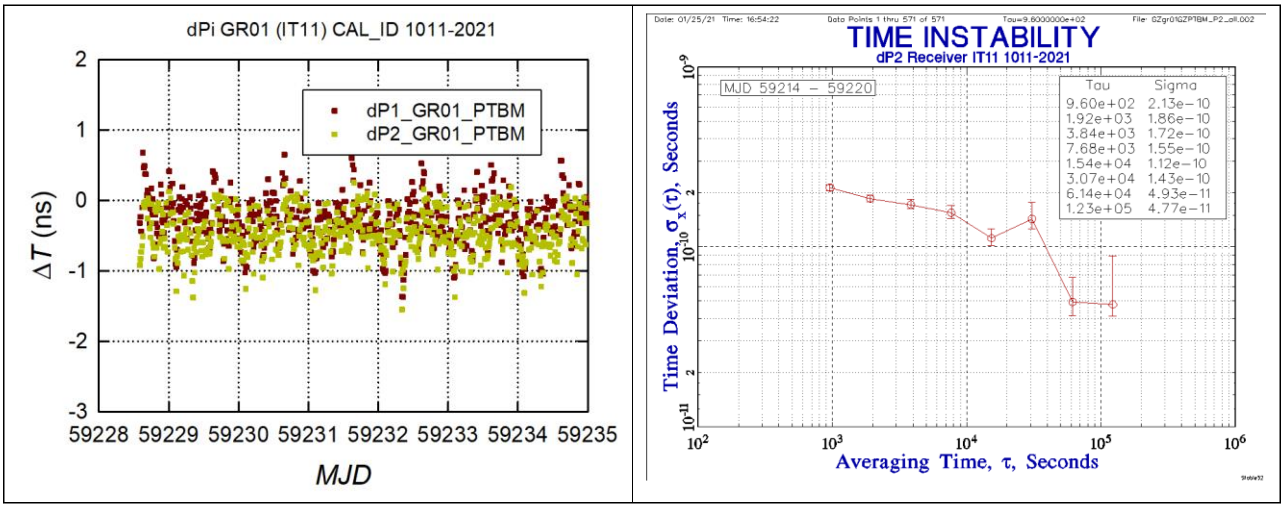

Figure 6-9. Left: Corrections to GPS INT DLY in IT11, reference PTBM; GPS ΔP1 (brown) and ΔP2 (olive), right: TDEV calculated from the dP2 values shown in the left panel.

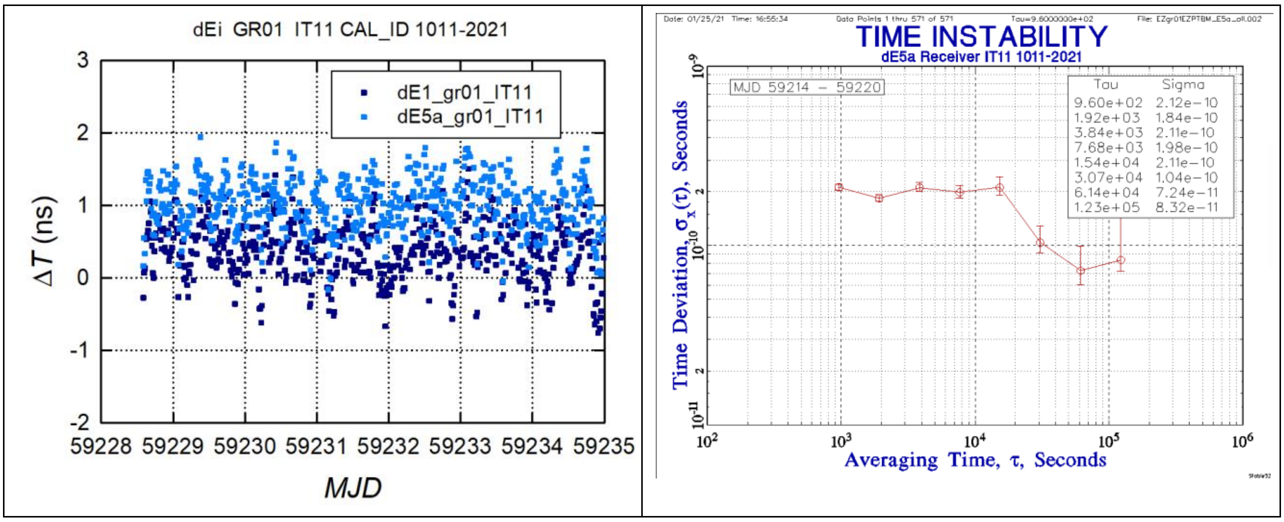

Figure 6-10. Galileo INT DLY in IT11, reference PTBM; left: Galileo ΔE1 (dark) and ΔE5a (bright), right: TDEV calculated from the dE5a values shown in the left panel.

6.5. CALIBRATION OF RECEIVER IT12 (GR02)

Internal delays of receiver IT12 (GR02) had previously been determined in campaign 1014-2019 (GPS) and earlier using the Defraigne method (Galileo) [RD.10]. In Figure 6-11 and Figure 6-12, the ΔIDi (3) derived from the raw data are depicted. The results are again collected in Table 6-2.

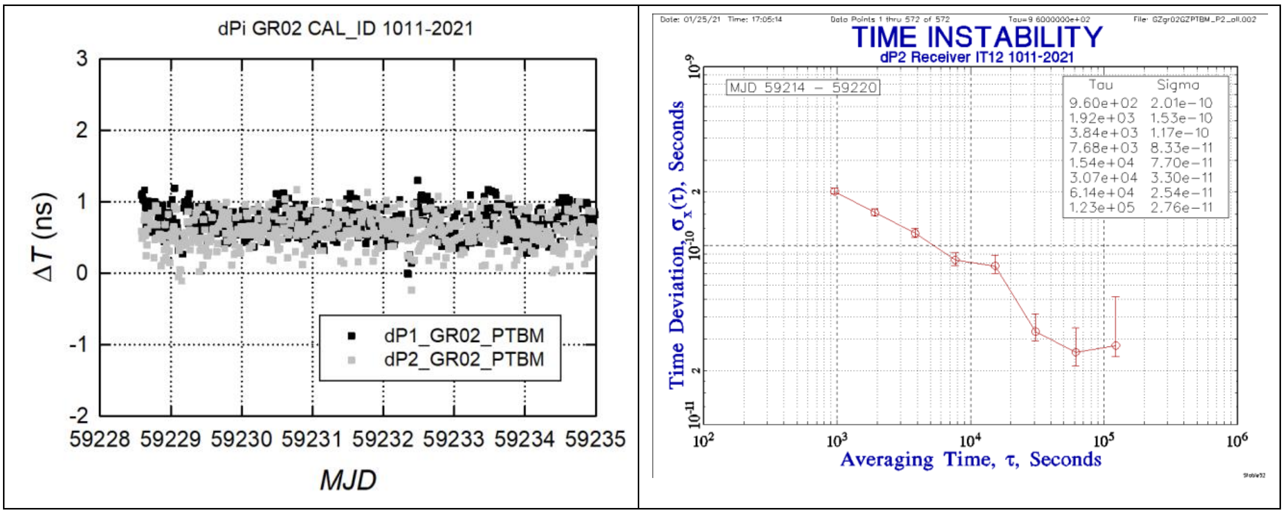

Figure 6-11. Left: Corrections to GPS INT DLY in IT12, reference PTBM; GPS ΔP1 (black) and ΔP2 (grey), right: TDEV calculated from the dP2 values shown in the left panel.

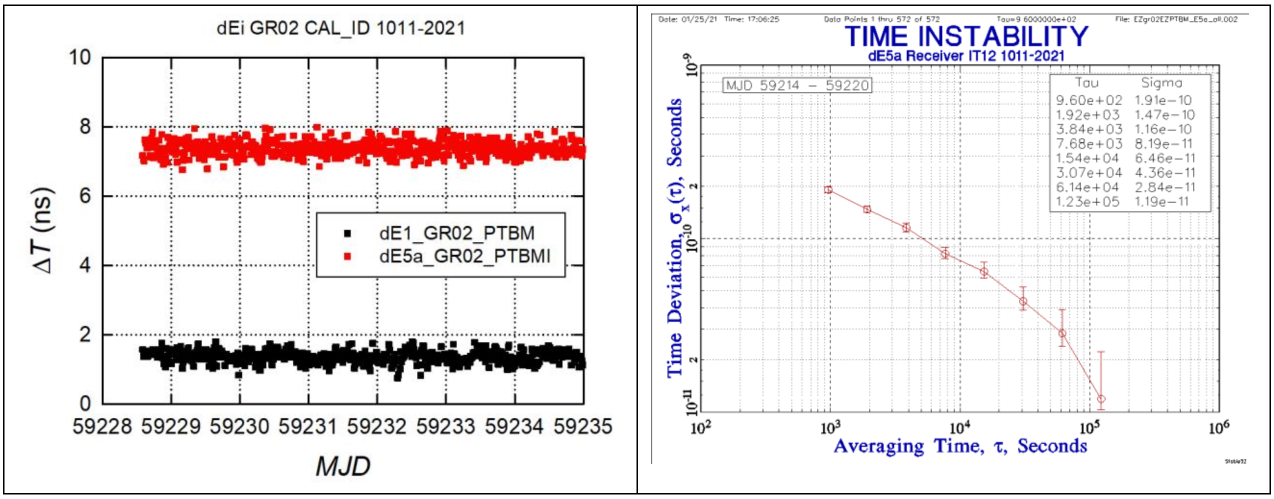

Figure 6-12. Galileo INT DLY in IT12, reference PTBM; left: Galileo ΔE1 (black) and ΔE5a (red), right: TDEV calculated from the dE5a values shown in the left panel.

6.6. CALIBRATION OF RECEIVER IT13 (GR03)

Galileo internal delays of receiver IT13 (GR03) had previously not been determined. The “old” GPS delays are due to a quite different installation as explained in the report sheet in the Annex. In Figure 6-13 and Figure 6-14, the ΔIDi (3) derived from the raw data are depicted. The results are again collected in Table 6-2.

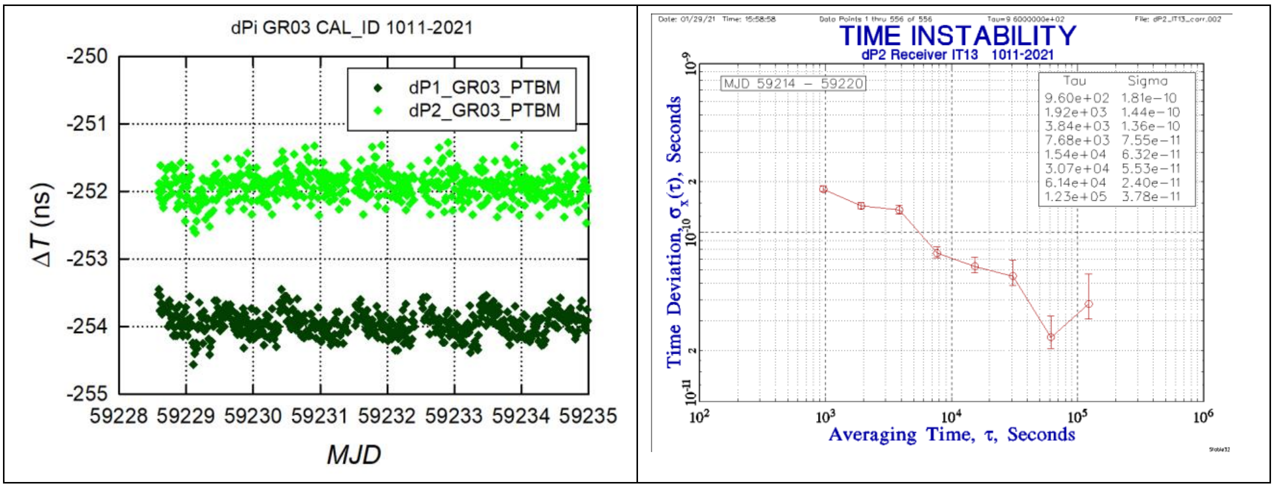

Figure 6-13. Left: Corrections to GPS INT DLY in IT13, reference PTBM; GPS ΔP1 (dark) and ΔP2 (light), right: TDEV calculated from the dP2 values shown in the left panel.

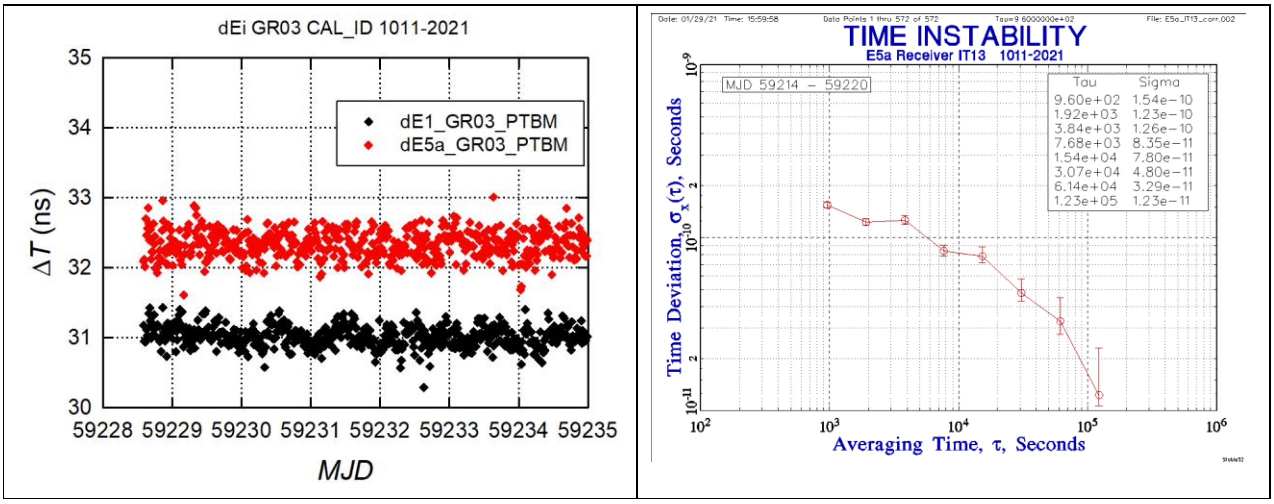

Figure 6-14. Galileo INT DLY in IT13 (GR03), reference PTBM; left: Galileo ΔE1 (black) and ΔE5a (red), right: TDEV calculated from the E5a values shown in the left panel

6.7. SUMMARY OF RESULTS OBTAINED AT INRIM

Table 6-2 ∆INT DLY(fi) values and statistical properties (in ns) obtained initially.

∆INT DLY (fi) for receiver at INRIM	Mean (ns)	Median (ns)	Sigma (ns)	TDEV (ns)	N
IT08 (INR5)					
dP1	0.89	0.89	0.20	0.1	565
dP2	0.43	0.43	0.27	0.1	565
dE1	1.53	1.53	0.17	0.1	572
dE5a	1.88	1.88	0.21	0.1	572
IT09 (INR6)					
dP1	0.99	0.99	0.22	0.1	529
dP2	0.31	0.30	0.22	0.1	529
E1	57.27	57.25	0.23	0.1	529
E5a	65.19	65.22	0.31	0.1	529
IT10 (IENG)					
dP1	0.88	0.89	0.19	0.1	564
dP2	0.56	0.57	0.22	0.1	564
dE1	56.41	56.41	0.16	0.1	572
dE5a	64.78	64.78	0.20	0.1	572
IT11 (GR01)					
dP1	-0.29	-0.28	0.34	0.15	571
dP2	-0.46	-0.49	0.31	0.15	571
dE1	0.36	0.37	0.38	0.15	571
dE5a	1.02	1.03	0.37	0.15	571
IT12 (GR02)					
dP1	0.71	0.70	0.19	0.1	572
dP2	0.58	0.59	0.22	0.1	572
dE1	1.36	1.37	0.17	0.1	572
dE5a	7.37	7.37	0.21	0.1	572

∆INT DLY (fi) for receiver at INRIM	Mean (ns)	Median (ns)	Sigma (ns)	TDEV (ns)	N
IT13 (GR03)					
dP1	-253.85	-253.96	0.18	0.1	556
dP2	-251.91	-251.90	0.22	0.1	556
dE1	31.02	31.02	0.15	0.1	572
dE5a	32.33	32.33	0.20	0.1	572

7. OPERATION OF PTBT AT PTB: SECOND PERIOD

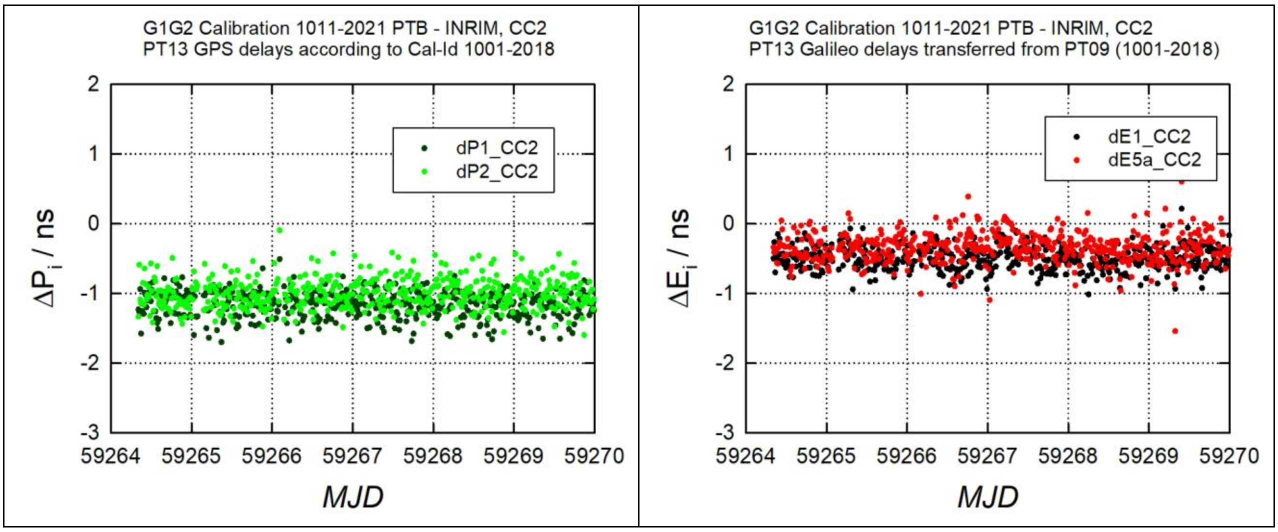

Figure 7-1. Left: Corrections to GPS delay in PTBM during CC2, ΔP1 (dark green) and ΔP2 (light green) Right: Corrections to Galileo delays in PTBM during CC2, ΔE1 (black) and ΔE5a (red).

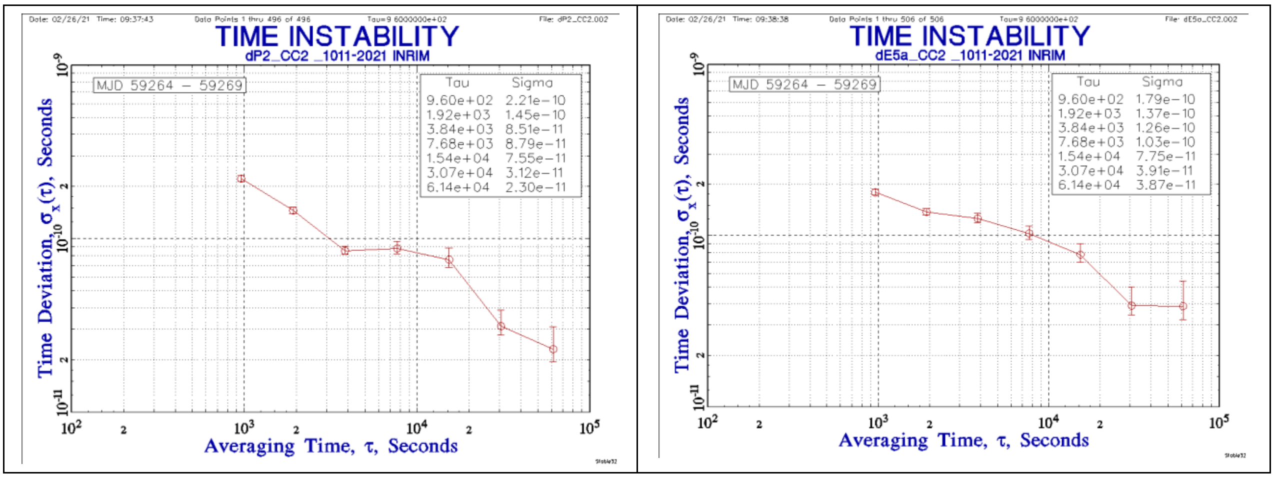

Figure 7-2. TDEV obtained for the data sets GPS dP2 (left) and Galileo dE5a (right) from Figure 7-1.

The period 59264 to 59269 (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 ΔIDi values obtained as mean values over all common view observations at a given epoch. The time instability (TDEV) plots for the two data sets representing dP2 and dE5a, respectively, follow as Figure 7-2. TDEV for the other data are even lower.

The installation of PTBM for the period CC2 suffered delay because of the winter conditions prevailing initially, as demonstrated in Figure 7-3.

Figure 7-3 Roof conditions at PTB at nominal start of campaign CC2

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 0.25 ns for ΔP2. 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)	-0.50	0.18	< 0.1
ΔP2 (CC1)	-0.12	0.23	< 0.1
ΔP3 (CC1)	-1.08		
ΔE1 (CC1)	+0.11	0.17	< 0.1
ΔE5a (CC1)	+0.41	0.18	< 0.1
ΔE3 (CC1)	-0.27		
ΔP1 (CC2)	-1.16	0.19	< 0.1
ΔP2 (CC2)	-0.99	0.22	< 0.1
ΔP3 (CC2)	-1.42		
ΔE1 (CC2)	-0.48	0.18	< 0.1
ΔE5a (CC2)	-0.34	0.22	< 0.1
ΔE3 (CC2)	-0.16		
Mean values used for evaluation of visited receivers' internal delays			
ΔP1	-0.83		
ΔP2	-0.56		

∆E1	-0.19		
∆E5a	0.04		

8. INT DLY UNCERTAINTY EVALUATION

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

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

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

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

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

Values in column P3 are calculated according to $u(P3) = \sqrt{\{u(P1)^2 + (1.54 \times u(P1\text{-}P2))^2\}}$. Uncertainties for the Galileo delays are calculated according to $\sqrt{\{u(E1)^2 + (1.26 \times u(E1\text{-}E5a))^2\}}$. Both rules do not apply for lines 3a and 3b in Table 8-1 as stated in the text.

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(INRIM)	0.1	0.1	0.14	0.23	CC measurement uncertainty, for the 2 INRIM receivers
Result of closure measurement at PTB						
3a	$u_{b,1}$ (GPS)	0.33	0.44		0.42	Misclosure, see Table 7-1
3b	$u_{b,1}$ (Galileo)	0.30	0.38		0.42	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	$u_{b,12}$(INRIM)	0.1	0.1	0.14	0.28	Position error at INRIM
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 INRIM
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(IT) (REF DLY)
10	$u_{b,23}$	0.2	0.2	0	0.2	Connection of receivers at INRIM to UTC(IT) (REF DEL)
11	$u_{b,24}$	0.2	0.2	0	0.2	REF DLY uncertainty PTBM
Antenna cable delay						
12	$u_{b,31}$(PTB)	0.5	0.5	0	0.5	Uncertainty estimate for the PTBM CAB DLY when installed at PTB
13	$u_{b,32}$(INRIM)	0.0	0.0	0	0.0	Uncertainty estimate for the PTBM CAB DLY when installed at INRIM
14	$u_{b,33}$(INRIM)	0.5	0.5	0	0.5	Uncertainty estimate for INRIM CAB DLY values

As demonstrated in Table 6-2, the receivers at INRIM show almost the same time instability. The TDEV plots (not all reproduced in this Report) show marginal differences, and the value of 0.1 ns is a conservative estimate anyway. In case of receiver IT11 the measurement noise is somewhat larger, but the effect is negligible in the combined statistic and systematic uncertainty. 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 from the mean value exceed the statistical measurement uncertainty by at least a factor of 2. So the difference from the respective mean value is considered as measure for the uncertainty. The value for the linear combination (P3 or E3, respectively) are based on the statistical uncertainty of the closure results.

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 INRIM.

PTBM was operated at both sites in the mode "auto determination of the compensation of the PPSIN delay". The manufacturer specifies the uncertainty as 0.1 ns. No experience has been gained up to now whether this auto-determination shows some dependence on the PPS to 10 MHz phase relation. The uncertainty contribution $u_{b,24}$ is thus set to 0.2 ns.

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 INRIM. 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 INRIM 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_1011_2021 are summarized in Table 9-1 and Table 9-2. They contain the designation of the visited receivers, the INT DLY values hitherto used, the offsets ∆IDi(V,T) and ∆IDi(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_1011_2021: GPS delays, all values in ns

Receiver	INT DLY(P1), old	INT DLY(P2); old	∆P1 (V,T)	∆P2 (V,T)	∆P1 (T,G)	∆(P2) (T,G)	INT DLY(P1), new	u_{cal}, P1	INT DLY(P2), new	u_{cal}, P2	u_{cal}, L3P
IT08 (INR5)	310.0	309.1	0.89	0.43	-0.83	-0.56	310.06	0.95	308.97	0.99	1.09
IT09 (INR6)	55.60	55.76	0.99	0.30	-0.83	-0.56	55.76	0.95	55.50	0.99	1.09
IT10 (IENG)	54.9	55.3	0.89	0.57	-0.83	-0.56	54.96	0.95	55.31	0.99	1.09
IT11 (GR01)	57.0	55.0	-0.28	-0.49	-0.83	-0.56	55.89	0.95	53.95	0.99	1.09
IT12(GR02)	353.7	353.1	0.70	0.59	-0.83	-0.56	353.57	0.95	353.13	0.99	1.09
IT13 (GR03)	283.0	280.4	-253.96	-251.9	-0.83	-0.56	28.21	0.95	27.94	0.99	1.09

Table 9-2. Results of the Calibration Campaign G1G2_1011_2021: 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
IT08 (INR5)	310.0	319.1	1.53	1.88	-0.19	0.04	311.34	0.93	321.02	0.96	1.09
IT09 (INR6)	0	0	57.25	65.22	-0.19	0.04	57.06	0.93	65.26	0.96	1.09
IT10 (IENG)	0	0	56.41	64.78	-0.19	0.04	56.22	0.93	64.82	0.96	1.09
IT11 (GR01)	57.0	62.5	0.37	1.03	-0.19	0.04	57.18	0.93	63.57	0.96	1.09
IT12(GR02)	353.7	355.3	1.37	7.37	-0.19	0.04	354.88	0.93	362.71	0.96	1.09
IT13 (GR03)	0	0	31.02	32.33	-0.19	0.04	30.83	0.93	32.37	0.96	1.09

ANNEX: BIPM CALIBRATION INFORMATION SHEETS

First common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of	2020-12-27 0:00 UTC (MJD 59210)
Date and hour of the end of measurements:	2021-01-02 24:00 UTC (MJD 59216)

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 (#)	43.2 +/- 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) (*) 32.0 (E1), 31.7 (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		43.2	
☐ Coordinates reference frame:	ITRF		ITRF	
X /m:	+3844059.86 (***)	Mast P10	+3844062.56 ($)	Mast P7
Y /m:	+709661.56 (***)		+709658.49 ($)	
Z /m	+5023129.87 (***)		+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 0.5° C

Notes valid for CC1 and CC2:

(#) values determined at installation of PT13 in March 2019, local measurements not repeated
($) Coordinates of mast P7 (APC) were determined on 26.05.2020 using NRCan PPP
(*) values based on G1 calib 1001-2018, transferred from receiver PT09 [RD08, RD09]]
(***) values provided by BIPM via Mail 2019-08-07
(****) PTBM 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 GZPTBMMJ.DDD, EZPTBMMJ.DDD
Reference receiver GZPT13MJ.DDD, EZPT13MJ.DDD

PTBM operation at INRIM: Receiver IT08 (INR5)

Laboratory	IT	
Date and hour beginning of measurements	59228 (14/01/2021) 14:02	
Date and hour end of measurements	59234 (20/01/2021) 24:00	
Information on the system		
	Local	**Traveling**
4-character BIPM code	IT08 (INR5)	PTBM
Receiver maker and type Receiver serial number	Septentrio PolaRx4-TR 3002130	PolaRx5TR (5.3.0) S/N 3048338
1 PPS trigger level /V	1 V	1
Antenna cable maker and type Phase stabilized cable (Y/N)	60 m low loss RF cable (RG214)	LMR-400 (N)
Cable length outside building /m	5 m	5 m
Antenna maker and type Antenna serial number	SEPCHOKE_B3E6 5410	Navexperience 3G+C REFERENCE S/N RE 0560
Temperature if stabilized /°C	NA	NA
Measured delays / ns		
	Local	**Traveling**
Delay from local UTC(k) to receiver 1 PPS_IN	%	124.8
Delay from 1 PPS_IN to internal reference (see Annex 1)	%	Automatic compensation activated
Delay from local UTC to receiver reference REFDLY	484.1 (2019) / 484.0 (2021) (#)	124.8
Antenna cable delay	0.0 (not measured)	264.9
Splitter delay	NA	
Additional cable delay	NA	
Data used for the generation of CGGTTS files		
	Local	**Traveling**
INT DLY (GPS) /ns	310.0 (P1), 309.1 (P2)	18.9 (P1), 17.1 ns (P2)
INT DLY (Galileo) /ns	310.0 (E1), 319.1 ns (E5a)	20.8 (GAL E1), 17.9 (E5a)
CAB DLY /ns	0.0	264.9
REF DLY /ns	484.1 (%)	124.8
Coordinate reference frame	ITRF (IGb08)	ITRF
Latitude or X /m	4476532.08	+4476543.78
Longitude or Y /m	600443.18	600409.75

Height or Z /m	4488760.24	4488742.34

General information	
Rise time of local UTC pulse	500 ps
Air conditioning (Y/N)	Y
Set temperature value and uncertainty	22 °C +- 1 °C (RadioNavigation Laboratory)
Set humidity value and uncertainty	Not Controlled. Measured as: 60% RU +- 10% RU

All coordinates (APC) determined using NRCCan PPP for day 15/2021. CAB DLY values represent the 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.

(#) The calculation of internal delays was based on RINEX files and parameter files that containted the REF DLY vales measured 2019. Data from 2021 (greyed-out) were reported after the fact and demonstrate the excellent stability of the installation. This note is valid for all receivers.

(%) During campaign 1014-2019, Xp and Xo had been measured separately, and its was verified that the Xo was within the typical values for Septentrio receivers. For the current campaign, 1011-2021, the global REF DLY was measured, without splitting among Xo and Xp components, but the sum value was found constant within ±0.1 ns

IT08: report of SYS DLY as CAB DLY unknown

Names of files to be used in processing for site INRIM

Travelling receiver GZPTBMMJ.DDD, EZPTBMMJ.DDD, DUT: GZINR5MJ.DDD, EZINR5MJ.DDD.

PTBM operation at INRIM: Receiver IT09 (INR6)

Laboratory	IT	
Date and hour beginning of measurements	59236 (22/01/2021) 0:00	
Date and hour end of measurements	59240 (27/01/2021) 24:00	
Information on the system		
	Local	**Traveling**
4-character BIPM code	IT09 (INR6)	PTBM
Receiver maker and type Receiver serial number	Septentrio PolaRx4-TR 3102240	PolaRx5TR (5.3.0) S/N 3048338
1 PPS trigger level /V	1 V	1
Antenna cable maker and type Phase stabilized cable (Y/N)	25 m low loss RF cable (RG214)	LMR-400 (N)
Cable length outside building /m	5 m	5 m
Antenna maker and type Antenna serial number	SEPCHOKE_MC NONE 5261	Navexperience 3G+C REFERENCE S/N RE 0560
Temperature if stabilized /°C	NA	NA
Measured delays / ns		
	Local	**Traveling**
Delay from local UTC(k) to receiver 1 PPS_IN	%	124.8
Delay from 1 PPS_IN to internal reference (see Annex 1)	%	Automatic compensation activated
Delay from local UTC to receiver reference REFDLY	484.1 (2019) / 484.0 (2021)	124.8
Antenna cable delay	128.8	264.9
Splitter delay	0.7 (shared with IT10)	
Additional cable delay	1.0	
Data used for the generation of CGGTTS files		
	Local	**Traveling**
INT DLY (GPS) /ns	55.601 (P1), 55.761 (P2)	18.9 (P1), 17.1 ns (P2)
INT DLY (Galileo) /ns	NA	20.8 (GAL E1), 17.9 (E5a)
CAB DLY /ns	130.5	264.9
REF DLY /ns	484.1 (%)	124.8
Coordinate reference frame	ITRF (IGb08)	ITRF
Latitude or X /m	4476537.23	+4476543.78
Longitude or Y /m	600431.74	600409.75

Height or Z /m	4488761.55	4488742.34

General information	
Rise time of local UTC pulse	500 ps
Air conditioning (Y/N)	Y
Set temperature value and uncertainty	22 °C +- 1 °C (RadioNavigation Laboratory)
Set humidity value and uncertainty	Not Controlled. Measured as: 60% RU +- 10% RU

(%) During campaign 1014-2019, Xp and Xo had been measured separately, and its was verified that the Xo was within the typical values for Septentrio receivers. For the current campaign, 1011-2021, the global REF DLY was measured, without splitting among Xo and Xp components, but the sum value was found constant within ±0.1 ns

Names of files to be used in processing for site INRIM
Travelling receiver GZPTBMMJ.DDD, EZPTBMMJ.DDD, DUT: GZINR6MJ.DDD, EZINR6MJ.DDD.

PTBM operation at INRIM: Receiver IT10 (IENG)

Laboratory	IT	
Date and hour beginning of measurements	59228 (14/01/2021) 14:02	
Date and hour end of measurements	59234 (20/01/2021) 24:00	
Information on the system		
	Local	**Traveling**
4-character BIPM code	IT10 (IENG)	PTBM
Receiver maker and type Receiver serial number	Septentrio PolaRx4-TR 3102220	PolaRx5TR (5.3.0) S/N 3048338
1 PPS trigger level /V	1 V	1
Antenna cable maker and type Phase stabilized cable (Y/N)	25 m low loss RF cable (RG214)	LMR-400 (N)
Cable length outside building /m	5 m	5 m
Antenna maker and type Antenna serial number	SEPCHOKE_MC NONE 5261	Navexperience 3G+C REFERENCE S/N RE 0560
Temperature if stabilized /°C	NA	
Measured delays / ns		
	Local	**Traveling**
Delay from local UTC(k) to receiver 1 PPS_IN	%	124.8
Delay from 1 PPS_IN to internal reference (see Annex 1)	%	Automatic compensation activated
Delay from local UTC to receiver reference REFDLY:	483.7 (2019) / 483.6 (2021)	124.8
Antenna cable delay	128.8	264.9
Splitter delay	0.7 (shared with IT09/IT13)	
Additional cable delay	1.0	
Data used for the generation of CGGTTS files		
	Local	**Traveling**
INT DLY (GPS) /ns	54.9 (P1), 55.3 (P2)	18.9 (P1), 17.1 ns (P2)
INT DLY (Galileo) /ns	NA	20.8 (GAL E1), 17.9 (E5a)
CAB DLY /ns	130.5	264.9
REF DLY /ns	483.7 (%)	124.8
Coordinate reference frame	ITRF (IGb08)	ITRF
Latitude or X /m	4476537.23	+4476543.78
Longitude or Y /m	600431.74	600409.75

Height or Z /m	4488761.55	4488742.34

General information	
Rise time of local UTC pulse	500 ps
Air conditioning (Y/N)	Y
Set temperature value and uncertainty	22 °C +- 1 °C (RadioNavigation Laboratory)
Set humidity value and uncertainty	Not Controlled. Measured as: 60% RU +- 10% RU

(%) During campaign 1014-2019, Xp and Xo had been measured separately, and its was verified that the Xo was within the typical values for Septentrio receivers. For the current campaign, 1011-2021, the global REF DLY was measured, without splitting among Xo and Xp components, but the sum value was found constant within ±0.1 ns

Names of files to be used in processing for site INRIM
Travelling receiver GZPTBMMJ.DDD, EZPTBMMJ.DDD, DUT: GZIENGMJ.DDD, EZIENGMJ.DDD.

PTBM operation at INRIM: Receiver IT11 (GR01)

Laboratory	IT	
Date and hour beginning of measurements	59228 (14/01/2021) 14:02	
Date and hour end of measurements	59234 (20/01/2021) 24:00	
Information on the system		
	Local	**Traveling**
4-character BIPM code	IT11 (GR01)	PTBM
Receiver maker and type Receiver serial number	Septentrio PolaRx4-TR 3008032	PolaRx5TR (5.3.0) S/N 3048338
1 PPS trigger level /V	1 V	1
Antenna cable maker and type Phase stabilized cable (Y/N)	60 m low loss RF cable (RG214)	LMR-400 (N)
Cable length outside building /m	5 m	5 m
Antenna maker and type Antenna serial number	SEPCHOKE_B3E6 5025	Navexperience 3G+C REFERENCE S/N RE 0560
Temperature if stabilized /°C	NA	
Measured delays / ns		
	Local	**Traveling**
Delay from local UTC(k) to receiver 1 PPS_IN	%	124.8
Delay from 1 PPS_IN to internal reference (see Annex 1)	N%	Automatic compensation activated
Delay from local UTC to receiver reference REFDLY	483.8 (2019) / 483.7 (2021)	124.8
Antenna cable delay	298.6	264.9
Splitter delay	NA	
Additional cable delay	NA	
Data used for the generation of CGGTTS files		
	Local	**Traveling**
INT DLY (GPS) /ns	57.0 (P1), 55.0 (P2)	18.9 (P1), 17.1 ns (P2)
INT DLY (Galileo) /ns	57.0 (GAL E1), 62.5 (GAL E5a)	20.8 (GAL E1), 17.9 (E5a)
CAB DLY /ns	298.6	264.9
REF DLY /ns	483.8 (%)	124.8
Coordinate reference frame	ITRF (IGb08)	ITRF
Latitude or X /m	4476537.727	+4476543.78
Longitude or Y /m	600441.720	600409.75

Height or Z /m	4488754.845	4488742.34

General information	
Rise time of local UTC pulse	500 ps
Air conditioning (Y/N)	Y
Set temperature value and uncertainty	22 °C +- 1 °C (RadioNavigation Laboratory)
Set humidity value and uncertainty	Not Controlled. Measured as: 60% RU +- 10% RU

(%) During campaign 1014-2019, Xp and Xo had been measured separately, and its was verified that the Xo was within the typical values for Septentrio receivers. For the current campaign, 1011-2021, the global REF DLY was measured, without splitting among Xo and Xp components, but the sum value was found constant within ±0.1 ns

Names of files to be used in processing for site INRIM

Travelling receiver GZPTBMMJ.DDD, EZPTBMMJ.DDD, DUT: GZGR01MJ.DDD, EZGR01MJ.DDD.

PTBM operation at INRIM: Receiver IT12 (GR02)

Laboratory	IT	
Date and hour beginning of measurements	59228 (14/01/2021) 14:02	
Date and hour end of measurements	59234 (20/01/2021) 24:00	
Information on the system		
	Local	**Traveling**
4-character BIPM code	IT12 (GR02)	PTBM
Receiver maker and type Receiver serial number	Septentrio PolaRx4-TR 3008058	PolaRx5TR (5.3.0) S/N 3048338
1 PPS trigger level /V	1 V	1
Antenna cable maker and type Phase stabilized cable (Y/N)	60 m low loss RF cable (RG214)	LMR-400 (N)
Cable length outside building /m	5 m	5 m
Antenna maker and type Antenna serial number	SEPCHOKE_B3E6 5004	Navexperience 3G+C REFERENCE S/N RE 0560
Temperature if stabilized /°C	NA	
Measured delays / ns		
	Local	**Traveling**
Delay from local UTC(k) to receiver 1 PPS_IN	%	124.8
Delay from 1 PPS_IN to internal reference (see Annex 1)	%	Automatic compensation activated
Delay from local UTC to receiver reference REFDLY	483.6 (2019) / 483.6 (2021)	124.8
Antenna cable delay	0.0 (not measured)	264.9
Splitter delay	NA	
Additional cable delay	NA	
Data used for the generation of CGGTTS files		
	Local	**Traveling**
INT DLY (GPS) /ns	353.7 (P1), 353.1 (P2)	18.9 (P1), 17.1 ns (P2)
INT DLY (Galileo) /ns	353.7 (E1), 355.3 (E5a)	20.8 (GAL E1), 17.9 (E5a)
CAB DLY /ns	0.0	264.9
REF DLY /ns	483.6 (%)	124.8
Coordinate reference frame	ITRF (IGb08)	ITRF
Latitude or X /m	4476534.49	+4476543.78
Longitude or Y /m	600442.61	600409.75

Height or Z /m	4488757.91	4488742.34

General information	
Rise time of local UTC pulse	500 ps
Air conditioning (Y/N)	Y
Set temperature value and uncertainty	22 °C +- 1 °C (RadioNavigation Laboratory)
Set humidity value and uncertainty	Not Controlled. Measured as: 60% RU +- 10% RU

(%) During campaign 1014-2019, Xp and Xo had been measured separately, and its was verified that the Xo was within the typical values for Septentrio receivers. For the current campaign, 1011-2021, the global REF DLY was measured, without splitting among Xo and Xp components, but the sum value was found constant within ±0.1 ns

IT12: report of SYS DLY as CAB DLY unknown

Names of files to be used in processing for site INRIM

Travelling receiver GZPTBMMJ.DDD, EZPTBMMJ.DDD, DUT: GZGR02MJ.DDD, EZGR02MJ.DDD.

PTBM operation at INRIM: Receiver IT13 (GR03)

Laboratory	IT	
Date and hour beginning of measurements	59228 (14/01/2021) 00:00 UTC	
Date and hour end of measurements	59234 (20/01/2021) 23:59 UTC	
Information on the system		
	Local	**Traveling**
4-character BIPM code	IT13 (GR03)	PTBM
Receiver maker and type Receiver serial number	Septentrio PolaRx5-TR 3047010	PolaRx5TR (5.3.0) S/N 3048338
1 PPS trigger level /V	1 V	1
Antenna cable maker and type Phase stabilized cable (Y/N)	25 m low loss RF cable (RG214)	LMR-400 (N)
Cable length outside building /m	5 m	5 m
Antenna maker and type Antenna serial number	SEPCHOKE_MC NONE 5261	Navexperience 3G+C REFERENCE S/N RE 0560
Temperature if stabilized /°C	NA	
Measured delays / ns		
	Local	**Traveling**
Delay from local UTC(k) to receiver 1 PPS_IN	%%	124.8
Delay from 1 PPS_IN to internal reference (see Annex 1)	%%	Automatic compensation activated
Delay from local UTC to receiver reference REFDLY	374.5	124.8
Antenna cable delay	128.8	264.9
Splitter delay	0.7 (shared with IT10)	
Additional cable delay	1.0	
Data used for the generation of CGGTTS files		
	Local	**Traveling**
INT DLY (GPS) /ns	283.0 (P1), 280.4 (P2)	18.9 (P1), 17.1 ns (P2)
INT DLY (Galileo) /ns	NA	20.8 (GAL E1), 17.9 (E5a)
CAB DLY /ns	130.5	264.9
REF DLY /ns	374.5 (%%)	124.8
Coordinate reference frame	ITRF (IGb08)	ITRF
Latitude or X /m	4476537.23	+4476543.78
Longitude or Y /m	600431.74	600409.75

Height or Z /m	4488761.55	4488742.34

General information	
Rise time of local UTC pulse	500 ps
Air conditioning (Y/N)	Y
Set temperature value and uncertainty	22 °C +- 1 °C (Time Laboratory)
Set humidity value and uncertainty	Not Controlled. Measured as: 60% RU +- 10% RU

NOTE: Current INT DLY had been measured in 1014-2019 with a different antenna/cable, whose delay was not measured. In the current campaign, 1011-2021, CAB DLY is 130.5 ns. In addition, REF DLY is different, due to a different installation of the receiver (i.e. at Radio Navigation Laboratory and not at the Time Laboratory anymore).

(%%) During campaign 1014-2019, Xp and Xo had been measured separately, and its was verified that the Xo was within the typical values for Septentrio receivers. For the current campaign, 1011-2021, the global REF DLY was measured, without splitting among Xo and Xp components.

Names of files to be used in processing for site INRIM
Travelling receiver GZPTBMMJ.DDD, EZPTBMMJ.DDD, DUT: GZGR03MJ.DDD, EZGR03MJ.DDD.

Second common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of	2021-02-26 08:10 UTC (MJD 59264)
Date and hour of the end of measurements:	2021-02-24 24:00 UTC (MJD 59269)

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 (#)	42.4 +/- 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), (*) 32.0 (E1), 31.2 (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		42.4+unknown	
☐ Coordinates reference frame:	ITRF (***)		ITRF (****)	
X /m:	+3844059.86 (***)	Mast P10	+3844062.56 ($)	Mast P7
Y /m:	+709661.56 (***)		+709659.49 ($)	
Z /m	+5023129.87 (***)		+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

END of DOCUMENT