



**Chunghwa Telecom Laboratories**

# **2023 Group 2 GNSS Calibration Report**

## **Cal\_ID: 1011-2023**

**National Standard Time and Frequency Lab**  
**Telecommunication Laboratories, Chunghwa Telecom Co., Ltd.**

Calvin Shinn-Yan Lin and Wen-Hung Tseng

sylin@cht.com.tw

05/06/2023 Version 1 (new)

## Summary

As one of the APMP G1 laboratories, TL conducted a relative calibration of the GNSS time transfer receivers of NMIM (National Metrology Institute of Malaysia, which acronyms listed in BIPM acronyms table is NMLS), Malaysia 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 LSM1 and LSM2 of NMLS. The data were collected between MJD 60006-60066 (3<sup>rd</sup> March 2023 – 2<sup>nd</sup> May 2022) by simultaneous operation of a pair of co-located GNSS receivers. This campaign was declared to BIPM on 6<sup>th</sup> 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 1011-2023.

### 1. Table of contents

List of Acronyms.....	2
1. Description of equipment and operations .....	3
1.1 Traveling System .....	3
1.2 Visited Receivers.....	3
2. Data Used.....	4
3. Results of Raw Data Processing .....	4
4. Calibration results .....	4
4.1 Traveling System with Respect to The Reference System .....	5
4.2 Traveling System with Respect to the Visited Systems .....	6
4.3 Visited Systems with Respect to Reference System .....	6
4.4 Uncertainty.....	7
<b>5. Final results for the visited systems .....</b>	<b>10</b>
<b>Acknowledgements .....</b>	<b>11</b>
Annex A: Information sheets .....	12
A.1 Information sheet of TLM2.....	12
A.2 Information sheet of LSM1 .....	14
A.3 Information sheet of LSM2.....	16
Annex B: Plots of raw data and Tdev analysis .....	18
B.1 Reference vs. traveling.....	18
B.2 Traveling vs. visited, LSM1 .....	19
B.3 Traveling vs. visited, LSM2 .....	20
B.4 Reference vs. traveling, closure .....	21
<b>Reference .....</b>	<b>22</b>

## List of Acronyms

<b>BIPM</b>	<b>Bureau International des Poids et Mesures, Sèvres, France</b>
<b>CGGTTS</b>	<b>CCTF Generic GNSS Time Transfer Standard</b>
<b>APMP</b>	<b>The Asia Pacific Metrology Programme</b>
<b>IGS</b>	<b>International GNSS Service</b>
<b>GNSS</b>	<b>Global Navigation Satellite System</b>
<b>GPS</b>	<b>Global Positioning System</b>
<b>GAL</b>	<b>Galileo satellite navigation system</b>
<b>PPP</b>	<b>Precise Point Positioning</b>
<b>TL</b>	<b>Telecommunication Laboratories, Chunghwa Telecom, Taiwan</b>
<b>TLT5</b>	<b>TL G1 Reference receiver</b>
<b>TLM2</b>	<b>TL travelling receiver</b>
<b>NMIM</b>	<b>National Metrology Institute of Malaysia, Malaysia</b>
<b>UTC(NMLS)</b>	<b>The standard time scale of NMLS (NMIM)</b>
<b>LSM1</b>	<b>Visited receiver of NMLS (NMIM)</b>
<b>LSM2</b>	<b>Visited receiver of NMLS (NMIM)</b>
<b>RINEX</b>	<b>Receiver Independent Exchange Format</b>
<b>R2CGGTTS</b>	<b>RINEX-to CGGTTS conversion software, provided by ORB/BIPM</b>
<b>DCLRINEX</b>	<b>differential calibration software using the pseudoranges directly read in the RINEX files, provided by the BIPM</b>
<b>TDEV</b>	<b>Time Deviation</b>
<b>TIC</b>	<b>Time Interval Counter</b>
<b>CABDLY</b>	<b>the antenna cable delay;</b>
<b>INTDLY</b>	<b>the internal signal delay (antenna + receiver internal);</b>
<b>REFDLY</b>	<b>the offset between the UTC reference point in the laboratory and the reference point of the receiver</b>
<b>SYSDLY</b>	<b>INTDLY + CABDLY</b>
<b>TOTDLY</b>	<b>SYSDLY – REFDLY</b>
<b>CLPDLY</b>	<b>the offset between the local UTC(k) point and the reference point of the traveling receiver</b>

# 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 LMR-200 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 are measured by TIC HP53132a (SN: KR91200267) provided by NMLS.

## 1.2 Visited Receivers

There were 2 receivers calibrated in this campaign, one is LSM1, a Javad Euro-80 receiver, its GPS L1C link was calibrated by 2017 TL-NIMT-NMIM-VMI G2 calibration campaign (CAL\_ID: 1013-2017) in 2017 [3] and would calibrate its GPS P3 link in this campaign. Another one is LSM2, a Septentrio PolaRx5TR receiver, did not calibrated before and would calibrate its GPS P3 link and Galileo E3 this time. The detail information can be found in their information sheets in Annex A.2 and A.3, LSM1 and LSM2 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	60006-60015	Septentrio PolaRx5 TR	TLM2	TLM2
TL	Group 1 reference	-	Septentrio PolaRx5 TR	TLT5	TLT5
NMLS	Group 2	60032-60043	JAVAD Euro-80	LSM1	LSM1
NMLS	Group 2	60032-60043	Septentrio PolaRx5 TR	LSM2	LSM2
TL	Traveling	60056-60066	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	60006-60015	29.54	0.12	29.37	0.08	24.04	0.10	29.51	0.05	22.45	0.09
TLM2-LSM1	60032-60043	7.09	0.06	8.59	0.06	-7.72	0.07	-	-	-	-
TLM2-LSM2	60032-60043	35.21	0.03	35.27	0.03	41.05	0.02	35.28	0.06	40.40	0.07
TLT5-TLM2	60056-60066	30.62	0.05	30.49	0.04	25.00	0.04	30.53	0.10	23.51	0.11

## 4. Calibration results

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

$$\text{TOTDLY}_{R(\text{code})} - \text{TOTDLY}_{T,TL}(\text{code}) = \text{RAWDIF}_{R-T}(\text{code}) \quad \dots\dots\dots (1)$$

Where the  $\text{TOTDLY}_{R(\text{code})}$  and  $\text{TOTDLY}_{T,TL}(\text{code})$  are the TOTDLY of reference receiver and traveling receiver at TL respectively; the  $\text{RAWDIF}_{R-T}(\text{code})$  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  $\text{TOTDLY}_{T,TL}(\text{code})$  and  $\text{TOTDLY}_{T,NMLS}(\text{code})$  in visited lab NMLS.

The TOTDLY can be also expressed using SYSDLY and REFDLY; and the REFDLY is equal to the CLPDLY plus the offset between the UTC reference point and calibration reference point in the lab:

$$\text{REFDLY}_{T, TL}(\text{code}) = \text{CLPDLY}_T(\text{code}) + \Delta\text{Ref\_Clb}_{TL} \quad \dots\dots\dots (2)$$

Where the  $\Delta\text{Ref\_Clb}$  is the offset between the UTC reference point and calibration reference point in the laboratory, the value of  $\Delta\text{Ref\_Clb}_{TL}$  and  $\Delta\text{Ref\_Clb}_{NMLS}$  are different but the value  $\text{CLPDLY}_T(\text{code})$  are all the same in the whole campaign due to we use the same reference 1 PPS cable for the traveling receiver.

We have:

$$\begin{aligned} \text{TOTDLY}_{T, TL}(\text{code}) &= \text{SYSDLY}_T(\text{code}) - \text{REFDLY}_{T, TL}(\text{code}) \\ &= \text{SYSDLY}_T(\text{code}) - [\text{CLPDLY}_T(\text{code}) + \Delta\text{Ref\_Clb}_{TL}] \quad \dots\dots\dots (3) \end{aligned}$$

### 4.1 Traveling System with Respect to The Reference System

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

$$\begin{aligned} \text{RAWDIF}_{R-T}(\text{code}) &= [\text{SYSDLY}_R(\text{code}) - \text{REFDLY}_R(\text{code})] \\ &\quad - [\text{SYSDLY}_T(\text{code}) - \text{CLPDLY}_T(\text{code}) - \Delta\text{Ref\_Clb}_{TL}] \quad \dots\dots\dots (4) \end{aligned}$$

**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	60006-60015	29.54	29.37	24.04	5.33
TLT5-TLM2	60056-60066	30.62	30.49	25.00	5.49
Misclosure	-	1.08	1.12	0.96	0.16
Mean	-	30.08	29.93	24.52	5.41

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

Pair	Date	E1	E5a	E1-E5a
		RawDIF	RawDIF	RawDIF
TLT5-TLM2	60006-60015	30.23	23.31	7.06
TLT5-TLM2	60056-60066	30.53	23.51	7.02
Misclosure	-	1.02	1.06	-0.04
Mean	-	30.02	22.98	7.04

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 (NMLS) can be expressed:

$$\begin{aligned} \text{RAWDIF}_{T,V}(\text{code}) = & \\ & [\text{SYSDLY}_T(\text{code}) - \text{CLPDLY}_T(\text{code}) - \Delta\text{Ref\_Clb}_{\text{NMLS}}] \\ & - [\text{SYSDLY}_V(\text{code}) - \text{REFDLY}_V(\text{code})] \end{aligned} \quad \dots\dots (5)$$

The  $\Delta\text{Ref\_Clb}_{\text{NMLS}}$  is the offset from UTC(NMLS) reference point to the calibration reference point of NMLS.

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

Pair	Date	$\Delta\text{Ref\_Clb}_{\text{NMLS}}$	REFDLY <sub>V</sub>	L1C	L1P	L2P
				RawDIF	RawDIF	RawDIF
TLM2-LSM1	60032-60043	-0.24	20.8	7.09	8.59	-7.72
TLM2-LSM2	60032-60043	-0.24	32.8	35.21	35.27	41.05

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

Pair	Date	$\Delta\text{Ref\_Clb}_{\text{NMLS}}$	REFDLY <sub>V</sub>	E1	E5a
				RawDIF	RawDIF
TLM2-LSM2	60032-60043	-0.24	32.8	35.28	40.40

### 4.3 Visited Systems with Respect to Reference System

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

$$\begin{aligned} & \text{RAWDIF}(\text{code})_{R,T} + \text{RAWDIF}(\text{code})_{T,V} \\ & = [\text{SYSDLY}_R(\text{code}) - \text{REFDLY}_R(\text{code})] - [\text{SYSDLY}_V(\text{code}) - \text{REFDLY}_V(\text{code})] \\ & + \Delta\text{Ref\_Clb}_{\text{TL}} - \Delta\text{Ref\_Clb}_{\text{NMLS}} \\ & = \text{TOTDLY}_R(\text{code}) - \text{TOTDLY}_V(\text{code}) + \Delta\text{Ref\_Clb}_{\text{TL}} - \Delta\text{Ref\_Clb}_{\text{NMLS}} \\ & = \Delta\text{TOTDLY}_{R-V}(\text{code}) + \Delta\text{Ref\_Clb}_{\text{TL}} - \Delta\text{Ref\_Clb}_{\text{NMLS}} \end{aligned}$$

or

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

$$\text{RAWDIF}(\text{code})_{\text{R-T}} + \text{RAWDIF}(\text{code})_{\text{T-V}} - \Delta\text{Ref\_Clb}_{\text{TL}} + \Delta\text{Ref\_Clb}_{\text{NMLS}} \dots\dots (6)$$

In TL, the calibration reference point and the UTC reference point are identical, that is the  $\Delta\text{Ref\_Clb}_{\text{TL}} = 0$ . 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	$\Delta\text{Ref\_Clb}_{\text{NMLS}}$	$\Delta\text{TOTDLY}_{\text{R-V}}$		
			C1	P1	P2
TLT5-LSM1	60032-60043	-0.24	36.93	38.28	16.56
TLT5-LSM2	60032-60043	-0.24	65.05	64.96	65.33

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

Pair	Date	$\Delta\text{Ref\_Clb}_{\text{NMLS}}$	$\Delta\text{TOTDLY}_{\text{R-V}}$	
			E1	E5a
TLT5-LSM2	60032-60043	-0.24	65.06	63.14

### 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  $u_{\text{CAL}}$  that is to be used as the accuracy of all GPS P3 and GAL E3 links at the epoch of calibration.

$$u_{\text{CAL}} = \sqrt{u_a^2 + u_b^2}$$

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  $u^2_{\text{P3}} = u^2_{\text{P1}} + (1.545 \times u_{\text{P1-P2}})^2$ . Uncertainties for the Galileo delays are calculated according to  $u^2_{\text{E3}} = u^2_{\text{E1}} + (1.261 \times u_{\text{E1-E5a}})^2$ . 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, and P2, GAL E1, and E5a) to compute a value  $u_{\text{CAL}}$  applicable to GPS P3 and GAL E3 links. We choose to compute  $u_{\text{CAL}}$  using for  $u_b$  the uncertainty  $u_{b,\text{TOT}}$  of  $\Delta\text{TOTDLY}_{\text{R-V}}$  from Eq. (6). Table 6.1 and 6.2 presents all components of the uncertainty budget along with the uncertainty  $u_{b,\text{TOT}}$  of  $\Delta\text{TOTDLY}_{\text{R-V}}$  from equation (6) and the resulting uncertainty value  $u_{\text{CAL}}$ . 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.
- $u_{b,31}$  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 NMLS, 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 NMLS, it includes at least one measurement with a TIC. We should note the visited station NMLS did not measure the CABDLY during this campaign.

**Table 6.1** 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
$u_a(T-R)$	0.12	0.08	0.10	0.13		Tdev of RAWDIF of TLT5 vs. TLM2 during MJD 60006-60015
$u_{a,LSM1}(T-V)$	0.06	0.06	0.07	0.09		Tdev of RAWDIF of TLM2 vs. LSM1
$u_{a,LSM2}(T-V)$	0.03	0.03	0.02	0.04		Tdev of RAWDIF of TLM2 vs. LSM2
$u_{a,LSM1}$	0.13	0.10	0.12	0.16	0.26	
$u_{a,LSM2}$	0.12	0.09	0.10	0.13	0.22	
Misclosure						
$u_{b,1}$	1.08	1.12	0.96	0.17	-	Observed misclosure of TLT5 vs. TLM2
Systematic components related to RAWDIF						
$u_{b,11}$	0.10	0.10	0.10	0.10	-	Position error at TL
$u_{b,12}$	0.10	0.10	0.10	0.10	-	Position error at NMLS
$u_{b,13}$	0.20	0.20	0.20	0.30	-	Multipath effect at TL
$u_{b,14}$	0.20	0.20	0.20	0.30	-	Multipath effect at NMLS

Link of the Traveling system to the local UTC(k)						
$u_{b,21}$	0	0	0	0.00	-	$\Delta\text{Ref\_Clb}_{TL}$ at TL (CLBDLY = REFDLY)
$u_{b,22}$	0.50	0.50	0.50	0.00	-	$\Delta\text{Ref\_Clb}_{NMLS}$ at NMLS
$u_{b,TOT}$	1.23	1.27	1.13	0.48	1.47	Components of equation (6)
$u_{CAL0,LSM1}$					1.49	Composed of $u_{a,LSM1}$ and $u_{b,TOT}$
$u_{CAL0,LSM2}$					1.49	Composed of $u_{a,LSM2}$ 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 LSM1/LSM2, did not measure during this campaign
Antenna cable delays						
$u_{b,41}$	0	0	0			TLT5 did not use REFDLY to calculate P3
$u_{b,42}$	0.50	0.50	0.50			CABDLY of LSM1/LSM2, did not measure during this campaign
$u_{b,INT}$	1.42	1.45	1.33	0.48	1.63	Components of equation (7)
$u_{CAL0,LSM1}$					1.65	Composed of $u_{a,LSM1}$ and $u_{b,INT}$
$u_{CAL0,LSM2}$					1.64	Composed of $u_{a,LSM2}$ and $u_{b,INT}$

**Table 6.2** Uncertainty contributions of GAL link,  $E3 = E1 + 1.261 \times (E1 - E5a)$ , all values in ns

Unc.	E1	E5a	E1-E5a	E3	Description
$u_a(T-R)$	0.10	0.11	0.15		Tdev of RAWDIF of TLT5 vs. TLM2 during MJD 60006-60015
$u_{a,LSM2}(T-V)$	0.06	0.07	0.09		Tdev of RAWDIF of TLM2 vs. LSM2
$u_{a,LSM2}$	0.12	0.13	0.17	0.25	
Misclosure					
$u_{b,1}$	1.02	1.06	0.04	-	Observed mis-closure of TLT5 vs. TLM2
Systematic components related to RAWDIF					
$u_{b,11}$	0.10	0.10	0.10	-	Position error at TL
$u_{b,12}$	0.10	0.10	0.10	-	Position error at NMLS
$u_{b,13}$	0.20	0.20	0.30	-	Multipath effect at TL
$u_{b,14}$	0.20	0.20	0.30	-	Multipath effect at NMLS
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0	0	-	-	$\Delta\text{Ref\_Clb}_{TL}$ at TL (CLBDLY = REFDLY)
$u_{b,22}$	0.50	0.50	-	-	$\Delta\text{Ref\_Clb}_{NMLS}$ at NMLS
$u_{b,TOT}$	1.18	1.21	0.45	1.31	Components of equation (6)
$u_{CAL0,LSM2}$				1.33	Composed of $u_{a,LSM2}$ and $u_{b,TOT}$

Link of the Reference system to its local UTC(k)					
u <sub>b,31</sub>	0	0			TLT5 did not use REFDLY to calculate E3
Link of the Visited system to its local UTC(k)					
u <sub>b,32</sub>	0.50	0.50	-		REFDLY of LSM2
Antenna cable delays					
u <sub>b,41</sub>	0	0	-		TLT5 did not use CABDLY to calculate E3
u <sub>b,42</sub>	0.50	0.50	-		CABDLY of LSM2, did not measure during this campaign
u <sub>b,INT</sub>	1.37	1.40	0.45	1.51	Components of equation (7)
u <sub>CAL0,LSM2</sub>				1.53	Composed of u <sub>a,LSM2</sub> and u <sub>b,INT</sub>

### 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<sub>v</sub>, can be obtained by using equation (7).

The calibrated INTDLYs of visited lab can be derived:

$$INTDLY_v(\text{code}) = \text{TOTDLY}_R(\text{code}) - \Delta\text{TOTDLY}_{R-v}(\text{code}) - \text{CABDLY}_v(\text{code}) + \text{REFDLY}_v(\text{code}) \quad \dots\dots (7)$$

Using the TOTDLY<sub>R</sub> values reported in 1001-2020 for the Reference system TLT5 and the values CABDLY<sub>v</sub>, REFDLY<sub>v</sub>, ΔRef\_Clb<sub>NMLS</sub> from the information sheet (Annex A), **Table 7.1 and 7.2** then reports INTDLY<sub>v</sub> for all visited systems. The uncertainty value u<sub>cal</sub> for P3 is obtained from **Table 6.1 and 6.2**. It is used by the BIPM to assign the value u<sub>b</sub> 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	<sup>1</sup> Feb. 02, 2021		206.1	204.0	202.9
Visited stations	Cal_id	Date	u <sub>CAL</sub> (P3)/ ns	INTDLY/ns		
				C1	P1	P2
LSM1	1013-2023	June. 05, 2023	1.7	34.6	31.1	51.7
LSM2	1013-2023	June. 05, 2023	1.6	21.2	19.1	17.7

<sup>1</sup> The date performed the calibration id 1001-2020

**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 <sub>CAL</sub> (E3)/ ns	INTDLY/ns	
				E1	E5a
LSM2	1013-2023	June. 05, 2022	1.5	21.34	21.06

## Acknowledgements

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

# Annexes

## Annex A: Information sheets

### A.1 Information sheet of TLM2

Laboratory:	TL	
Date and hour of the beginning of measurements:	2023-03-02 00:00:00 UTC	
Date and hour of the end of measurements:	2023-06-15 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 <sup>2</sup>
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:	P1:106.408, P2: 111.486 <sup>3</sup>	
● INT DLY (GAL) /ns:	E1: 108.032, E5a: 113.769	

<sup>2</sup> The reference cable of TLM2 is connected to the UTC(TL) reference point.

<sup>3</sup> The P1/P2 and E1/E5a INTDLY of TLM2 used for generating CGGTTS are actually TOTDLY, already including CABDLY and REFDLY

● CAB DLY /ns:	Included in INTDLY
● REF DLY /ns:	Included in INTDLY
● Coordinates reference frame:	WGS-84
Latitude or X /m:	-
Longitude or Y /m:	-
Height or Z /m:	-
<b>General information</b>	
● Rise time of the local UTC pulse:	1 ns
● Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	$23 \pm 1$ °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 LSM1

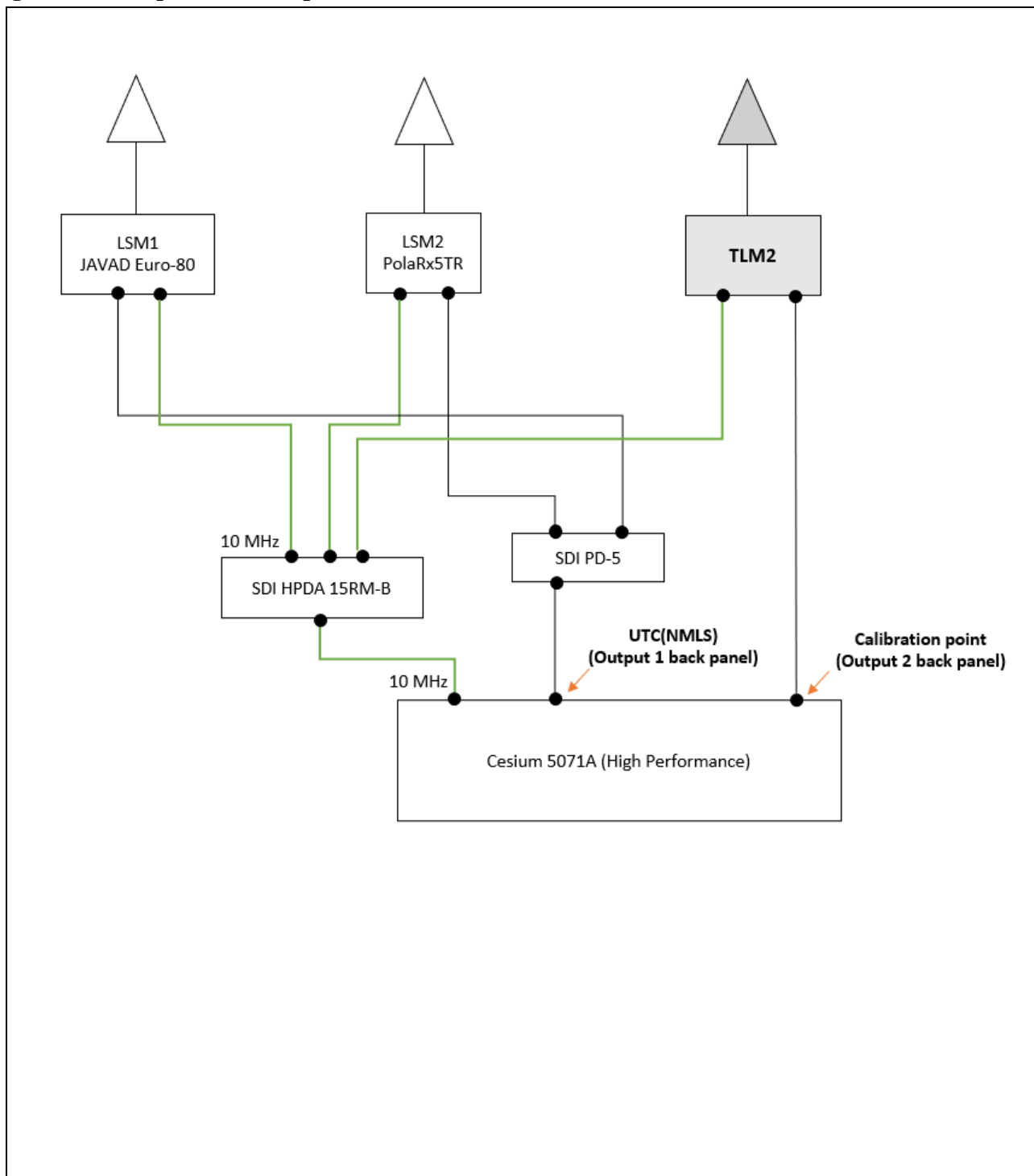
# Information Sheet

Laboratory:	NMLS	
Date and hour of the beginning of measurements:	2023-03-29 00:00:00 UTC	
Date and hour of the end of measurements:	2023-04-09 23:59:00 UTC	
Information on the system		
	Local:	Travelling:
4-character BIPM code	LSM1	TLM2
● Receiver maker and type/serial number:	JAVAD Euro-80 S/N JAVAD-01/CSIRO2001	Septentrio/PolaRx5TR/ 4701426
1 PPS trigger level /V:	1 V	
● Antenna cable maker/type: Phase stabilized cable (Y/N):	LMR-400/N	~/LMR-200/N
Length outside the building /m:	15.3 m	~10 m
● Antenna maker and type/serial number:	Topcon Javad Choke Ring, S/N 00147	HEMA45/A45/280600336
Temperature (if stabilized) /°C	N/A	
Measured delays/ns (if needed fill box "Additional Information" below)		
	Local:	Travelling:
● Delay from local UTC to receiver 1 PPS-in:	20.8 ns	-0.24 ns <sup>4</sup>
Delay from 1 PPS-in to internal Reference (if different):	N/A	N/A
● Antenna cable delay:	155.4 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:	C1:35.1	
● INT DLY (GLONASS) /ns:	-	
● CAB DLY /ns:	155.4	
● REF DLY /ns:	20.8	
● Coordinates reference frame:		
Latitude or X /m:	-1295535.614 m	
Longitude or Y /m:	+6237440.812 m	

<sup>4</sup> the offset between the UTC(NMLS) point and the reference point of the traveling receiver

Height or Z /m:	+310809.199 m
<b>General information</b>	
● Rise time of the local UTC pulse:	< 5 ns
● Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	23±2 °C
Set humidity value and uncertainty:	60 ± 10 % RH

**Diagram of the experiment set-up:**





### A.3 Information sheet of LSM2

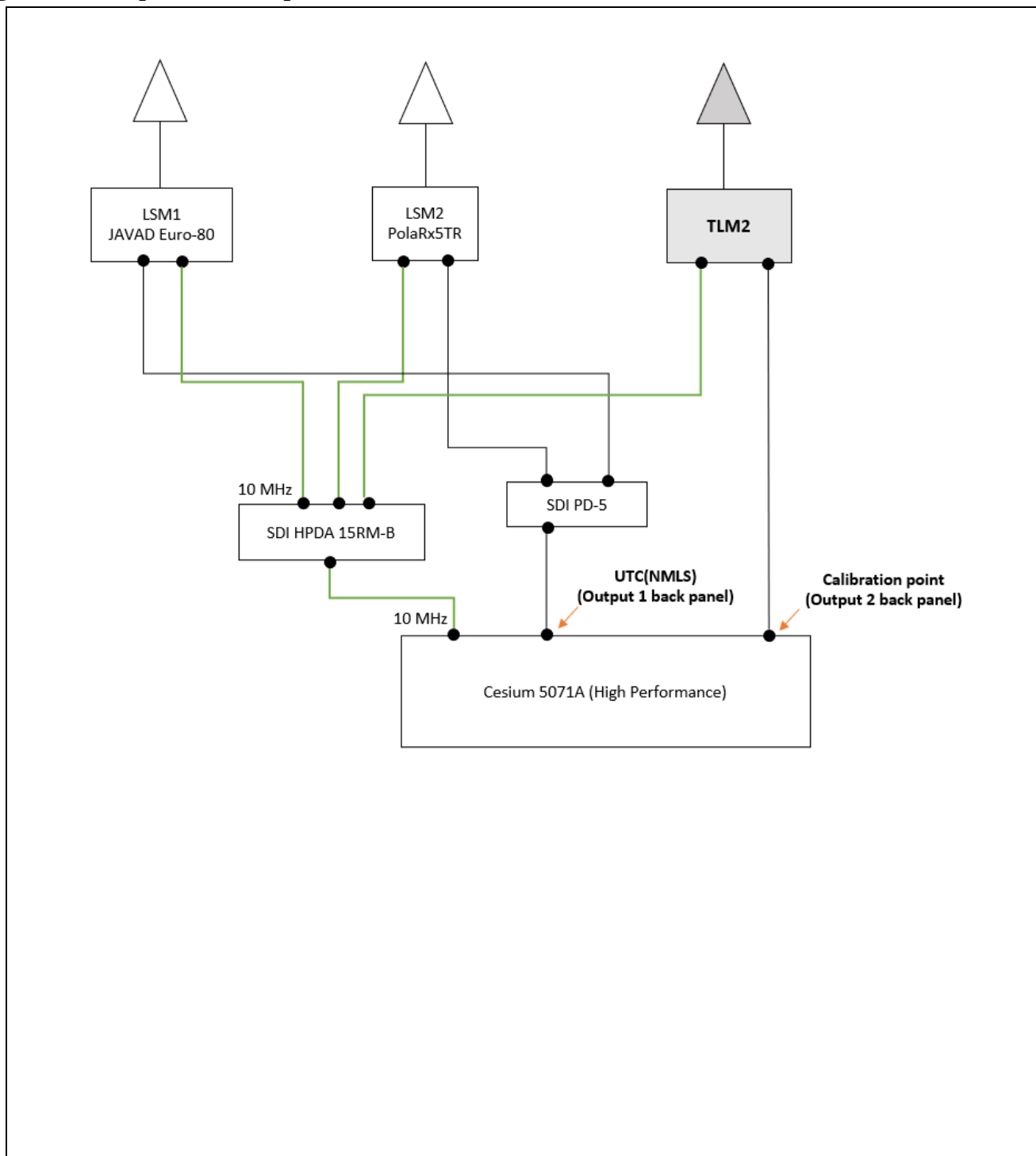
# Information Sheet

Laboratory:	NMLS	
Date and hour of the beginning of measurements:	2023-03-29 00:00:00 UTC	
Date and hour of the end of measurements:	2023-04-09 23:59:00 UTC	
Information on the system		
	Local:	Travelling:
4-character BIPM code	LSM2	TLM2
● Receiver maker and type/serial number:	Septentrio/PolaRx5TR/470189	Septentrio/PolaRx5TR/4701426
1 PPS trigger level /V:	1 V	
● Antenna cable maker/type: Phase stabilized cable (Y/N):	LMR-400/N	~/LMR-200/N
Length outside the building /m:	12.5 m	~ 10 m
● Antenna maker and type/serial number:	Septentrio VeraChoke, S/N 710152	HEMA45/A45/280600336
Temperature (if stabilized) /°C	N/A	
Measured delays/ns (if needed fill box "Additional Information" below)		
	Local:	Travelling:
● Delay from local UTC to receiver 1 PPS-in:	32.8 ns	-0.24 ns <sup>5</sup>
Delay from 1 PPS-in to internal Reference (if different):	N/A	
● Antenna cable delay:	152.7 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:	0	
● INT DLY (GLONASS) /ns:	-	
● CAB DLY /ns:	152.7	
● REF DLY /ns:	32.8	
● Coordinates reference frame:		
Latitude or X /m:	-1295538.528	
Longitude or Y /m:	6237440.140	
Height or Z /m:	310809.197	

<sup>5</sup> the offset between the UTC(NMLS) point and the reference point of the traveling receiver

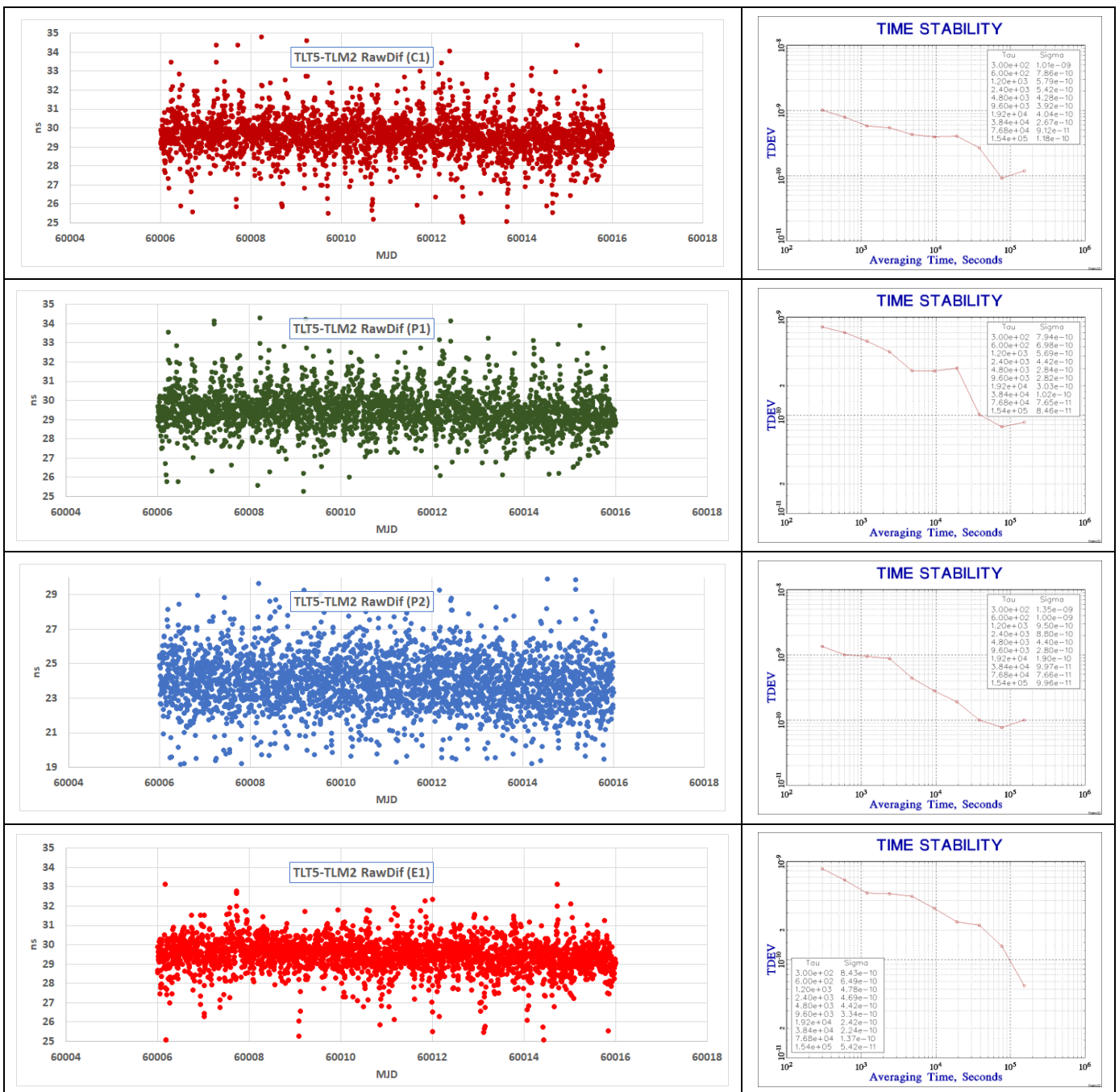
<b>General information</b>	
● Rise time of the local UTC pulse:	$< 5 \text{ ns}$
● Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	$23 \pm 2 \text{ }^\circ\text{C}$
Set humidity value and uncertainty:	$60 \pm 10 \text{ \% RH}$

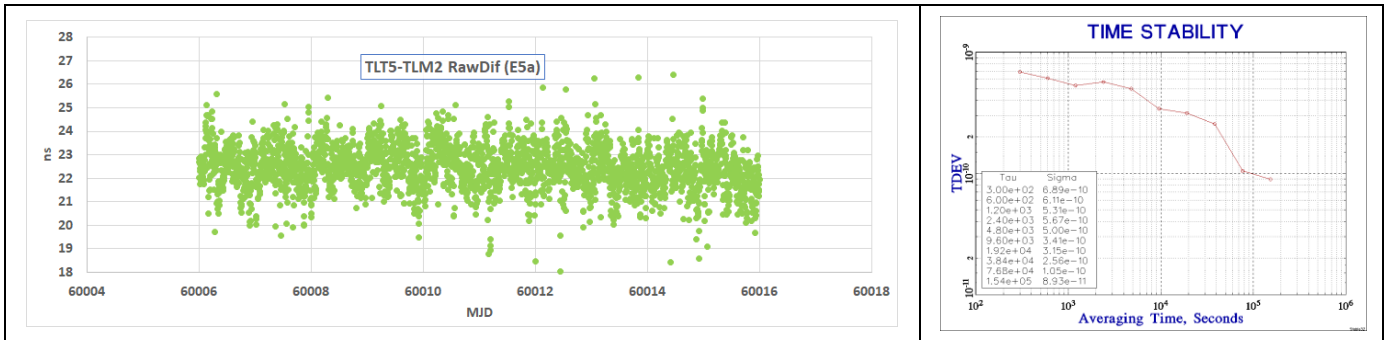
**Diagram of the experiment set-up:**



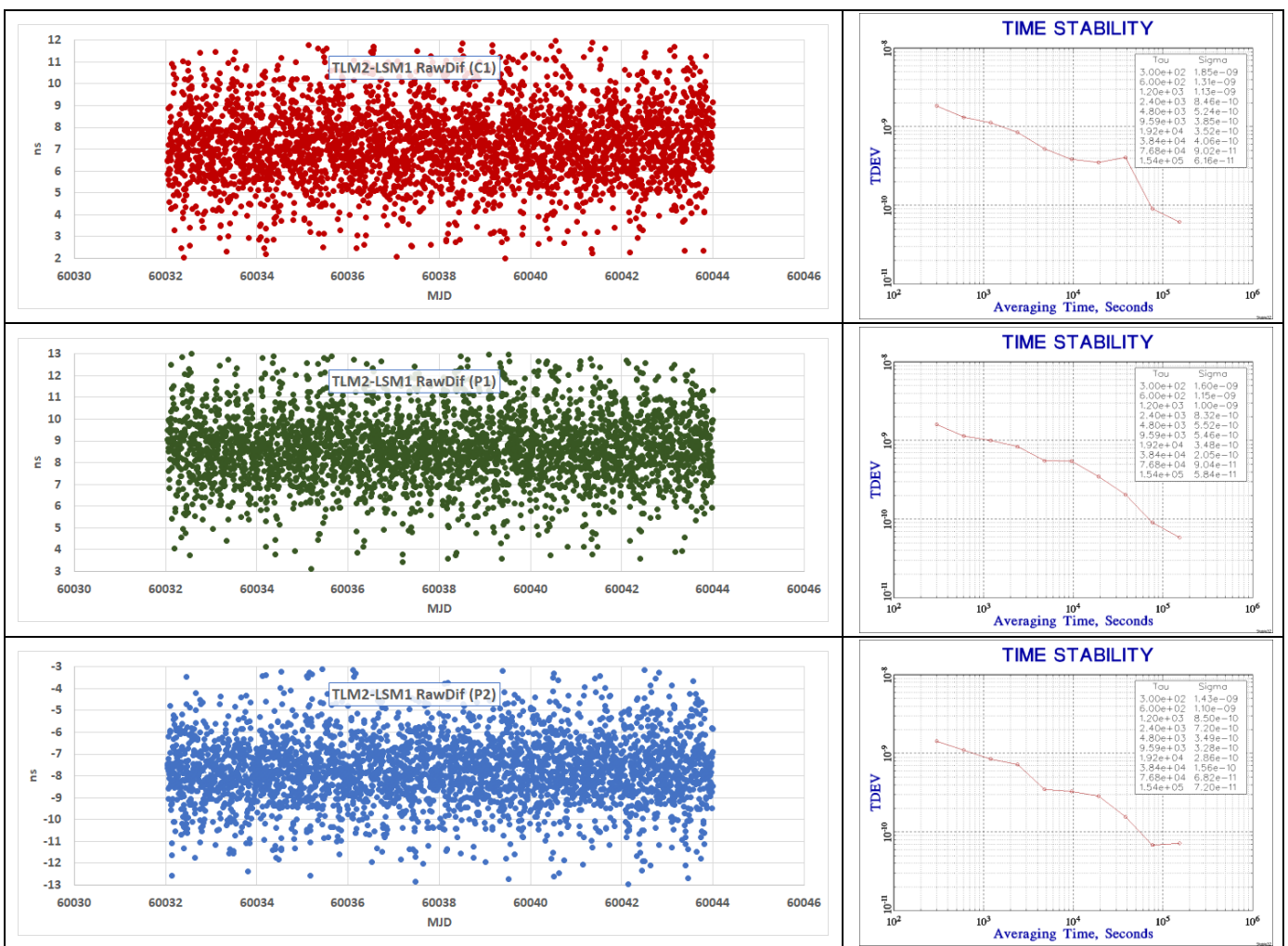
## Annex B: Plots of raw data and Tdev analysis

### B.1 reference vs. traveling

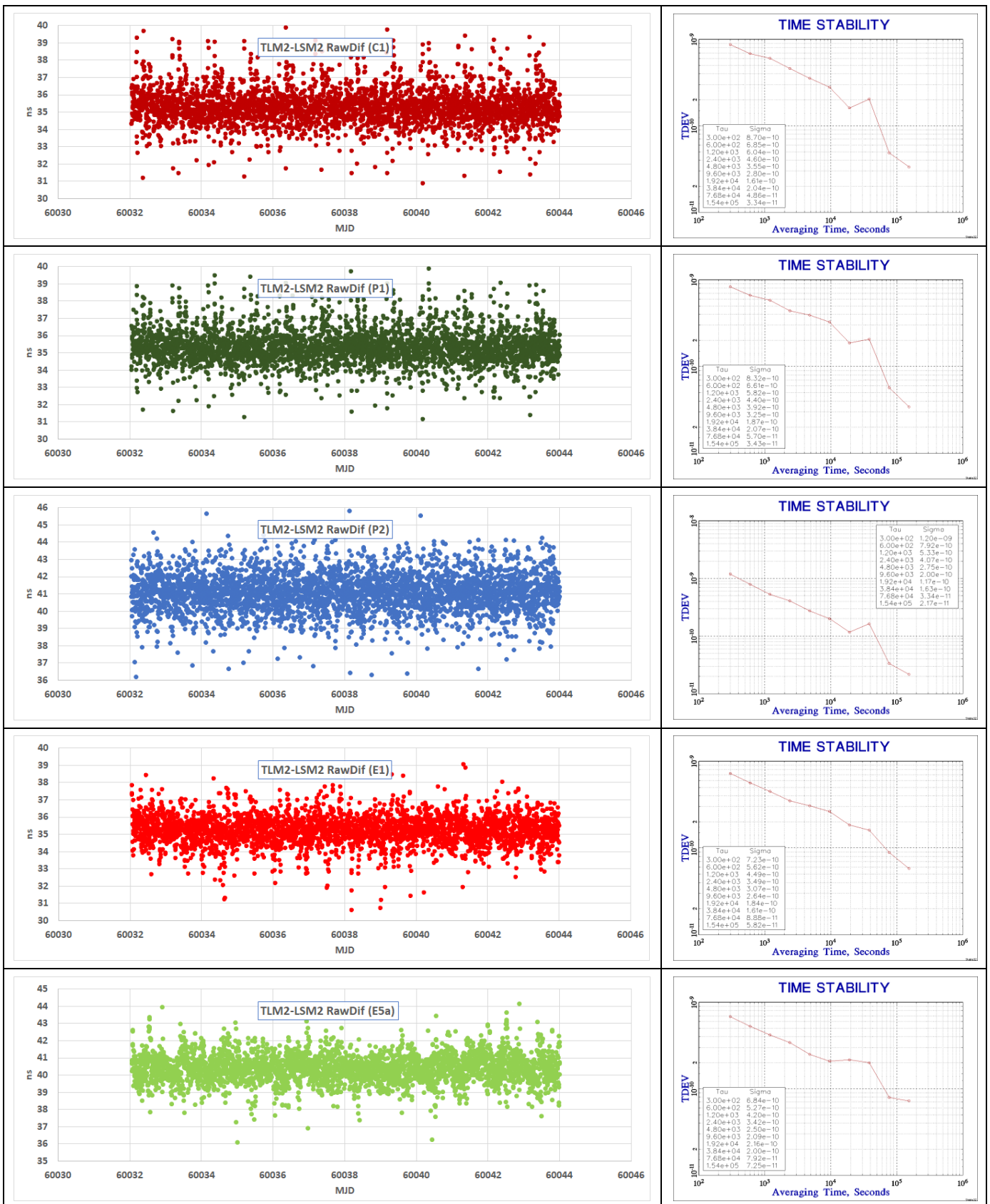




### B.2 Traveling vs. visited, LSM1

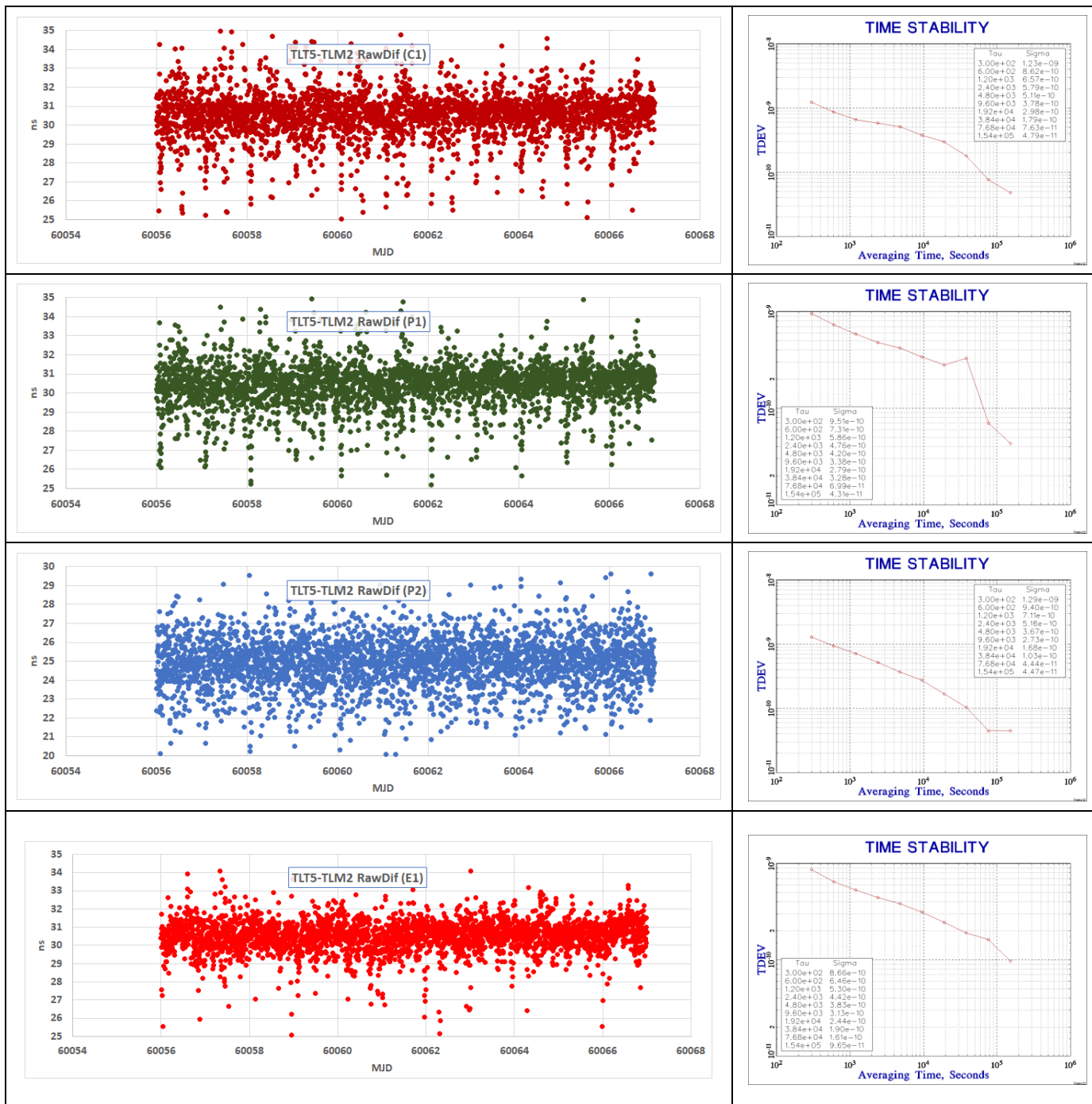


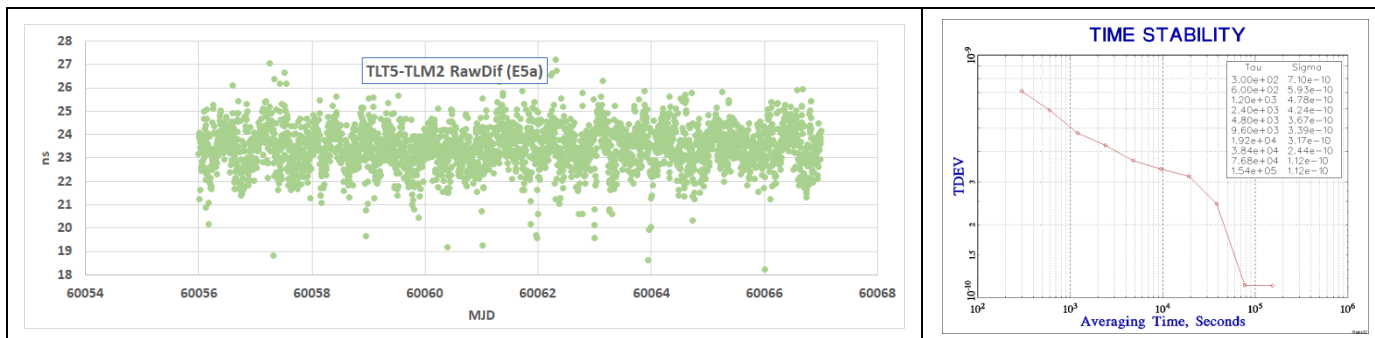
### B.3 traveling vs. visited, LSM2





### B.4 reference vs. traveling, closure





## 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] BIPM 1013-2017\_v13.pdf,  
<ftp://ftp2.bipm.fr/pub/tai/publication/gnss-calibration/group2/2017/1013-2017>
- [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
- [7] J. Kouba, P. Heroux, 2002, “Precise Point Positioning Using IGS Orbit and Clock Products,” GPS Solutions, Vol 5, No. 2, 12-28
- [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