Chunghwa Telecom Laboratories

2023 Group 2 GNSS Calibration Report
Cal_ID: 1018-2023

National Standard Time and Frequency Lab

Telecommunication Laboratories, Chunghwa Telecom Co., Ltd.

Calvin Shinn-Yan Lin and Wen-Hung Tseng

sylin@cht.com.tw

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Summary

As one of the APMP G1 laboratories, TL conducted a relative calibration of the GNSS time transfer receivers of A*Star (Agency for Science, Technology and Research, which acronyms listed in BIPM acronyms table is SG), Singapore with respect to the calibrated TL receiver TLT5 which setup configuration is kept unchanged since 2020. The signal delays of TLT5 for GPS and Galileo were calibrated by BIPM as reported with CAL_ID 1001-2020 [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 SG01 and SG02 of SG. The data were collected between MJD 60134-60196 (9th July 2023 – 9th September 2023) by simultaneous operation of a pair of co-located GNSS receivers. This campaign was declared to BIPM on 6th March 2023 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 the Galileo E1 and E5a signals. The results will be reported using Cal_ID 1018-2023.

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
PPP	Precise Point Positioning
TL	Telecommunication Laboratories, Chunghwa Telecom, Taiwan
TLT5	TL G1 Reference receiver
TLM2	TL travelling receiver
A*STAR	Agency for Science, Technology and Research, Singapore
UTC(SG)	The standard time scale of SG (ASTAR)
SG01	Visited receiver of SG (ASTAR)
SG02	Visited receiver of SG (ASTAR)
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
CLPDLY	the offset between the local UTC(k) point 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 (Hemisphere A45), 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 usage of TLM2 antenna cables were different during this trip, the TLM2 connected with a 50 meters LMR-200 antenna cable at TL, and the antenna cable delay was measured by SR-620 (SN: 4293); and connected with a Spuma 400-FR-01 and a RG-213 cable around 16 meters at SG and the antenna cable delay was measured by TIC HP53132a (SN: KR91200267 provided by SG). The detail information can be found in the Annex A information sheets.

1.2 Visited Receivers

There were 2 GNSS receivers, SG01 and SG02, calibrated in this campaign, both are Septentrio PolaRx5TR receivers, their GPS L1C/L1P/L2P links were calibrated by 2018 NIM-MASM-NMC-A*STAR-NIM G2 calibration campaign (CAL_ID: 1019-2018) in 2018 [3] and would calibrate their GPS P3 and Galileo E3 links this time. The detail information can be found in their information sheets in Annex A.2 and A.3, SG01 and SG02 information sheets.

Table 1. Summary information on the calibration trip

Institute	Status of equipment	Dates of measurement	Receiver type	BIPM code	RINEX name
TL	Traveling	60134-60143	Septentrio PolaRx5 TR	TLM2	TLM2
TL	Group 1 reference	-	Septentrio PolaRx5 TR	TLT5	TLT5
SG	Group 2	60155-60164	Septentrio PolaRx5 TR	SG01	SG01
SG	Group 2	60155-60164	Septentrio PolaRx5 TR	SG02	SG02
TL	Traveling	60187-60196	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 provide by BIPM [4] 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	60134-60143	30.53	0.08	30.42	0.04	25.01	0.05	30.52	0.06	23.70	0.09
TLM2-SG01	60155-60164	-68.77	0.05	-68.52	0.06	-60.72	0.03	-68.81	0.07	-63.34	0.13
TLM2-SG02	60155-60164	-66.07	0.04	-66.39	0.05	-58.95	0.03	-66.05	0.07	-61.69	0.06
TLT5-TLM2	60187-60196	29.95	0.05	29.93	0.05	24.01	0.03	29.84	0.06	22.30	0.10

4. Calibration results

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

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

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 and Galileo E1/E5a.

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

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:

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

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_{SG} may be different but the value $CLPDLY_{T}$(code) are all the same in the whole campaign due to we use the same reference 1 PPS cable for the traveling receiver in this trip. We have:

$$TOTDLY_{T,\,TL}(code) = CABDLY_{T,\,TL}(code) + INTDLY_{T}(code) - REFDLY_{T,\,TL}(code)$$
$$= CABDLY_{T,\,TL}(code) + INTDLY_{T}(code) - [CLPDLY_{T}(code) + \Delta Ref\_Clb_{TL}] \qquad \text{........ (3)}$$

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

$$RAWDIF_{R\text{-}T}(code)$$
$$= TOTDLY_{R}(code)$$
$$- [CABDLY_{T,\,TL}(code) + INTDLY_{T}(code) - CLPDLY_{T}(code) - \Delta Ref\_Clb_{TL}] \qquad \text{........ (4)}$$

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	60134-60143	30.53	30.42	25.01	5.41
TLT5-TLM2	60187-60196	29.95	29.93	24.01	5.92
Misclosure	-	-0.58	-0.49	-1.00	0.51
Mean	-	30.24	30.18	24.51	5.67

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

Pair	Date	E1	E5a	E1-E5a
		RawDIF	RawDIF	RawDIF
TLT5-TLM2	60134-60143	30.52	23.70	6.82
TLT5-TLM2	60187-60196	29.84	22.30	7.54
Misclosure	-	-0.68	-1.40	0.72
Mean	-	30.18	23.00	7.18

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 vanished in the visited INTDLYs deriving processes.

4.2 Traveling System with Respect to the Visited Systems

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

$RAWDIF_{T\text{-}V}(code) =$

$-TOTDLY_{V}(code)$

$+ [CABDLY_{T,\,SG}(code) + INTDLY_{T}(code) - CLPDLY_{T}(code) - \Delta Ref\_Clb_{SG}]$ …….. (5)

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

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

Pair	Date	ΔRef_Clb_{SG}	$REFDLY_{V}$	C1	P1	P2
				RawDIF	RawDIF	RawDIF
TLM2-SG01	60032-60043	0	5.0	-68.77	-68.52	-60.72
TLM2-SG02	60032-60043	0	5.0	-66.07	-66.39	-58.95

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

Pair	Date	ΔRef_Clb_{SG}	$REFDLY_{V}$	E1	E5a
				RawDIF	RawDIF
TLM2-SG01	60155-60164	0	5.0	-68.81	-63.34
TLM2-SG02	60155-60164	0	5.0	-66.05	-61.69

4.3 Visited Systems with Respect to Reference System

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

$RAWDIF(code)_{R\text{-}T} + RAWDIF(code)_{T\text{-}V}$

$= TOTDLY_{R}(code) - TOTDLY_{V}(code)$

$+ [CABDLY_{T,\,SG}(code) - CABDLY_{T,\,TL}(code)] + \Delta Ref\_Clb_{TL} - \Delta Ref\_Clb_{SG}$

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

$+ [CABDLY_{T,\,SG}(code) - CABDLY_{T,\,TL}(code)] + \Delta Ref\_Clb_{TL} - \Delta Ref\_Clb_{SG}$

or

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

$= RAWDIF(code)_{R\text{-}T} + RAWDIF(code)_{T\text{-}V}$
$+ [CABDLY_{T,\,TL}(code) – CABDLY_{T,\,SG}(code)] – ΔRef\_Clb_{TL} + ΔRef\_Clb_{SG}$ …… (6)

Both in TL and SG, the calibration reference point and the UTC(k) reference point are identical, that is both the $ΔRef\_Clb_{TL}$ and $ΔRef\_Clb_{SG} = 0$. The $CABDLY_{T,\,TL}(code)$ and $CABDLY_{T,\,SG}(code)$ can be found in their information sheets in Annex A, where the $CABDLY_{T,\,TL}(code) = 206.7$ ns and the $CABDLY_{T,\,SG}(code) = 81.8$ ns. 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	$ΔRef\_Clb_{SG}$	$ΔTOTDLY_{R\text{-}V}$		
			C1	P1	P2
TLT5-SG01	60155-60164	0	86.37	86.56	88.69
TLT5-SG02	60155-60164	0	89.07	88.69	90.46

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

Pair	Date	$ΔRef\_Clb_{SG}$	$ΔTOTDLY_{R\text{-}V}$	
			E1	E5a
TLT5-SG01	60155-60164	0	86.27	84.56
TLT5-SG02	60155-60164	0	89.03	86.21

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 the 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 $u^2_{P3}=u^2_{P1}+(1.545\times u_{P1\text{-}P2})^2$. Uncertainties for the Galileo delays are calculated according to $u^2_{E3}=u^2_{E1}+(1.261\times u_{E1\text{-}E5a})^2$. 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, and P2, GAL E1, and E5a) to compute a value u_{CAL} applicable to GPS P3 and GAL E3 links. 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 presents 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.

- $u_{b,1}$ accounts 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[5].
- $u_{b,21}$ and $u_{b,22}$ account for the measurement between the calibration reference point of the traveling receiver and the local UTC(k). The values $u_{b,21}$ = 0.0 ns since the calibration reference point is the UTC(k) reference point in TL.
- $u_{b,23}$ and $u_{b,24}$ account for the measurements of $CABDLY_{T,\,TL}$(code) and $CABDLY_{T,\,SG}$(code) at TL and SG, $u_{b,23}$ = $u_{b,24}$ = 0.5 ns include at least one measurement with TIC.
- $u_{b,31}$ 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; $u_{b,32}$ = 0.5 ns at the visited stations SG01 and SG02, it includes at least one measurement with a TIC.
- $u_{b,41}$ and $u_{b,42}$ accounts 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; $u_{b,42}$ = 0.5 ns at the visited stations SG01 and SG02, it includes at least one measurement with a TIC. We should note the visited site SG did not measure the CABDLY during this campaign.

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)	0.08	0.05	0.05	0.07		Tdev of RAWDIF of TLT5 vs. TLM2 during MJD 60134-60143 and 60187-60196.
$u_{a,SG01}$(T-V)	0.05	0.06	0.03	0.07		Tdev of RAWDIF of TLM2 vs. SG01
$u_{a,SG02}$(T-V)	0.04	0.05	0.03	0.06		Tdev of RAWDIF of TLM2 vs. SG02
$u_{a,SG01}$	0.09	0.08	0.06	0.10	0.17	
$u_{a,SG02}$	0.09	0.07	0.06	0.09	0.16	
	Misclosure					
$u_{b,1}$	-0.58	-0.49	-1.00	0.51	-	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 SG
$u_{b,13}$	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 SG
	Link of the Traveling system to the local UTC(k) and CABDLY measurements					
$u_{b,21}$	0.00	0.00	0.00	0.00	-	ΔRef_Clb$_{TL}$ at TL (CLBDLY = REFDLY)
$u_{b,22}$	0.00	0.00	0.00	0.00	-	ΔRef_Clb$_{SG}$ at SG (CLBDLY = REFDLY)
$u_{b,23}$	0.50	0.50	0.50	0.00		the measurement of CABDLY$_{T,\ TL}$(code) at TL
$u_{b,24}$	0.50	0.50	0.50	0.00		the measurement of CABDLY$_{T,\ SG}$(code) at SG
$u_{b,TOT}$	0.96	0.91	1.26	0.69	1.40	Components of equation (6)
$u_{CAL0,SG01}$					1.41	Composed of $u_{a,SG01}$ and $u_{b,TOT}$
$u_{CAL0,SG02}$					1.41	Composed of $u_{a,SG02}$ 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)					
$u_{b,32}$	0.50	0.50	0.50			REFDLY of SG01/SG02, did not measure during this campaign
Antenna cable delays						
$u_{b,41}$	0.00	0.00	0.00			CABDLY of TLM2, see Annex A.1 and A.2
$u_{b,42}$	0.50	0.50	0.50			CABDLY of SG01/SG02, did not measure during this campaign
$u_{b,INT}$	1.19	1.15	1.45	0.69	1.57	Components of equation (7)
$u_{CAL0,SG01}$					1.58	Composed of $u_{a,SG01}$ and $u_{b,INT}$
$u_{CAL0,SG02}$					1.58	Composed of $u_{a,SG02}$ 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)	0.06	0.10	0.12		Tdev of RAWDIF of TLT5 vs. TLM2 during MJD 60134-60143 and 60187-60196.
$u_{a,SG01}$(T-V)	0.07	0.13	0.15		Tdev of RAWDIF of TLM2 vs. SG01
$u_{a,SG02}$(T-V)	0.07	0.06	0.09		Tdev of RAWDIF of TLM2 vs. SG02
$u_{a,SG01}$	0.09	0.16	0.19	0.25	
$u_{a,SG02}$	0.09	0.12	0.15	0.21	
Misclosure					
$u_{b,1}$	-0.68	-1.40	0.72	-	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 SG
$u_{b,13}$	0.20	0.20	0.28	-	Multipath effect at TL
$u_{b,14}$	0.20	0.20	0.28	-	Multipath effect at SG
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.00	0.00	0.00		ΔRef_Clb$_{TL}$ at TL (CLBDLY = REFDLY)
$u_{b,22}$	0.00	0.00	0.00		ΔRef_Clb$_{SG}$ at SG
$u_{b,23}$	0.50	0.50	0.50		the measurement of CABDLY$_{T, TL}$(code) at TL
$u_{b,24}$	0.50	0.50	0.50		the measurement of CABDLY$_{T, SG}$(code) at SG
$u_{b,TOT}$	1.03	1.61	1.11	1.74	Components of equation (6)
$u_{CAL0,SG01}$				1.76	Composed of $u_{a,SG01}$ and $u_{b,TOT}$
$u_{CAL0,SG02}$				1.75	Composed of $u_{a,SG02}$ 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)				
$u_{b,32}$	0.50	0.50	-		REFDLY of SG01/SG02, , did not measure during this campaign
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 SG01/SG02, did not measure during this campaign
$u_{b,INT}$	1.25	1.76	1.11	1.88	Components of equation (7)
$u_{CAL0,SG01}$				1.89	Composed of $u_{a,SG01}$ and $u_{b,INT}$
$u_{CAL0,SG02}$				1.89	Composed of $u_{a,SG02}$ 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:

$$\text{INTDLY}_V(\text{code}) = \text{TOTDLY}_R(\text{code}) - \Delta\text{TOTDLY}_{R\text{-}V}(\text{code}) - \text{CABDLY}_V(\text{code}) + \text{REFDLY}_V(\text{code}) \quad \text{......} (7)$$

Using the $TOTDLY_R$ values reported in 1001-2020 for the Reference system TLT5 and the values $CABDLY_V$, $REFDLY_V$, ΔRef_Clb_{SG} from the information sheet (Annex A), **Table 7.1 and 7.2** then reports $INTDLY_V$ for all visited systems. The uncertainty value u_{cal} for P3 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		TOTDLY/ns		
				C1	P1	P2
TLT5	1001-2020	[1]Feb. 02, 2021		206.1	204.0	202.9
Visited stations	**Cal_Id**	**Date**	**u_{CAL} (P3)/ ns**	**INTDLY/ns**		
				C1	**P1**	**P2**
SG01	1018-2023	Oct. 05, 2023	1.6	25.4	23.1	19.9
SG02	1018-2023	Oct. 05, 2023	1.6	30.5	28.8	25.9

Table 7.2 Summary of final results of GAL link

Reference System	Cal_Id	Date		TOTDLY/ns	
				E1	E5a
TLT5	1001-2020	Feb. 02, 2021		206.3	204.1
Visited stations	**Cal_Id**	**Date**	**u_{CAL} (E3)/ ns**	**INTDLY/ns**	
				E1	**E5a**
SG01	1018-2023	Sep. 27, 2023	1.9	25.7	25.2
SG02	1018-2023	Sep. 27, 2023	1.9	30.8	31.4

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[1] The date performed the calibration id 1001-2020

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	LMR-200 no
Length outside the building /m:	~ 30	~10
● Antenna maker and type: Antenna serial number:	SEPCHOKE_B3E6 SPKE 5303	Hemisphere A45 A45280600336
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	206.7 ns[3]
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:	

[2] The reference cable of TLM2 is connected to the UTC(TL) reference point.
[3] The antenna cables of TLM2 were different when installed at TL and SG

● 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.

A.2 Information sheet of SG01

Information Sheet

Laboratory:	SG
Date and hour of the beginning of measurements:	2023-07-30 00:00:00 UTC
Date and hour of the end of measurements:	2023-08-08 23:59:00 UTC

Information on the system

	Local:	Travelling:
4-character BIPM code	SG01	TLM2
● Receiver maker and type/serial number:	Septentrio PolaRx5TR / S/N: 4701189	Septentrio/PolaRx5TR/ 4701426
1 PPS trigger level /V:	1 V	
● Antenna cable maker/type: Phase stabilized cable (Y/N):	Huber+Suhner RG 213/U	Spuma 400-FR-01+RG-213[4]
Length outside the building /m:	–	~
● Antenna maker and type/serial number:	Leica AR25 / S/N: 726808	HEMA45/**A45/280600336**
Temperature (if stabilized) /°C	N/A	N/A

Measured delays/ns (if needed fill box "Additional Information" below)

	Local:	Travelling:
● Delay from local UTC to receiver 1 PPS-in:	4.96 ns	0 ns[5]
Delay from 1 PPS-in to internal Reference (if different):	N/A	N/A
● Antenna cable delay:	99.3 ns	81.8 ns
Splitter delay (if any):	N/A	N/A
Additional cable delay (if any):	N/A	N/A

Data used for the generation of CGGTTS files

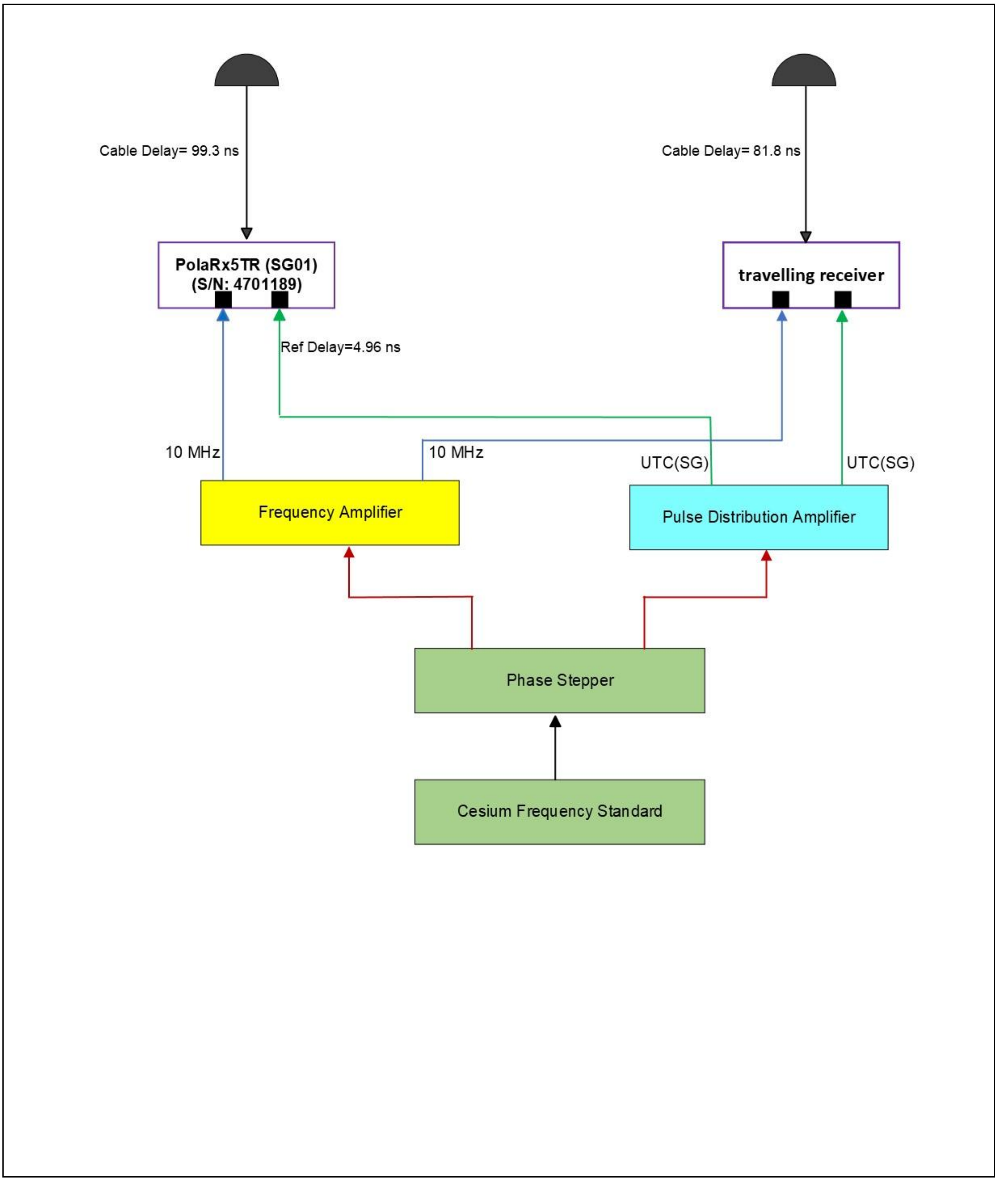
● INT DLY (GPS) /ns:	61.2 ns (P1) / 57.7 ns (P2)
● INT DLY (GLONASS) /ns:	–
● CAB DLY /ns:	99.3 ns
● REF DLY /ns:	5.0 ns
● Coordinates reference frame:	
Latitude or X /m:	-1509599.870 m
Longitude or Y /m:	6195163.060 m
Height or Z /m:	149690.720 m

General information

[4] Used different cable in reference and visited sites
[5] The reference cable of TLM2 is connected to the UTC(SG) reference point.

● Rise time of the local UTC pulse:	1.14 ns
● Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23±2)^{0}C
Set humidity value and uncertainty:	(55 ± 10) % relative humidity

Diagram of the experiment set-up:



A.3 Information sheet of SG02

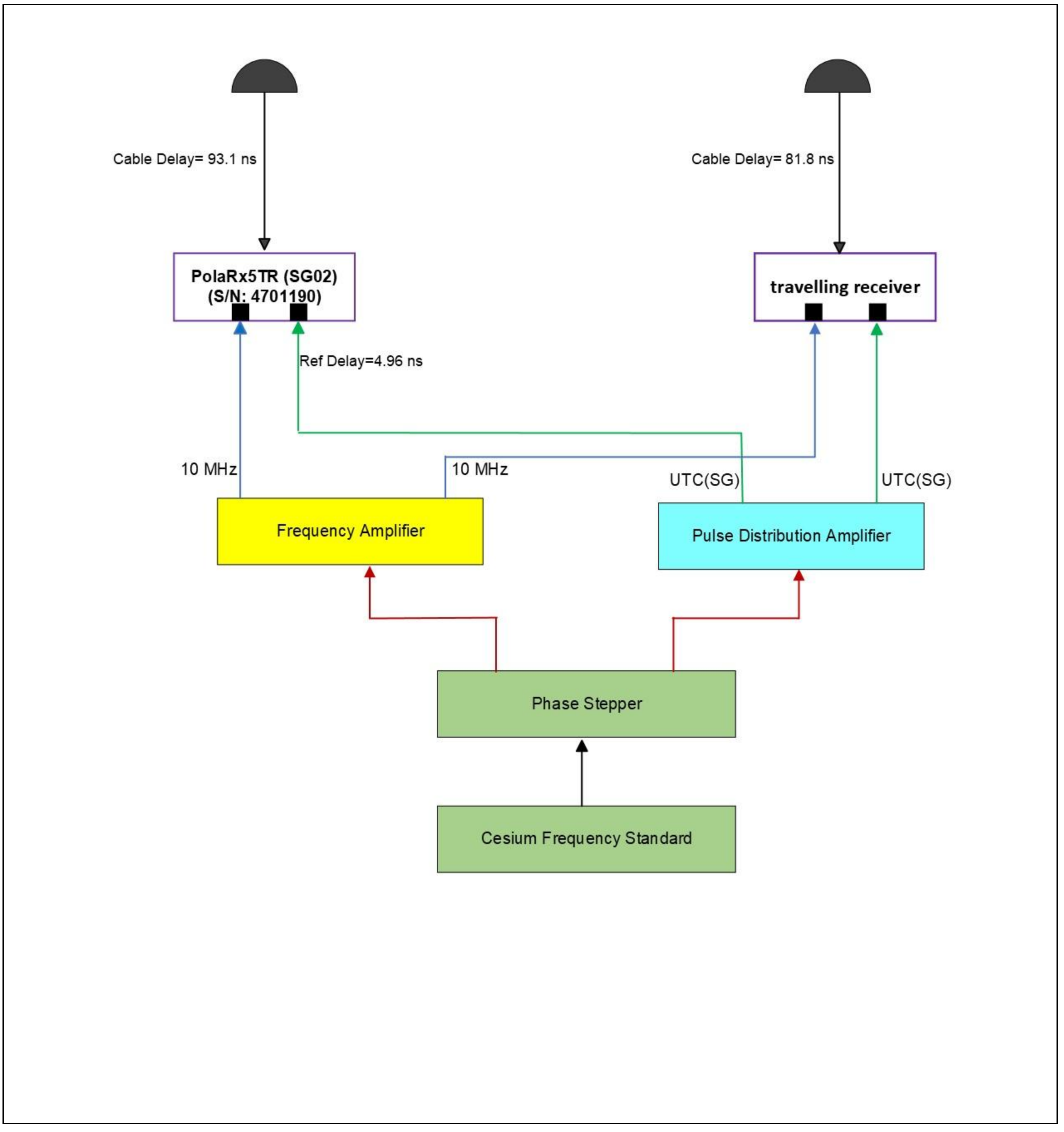
Information Sheet

Laboratory:	SG	
Date and hour of the beginning of measurements:	2023-07-30 00:00:00 UTC	
Date and hour of the end of measurements:	2023-08-08 23:59:00 UTC	
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	SG02	TLM2
● Receiver maker and type/serial number:	Septentrio PolaRx5TR /S/N: 4701190	Septentrio/PolaRx5TR/4701426
1 PPS trigger level /V:	–	
● Antenna cable maker/type: Phase stabilized cable (Y/N):	Huber+Suhner RG 213/U	Spuma 400-FR-01 and an RG-213[6]
Length outside the building /m:	–	~
● Antenna maker and type/serial number:	GNSS-750 / S/N: 09310029	HEMA45/**A45/280600336**
Temperature (if stabilized) /℃	Septentrio PolaRx5TR /S/N: 4701190	N/A
Measured delays/ns (if needed fill box "Additional Information" below)		
	Local:	**Travelling:**
● Delay from local UTC to receiver 1 PPS-in:	4.96 ns	0 ns[7]
Delay from 1 PPS-in to internal Reference (if different):		
● Antenna cable delay:	91.5 ns	81.8 ns
Splitter delay (if any):	N/A	
Additional cable delay (if any):	N/A	
Data used for the generation of CGGTTS files		
● INT DLY (GPS) /ns:	68.6 ns (P1) / 64.3 ns (P2)	
● INT DLY (GLONASS) /ns:	–	
● CAB DLY /ns:	91.5 ns	
● REF DLY /ns:	5.0 ns	
● Coordinates reference frame:		
Latitude or X /m:	-1509598.535 m	
Longitude or Y /m:	6195163.165 m	

[6] Used different cables in reference and visited sites.
[7] the offset between the UTC(NMLS) point and the reference point of the traveling receiver

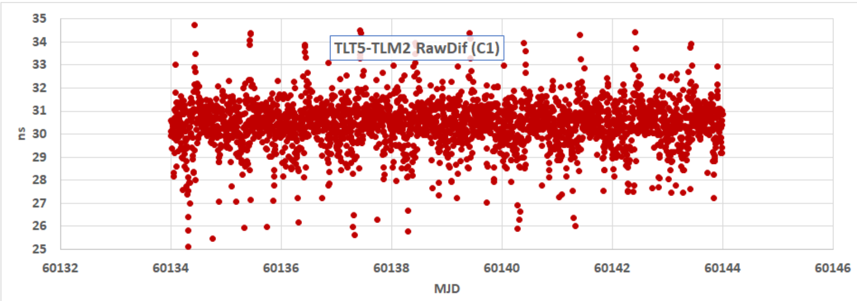
Height or Z /m:	149692.793 m
General information	
● Rise time of the local UTC pulse:	1.14 ns
● Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23±2)^{0}C
Set humidity value and uncertainty:	(55 ± 10) % relative humidity

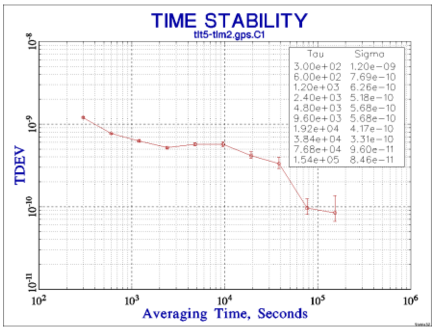
Diagram of the experiment set-up:

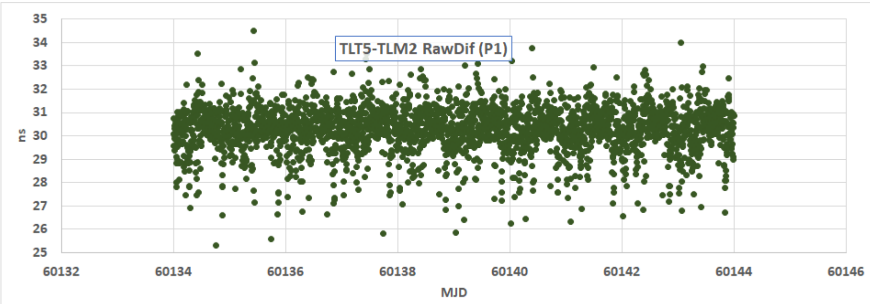


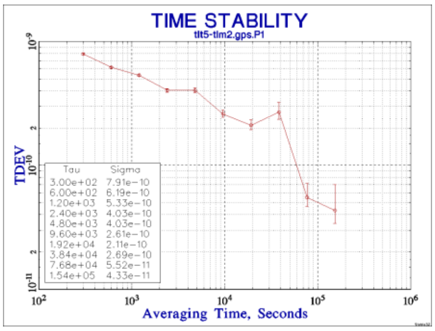
Annex B: Plots of raw data and Tdev analysis

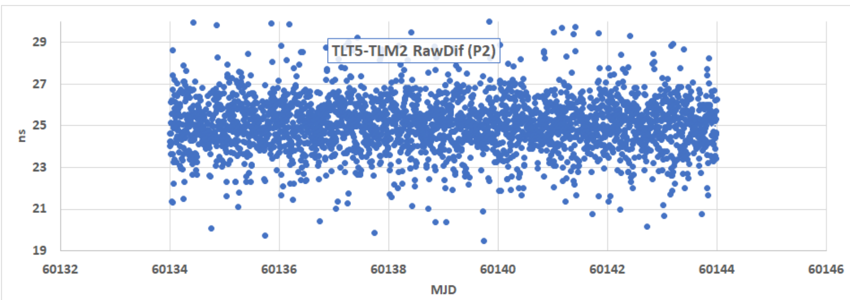
B.1 reference vs. traveling

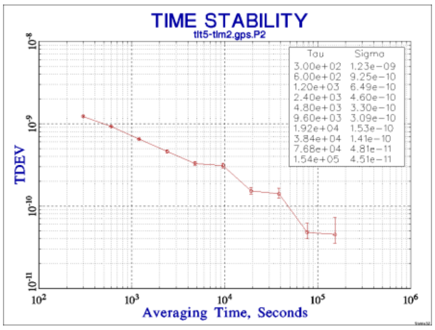


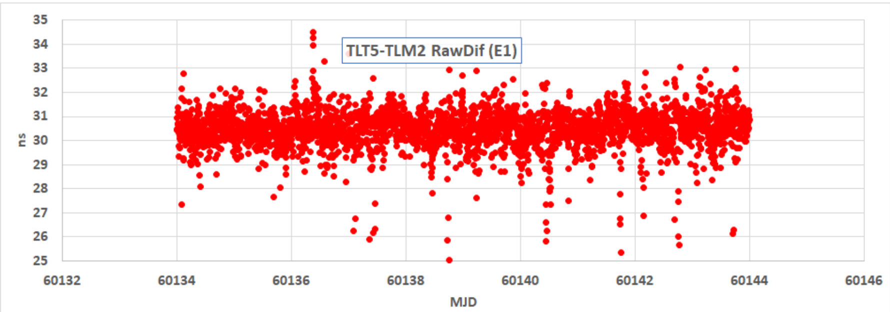


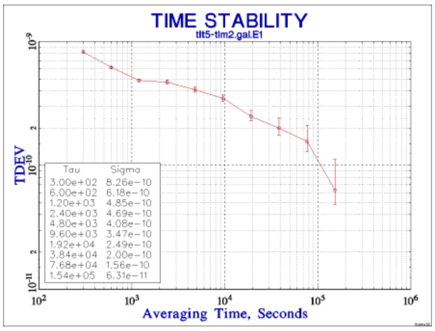


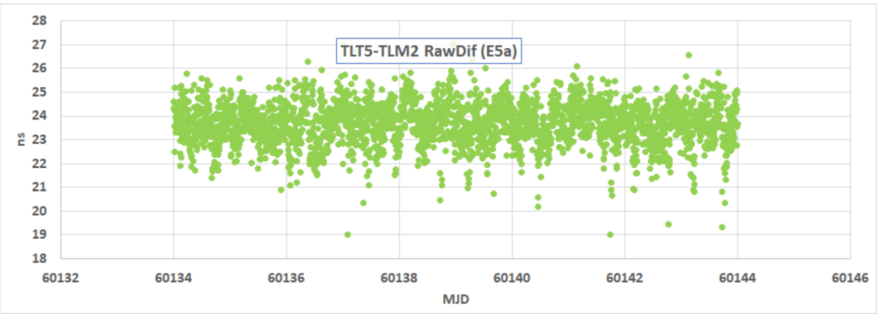


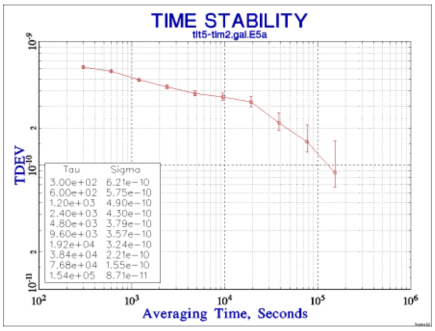




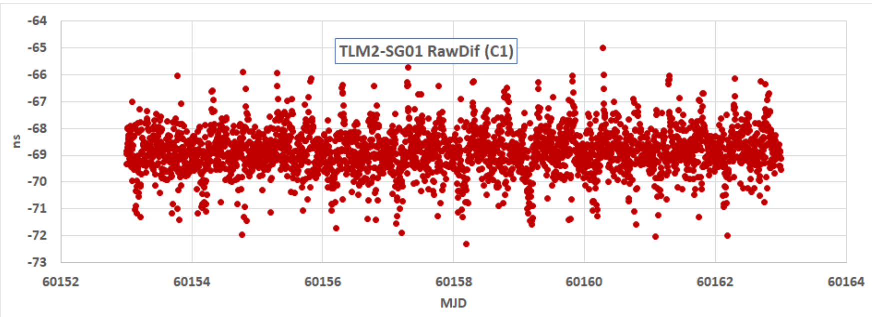


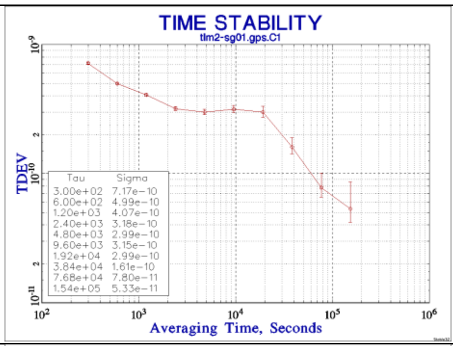


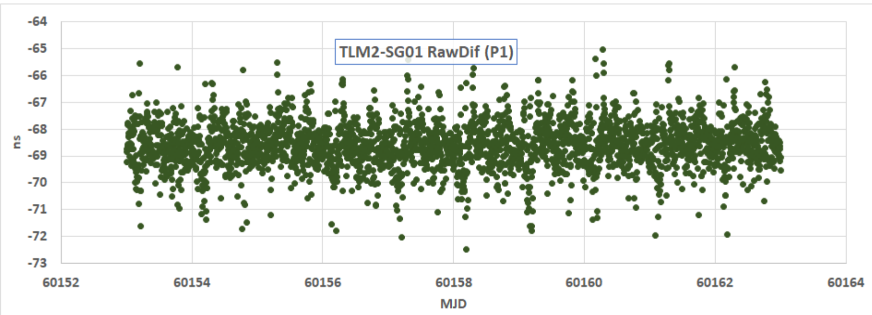


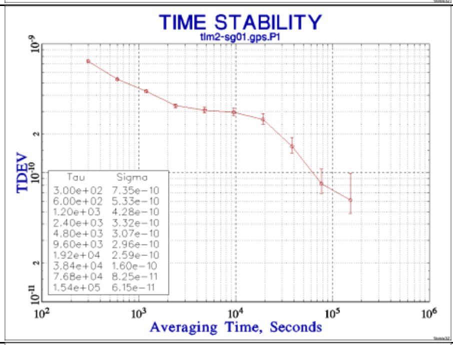


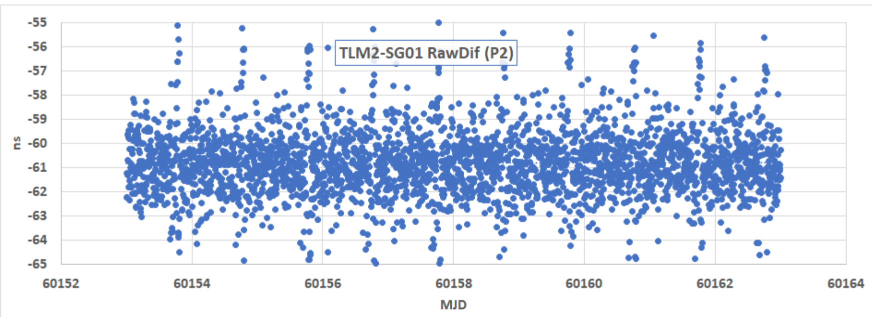
B.2 Traveling vs. visited, SG01

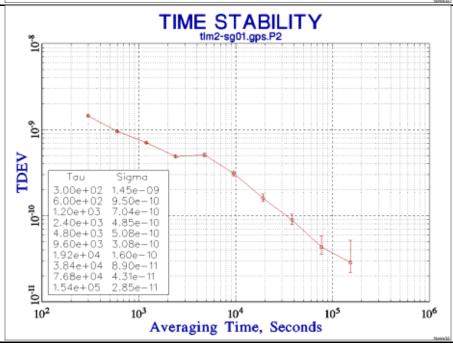


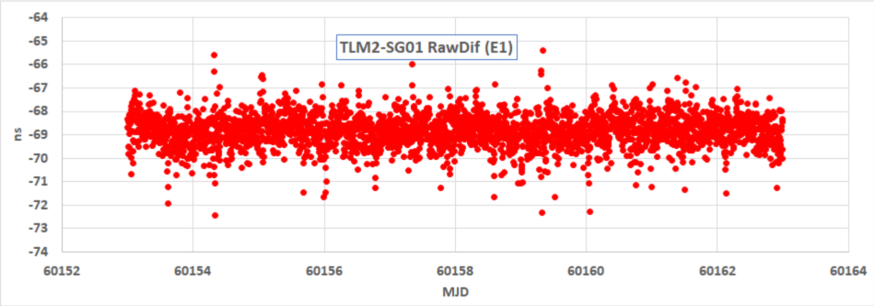


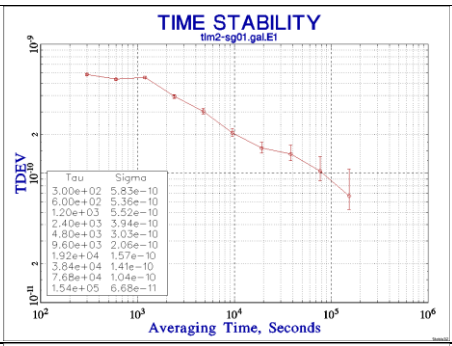


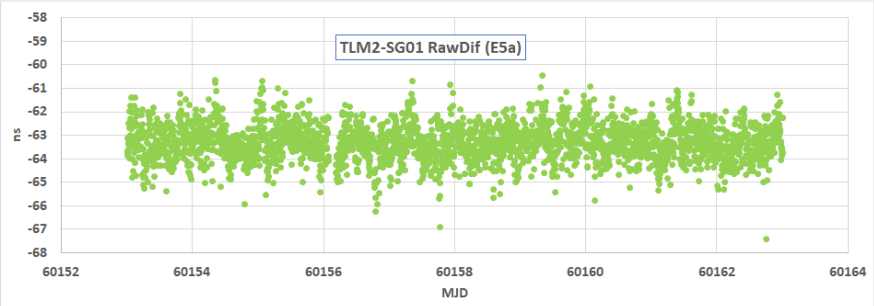


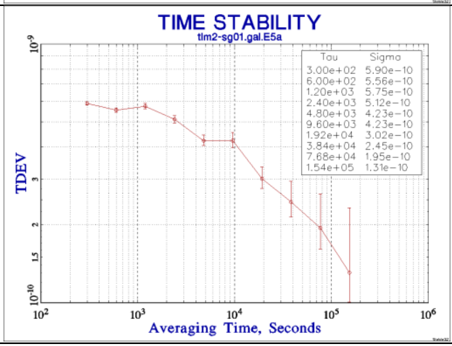




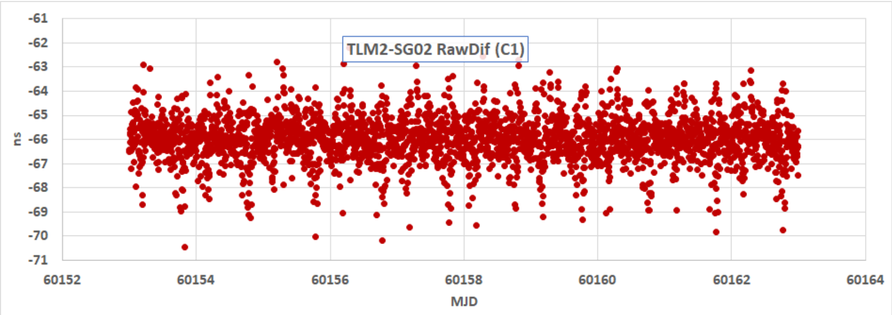


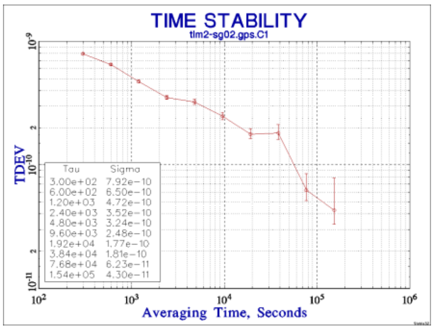


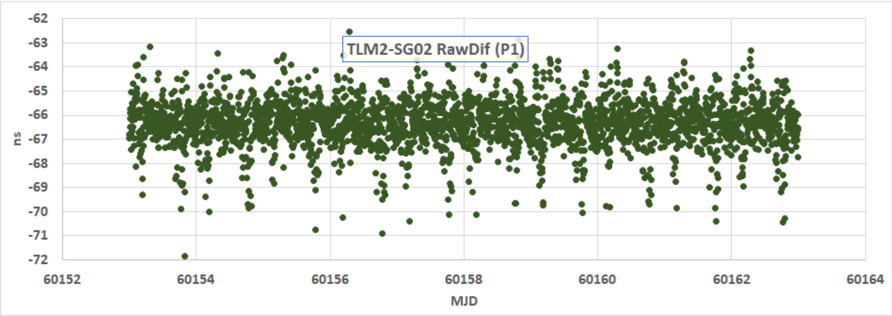


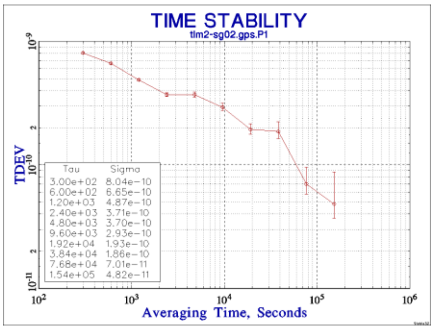


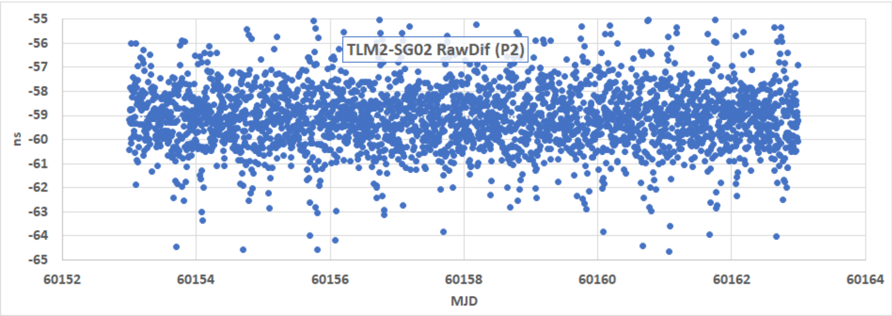
B.3 traveling vs. visited, SG02

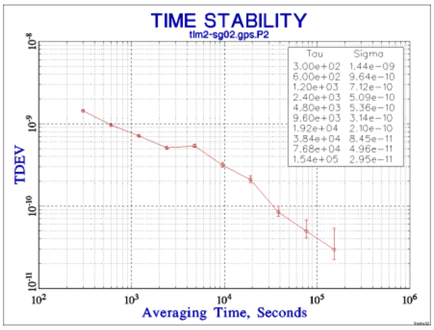


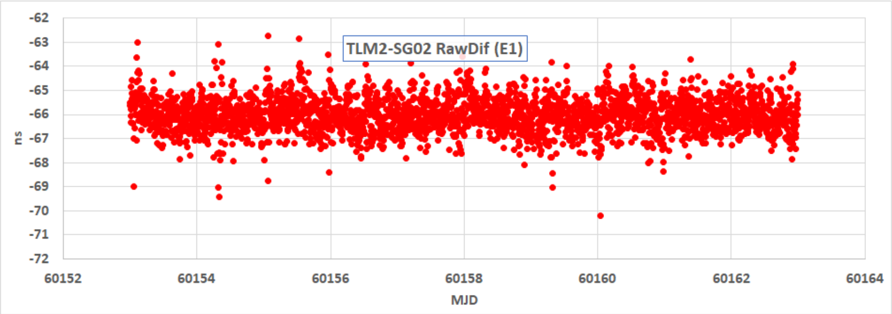


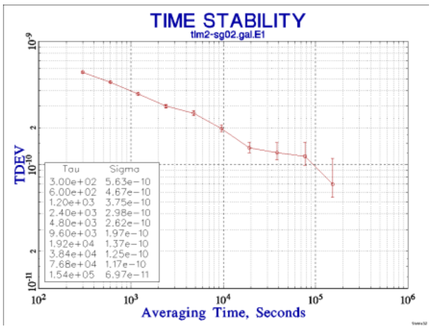


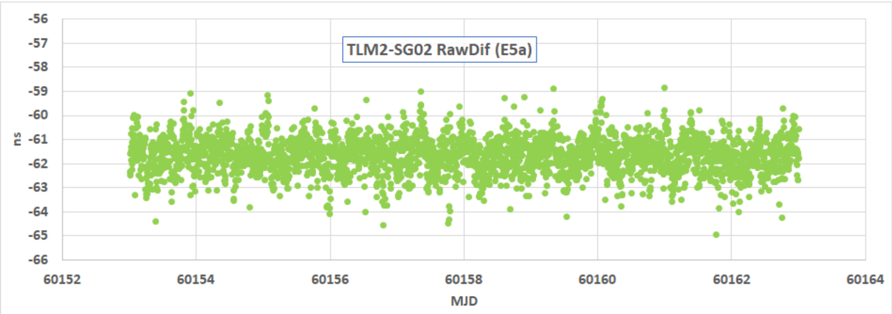


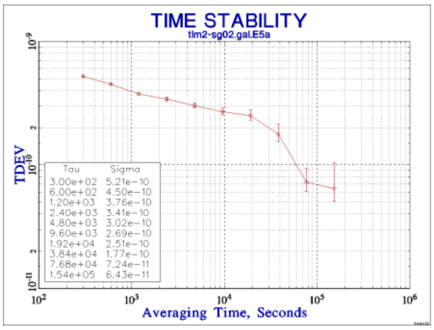




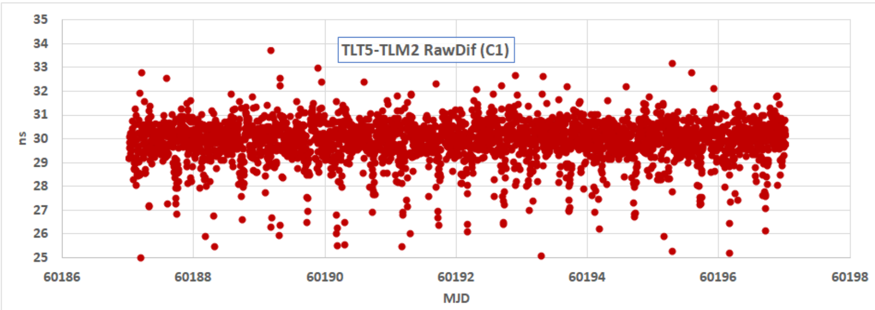


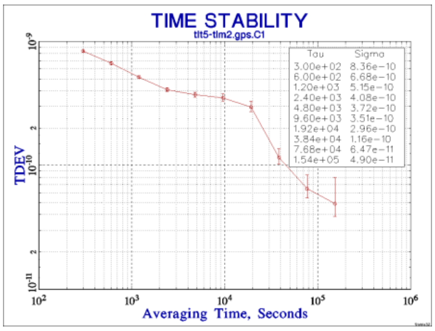


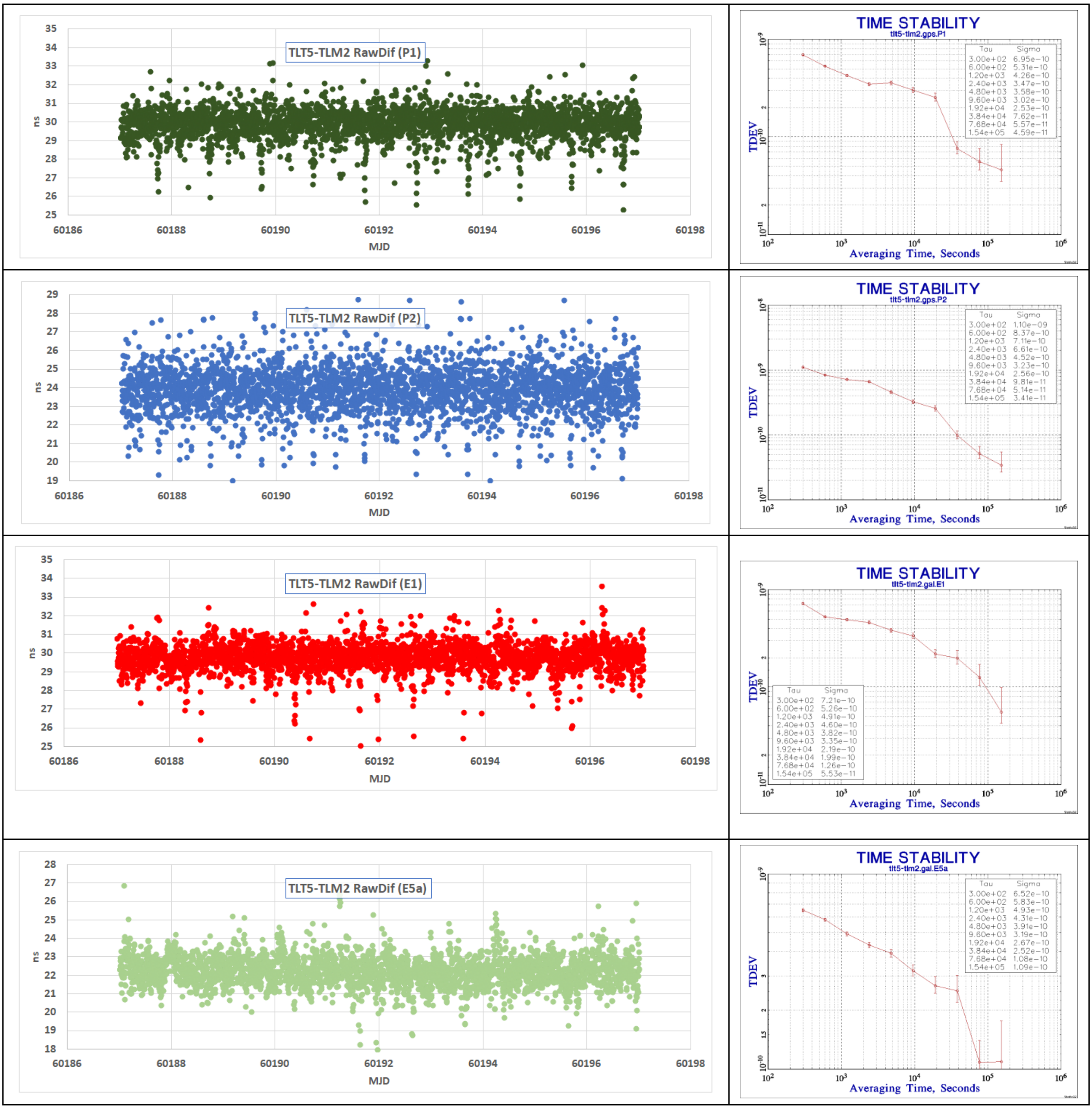




B.4 reference vs. traveling, closure







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[1] BIPM “2020 Group 1 GPS calibration trip”, ftp://ftp2.bipm.fr /pub/tai/publication/gnss-calibration/group1/1001-2020

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

[3] BIPM Calibration-report-MASM&NMC_v2.7.pdf, ftp://ftp2.bipm.fr /pub/tai/publication/gnss-calibration/group2/2018/1019-2018

[4] BIPM guidelines Annex3 “Procedure for computing raw difference of GNSS code measurements for geodetic receivers”, V3.2, 12/07/2021
[5] W. Lewandowski, C. Thomas, 1991, *“GPS Time transfers,”* Proc. IEEE, Vol. 79, No. 7, 991-1000
[6] G. Petit et al. BIPM TM212, Nov. 2012
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[8] W. Lewandowski, C. Thomas, 1991, “GPS Time transfers,” Proc. IEEE, Vol. 79, No. 7, 991-1000
[9] P. Defraigne and G. Petit, “CGGTTS-Version 2E: an extended standard for GNSS time transfer”, Metrologia 52 (2015) G1