GNSS CALIBRATION REPORT

G1G2_1013_2021

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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 des Poids et Mesures, Sèvres, France
CGGTTS	CCTF Generic GNSS Time Transfer Standard
ESA	European Space Agency
EURAMET	The European Association of National Metrology Institutes
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
UFE	Institute of Photonics and Electronics, Czech Academy of Sciences
VSL	Van Swinden Laboratory (NL)

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 UFE and VSL 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 traveling equipment. The current campaign followed as much as possible the BIPM Guide [RD02] and results will be reported using Cal_Id 1013_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].

During the campaign, new delay values for PT13 were published by BIPM and implemented for routine use starting August 2021. PT13 data used for the final closure CC4 were generated based on the old values for consistency.

The final results are included in Table 12-9 and Table 12-10. 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 UFE and VSL 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 traveling equipment.

During the campaign, new delay values for PT13 were published by BIPM and implemented for routine use starting August 2021. PT13 data used for the final closure CC4 were generated based on the old values for consistency.

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 traveling 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 UFE. 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	07.05.2021	Version 0, all new
0.2	13.07.2021	CC2 in PTB without text, data UFE
0.3	06.08.2021	CC2 section completed, CCD3 and VSL data integrated
0.4	17.08.2021	CC4 data included, evaluation of delays
0.5	18.08.2021	UFE data and figures
1.0	31.08.2021	Uncertainty estimate completed, text completed
1.1	02.09.2021	Typos corrected, final delay values in Tab. 12.1 corrected
1.2	07.09.2021	Update or results for VSL: corrected REF DLY values provided, duration of data taking adjusted.

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
UFE	Alexander Kuna Phone: +420 266 773 400 kuna@ufe.cz	Institute of Photonics and Electronics, Czech Academy of Sciences Chaberská 1014/57 182 51 Praha 8 - Kobylisy Czech Republic
VSL	Erik Dierikx Phone: +31-631119878 edierikx@vsl.nl	VSL Thijsseweg 11 2629 JA, Delft The Netherlands

Table 2-2: Schedule of the campaign

Date	Institute	Action	Remarks
2021-04-29 until 2021-05-04	PTB	First common-clock comparison between PTBM and PT13	6 days used for determination of delays, MJD 59333 – 59338
2021-05-24 until 2021-07-01	UFE	Operation of PTBM in parallel with receivers TP01 and TP02	About 6.5 days used for determination of delays. MJD 59376 - 59382
2021-07-06 until 2021-07-19	PTB	Operation of PTBM after return	Two separate sessions for determination of delays, MJD – 59401 – 59406 and 59408 - 59413
2021-07-27 until 2021-08-01	VSL	Operation of PTBM in parallel with receivers VSLF and VSLG	About 5.5 days used for determination of delays. MJD 59422 - 59427
2021-08-11 until 2021-08-15	PTB	Operation of PTBM after return	4.5 days used for determination of delays, MJD 59437.5 - 59441

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 principle we distinguish receivers V, T, and G: V for visited, T for traveling, 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 traveling 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) has been installed in April 2019, and the PPS IN Delay Compensation option has never been used. On the contrary, PTBM (PolaRx5TR) normally makes use of the auto-compensation option as it reduces the number of measurements and potential errors at the visited site. In this case, the REF DLY is the offset between the UTC(k) reference point and the input to the PPS IN socket on the PTBM rack.
For clarity, Figure 3-1 shows the traveling equipment in two views and screenshots of the PPS configuration menu of the PolaRx5 RxControl software and the receiver message received when the auto-compensation is active.

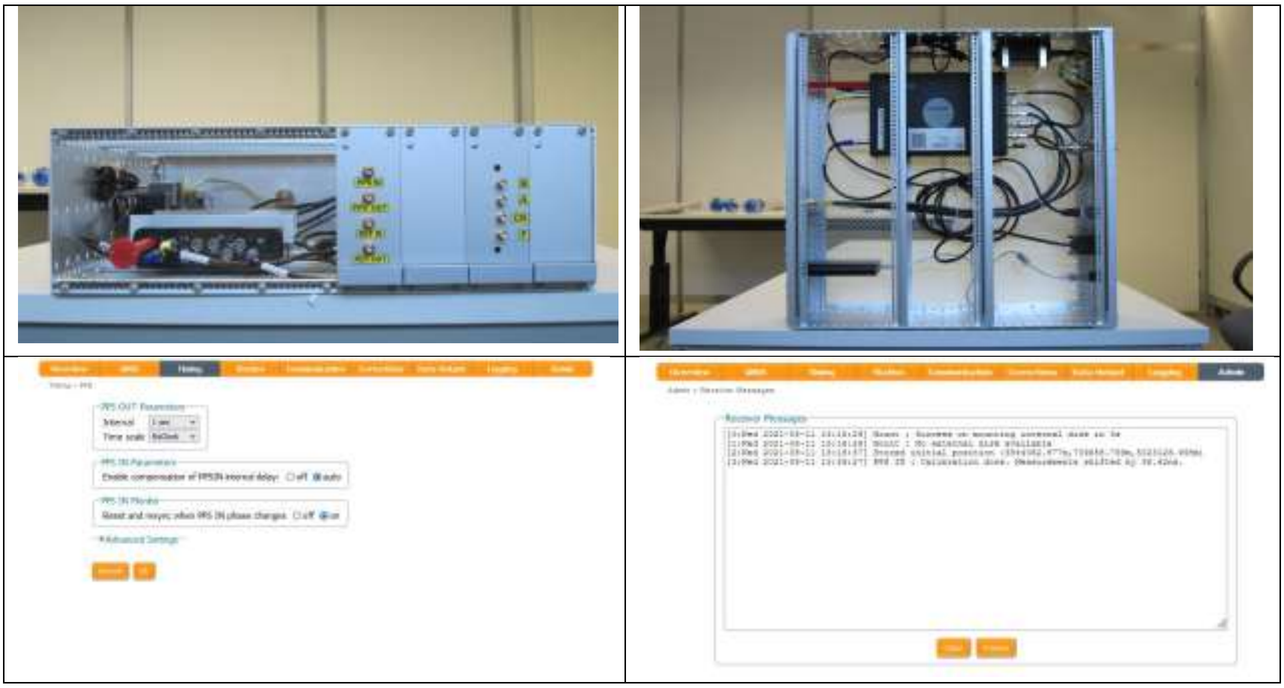

Figure 3-1 PTBM: views of the device and RxControl configuration and messages regarding PPS In and OUT.

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 iono-free observation (L3P or L3E, in short “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: INT DLY(fi)_T_corr = ΔIDi(T,G) + INT DLY(fi)_T_old, (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

INT DLY(fi)_V_new = ΔIDi(V,T) + <ΔIDi(T,G)> + INT DLY(fi)_V_old, (5) where <∆IDi(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, 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

After closure of the preceding campaign 1011-2021, PTBM was temporarily out of operation as the antenna mast was occupied by one of the BIPM G1 traveling GNSS antennas. In the following, we document in Figure 4-2, the stability of PT13 in comparison with another receiver, PT09 during periods of eight weeks.

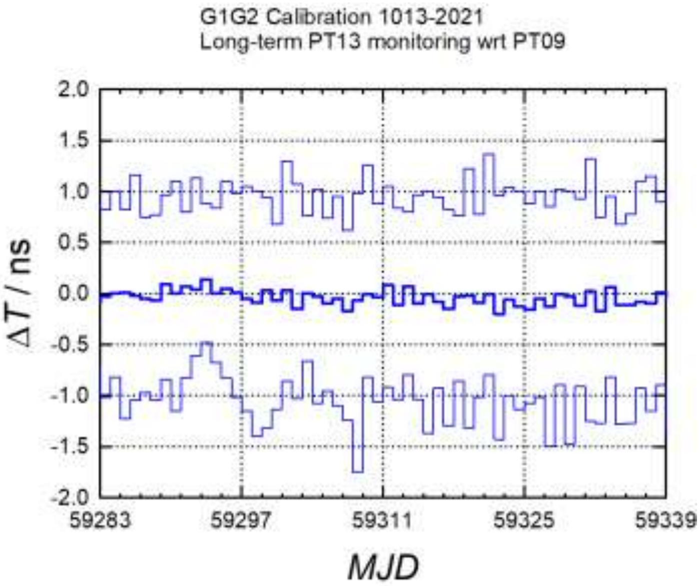

Figure 4-2: Common-clock common-view Galileo comparison between PT09 and PT13 in a period preceding campaign 1013-2021; thick lines: daily mean values, thin lines: maximum and minimum value (13-min average) during the respective day.

The installation of the receivers in PTB is depicted in Figure 4-3 for 1 PPS signals and in Figure 4-4 for 5 MHz signals.

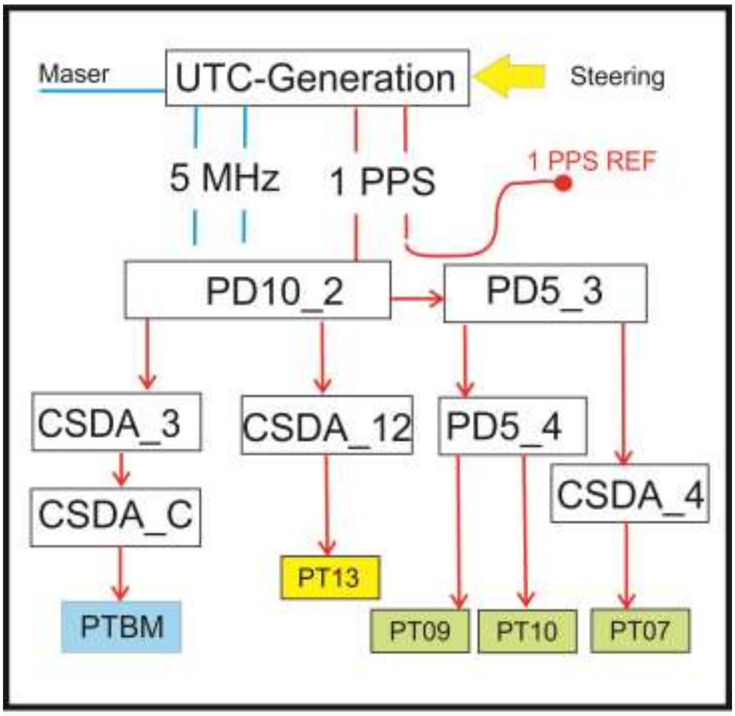

Figure 4-3: UTC(PTB) reference point and 1 PPS signal distribution to PT13, PTBM, and other receivers; PD10 stands for pulse distributor, CSDA stands for clock signal distribution amplifier

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 4-5 illustrates the installation of GNSS antennas on the roof of the PTB time laboratory (clock hall) during CC1.

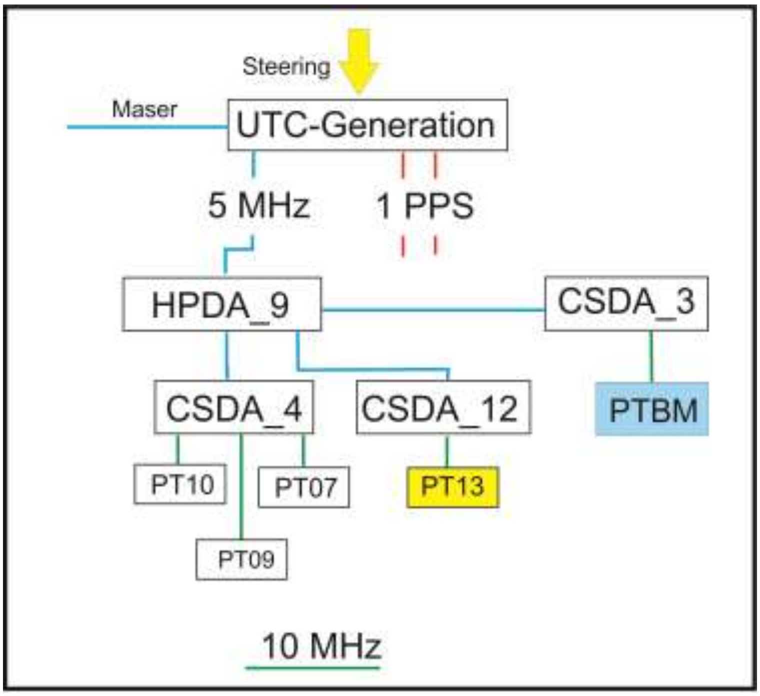

Figure 4-4: UTC(PTB) signal distribution (5 MHz, 10 MHz) to PT13, PTBM, and other receivers HPDA stands for High-precision distribution amplifier (for rf frequencies)

Figure 4-5: 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

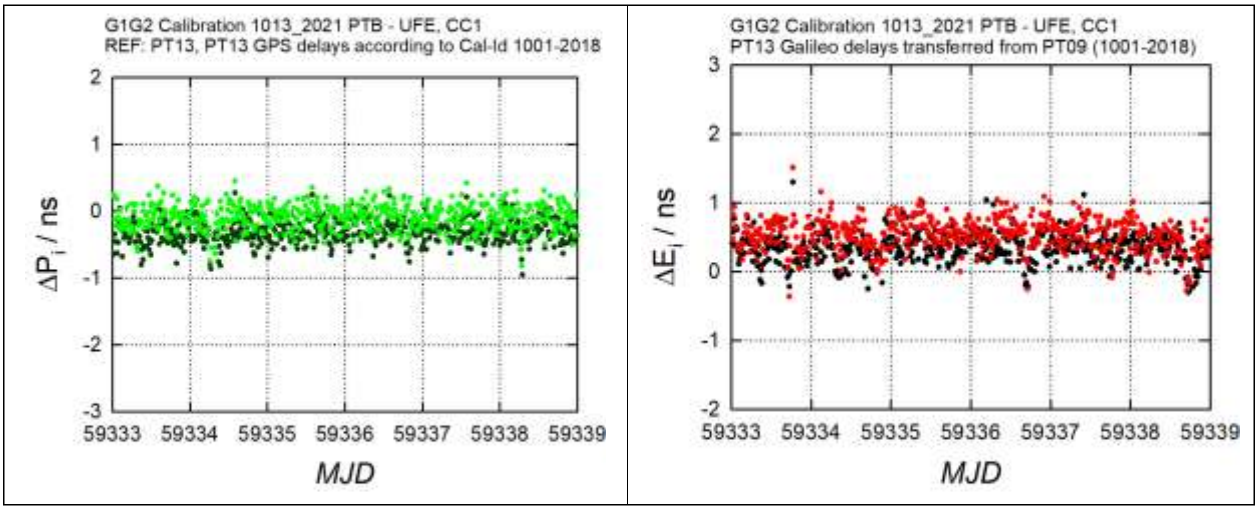

Figure 5-6: Left: Corrections to GPS delay in PTBM during CC1, ∆P1 (dark green) and ∆P2 (light green) Right: Corrections to Galileo delays in PTBM during CC1, ∆E1 (black) and ∆E5a (red).

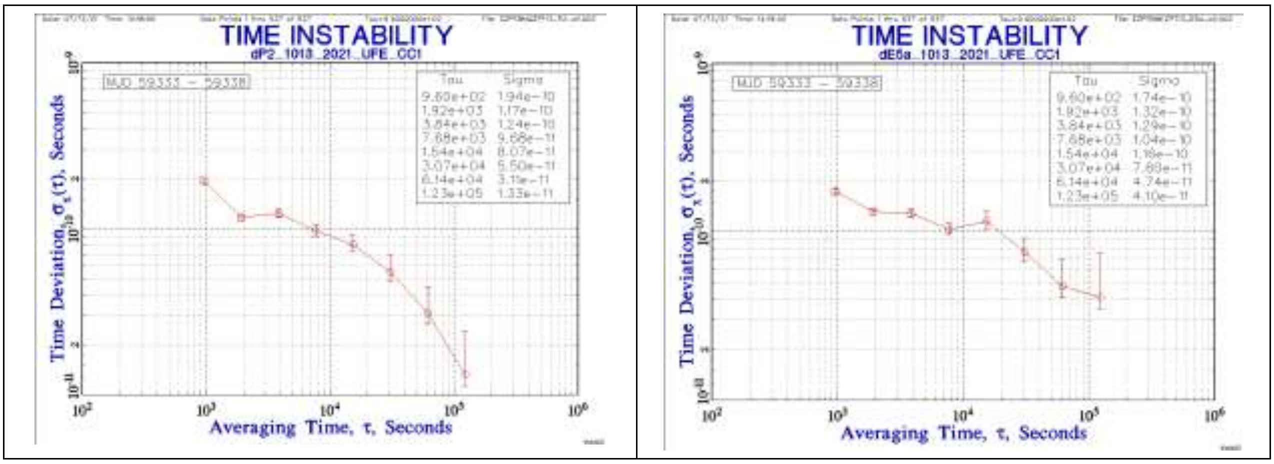

Figure 5-7: TDEV obtained for the two noisier data sets shown in Figure 5-6, GPS dP2 (left), and Galileo dE5a (right).

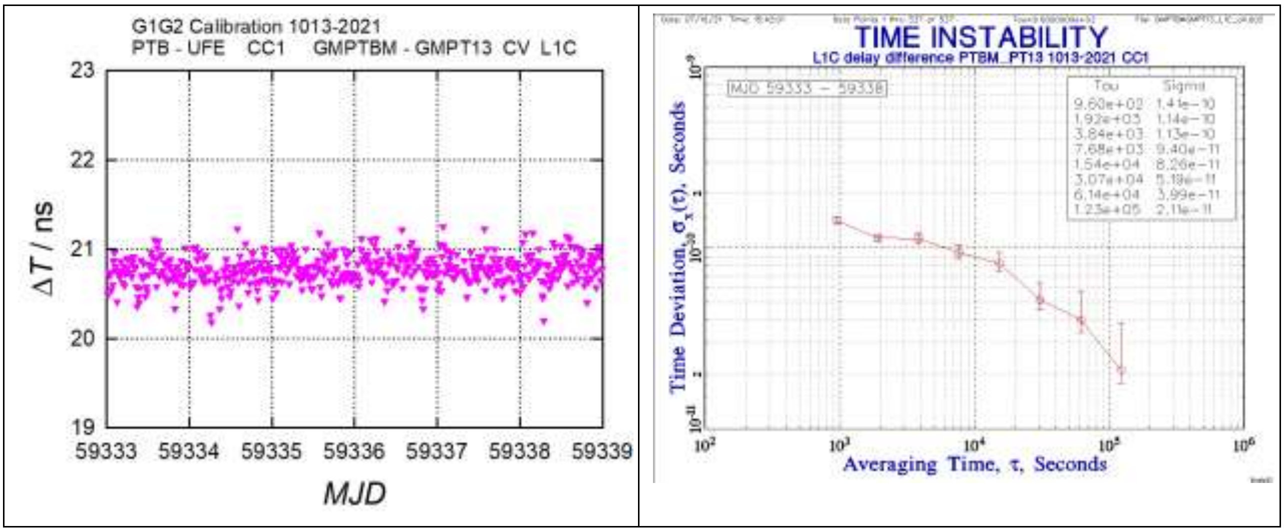

Figure 5-8 Left: PTBM GPS delay (L1C) during CC1 and TDEV for the data set

The period 59333 to 59338 (6 days) was chosen to determine the initial PTBM INT DLY values (CC1). The result of comparison with PT13 as the reference are shown in Figure 5-6 illustrating in total 531 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 5-7. 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. Inadvertently, no L1C signal delay had been stated in the PTBM parameter file. So a large offset in L1C – common view data appears in Figure 5-8. This has no impact on the feasibility to provide LC delays for receivers at UFE and VSL.

6. OPERATION OF PTBM AT UFE

PTBM was operated at UFE during weeks 21-26, 2021, in the Laboratory of the National Time and Frequency Standard. UFE operates two GNSS time transfer receivers designated as TP01 and TP02. The same acronym is used for CGGTTS as well as RINEX files reported to the BIPM.

The 10 MHz signal distribution to receiver PTBM and UFE receivers is illustrated in Figure 6-9.

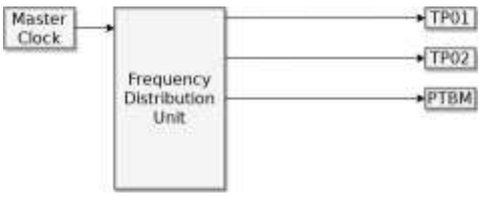

Figure 6-9. 10 MHz signal distribution at UFE to the receivers

The 1 PPS signal distribution to receiver PTBM and UFE receivers is illustrated below

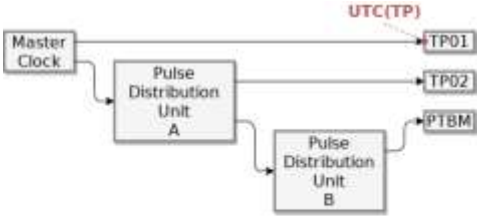

Figure 6-10. 1 PPS signal distribution at UFE to the receivers

At UFE, PTBM was operated with PPS IN Delay Compensation off during the days used for the delay calibration. In this case, REF DLY can be determined by measuring the offset between PPS Out and UTC(TP) using a cable of known delay. The value obtained has been stated in the report sheets (at the end of the document) and was used in the processing of the data.
In order to compare the configuration at UFE and during CC1, one needs to correct the REF DLY value at UFE (and later at CC2) by the sum of the delays of the two short cables (plus feedthrough) between the front plate and the input sockets on the receiver case (see Figure 3-1). The correction amounts to 4.88 ns and was determined with an uncertainty of 0.2 ns.

6.1. CALIBRATION OF RECEIVER TP01

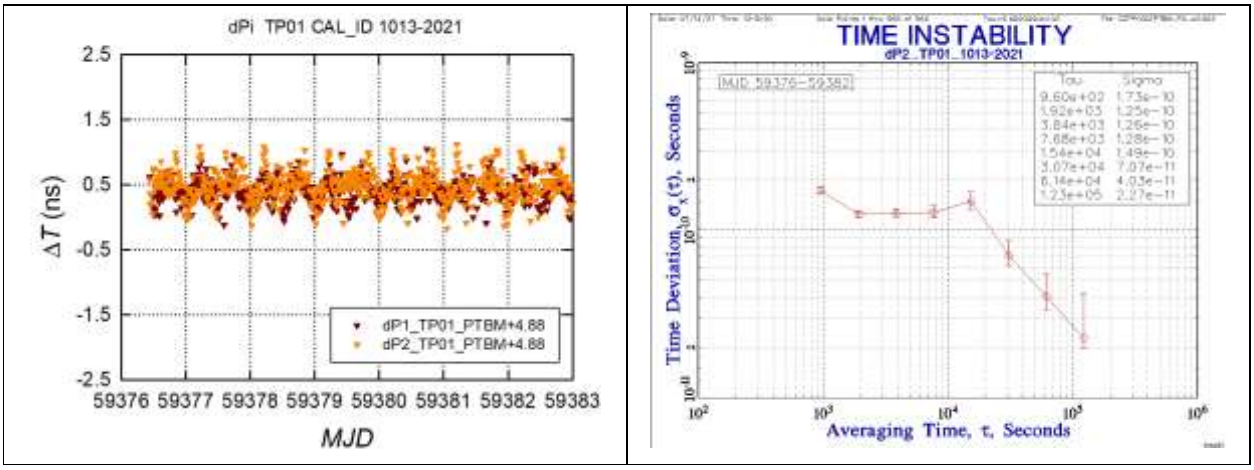

Figure 6-11. Left: Corrections to GPS INT DLY in TP01, reference PTBM; GPS ΔP1 (brown) and ΔP2 (orange), right: TDEV calculated from the dP2 values shown in the left panel.

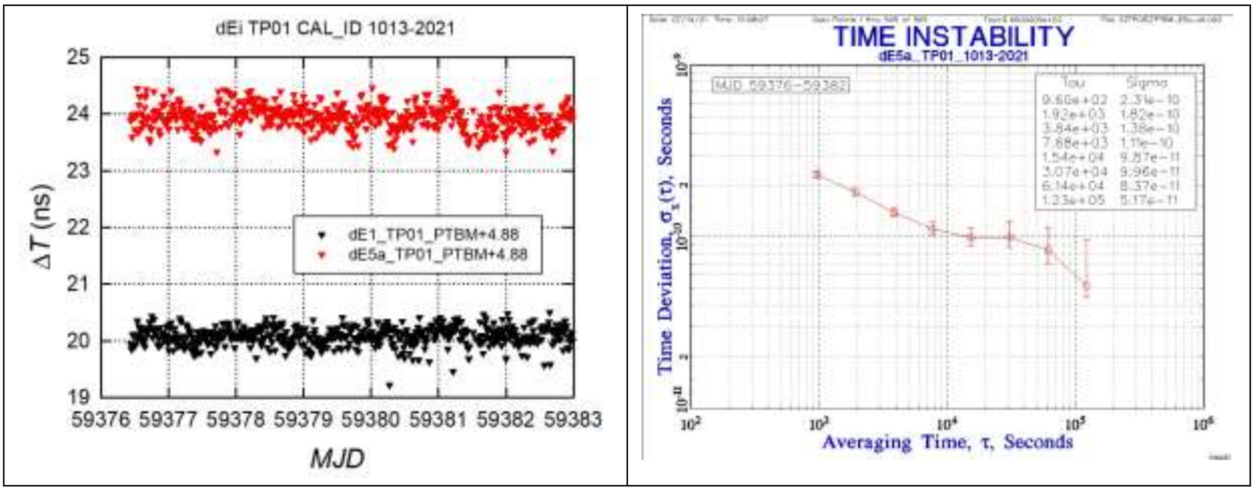

Figure 6-12. Left: Corrections to Galileo INT DLY in TP01, reference PTBM; left: Galileo ΔE1 (black) and ΔE5a (red), right: TDEV calculated from the d5a values shown in the left panel.

In Figure 6-11 and Figure 6-12, the ΔIDi (3) derived from the raw data are depicted. The results are collected in Table 6-3 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 explanations are valid for both receivers and not repeated each time.

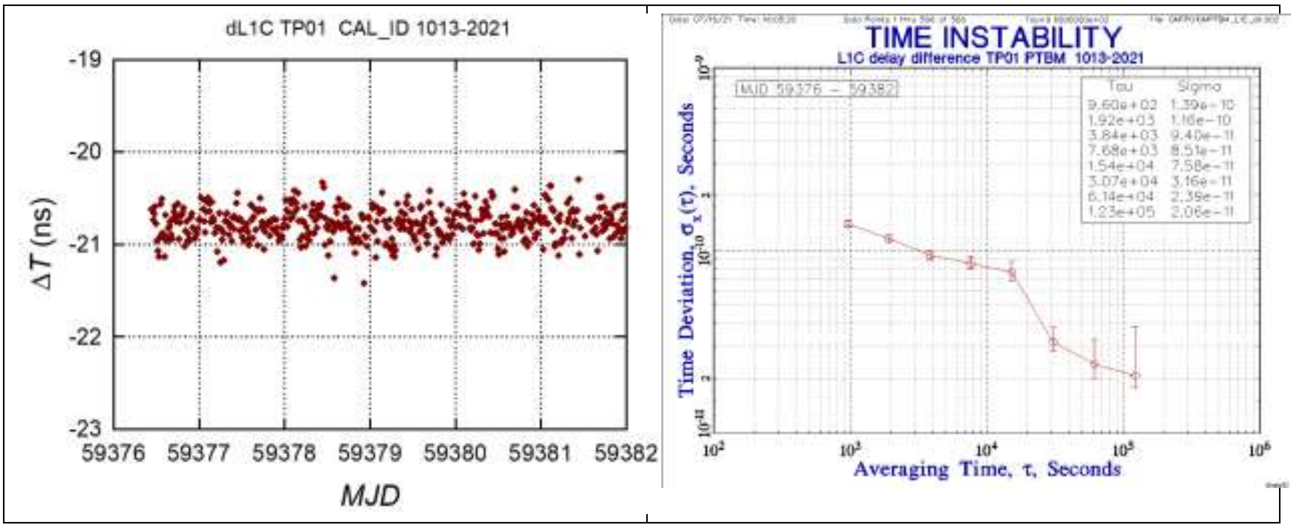

Figure 6-13 Left: Correction to the GPS delay (L1C) of receiver TP01 and TDEV for the data set

6.2. CALIBRATION OF RECEIVER TP02

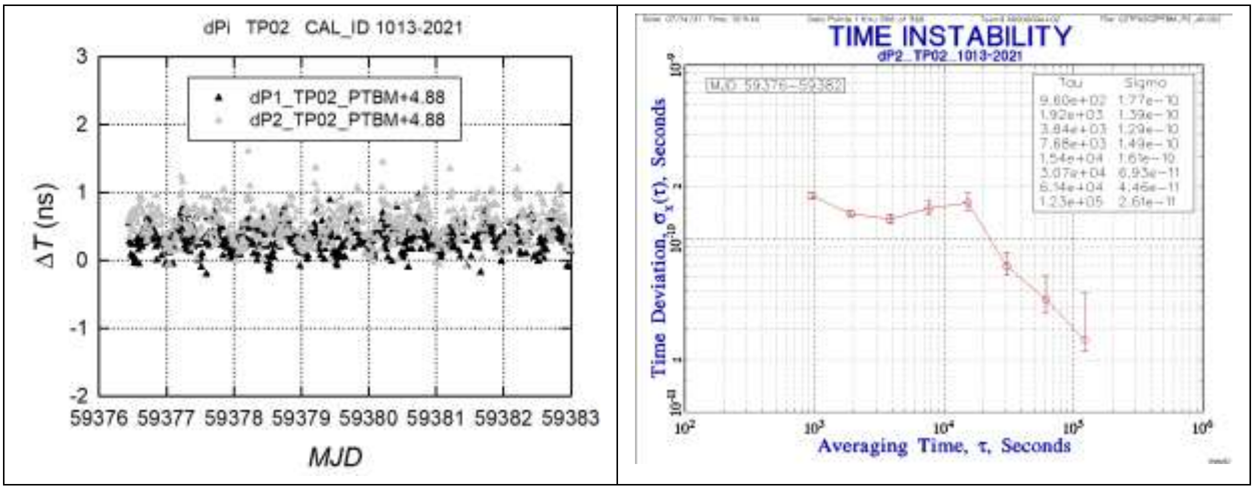

Figure 6-14. Left: INT DLY of TP02, reference PTBM; GPS P1 (black) and P2 (grey), right: TDEV calculated from the P2 values shown in the left panel.

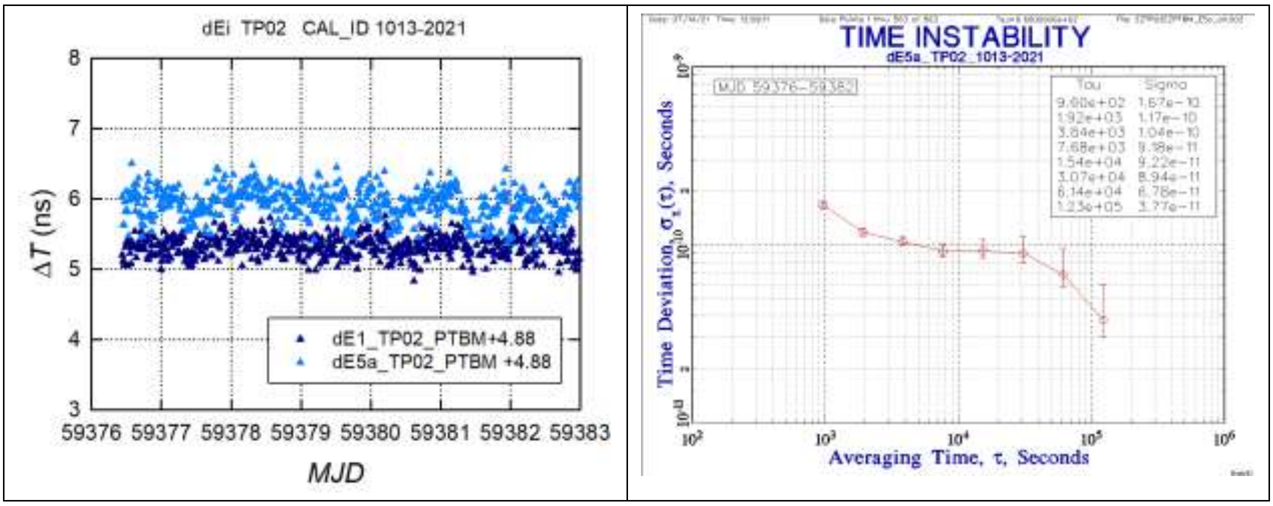

Figure 6-15. INT DLY of TP02, reference PTBM; left: Galileo E1 (dark blue) and E5a (light blue), right: TDEV calculated from the E5a values shown in the left panel.

In Figure 6-14 and Figure 6-15, the ΔIDi (3) derived from the raw data are depicted. The results are again collected in Table 6-3.

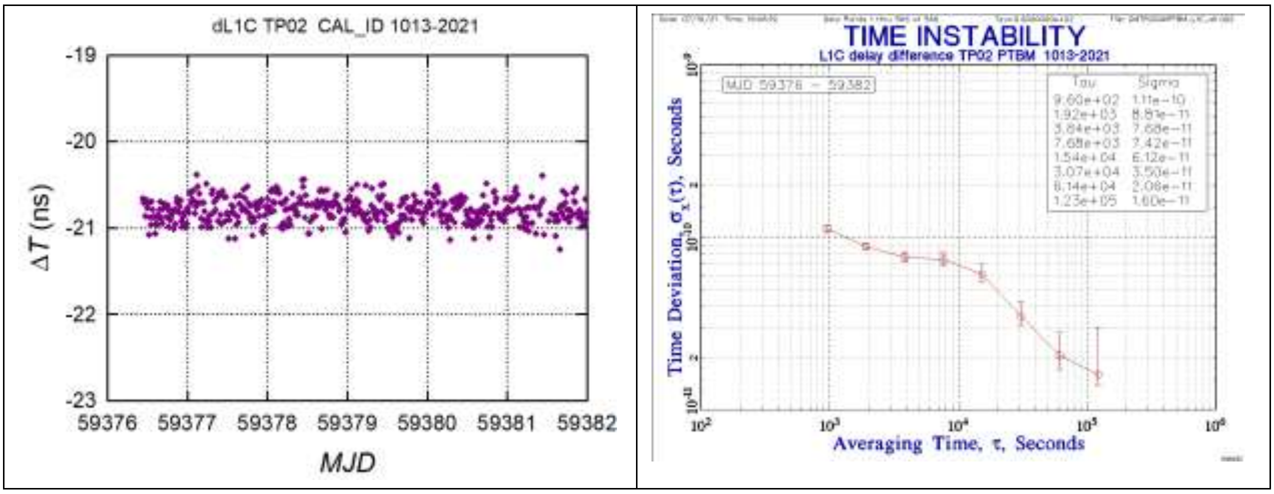

Figure 6-16 Left: Correction to the GPS delay (L1C) of receiver TP02 and TDEV for the data set

6.3. SUMMARY OF RESULTS OBTAINED AT UFE

Table 6-3 ∆INT DLY(fi) values for UFE receivers and statistical properties (in ns) obtained initially.

∆INT DLY (fi) for receiver at UFE	Mean (ns)	Sigma (ns)	TDEV (ns)	N
TP01				
dP1	0.41	0.19	<0.1	566
dP2	0.48	0.24	0.1	566
dE1	20.08	0.19	<0.1	565
dE5a	23.94	0.28	0.1	565
dL1C	-20.77	0.17	<0.1	565
TP02				
dP1	0.33	0.19	<0.1	566
dP2	0.53	0.26	0.1	566
E1	5.33	0.15	<0.1	563
E5a	5.93	0.22	0.1	563
dL1C	-20.80	0.14	<0.1	565

7. OPERATION OF PTBM AT PTB: SECOND PERIOD

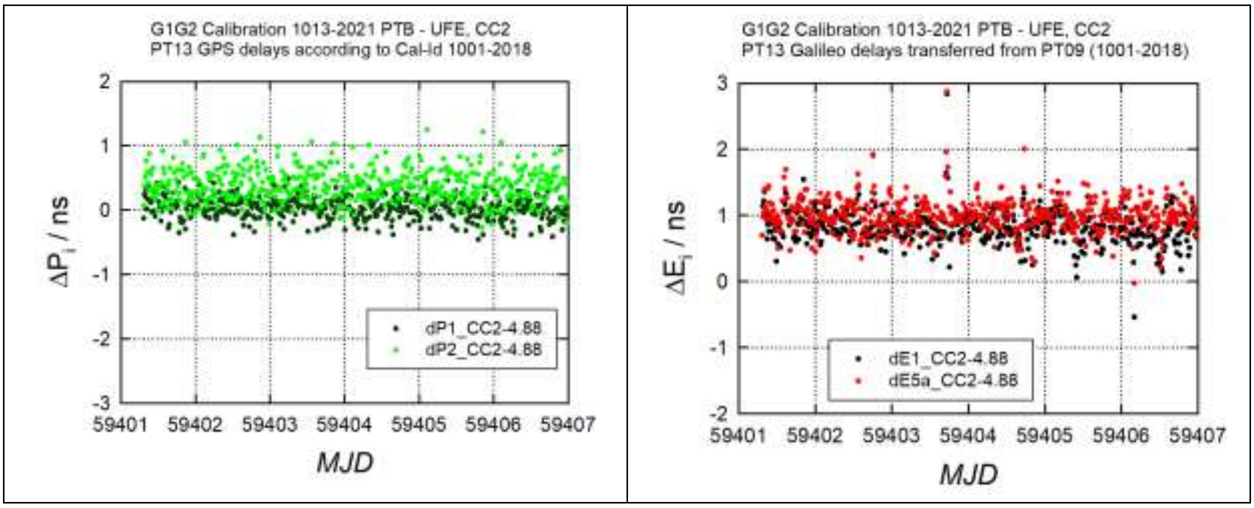

Figure 7-17. Left: Corrections to GPS delay in PTBM during CC2, ΔP1 (dark green) and ΔP2 (light green) Right: Corrections to Galileo delays in PTBM during CC2, ΔE1 (black) and ΔE5a (red).

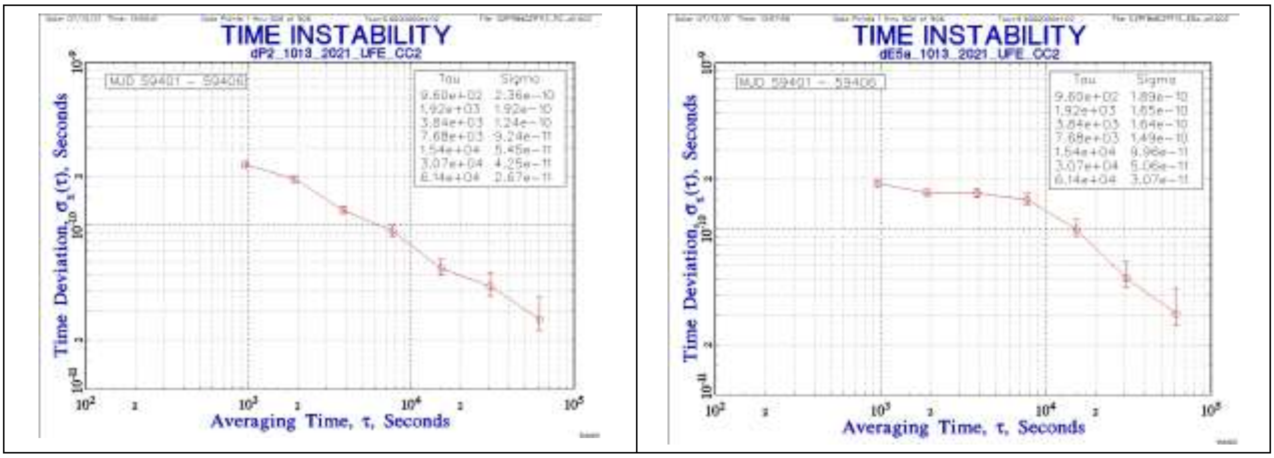

Figure 7-18. TDEV obtained for the data sets GPS dP2 (left) and Galileo dE5a (right) from Figure 7-17.

The period 59401 to 59406 (5.5 days) was chosen to determine PTBM INT DLY values during the common clock period CC2. The configuration of PTBM was chosen as it was reported by UFE for the preceding period: The automatic PPS IN delay compensation was deactivated, PPS OUT of PTBM configured to provide the Rx clock, and and the PPS Out at the front plate of the PTBM rack was used to determine the REF DLY, including the correction by 4.88 ns. The results of comparison with PT13 as the reference are shown in Figure 7-17, 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 7-18. TDEV for the other data are even lower.

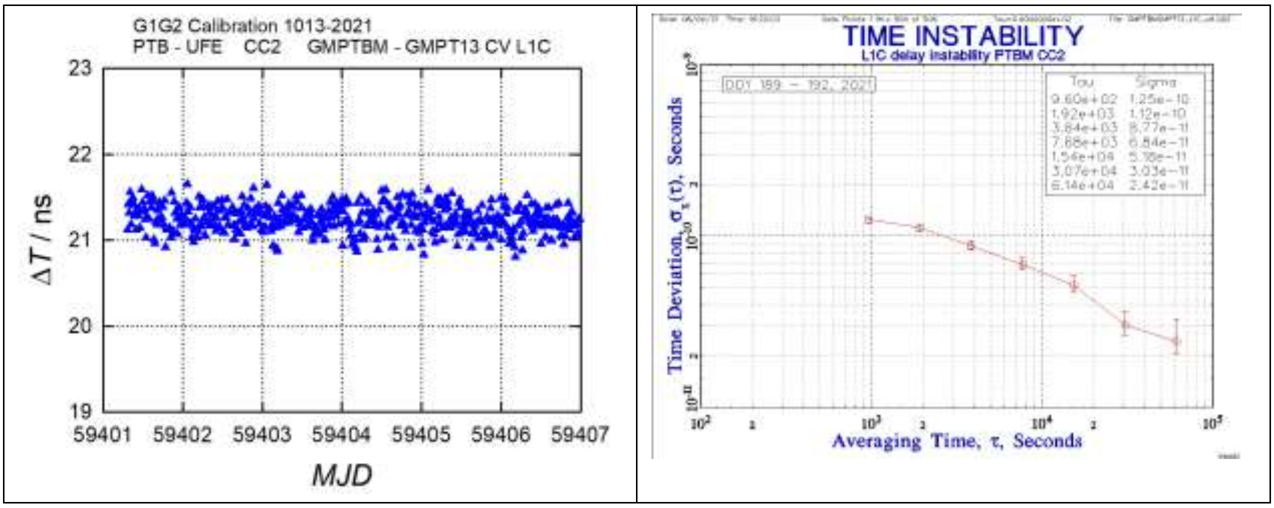

Figure 7-19 PTBM GPS delay (L1C) during CC2 and TDEV for the data set

7.1. SUMMARY OF CAMPAIGNS CC1 AND CC2

The numerical results of the two common-clock campaigns at PTB are given in Table 7-4. The largest change noted between CC1 and CC2 amounts 0.46 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 11.

Table 7-4: Result of common clock measurements CC1 and CC2 at PTB

Quantity	Median (ns)	Sigma (ns)	TDEV (ns)
ΔP1 (CC1)	-0.31	0.18	< 0.1
ΔP2 (CC1)	-0.09	0.19	< 0.1
ΔP3 (CC1)	-0.65		
ΔC1 (CC1)	20.77	0.16	
ΔE1 (CC1)	+0.35	0.22	< 0.1
ΔE5a (CC1)	+0.54	0.23	< 0.1
ΔE3 (CC1)	+0.11		
ΔP1 (CC2)	0.04	0.17	<0.1
ΔP2 (CC2)	0.39	0.25	0.1
ΔP3 (CC2)	-0.50		
ΔC1 (CC2)	21.25	0.15	<0.1
ΔE1 (CC2)	0.82	0.25	< 0.1
ΔE5a (CC2)	1.0	0.26	
ΔE3 (CC2)	0.59		
Mean values used for evaluation of visited receivers' internal delays			
ΔP1	-0.14		

ΔP2	+0.15		
ΔC1	21.01		
ΔE1	0.59		
ΔE5a	0.77		

8. OPERATION AT PTB THIRD PERIOD

The period 59408 to 59413 (6 days) was chosen to determine PTBM INT DLY values during the common clock period CC3, preparing for the shipment to VSL. The configuration of PTBM was "standard", the automatic PPS IN delay compensation was activated. The results of comparison with PT13 as the reference are shown in Figure 8-20, 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 8-21. TDEV for the other data are even lower.

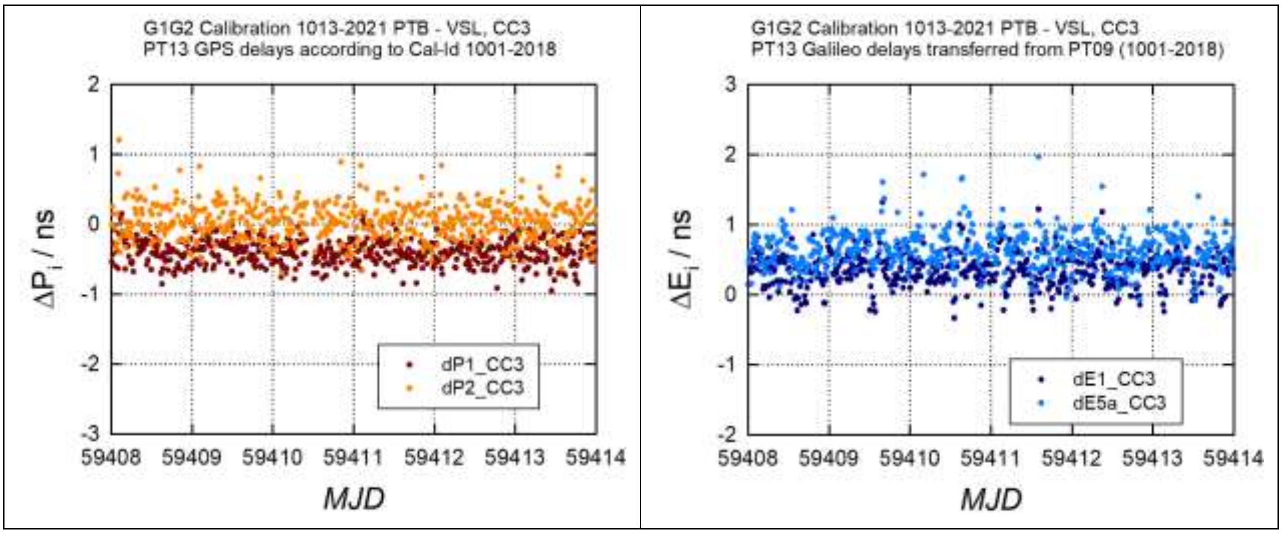

Figure 8-20 Corrections to GPS delay in PTBM during CC3, ΔP1 (brown) and ΔP2 (orange) Right: Corrections to Galileo delays in PTBM during CC2, ΔE1 (dark blue) and ΔE5a (light blue).

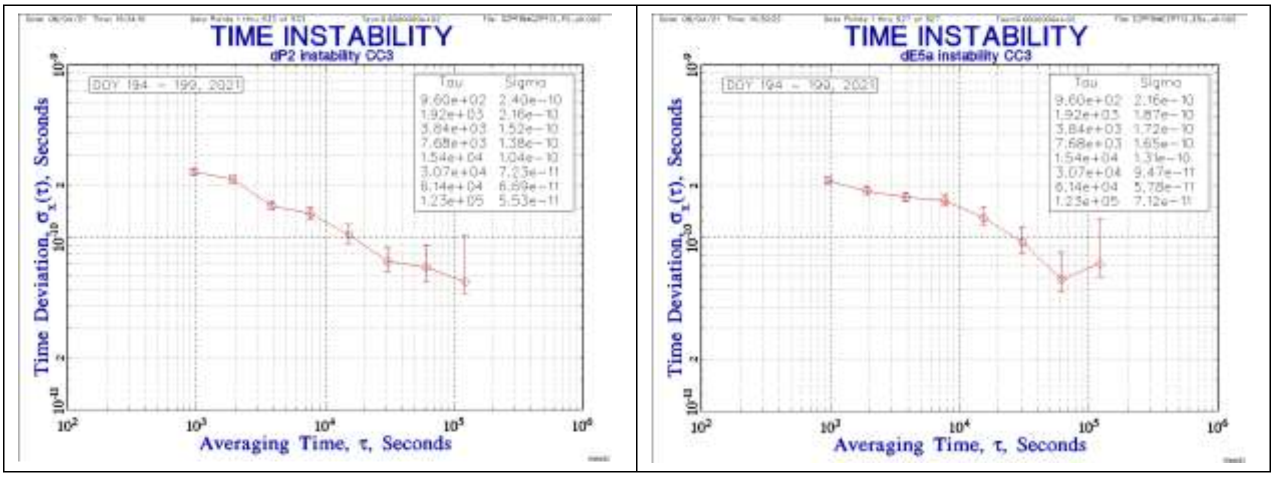

Figure 8-21 TDEV obtained for the data sets GPS dP2 (left) and Galileo dE5a (right) from Figure 8-20

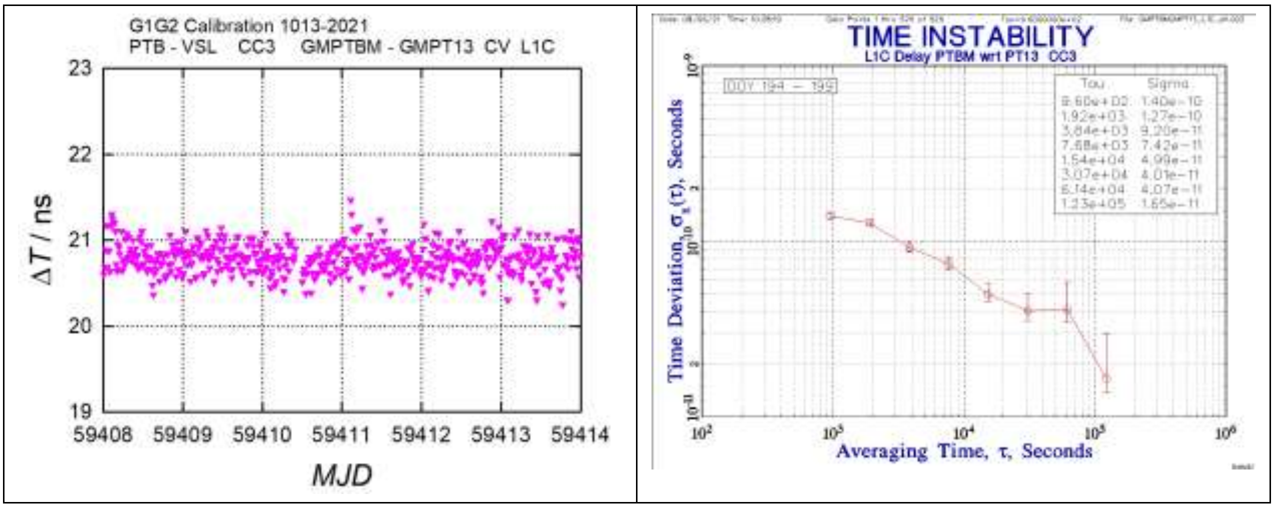

Figure 8-22 PTBM GPS delay (L1C) during CC3 and TDEV for the data set

9. OPERATION AT VSL

PTBM was operated at VSL during weeks 30/31, 2021. VSL operates two receivers with designation VSLF and VSLG. CGGTTS data of VSLF are reported to BIPM with designation VS06.

The signal distribution to receiver PTBM and VSL receivers is illustrated in Figure 9-23. The main motivation of the current campaign was that the Galileo signal delays in all receivers should be determined, aligned to the G1 reference value provided by BIPM as explained above. The installation of the PTBM antenna is shown in Figure 9-24.

After release of version 1.0 of this Report, VSL provided corrected REF DLY values for VSLF. All graphs showing results were kept unchanged compared to the version 1.0, only the results and report tables were corrected. No results were reported after final discussions for VSLG.

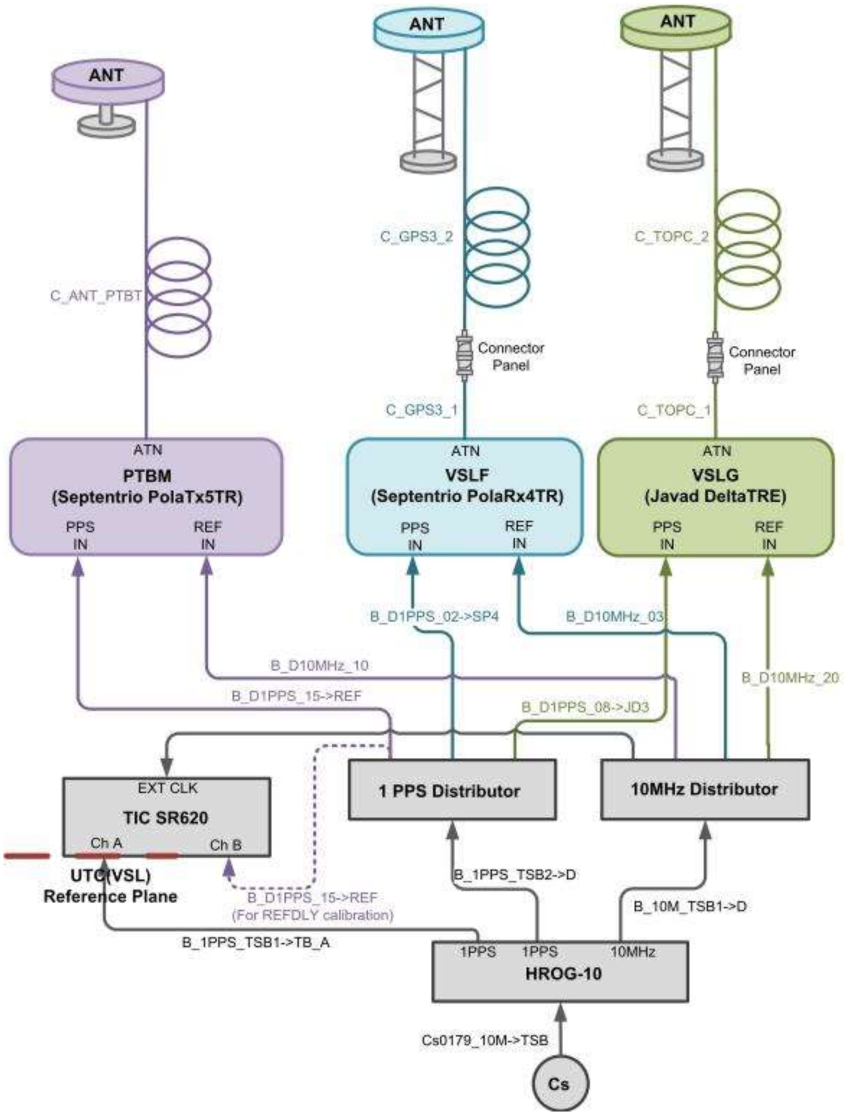

Figure 9-23 Signal distribution at VSL to the receivers

Figure 9-24 GNSS antenna of PTBM on the VSL building

9.1. CALIBRATION OF RECEIVER VSLF

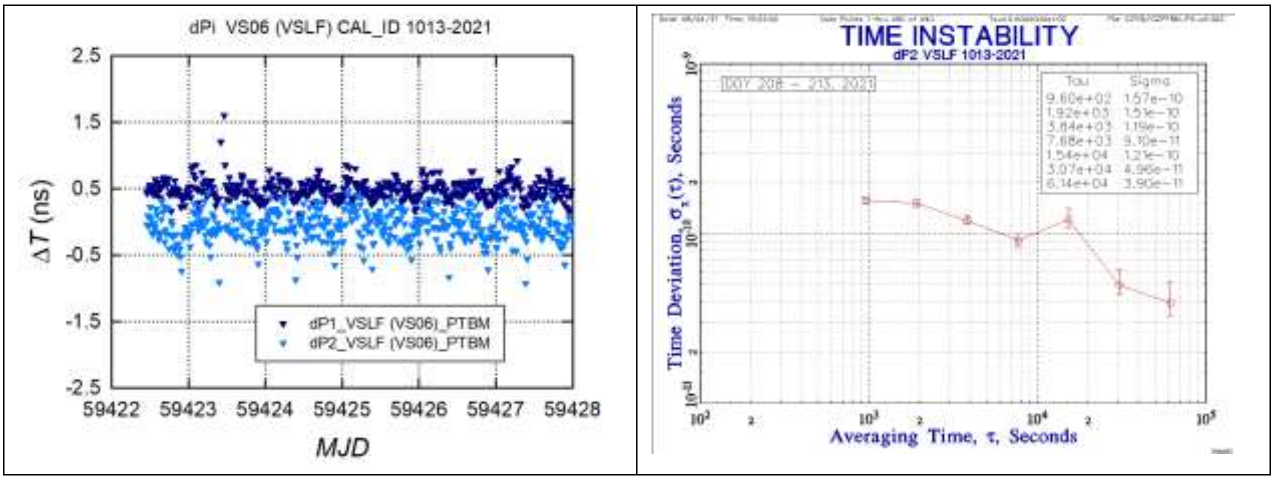

Figure 9-25 Left: INT DLY of VSLF (VS06), reference PTBM; GPS P1 (dark blue) and P2 (light blue), right: TDEV calculated from the P2 values shown in the left panel.

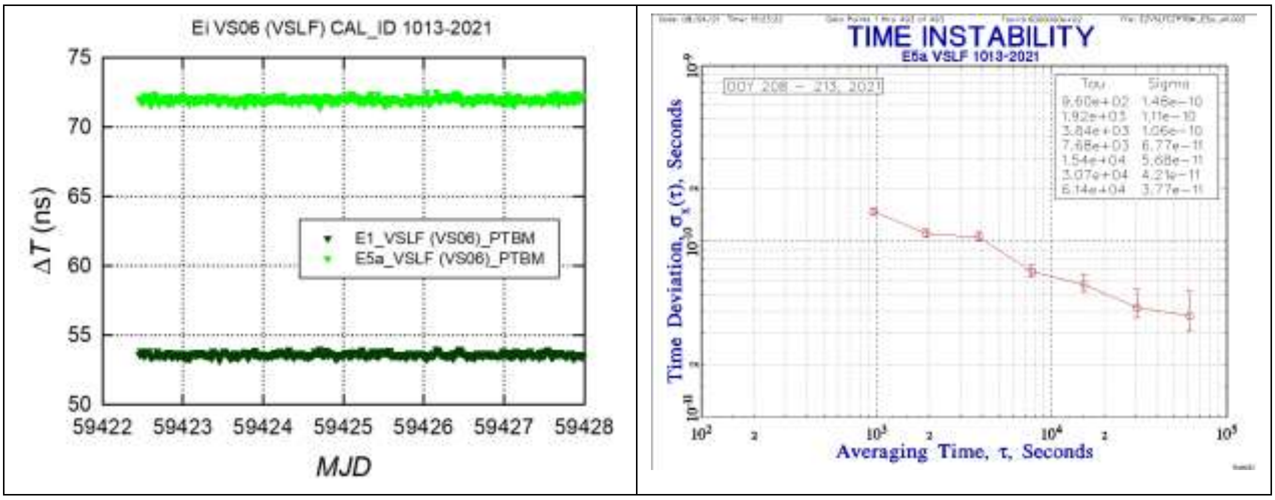

Figure 9-26 INT DLY of VSLF, reference PTBM; left: Galileo E1 (dark green) and E5a (light green), right: TDEV calculated from the E5a values shown in the left panel.

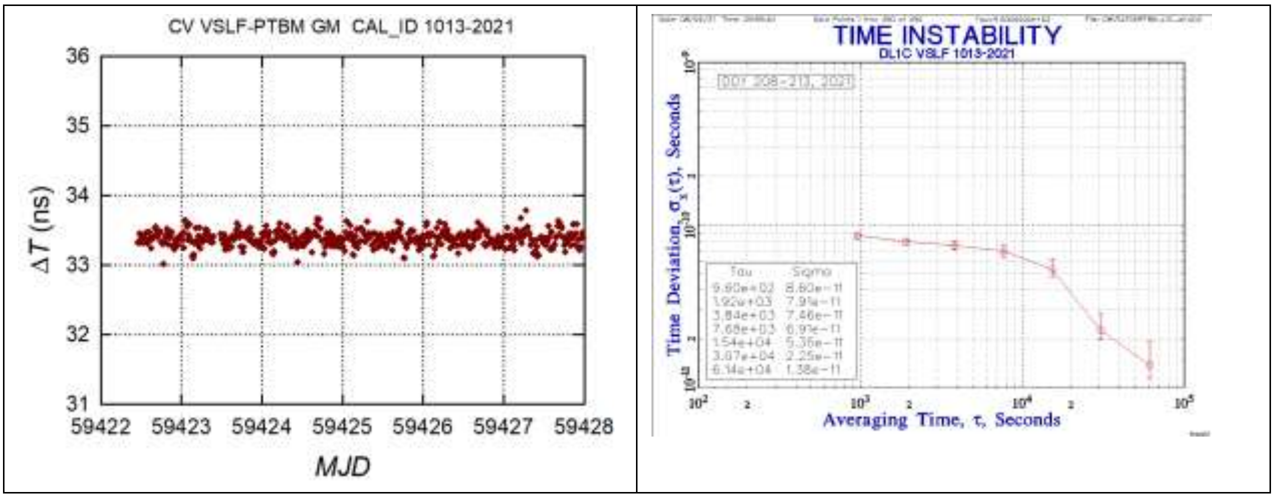

Figure 9-27 VSLF GPS delay (L1C) wrt PTBM and TDEV for the data set

9.2. SUMMARY OF RESULTS OBTAINED AT VSL

Table 9-5 ΔINT DLY(fi) values for VSL receivers and statistical properties (in ns) obtained initially

ΔINT DLY (fi) for receiver at VSL	Mean (ns)	Sigma (ns)	TDEV (ns)	N
VSLF (VS06)				
dP1	1.07 ~~0.47~~ (new ~~old~~)	0.15	<0.1	490
dP2	0.53 ~~-0.07~~	0.22	0.1	490
dE1	54.18 ~~53.58~~	0.13	<0.1	493
dE5a	72.55 ~~71.95~~	0.17	0.1	493
dL1C	33.98 ~~33.38~~	0.12	0.1	490

10. OPERATION AT PTB FOURTH PERIOD

The period 59437 to 59441 (4.5 days) was chosen to determine PTBM INT DLY values during the common clock period CC4, after returning of operations at VSL. The configuration of PTBM was "standard", the automatic PPS IN delay compensation was activated. The results of comparison with PT13 as the reference are shown in Figure 10-28, illustrating ∆IDi 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 10-29. TDEV for the other data are even lower.

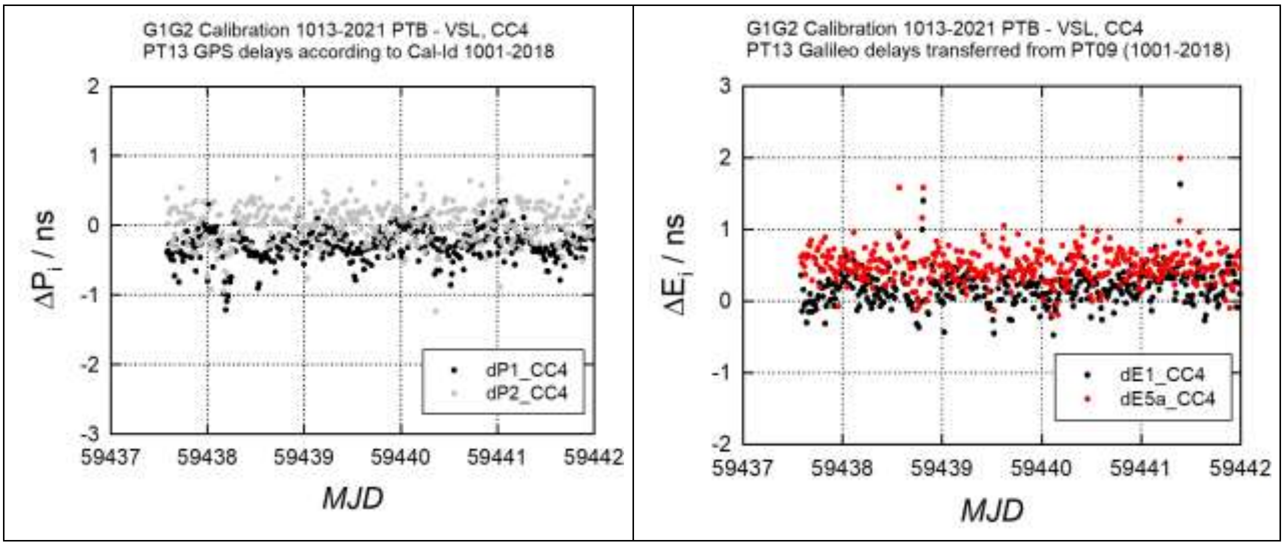

Figure 10-28 . Left: Corrections to GPS delay in PTBM during CC4, ∆P1 (black) and ∆P2 (grey) Right: Corrections to Galileo delays in PTBM during CC4, ∆E1 (black) and ∆E5a (red).

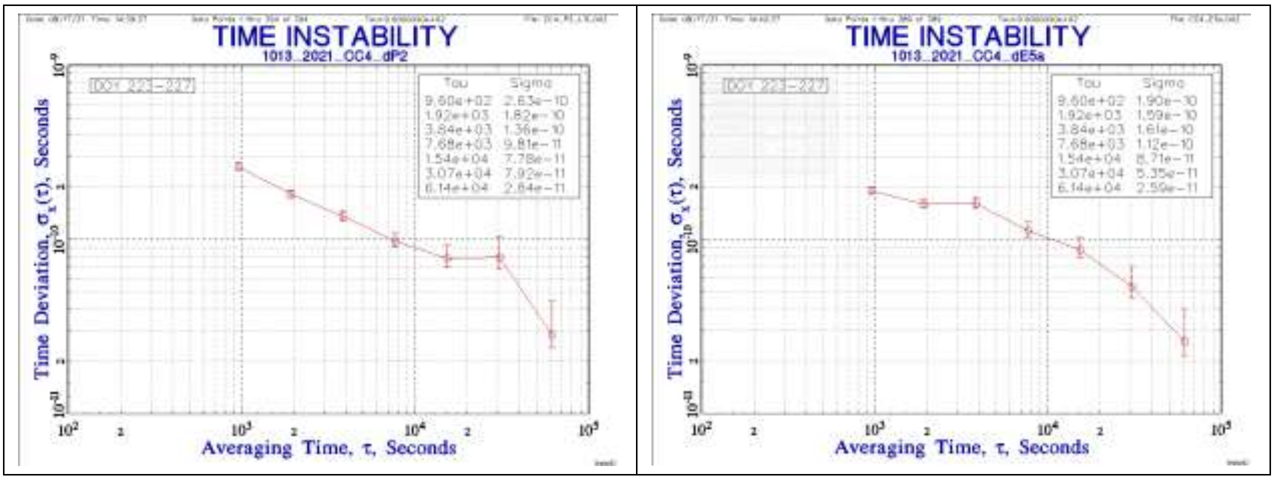

Figure 10-29 TDEV obtained for the data sets GPS dP2 (left) and Galileo dE5a (right) from Figure 10-28

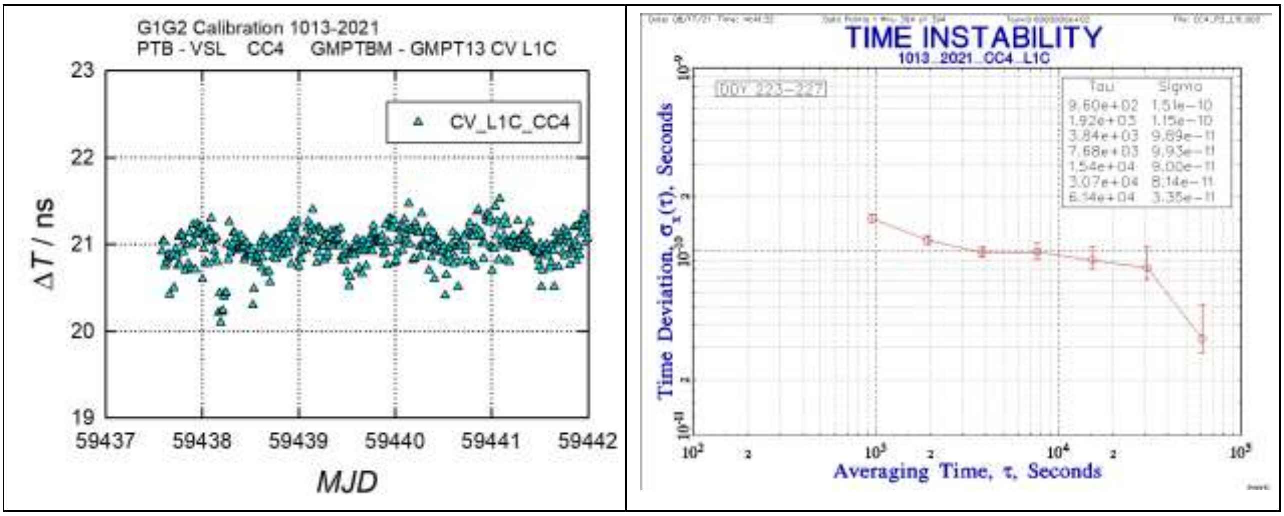

Figure 10-30 PTBM GPS delay (L1C) during CC4 and TDEV for the data set

10.1. SUMMARY OF CAMPAIGNS CC3 AND CC4

The numerical results of the two common-clock campaigns at PTB are given in Table 10-6. The largest change noted between CC3 and CC4 amounts 0.17 ns for ΔE1. 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 11.

Table 10-6 Result of common clock measurements CC3 and CC4 at PTB

Quantity	Median (ns)	Sigma (ns)	TDEV (ns)
ΔP1 (CC3)	-0.39	0.18	< 0.1
ΔP2 (CC3)	0.05	0.26	< 0.1
ΔP3 (CC3)	-1.07		
ΔC1 (CC3)	20.79	0.17	< 0.1
ΔE1 (CC3)	+0.36	0.22	0.1
ΔE5a (CC3)	+0.65	0.23	0.1
ΔE3 (CC3)	-0.01		
ΔP1 (CC4)	-0.28	0.22	<0.1
ΔP2 (CC4)	0.01	0.27	0.1
ΔP3 (CC4)	-0.73		
ΔC1 (CC4)	20.98	0.20	<0.1
ΔE1 (CC4)	0.19	0.23	< 0.1
ΔE5a (CC4)	0.50	0.24	0.1
ΔE3 (CC4)	-0.21		
Mean values used for evaluation of VSL receivers' internal delays			

∆P1	-0.34		
∆P2	+0.03		
∆C1	20.89		
∆E1	0.27		
∆E5a	0.58		

11. 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 UFE 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 11-7 and Table 12-10 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 11-7: Uncertainty contributions for the calibration of receiver delays at UFE

	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(UFE)	0.1	0.1	0.14	0.23	CC measurement uncertainty, for the 2 UFE receivers
Result of closure measurement at PTB						
3a	$u_{b,1}$ (GPS)	0.35	0.48		0.48	Misclosure, see Table 7-4
3b	$u_{b,1}$ (Galileo)	0.47	0.46		0.47	Misclosure, see Table 7-4
Systematic components due to antenna installation						
4	$u_{b,11}$	0.1	0.1	0.14	0.28	Position error at PTB
5a	$u_{b,12}$(UFE)	0.1	0.1	0.14	0.28	Position error at UFE
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 UFE
Installation of PTBM and visited receivers						
8	$u_{b,21}$	0.2	0.2	0	0.2	Connection of PTBM to UTC(PTB) (REF DLY)
9	$u_{b,22}$	0.7	0.7	0	0.7	Connection of PTBM to UTC(TP) (REF DLY)
10	$u_{b,23}$	0.2	0.2	0	0.2	Connection of receivers at UFE to UTC(TP) (REF DEL)
Antenna cable delay						
11	$u_{b,31}$(PTB)	0.5	0.5	0	0.5	Uncertainty estimate for the PTBM CAB DLY when installed at PTB
12	$u_{b,32}$(UFE)	0.0	0.0	0	0.0	Uncertainty estimate for the PTBM CAB DLY when installed at UFE
13	$u_{b,33}$(UFE)	0.5	0.5	0	0.5	Uncertainty estimate for UFE CAB DLY values

Table 11-8 Uncertainty contributions for the calibration of receiver delays at VSL

	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(VSL)	0.1	0.1	0.14	0.23	CC measurement uncertainty, for the 2 VSL receivers

Result of closure measurement at PTB						
3a	$u_{b,1}$ (GPS)	0.11	0.04		0.11	Misclosure, see Table 7-4
3b	$u_{b,1}$ (Galileo)	0.17	0.15		0.17	Misclosure, see Table 7-4
Systematic components due to antenna installation						
4	$u_{b,11}$	0.1	0.1	0.14	0.28	Position error at PTB
5a	$u_{b,12}$(VSL)	0.1	0.1	0.14	0.28	Position error at VSL
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 VSL
Installation of PTBM 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(VSL) (REF DLY)
10	$u_{b,23}$	0.2	0.2	0	0.2	Connection of receivers at VSL to UTC(VSL) (REF DEL)
Antenna cable delay						
11	$u_{b,31}$(PTB)	0.5	0.5	0	0.5	Uncertainty estimate for the PTBM CAB DLY when installed at PTB
12	$u_{b,32}$(VSL)	0.0	0.0	0	0.0	Uncertainty estimate for the PTBM CAB DLY when installed at VSL
13	$u_{b,33}$(VSL)	0.5	0.5	0	0.5	Uncertainty estimate for VSL CAB DLY values

As demonstrated in Table 6-3 and Table 9-5, the receivers at UFE and VSL 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.

The uncertainty contribution $u_{b,1}$ is based on the difference between the two common clock campaigns involved. The respective differences from the mean value exceed the statistical measurement uncertainty by at least a factor of 2. So the difference itself is considered as measure for the uncertainty which is a more pessimistic estimate as usual, made in view of the PTBM configuration changes during the campaign to UFE. The value for the linear combination (P3 or E3, respectively) is chosen as the largest of the values in the respective line in the table.

At PTB, the PPS IN Delay Compensation has been initiated several times, with the PTBM receiver connected to different 10 MHz cables in sequence. Results reported (see Figure 3-1) agreed within 0.1 ns. Thus when the receiver is operated in the same modus at each site the achievable uncertainty is likely the lowest.

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 0.2 ns for the internal set-up at UFE and VSL. For PTBM, a larger values was chosen for UFE because of considerable confusion during the initial installation of PTBM and 0.2 ns otherwise.

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 at each occasion. 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 UFE and VSL 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.

12. FINAL RESULTS

The results of the calibration campaign G1G2_1013_2021 are summarized in Table 12-9 and Table 12-10. They contain the designation of the visited receivers, 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 11-7, 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 12-9. Results of the Calibration Campaign G1G2_1013_2021: GPS delays, all values in ns

Receiver	INT DLY(P1), old	INT DLY(P2); old	INT DLY(C1) old	ΔP1 (V,T)	ΔP2 (V,T)	ΔC1 (V,T)	ΔP1 (T,G)	Δ(P2) (T,G)	Δ(C1) (T,G)	INT DLY(C1) new	INT DLY(P1), new	u_{cal}, P1	INT DLY(P2), new	u_{cal}, P2	u_{cal}, L3P
TP01	19.8	23.4	20.9	0.41	0.48	-20.77	-0.14	+0.15	21.01	21.14	20.07	1.15	24.03	1.20	1.28
TP02	19.2	20.6	20.1	0.33	0.53	-20.88	-0.14	+0.15	21.01	20.23	19.39	1.15	21.28	1.20	1.28
VSLF	~~52.5~~	~~61.1~~	~~0.0~~	~~0.47~~	~~-0.07~~	~~33.38~~	~~-0.34~~	~~0.03~~	~~20.89~~	~~54.27~~	~~52.63~~	~~0.88~~	~~61.06~~	~~0.89~~	~~1.00~~
VSLF	52.5	61.1	0.0	1.07	0.53	33.98	-0.34	0.03	20.89	54.87	53.23	0.88	61.66	0.89	1.00

Table 12-10. Results of the Calibration Campaign G1G2_1013_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
TP01	0	0	20.08	23.94	+0.59	+0.77	20.67	1.19	24.71	1.20	1.28
TP02	14.3	16.7	5.33	5.93	+0.59	+0.77	20.22	1.19	23.40	1.20	1.28
~~VSLF~~	~~0~~	~~0~~	~~53.59~~	~~71.95~~	~~0.27~~	~~0.58~~	~~53.85~~	~~0.87~~	~~72.53~~	~~0.88~~	~~1.00~~
VSLF	0	0	54.18	72.55	0.27	0.58	54.45	0.87	73.13	0.88	1.00

ANNEX: BIPM CALIBRATION INFORMATION SHEETS

First common clock measurement at PTB

Laboratory:	**PTB**	
Date and hour of the beginning of	2021-04-29 0:00 UTC (MJD 59333)	
Date and hour of the end of measurements:	2021-05-04 24:00 UTC (MJD 59338)	
Information on the system		
	Local:	**Traveling:**
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 stabilized) /°C		
Measured delays /ns		
	Local:	**Traveling:**
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:		Traveling	
☐ 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) (****) 0.0 (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		41.9	
☐ 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, peak-to-peak variations 0.5° C

Notes valid for CC1 – CC4:

(#) 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 UFE: Receiver TP01

Laboratory	TP	
Date and hour beginning of measurements	2021-06-11 10:56 UTC (MJD 59376)	
Date and hour end of measurements	2021-06-17 24:00 UTC (MJD 59382)	
Information on the system		
	Local	**Traveling**
4-character BIPM code	TP01	PTBM
Receiver maker and type Receiver serial number	MESIT asd. GTR55 1541941	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)	~35 m low loss RF cable (Andrew Heliax LDF1-50) N	LMR-400 (N)
Cable length outside building /m	~20 m	~30 m
Antenna maker and type Antenna serial number	Novatel GNSS-850 NMLK18480006L	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	0.0	
Delay from 1 PPS_IN to internal reference (see Annex 1)		PPS IN Delay Compensation off
Delay from local UTC to receiver reference REFDLY	0.0	57.9 (&&)
Antenna cable delay	149.0	264.9
Splitter delay		
Additional cable delay		
Data used for the generation of CGGTTS files		
	Local	**Traveling**
INT DLY (GPS) /ns	19.8 (P1), 23.4(P2)	18.9 (P1), 17.1 ns (P2)
INT DLY (Galileo) /ns	0.0 (E1), 0.0 ns (E5a)	20.8 (GAL E1), 17.9 (E5a)
CAB DLY /ns	149.0	264.9
REF DLY /ns	0.0	57.9
Coordinate reference frame	ITRF (IGb08)	ITRF
Latitude or X /m	+3967283.08	+3967279.63
Longitude or Y /m	+1022538.24	+1022550.87

Height or Z /m	+4872414.50	+4872413.20

General information	
Rise time of local UTC pulse	500 ps
Air conditioning (Y/N)	Y
Set temperature value and uncertainty	23 °C +/- 1 °C
Set humidity value and uncertainty	Not Controlled.

&& measured by UFE based on PPS OUT of PTBM

All coordinates (APC) determined using NRCan PPP for day 145/2021. 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.

Names of files to be used in processing for site UFE
Traveling receiver GZPTBMMJ.DDD, EZPTBMMJ.DDD, DUT: GZTP01MJ.DDD, EZTP01MJ.DDD.

PTBM operation at UFE: Receiver TP02

Laboratory	TP	
Date and hour beginning of measurements	2021-06-11 10:56 UTC (MJD 59376)	
Date and hour end of measurements	2021-06-17 24:00 UTC (MJD 59382)	
Information on the system		
	Local	**Traveling**
4-character BIPM code	TP02	PTBM
Receiver maker and type Receiver serial number	MESIT asd GTR55 1711887	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)	~35 m low loss RF cable (Andrew Heliax LDF1-50) N	LMR-400 (N)
Cable length outside building /m	~20 m	~30 m
Antenna maker and type Antenna serial number	Novatel GNSS-850 NMLK18480038D	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	10.6	
Delay from 1 PPS_IN to internal reference (see Annex 1)		PPS IN Delay Compensation OFF
Delay from local UTC to receiver reference REFDLY	10.6	57.9 (&&)
Antenna cable delay	137.6	264.9
Splitter delay		
Additional cable delay		
Data used for the generation of CGGTTS files		
	Local	**Traveling**
INT DLY (GPS) /ns	19.2 (P1), 20.6 (P2)	18.9 (P1), 17.1 ns (P2)
INT DLY (Galileo) /ns	14.3 (E1), 16.7 (E5a)	20.8 (GAL E1), 17.9 (E5a)
CAB DLY /ns	137.6	264.9
REF DLY /ns	10.6 (%)	57.9
Coordinate reference frame	ITRF (IGb08)	ITRF
Latitude or X /m	+3967284.91	+3967279.63

Longitude or Y /m	+1022539.82	+1022550.87
Height or Z /m	+4872412.69	+4872413.20

General information	
Rise time of local UTC pulse	500 ps
Air conditioning (Y/N)	Y
Set temperature value and uncertainty	23 °C +/- 1 °C
Set humidity value and uncertainty	Not Controlled.

&& measured by UFE based on PPS OUT of PTBM.

All coordinates (APC) determined using NRCan PPP for day 145/2021. 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.

Names of files to be used in processing for site UFE
Traveling receiver GZPTBMMJ.DDD, EZPTBMMJ.DDD, DUT: GZTP02MJ.DDD, EZTP02MJ.DDD.

Second common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of	2021-07-06 07:30 UTC (MJD 59401)
Date and hour of the end of measurements:	2021-07-11 24:00 UTC (MJD 59406)

Information on the system		
	Local:	**Traveling:**
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:	**Traveling:**
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	9.33 ± 0.1 (#)	41.87 +/- 0.2
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	45.0 ± 0.1 (#)	40.33 (%%)
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:		Traveling	
☐ INT DLY (or X_R+X_S) (GPS) /ns:	29.7 (P1), 27.2 (P2), (*) 32.0 (E1), 31.7 (E5a) (*)		18.9 (P1) 17.1 (P2) (****) 0.0 (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		82.2 (%%)	
☐ 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, peak-to-peak variations 0.6° C

(%%) operation during CC2 with auto delay compensation off. In order to compare CC1 and CC2, the values need to be corrected by the sum of the delay of the two cables connecting the case front sockets and the receiver plus two feed-throughs, in total by 4.88 ns.

Names of files to be used in processing for site PTB
Traveling receiver GZPTBMMJ.DDD, EZPTBMMJ.DDD
Reference receiver GZPT13MJ.DDD, EZPT13MJ.DDD

Third common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of	2021-07-13 07:30 UTC (MJD 59408)
Date and hour of the end of measurements:	2021-07-18 24:00 UTC (MJD 59413)

Information on the system		
	Local:	**Traveling:**
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:	**Traveling:**
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	9.33 ± 0.1 (#)	41.87 +/- 0.2
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	45.0 ± 0.1 (#)	(%%)
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:		Traveling	
☐ INT DLY (or X_R+X_S) (GPS) /ns:	29.7 (P1), 27.2 (P2), (*) 32.0 (E1), 31.7 (E5a) (*)		18.9 (P1) 17.1 (P2) (****) 0.0 (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		41.9 (%%)	
☐ 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, peak-to-peak variations 0.6° C

(%%) operation during CC3 with auto delay compensation on.

PTBM operation at VSL: Receiver VSLF

Laboratory:	VSL
Date and hour of the beginning of measurements:	UTC 2021-07-27T11:00 DOY 208 MJD 59422
Date and hour of the end of measurements:	UTC 2021-08-01T23:59

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	VSLF	PTBM
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx4TR 3001395	Septentrio PolaRx5TR (5.3.0) 3048338
1 PPS trigger level /V:	1.0	1.0
• Antenna cable maker and type: Phase stabilised cable (Y/N):	SSB Electronic GmbH, Aircom Plus (N)	 LMR-400-UF (N)
Length outside the building /m:	10 m	28 m
• Antenna maker and type: Antenna serial number:	Topcon TPSCR.G3(TPSH) 383-1235	Navxperience 3G+C reference S/N: RE 0560
Temperature (if stabilised) /°C	N/A	N/A

Measured delays /ns (if needed fill box “Additional Information” below)		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	34.5 (new)	34.0
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	146.2 (new)	%%
• Antenna cable delay:	124.7	264.9
Splitter delay (if any):	N/A	N/A
Additional cable delay (if any):	N/A	N/A

Data used for the generation of CGGTTS files		
	Local:	**Travelling:**
• INT DLY (GPS) /ns:	52.5 (P1) 61.1 (P2)	18.88 (P1) 17.11 (P2)
• INT DLY (GLONASS) /ns:	N/A	N/A
• CAB DLY /ns:	124.7	264.9
• REF DLY /ns:	180.7 (new)	34.0
• Coordinates reference frame:	ITRF	ITRF
Latitude or X /m:	+3924692.574	+3924688.949
Longitude or Y /m:	+301141.187	+301145.833

Height or Z /m:	+5001908.320	+5001909.214
General information		
• Rise time of the local UTC pulse:	0.7 ns	
• Is the laboratory air conditioned:	Yes	
Set temperature value and uncertainty:	(23.0±0.5) °C	
Set humidity value and uncertainty:	(45±5) %	

(%%) operation with PPS IN Delay Compensation on.
Antenna coordinates (APC) were determined using NRCan PPP tool for day 210, 2021.

Names of files to be used in processing (for site VSL)
Local receiver: GZ/EZ VSLFMJ.DDD (BIPM – designation VS06)
Travelling receiver GZ / EZ PTBMMJ.DDD

Fourth common clock measurement at PTB

Laboratory:	**PTB**	
Date and hour of the beginning of	2021-08-11 (MJD 59437) 13 UTC	
Date and hour of the end of	2021-08-15 24:00 UTC (MJD 59441)	
Information on the system		
	Local:	**Traveling:**
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		
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	9.33 ± 0.1 (#)	40.48
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	45.0 ± 0.1 (#)	(%%)
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:		Traveling	
☐ INT DLY (or X_R+X_S) (GPS) /ns:	29.7 (P1), 27.2 (P2), (*) 32.0 (E1), 31.7 (E5a) (*)		18.9 (P1) 17.1 (P2) (****) 0.0 (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		(%%)	
☐ 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, peak-to-peak variations 0.6° C

(%%) operation during CC4 with PPS IN Delay Compensation on.

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