Chunghwa Telecom Laboratories

# 2025 Group 2 GNSS Calibration Report
# Cal_ID: 1013-2025

**National Standard Time and Frequency Lab**

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**08/30/2025 Version 1 (new)**

**10/08/2025 Version 2 (revised the REFDLY measurement of TTS-5)**

**10/31/2025 Version 2.1 (footnote added to the information sheet for REFDLY measurement description)**

# Summary

As one of the APMP G1 laboratories, TL conducted a relative calibration of the GNSS time transfer receivers of UzNIM (Uzbek National Institute of Metrology of Uzstandard Agency, which acronym in BIPM list is UZ), Uzbekistan with respect to the calibrated TL receiver TLT5 which setup configuration is kept unchanged since 2022. The signal delays of TLT5 for GPS, Galileo, and Beidou were calibrated by BIPM as reported with CAL_ID 1001-2022 [1]. The receiver system TLM2 of TL was used as traveling equipment to transfer the signal delays of TLT5 to the visited GNSS receivers UZ__ of UzNIM. The data were collected between MJD 60770-60894 (5th April 2025 – 7th August 2025) by simultaneous operation of pairs of co-located GNSS receivers. This campaign was declared to BIPM on 2nd July 2025 and followed as closely as possible the BIPM Guideline [2]. The results provided are the visited receivers' internal delays for GPS C1, P1, and P2 signals and Galileo E1 and E5a signals. The results will be reported using Cal_ID 1013-2025.

# 1. Table of contents

# List of Acronyms

| | |
|---|---|
| BIPM | Bureau International des Poids et Mesures, Sèvres, France |
| CGGTTS | CCTF Generic GNSS Time Transfer Standard |
| APMP | The Asia Pacific Metrology Programme |
| IGS | International GNSS Service |
| PikTime | PikTime Systems, the manufacturer of TTS-5 GNSS receiver |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| GAL | Galileo satellite navigation system |
| BDS | Beidou satellite navigation system |
| PPP | Precise Point Positioning |
| TL | Telecommunication Laboratories, Chunghwa Telecom, Taiwan |
| TLT5 | TL G1 Reference receiver |
| TLM2 | TL travelling receiver |
| UzNIM | Uzbek National Institute of Metrology, Uzbekistan |
| UTC(UZ) | The standard time scale of UzNIM |
| UZ__ | Visited receiver of UzNIM |
| RINEX | Receiver Independent Exchange Format |
| R2CGGTTS | RINEX-to CGGTTS conversion software, provided by ORB/BIPM |
| DCLRINEX | differential calibration software using the pseudoranges directly read in the RINEX files, provided by the BIPM |
| TDEV | Time Deviation |
| TIC | Time Interval Counter |
| CABDLY | the antenna cable delay; |
| INTDLY | the internal signal delay (antenna + receiver internal); |
| REFDLY | the offset between the UTC reference point in the laboratory and the reference point of the visited receiver |
| SYSDLY | INTDLY + CABDLY |
| TOTDLY | SYSDLY – REFDLY |
| CLPDLY | the offset between the calibration point of the laboratory and the reference point of the traveling receiver |

# 1. Description of equipment and operations

## 1.1 Traveling System

The TL Traveling System consists of a GNSS receiver TLM2 (Septentrio PolaRx5TR, which auto compensation mode was set to "ON" during all calibration trip), an antenna (PolaNt-x MF.v2), 35 meters CFD-300 antenna cable, a laptop, and two auxiliary cables (RG-316 and RG-58 with BNC connectors) to connect the calibration reference point and 10 MHz frequency reference of visited lab. The detailed information can be found in Annex A.1, TLM2 information sheet.

The 1 PPS reference cable of traveling receiver was connected to the calibration point in the visited laboratory UzNIM, the CLPDLY is 15.49 ns measured by UzNIM in this campaign.

## 1.2 Visited Receivers

There was one GNSS receiver UZ__ which would be calibrated in this campaign. UZ__ is a PikTime TTS-5 receiver and was calibrated by PikTime at 2022 (CAL_ID 2005-2022). We would calibrate its GPS P3 and Galileo E3 links this time. The detailed information can be found in their information sheets in Annex A.2 Information sheet of UZ__.

Table 1. Summary information on the calibration trip

| Institute | Status of equipment | Dates of measurement | Receiver type | BIPM code | RINEX name |
|---|---|---|---|---|---|
| TL | Traveling | 60770-60779 | Septentrio PolaRx5 TR | TLM2 | TLM2 |
| TL | Group 1 reference | - | Septentrio PolaRx5 TR | TLT5 | TLT5 |
| UzNIM | Group 2 | 60881-60885 | PikTime, TTS-5 | UZ__ | UZ__ |
| TL | Traveling | 60889-60894 | Septentrio PolaRx5 TR | TLM2 | TLM2 |
| TL | Group 1 reference | - | Septentrio PolaRx5 TR | TLT5 | TLT5 |

# 2. Data Used

Since the reference, traveling, and visited receivers are all GNSS geodetic receivers and provide RINEX files, we use their pseudoranges directly read in their RINEX files by the software 'dclrinex' which provided by BIPM [5] dedicated to differential calibration.

## 3. Results of Raw Data Processing

The raw code differences of the pairs of co-located receivers during the data acquisition period, MJD column in Table 2, are generated by dclrinex. The inferred raw calibration results are taken as the median of the raw differences. The associated uncertainties are taken as the floor of their Tdev values (see Annex B). The values for INTDLY between a given pair of receivers are computed using Eq. (7) and given in Table 7.1 and 7.2.

Table 2. Summary information on the raw calibration results (all values in ns)

| Pair | Date | C1 | Unc | P1 | Unc | P2 | Unc | E1 | Unc | E5a | Unc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TLT5-TLM2 | 60770-60779 | 91.30 | 0.10 | 91.03 | 0.05 | 89.41 | 0.04 | 91.25 | 0.13 | 89.05 | 0.07 |
| TLM2-UZ__ | 60881-60885 | -101.62 | 0.08 | -101.04 | 0.06 | -108.09 | 0.07 | -102.22 | 0.13 | -108.34 | 0.07 |
| TLT5-TLM2 | 60889-60894 | 91.04 | 0.17 | 91.23 | 0.05 | 88.96 | 0.05 | 91.02 | 0.12 | 89.06 | 0.07 |

## 4. Calibration results

From the definition, the raw calibration results of a pair of receivers are equal to their TOTDLY difference:

$$\mathrm{TOTDLY_R(code)} - \mathrm{TOTDLY_{T,\,TL}\,(code)} = \mathrm{RAWDIF_{R\text{-}T}(code)} \qquad (1)$$

Where the $\mathrm{TOTDLY_R(code)}$ and $\mathrm{TOTDLY_{T,\,TL}(code)}$ are the TOTDLY of reference receiver and traveling receiver at TL respectively; the $\mathrm{RAWDIF_{R\text{-}T}(code)}$ is the raw calibration result of the reference and traveling pair read from Table 2. The code can be GPS C1/P1/P2, GAL E1/E5a, and BDS BC/B5.

We note the calibration reference point of traveling receiver and UTC reference point of visited UTC lab may not be identical. For traveling receiver, its TOTDLY in reference and visited lab may be different, here we denote the TOTDLY of traveling receiver in reference lab TL to be $\mathrm{TOTDLY_{T,\,TL}\,(code)}$ and $\mathrm{TOTDLY_{T,\,UzNIM}\,(code)}$ in visited lab.

The TOTDLY can be also expressed using SYSDLY and REFDLY; and the REFDLY is equal to the CLPDLY pluses the offset between the UTC reference point and calibration reference point in the lab:

$$\mathrm{REFDLY_{T,\,TL}\,(code)} = \mathrm{CLPDLY_T\,(code)} + \Delta\mathrm{Ref\_Clb_{TL}} \qquad (2)$$

Where the ΔRef_Clb is the offset between the UTC reference point and calibration reference point in the laboratory, the value of $\Delta\mathrm{Ref\_Clb_{TL}}$ and $\Delta\mathrm{Ref\_Clb_{UzNIM}}$ may be different, but the value $\mathrm{CLPDLY_T(code)}$ are all the same in the whole campaign because we use the same reference 1 PPS cable for the traveling receiver in this trip. We have:

$$\mathrm{TOTDLY_{T,\,TL}(code)} = \mathrm{SYSDLY_{T,\,TL}(code)} - \mathrm{REFDLY_{T,\,TL}(code)}$$

$$= \mathrm{SYSDLY}_{T,\,TL}(\mathrm{code}) - [\mathrm{CLPDLY}_{T}(\mathrm{code}) + \Delta\mathrm{Ref\_Clb}_{TL}] \quad \cdot (3)$$

## 4.1 Traveling System with Respect to The Reference System

From Eq. (1), (2), and (3), the $\mathrm{RAWDIF}_{R\text{-}T}$(code) can be express by

$$\begin{aligned} &\mathrm{RAWDIF}_{R\text{-}T}(\mathrm{code}) \\ &= [\mathrm{SYSDLY}_{R}(\mathrm{code}) - \mathrm{REFDLY}_{R}(\mathrm{code})] \\ &- [\mathrm{SYSDLY}_{T}(\mathrm{code}) - \mathrm{CLPDLY}_{T}(\mathrm{code}) - \Delta\mathrm{Ref\_Clb}_{TL}] \quad \ldots\ldots (4) \end{aligned}$$

**Table 3.1** Traveling vs. Reference system (GPS, all values in ns)

| Pair | Date | C1 | P1 | P2 | P1-P2 |
|---|---|---|---|---|---|
| | | RawDIF | RawDIF | RawDIF | RawDIF |
| TLT5-TLM2 | 60770-60779 | 91.30 | 91.03 | 89.41 | 1.62 |
| TLT5-TLM2 | 60889-60894 | 91.04 | 91.23 | 88.96 | 2.27 |
| Misclosure | - | -0.25 | 0.20 | -0.46 | 0.66 |
| Mean | - | 91.17 | 91.13 | 89.19 | 1.94 |

**Table 3.2** Traveling vs. Reference system (Galileo, all values in ns)

| Pair | Date | E1 | E5a | E1-E5a |
|---|---|---|---|---|
| | | RawDIF | RawDIF | RawDIF |
| TLT5-TLM2 | 60770-60779 | 91.25 | 89.05 | 2.19 |
| TLT5-TLM2 | 60889-60894 | 91.02 | 89.06 | 1.96 |
| Misclosure | - | -0.23 | 0.01 | -0.23 |
| Mean | - | 91.13 | 89.06 | 2.08 |

Table 3.1 and 3.2 are the raw difference values of traveling vs. reference receiver. We don't need to measure the REFDLY of the traveling and reference receivers because they will be cancelled out against each other in the derivation of INTDLY.

## 4.2 Traveling System with Respect to the Visited Systems

Like Eq. (4), the raw difference of traveling receiver at visited lab (UzNIM) can be expressed:

$$\begin{aligned} &\mathrm{RAWDIF}_{T\text{-}V}(\mathrm{code}) = \\ &[\mathrm{SYSDLY}_{T}(\mathrm{code}) - \mathrm{CLPDLY}_{T}(\mathrm{code}) - \Delta\mathrm{Ref\_Clb}_{UzNIM}] \\ &-[\mathrm{SYSDLY}_{V}(\mathrm{code}) - \mathrm{REFDLY}_{V}(\mathrm{code})] \quad \ldots\ldots\ldots (5) \end{aligned}$$

The $\Delta Ref\_Clb_{UzNIM}$ is the offset from UTC(UZ) reference point to the calibration reference point of UzNIM.

**Table 4.1** Traveling with respect to the visited system (GPS, all values in ns)

| Pair | Date | $\Delta Ref\_Clb_{UzNIM}$ | $REFDLY_V$ | C1 | P1 | P2 |
|---|---|---|---|---|---|---|
| | | | | RawDIF | RawDIF | RawDIF |
| TLM2-UZ__ | 60881-60885 | 15.49 | 14.95 | -101.62 | -101.04 | -108.09 |

**Table 4.2** Traveling with respect to the visited system (Galileo, all values in ns)

| Pair | Date | $\Delta Ref\_Clb_{UzNIM}$ | $REFDLY_V$ | E1 | E5a |
|---|---|---|---|---|---|
| | | | | RawDIF | RawDIF |
| TLM2-UZ__ | 60881-60885 | 15.49 | 14.95 | -102.22 | -108.34 |

## 4.3 Visited Systems with Respect to Reference System

Combine Eq. (4) and (5), we get:

$$
\begin{aligned}
& RAWDIF(code)_{R\text{-}T} + RAWDIF(code)_{T\text{-}V} \\
&\quad = [SYSDLY_R(code) - REFDLY_R(code)] - [SYSDLY_V(code) - REFDLY_V(code)] \\
&\quad + \Delta Ref\_Clb_{TL} - \Delta Ref\_Clb_{UzNIM} \\
&\quad = TOTDLY_R(code) - TOTDLY_V(code) + \Delta Ref\_Clb_{TL} - \Delta Ref\_Clb_{UzNIM} \\
&\quad = \Delta TOTDLY_{R\text{-}V}(code) + \Delta Ref\_Clb_{TL} - \Delta Ref\_Clb_{UzNIM}
\end{aligned}
$$

or

$$
\begin{aligned}
& \Delta TOTDLY_{R\text{-}V}(code) \\
& = RAWDIF(code)_{R\text{-}T} + RAWDIF(code)_{T\text{-}V} - \Delta Ref\_Clb_{TL} + \Delta Ref\_Clb_{UzNIM} \qquad \ldots\ldots (6)
\end{aligned}
$$

In TL, the calibration reference point and the UTC(TL) reference point are identical, that is the $\Delta Ref\_Clb_{TL} = 0$. The $\Delta Ref\_Clb_{UzNIM} = 15.49$ ns was measured by UzNIM. The TOTDLY of traveling with respect to the visited system are listed in Table 5.1 and 5.2.

**Table 5.1** Visited system with respect to the reference system (GPS, all values in ns)

| Pair | Date | $\Delta Ref\_Clb_{UzNIM}$ | $\Delta TOTDLY_{R\text{-}V}$ | | |
|---|---|---|---|---|---|
| | | | C1 | P1 | P2 |
| TLT5-UZ__ | 60881-60885 | 15.49 | 5.04 | 5.58 | -3.41 |

**Table 5.2** Visited system with respect to the reference system (Galileo, all values in ns)

| Pair | Date | $\Delta Ref\_Clb_{UzNIM}$ | $\Delta TOTDLY_{R\text{-}V}$ | |
|---|---|---|---|---|
| | | | E1 | E5a |
| TLT5-UZ__ | 60881-60885 | 15.49 | 4.40 | -3.79 |

## 4.4 Uncertainty

In this section, we use the same method as [1] to determine the uncertainty of INTDLY. We estimate all components that can affect accuracy and determine a value $u_{CAL}$ that is to be used as the accuracy of all GPS P3 and GAL E3 links at the epoch of calibration.

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

Where $u_a$ and $u_b$ are the statistical uncertainty the systematic uncertainty respectively.

The statistical uncertainty $u_a$ originates from the Tdev of each pair of RAWDIF listed in Table 2 (graphs can be found in Annex B). We find the minimum for each Tdev curve, and then we choose the largest one among the minimums as the $u_a$.

The systematic uncertainty $u_b$ is given by

$$u_b = \sqrt{\sum_n u_{b,n}^2}$$

Uncertainty values in column P3 are calculated according to $u^2_{P3}=u^2_{P1}+(1.545\times u_{P1-P2})^2$; for the Galileo delays are calculated according to $u^2_{E3}=u^2_{E1}+(1.261\times u_{E1-E5a})^2$. All possible terms to be considered in the summary are to be listed in Table 6.1 and 6.2. Values appear separately for each code (GPS C1, P1, and P2, GAL E1, and E5a) to compute a value $u_{CAL}$ applicable to GPS P3 and GAL E3. We choose to compute $u_{CAL}$ using for $u_b$ the uncertainty $u_{b,TOT}$ of $\Delta$TOTDLY$_{R-V}$ from Eq. (6). Table 6.1 and 6.2 present all components of the uncertainty budget along with the uncertainty $u_{b.TOT}$ of $\Delta$TOTDLY$_{R-V}$ from equation (6) and the resulting uncertainty value $u_{CAL}$. The items in Table 6 are separated into several categories.

- $u_{b,1}$ account for possible variation of the delays of the traveling receiver with respect to the reference receiver during this campaign. This is evaluated by the observed the mis-closure values in Table 3.1 and 3.2.
- $u_{b,11}$ and $u_{b,12}$ account for errors in the antenna coordinates. In general, they are estimated to be 3.0 cm (0.1 ns) because the standard uncertainty of the coordinates obtained with the data used for calibration is typically at or below this level. The $u_{b,13}$ and $u_{b,14}$ account for multipath effect. This is difficult to estimate, and 0.2 ns is conventionally used, following a discussion in the CCTF working group meeting on GNSS in 2017[6].
- $u_{b,21}$ and $u_{b,22}$ account for the measurement between the calibration reference point of the traveling receiver and the local UTC(k). $u_{b,21}$ = 0 ns since the calibration reference point is the UTC(k) reference point in TL. $u_{b,22}$ = 0.5 ns, it includes at least one measurement measured by UzNIM and using TIC Agilent 53230A, trigger level 1.0 V.
- $u_{b,31}$ and $u_{b,32}$ account for the measurements between the reference point of the reference station and the local UTC(k). $u_{b,31}$ = 0.0 ns since the reference receiver TLT5 did not use REFDLY during calibration and time transfer, its INTDLY is in fact the TOTDLY; $u_{b,32}$ = 0.71 ns at the visited site

UzNIM, it includes one 1 PPS-in and 10 MHz-in phase difference measurement measured by UzNIM and using TIC Agilent 53230A, trigger level 0.5V for 1 PPS signal, trigger level 0 V for 10 MHz signal, and the delay measurement from UTC(UZ) point to the 1 PPS-in of UZ__ measured by UzNIM.

- $u_{b,41}$ and $u_{b,42}$ account for the measurement of CABDLY. $u_{b,41} = 0$ ns since the reference receiver TLT5 did not use CABDLY in calibration and time transfer, its INTDLY is in fact the TOTDLY; $u_{b,42} = 0.5$ ns at the visited stations UzNIM, it includes at least one measurement measured by PikTime.

**Table 6.1** Uncertainty contributions of GPS link, Value P3 = P1+1.545×(P1−P2). All values in ns.

| Unc. | C1 | P1 | P2 | P1-P2 | P3 | Description |
|---|---|---|---|---|---|---|
| $u_a$(T-R) | 0.17 | 0.05 | 0.05 | 0.07 | - | Tdev of RAWDIF of TLT5 vs.TLM2 during MJD 60770-60779 and 60889-60894 |
| $u_{a,\mathrm{UZ\_\_}}$(T-V) | 0.08 | 0.06 | 0.07 | 0.09 | - | Tdev of RAWDIF of TLM2 vs. UZ__ |
| $u_{a,\mathrm{UZ\_\_}}$ | 0.18 | 0.08 | 0.08 | 0.12 | 0.20 | |
| | Misclosure | | | | | |
| $u_{b,1}$ | -0.25 | 0.20 | -0.46 | 0.66 | - | Observed misclosure of TLT5 vs. TLM2 |
| | Systematic components related to RAWDIF | | | | | |
| $u_{b,11}$ | 0.10 | 0.10 | 0.10 | 0.14 | - | Position error at TL |
| $u_{b,12}$ | 0.10 | 0.10 | 0.10 | 0.14 | - | Position error at UzNIM |
| $u_{b,13}$ | 0.20 | 0.20 | 0.20 | 0.28 | - | Multipath effect at TL |
| $u_{b,14}$ | 0.20 | 0.20 | 0.20 | 0.28 | - | Multipath effect at UzNIM |
| | Link of the Traveling system to the local UTC(k) and CABDLY measurements | | | | | |
| $u_{b,21}$ | 0 | 0 | 0 | - | - | $\Delta$Ref_Clb$_{TL}$ at TL, calibration point = UTC(TL) point |
| $u_{b,22}$ | 0.50 | 0.50 | 0.50 | - | - | $\Delta$Ref_Clb$_{UzNIM}$ at UzNIM |
| $u_{b,TOT}$ | 0.64 | 0.62 | 0.75 | 0.79 | 1.38 | Components of equation (6) |
| $u_{CAL0,\mathrm{UZ\_\_}}$ | | | | | 1.39 | Composed of $u_{a,\mathrm{UZ\_\_}}$ and $u_{b,TOT}$ |
| | Link of the Reference system to its local UTC(k) | | | | | |
| $u_{b,31}$ | 0 | 0 | 0 | - | - | TLT5 did not use REFDLY to calculate P3 |
| | Link of the Visited system to its local UTC(k) | | | | | |
| $u_{b,32}$ | 0.71 | 0.71 | 0.71 | - | - | REFDLY measurement of UZ__ |
| Antenna cable delays | | | | | | |
| $u_{b,41}$ | 0 | 0 | 0 | - | - | TLT5 did not use CABDLY to calculate P3 |
| $u_{b,42}$ | 0.50 | 0.50 | 0.50 | - | - | CABDLY measurement of UZ__ (measured by PikTime) |
| $u_{b,INT}$ | 1.08 | 1.07 | 1.15 | 0.79 | 1.63 | Components of equation (7) |
| $u_{CAL0,\mathrm{UZ\_\_}}$ | | | | | 1.64 | Composed of $u_{a,\mathrm{UZ\_\_}}$ and $u_{b,INT}$ |

**Table 6.2** Uncertainty contributions of GAL link, E3 = E1+1.261×(E1-E5a), all values in ns

| Unc. | E1 | E5a | E1-E5a | E3 | Description |
|---|---|---|---|---|---|
| $u_a$(T-R) | 0.13 | 0.07 | 0.15 | | Tdev of RAWDIF of TLT5 vs.TLM2 during MJD 60681-60690 and 60770-60779 |
| $u_{a,UZ\_}$(T-V) | 0.13 | 0.07 | 0.15 | | Tdev of RAWDIF of TLM2 vs. UZ__ |
| $u_{a,UZ\_}$ | 0.18 | 0.10 | 0.21 | 0.32 | |
| Misclosure | | | | | |
| $u_{b,1}$ | -0.23 | 0.01 | -0.23 | - | Observed mis-closure of TLT5 vs. TLM2 |
| Systematic components related to RAWDIF | | | | | |
| $u_{b,11}$ | 0.10 | 0.10 | 0.14 | - | Position error at TL |
| $u_{b,12}$ | 0.10 | 0.10 | 0.14 | - | Position error at UzNIM |
| $u_{b,13}$ | 0.20 | 0.20 | 0.28 | - | Multipath effect at TL |
| $u_{b,14}$ | 0.20 | 0.20 | 0.28 | - | Multipath effect at UzNIM |
| Link of the Traveling system to the local UTC(k) | | | | | |
| $u_{b,21}$ | 0 | 0 | - | - | ΔRef_Clb$_{TL}$ at TL, calibration point = UTC(TL) point |
| $u_{b,22}$ | 0.50 | 0.50 | - | - | ΔRef_Clb$_{UzNIM}$ at UzNIM |
| $u_{b,TOT}$ | 0.63 | 0.59 | 0.50 | 0.90 | Components of equation (6) |
| $u_{CAL0,UZ\_}$ | | | | 0.95 | Composed of $u_{a,UZ\_}$ and $u_{b,TOT}$ |
| Link of the Reference system to its local UTC(k) | | | | | |
| $u_{b,31}$ | 0 | 0 | - | - | TLT5 did not use REFDLY to calculate E3 |
| | Link of the Visited system to its local UTC(k) | | | | |
| $u_{b,32}$ | 0.71 | 0.71 | - | - | REFDLY of UZ__ |
| Antenna cable delays | | | | | |
| $u_{b,41}$ | 0 | 0 | - | - | TLT5 did not use CABDLY to calculate E3 |
| $u_{b,42}$ | 0.50 | 0.50 | - | - | CABDLY of UZ__ |
| $u_{b,INT}$ | 1.08 | 1.05 | 0.50 | 1.25 | Components of equation (7) |
| $u_{CAL0,UZ\_}$ | | | | 1.29 | Composed of $u_{a,UZ\_}$ and $u_{b,INT}$ |

# 5. Final results for the visited systems

The Final results are presented for each visited system as they need to be entered to produce timing data in the CGGTTS format, i.e., in the form of INTDLY. The value INTDLY for each visited station, $INTDLY_V$, can be obtained by using equation (7).

The calibrated INTDLYs of visited lab can be derived:

$$INTDLY_V(code) = TOTDLY_R(code) - \Delta TOTDLY_{R-V}(code) - CABDLY_V(code) + REFDLY_V(code) \quad \ldots\ldots (7)$$

Using the $TOTDLY_R$ values reported in 1001-2022 for the Reference system TLT5 and the values $CABDLY_V$, $REFDLY_V$, $\Delta Ref\_Clb_{UzNIM}$ from the information sheet (Annex A), **Table 7.1 and 7.2** then reports $INTDLY_V$ for all systems visited. The uncertainty value $u_{cal}$ for P3, E3, and B3 is obtained from **Table 6.1 and 6.2**. It is used by the BIPM to assign the value $u_b$ which will apply to all links to which the system participates.

**Table 7.1** Summary of final results of GPS link

| Reference System | Cal_Id | Date | | INTDLY/ns | | |
|---|---|---|---|---|---|---|
| | | | | C1 | P1 | P2 |
| TLT5 | 1001-2022 | [1]Jan. 07, 2023 | | 206.80 | 204.50 | 203.30 |
| **Visited stations** | **Cal_Id** | **Date** | **$u_{CAL}$ (P3)/ ns** | **INTDLY/ns** | | |
| | | | | **C1** | **P1** | **P2** |
| TLT5-UZ__ | 1013-2025 | July 29, 2025 | 1.6 | 31.0 | 28.2 | 36.0 |

**Table 7.2** Summary of final results of GAL link

| Reference System | Cal_Id | Date | | INTDLY/ns | |
|---|---|---|---|---|---|
| | | | | E1 | E5a |
| TLT5 | 1001-2022 | Jan. 07, 2023 | | 206.80 | 204.60 |
| **Visited stations** | **Cal_Id** | **Date** | **$u_{CAL}$ (E3)/ ns** | **INTDLY/ns** | |
| | | | | **E1** | **E5a** |
| TLT5-UZ__ | 1013-2025 | July 29, 2025 | 1.3 | 31.7 | 37.7 |

# Acknowledgements

The authors appreciate colleagues in UzNIM for their efforts on installation of traveling equipment and data collection.

[1] The date performed the calibration id 1001-2022

# Annexes

## Annex A: Information sheets

## A.1 Information sheet of TLM2

| | |
|---|---|
| Laboratory: | TL |
| Date and hour of the beginning of measurements: | 2025-04-05 00:00:00 UTC |
| Date and hour of the end of measurements: | 2025-08-07 23:59:00 UTC |

| Information on the system | | |
|---|---|---|
| | **Local:** | **Travelling:** |
| 4-character BIPM code | TLT5 | TLM2 |
| ● Receiver maker and type:<br>Receiver serial number: | Septentrio PolaRx5TR<br>3227923 | Septentrio PolaRx5TR<br>4701426 |
| 1 PPS trigger level /V: | 1 V | 1 V |
| ● Antenna cable maker and type:<br>Phase stabilised cable (Y/N): | Andrew FSJ<br>yes | CFD-300<br>No |
| Length outside the building /m: | ~ 30 | ~10 (total length 35 m) |
| ● Antenna maker and type:/Serial number: | SEPCHOKE_B3E6 SPKE/5303 | PolaNt-x MF.v2/23674 |
| Temperature (if stabilised) /°C | 23 | 23 |

| Measured delays/ns | | |
|---|---|---|
| | **Local:** | **Travelling:** |
| ● Delay from local UTC to receiver 1 PPS-in: | 14.593±0.017 ns | 0[2] |
| Delay from 1 PPS-in to internal Reference (if different): | - | - |
| ● Antenna cable delay: | No measurement | No measurement |
| Splitter delay (if any): | Null | (1) |
| Additional cable delay (if any): | Null | (1) |

| Data used for the generation of CGGTTS files | |
|---|---|
| ● INT DLY (GPS) /ns: | |
| ● INT DLY (GAL) /ns: | |
| ● CAB DLY /ns: | |
| ● REF DLY /ns: | |
| ● Coordinates reference frame: | WGS-84 |
| Latitude or X /m: | – |
| Longitude or Y /m: | – |
| Height or Z /m: | – |

| General information | |
|---|---|
| ● Rise time of the local UTC pulse: | 1 ns |
| ● Is the laboratory air conditioned: | Yes |
| Set temperature value and uncertainty: | 23 ± 1 °C |
| Set humidity value and uncertainty: | No humidity control |

(1) For a trip with closure, it is not needed if the traveling equipment is used in the same set-up throughout.

[2] The reference cable of TLM2 is connected to the UTC(TL) reference point.

## A.2 Information sheet of UZ__

| | |
|---|---|
| Laboratory: | UzNIM |
| Date and hour of the beginning of measurements: | July 25, 2025, MJD 60881 |
| Date and hour of the end of measurements: | July 29, 2025, MJD 60885 |

| **Information on the system** | | |
|---|---|---|
| | **Local:** | **Travelling:** |
| 4-character BIPM code | UZ__ | TLM2 |
| • Receiver maker and type:<br>Receiver serial number: | Pik Time TTS-5<br>1027 | Septentrio<br>4701426 |
| 1 PPS trigger level /V: | 1.0 V | - |
| • Antenna cable maker and type:<br>Phase stabilised cable (Y/N): | Andrew Helix FSJ<br>Y | CFD-300 |
| Length outside the building /m: | Length outside the building<br>25 m (total length is 46 m) | 35 |
| • Antenna maker and type:<br>Antenna serial number: | JAVAD RinGantG5T<br>RA 10041 | Septentrio, PolaRx5TR<br>4701426 |
| 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: | 19.60 ns | 15.49 ns (Local UTC to calibration point) |
| Delay from 1 PPS-in to internal Reference (if different): | -4.65[3] | - |
| • Antenna cable delay: | 185.68 ns | - |
| Splitter delay (if any): | - | - |
| Additional cable delay (if any): | - | - |

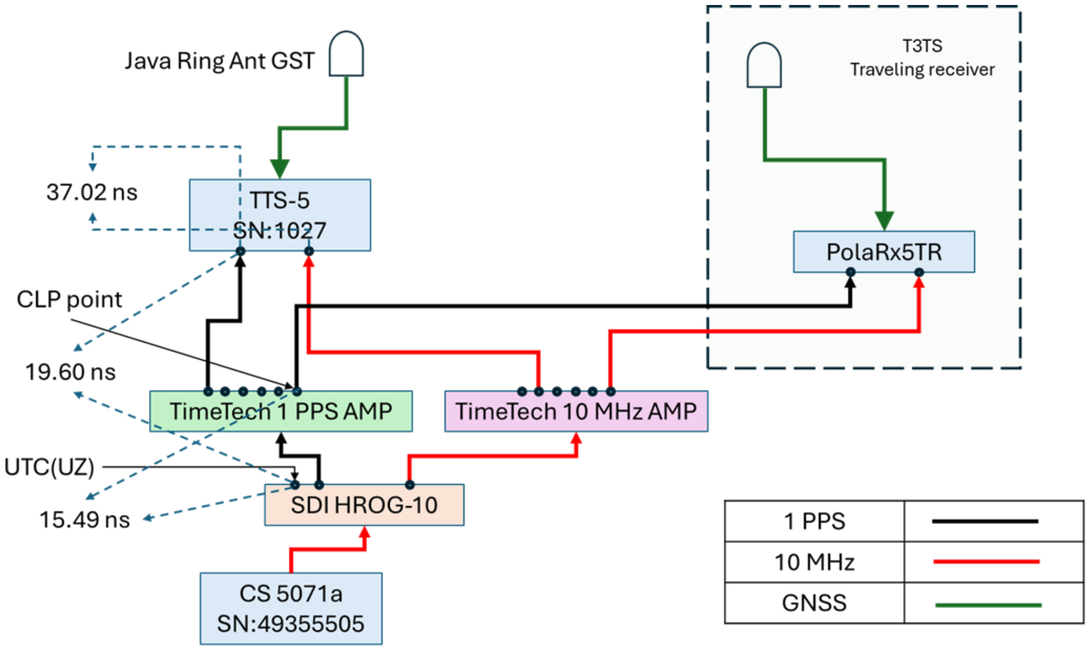
| **Data used for the generation of CGGTTS files** | |
|---|---|
| • INT DLY (GPS) /ns: | 48,17 |
| • INT DLY (GLONASS) /ns: | 67,32 |
| • CAB DLY /ns: | 185,68 |
| • REF DLY /ns: | 4,170 |
| • Coordinates reference frame: | ITRF |
| Latitude or X /m: | +1702150,8743 |
| Longitude or Y /m: | +4483774,5549 |
| Height or Z /m: | +4191194,0365 |

| **General information** | |
|---|---|
| • Rise time of the local UTC pulse: | 4.0 |
| • Is the laboratory air conditioned: | Yes |

[3] The delay from UTC(UZ) to UZ__ 1 PPS-in is 19.60 ns. The phase difference between UZ__ 1 PPS-in and the 10 MHz-in is 37.02 ns. UZ__'s actual REFDLY is 14.95 ns, a value calculated by the internal operating software (TTS-5) within UZ__.

| | |
|---|---|
| Set temperature value and uncertainty: | 23 ± 1°C |
| Set humidity value and uncertainty: | 50% ±15% |

## Diagram of the experiment set-up:



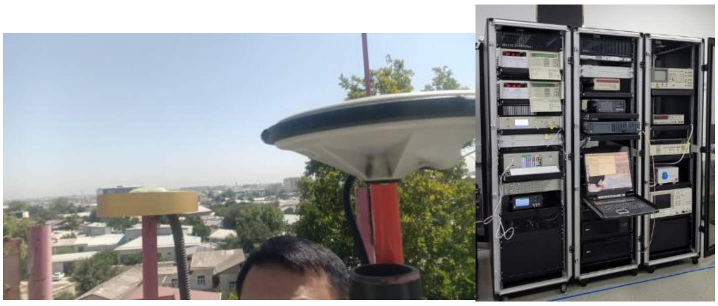



Figure1, Experimental set-up

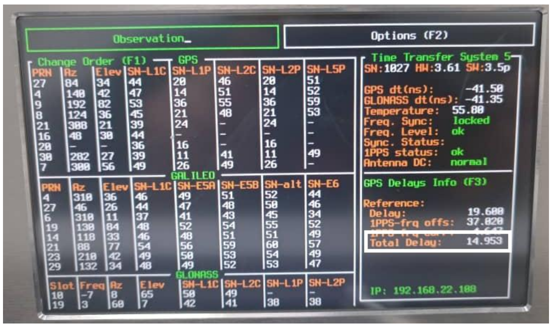


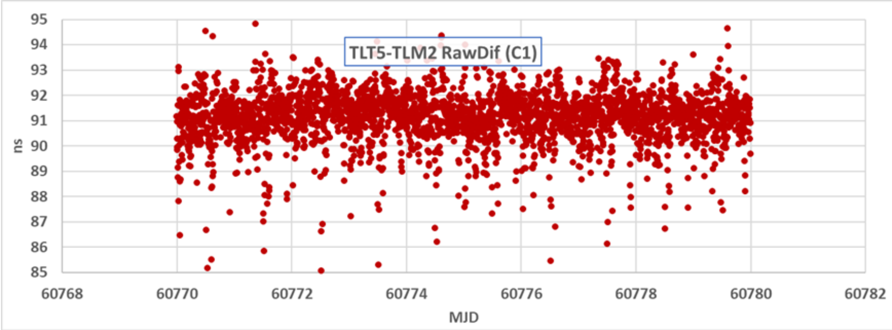

Figure 2, the REFDLY of TTS-5 (Screen showed as Total Delay)

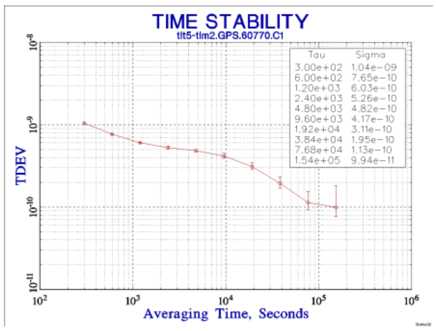
# Log of Events / Additional Information:

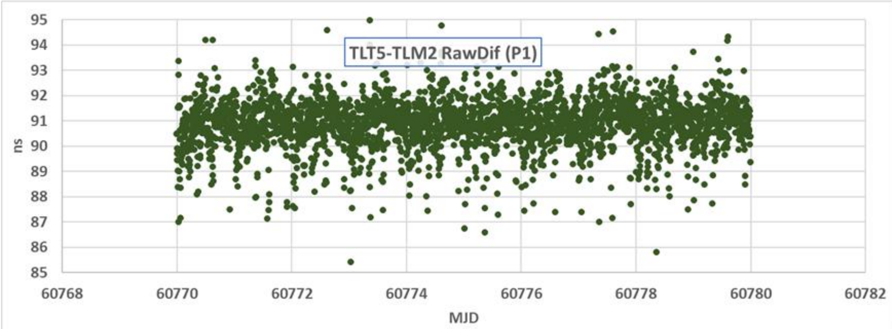
- The original REFDLY and CABDLY measured by PikTime
- The REFDLY was re-measured by UzNIM using TIC Agilent 53230A
- The definition point of UTC(UZ) is set to be the 2$^{nd}$ 1 PPS output of micro-phase-stepper SDI HROG-10, and the HROG-10 was re-boot at MJD 60900

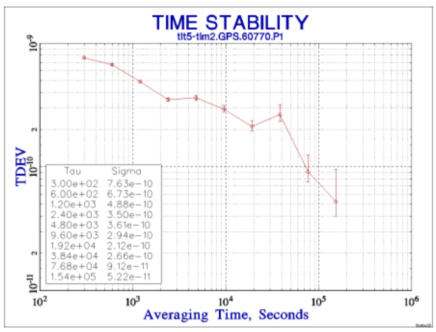
# Annex B: Plots of raw data and Tdev analysis

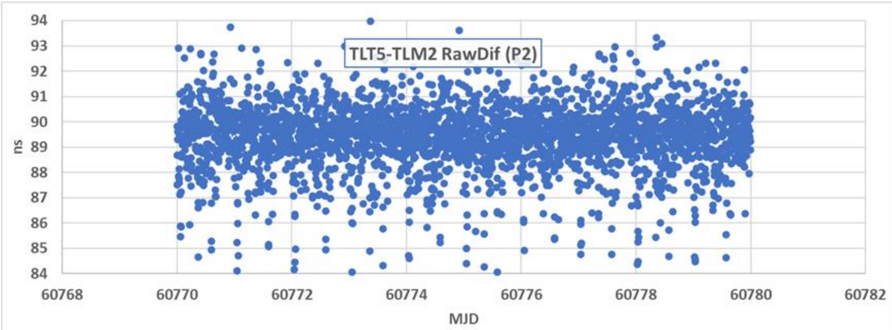
## B.1 reference vs. traveling

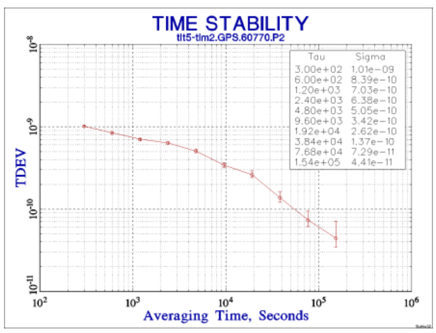


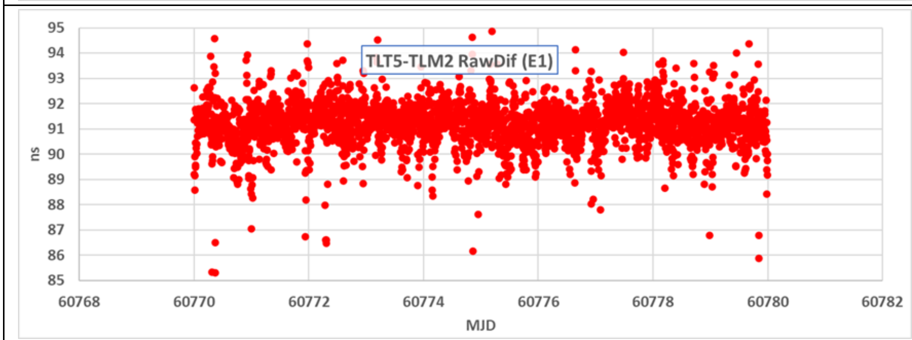



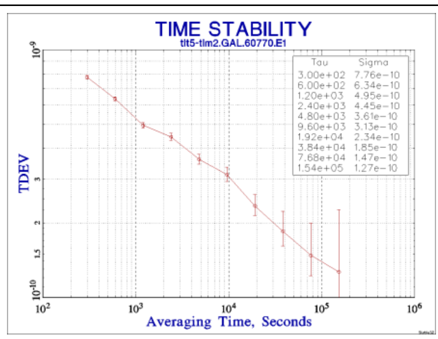



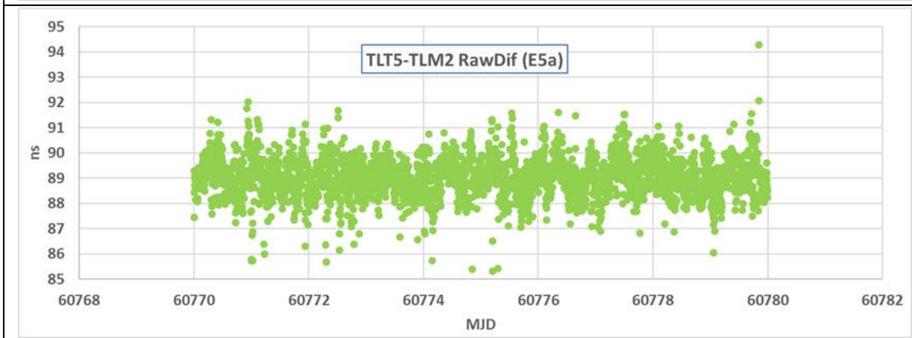



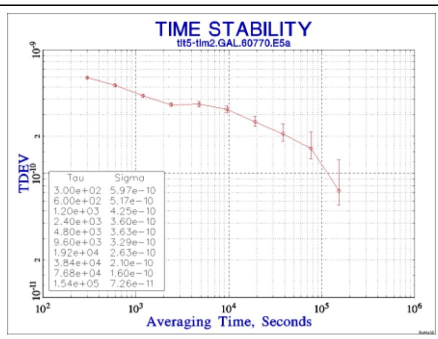



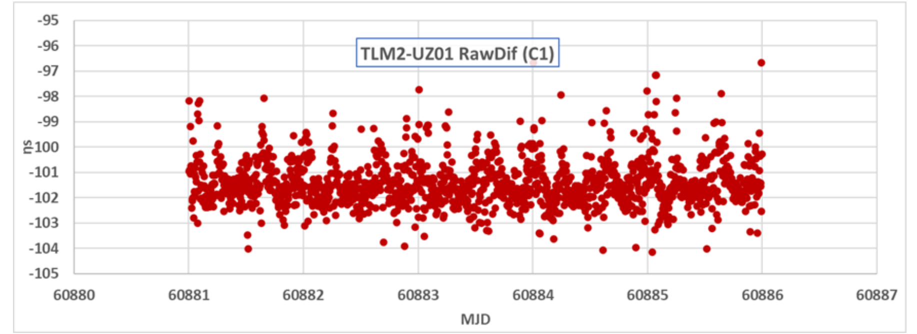



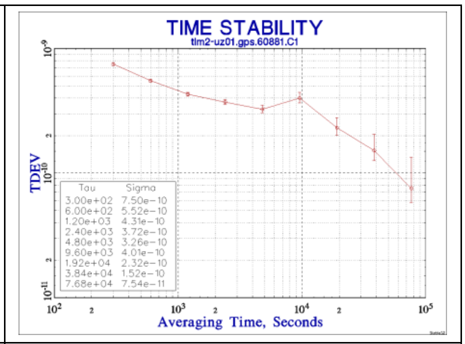



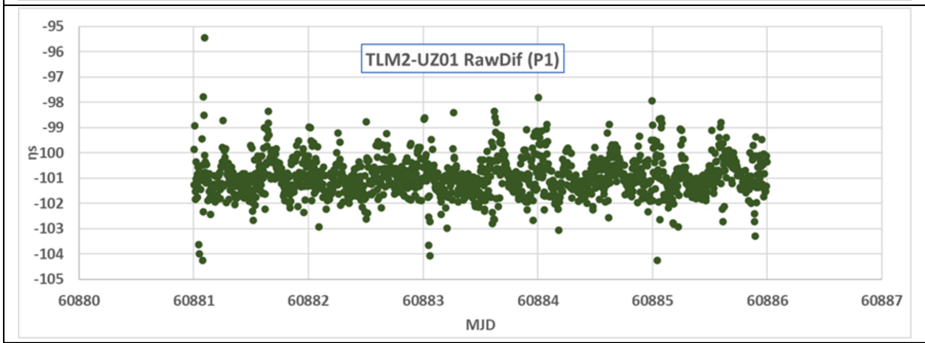



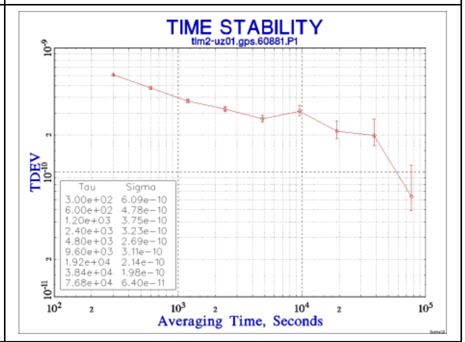



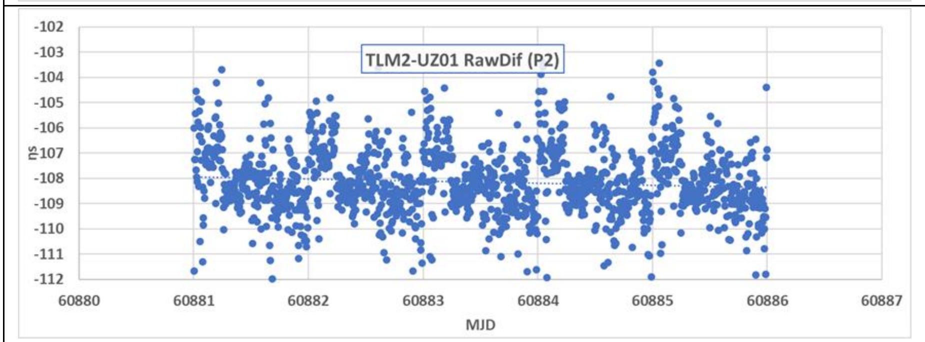
# B.2 traveling vs. visited, UZ__

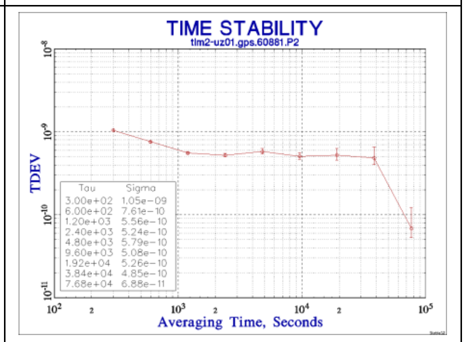


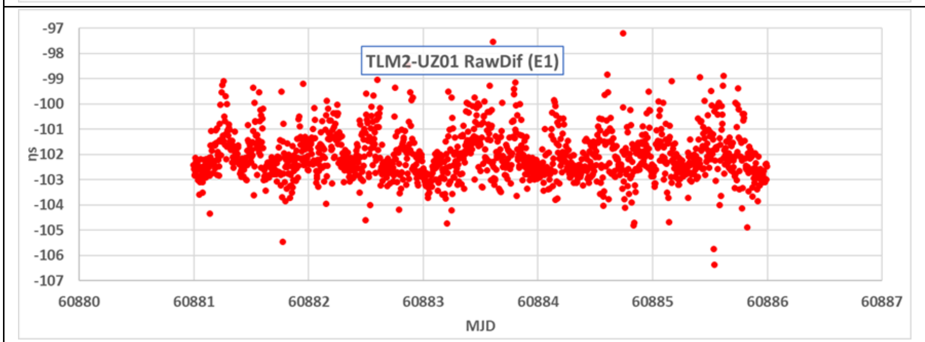



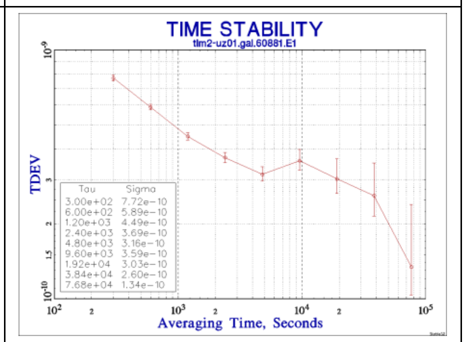



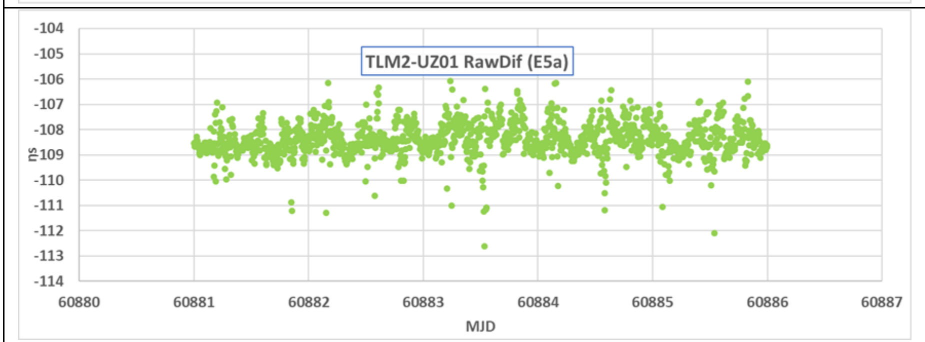



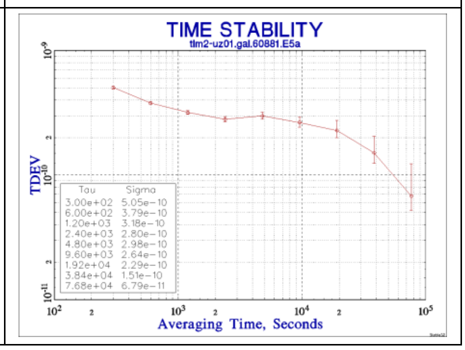



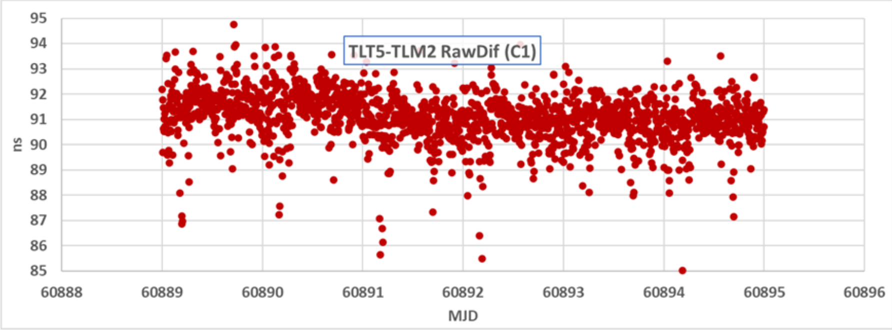



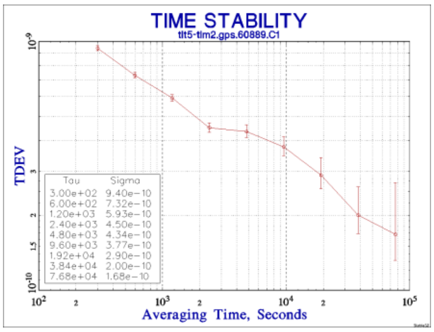



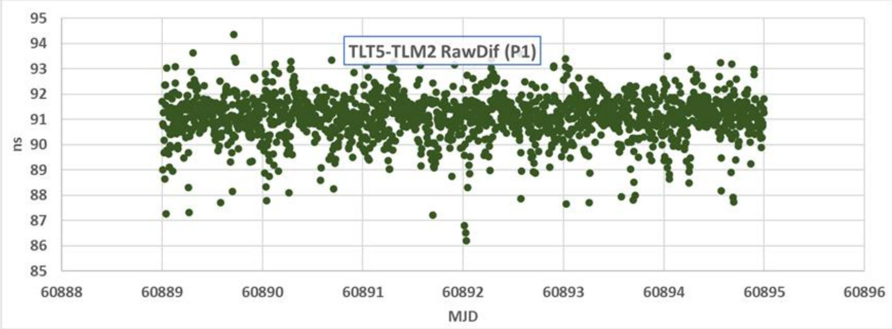



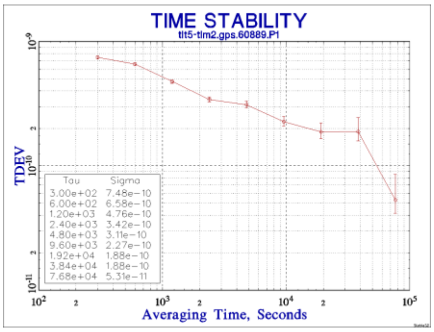



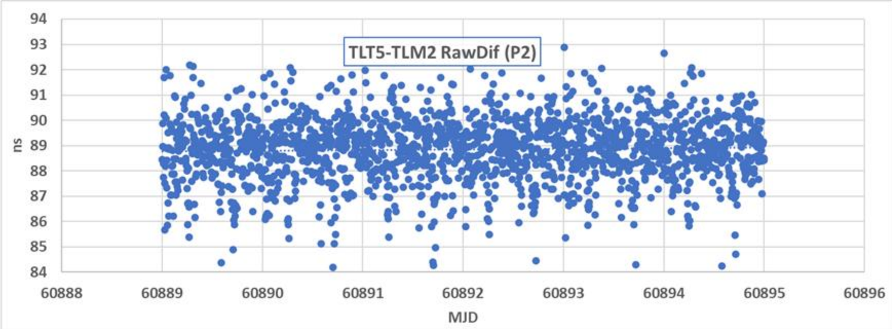
# B.3 reference vs. traveling, closure

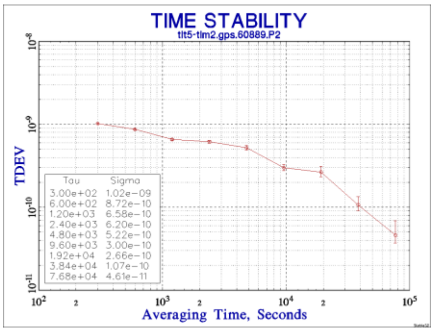


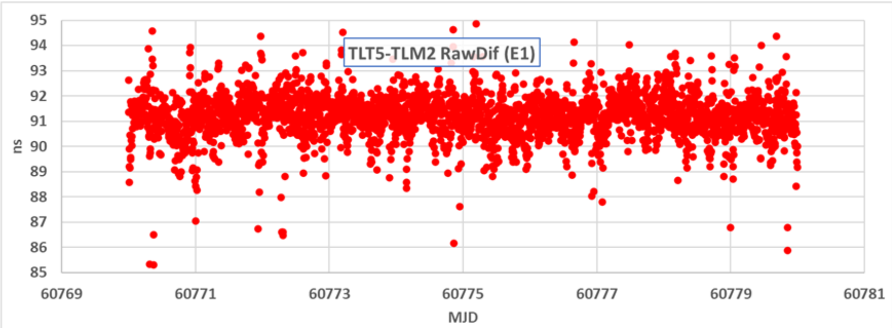



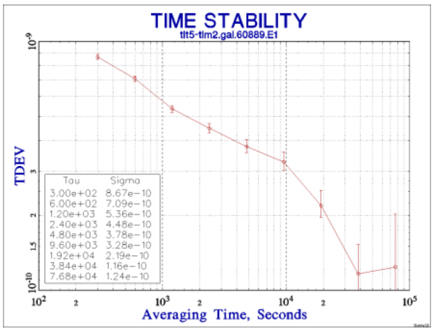



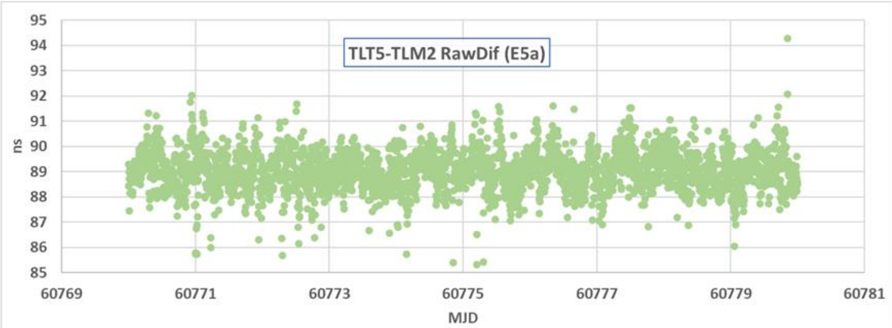



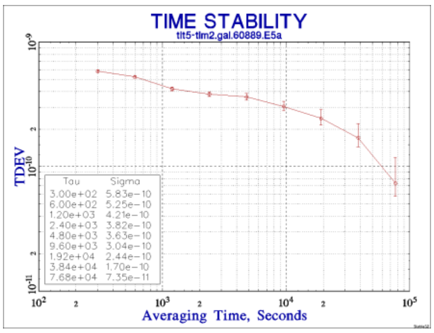



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[3] https://webtai.bipm.org/ftp/pub/tai/publication/time-calibration/Current/1013-2018_GPSP3C1_UzNIM_V1-0.pdf

[4] https://webtai.bipm.org/ftp/pub/tai/publication/time-calibration/Current/1201-2019_GPSP3C1_UzNIM-TC_V1-0.pdf

[5] BIPM guidelines Annex3 “Procedure for computing raw difference of GNSS code measurements for geodetic receivers”, V3.2, 12/07/2021

[6] W. Lewandowski, C. Thomas, 1991, *“GPS Time transfers,”* Proc. IEEE, Vol. 79, No. 7, 991-1000

[7] G. Petit et al. BIPM TM212, Nov. 2012

[8] J. Kouba, P. Heroux, 2002, “Precise Point Positioning Using IGS Orbit and Clock Products,” GPS Solutions, Vol 5, No. 2, 12-28

[9] P. Defraigne and G. Petit, “CGGTTS-Version 2E: an extended standard for GNSS time transfer”, Metrologia 52 (2015) G1