GNSS CALIBRATION REPORT

G1G2_1012_2026

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REFERENCES

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RD01	**2025 Group 1 GNSS calibration trip (CAL_ID 1001-2025)**
RD02	**BIPM guidelines for GNSS calibration, V3.0, 02/04/2015**
RD03	**BIPM Procedure for computing raw difference of GNSS code measurements for geodetic receivers, dclrinex software version 3.1, April 2021**
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	**P. Defraigne and G. Petit, "CGGTTS-Version 2E: an extended standard for GNSS time transfer", Metrologia 52 (2015) G1**
RD07	**D. A. Howe and N. Schlossberger, "Characterizing Frequency Stability Measurements Having Multiple Data Gaps", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. 69, No. 2 (2022)**
RD08	**BIPM Template for calibration report to the BIPM, V3.1, 29/08/2015**

ACRONYMS

ACRONYMS	
BIPM	**Bureau International des Poids et Mesures, Sèvres, France**
CAB DLY	**Antenna Cable Delay**
CGGTTS	**CCTF Generic GNSS Time Transfer Standard**
EURAMET	**The European Association of National Metrology Institutes**
GNSS	**Global Navigation Satellite System**
IGS	**International GNSS Service**
INT DLY	**Internal Signal Delay**
PPP	**Precise Point Positioning**
PTB	**Physikalisch-Technische Bundesanstalt, Braunschweig, Germany**
REF DLY	**Reference Delay**
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 Metrosert with respect to the calibration of PTB receiver PT13, which currently serves as the reference receiver in all GNSS time links to PTB in the context of realization of TAI. The PT13 signal delays for GPS and Galileo were determined by BIPM as reported with CAL_ID 1001-2025 [RD01]. 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 1012-2026. Results provided are the visited receiver's internal delays for GPS P-code signals on the two frequencies L1 and L2 (INT DLY (P1), and INT DLY(P2)), the C/A-code signal on L1 (L1C) and the equivalent for Galileo on frequencies E1 and E5a. The delays were determined using the DCLRINEX software, which was provided by the BIPM [RD03].

This report documents the installation, data taking and evaluation during the campaign. It is structured based on the BIPM template [RD08].

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. The final results and the uncertainty discussion close the report. In the Annex the BIPM information tables are reproduced.

The final results are included in Table 5-1 and Table 5-2. The internal delays of receivers EE01 and EE02 were determined with an uncertainty of 1.13 ns (GPS) and 1.02 ns (Galileo) for dual frequency observations.

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

The responsible party at PTB quality management 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. DESCRIPTION OF EQUIPMENT AND OPERATIONS

1.1. PARTICIPANTS

Table 1-1 List of participants

Institute	Point of contact	Site address
PTB	Florian Heimbach +49 531 592 4422 florian.heimbach@ptb.de	PTB, AG 4.42 Bundesallee 100 38116 Braunschweig, Germany
Metrosert	Mihkel Rähn +372 5667 8866 mihkel.rahn@metrosert.ee	AS Metrosert Teaduspargi 8, 12618 Tallinn, Estonia

1.2. TRAVELING EQUIPMENT

The PTBM traveling measurement set-up consists of a 19''-chassis, containing a GNSS receiver (Septentrio PolaRx5TR), a TIC (Piktime T4100U) and internal cabling. The auto compensation mode of the GNSS receiver was set to "ON" during the whole calibration trip. The set-up further includes an antenna (Navexperience 3G+C REFERENCE), 65-meter LMR-400 antenna cable, an additional 10-meter extension antenna cable, an N-to-TNC adapter, as well as an N-to-N adapter and a laptop.

1.3. VISITED EQUIPMENT

Table 1-2 List of the visited equipment

Institute	Status of equipment	Dates of measurement	Receiver type	BIPM code	RINEX name
Metrosert	Group 2	2025-12-10 until 2025-12-16	GTR51	EE01	EE01
Metrosert	Group 2		GTR51	EE02	EE02

1.4. SCHEDULE

Table 1-3 Schedule of the campaign

Date	Institute	Action	Remarks
2026-05-20 until 2026-05-25	PTB	First common-clock comparison between PTBM and PT13	6 days used for the evaluation, MJD 61180 - 61185
2026-06-14 until 2026-06-24	Metrosert	Operation of PTBM in parallel with local receivers	11 days used for the evaluation, MJD 61205 - 61215
2026-07-28 until 2026-08-02	PTB	Second common-clock comparison between PTBM and PT13	6 days used for the evaluation, MJD 61249 - 61254

1.5. CALIBRATION PROCEDURE

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 have 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. The PT13 signal delays for GPS and Galileo were determined by BIPM as reported with CAL_ID 1001-2022 [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 internal signal delay represents the sum of $X_R + X_S$.

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 antenna cable delay (CAB DLY).
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 reference delay (REF DLY).
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 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 1-1 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.

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 the INT DLY. The 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 to be applied is considered only when INT DLY of V is adjusted to G, using T as intermediate for the measurements made at the different sites.

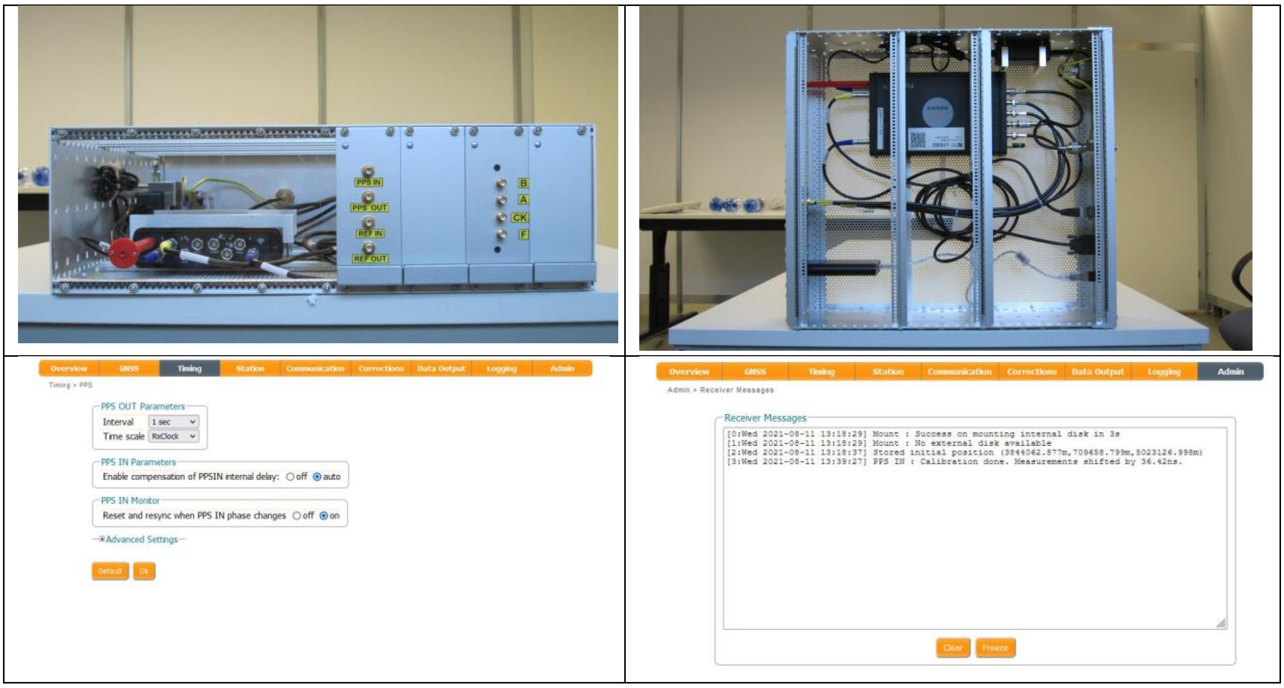

Figure 1-1 PTBM: views of the device and RxControl configuration and messages regarding PPS In and OUT.

2. DATA USED

The G, T, and V receivers are all GNSS geodetic receivers and provide RINEX observation files. RINEX navigation files produced by the PT13 receiver were used for CC1 and CC2 analysis. RINEX navigation files from PTBM were used at all stages. Code measurements were taken from the pseudoranges directly read from the RINEX files by the software DCLRINEX dedicated to differential calibration, as provide by BIPM [RD03]. The software produces raw code differences of co-located receivers from the pseudoranges as

$$\mathrm{RAW\ DIF}_{\mathrm{T-G}}(f) = \mathrm{TOT\ DLY}_{\mathrm{T}}(f) - \mathrm{TOT\ DLY}_{\mathrm{G}}(f), \tag{1}$$

with $TOT\ DLY_R(f)$ and $TOT\ DLY_T(f)$ representing the total delays of the reference and traveling receiver respectively. The total delay of G, or T can be written as

$$\mathrm{TOT\ DLY}(f) = \mathrm{INT\ DLY}(f) + \mathrm{CAB\ DLY} - \mathrm{REF\ DLY}. \tag{2}$$

This report states the differences in system delays ΔSYS DLY according to [RD08]. The system delay is described as the sum of the INT DLY and the CAB DLY.

$$\mathrm{SYS\ DLY}(f) = \mathrm{INT\ DLY}(f) + \mathrm{CAB\ DLY} \tag{3}$$

The ΔSYS DLY for T-G and T-V can therefore be calculated from the raw code differences and the reference delays as

$$\Delta\mathrm{SYS\ DLY}_{\mathrm{T-G}}(f) = \mathrm{RAW\ DIF}_{\mathrm{T-G},median}(f) + \mathrm{REF\ DLY}_{\mathrm{T}} - \mathrm{REF\ DLY}_{\mathrm{G}} \tag{4}$$

and

$$\Delta\mathrm{SYS\ DLY}_{\mathrm{T-V}}(f) = \mathrm{RAW\ DIF}_{\mathrm{T-V},median}(f) + \mathrm{REF\ DLY}_{\mathrm{T}} - \mathrm{REF\ DLY}_{\mathrm{V}}. \tag{5}$$

For the analysis of a measurement series, the RAW DIFs of all available satellites were averaged for each epoch. From this data, the median and standard deviation were determined.
Using (4) & (5), the ΔSYS DLY for V-G can be written in the form

$$\Delta\mathrm{SYS\ DLY}_{\mathrm{V-G}}(f) = \Delta\mathrm{SYS\ DLY}_{\mathrm{T-G}}(f) - \Delta\mathrm{SYS\ DLY}_{\mathrm{T-V}}(f). \tag{6}$$

Therefore, the equation

$$\mathrm{INT\ DLY}_{\mathrm{V}}(f) = \mathrm{INT\ DLY}_{\mathrm{G}}(f) + \Delta\mathrm{SYS\ DLY}_{\mathrm{V-G}}(f) + \mathrm{CAB\ DLY}_{\mathrm{G}} - \mathrm{CAB\ DLY}_{\mathrm{V}} \tag{7}$$

can be used to calculate the INT DLY of all visited receivers.

The analysis also includes the time deviations of the measurement series. The time instability (TDEV) values were determined from the epoch-averaged timelines. If applicable, data gaps in the timeline were filled using the algorithm developed by D. A. Howe and N. Schlossberger [RD07], before TDEV analysis.

3. RESULTS OF RAW DATA PROCESSING

3.1. OVERVIEW

The raw code differences of the pairs of co-located receivers during the data acquisition period are generated using the DCLRINEX software. The stated raw calibration results are taken as the median of the raw differences. The associated uncertainties are derived from the TDEV at 50000 s. The default value of 0.1 ns is chosen if the measured TDEV is less than 0.1 ns.

Table 3-1 Summary information on the raw calibration results for GPS signals (all values in ns)

Pair	Date	RAW(P1)	Unc.	RAW(P2)	Unc.	RAW(C1)	Unc.
PTBM-PT13	61180 - 61185	31.59	0.1	32.45	0.1	31.62	0.1
PTBM-EE01	61205 - 61215	83.67	0.1	105.88	0.1	85.74	0.1
PTBM-EE02	61205 - 61215	83.23	0.1	104.66	0.1	84.95	0.1
PTBM-PT13	61249 - 61254	38.93	0.1	39.66	0.1	38.99	0.1

Table 3-2 Summary information on the raw calibration results for Galileo signals (all values in ns)

Pair	Date	RAW(E1)	Unc.	RAW(E5a)	Unc.
PTBM-PT13	61180 - 61185	31.73	0.1	28.89	0.1
PTBM-EE01	61205 - 61215	83.93	0.1	108.78	0.1
PTBM-EE02	61205 - 61215	83.15	0.1	107.28	0.1
PTBM-PT13	61249 - 61254	39.08	0.1	36.66	0.1

3.2. COMMON-CLOCK SET-UP IN PTB: PERIOD 1

For CC1, PTBM was operated for 6 days at PTB. The installation of the receivers in PTB is depicted in Figure 3-1 for PPS signals and in Figure 3-2 for 5 MHz (and 10 MHz) signals.

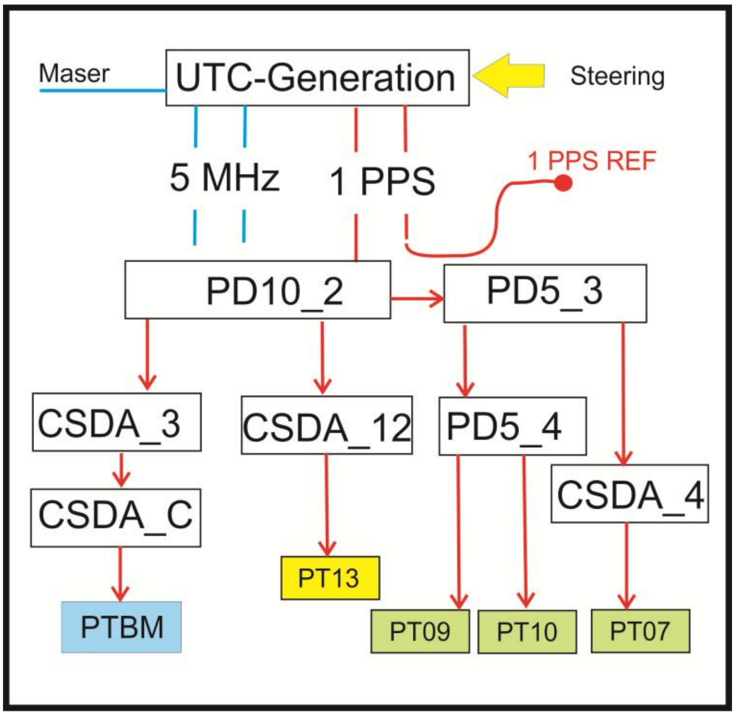

Figure 3-1 UTC(PTB) reference point and 1 PPS signal distribution to PT13, PTBM, and other receivers; PD10 stands for pulse distributor, CSDA stands for clock signal distribution amplifier

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 3-3 shows the installation of GNSS antennas on the roof of the PTB time laboratory (clock hall) during CC1.

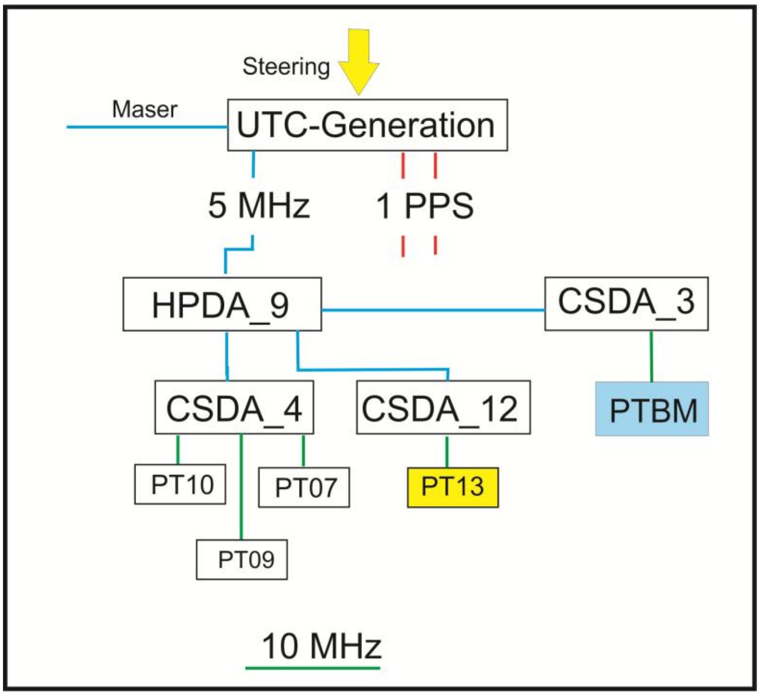

Figure 3-2 UTC(PTB) signal distribution (5 MHz, 10 MHz) to PT13, PTBM, and other receivers

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

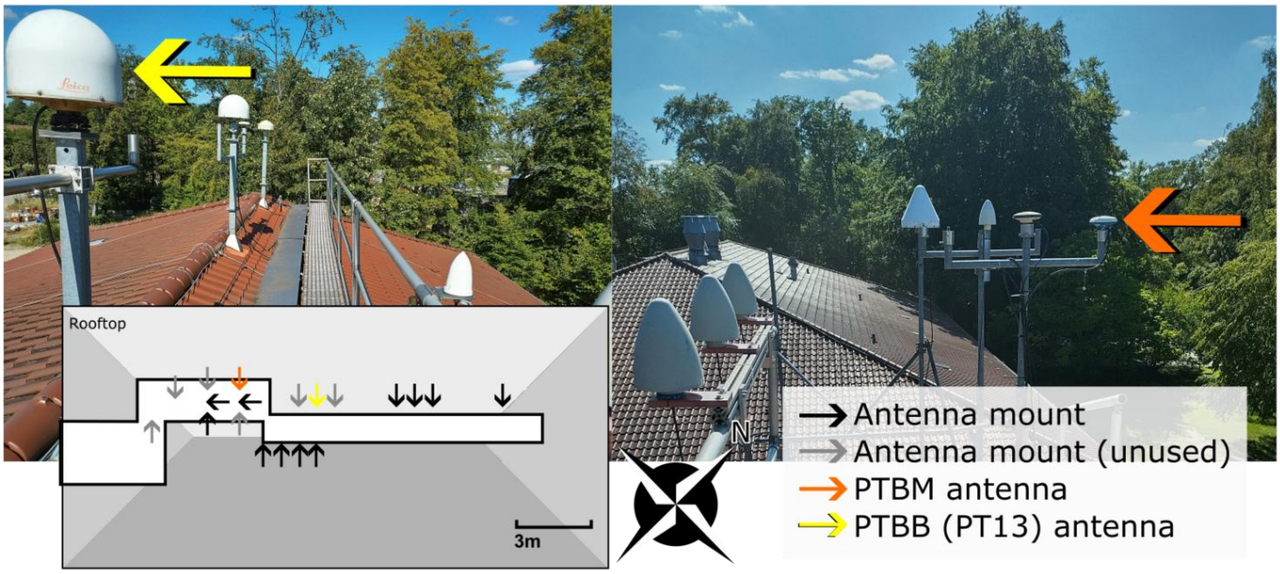

Figure 3-3 Installation of GNSS antennas at PTB, PT13 antenna (yellow) and PTBM antenna during CC1 (orange)

The period 61180 to 61185 (6 days) was chosen to determine the initial PTBM INT DLY values (CC1). The results of the comparison with PT13 as the reference are shown in Figure B-1, Figure B-2 and Figure B-3. The figures show the raw code differences and the corresponding TDEVs. The numerical results are given in Table 3-1 and Table 3-2.

3.3. OPERTATION OF PTBM AT METROSERT

The mobile receiver PTBM was dispatched on the 28th of May 2026 from PTB and set-up at Metrosert in week 45 of 2026. Metrosert operates two GNSS receivers with the designations EE01 and EE02 whose delays were determined. Information sheets about these receivers are shown in Annex A. The setup at Metrosert is depicted in Figure 3-5.

The PPS and 10 MHz signal distribution to PTBM and the Metrosert local receivers is illustrated in Figure 3-4.

PTBM was operated with its own antenna and antenna cable. The antenna installation at DLR is shown in Figure 3-5.

Raw code differences and the corresponding TDEVs are shown in Annex B in Figures B-4 to B-9. The numerical results are given in table 3-1 and table 3-2.

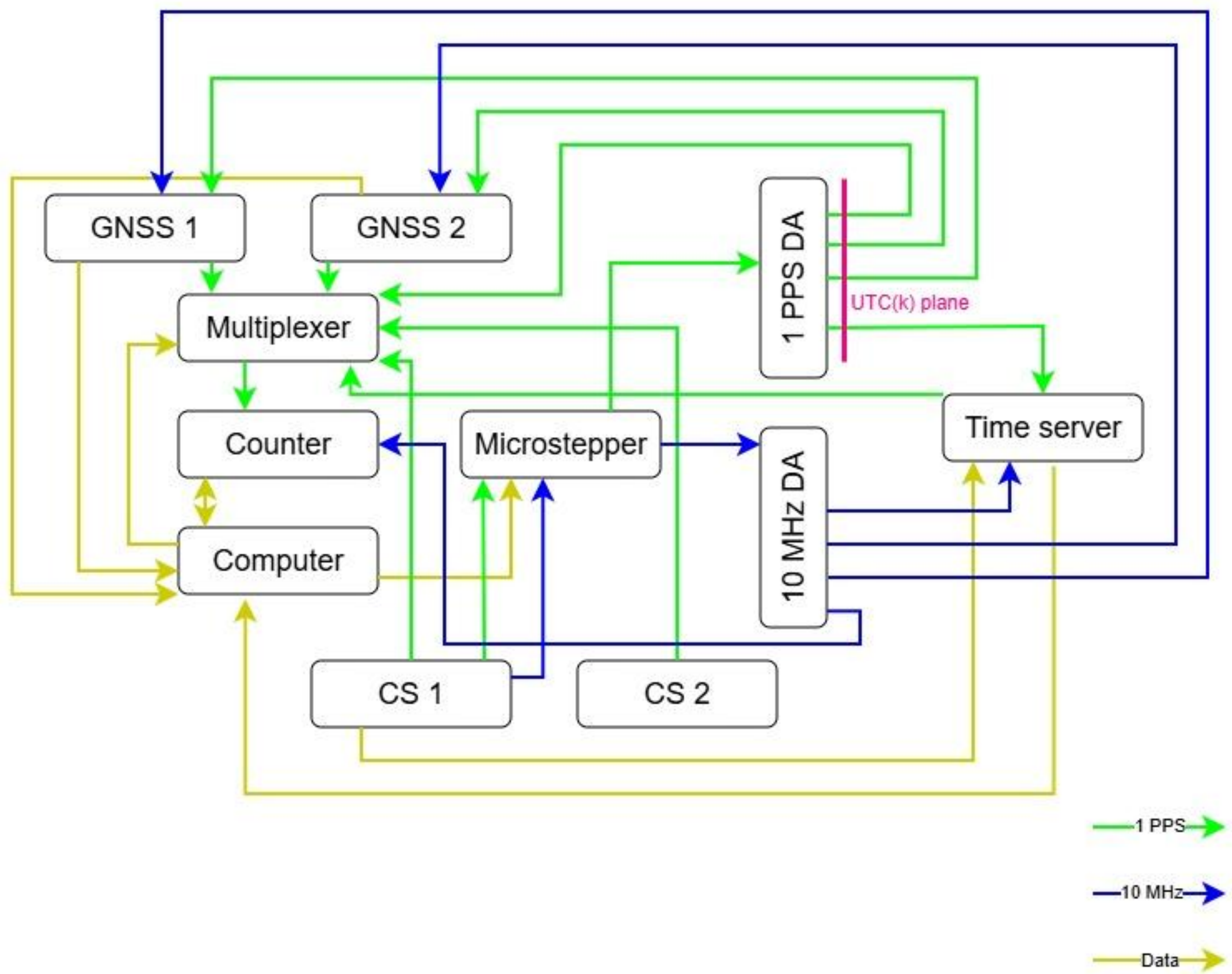

Figure 3-4 PPS and frequency signal distribution at Metrosert.

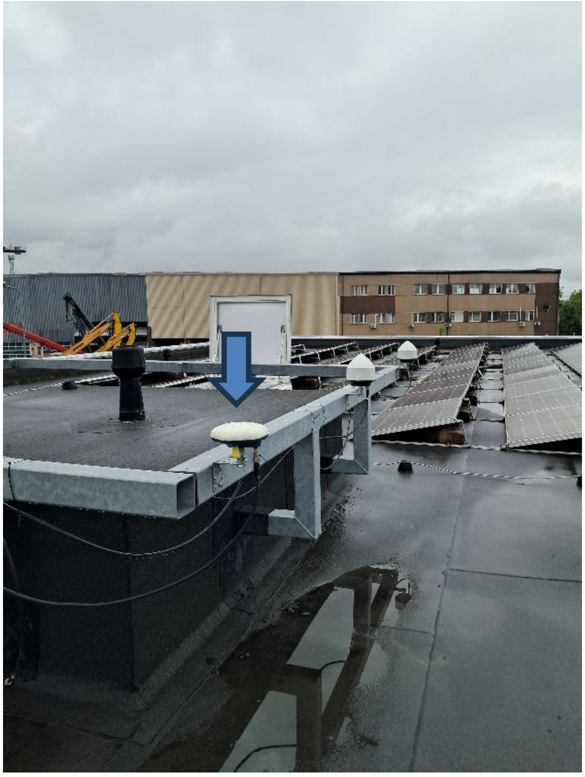

Figure 3-5 The PTBM antenna installed at Metrosert. The blue arrow points towards the PTBM antenna. The EE01 and EE02 antennas can be seen in the background.

3.4. COMMON-CLOCK SET-UP IN PTB: PERIOD 2

The mobile receiver was dispatched from Metrosert and arrived at PTB on the 27th of July 2026. It was set up at PTB on the same day, after being on the road for a total of 60 days.
The period 61249 to 61254 (6 days) was chosen to determine PTBM INT DLY values during the common clock period CC2. The configuration of PTBM was “standard”, the automatic PPS IN delay compensation was activated. The results of the comparison with PT13 as the reference are shown in Figure B-10, Figure B-11 and Figure B-12. The figure shows the raw code differences and the corresponding TDEVs. The numerical results are given in Table 3-1 and Table 3-2.

4. CALIBRATION RESULTS

4.1. TRAVELING SYSTEM WITH RESPECT TO THE REFERENCE SYSTEM

The numerical results of the two common-clock campaigns at PTB are given in Table 4-1. The ΔSYS DLY_{T-G} values agree largely with one another. The biggest change between CC1 and CC2 was noted for Galileo E5a. Here the values differ by 0.31 ns.

Table 4-1 Calibration results T vs. G (all values in ns)

Pair	Date	REF DLY_T	REF DLY_G	RAW DIF	ΔSYS DLY_{T-G}	Code
PTBM-PT13	61180 - 61185	107.88	55.73	31.59	83.74	P1
PTBM-PT13	61180 - 61185	107.88	55.73	32.45	84.60	P2
PTBM-PT13	61180 - 61185	107.88	55.73	31.62	83.77	C1
PTBM-PT13	61180 - 61185	107.88	55.73	31.73	83.88	E1
PTBM-PT13	61180 - 61185	107.88	55.73	28.89	81.04	E5a
PTBM-PT13	61249 - 61254	100.42	55.73	38.93	83.62	P1
PTBM-PT13	61249 - 61254	100.42	55.73	39.66	84.35	P2
PTBM-PT13	61249 - 61254	100.42	55.73	38.99	83.68	C1
PTBM-PT13	61249 - 61254	100.42	55.73	39.08	83.77	E1
PTBM-PT13	61249 - 61254	100.42	55.73	36.66	81.35	E5a

4.2. TRAVELING SYSTEM WITH RESPECT TO THE VISITED SYSTEM

Table 4-2 Calibration results T vs. V for GPS Signals (all values in ns)

Pair	Date	REF DLY_T	REF DLY_V	RAW DIF	ΔSYS DLY_{T-V}	Code
PTBM-EE01	61205 - 61215	10.20	10.20	83.87	83.87	P1
PTBM-EE01	61205 - 61215	10.20	10.20	105.88	105.88	P2
PTBM-EE01	61205 - 61215	10.20	10.20	85.74	85.74	C1
PTBM-EE02	61205 - 61215	10.20	10.20	83.23	83.23	P1
PTBM-EE02	61205 - 61215	10.20	10.20	104.66	104.66	P2
PTBM-EE02	61205 - 61215	10.20	10.20	84.95	84.95	C1

Table 4-3 Calibration results T vs. V for Galileo Signals (all values in ns)

Pair	Date	REF DLY_T	REF DLY_V	RAW DIF	ΔSYS DLY_{T-V}	Code
PTBM-EE01	61205 - 61215	10.20	10.20	83.93	83.93	E1
PTBM-EE01	61205 - 61215	10.20	10.20	108.78	108.78	E5a
PTBM-EE02	61205 - 61215	10.20	10.20	83.15	83.15	E1
PTBM-EE02	61205 - 61215	10.20	10.20	107.28	107.28	E5a

4.1. VISITED SYSTEM WITH RESPECT TO THE REFERENCE SYSTEM

Table 4-4 Calibration results V vs. G for GPS Signals (all values in ns)

Pair	CAB DLY_V	CAB DLY_G	ΔSYS DLY_{V-G}	ΔINT DLY_{V-G}	Code
PT13-EE01	278.7	205.7	-0.19	49.51	P1
PT13-EE01	278.7	205.7	-21.41	28.29	P2
PT13-EE01	278.7	205.7	-2.02	47.68	C1
PT13-EE02	280.4	205.7	0.45	50.15	P1
PT13-EE02	280.4	205.7	-20.19	29.51	P2
PT13-EE02	280.4	205.7	-1.23	48.48	C1

Table 4-5 Calibration results V vs. G for Galileo Signals (all values in ns)

Pair	CAB DLY_V	CAB DLY_G	ΔSYS DLY_{V-G}	ΔINT DLY_{V-G}	Code
PT13-EE01	278.7	205.7	-0.11	49.59	E1
PT13-EE01	278.7	205.7	-27.58	22.12	E5a
PT13-EE02	280.4	205.7	0.68	50.38	E1
PT13-EE02	280.4	205.7	-26.08	23.62	E5a

5. FINAL RESULTS FOR THE VISITED SYSTEMS

The results of the calibration campaign G1G2_1012-2026 are summarized in Table 5-1 and Table 5-2. INT DLY values for the golden reference receiver PT13 were determined in 2025 [RD01]. The uncertainty values are taken from Table 5-3. The final INT DLY values were calculated using equation (7) with the values listed in the Table 4-1 to 4-5.

Table 5-1 Summary of final results for GPS links, all values in ns

Reference system	Cal_Id	Date		INT DLY (P1)	INT DLY (P2)	INT DLY (C1)
PT13	1001-2025	61108		30.83	28.57	32.85
Visited system	**Cal_Id**	**Date**	**u_{CAL} (P3)**	**INT DLY (P1)**	**INT DLY (P2)**	**INT DLY (C1)**
EE01	1012-2026	61262	1.08	80.34	56.86	80.53
EE02	1012-2026	61262	1.08	80.98	58.08	81.33

Table 5-2 Summary of final results for Galileo links, all values in ns

Reference system	Cal_Id	Date		INT DLY (E1)	INT DLY (E5a)
PT13	1001-2025	61108		32.91	32.79
Visited system	**Cal_Id**	**Date**	**u_{CAL} (P3)**	**INT DLY (E1)**	**INT DLY (E5a)**
EE01	1012-2026	61262	0.98	82.50	54.91
EE02	1012-2026	61262	0.98	83.29	56.41

5.1. INT DLY UNCERTAINTY EVALUATION

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

$$\mathrm{u_{CAL}} = \sqrt{\mathrm{u_a^2} + \mathrm{u_b^2}}\,, \tag{8}$$

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 the visited sites and PTB, respectively. The systematic uncertainty is given by

$$\mathrm{u_b} = \sqrt{\sum_n u_{b,n}^2}. \tag{9}$$

The contributions to the sum (9) are listed and explained subsequently. Values in column P3 are calculated according to $u(P3) = \sqrt{u(P1)^2 + (1.54 \times u(P1-P2))^2}$. Uncertainties for the Galileo delays are calculated according to $\sqrt{u(E1)^2 + (1.26 \times u(E1-E5a))^2}$.

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

Table 5-3 Uncertainty contributions for the calibration of receiver delays at Metrosert, all values in ns

	Uncertainty	Value f1	Value f2	Value f1-f2	Value f3	Description
1	u_a (PTB)	0.1	0.1	0.14		CC measurement uncertainty at PTB, TDEV max. of the two CC campaigns
2	u_a (V)	0.1	0.1	0.14		CC measurement uncertainty for V, TDEV at 50.000 seconds
3a	u_a (GPS)	0.14	0.14	0.2	0.34	
3b	u_a (Galileo)	0.14	0.14	0.2	0.29	
Result of closure measurement at PTB						
4a	$u_{b,1}$ (GPS)	0.12	0.25	0.28		Misclosure, see Table 4-1
4b	$u_{b,1}$ (Galileo)	0.11	0.31	0.33		Misclosure, see Table 4-2
Systematic components due to antenna installation						
5	$u_{b,11}$	0.2	0.2	0.28		Multipath at PTB
6	$u_{b,12}$	0.2	0.2	0.28		Multipath at V
7	$u_{b,13}$	0.1	0.1	0.14		Position Error at PTB
8	$u_{b,14}$	0.1	0.1	0.14		Position Error at V
Installation of PTBM and visited receivers						
9	$u_{b,21}$	0.2	0.2	0		Connection of PTBM to UTC(PTB) (REF DLY)
10	$u_{b,22}$	0.2	0.2	0		Connection of PTBM to local UTC (REF DLY)
11	$u_{b,23}$	0.2	0.2	0		Connection of receivers at V to local UTC (REF DEL)
12	$u_{b,24}$	0.1	0.1	0		TIC nonlinearities at PTB
13	$u_{b,25}$	0.1	0.1	0		TIC nonlinearities at V
Antenna cable delay						
14	$u_{b,33}$(V)	0.5	0.5	0		Uncertainty estimation for V CAB DLY values
Total						
15a	$u_{b,INT}$ (GPS)	0.71	0.74	0.53	1.08	
15b	$u_{b,INT}$ (Galileo)	0.69	0.75	0.56	0.98	
16a	$u_{CAL,0}$ (GPS)				1.13	
16b	$u_{CAL,0}$ (Galileo)				1.02	

As demonstrated in Table 3-1, the receivers at Metrosert show almost the same time instability. The uncertainty u_a is derived from the TDEV at 50.000 s. If the value is lower than 0.1 ns, the conservative estimation of 0.1 ns is used instead.

The uncertainty contribution $u_{b,1}$ is based on the difference between the two common clock campaigns at PTB. Between these, the mobile receiver was on the road for 84 days. The campaigns showed discrepancies between 0.11 ns and 0.31 ns, depending on the frequency.

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 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. This was the case during the current campaign.

An uncertainty contribution due to potential multipath disturbance is added as $u_{b,11}$ and $u_{b,12}$. 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 all cases.

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

The measurement of antenna cable delays causes the contribution $u_{b,31.}$ CAB DLY values were measured at PTB in previous campaigns, with the cable rolled out and 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 if 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 an uncertainty contribution $u_{b,31}$ of 0.5 ns for the stationary antenna cables at Metrosert. The same PTBM cable was employed throughout the current campaign.

ANNEXES

ANNEX A: BIPM INFORMATION SHEETS
ANNEX B: PLOTS OF RAW DATA AND TDEV ANALYSIS

ANNEX A: BIPM CALIBRATION INFORMATION SHEETS

First common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of	2026-05-20 00:00 UTC (MJD 61180)
Date and hour of the end of measurements:	2026-05-25 23:59 UTC (MJD 61185)

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 (5.4.0) S/N 3048338
1 PPS trigger level /V:	1	1
Antenna cable maker and type: Phase stabilized 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	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	9.59	107.88
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	46.63	Determined automatically by receiver software
Antenna cable delay: (X_C) / ns	205.7	264.9
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:	30.96 (P1), 28.5 (P2)		18.9 (P1) 17.1 (P2) 0.0 (C1)	
☐ INT DLY (or X_R+X_S) (GALILEO) /ns:	33.19 (E1), 33.05 (E5a)		20.8 (E1), 17.9 (E5a)	
☐ CAB DLY (or X_C) /ns:	205.7		264.9	
☐ REF DLY (or X_P+X_O) /ns:	56.2		107.88	
☐ 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

PTBM operation at Metrosert: Receiver EE01

Laboratory:	EE
Date and hour of the beginning of measurements:	**2026-06-15 00:00:00 UTC**
Date and hour of the end of measurements:	**2026-06-24 23:59:30 UTC**

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	EE01	PTBM
• Receiver maker and type: Receiver serial number:	MESIT asd. s.r.o. GTR51 2204006	Septentrio PolaRx5TR 3048338
1 PPS trigger level /V:	1.0	1.0
• Antenna cable maker and type: Phase stabilised cable (Y/N):	SSB Ecoflex 10 N	LMR-400 N
Length outside the building /m:	5	3
• Antenna maker and type: Antenna serial number:	Tallysman VP6000 VP6150C2401170001	NavXperience 3G+C Reference 0560
Temperature (if stabilised) /°C	-	-

Measured delays /ns (if needed fill box "Additional Information" below)		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	10.2	10.2
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	N/A	N/A
• Antenna cable delay:	156	265(1)
Splitter delay (if any):	-	(1)
Additional cable delay (if any):	-	(1)

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	
• INT DLY (GLONASS) /ns:	
• CAB DLY /ns:	
• REF DLY /ns:	
• Coordinates reference frame:	
Latitude or X /m:	
Longitude or Y /m:	
Height or Z /m:	

General information	
• Rise time of the local UTC pulse:	NA
• Is the laboratory air conditioned:	Y
Set temperature value and uncertainty:	24.5 °C ± 1 °C
Set humidity value and uncertainty:	44 % ± 6 %

Receiver EE01

Laboratory:	EE
Date and hour of the beginning of measurements:	**2026-06-15 00:00:00 UTC**
Date and hour of the end of measurements:	**2026-06-24 23:59:30 UTC**

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	EE02	PTBM
• Receiver maker and type: Receiver serial number:	MESIT asd. s.r.o. GTR51 2204007	Septentrio PolaRx5TR 3048338
1 PPS trigger level /V:	1.0	1.0
• Antenna cable maker and type: Phase stabilised cable (Y/N):	SSB Ecoflex 10 N	LMR-400 N
Length outside the building /m:	5	3
• Antenna maker and type: Antenna serial number:	Tallysman VP6000 VP6150C2401170002	NavXperience 3G+C Reference 0560
Temperature (if stabilised) /°C	-	-

Measured delays /ns (if needed fill box "Additional Information" below)		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	10.2	10.2
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	N/A	N/A
• Antenna cable delay:	156	265(1)
Splitter delay (if any):	-	(1)
Additional cable delay (if any):	-	(1)

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	
• INT DLY (GLONASS) /ns:	

• CAB DLY /ns:	
• REF DLY /ns:	
• Coordinates reference frame:	
Latitude or X /m:	
Longitude or Y /m:	
Height or Z /m:	
General information	
• Rise time of the local UTC pulse:	NA
• Is the laboratory air conditioned:	Y
Set temperature value and uncertainty:	24.5 °C ± 1 °C
Set humidity value and uncertainty:	44 % ± 6 %

Second common clock measurement at PTB

Laboratory:	**PTB**	
Date and hour of the beginning of	2026-07-27 12:30 UTC (MJD 61248)	
Date and hour of the end of measurements:	2026-08-02 23:59 UTC (MJD 61254)	
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 stabilized 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	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	9.59 ± 0.1	100.42
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	46.63 ± 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:	30.96 (P1), 28.5 (P2)		18.9 (P1) 17.1 (P2) 0.0 (C1)	
☐ INT DLY (or X_R+X_S) (GALILEO) /ns:	33.19 (E1), 33.05 (E5a)		20.8 (E1), 17.9 (E5a)	
☐ CAB DLY (or X_C) /ns:	205.7		264.9	
☐ REF DLY (or X_P+X_O) /ns:	54.3		100.42	
☐ 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			

. ANNEX B: PLOTS OF RAW DATA AND TDEV ANALYSIS

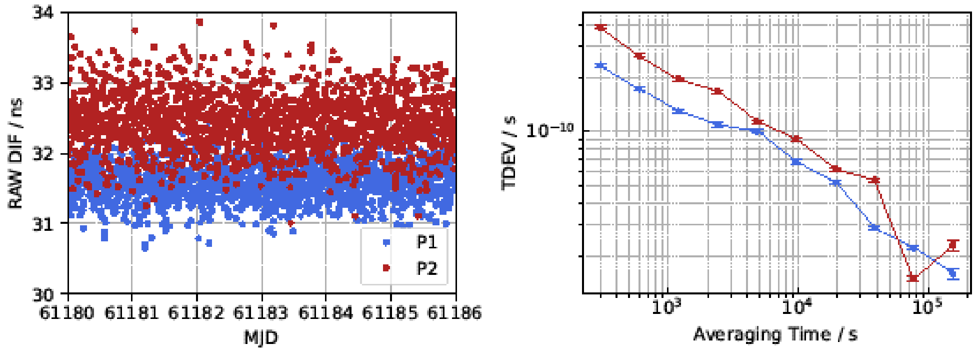

Figure B-1 Left: Raw code differences between T and G for GPS signals during CC1, ΔP1 (blue) and ΔP2 (red) Right: TDEV of the raw code differences between T and G for GPS signals during CC1.

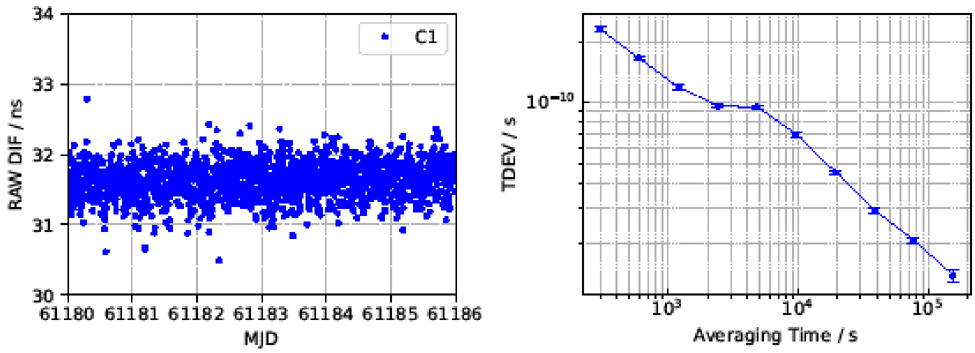

Figure B-2 Left: Raw code differences between T and G for GPS signals during CC1, ΔC1 (blue) Right: TDEV of the raw code differences between T and G for GPS signals during CC1.

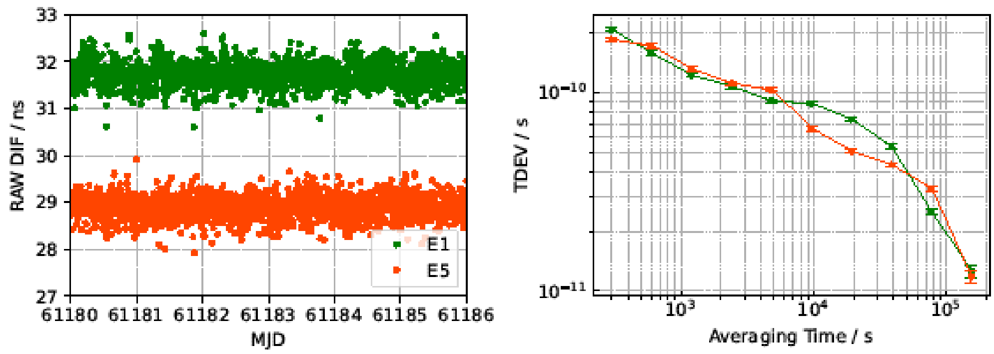

Figure B-3 Left: Raw code differences between T and G for Galileo signals during CC1, ΔE1 (green) and ΔE5a (orange) Right: TDEV of the raw code differences between T and G for Galileo signals during CC1.

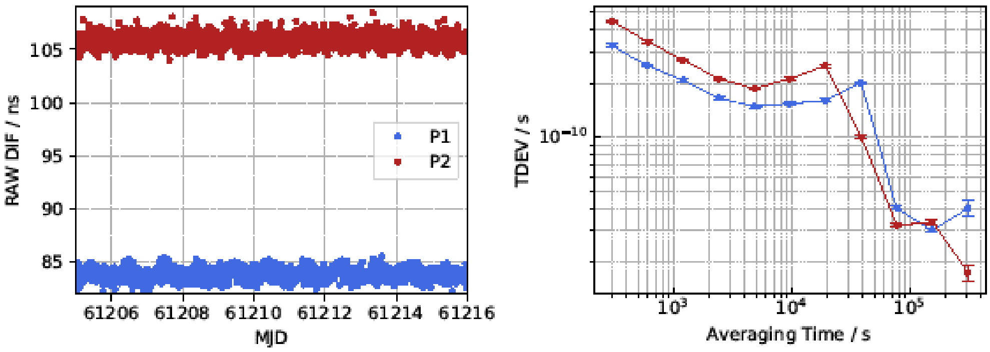

Figure B-4 Left: Left: Raw code differences between PTBM and DLEE01 for GPS signals, ∆P1 (blue) and ∆P2 (red) Right: TDEV of the raw code differences between PTBM and EE01 for GPS signals.

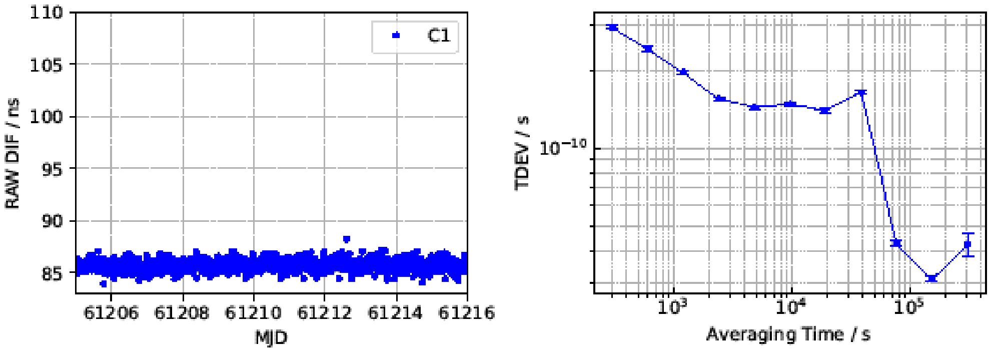

Figure B-5 Left: Left: Raw code differences between PTBM and EE01 for GPS signals, ∆C1 (blue) and ∆C2 (red) Right: TDEV of the raw code differences between PTBM and EE01 for GPS signals.

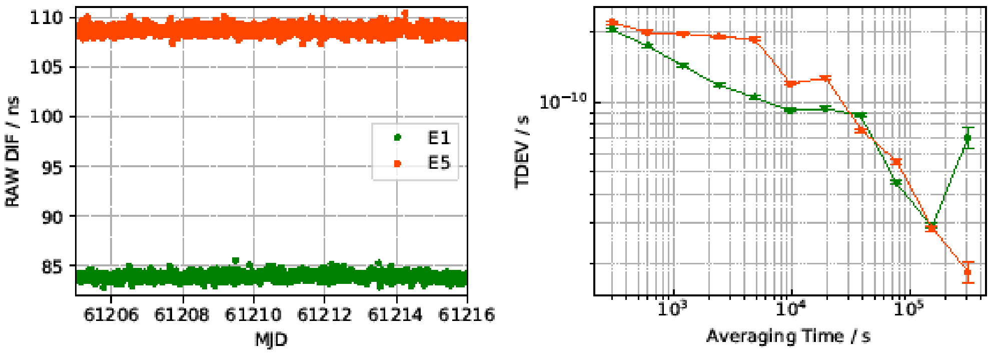

Figure B-6 Left: Left: Raw code differences between PTBM and EE01 for Galileo signals, ∆E1 (green) and ∆E5a (orange) Right: TDEV of the raw code differences.

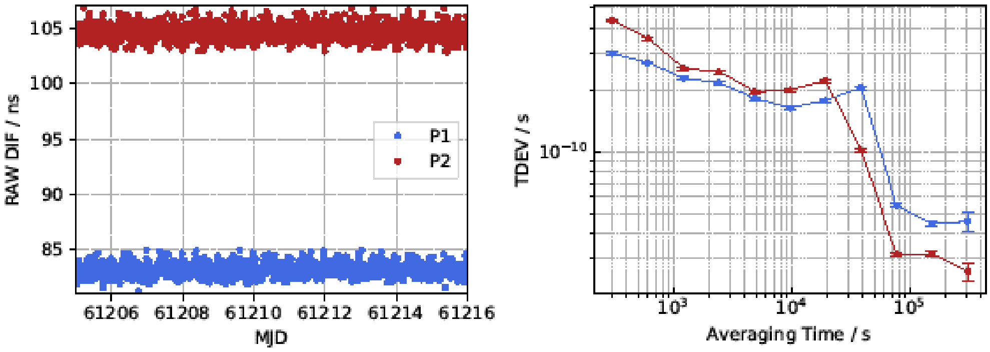

Figure B-7 Left: Left: Raw code differences between PTBM and DLEE02 for GPS signals, ΔP1 (blue) and ΔP2 (red) Right: TDEV of the raw code differences between PTBM and EE02 for GPS signals.

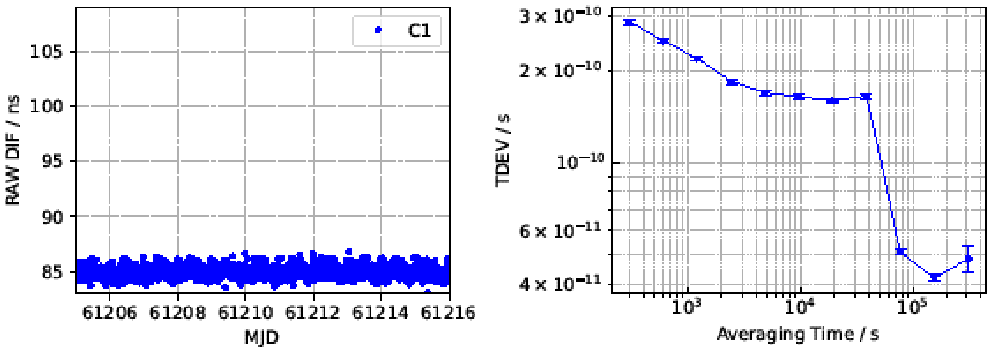

Figure B-8 Left: Left: Raw code differences between PTBM and EE02 for GPS signals, ΔC1 (blue) and ΔC2 (red) Right: TDEV of the raw code differences between PTBM and EE02 for GPS signals.

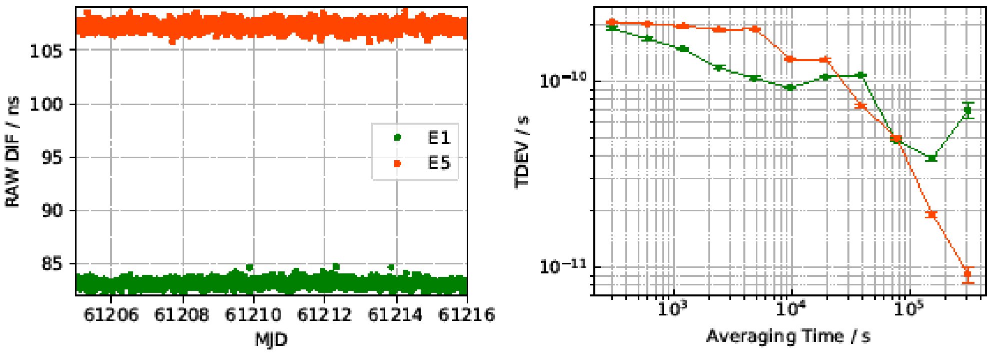

Figure B-9 Left: Left: Raw code differences between PTBM and EE02 for Galileo signals, ΔE1 (green) and ΔE5a (orange) Right: TDEV of the raw code differences.

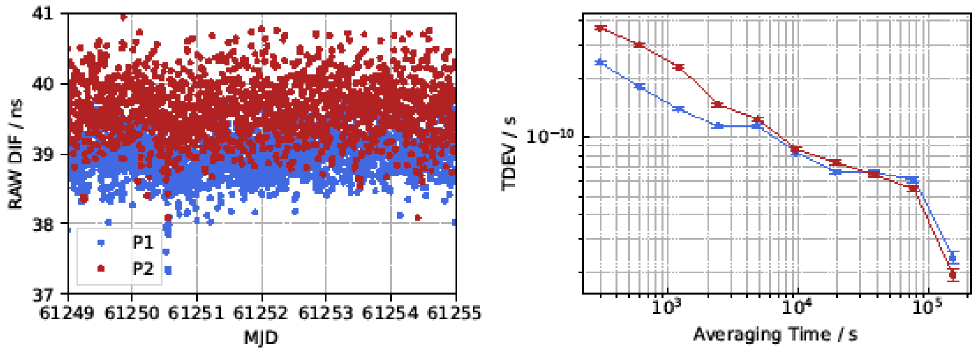

Figure B-10 Left: Raw code differences between T and G for GPS signals during CC2, ΔP1 (blue) and ΔP2 (red) Right: TDEV of the raw code differences between T and G for GPS signals during CC2.

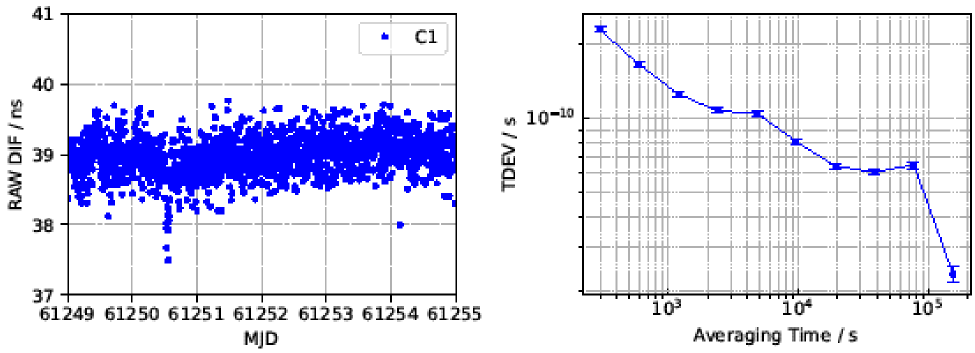

Figure B-11 Left: Raw code differences between T and G for GPS signals during CC2, ΔC1 (blue) Right: TDEV of the raw code differences between T and G for GPS C1 signal during CC2.

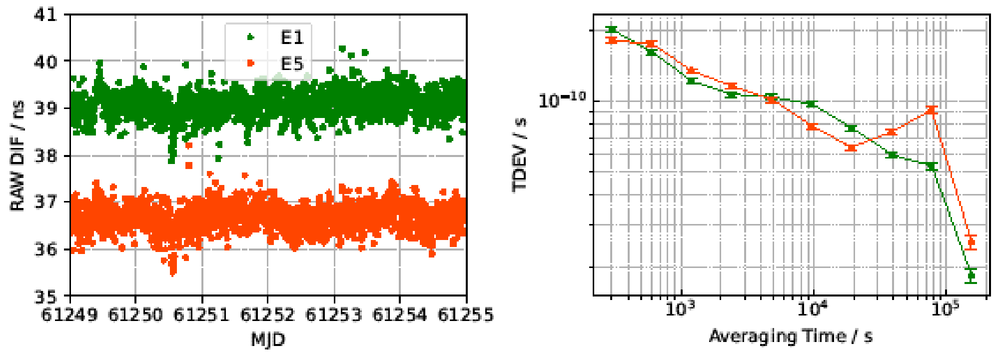

Figure B-12 Left: Raw code differences between T and G for Galileo signals during CC2, ΔE1 (green) and ΔE5a (orange) Right: TDEV of the raw code differences between T and G for Galileo signals during CC2.

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