TLT0 Calibration Transfer Report
Cal_ID: 1001-2022

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Summary

On 2nd August 2024, the TL GNSS time transfer receiver, TLT0 (rinex code TWTF) changed its antenna from ASH701945C_M into Septentrio B3E6. To keep its time transfer result traceable, TL re-calibrated TLT0 with respect to the calibrated receiver TLT5 which GPS and Galileo signal delays were calibrated by BIPM as reported with CAL_ID 1001-2022 [1] and its setup configuration has been kept unchanged since 2022. The common clock data were collected between MJD 60859-60864 (the 3rd July 2025 – 8th July 2025) by simultaneous operation of a pair of co-located TLT5. This report was declared to BIPM on 18th August and followed as closely as possible the BIPM Guideline [2]. The results provided the calibrated receiver's total delays for GPS C1, P1, P2 and Galileo E1 and E5a.

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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**
GPS P3	**The ionosphere free combination of GPS P1 and P2 signal**
GAL	**Galileo satellite navigation system**
GAL E3	**The ionosphere free combination of GAL E1 and E5a signal**
BDS	**Beidou satellite navigation system**
BDS 3B3	**The ionosphere free combination of BDS BC and B5 signal**
PPP	**Precise Point Positioning**
TL	**Telecommunication Laboratories, Chunghwa Telecom, Taiwan**
TLT5	**TL G1 Reference receiver**
TWTF	**TL receiver to be calibrated**
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 receiver**
SYSDLY	**INTDLY + CABDLY**
TOTDLY	**SYSDLY – REFDLY**

1. DESCRIPTION OF EQUIPMENT AND OPERATIONS

1.1 The Setup of GNSS receivers at TL

The set-up of the reference receiver TLT5 and the receiver to be calibrated TLT0 (Table 1) are depicted in Annex A for 1 PPS signals and 10 MHz signals. The type of receiver to be calibrated, TLT0, is Septentrio PolaRx4 Pro TR, since its CABDLY and INTDLY were not accurately measured, we only calibrated its TOTDLY this time. The details can be found in the calibration information sheet in Annex A.

Table 1. Summary information of reference receiver and the receiver to be calibrated

BIPM code	RINEX name	Receiver type	Status of equipment	Dates of measurement
TLT5	TLT5	Septentrio PolaRx5 TR	Local Reference	MJD 60859-60864
TLT0	TWTF	Septentrio PolaRx4 Pro TR	To be Calibrated	

2. DATA USED

Since the reference TLT5 and TLT0 are all GNSS geodetic receivers and provide RINEX files, we use their pseudoranges directly read in their RINEX files by the software dclrinex provide by BIPM [5] dedicated to differential calibration.

3. RESULTS OF RAW DATA PROCESSING

The raw code differences of TLT5 and TLT0 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 TOTDLY between a given pair of receivers will be computed using Eq. (4) and given in Table 5.1 and 5.2.

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

Pair	Date	C1	P1	P2	E1	E5a
		Unc.	Unc.	Unc.	Unc.	Unc.
TLT5-TLT0	60859-60864	189.53	188.66	187.92	190.01	177.72
		0.06	0.07	0.03	0.05	0.07

4. CALIBRATION RESULTS

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

$$TOTDLY_R(code) = CABDLY_R(code) + INTDLY_R(code) - REFDLY_R(code) \quad …….. (1)$$

For the reference receiver TLT5 and the receiver under calibration TLT0 use the common clock and frequency reference source UTC(TL):

$$RAW_R(code) - TOTDLY_R(code) = RAW_U(code) - TOTDLY_U(code) \quad …….. (2)$$

Where the $TOTDLY_R(code)$ and $TOTDLY_U(code)$ are the TOTDLY of TLT5 and TLT0 respectively; the $RAW_R(code)$ and $RAW_U(code)$ is the raw calibration result of the TLT5 and TLT0 read from table 2. The code can be GPS C1/P1/P2, Galileo E1/E5a and Beidou B1/B2.

From (1) and (2)

$TOTDLY_U(code)$

$= TOTDLY_R(code) - [RAW_R(code) - RAW_U(code)]$ …….. (3)

The raw calibration of TOTDLYs of TLT0 are listed in Table 3:

Table 3. Summary information on the raw calibration results (all values in ns)

	TOTDLY				
	C1	P1	P2	E1	E5a
TLT5 (ID 1001_2022)	206.80	204.50	203.30	206.80	204.60
TLT0	17.27	15.84	15.38	16.79	26.88

4.4 Uncertainty

In this section, we use the same method as [1] to determine the uncertainty of TOTDLY. 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 $u^2_{P3}=u^2_{P1}+(1.545\times u_{P1-P2})^2$. Uncertainties 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 sum are to be listed in Table 6.1 and 6.2. Values appear separately for each code (GPS C1, P1, P2, GAL E1, and E5a) to compute a value u_{CAL} applicable to GPS P3 and GAL E3 links. We chose to compute u_{CAL} using for u_b the uncertainty $u_{b,TOT}$ of $TOTDLY_{TLT0}$ from Eq. (4). Table 5.1 and 5.2 presents all components of the uncertainty budget along with the uncertainty $u_{b.TOT}$ of $INTDLY_{TLT0}$ from equation (4) and the resulting uncertainty value u_{CAL}. The items in Table 5 are separated into several categories.

- $u_{b,11}$ 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 be estimated, 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 reference point of the reference station and the local UTC(k). $u_{b,31} = u_{b,32} = 0$ ns at TLT0 because we did not use the measurement of the REFDLY of TLT0 this time.
- $u_{b,31}$ and $u_{b,32}$ account for the measurement of CABDLY. $u_{b,41} = u_{b,42} = 0.0$ ns at TLT0 because we did not use measurement of the CABDLY of TLT0 this time.

Table 4.1 Uncertainty contributions of GPS link, Value P3 = P1+1.545×(P1−P2). All value in ns.

Unc.	C1	P1	P2	P1-P2	P3	Description
$u_{a,TLT5-TLT0}$	0.06	0.07	0.03	0.07	0.13	Tdev of RAWDIF of TLT5 vs. TLT0
	Systematic components related to RAWDIF					
$u_{b,11}$	0.10	0.10	0.10	0.14	-	Position error at TLT5
$u_{b,12}$	0.20	0.20	0.20	0.28	-	Multipath effect at TLT5
	Link of the Reference system to UTC(TL)					
$u_{b,21}$	0	0	0	-		REFDLY of TLT5, did not use measurement this time
$u_{b,22}$	0	0	0	-	-	REFDLY of TLT0, did not use the measurement this time,
Antenna cable delays						
$u_{b,31}$	0	0	0	-	-	CABDLY of TLT5, did not use the measurement this time
$u_{b,32}$	0	0	0	-	-	CABDLY of TLT0, did not use the measurement this time,
$u_{b,TOT}$	0.22	0.22	0.22	0.32	0.54	Components of equation (4)
$u_{CAL0,TLT0}$					0.55	Composed of $u_{a,TLT5-TLT0}$ and $u_{b,TOT}$

Table 4.2 Uncertainty contributions of GAL link, E3 = E1+1.261×(E1-E5a), all values in ns

Unc.	E1	E5a	E1-E5a	E3	Description
$u_{a,TLT5-TLT0}$	0.05	0.07	0.09	0.12	Tdev of RAWDIF of TLT5 vs. TLT0
Systematic components related to RAWDIF					
$u_{b,11}$	0.10	0.10	0.14	-	Position error at TLT5
$u_{b,12}$	0.20	0.20	0.28	-	Multipath effect at TLT5
	Link of the References to the UTC(TL)				
$u_{b,21}$	0	0	-	-	REFDLY of TLT5
$u_{b,22}$	0	0	-	-	REFDLY of TLT0

Antenna cable delays					
$u_{b,31}$	0	0	-	-	CABDLY of TLT5, did not measure this time
$u_{b,32}$	0	0	-	-	CABDLY of TLT0
$u_{b,INT}$	0.22	0.22	0.32	0.46	Components of equation (4)
$u_{CAL0,TLT0}$				0.47	Composed of $u_{a,TLT5-TLT0}$ and $u_{b,INT}$

5. The final results for the transferred systems

Table 5.1 Summary of the final results of GPS link

Reference Receiver	Cal_Id	Date		TOTDLY/ns		
				C1	P1	P2
TLT5	1001-2022	Oct. 30, 2022		**206.80**	**204.50**	**203.30**
Transferred Reciever	**Cal_Id**	**Date**	**u_{CAL} (P3)/ ns**	**TOTDLY/ns**		
				C1	**P1**	**P2**
TLT0	1001-2022		**0.55**	**17.3**	**15.8**	**15.4**

Table 5.2 Summary of the final results of GAL link

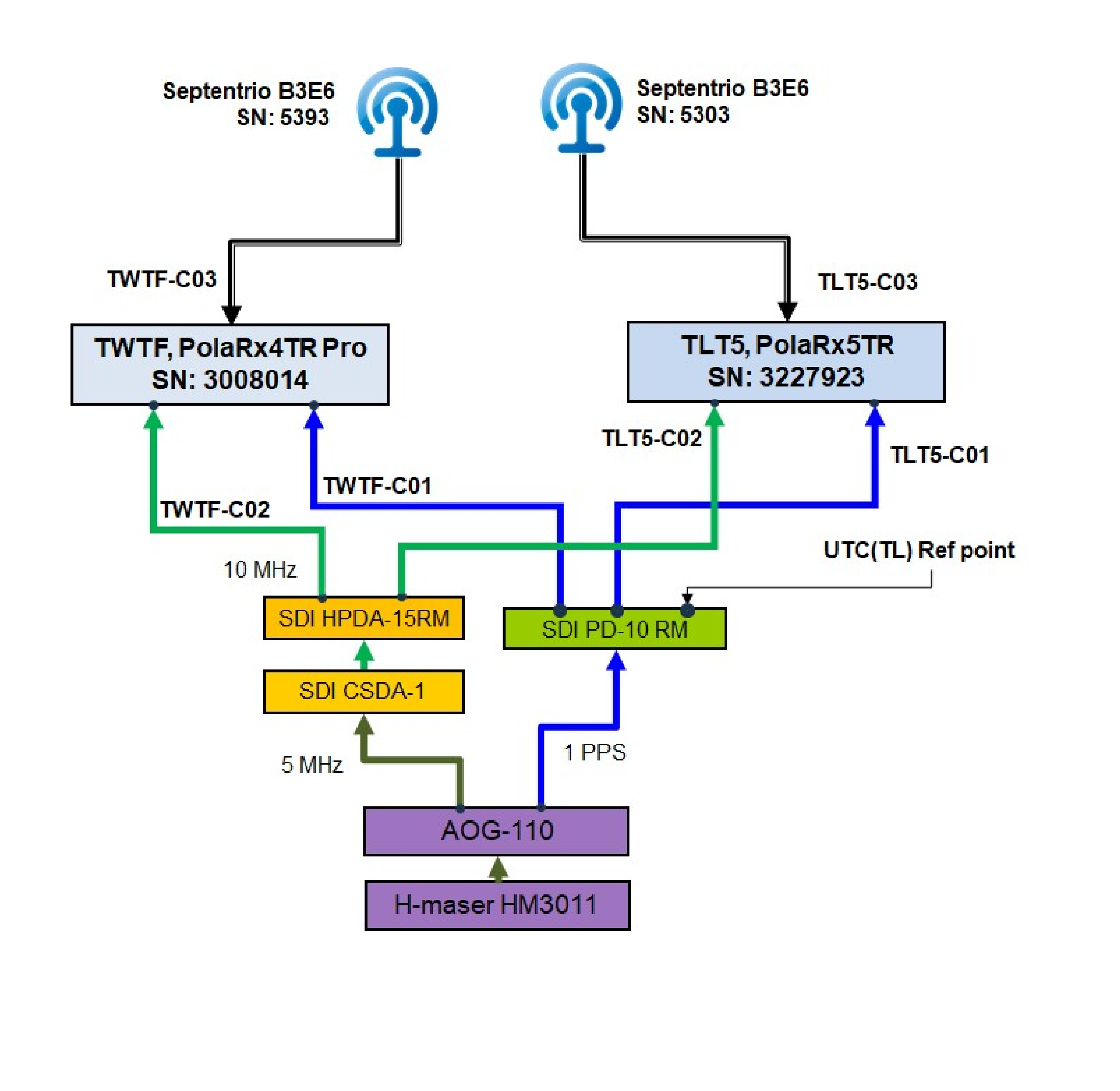
Reference Receiver	Cal_Id	Date		TOTDLY/ns	
				E1	E5a
TLT5	1001-2022	Oct. 10, 2022		**206.80**	**204.60**
Transferred Receiver	**Cal_Id**	**Date**	**u_{CAL} (E3)/ ns**	**TOTDLY/ns**	
				E1	**E5a**
TLT0	1001-2022		**0.47**	**16.8**	**26.9**

ANNEXES

Annex A: Information sheets

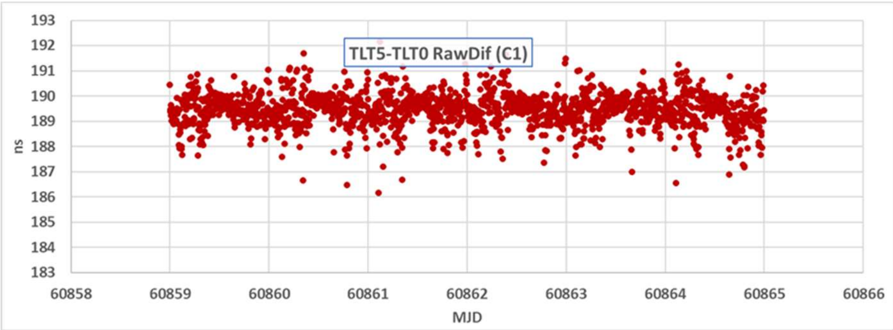
Laboratory: TL		
Date and hour of the beginning of measurements:	00:00 UTC, 03rd JUL, 2025	
Date and hour of the end of measurements:	23:59 UTC, 08th JUL, 2025	
Information on the system		
	Reference:	**To be Calibrated:**
4-character BIPM code	TLT5	TLT0
● Receiver maker and type: Receiver serial number:	Septentrio/PolaRx5TR/ 3227923	Septentrio/PolaRx4TR Pro 3008014
1 PPS trigger level /V:	1 V	1 V
● Antenna cable maker and type: Phase stabilised cable (Y/N):	Andrew FSJ/Y	Andrew FSJ/Y
Length outside the building /m:	~35	~35
● Antenna maker and type: Antenna serial number:	SEPCHOKE_B3E6 SPKE/ 5303	SEPCHOKE_B3E6_SPKE/ 5393
Temperature (if stabilised) /°C		
Measured delays/ns		
	Local:	**Travelling:**
● Delay from local UTC to receiver 1 PPS-in:	No measurement	No measurement
Delay from 1 PPS-in to internal Reference (if different):	-	-
● Antenna cable delay:	No measurement	No measurement
Splitter delay (if any):	-	-
Additional cable delay (if any):	-	-
Data used for the generation of CGGTTS files (TLT5)		
● INT DLY (GPS) /ns:	P1: 204.5, P2: 203.3[1]	
● INT DLY (GAL) /ns:	E1: 206.8, E5a: 204.6	
● CAB DLY /ns:	Included in INTDLY	
● REF DLY /ns:	Included in INTDLY	
● Coordinates reference frame:	WGS-84	
Latitude or X /m:	-2994423.91	
Longitude or Y /m:	+4951311.91	
Height or Z /m:	+2674499.18	
General information		
● Rise time of the local UTC pulse:	2 ns	
● Is the laboratory air conditioned:	Yes	
Set temperature value and uncertainty:	(23.0 ± 2.0) °C	
Set humidity value and uncertainty:	(50 ± 15) %.RH	

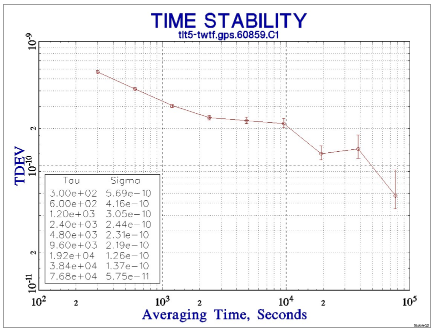
[1] The P1/P2/E1/E5a/B1/B2 INTDLY of TLT5 used for generating CGGTTS are actually TOTDLY, already including CABDLY and REFDLY

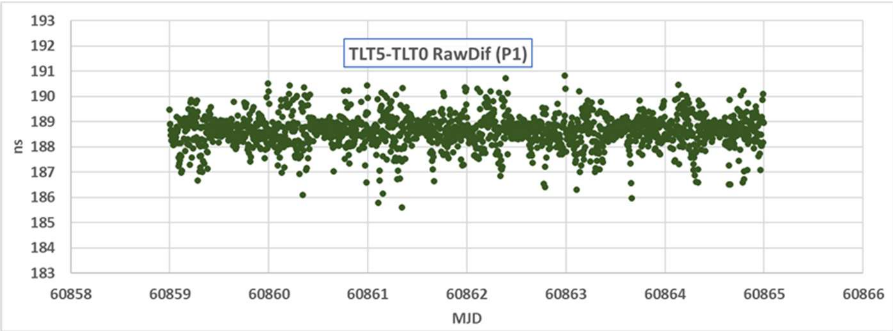

Septentrio B3E6
SN: 5393
Septentrio B3E6
SN: 5303
TWTF-C03
TLT5-C03
TWTF, PolaRx4TR Pro
SN: 3008014
TLT5, PolaRx5TR
SN: 3227923
TLT5-C02
TLT5-C01
TWTF-C01
TWTF-C02
UTC(TL) Ref point
10 MHz
SDI HPDA-15RM
SDI PD-10 RM
SDI CSDA-1
5 MHz
1 PPS
AOG-110
H-maser HM3011

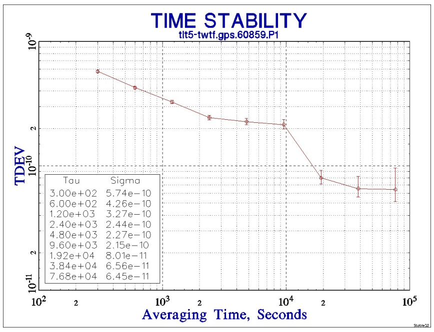
Annex B: Plots of raw data and Tdev analysis

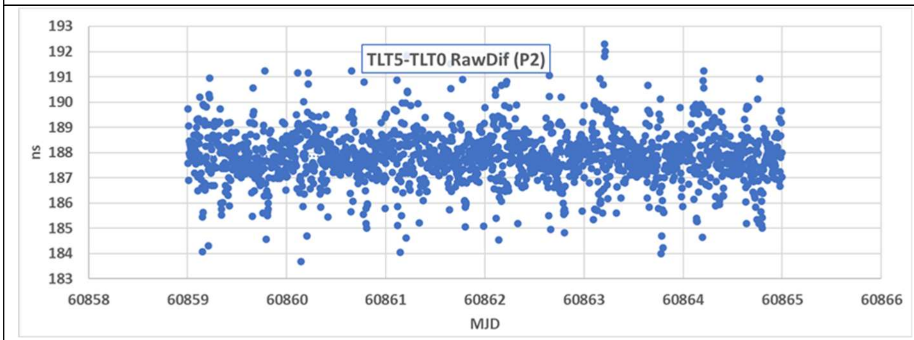
B.1 reference receiver vs. TLT0

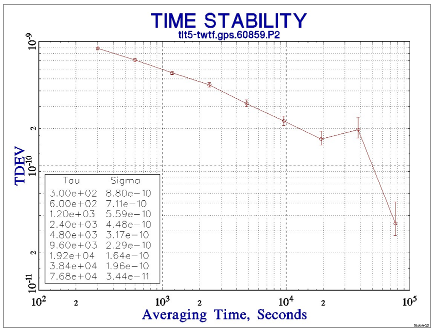


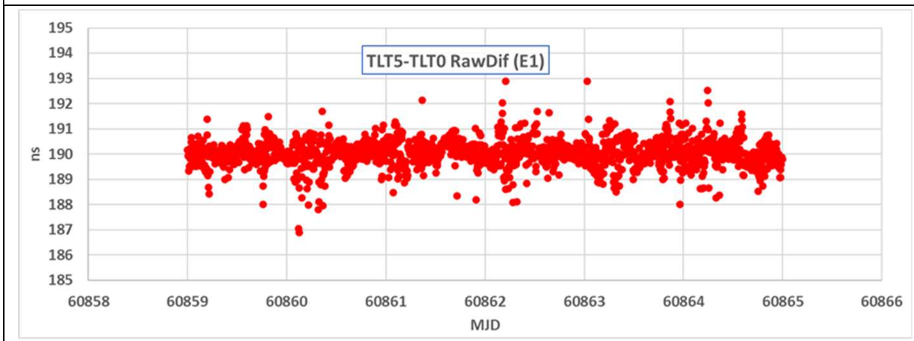


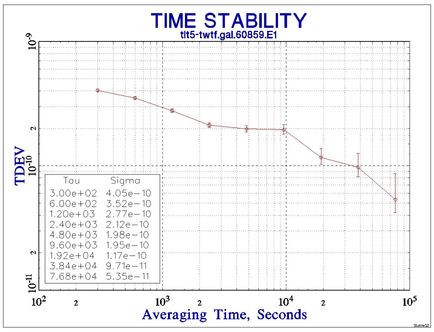


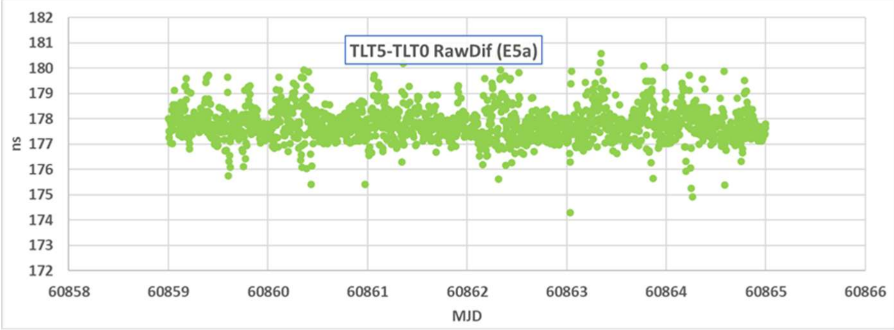


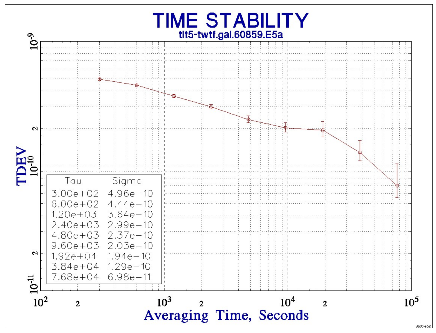









TLT5-TLT0 RawDif (E5a)
ns
182
181
180
179
178
177
176
175
174
173
172
60858
60859
60860
60861
60862
60863
60864
60865
60866
MJD


TIME STABILITY
tlt5-twtf.gal.60859.E5a
TDEV
Averaging Time, Seconds
Tau Sigma
3.00e+02 4.96e−10
6.00e+02 4.44e−10
1.20e+03 3.64e−10
2.40e+03 2.99e−10
4.80e+03 2.37e−10
9.60e+03 2.03e−10
1.92e+04 1.94e−10
3.84e+04 1.29e−10
7.68e+04 6.98e−11

Reference

[1] BIPM "2022 Group 1 GPS calibration trip", https://webtai.bipm.org/ftp/pub/tai/publication/time-calibration/Current/1001-2022_GPSP3C1-GALE3-BDSB3_Group1-trip_V1-1.pdf

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

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

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

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

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

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