Chunghwa Telecom Laboratories

2025 Group 2 GNSS Calibration Report
Cal_ID: 1012-2025

National Standard Time and Frequency Lab

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Summary

As one of the APMP G1 laboratories, TL conducted a relative calibration of the GNSS time transfer receivers of EMI (Emirates Metrology Institute, which acronym in BIPM list is UAE), The United Arab Emirates 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 the traveling equipment to transfer the signal delays of TLT5 to the visited GNSS receivers AE01 of EMI. The data were collected between MJD 60681-60779 (6th January 2025 – 14th April 2025) by simultaneous operation of pairs of co-located GNSS receivers. This campaign was declared to BIPM on 11st February 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; Galileo E1 and E5a signals; and Beidou BC and B5 signals. The results will be reported using Cal_ID 1012-2025.

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
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
EMI	Emirates Metrology Institute
UTC(UAE)	The standard time scale of EMI
AE01	Visited receiver of EMI of The United Arab Emirates
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 cable of traveling receiver was connected to the UTC reference point in the visited laboratory EMI, the CLPDLY was 0 in this campaign.

1.2 Visited Receivers

There was one GNSS receiver, AE01, which was calculated in this campaign. AE01 is a Septentrio PolaRx5TR receiver and was never calibrated before. We would calibrate its GPS P3, Galileo E3, and Beidou B3 links this time. The detailed information can be found in their information sheets in Annex A.2 Information sheet of AE01.

Table 1. Summary information on the calibration trip

Institute	Status of equipment	Dates of measurement	Receiver type	BIPM code	RINEX name
TL	Traveling	60681-60690	Septentrio PolaRx5 TR	TLM2	TLM2
TL	Group 1 reference	-	Septentrio PolaRx5 TR	TLT5	TLT5
EMI	Group 2	60740-60749	Septentrio, PolaRx5 TR	AE01	AE01
TL	Traveling	60770-60779	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, 7.2, and 7.3.

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	BC	Unc	B5	Unc
TLT5-TLM2	60681-60690	90.93	0.06	90.57	0.04	88.98	0.04	90.89	0.06	88.66	0.06	91.02	0.07	88.66	0.11
TLM2-AE01	60740-60749	-40.19	0.04	-40.45	0.04	-35.39	0.03	-40.26	0.05	-39.78	0.05	-40.26	0.07	-39.80	0.07
TLT5-TLM2	60770-60779	91.30	0.10	91.03	0.05	89.41	0.04	91.25	0.13	89.05	0.07	91.33	0.20	89.04	0.06

4. Calibration results

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

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

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

$$REFDLY_{T,\,TL}(code) = CLPDLY_{T}(code) + \Delta Ref\_Clb_{TL} \quad (2)$$

Where the ΔRef_Clb is the offset between the UTC reference point and calibration reference point in the laboratory, the value of ΔRef_Clb_{TL} and ΔRef_Clb_{EMI} may be different but the value $CLPDLY_{T}$(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:

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

$= SYSDLY_{T,\,TL}(code) - [CLPDLY_T(code) + \Delta Ref\_Clb_{TL}]$ · (3)

4.1 Traveling System with Respect to The Reference System

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

$RAWDIF_{R\text{-}T}(code)$

$= [SYSDLY_R(code) - REFDLY_R(code)]$

$- [SYSDLY_T(code) - CLPDLY_T(code) - \Delta Ref\_Clb_{TL}]$ ……. (4)

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	60681-60690	90.93	90.57	88.98	1.58
TLT5-TLM2	60770-60779	91.30	91.03	89.41	1.62
Misclosure	-	0.36	0.47	0.43	0.03
Mean	-	91.11	90.80	89.20	1.60

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

Pair	Date	E1	E5a	E1-E5a
		RawDIF	RawDIF	RawDIF
TLT5-TLM2	60681-60690	90.89	88.66	2.23
TLT5-TLM2	60770-60779	91.25	89.05	2.19
Misclosure	-	0.36	0.39	-0.04
Mean	-	91.07	88.86	2.21

Table 3.3 Traveling vs. Reference system (Beidou, all values in ns)

Pair	Date	BC	B5	BC-B5
		RawDIF	RawDIF	RawDIF
TLT5-TLM2	60681-60690	91.02	88.66	2.37
TLT5-TLM2	60770-60779	91.33	89.04	2.30
Misclosure	-	0.31	0.38	-0.07
Mean	-	91.18	88.85	2.33

Table 3.1, 3.2, and 3.3 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 (EMI) can be expressed:

$$RAWDIF_{T\text{-}V}(code) = [SYSDLY_T(code) - CLPDLY_T(code) - \Delta Ref\_Clb_{EMI}] - [SYSDLY_V(code) - REFDLY_V(code)] \quad \ldots\ldots\ (5)$$

The ΔRef_Clb_{EMI} is the offset from UTC(UAE) reference point to the calibration reference point of EMI.

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

Pair	Date	ΔRef_Clb_{EMI}	$REFDLY_V$	C1	P1	P2
				RawDIF	RawDIF	RawDIF
TLM2-AE01	60740-60749	0	0.09	-40.19	-40.45	-35.39

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

Pair	Date	ΔRef_Clb_{EMI}	$REFDLY_V$	E1	E5a
				RawDIF	RawDIF
TLM2-AE01	60740-60749	0	0.09	-40.26	-39.78

Table 4.3 Traveling with respect to the visited system (Beidou, all values in ns)

Pair	Date	ΔRef_Clb_{EMI}	$REFDLY_V$	BC	B5
				RawDIF	RawDIF
TLM2-AE01	60740-60749	0	0.09	-40.26	-39.80

4.3 Visited Systems with Respect to Reference System

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

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

or

$$\Delta TOTDLY_{R\text{-}V}(code)$$

$$= RAWDIF(code)_{R\text{-}T} + RAWDIF(code)_{T\text{-}V} - \Delta Ref\_Clb_{TL} + \Delta Ref\_Clb_{EMI} \qquad \ldots\ldots (6)$$

In TL, the calibration reference point and the UTC(k) reference point are identical, that is the $\Delta Ref\_Clb_{TL} = 0$. The $\Delta Ref\_Clb_{EMI} = 0$ ns was measured by EMI. The TOTDLY of traveling with respect to the visited system are listed in Table 5.1, 5.2, and 5.3.

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

Pair	Date	ΔRef_Clb_{EMI}	$\Delta TOTDLY_{R\text{-}V}$		
			C1	P1	P2
TLT5-AE01	60740-60749	0	50.92	50.34	53.81

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

Pair	Date	ΔRef_Clb_{EMI}	$\Delta TOTDLY_{R\text{-}V}$	
			E1	E5a
TLT5-AE01	60740-60749	0	50.81	49.08

Table 5.3 Visited system with respect to the reference system (Beidou, all values in ns)

Pair	Date	ΔRef_Clb_{EMI}	$\Delta TOTDLY_{R\text{-}V}$	
			BC	B5
TLT5-AE01	60740-60749	0	50.92	49.05

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 the accuracy and determine a value u_{CAL} that is to be used as the accuracy of all GPS P3, GAL E3, and BDS B3 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 $u^2_{P3}=u^2_{P1}+(1.545\times u_{P1\text{-}P2})^2$; for the Galileo delays are calculated according to $u^2_{E3}=u^2_{E1}+(1.261\times u_{E1\text{-}E5a})^2$; for the Beidou delays are calculated according to $u^2_{B3}=u^2_{BC}+(1.261\times u_{BC\text{-}B5})^2$. All possible terms to be considered in the sum are to be listed in Table 6.1, 6.2, and 6.3. Values appear separately for each code (GPS C1, P1, and P2, GAL E1, and E5a, BDS BC, and B5) to compute a value u_{CAL} applicable to GPS P3, GAL E3, and BDS B3 links. We choose to compute u_{CAL} using for u_b the uncertainty $u_{b,TOT}$ of $\Delta TOTDLY_{R\text{-}V}$ from Eq. (6). Table 6.1, 6.2, and 6.3 presents all components of the uncertainty budget along with the uncertainty $u_{b.TOT}$ of $\Delta TOTDLY_{R\text{-}V}$ 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, 3.2, and 3.3.
- $u_{b,11}$ 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). Both $u_{b,21}$ and $u_{b,21} = 0$ ns since the calibration reference point is the UTC(k) reference point in TL and EMI.
- $u_{b,31}$ 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; $u_{b,32} = 1.0$ ns at the visited stations EMI, it includes at least one measurement measured by EMI and using TIC Agilent 53230A, SN MY50002151, trigger level 2.3V.
- $u_{b,41}$ and $u_{b,42}$ account for the measurement of CABDLY. $u_{b,41} = 0.0$ ns since the reference receiver TLT5 did not use CABDLY in calibration and time transfer, its INTDLY is in fact the TOTDLY; $u_{b,42} = 1.0$ ns at the visited stations EMI, it includes at least one measurement measured by EMI and using TIC Agilent 53230A, SN MY50002151, trigger level 2.3V.

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

Unc.	C1	P1	P2	P1-P2	P3	Description
u_a(T-R)	0.10	0.05	0.04	0.06	-	Tdev of RAWDIF of TLT5 vs.TLM2 during MJD 60681-60690 and 60770-60779
$u_{a,\,AE01}$(T-V)	0.04	0.04	0.03	0.05	-	Tdev of RAWDIF of TLM2 vs. AE01
$u_{a,\,AE01}$	0.11	0.06	0.05	0.08	0.14	
	Misclosure					
$u_{b,1}$	0.36	0.47	0.43	0.03	-	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 EMI
$u_{b,13}$	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 EMI
	Link of the Traveling system to the local UTC(k) and CABDLY measurements					
$u_{b,21}$	0	0	0	0	-	ΔRef_Clb$_{TL}$ at TL, calibration point = UTC(TL) point
$u_{b,22}$	0	0	0	0	-	ΔRef_Clb$_{EMI}$ at EMI, calibration point = UTC(UAE) point
$u_{b,TOT}$	0.48	0.56	0.54	0.45	0.89	Components of equation (6)
$u_{CAL0,\ AE01}$					0.90	Composed of $u_{a,AE01}$ and $u_{b,TOT}$
	Link of the Reference system to its local UTC(k)					
$u_{b,31}$	0	0	0	0	-	TLT5 did not use REFDLY to calculate P3
	Link of the Visited system to its local UTC(k)					
$u_{b,32}$	1.00	1.00	1.00	0	-	REFDLY of AE01
Antenna cable delays						
$u_{b,41}$	0	0	0	0	-	TLT5 did not use CABDLY to calculate P3
$u_{b,42}$	1.00	1.00	1.00	0	-	CABDLY of AE01
$u_{b,INT}$	1.49	1.52	1.51	0.45	1.67	Components of equation (7)
$u_{CAL0,\ AE01}$					1.68	Composed of $u_{a,\ AE01}$ 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
$u_{a,AE01}$(T-V)	0.05	0.05	0.07		Tdev of RAWDIF of TLM2 vs. AE01
$u_{a,AE01}$	0.14	0.09	0.16	0.25	
Misclosure					
$u_{b,1}$	0.36	0.39	-0.04	-	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 EMI
$u_{b,13}$	0.20	0.20	0.28	-	Multipath effect at TL
$u_{b,14}$	0.20	0.20	0.28	-	Multipath effect at EMI
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0	0	0	-	ΔRef_Clb$_{TL}$ at TL, calibration point = UTC(TL) point
$u_{b,22}$	0	0	0	-	ΔRef_Clb$_{EMI}$ at EMI, calibration point = UTC(UAE) point
$u_{b,TOT}$	0.48	0.51	0.45	0.74	Components of equation (6)
$u_{CAL0,AE01}$				0.78	Composed of $u_{a,AE01}$ 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 E3
	Link of the Visited system to its local UTC(k)				
$u_{b,32}$	1.00	1.00	0	-	REFDLY of AE01
Antenna cable delays					
$u_{b,41}$	0	0	0	-	TLT5 did not use CABDLY to calculate E3
$u_{b,42}$	1.00	1.00	0	-	CABDLY of AE01
$u_{b,INT}$	1.49	1.50	0.45	1.60	Components of equation (7)
$u_{CAL0,AE01}$				1.62	Composed of $u_{a,AE01}$ and $u_{b,INT}$

Table 6.3 Uncertainty contributions of BDS link, B3 = BC+1.261×(BC-B5), all values in ns

Unc.	BC	B5	BC-B5	B3	Description
u_a(T-R)	0.20	0.11	0.23		Tdev of RAWDIF of TLT5 vs.TLM2 during MJD 60681-60690 and 60770-60779
$u_{a,AE01}$(T-V)	0.07	0.07	0.10		Tdev of RAWDIF of TLM2 vs. AE01
$u_{a,AE01}$	0.21	0.13	0.25	0.38	
Misclosure					
$u_{b,1}$	0.31	0.38	-0.07	-	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 EMI
$u_{b,13}$	0.20	0.20	0.28	-	Multipath effect at TL
$u_{b,14}$	0.20	0.20	0.28	-	Multipath effect at EMI
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0	0	0	-	ΔRef_Clb_{TL} at TL, calibration point = UTC(TL) point
$u_{b,22}$	0	0	0	-	ΔRef_Clb_{EMI} at EMI, calibration point = UTC(UAE) point
$u_{b,TOT}$	0.44	0.49	0.45	0.72	Components of equation (6)
$u_{CAL0,AE01}$				0.81	Composed of $u_{a,AE01}$ 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 E3
	Link of the Visited system to its local UTC(k)				
$u_{b,32}$	1.00	1.00	0	-	REFDLY of AE01
Antenna cable delays					
$u_{b,41}$	0	0	0	-	TLT5 did not use CABDLY to calculate E3
$u_{b,42}$	1.00	1.00	0	-	CABDLY of AE01
$u_{b,INT}$	1.48	1.50	0.45	1.59	Components of equation (7)
$u_{CAL0,AE01}$				1.63	Composed of $u_{a,AE01}$ 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:

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

Using the $TOTDLY_R$ values reported in 1001-2022 for the Reference system TLT5 and the values $CABDLY_V$, $REFDLY_V$, ΔRef_Clb_{EMI} from the information sheet (Annex A), **Table 7.1, 7.2, and 7.3** then reports $INTDLY_V$ for all visited systems. The uncertainty value u_{cal} for P3, E3, and B3 is obtained from **Table 6.1 , 6.2, and 6.3**. 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		TOTDLY/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-AE01	1012-2025	Mar. 06, 2025	1.7	37.2	35.4	30.8

Table 7.2 Summary of final results of GAL link

Reference System	Cal_Id	Date		TOTDLY/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-AE01	1012-2025	Mar. 06, 2025	1.6	37.3	36.8

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

Table 7.3 Summary of final results of BDS link

Reference System	Cal_Id	Date		TOTDLY/ns	
				BC	B5
TLT5	1001-2022	Jan. 07, 2023		206.60	204.00
Visited stations	**Cal_Id**	**Date**	**u_{CAL} (B3)/ ns**	**INTDLY/ns**	
				BC	**B5**
TLT5-AE01	1012-2025	Mar. 06, 2025	1.6	37.0	36.2

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The authors appreciate colleagues in EMI for their efforts on shipment, installation of the traveling equipment and data collection.

Annexes

Annex A: Information sheets

A.1 Information sheet of TLM2

Laboratory:	TL
Date and hour of the beginning of measurements:	2023-07-09 00:00:00 UTC
Date and hour of the end of measurements:	2023-07-18 23:59:00 UTC

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	TLT5	TLM2
● Receiver maker and type: Receiver serial number:	Septentrio PolaRx5TR 3227923	Septentrio PolaRx5TR 4701426
1 PPS trigger level /V:	1 V	1 V
● Antenna cable maker and type: Phase stabilised cable (Y/N):	Andrew FSJ yes	CFD-300 No
Length outside the building /m:	~ 30	~10
● 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, 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 AE01

Laboratory:	EMI
Date and hour of the beginning of measurements:	March 06 2025 MJD 60740
Date and hour of the end of measurements:	March 15 2025 MJD 60749

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	AE01	TLM2
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx5TR (5.5.0) 4100330	Septentrio 4701426
1 PPS trigger level /V:	2.3	-
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Times Microwave Systems LMR-400 N	CFD-300
Length outside the building /m:	Cable length is 25 m. Approx 11 m is outside the building	35
• Antenna maker and type: Antenna serial number:	Septentrio Sepchoke_B3E6 6184	Septentrio, PolaRx5TR 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:	94 ps	0 ns
Delay from 1 PPS-in to internal Reference (if different):	-	-
• Antenna cable delay:	118.8 ns	-
Splitter delay (if any):	-	-
Additional cable delay (if any):	-	-

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	-
• INT DLY (GLONASS) /ns:	-
• CAB DLY /ns:	118.8
• REF DLY /ns:	0.094
• Coordinates reference frame:	ITRF
Latitude or X /m:	3364706.208
Longitude or Y /m:	4736625.729
Height or Z /m:	2622439.757

General information	
• Rise time of the local UTC pulse:	<2 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	23 ºC ± 1 °C
Set humidity value and uncertainty:	50 % ± 20 %

Diagram of the experiment set-up:

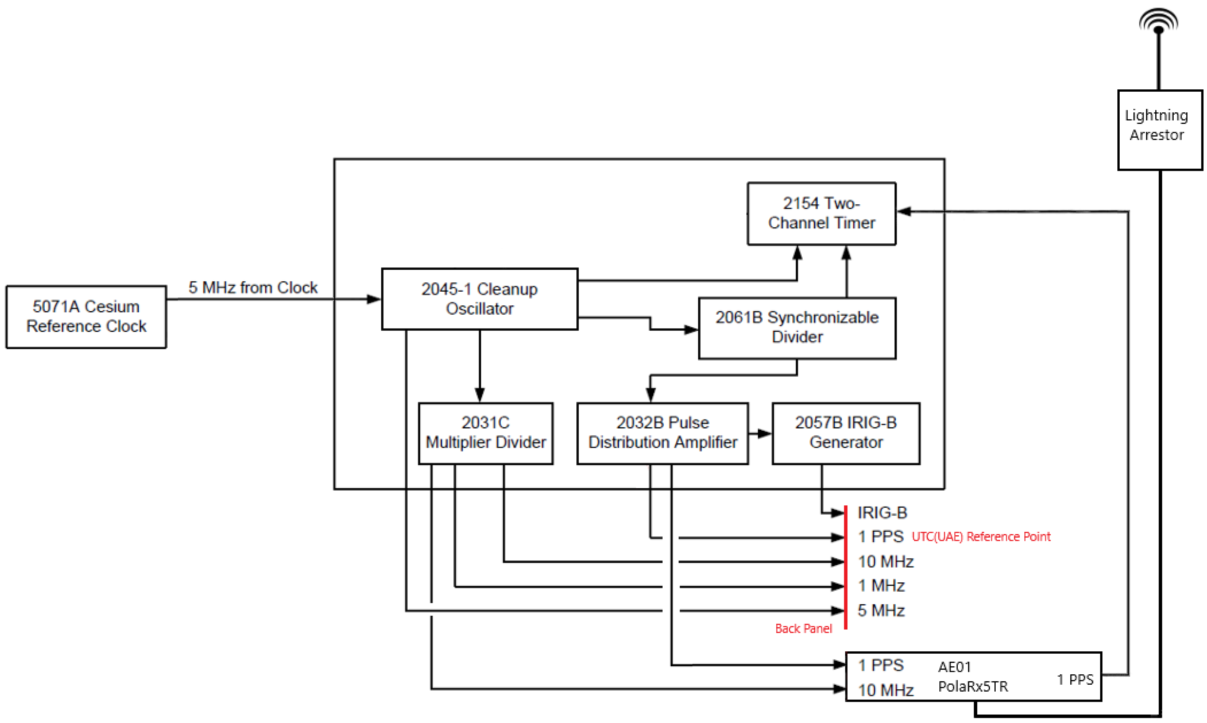
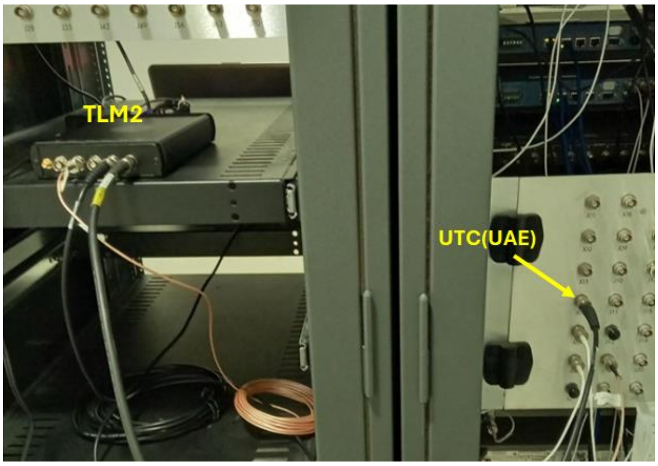


Figure1: Experimental set-up

Log of Events / Additional Information:



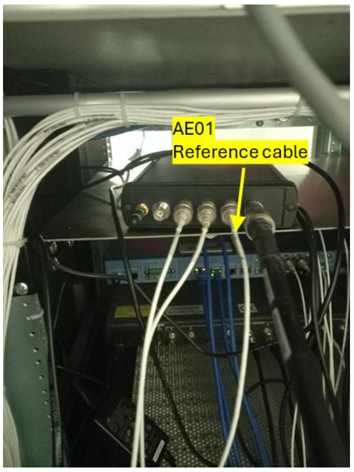
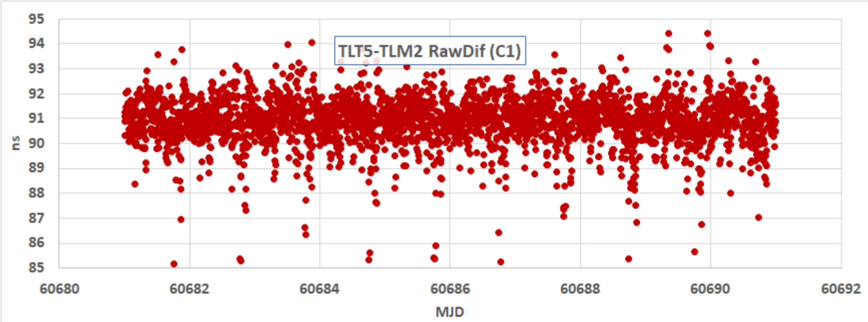


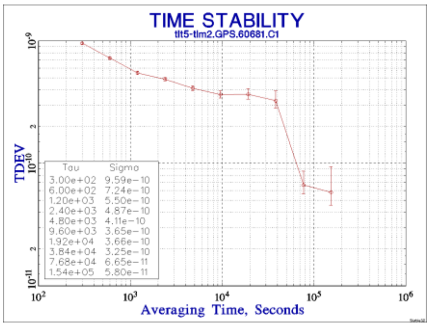
Figure2: The photos of Experimental set-up

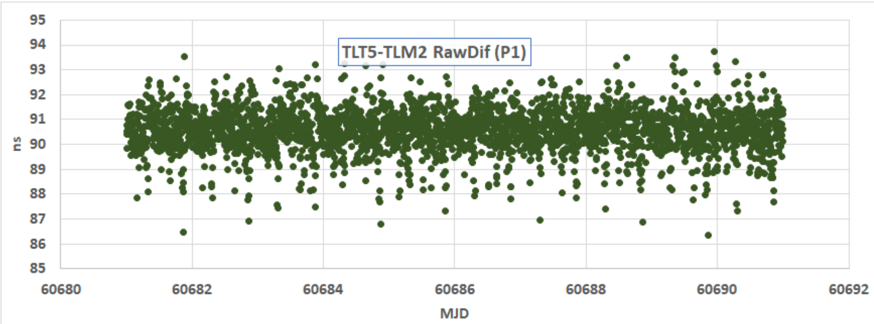
- The REFDLY and CABDLY measured by EMI using TIC Agilent 53230A, SN MY50002151, trigger level 2.3V

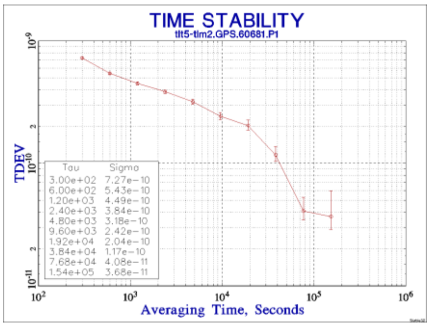
Annex B: Plots of raw data and Tdev analysis

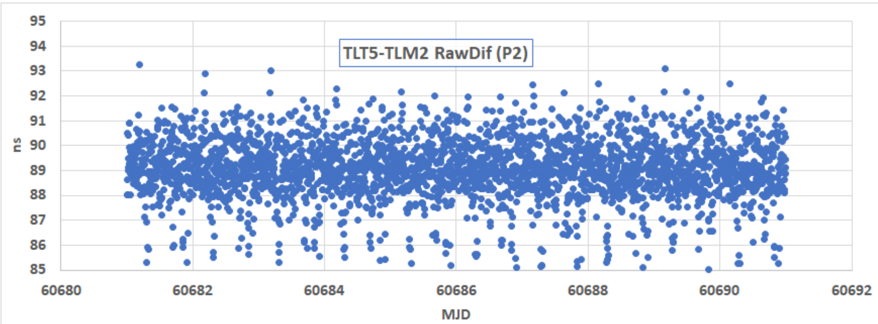
B.1 reference vs. traveling

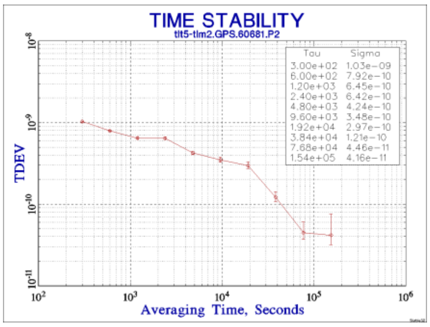


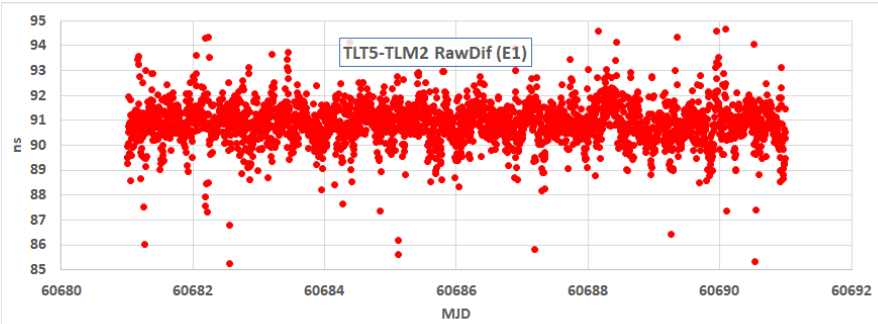


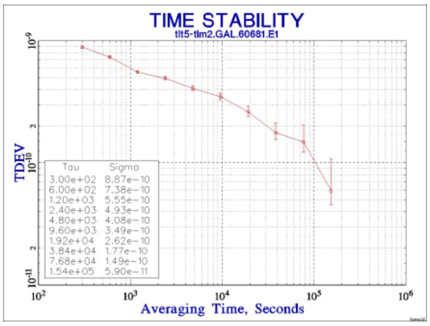


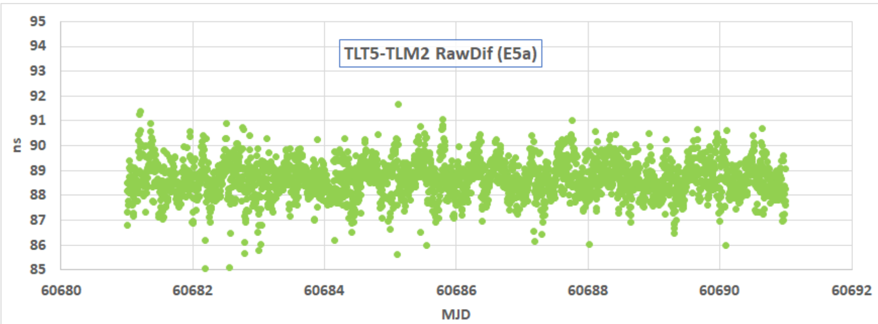


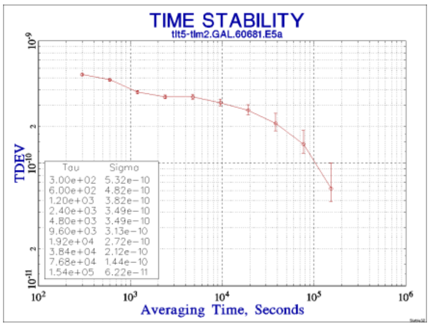


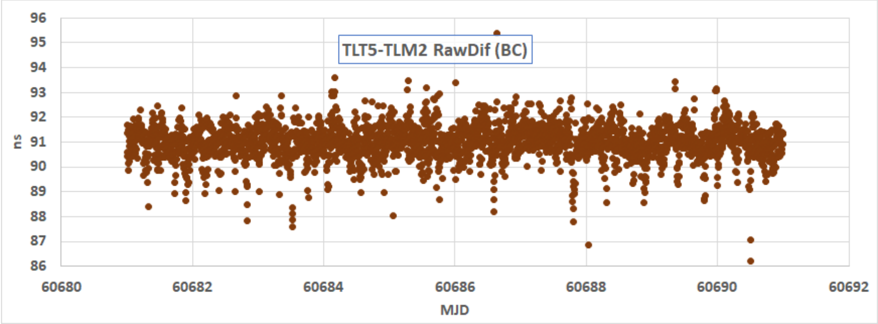


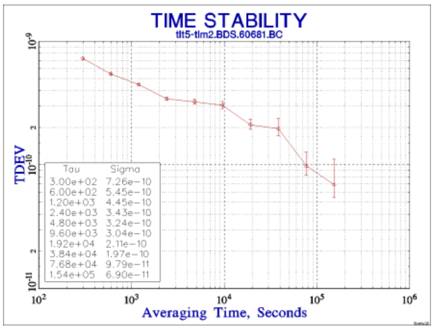


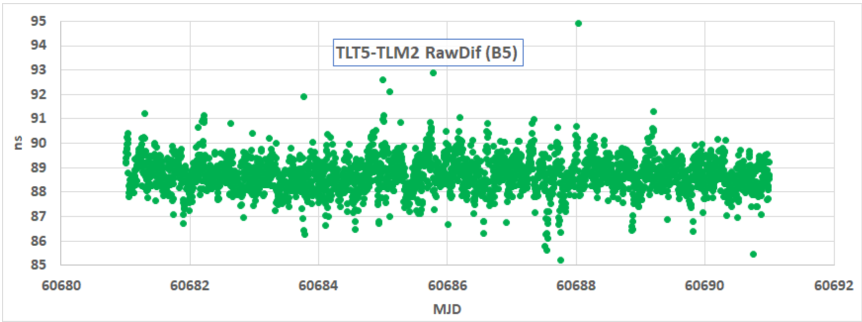







TLT5-TLM2 RawDif (BC)
ns
96
95
94
93
92
91
90
89
88
87
86
60680
60682
60684
60686
60688
60690
60692
MJD


TIME STABILITY
tlt5-tlm2.BDS.60681.BC
TDEV
Tau Sigma
3.00e+02 7.26e−10
6.00e+02 5.45e−10
1.20e+03 4.45e−10
2.40e+03 3.43e−10
4.80e+03 3.24e−10
9.60e+03 3.04e−10
1.92e+04 2.11e−10
3.84e+04 1.97e−10
7.68e+04 9.79e−11
1.54e+05 6.90e−11
Averaging Time, Seconds


TLT5-TLM2 RawDif (B5)
ns
95
94
93
92
91
90
89
88
87
86
85
60680
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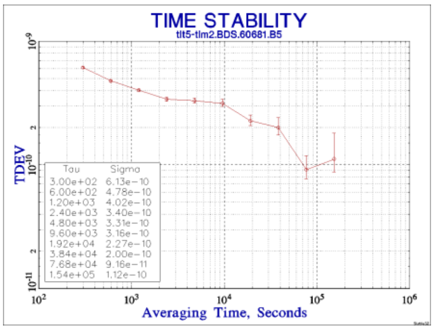
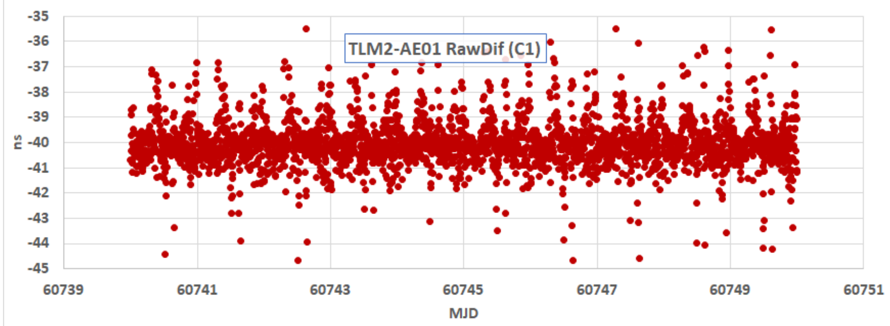
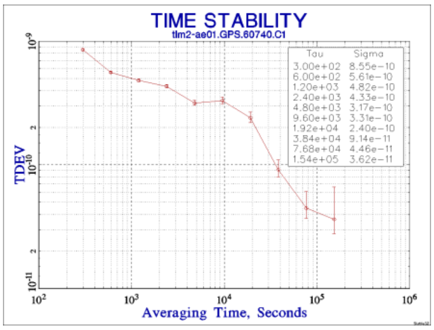
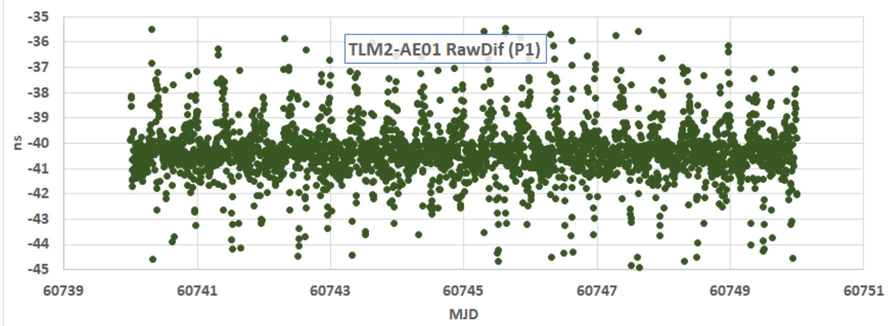
60688
60690
60692
MJD

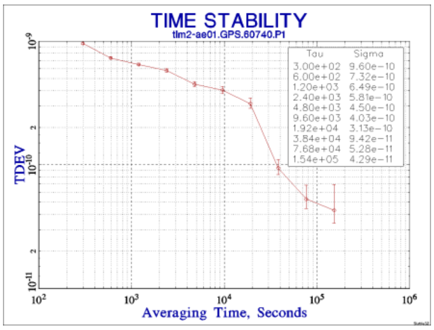

TIME STABILITY
tlt5-tlm2.BDS.60681.B5
TDEV
Tau Sigma
3.00e+02 6.13e−10
6.00e+02 4.78e−10
1.20e+03 4.02e−10
2.40e+03 3.40e−10
4.80e+03 3.31e−10
9.60e+03 3.16e−10
1.92e+04 2.27e−10
3.84e+04 2.00e−10
7.68e+04 9.16e−11
1.54e+05 1.12e−10
Averaging Time, Seconds

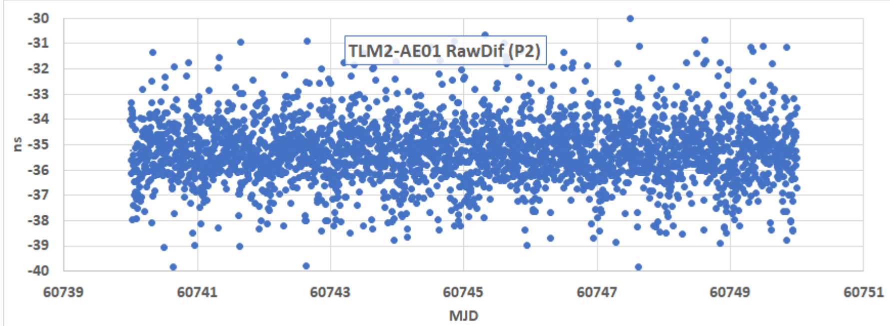
B.2 traveling vs. visited, AE01

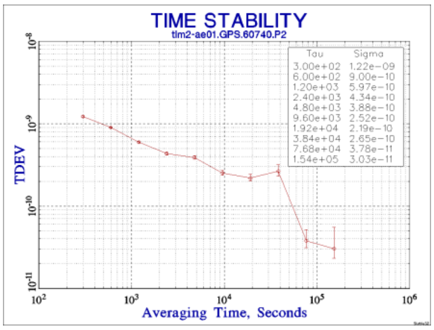


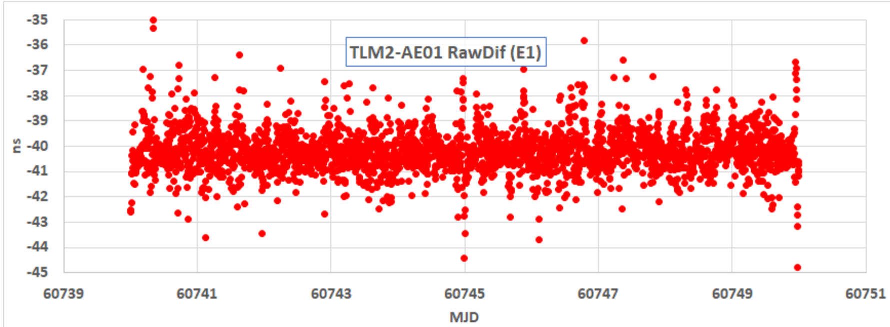


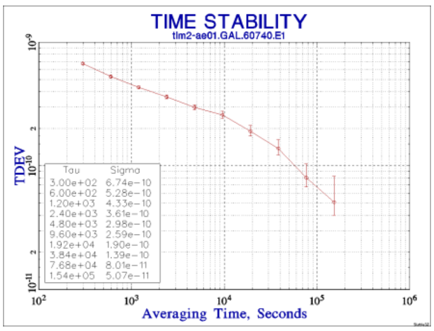


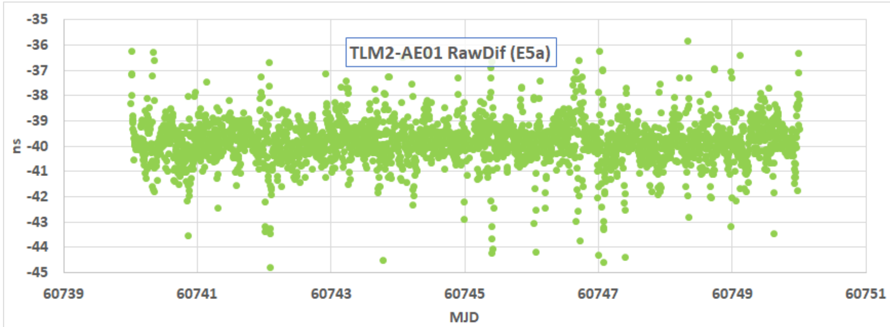


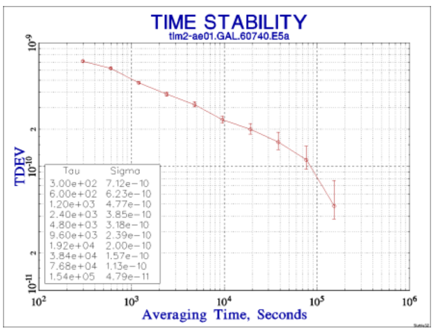


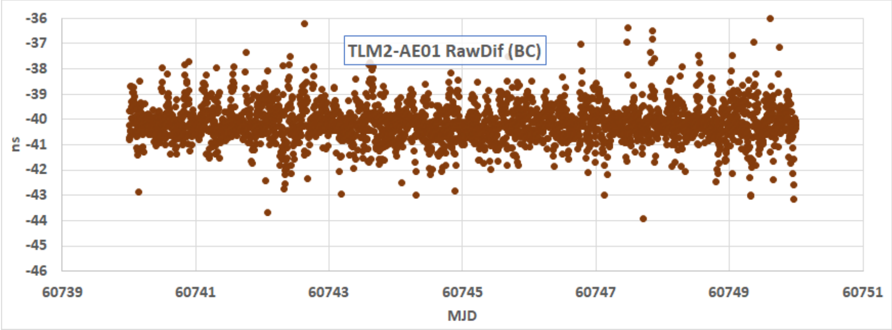


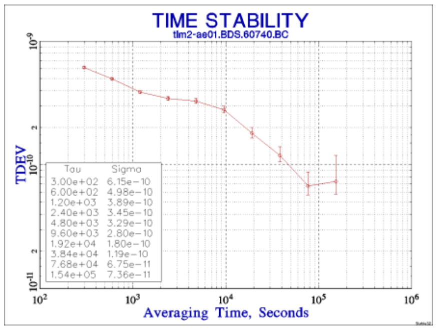


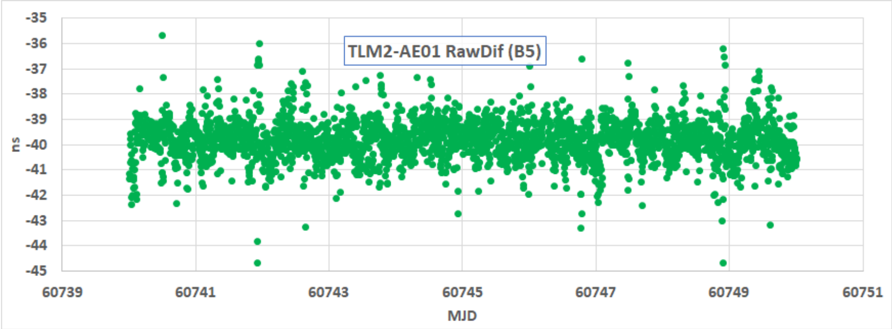


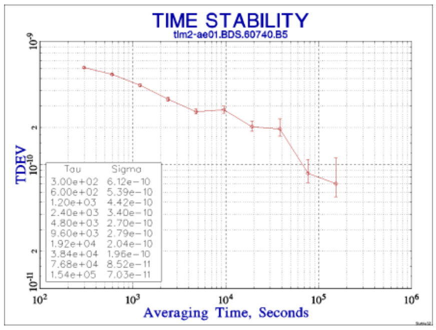




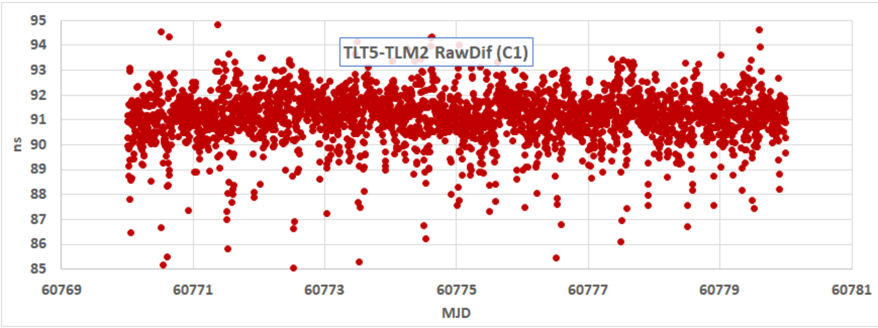

TLM2-AE01 RawDif (BC)
ns
-36
-37
-38
-39
-40
-41
-42
-43
-44
-45
-46
60739 60741 60743 60745 60747 60749 60751
MJD

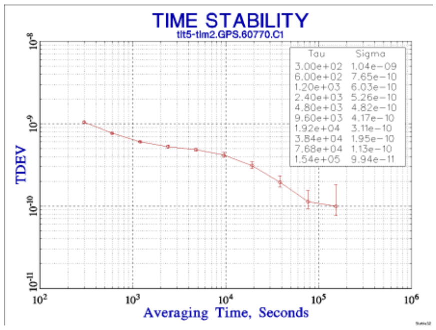

TIME STABILITY
tlm2-ae01.BDS.60740.BC
TDEV
Tau Sigma
3.00e+02 6.15e−10
6.00e+02 4.98e−10
1.20e+03 3.89e−10
2.40e+03 3.45e−10
4.80e+03 3.29e−10
9.60e+03 2.80e−10
1.92e+04 1.80e−10
3.84e+04 1.19e−10
7.68e+04 6.75e−11
1.54e+05 7.36e−11
Averaging Time, Seconds

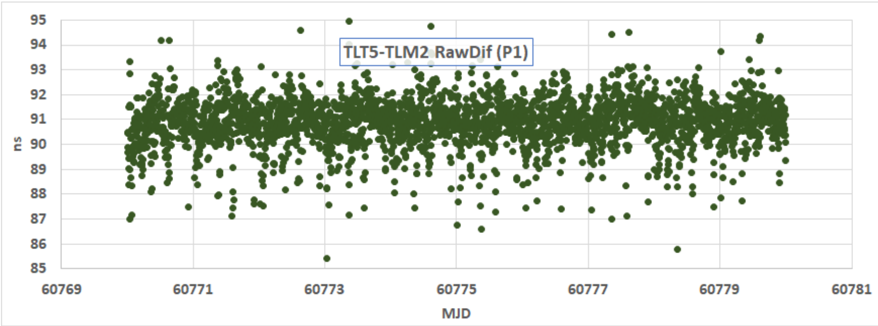

TLM2-AE01 RawDif (B5)
ns
-35
-36
-37
-38
-39
-40
-41
-42
-43
-44
-45
60739 60741 60743 60745 60747 60749 60751
MJD

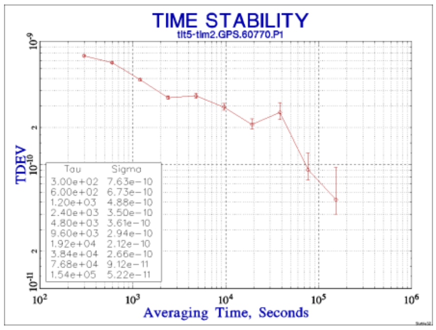

TIME STABILITY
tlm2-ae01.BDS.60740.B5
TDEV
Tau Sigma
3.00e+02 6.12e−10
6.00e+02 5.39e−10
1.20e+03 4.42e−10
2.40e+03 3.40e−10
4.80e+03 2.70e−10
9.60e+03 2.79e−10
1.92e+04 2.04e−10
3.84e+04 1.96e−10
7.68e+04 8.52e−11
1.54e+05 7.03e−11
Averaging Time, Seconds

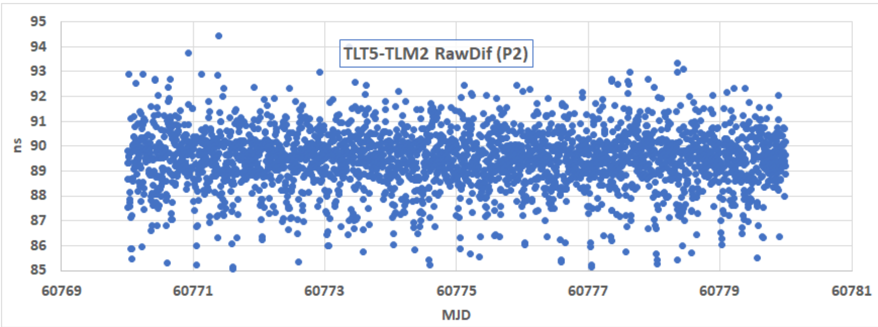
B.3 reference vs. traveling, closure

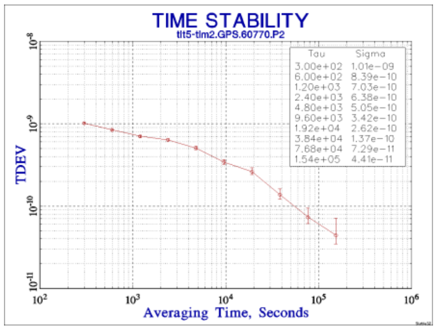


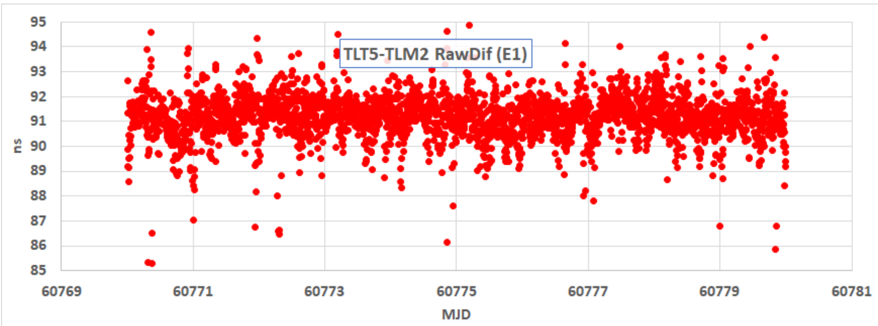


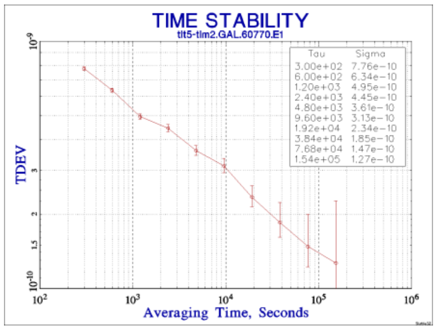


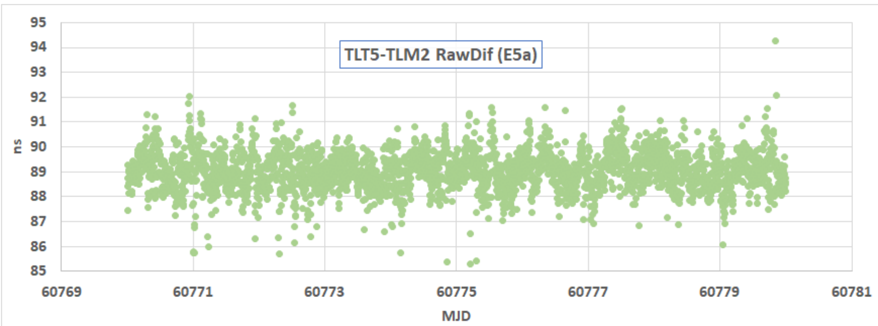


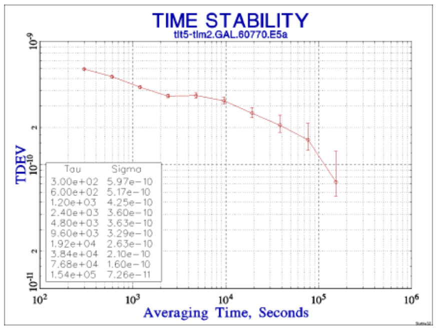


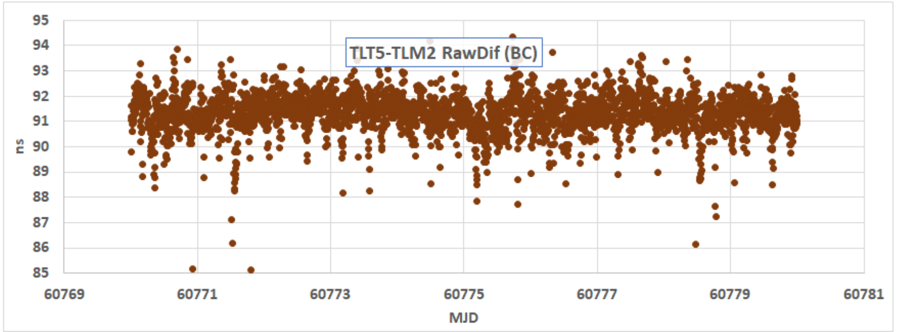


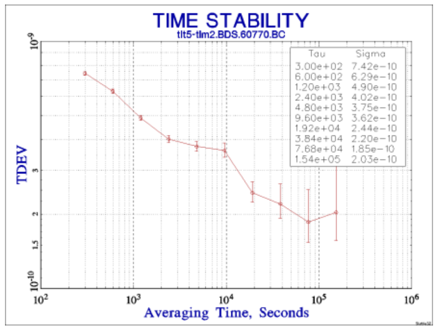


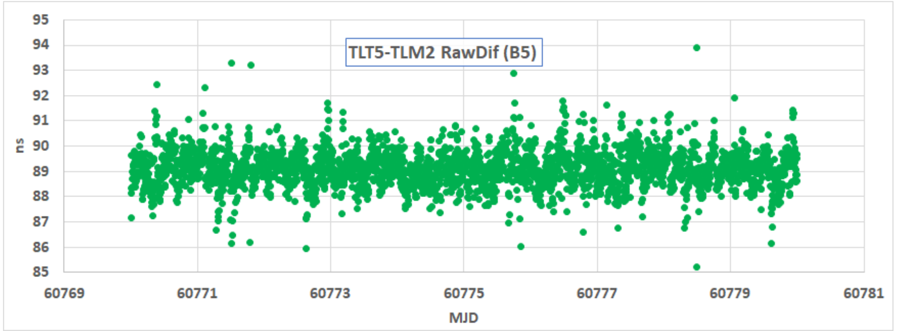


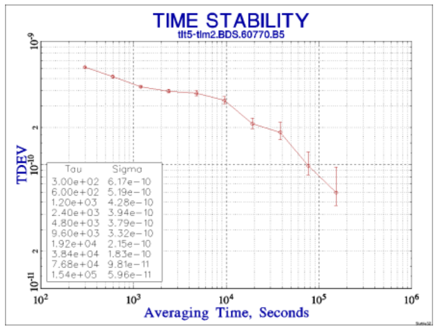





TLT5-TLM2 RawDif (BC)
ns
MJD
95
94
93
92
91
90
89
88
87
86
85
60769 60771 60773 60775 60777 60779 60781


TIME STABILITY
tlt5-tlm2.BDS.60770.BC
TDEV
Averaging Time, Seconds
Tau Sigma
3.00e+02 7.42e−10
6.00e+02 6.29e−10
1.20e+03 4.90e−10
2.40e+03 4.02e−10
4.80e+03 3.75e−10
9.60e+03 3.62e−10
1.92e+04 2.44e−10
3.84e+04 2.20e−10
7.68e+04 1.85e−10
1.54e+05 2.03e−10


TLT5-TLM2 RawDif (B5)
ns
MJD
95
94
93
92
91
90
89
88
87
86
85
60769 60771 60773 60775 60777 60779 60781


TIME STABILITY
tlt5-tlm2.BDS.60770.B5
TDEV
Averaging Time, Seconds
Tau Sigma
3.00e+02 6.17e−10
6.00e+02 5.19e−10
1.20e+03 4.28e−10
2.40e+03 3.94e−10
4.80e+03 3.79e−10
9.60e+03 3.32e−10
1.92e+04 2.15e−10
3.84e+04 1.83e−10
7.68e+04 9.81e−11
1.54e+05 5.96e−11

Reference

[1] BIPM "2022 Group 1 GPS calibration trip", ftp://ftp2.bipm.fr /pub/tai/publication/gnss-calibration/group1/1001-2022

[2] BIPM guidelines for GNSS calibration, V4.0, 05/08/2021

[3] https://webtai.bipm.org/ftp/pub/tai/publication/time-calibration/Current/1013-2018_GPSP3C1_EMI_V1-0.pdf

[4] https://webtai.bipm.org/ftp/pub/tai/publication/time-calibration/Current/1201-2019_GPSP3C1_EMI-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] W. Lewandowski, C. Thomas, 1991, "GPS Time transfers," Proc. IEEE, Vol. 79, No. 7, 991-1000

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