

TL1A Calibration Transfer Report

Cal_ID: 1001-2022

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Summary

On 6th June 2025, the TL GNSS time transfer receiver, TLT1, became unstable and was replaced from Ashtech Z12T into PolaRx5TR, its 4-letters code into TL1A for distinguish. To keep its time transfer result traceable, we calibrated the hardware delays of TL1A with respect to the calibrated receiver TLT5 which hardware delays of GPS, Galileo, and Beidou signal 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, Galileo E1, E5a, Beidou BC, and B5.

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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
TL1A	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 TL1A (Table 1) are depicted in Annex A for 1 PPS signals and 10 MHz signals. The type of receiver to be calibrated, TL1A, is Septentrio PolaRx5 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
TL1A	TL1A	Septentrio Polar5TR	To be Calibrated	

2. DATA USED

Since the reference receiver TLT5 and the receiver to be calibrated TL1A 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 TL1A 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	BC	B5
		Unc.	Unc.	Unc.	Unc.	Unc.	Unc.	Unc.
TLT5-TL1A	60859-60864	17.88	17.81	18.79	17.88	16.50	17.84	16.49
		0.05	0.11	0.12	0.08	0.05	0.05	0.05

4. CALIBRATION RESULTS

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

$$\text{TOTDLY}_R(\text{code}) = \text{CABDLY}_R(\text{code}) + \text{INTDLY}_R(\text{code}) - \text{REFDLY}_R(\text{code}) \quad \dots\dots\dots (1)$$

For the reference receiver TLT5 and the receiver under calibration TL1A use the common clock and frequency reference source UTC(TL):

$$\text{RAW}_R(\text{code}) - \text{TOTDLY}_R(\text{code}) = \text{RAW}_U(\text{code}) - \text{TOTDLY}_U(\text{code}) \quad \dots\dots\dots (2)$$

Where the $TOTDLY_R(\text{code})$ and $TOTDLY_U(\text{code})$ are the TOTDLY of TLT5 and TL1A respectively; the $RAW_R(\text{code})$ and $RAW_U(\text{code})$ is the raw calibration result of the TLT5 and TL1A read from table 2. The code can be GPS C1/P1/P2, Galileo E1/E5a and Beidou B1/B2.

From (1) and (2)

$$\begin{aligned} &TOTDLY_U(\text{code}) \\ &= TOTDLY_R(\text{code}) - [RAW_R(\text{code}) - RAW_U(\text{code})] \end{aligned} \quad \dots\dots\dots (3)$$

The raw calibration of TOTDLYs of TL1A are listed in Table 3:

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

	TOTDLY						
	C1	P1	P2	E1	E5a	BC	B5
TLT5 (ID 1001_2022)	206.80	204.50	203.30	206.80	204.60	206.60	204.00
TL1A	188.92	186.69	184.51	188.92	188.10	188.76	187.51

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, GAL E3, and BDS 3B3 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 $u_{P3}^2 = u_{P1}^2 + (1.545 \times u_{P1-P2})^2$. Uncertainties for the Galileo delays are calculated according to $u_{E3}^2 = u_{E1}^2 + (1.261 \times u_{E1-E5a})^2$. Uncertainties for the Beidou delays are calculated according to $u_{3B3}^2 = u_{BC}^2 + (1.261 \times u_{BC-B5})^2$. 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, P2, GAL E1, E5a, BDS BC, and

B5) to compute a value u_{CAL} applicable to GPS P3, GAL E3, and BDS 3B3 links. We chose to compute u_{CAL} using for u_b the uncertainty $u_{b,\text{TOT}}$ of $\text{TOTDLY}_{\text{TL1A}}$ from Eq. (4). Table 5.1, 5.2, and 5.3 presents all components of the uncertainty budget along with the uncertainty $u_{b,\text{TOT}}$ of $\text{INTDLY}_{\text{TL1A}}$ 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). $u_{b,21} = u_{b,22} = 0$ ns at TL1A because we did not use the measurement of the REFDLY of TL1A this time.
- $u_{b,31}$ and $u_{b,32}$ account for the measurement of CABDLY. $u_{b,31} = u_{b,32} = 0$ ns at TL1A because we did not use measurement of the CABDLY of TL1A this time.

Table 4.1 Uncertainty contributions of GPS link, Value $P3 = P1 + 1.545 \times (P1 - P2)$. All value in ns.

Unc.	C1	P1	P2	P1-P2	P3	Description
$u_{a,\text{TLT5-TL1A}}$	0.05	0.11	0.12	0.16	0.27	Tdev of RAWDIF of TLT5 vs. TL1A
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 TL1A, 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 TL1A, did not use the measurement this time,
$u_{b,\text{TOT}}$	0.22	0.22	0.22	0.32	0.54	Components of equation (4)
$u_{\text{CAL0,TL1A}}$					0.60	Composed of $u_{a,\text{TLT5-TL1A}}$ and $u_{b,\text{TOT}}$

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

Unc.	E1	E5a	E1-E5a	E3	Description
$u_{a,\text{TLT5-TL1A}}$	0.08	0.05	0.10	0.14	Tdev of RAWDIF of TLT5 vs. TL1A
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, did not use measurement this time
$u_{b,22}$	0	0	-	-	REFDLY of TL1A, did not use the measurement this time,
Antenna cable delays					
$u_{b,31}$	0	0	-	-	CABDLY of TLT5, did not use the measurement this time
$u_{b,32}$	0	0	-	-	CABDLY of TL1A, did not use the measurement this time,
$u_{b,INT}$	0.22	0.22	0.32	0.46	Components of equation (4)
$u_{CAL0,TL1A}$				0.48	Composed of $u_{a,TLT5-TL1A}$ and $u_{b,INT}$

Table 4.3 Uncertainty contributions of BDS link, $3B3 = BC + 1.261 \times (BC - B5)$, all values in ns

Unc.	BC	B5	BC-B5	3B3	Description
$u_{a,TLT5-TL1A}$	0.05	0.05	0.07	0.10	Tdev of RAWDIF of TLT5 vs. TL1A
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, did not use measurement this time
$u_{b,22}$	0	0	-	-	REFDLY of TL1A, did not use the measurement this time,
Antenna cable delays					
$u_{b,31}$	0	0	-	-	CABDLY of TLT5, did not use the measurement this time
$u_{b,32}$	0	0	-	-	CABDLY of TL1A, did not use the measurement this time,
$u_{b,INT}$	0.22	0.22	0.32	0.46	Components of equation (4)
$u_{CAL0,TL1A}$				0.47	Composed of $u_{a,TLT5-TL1A}$ 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		206.8	204.5	203.3
Transferred Reciever	Cal_Id	Date	$u_{CAL} (P3)/ ns$	TOTDLY/ns		
				C1	P1	P2
TL1A	1001-2022		0.6	188.9	186.7	184.5

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		206.8	204.6
Transferred Receiver	Cal_Id	Date	u _{CAL} (E3)/ ns	TOTDLY/ns	
				E1	E5a
TL1A	1001-2022		0.5	188.9	188.1

Table 5.3 Summary of the final results of BDS link

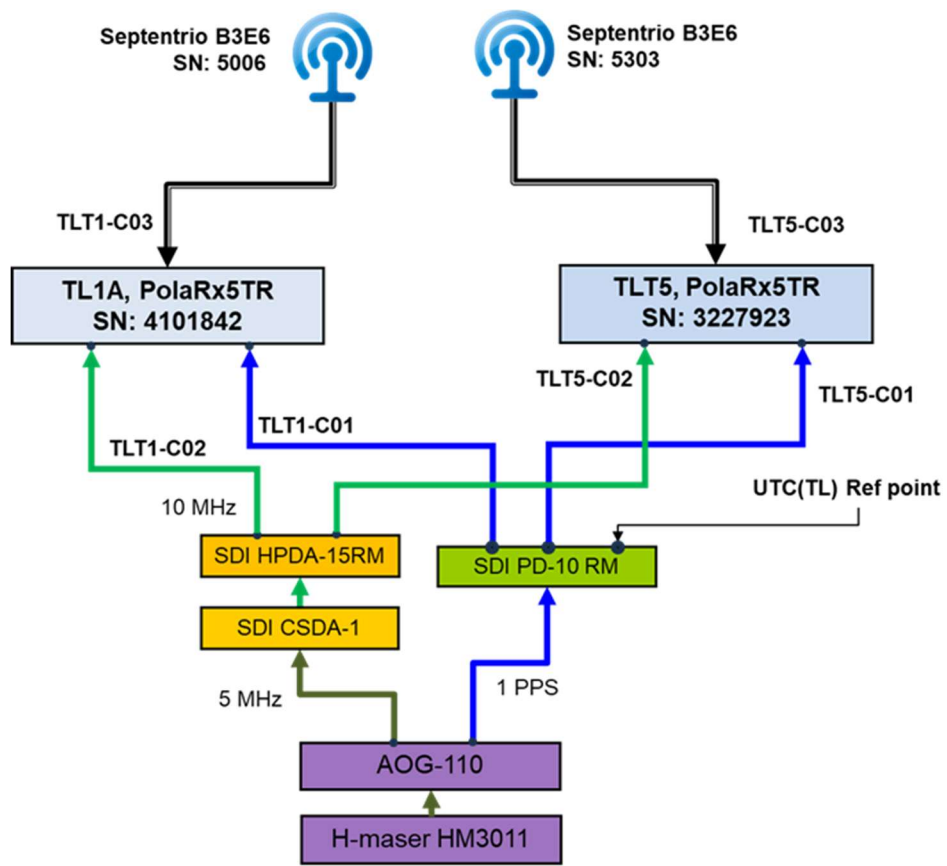
Reference Receiver	Cal_Id	Date		TOTDLY/ns	
				BC	B5
TLT5	1001-2022	Oct. 10, 2022		206.8	204.6
Transferred Receiver	Cal_Id	Date	u _{CAL} (E3)/ ns	TOTDLY/ns	
				BC	B5
TL1A	1001-2022		0.5	188.8	187.5

ANNEXES

Annex A: Information sheets

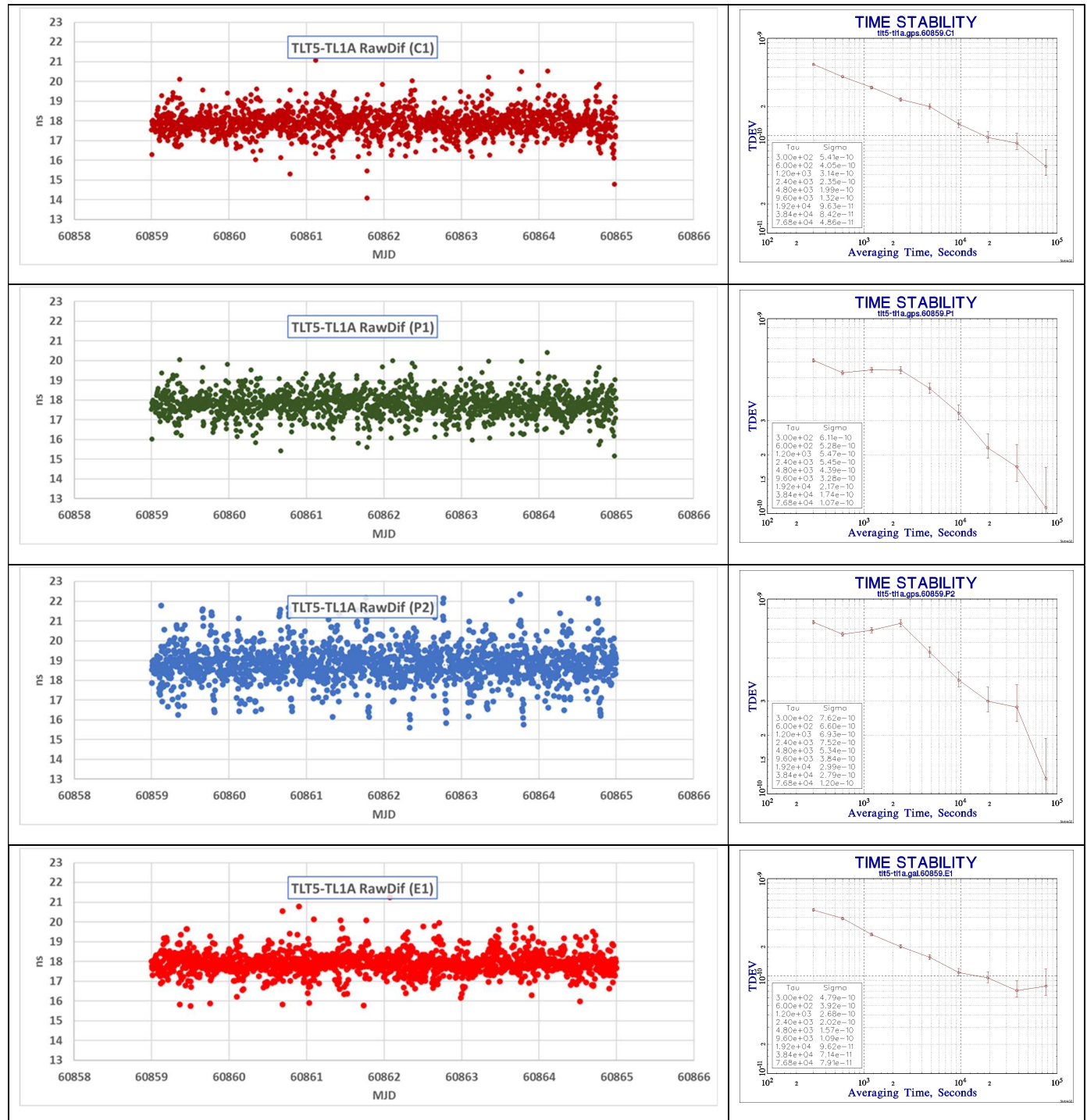
Laboratory: TL		
Date and hour of the beginning of measurements:	00:00 UTC, 03 rd JUL, 2025	
Date and hour of the end of measurements:	23:59 UTC, 08 th JUL, 2025	
Information on the system		
	Reference:	To be Calibrated:
4-character BIPM code	TLT5	TL1A
● Receiver maker and type: Receiver serial number:	Septentrio/PolaRx5TR/ 3227923	Septentrio/PolaRx5TR 4101842
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/ 5006
Temperature (if stabilised) /°C		
Measured delays/ns		
	Reference:	To be Calibrated:
● 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):		(1)
Additional cable delay (if any):		(1)
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	

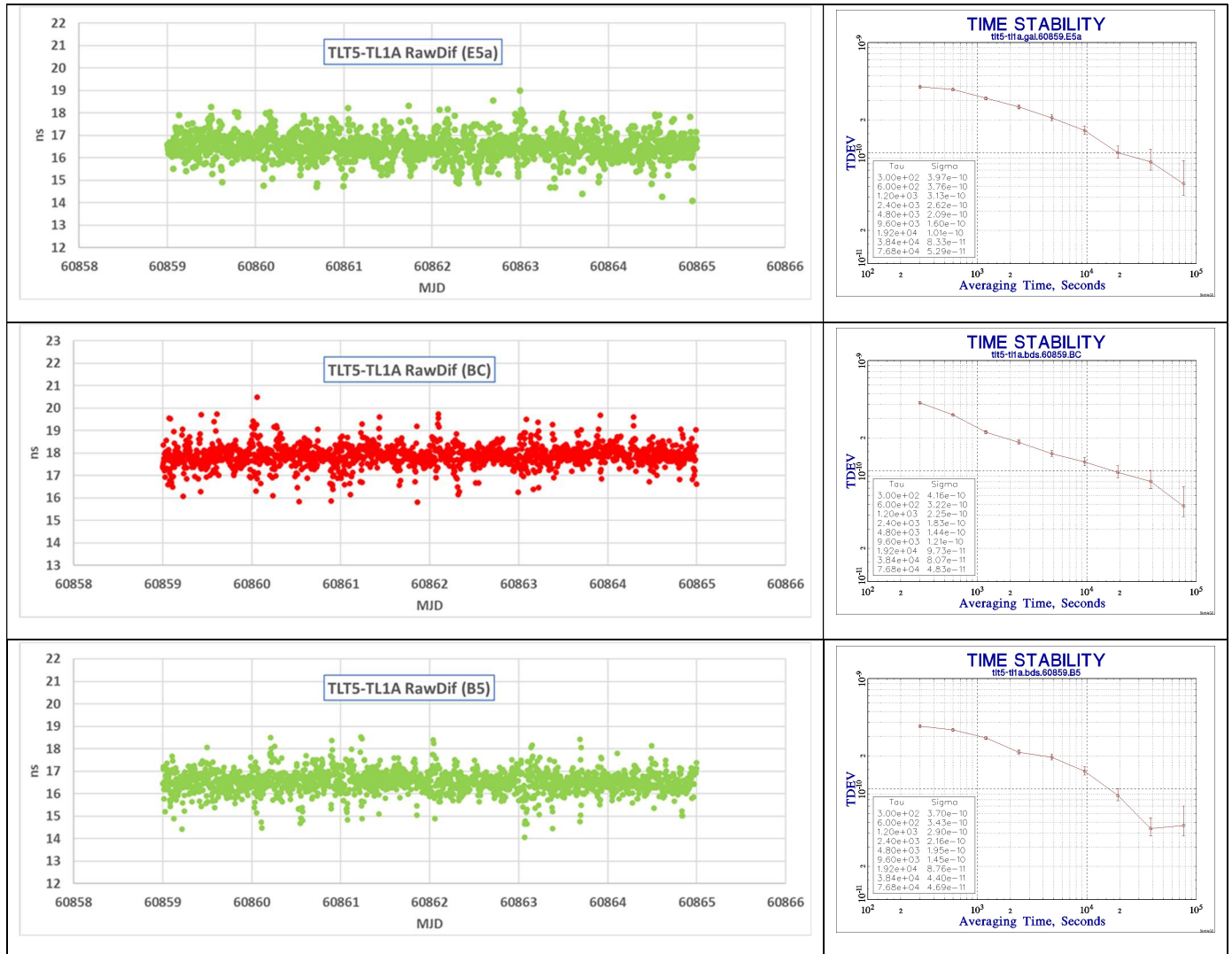
¹ The P1/P2/E1/E5a/B1/B2 INTDLY of TLT5 used for generating CGGTTS are actually TOTDLY, already including CABDLY and REFDLY



Annex B: Plots of raw data and Tdev analysis

B.1 reference receiver vs. TL1A





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