Chunghwa Telecom Laboratories

2022 Group 2 GNSS Calibration Report

Cal_ID: 1016-2022

National Time and Frequency Standard 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 NIMT, Thailand 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 1016-2020 [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 MTTI and MTME of NIMT. The data were collected between MJD 59799-59869 (August 8, 2022 - October 17, 2022) by simultaneous operation of a pair of co-located GNSS receivers. This campaign was declared to BIPM on 4th August 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 final results will be reported using Cal_Id 1016-2022.

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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**
GAL	**Galileo satellite navigation system**
PPP	**Precise Point Positioning**
TL	**Telecommunication Laboratories, Chunghwa Telecom, Taiwan**
TLT5	**TL G1 Reference receiver**
TLM2	**TL travelling receiver**
NIMT	**National Institute of Metrology, Thailand**
MTTI	**NIMT visited receiver**
MTME	**NIMT visited receiver**
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 calibration reference point in 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 (Hemisphere A45), 50 meters PEWC/CFD-200/N 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 detail information can be found in the Annex A.1, TLM2 information sheet.

The delay from visited UTC reference point to calibration reference point was measured by TIC HP53132a (SN:MY40002955) provided by NIMT.

1.2 Visited receivers

There were 2 receivers calibrated in this campaign, one is MTTI, a MESIT GTR-55 receiver, its GPS P3 link was calibrated by MESIT/UFE in 2021[3]. Another one is MTME, also a MESIT GTR-55 receiver, its GPS P3 link was also calibrated by MESIT/UFE in 2022 [4]. Both MTTI and MTME would calibrate their GPS P3 link and GAL E3 link in this campaign. The detail information can be found in their information sheets in Annex A.2 and A.3, MTTI and MTME 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	59799-59808	Septentrio PolaRx5 TR	TLM2	TLM2
TL	Group 1 reference	-	Septentrio PolaRx5 TR	TLT5	TLT5

NIMT	Group 2	59838-59847	MESIT GTR-55	MTTI	MTTI
NIMT	Group 2	59838-59847	MESIT GTR-55	MTME	MTME
TL	Traveling	59860-59869	Septentrio PolaRx5 TR	TLM2	TLM2
TL	Group 1 reference	-	Septentrio PolaRx5 TR	TLT5	TLT5

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 [5] dedicated to differential calibration.

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	59799-59808	30.4	0.1	29.9	0.1	25.1	0.1	30.2	0.1	23.3	0.1
TLM2-MTTI	59838-59847	-26.6	0.1	-28.0	0.1	-21.7	0.1	-26.4	0.1	-21.4	0.1
TLM2-MTME	59838-59847	-29.3	0.1	-28.5	0.1	-19.2	0.1	-29.8	0.1	-19.0	0.1
TLT5-TLM2	59860-59869	30.6	0.2	30.0	0.1	24.8	0.1	30.4	0.2	23.2	0.1

CALIBRATION RESULTS

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

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

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 are different. Here we denote the TOTDLY of traveling receiver in reference lab TL to be $TOTDLY_{T,\ TL}$(code) and $TOTDLY_{T,\ NIMT}$(code) in visited lab NIMT.

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_{NIMT} are 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.

We have:

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

$$=SYSDLY_{T}(code) - [CLPDLY_{T}(code) + \Delta Ref\_Clb_{TL}] \qquad \text{…….. (3)}$$

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

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

$$= [SYSDLY_{R}(code) - REFDLY_{R}(code)]$$

$$- [SYSDLY_{T}(code) - CLPDLY_{T}(code) - \Delta Ref\_Clb_{TL}] \qquad \text{…….. (4)}$$

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	59799-59808	30.35	29.94	25.10	4.84
TLT5-TLM2	59860-59869	30.57	30.01	24.82	5.19
Misclosure	-	0.22	0.07	-0.28	0.35
Mean	-	30.46	29.98	24.96	5.02

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

Pair	**Date**	**E1**	**E5a**	**E1-E5a**
		RawDIF	RawDIF	RawDIF
TLT5-TLM2	59799-59808	30.23	23.31	6.92
TLT5-TLM2	59860-59869	30.43	23.20	7.23
Misclosure	-	0.20	-0.11	0.31
Mean	-	30.33	23.26	7.08

Table 3.1 and 3.2 are the raw difference values of traveling vs. reference receiver. We don't need to measure the REFDLY of the traveling and reference receivers because they will be 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 (NIMT) can be expressed:

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

$$[SYSDLY_T(code) - CLPDLY_T(code) - \Delta Ref\_Clb_{NIMT}]$$

$$-[SYSDLY_V(code) - REFDLY_V(code)] \qquad \ldots\ldots (5)$$

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

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

Pair	Date	ΔRef_Clb_{NIMT}	$REFDLY_V$	**L1C**	**L1P**	**L2P**
				RawDIF	RawDIF	RawDIF
TLM2-MTTI	59838-59847	-1.0	23.9	-26.6	-28.0	-21.7
TLM2-MTME	59838-59847	-1.0	24.6	-29.3	-28.5	-19.2

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

Pair	**Date**	ΔRef_Clb_{NIMT}	$REFDLY_V$	**E1**	**E5a**
				RawDIF	RawDIF
TLM2-MTTI	59838-59847	-1.0	23.9	-26.4	-21.4

TLM2-MTME	59838-59847	-1.0	24.6	-29.8	-19.0

1.3 Visited systems with respect to reference system

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

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

$= [SYSDLY_R(code) – REFDLY_R(code)]–[SYSDLY_V(code) – REFDLY_V(code)]$

$+ \Delta Ref\_Clb_{TL} – \Delta Ref\_Clb_{NIMT}$

$= TOTDLY_R(code) – TOTDLY_V(code) + \Delta Ref\_Clb_{TL} – \Delta Ref\_Clb_{NIMT}$

$= \Delta TOTDLY_{R\text{-}V}(code) + \Delta Ref\_Clb_{TL} – \Delta Ref\_Clb_{NIMT}$

or

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

$RAWDIF(code)_{R\text{-}T} + RAWDIF(code)_{T\text{-}V} – \Delta Ref\_Clb_{TL} + \Delta Ref\_Clb_{NIMT}$ …… (6)

In TL, the calibration reference point and the UTC reference point are identical, that is the $\Delta Ref\_Clb_{TL} = 0$. The traveling with respect to the visited system are listed in Table 5.1 and 5.2.

Table 5.1 Traveling with respect to the visited system (GPS, all values in ns)

Pair	Date	ΔRef_Clb_{NIMT}	$\Delta TOTDLY_{R\text{-}V}$		
			C1	**P1**	**P2**
TLT5-MTTI	59838-59847	-1.0	2.86	0.98	2.26
TLT5-MTME	59838-59847	-1.0	0.16	0.48	4.76

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– **Table 5.2** Traveling with respect to the visited system (Galileo, all values in ns)

Pair	Date	ΔRef_Clb_{NIMT}	$\Delta TOTDLY_{R\text{-}V}$	
			E1	**E5a**
TLT5-MTTI	59838-59847	-1.0	2.93	0.86
TLT5-MTME	59838-59847	-1.0	-0.47	3.26

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 $\Delta TOTDLY_{R\text{-}V}$ from Eq. (6). Table 6.1 and 6.2 presents all components of the uncertainty budget along with the uncertainty $u_{b.TOT}$ of $\Delta TOTDLY_{R\text{-}V}$ from equation (6) and the resulting uncertainty value u_{CAL}. The items in Table 6 are separated into several categories.

- $u_{b,1}$ 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[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). The values $u_{b,21}$ = 0.0 ns since the calibration reference point is the UTC(k) reference point in TL.

- $u_{b,31}$ and $u_{b,32}$ accounts for the measurement 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 NIMT, 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 NIMT, it includes at least one measurement with a TIC. We should note the visited station NIMT 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)	0.2	0.1	0.1	0.1		Tdev of RAWDIF of TLT5 vs. TLM2 during MJD 59860-59869
$u_{a,MTTI}$(T-V)	0.1	0.1	0.1	0.1		Tdev of RAWDIF of TLM2 vs. MTTI
$u_{a,MTME}$(T-V)	0.1	0.1	0.1	0.1		Tdev of RAWDIF of TLM2 vs. MTME
$u_{a,MTTI}$	0.2	0.1	0.1	0.2	0.3	
$u_{a,MTME}$	0.2	0.1	0.1	0.2	0.3	
	Misclosure					
$u_{b,1}$	0.2	0.1	0.3	0.4	-	Observed misclosure of TLT5 vs. TLM2
	Systematic components related to RAWDIF					
$u_{b,11}$	0.1	0.1	0.1	0.1	-	Position error at TL
$u_{b,12}$	0.1	0.1	0.1	0.1	-	Position error at NIMT
$u_{b,13}$	0.2	0.2	0.2	0.3	-	Multipath effect at TL
$u_{b,14}$	0.2	0.2	0.2	0.3	-	Multipath effect at NIMT
	Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0	0	0	0.0	-	ΔRef_Clb$_{TL}$ at TL (CLBDLY = REFDLY)
$u_{b,22}$	0.5	0.5	0.5	0.0	-	ΔRef_Clb$_{NIMT}$ at NIMT
$u_{b,TOT}$	0.6	0.6	0.7	0.6	1.1	Components of equation (6)
$u_{CAL0,MTTI}$					1.1	Composed of $u_{a,MTTI}$ and $u_{b,TOT}$
$u_{CAL0,MTME}$					1.1	Composed of $u_{a,MTME}$ 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)					
$u_{b,32}$	0.5	0.5	0.5			REFDLY of MTTI/MTME,
Antenna cable delays						
$u_{b,41}$	0	0	0			TLT5 did not use REFDLY to calculate P3
$u_{b,42}$	0.5	0.5	0.5			CABDLY of MTTI/MTME, did not measure during this campaign
$u_{b,INT}$	0.9	0.9	1.0	0.6	1.3	Components of equation (7)
$u_{CAL0,MTTI}$					1.3	Composed of $u_{a,MTTI}$ and $u_{b,INT}$
$u_{CAL0,MTME}$					1.3	Composed of $u_{a,MTME}$ 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)	0.2	0.1	0.2		Tdev of RAWDIF of TLT5 vs. TLM2 during MJD 59860-59869
$u_{a,MTTI}$(T-V)	0.1	0.1	0.1		Tdev of RAWDIF of TLM2 vs. MTTI
$u_{a,MTME}$(T-V)	0.1	0.1	0.1		Tdev of RAWDIF of TLM2 vs. MTME
$u_{a,MTTI}$	0.2	0.1	0.3	0.4	
$u_{a,MTME}$	0.2	0.1	0.3	0.4	
Misclosure					
$u_{b,1}$	0.2	0.1	0.3	-	Observed mis-closure of TLT5 vs. TLM2
Systematic components related to RAWDIF					
$u_{b,11}$	0.1	0.1	0.1	-	Position error at TL
$u_{b,12}$	0.1	0.1	0.1	-	Position error at NIMT
$u_{b,13}$	0.2	0.2	0.3	-	Multipath effect at TL
$u_{b,14}$	0.2	0.2	0.3	-	Multipath effect at NIMT
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0	0	-	-	ΔRef_Clb$_{TL}$ at TL (CLBDLY = REFDLY)
$u_{b,22}$	0.5	0.5	-	-	ΔRef_Clb$_{NIMT}$ at NIMT
$u_{b,TOT}$	0.6	0.6	0.5	0.9	Components of equation (6)
$u_{CAL0,MTTI}$				1.0	Composed of $u_{a,MTTI}$ and $u_{b,TOT}$
$u_{CAL0,MTME}$				1.0	Composed of $u_{a,MTME}$ 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 P3
	Link of the Visited system to its local UTC(k)				
$u_{b,32}$	0.5	0.5	-		REFDLY of MTTI/MTME

Antenna cable delays					
$u_{b,41}$	0	0	-		TLT5 did not use REFDLY to calculate P3
$u_{b,42}$	0.5	0.5	-		CABDLY of MTTI/MTME, did not measure during this campaign
$u_{b,INT}$	0.9	0.9	0.5	1.1	Components of equation (7)
$u_{CAL0,MTTI}$				1.2	Composed of $u_{a,MTTI}$ and $u_{b,INT}$
$u_{CAL0,MTME}$				1.2	Composed of $u_{a,MTME}$ and $u_{b,INT}$

5. The 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:

$$INTDLY_V(code)$$

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

Using the $TOTDLY_R$ values reported in 1001-2020 for the Reference system TLT5 and the values $CABDLY_V$, $REFDLY_V$, ΔRef_Clb_{NIMT} 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 and E3 are 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 the 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

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

Visited stations	Cal_Id	Date	u_{CAL} (P3)/ ns	INTDLY/ns		
				C1	P1	P2
MTTI	1016-2022	Oct. 30, 2022	1.3	12.4	12.2	9.8
MTME	1016-2022	Oct. 30, 2022	1.3	16.0	13.6	8.2

Table 7.2 Summary of the 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**
MTTI	1016-2022	Oct. 30, 2022	1.2	12.6	12.4
MTME	1016-2022	Oct. 30, 2022	1.2	16.9	10.9

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ANNEXES

Annex A: Information sheets

A.1 Information sheet of TLM2

Laboratory: TL	
Date and hour of the beginning of measurements:	2022-08-08 00:00:00 UTC
Date and hour of the end of measurements:	2020-10-17 23:59:00 UTC

Information on the system

	Local:	Travelling:
4-character BIPM code	TLT5	TLM2
● Receiver maker and type:	Septentrio PolaRx5TR	Septentrio PolaRx5TR
Receiver serial number:	3227923	3228270
1 PPS trigger level /V:	1 V	1 V
● Antenna cable maker and type:	Andrew FSJ	PEWC/CFD-200/N
Phase stabilised cable (Y/N):	yes	
Length outside the building /m:	~ 35	50
● Antenna maker and type:	SEPCHOKE_B3E6 SPKE	Hemisphere A45
Antenna serial number:	5303	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	(1)
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:	–

[2] The 1 PPS reference cable of TLM2 is connected to the UTC(TL) reference point.

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 MTTI

Information Sheet

Laboratory:	National Institute of Metrology Thailand (NIMT)
Date and hour of the beginning of measurements:	12 September 2022 6:39:30 UTC
Date and hour of the end of measurements:	26 September 2022 24:00:00 UTC

Information on the system

	Local:	**Travelling:**
4-character BIPM code	MTTI	TLM2
● Receiver maker and type/serial number:	MESIT/GTR55/ MTTI SN 2010010	Septentrio/PolaRx5TR/3228270
1 PPS trigger level /V:	1 V	
● Antenna cable maker/type: Phase stabilized cable(Y/N):	Belden/H155PE/N	PEWC/CFD-200/N
Length outside the building /m:	50 m	50 m
● Antenna maker and type/serial number:	NOV850 NONE/NMLK20420007H	HEMA45/**A45/280600336**
Temperature (if stabilized) /℃		

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

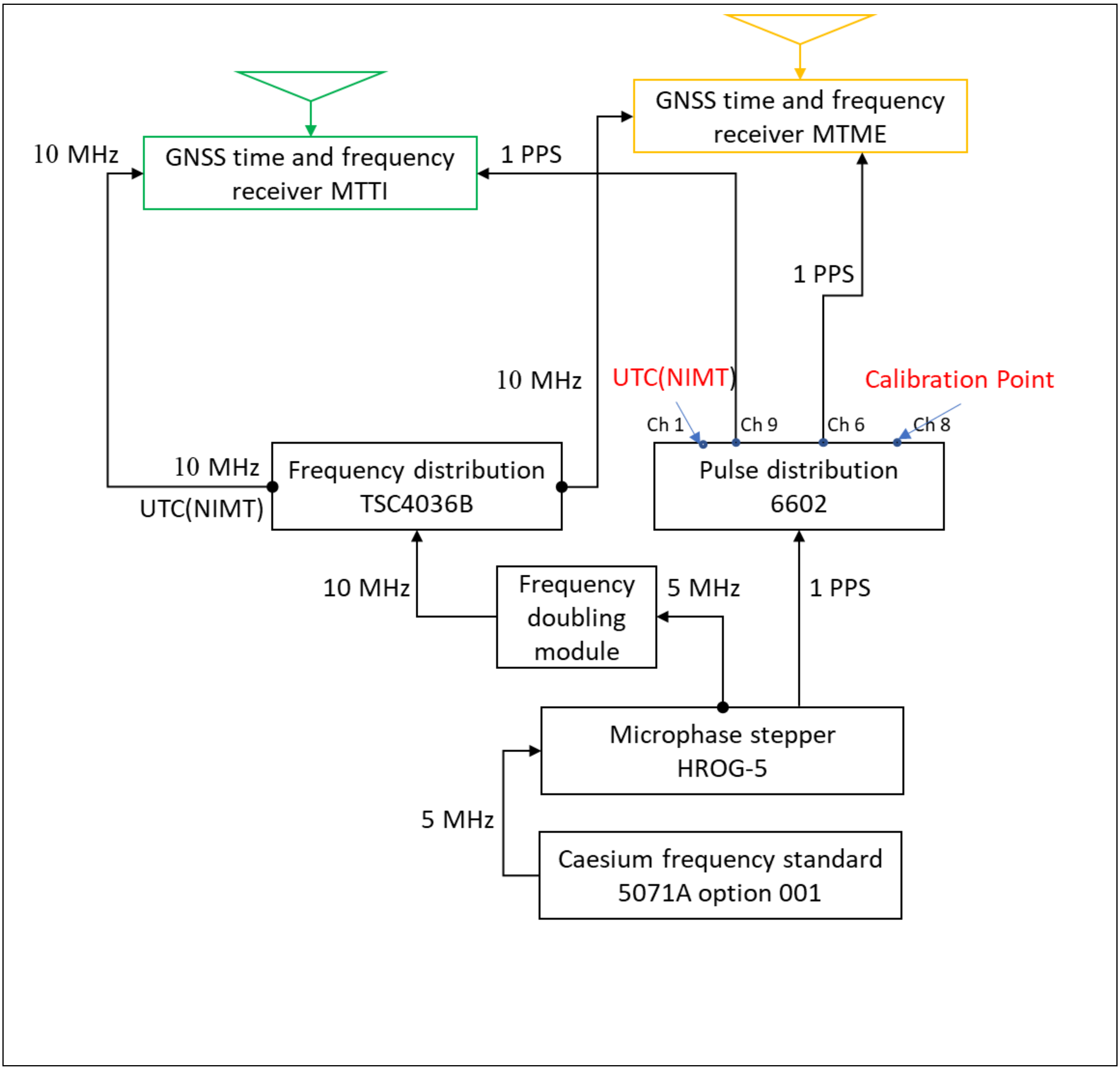
	Local:	**Travelling:**
● Delay from local UTC to receiver 1PPS-in:	23.9 ns	
● Delay from local UTC to calibration point	-	-1.0 ns
Delay from 1 PPS-in to internal Reference (if different):	-	-
● Antenna cable delay:	214.7 ns	
Splitter delay (if any):	-	
Additional cable delay (if any):		

Data used for the generation of CGGTTS files

● INT DLY (GPS)/ns:	13.70 (GPS P1), 10.0 ns (GPS P2)
● INT DLY (GLONASS)/ns:	-
● CAB DLY/ns:	214.7

● REF DLY/ns:	25.5
● Coordinates reference frame:	ITRF2014 epoch t0 = 2013.84
Latitude or X /m:	-1150479.26
Longitude or Y /m:	+6080855.36
Height or Z /m:	+1537596.57
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

Diagram of the experiment set-up:


GNSS time and frequency receiver MTME
10 MHz
GNSS time and frequency receiver MTTI
1 PPS
1 PPS
10 MHz
UTC(NIMT)
Calibration Point
Ch 1
Ch 9
Ch 6
Ch 8
10 MHz
Frequency distribution TSC4036B
UTC(NIMT)
Pulse distribution 6602
10 MHz
Frequency doubling module
5 MHz
1 PPS
Microphase stepper HROG-5
5 MHz
Caesium frequency standard 5071A option 001

A.3 Information sheet of MTME

Information Sheet

Laboratory:	National Institute of Metrology Thailand (NIMT)
Date and hour of the beginning of measurements:	12 September 2022 6:39:30 UTC
Date and hour of the end of measurements:	26 September 2022 24:00:00 UTC

Information on the system

	Local:	Travelling:
4-character BIPM code	MTME	TLM2
● Receiver maker and type/serial number:	MESIT/GTR55/2202002	Septentrio/PolaRx5TR/3228270
1 PPS trigger level /V:	1 V	
● Antenna cable maker/type: Phase stabilized cable(Y/N):	Belden/H155PE/N	PEWC/CFD-200/N
Length outside the building /m:	50 m	50 m
● Antenna maker and type/serial number:	NOV850 NONE/NMLK21430018S	HEMA45/**A45/280600336**
Temperature (if stabilized) /°C		

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

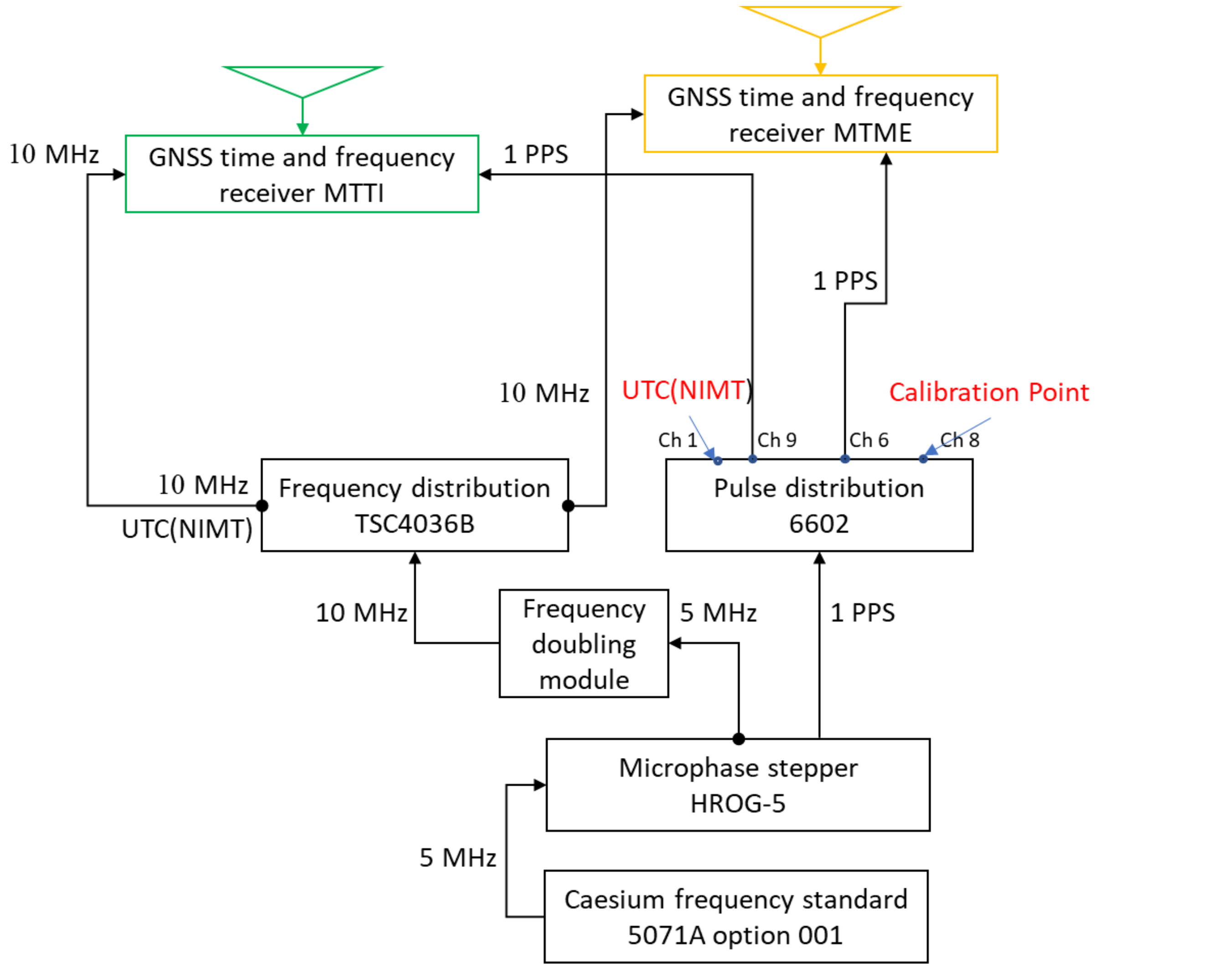
	Local:	Travelling:
● Delay from local UTC to receiver 1PPS-in:	24.6 ns	
● Delay from local UTC to calibration point	-	-1.0 ns
Delay from 1 PPS-in to internal Reference (if different):	-	-
● Antenna cable delay:	214.5 ns	
Splitter delay (if any):	-	
Additional cable delay (if any):		

Data used for the generation of CGGTTS files

● INT DLY (GPS)/ns:	15.70 (GPS P1), 9.2 ns (GPS P2)
● INT DLY (GLONASS)/ns:	-
● CAB DLY/ns:	214.5
● REF DLY/ns:	25.5

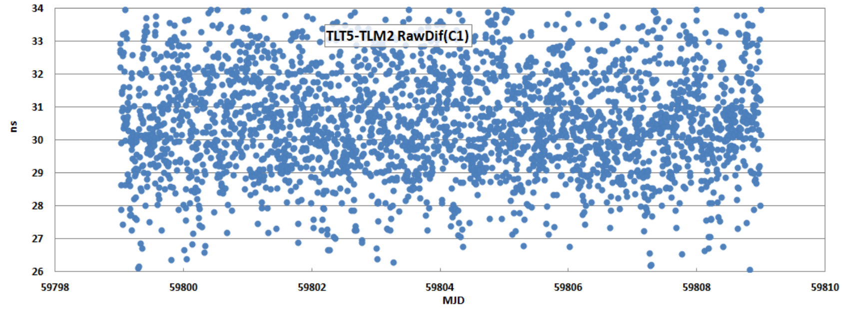
● Coordinates reference frame:	ITRF2014epoch t0 = 2013.84
Latitude or X /m:	-1150480.80
Longitude or Y /m:	+6080861.40
Height or Z /m:	+1537595.90
General information	
● Rise time of the local UTC pulse:	2 ns
● Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23.0 ± 2.0) °C
Set humidity value and uncertainty:	(50 ± 15) %.RH

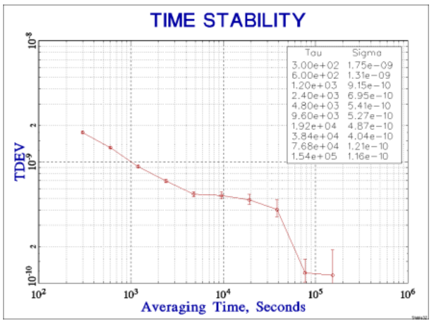
Diagram of the experiment set-up:

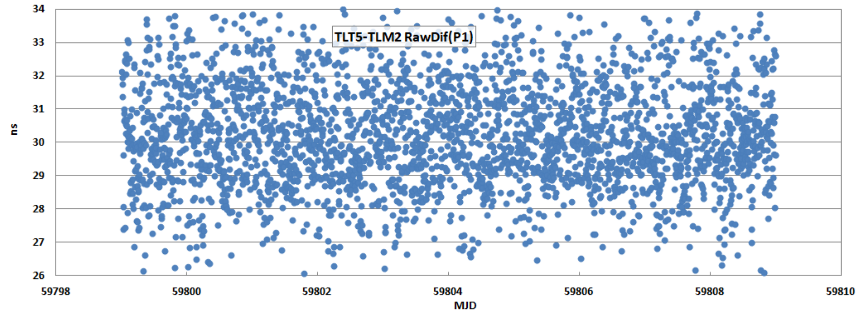

GNSS time and frequency receiver MTME
10 MHz
GNSS time and frequency receiver MTTI
1 PPS
1 PPS
10 MHz
UTC(NIMT)
Calibration Point
Ch 1
Ch 9
Ch 6
Ch 8
10 MHz
UTC(NIMT)
Frequency distribution TSC4036B
Pulse distribution 6602
10 MHz
Frequency doubling module
5 MHz
1 PPS
Microphase stepper HROG-5
5 MHz
Caesium frequency standard 5071A option 001

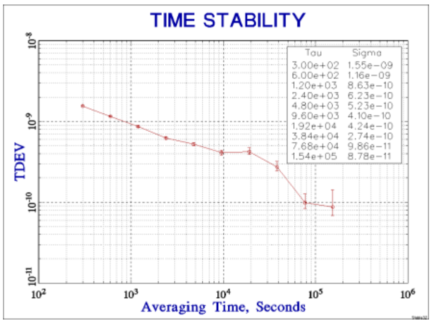
Annex B: Plots of raw data and Tdev analysis

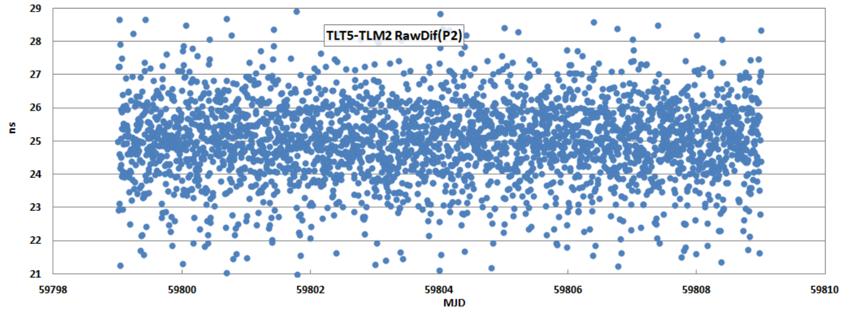
B.1 reference vs. traveling

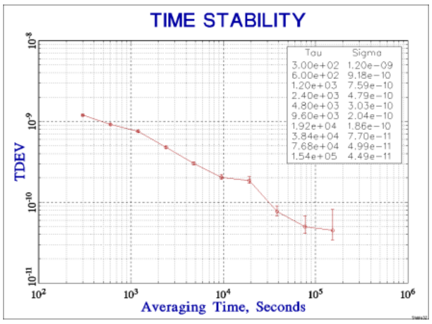


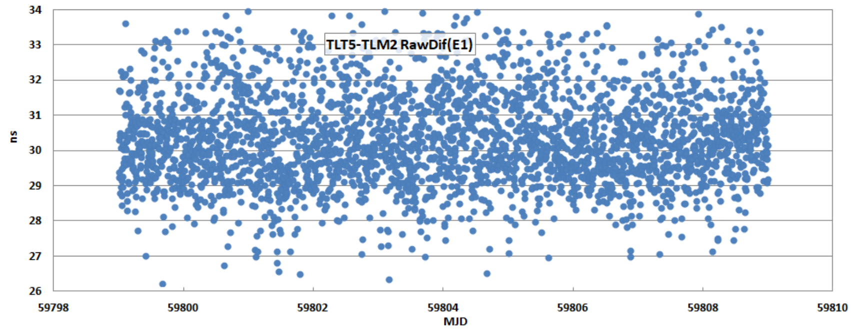


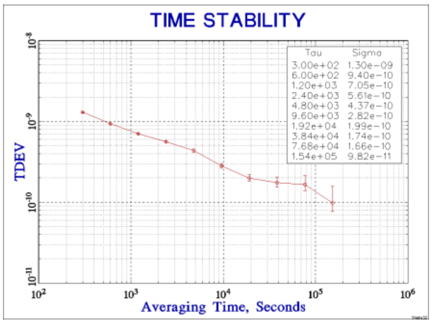


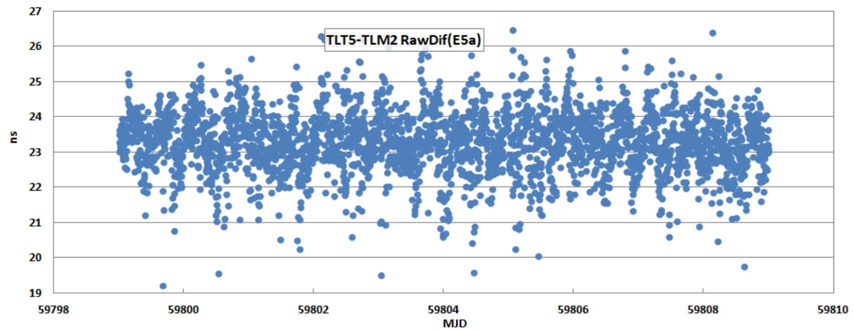


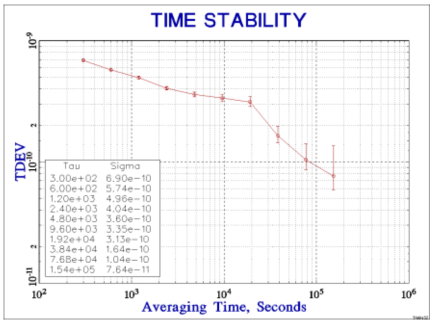




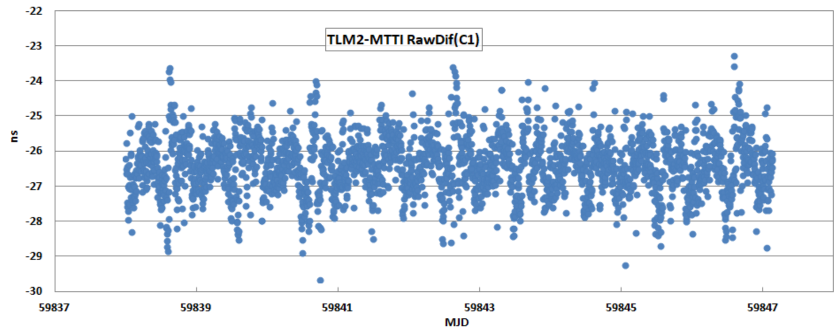


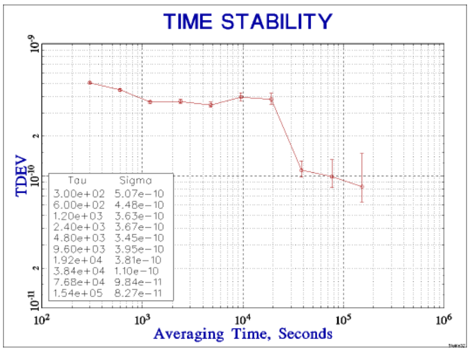


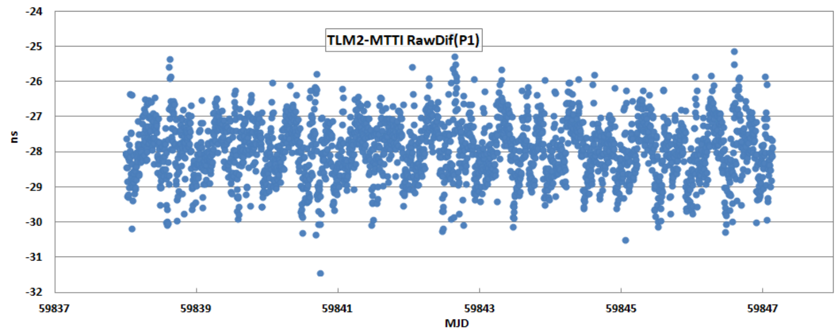


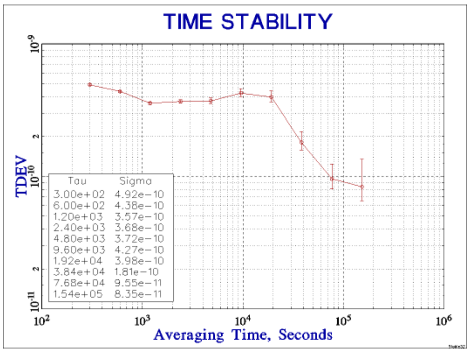


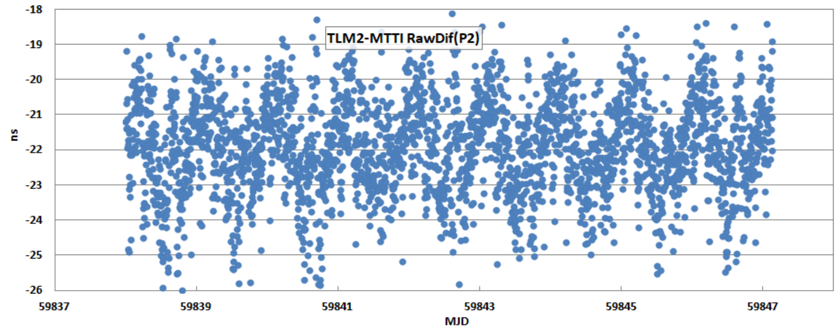
B.2 Traveling vs. visited, MTTI

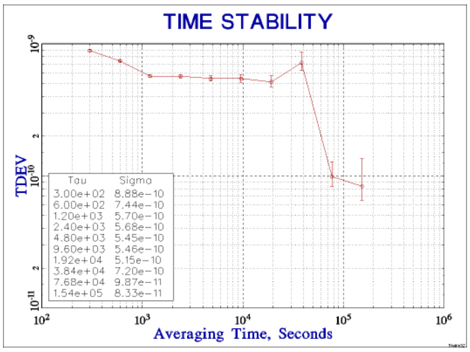


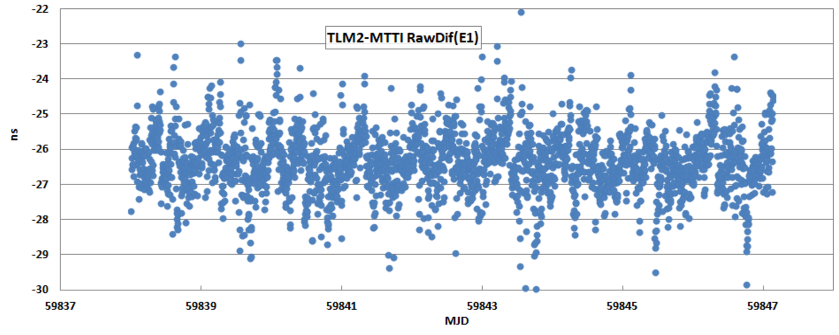


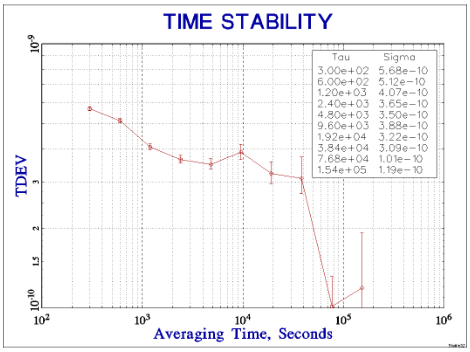


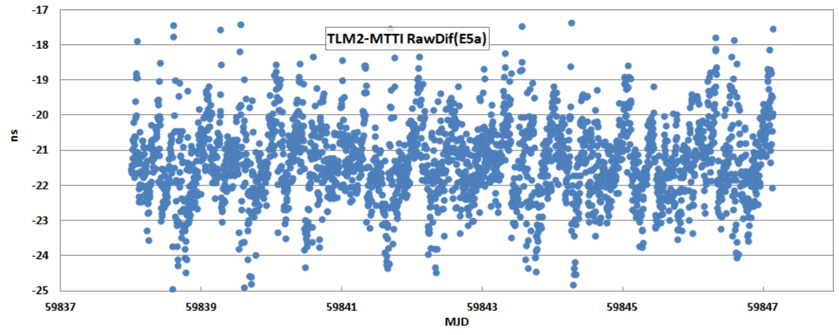


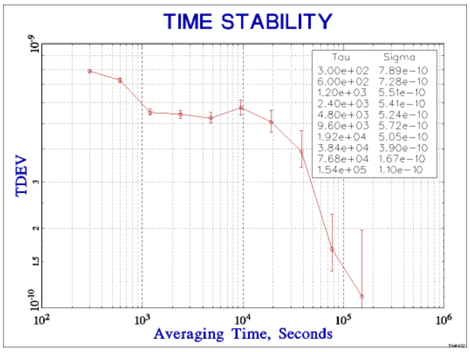

TLM2-MTTI RawDif(P2)
ns
MJD
-18
-19
-20
-21
-22
-23
-24
-25
-26
59837
59839
59841
59843
59845
59847


TIME STABILITY
TDEV
Averaging Time, Seconds
Tau Sigma
3.00e+02 8.88e−10
6.00e+02 7.44e−10
1.20e+03 5.70e−10
2.40e+03 5.68e−10
4.80e+03 5.45e−10
9.60e+03 5.46e−10
1.92e+04 5.15e−10
3.84e+04 7.20e−10
7.68e+04 9.87e−11
1.54e+05 8.33e−11

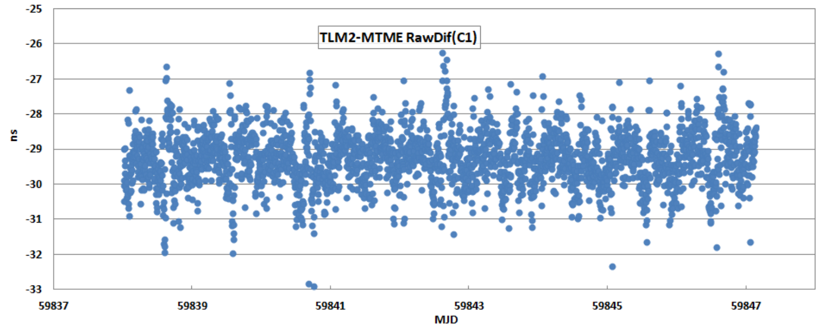

TLM2-MTTI RawDif(E1)
ns
MJD
-22
-23
-24
-25
-26
-27
-28
-29
-30
59837
59839
59841
59843
59845
59847

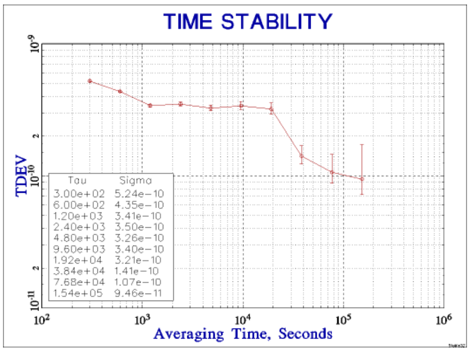

TIME STABILITY
TDEV
Averaging Time, Seconds
Tau Sigma
3.00e+02 5.68e−10
6.00e+02 5.12e−10
1.20e+03 4.07e−10
2.40e+03 3.65e−10
4.80e+03 3.50e−10
9.60e+03 3.88e−10
1.92e+04 3.22e−10
3.84e+04 3.09e−10
7.68e+04 1.01e−10
1.54e+05 1.19e−10

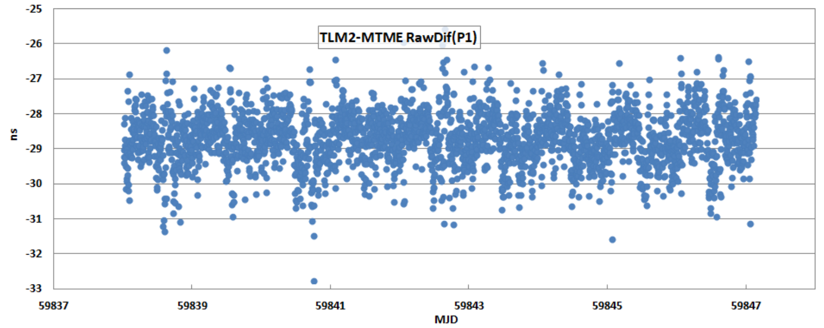

TLM2-MTTI RawDif(E5a)
ns
MJD
-17
-18
-19
-20
-21
-22
-23
-24
-25
59837
59839
59841
59843
59845
59847

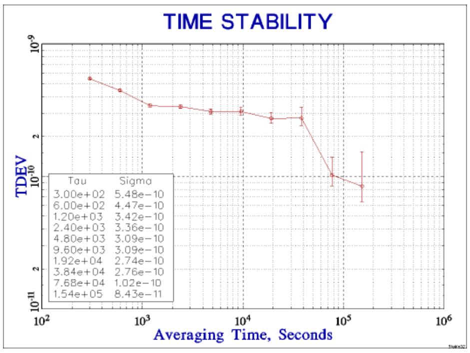

TIME STABILITY
TDEV
Averaging Time, Seconds
Tau Sigma
3.00e+02 7.89e−10
6.00e+02 7.28e−10
1.20e+03 5.51e−10
2.40e+03 5.41e−10
4.80e+03 5.24e−10
9.60e+03 5.72e−10
1.92e+04 5.05e−10
3.84e+04 3.90e−10
7.68e+04 1.67e−10
1.54e+05 1.10e−10

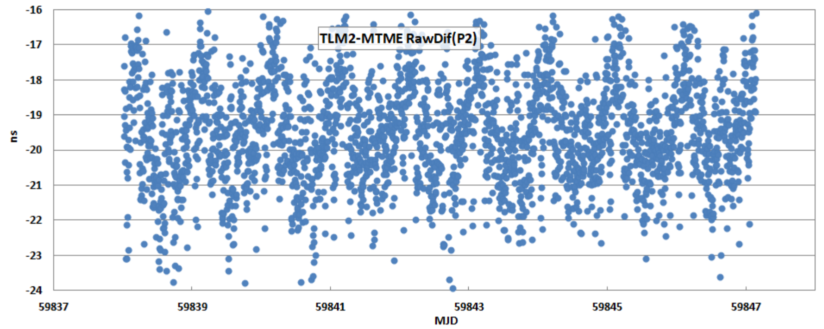
B.3 traveling vs. visited, MTME

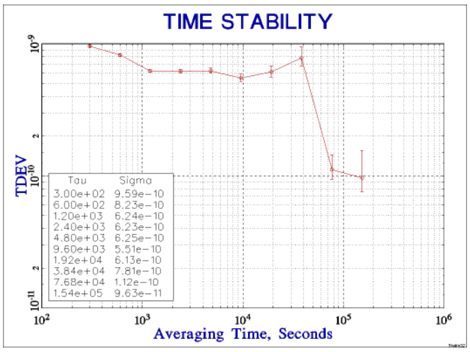


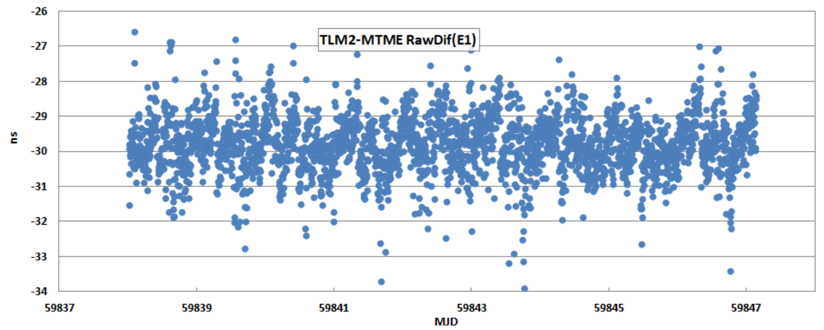


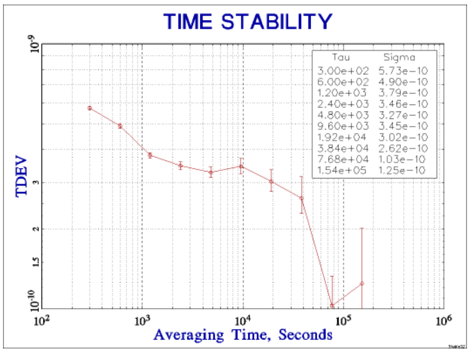


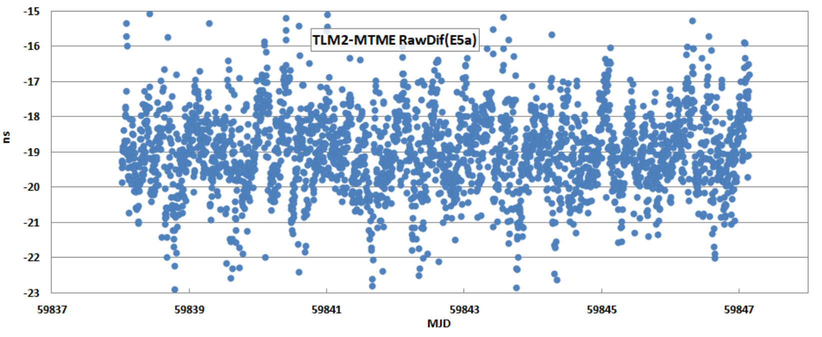


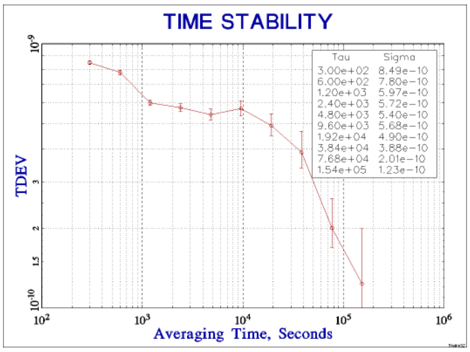




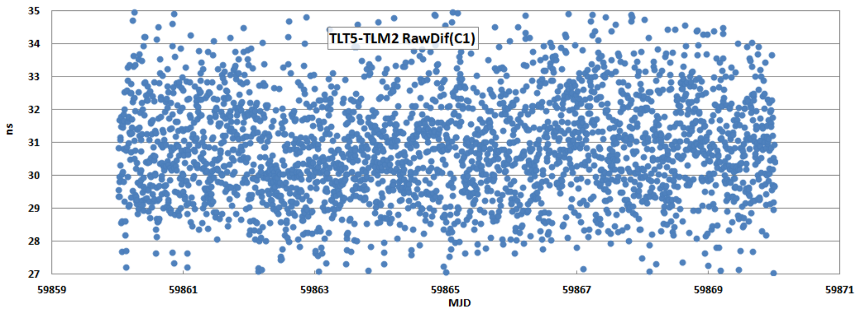


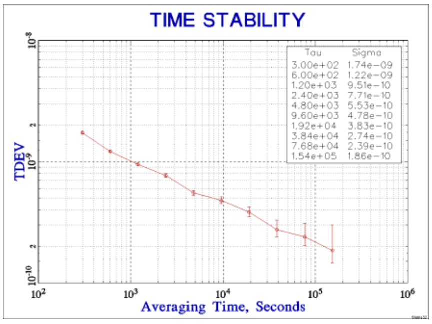


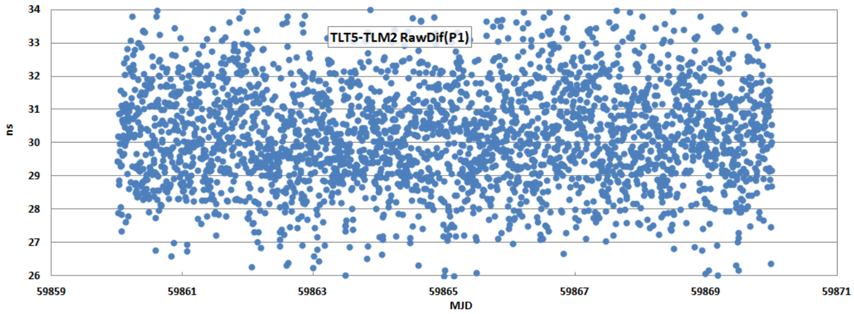


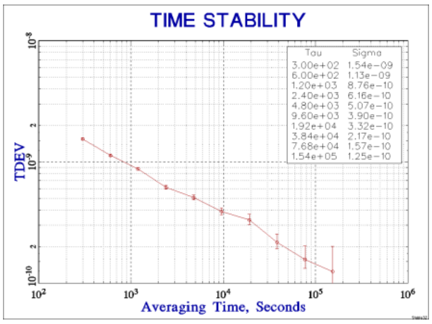


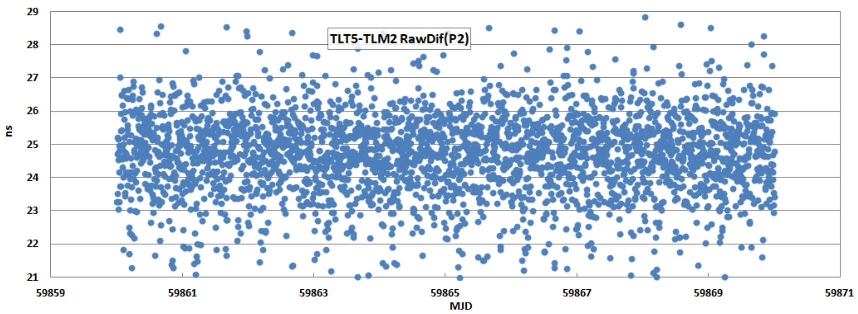
B.4 reference vs. traveling, closure

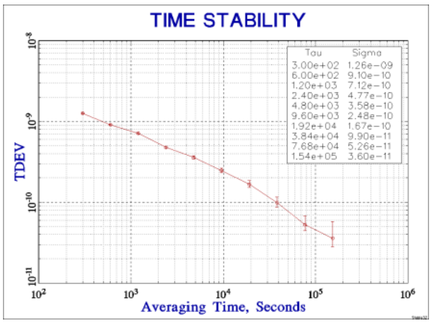


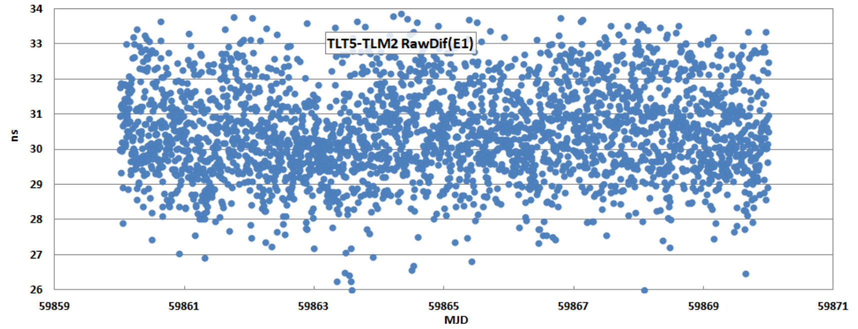


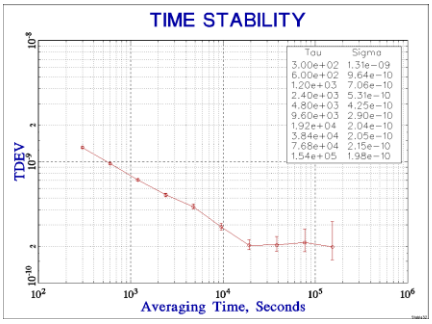


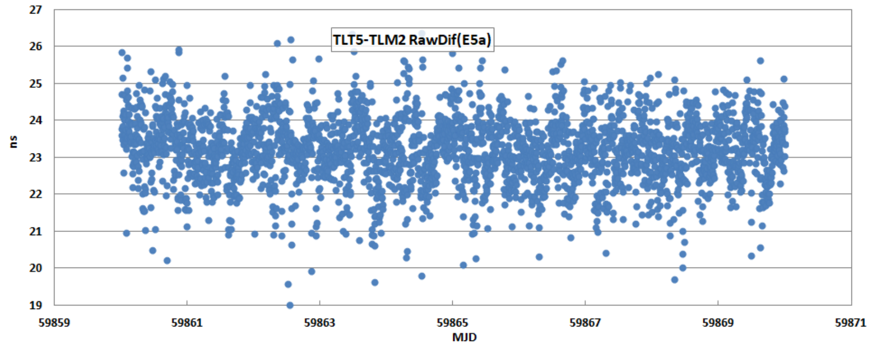


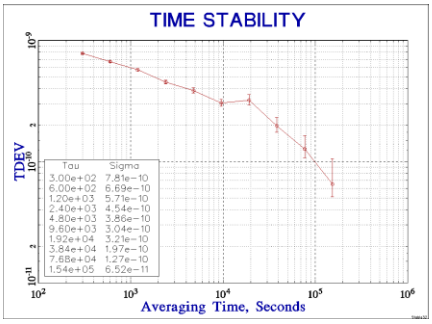





TLT5-TLM2 RawDif(E1)
ns
MJD
34
33
32
31
30
29
28
27
26
59859
59861
59863
59865
59867
59869
59871


TIME STABILITY
TDEV
Averaging Time, Seconds
Tau Sigma
3.00e+02 1.31e−09
6.00e+02 9.64e−10
1.20e+03 7.06e−10
2.40e+03 5.31e−10
4.80e+03 4.25e−10
9.60e+03 2.90e−10
1.92e+04 2.04e−10
3.84e+04 2.05e−10
7.68e+04 2.15e−10
1.54e+05 1.98e−10


TLT5-TLM2 RawDif(E5a)
ns
MJD
27
26
25
24
23
22
21
20
19
59859
59861
59863
59865
59867
59869
59871


TIME STABILITY
TDEV
Averaging Time, Seconds
Tau Sigma
3.00e+02 7.81e−10
6.00e+02 6.69e−10
1.20e+03 5.71e−10
2.40e+03 4.54e−10
4.80e+03 3.86e−10
9.60e+03 3.04e−10
1.92e+04 3.21e−10
3.84e+04 1.97e−10
7.68e+04 1.27e−10
1.54e+05 6.52e−11

Reference

[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] Calibration report No 2001-2021/UFE, Institute of Photonics and Electronics of the Czech Academy of Sciences, Czech Republic.

[4] Calibration report No 2003-2022/UFE, Institute of Photonics and Electronics of the Czech Academy of Sciences, Czech Republic.

[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