# GNSS CALIBRATION REPORT

## PT10 INTERNAL

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

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

Authorized by: BIPM

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|---|---|
| Project: | PTB_PT10_internal |
| Code: | 1104_2020 |
| Version: | 1.0 |
| Safe date: | 27.07.2020 15:26 |

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# REFERENCES


| REFERENCES | |
|---|---|
| **RD01** | **BIPM report 2018 Group 1 GPS calibration trip 1001-2018_GPSP3C1_Group1-trip_V2** |
| **RD02** | **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.** |
| **RD03** | **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** | **P. Defraigne and G. Petit, "CGGTTS-Version 2E: an extended standard for GNSS time transfer, Metrologia 52 (2015) G1** |
| **RD07** | **BIPM / GP Continuity of GNSS "INTDLY" values of Group 1 geodetic receivers in successive Group 1 trips, TM 266 V2.5 19 June 2020.** |

# ACRONYMS

| ACRONYMS | |
|---|---|
| **BIPM** | **Bureau International de Poids et Mesures, Sèvres, France** |
| **BKG** | **Bundesamt für Kartografie und Geodäsie, Frankfurt, Germany** |
| **CGGTTS** | **CCTF Generic GNSS Time Transfer Standard** |
| **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** |

# SUMMARY

PTB operates receiver PT10 (Mesit GTR51) as part of its GNSS infrastructure. GPS data collected with PT10 are contractually provided to the Galileo Time Service Provider (GTSP). In parallel its data are provided to BIPM as back-up. In May 2019 a new firmware was installed in PT10 which required a new determination of GPS- and Galileo internal delays. Because of the involvement in GTSP, receiver PT07 served as reference for GPS internal delays, and the receiver GRCP for Galileo delays. The GRCP Galileo delays were obtained by the methode published by Defraigne et al. [RD02]. The exercise of transfer of the calibration to PT10 followed as much as possible the BIPM Guide [RD03]. 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 Galileo E1 and E5a delays. The delays for the C/A-code signals on L1 were also determined during this campaign using PT07 as the reference.

With publication of V2 of [RD01] and V2.5 of [RD07] in June 2020, Galileo delay values for the G1 laboratories were published. In case of PTB, values for PT10 were provided, but these were not useable as they referred to the old GTR51 firmware version. Thus, the PT10 Galileo delay values were aligned to those of PT09 for which valid Galileo delays were provided in [RD01]. Results are illustrated in Section 2.2.

Section 3. As a reminder: All uncertainty values reported in this document are 1-$\sigma$ values. In the Annex the BIPM information table is added.

# 1. RECEIVER INSTALLATION AT PTB

The installation of the receivers in PTB is depicted in Figure 1-1 for 1 PPS signals and in Figure 1-2 for 5 MHz signals. The connection between PT10 and 1PPS was modified in August 2019 (REV Date 09.08.2019) and the picure reflects the installation after that date. The PT03 receiver is supplied with 20 MHz from a times 4 multiplier, but was decommissioned in February 2020. PTB's mobile receiver PTBT is mentioned in the pictures but was not involved in the current exercise. The Calibration Information Sheet in the Annex gives all details, dates given are for the recent Galileo L3E delay determination.

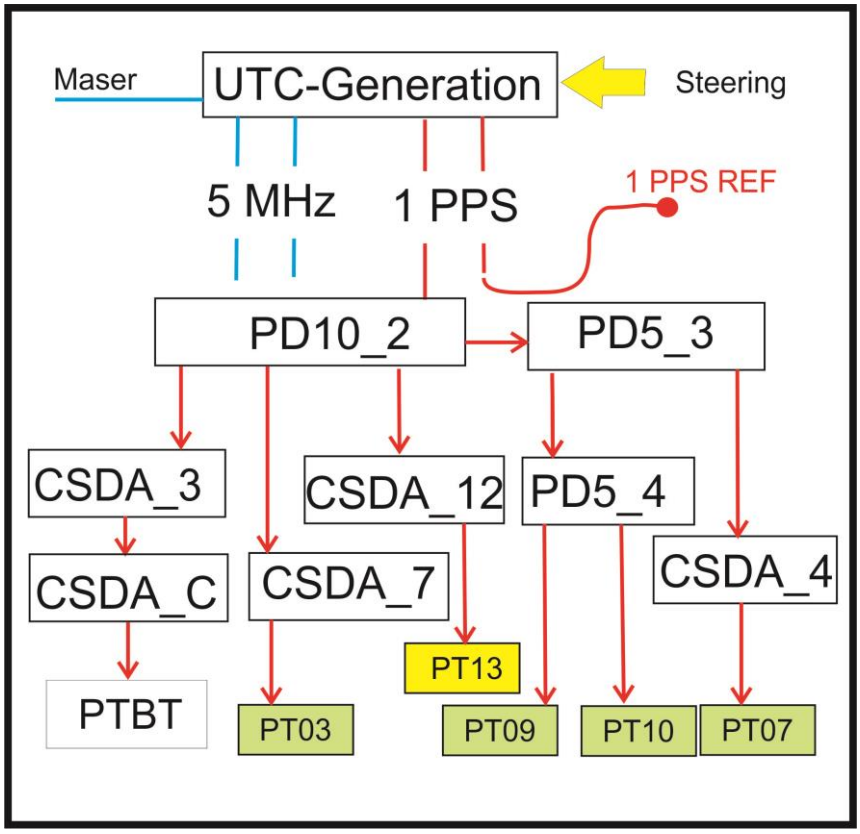


**Figure 1-1: UTC(PTB) reference point and 1 PPS signal distribution to PTB GNSS receivers; PD5 and PD10 stand for pulse distributor, CSDA stands for clock signal distribution amplifier**

Figure 1-3 illustrates the installation of GNSS antennas on the roof of the PTB time laboratory (clock hall). The PT13 antenna is marked with a yellow arrow, the PT09 antenna is the geodetic antenna next to the right, the PT10 antenna is the next one (NavXperience 3G+C) to the right.

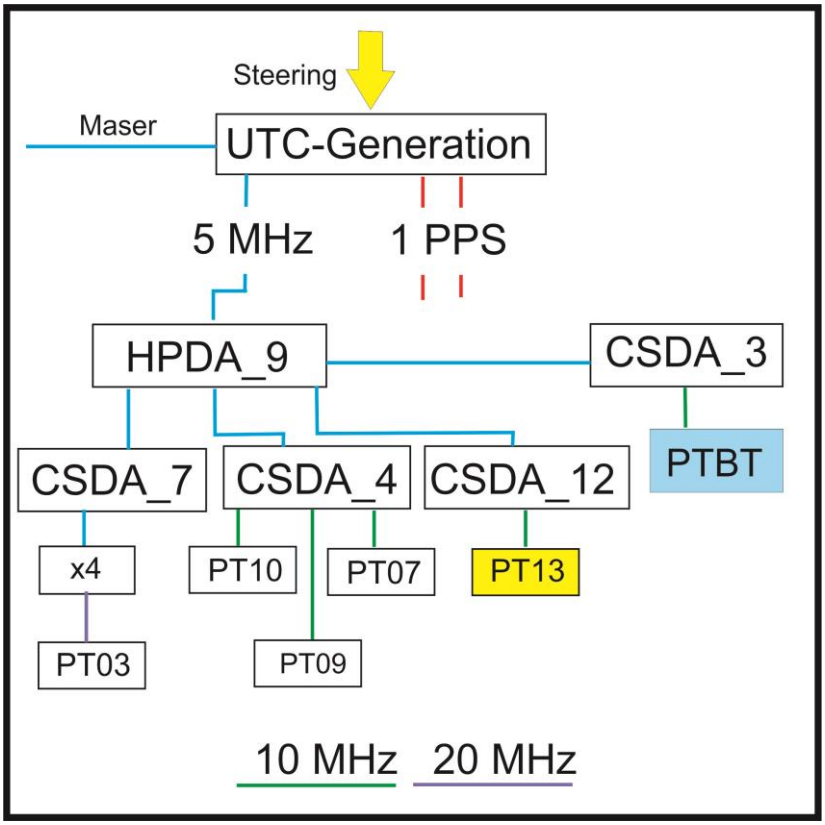


**Figure 1-2: UTC(PTB) signal distribution (5 MHz, 10 MHz, 20 MHz) to PTB GNSS receivers; HPDA stands for High-precision distribution amplifier (for rf frequencies)**

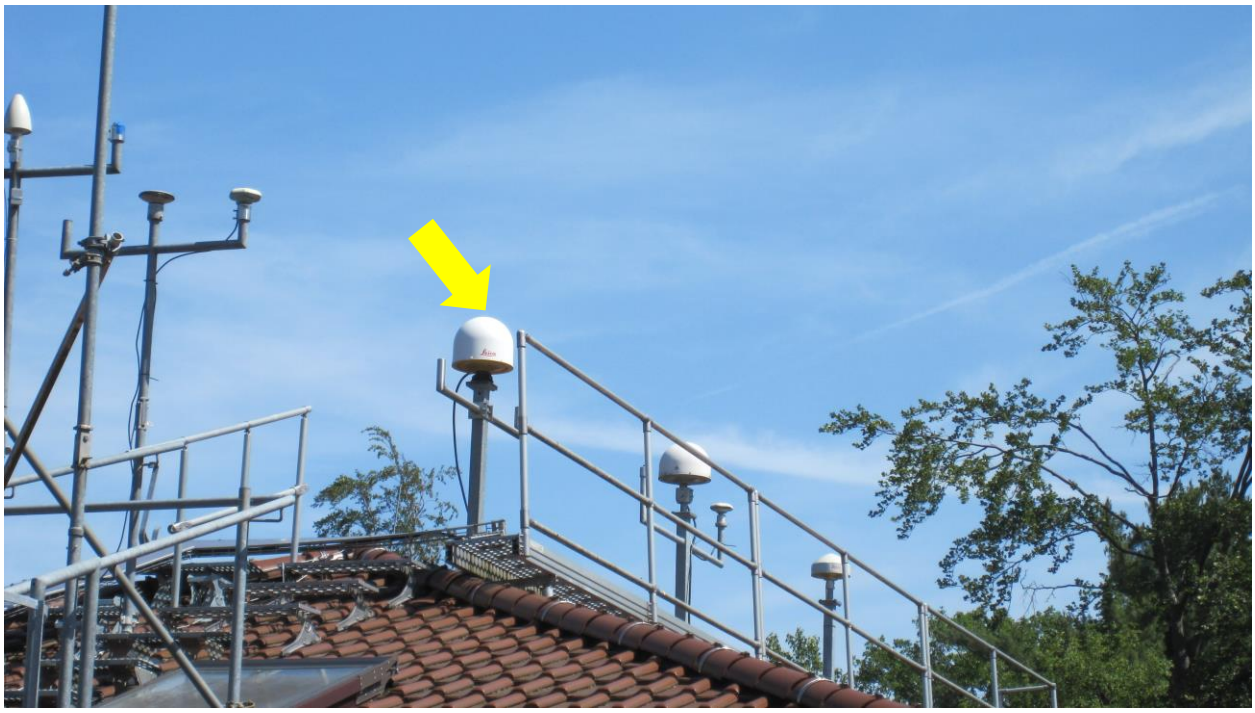

**Figure 1-3: Installation of GNSS antennas at PTB, the PTBB/PT13 antenna marked**

# 2. RESULTS OF COMMON-CLOCK DATA TAKING

## 2.1. DETERMINATION OF PT10 INT DELAYS MAY 2019

The period 58606 to 58609 (4 days) was chosen to determine the PT10 INT DLY values. PT07 served as reference for GPS delay, GRCP for Galielo delays. The results are given in

**Table 2-1 INT DLY values in ns determined for receiver PT10 in May 2019**

| GNSS | INT DLY 1 | SigmaE | INT DLY 2 | SigmaE | Nepoch |
|---|---|---|---|---|---|
| GPS | P1: 31.93 | P1: 0.23 | P2: 25.34 | P2: 0.32 | 327 |
| GPS | L1C: 33.98 | L1C: 0.17 | | | |
| Galileo | E1: 34.49 | E1:0.16 | E5a: 23.57 | E5a: 0.25 | 238 |

Results became effective with REV DATE 2019-05-08 in CGGTTS files.
With REV DATE 2019-09-08 the new installation of PT10 was reported.

## 2.2. DETERMINATION OF PT10 GALILEO DELAY IN JUNE 2020

The period 59024 to 59028 (5 days) was chosen to determine the new PT10 Galileo INT DLY values. The result of comparison with PT09 as the reference are shown in Figure 2-1 illustrating in total 445 ΔEi values obtained as mean over all common view observations at a given epoch. The numerical results are given in Section 3.

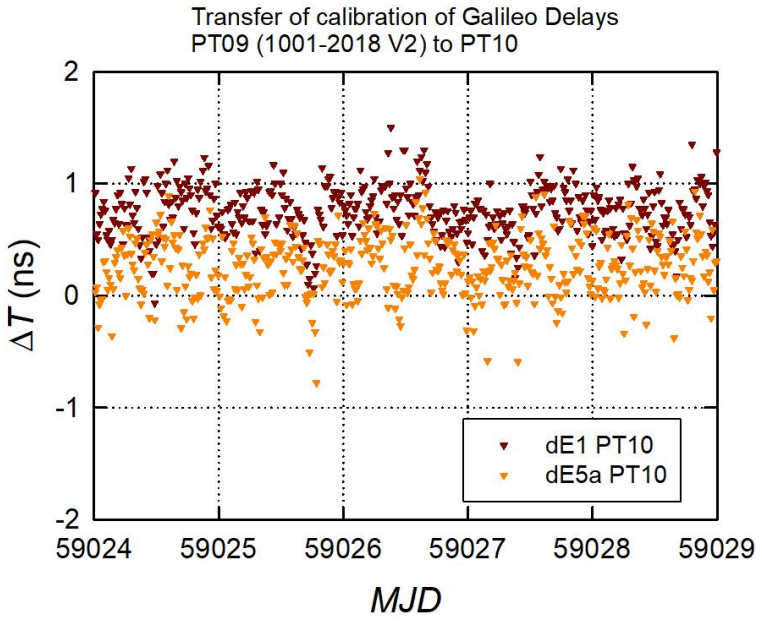


**Figure 2-1 ΔE1 (brown) and ΔE5a (orange) values obtained during the common-clock set-up in PTB**

# 3. RESULTS

Table 3-1 represent the delay values in use after 2019-05-08 for GPS and after 2020-07-02 for Galileo.

**Table 3-1: PT10 INT DLY values in ns valid after 2020-07-02**

| INT DLY | Median (ns) | Sigma (ns) | TDEV (ns) |
|---|---|---|---|
| P1 (PT10) | 31.9 | 0.23 | 0.1 |
| P2 (PT10) | 25.30 | 0.32 | 0.1 |
| L1C (PT10) | 34.0 | 0.17 | |
| | | | |
| ∆E1 (PT10) | 0.75 | 0.23 | 0.1 |
| E1 new | 35.1 | | |
| ∆E5a (PT10) | 0.26 | 0.27 | 0.1 |
| E5a new | 23.8 | | |
| | | | |

The new PT10 delay Galileo delay values have been used in processing per 02 July 2020 (Rev Date in CGGTTS File).

# 4. INT DLY UNCERTAINTY EVALUATION

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

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

with the statistical uncertainty $u_a$ and the systematic uncertainty $u_b$. The statistical uncertainty is related to the instability of the common clock data collected at PTB. The systematic uncertainty is given by

$$u_b = \sqrt{\sum_n u_{b,n}}\,. \tag{7}$$

The contributions to the sum (7) are listed and explained subsequently. Values in column P3 are calculated according to u(P3) = $\sqrt{\{u(P1)^2 + (1.54 \times u(P1\text{-}P2))^2\}}$. Note that the uncertainty of the INT DLY values of PTB's fixed receiver PT09 which served as the reference is not included.

**Table 4-1: Uncertainty contributions for the GPS calibration of receiver delays**

| | Uncertainty | | Value P1 (ns) | Value P2 (ns) | Value P1-P2 (ns) | Value P3 (ns) | Description |
|---|---|---|---|---|---|---|---|
| 1 | $u_a$ (PTB) | | 0.1 | 0.1 | 0.14 | 0.18 | CC measurement uncertainty at PTB, TDEV |
| | | | | | | | |
| | **Systematic components due to antenna installation** | | | | | | |
| 2 | $u_{b,11}$ | | 0.1 | 0.1 | 0.14 | 0.28 | Position error at PTB |
| 3 | $u_{b,13}$ | | 0.2 | 0.2 | 0.0 | 0.20 | Multipath at PTB |
| | **Installation of receivers to UTC(PTB)** | | | | | | |
| 4 | $u_{b,21}$ | | 0.2 | 0.2 | 0 | 0.2 | Connection of receivers to UTC(PTB) (REF DLY) |
| 5 | $u_{b,24}$ | | 0.1 | 0.1 | 0 | 0.1 | TIC nonlinearities at PTB |

All uncertainties considered are small compared to the "standard" uncertainty attributed to a link between PTB and any laboratory contributing to TAI. Any error in the CAB DLY measurements is absorbed in the INT DLY values. Although the installation of the two receivers requires signal distribution via different distribution equipment, the final REF DLY measurements have been made (for PT09 in Nov. 2018 during campaign 1001-2018) and for PT10 in August 2019 using the same method so that only a small uncertainty due to possible non-linearities need to be considered.

The uncertainty estimate is considered valid in 2020. The slightly different frequency ratio in case of Galileo compared to GPS results in slightly different values, but after rounding to 0.1 ns the differences are negligible.

## ANNEX: BIPM CALIBRATION INFORMATION SHEETS

# Common clock measurement at PTB

| **Laboratory:** | **PTB** |
|---|---|
| Date and hour of the beginning of | 2020-06-24 0:00 UTC (MJD 59024) |
| Date and hour of the end of measurements: | 2020-06-28 24:00 UTC (MJD 59028) |

| **Information on the system** | | |
|---|---|---|
| | **Reference:** | **DUT:** |
| 4-character BIPM code | **PT09** | **PT10** |
| Receiver maker and type:<br>Receiver serial number: | PolaRx4TR (2.9.6), S/N 3001148 | MESIT GTR51<br>1309042 1.9.0 |
| 1 PPS trigger level /V: | 1 | 1 |
| Antenna cable maker and type:<br>Phase stabilised cable (Y/N): | ECOFLEX 15plus | ANDREWS LDF-1 |
| Length outside the building /m: | approx. 25 | 25 |
| Antenna maker and type: Antenna serial number: | NOV750.R4 | NavXperience S/N 121 |
| Temperature (if stabilised) /°C | | |

| **Measured delays /ns** | | |
|---|---|---|
| | **Reference:** | **DUT:** |
| Delay from local UTC to receiver 1 PPS-in ($X_P$) / ns | 35.25 ± 0.1 (**) | 36.8 |
| Delay from 1 PPS-in to internal Reference (if different): ($X_O$) / ns | 147.92 ± 0.1 (**) | 0 |
| Antenna cable delay: ($X_C$) / ns | 198.7 ± 0.1 | 250.0 ± 0.1 |
| Splitter delay (if any): | N/A | |

| **Data used for the generation of CGGTTS files** | | | | |
|---|---|---|---|---|
| | **Reference:** | | **DUT** | |
| ☐ INT DLY (or $X_R$+$X_S$) (GALILEO) /ns: | 57.6 (E1), 66.3 (E5a), (**) | | 34.4 (E1) 23.5 (E5a) (***) | |
| ☐ INT DLY (or $X_R$+$X_S$) (GLONASS) /ns: | | | | |
| ☐ CAB DLY (or $X_C$) /ns: | 198.7 | | 250.0 | |
| ☐ REF DLY (or $X_P$+$X_O$) /ns: | 183.2 (**) | | 36.8 | |
| ☐ Coordinates reference frame: | ITRF (*) | | ITRF | |
| X /m: | +3844057.34 (*) | Mast P12 | +3844056.64 | Mast P13 |
| Y /m: | +709663.82 (*) | | +709664.25 | |
| Z /m | +5023131.76 (*) | | +5023131.88 | |

| **General information** | |
|---|---|
| ☐ Rise time of the local UTC pulse: | 3 ns |
| ☐ Is the laboratory air conditioned: | Yes |
| Set temperature value and uncertainty: | 23.0 °C, peakt-to-peak variations 0.5° C |

Notes:

(*) values provided by BIPM as part of coordinate alignment 2018 reported in TM.281.

(**) Local measurement 2018-11-05, other results based on report Cal-ID1001-2018 V2

(***) values as reported after 08.05.2019

Names of files to be used in processing:

DUT EZPT10MJ.DDD,

Reference receiver EZPT09MJ.DDD

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