NIMT Calibration Transfer Report

Cal_ID: 1016-2022

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Summary

As one of the APMP G1 laboratories, TL helped the NIMT of Thailand to calibrate a new installed GNSS time transfer receiver, MTTN, with respect to the calibrated receiver MTTI which setup configuration is kept unchanged since 2022. The GPS and Galileo signal delays of MTTI were calibrated by BIPM as reported with CAL_ID 1016-2022 [1]. The GNSS receiver to be calibrated is MTTN. The data were collected between MJD 60153-60160 (the 28th Jul 2023 – 4th August 2023) by simultaneous operation of a pair of co-located MTTI and MTTN. This report was declared to BIPM on 10th August and followed as closely as possible the BIPM Guideline [2]. The results provided are the calibrated receiver's internal delays for GPS C1, P1, and P2 signals and the Galileo E1 and E5a signals.

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
NIMT	National Institute of Metrology, Thailand
MTTI	NIMT reference receiver
MTME	NIMT reference receiver
MTTN	NIMT receiver to be calibrated
RINEX	Receiver Independent Exchange Format
R2CGGTTS	RINEX-to CGGTTS conversion software, provided by ORB / BIPM
DCLRINEX	differential calibration software using the pseudoranges directly read in the RINEX files, provided by the BIPM
TDEV	Time Deviation
TIC	Time Interval Counter
CABDLY	the antenna cable delay;
INTDLY	the internal signal delay (antenna + receiver internal);
REFDLY	the offset between the UTC reference point in the laboratory and the reference point of the receiver
SYSDLY	INTDLY + CABDLY
TOTDLY	SYSDLY – REFDLY

1. DESCRIPTION OF EQUIPMENT AND OPERATIONS

1.1 The Setup of GNSS receivers at NIMT

The set-up of the reference receiver MTTI and the receiver to be calibrated MTTN (Table 1) are depicted in Figure 1 for 1 PPS signals and 10 MHz signals. The type of the receiver to be calibrated, MTTN, is Septentrio PolaRx5TR, which auto compensation mode was set to “ON”. The details can be found in the calibration information sheet in the Annex A.

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

BIPM code	RINEX name	Receiver type	Status of equipment	Dates of measurement
MTTI	MTTI	MESIT GTR-55	Local Reference	60153-60160
MTTN	MTTN	Septentrio PolaRx5 TR	To be Calibrated	60153-60160

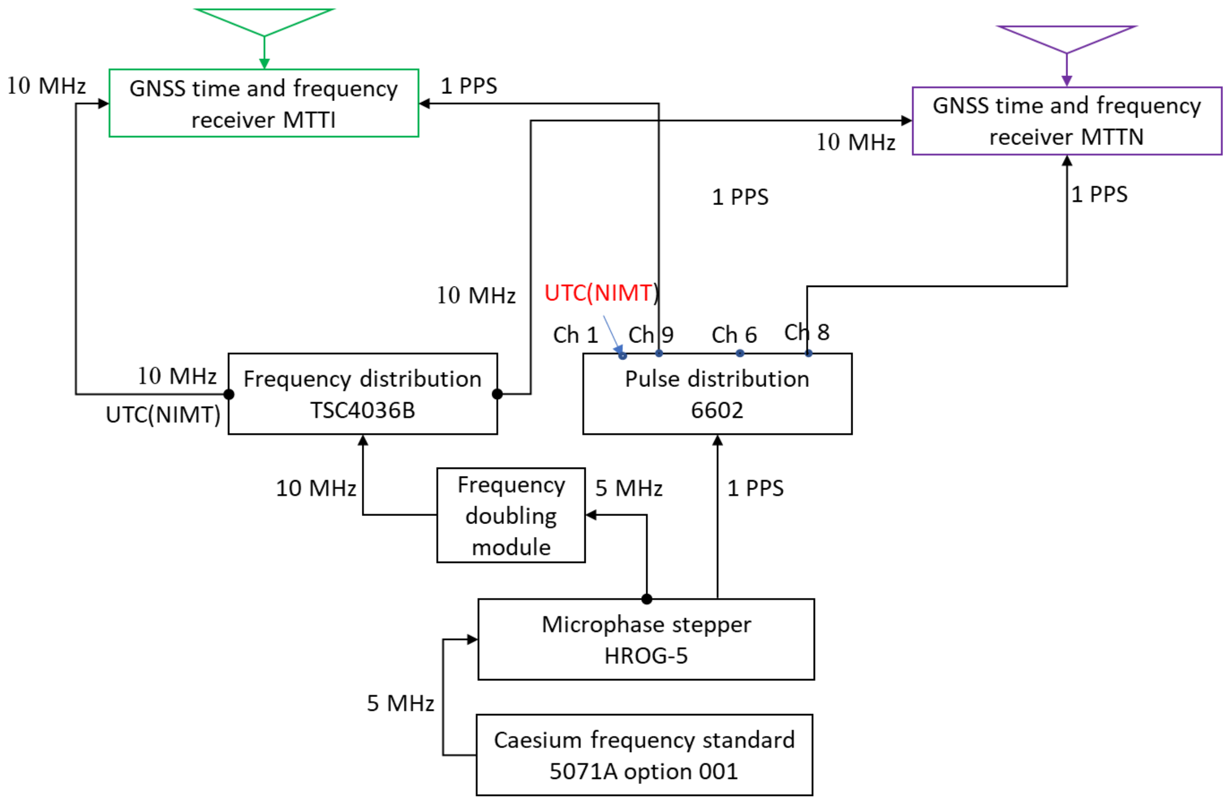


Figure 1, the setup diagram

2. DATA USED

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

3. RESULTS OF RAW DATA PROCESSING

The raw code differences of MTTI and MTTN 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 will be computed using Eq. (4) and given in Table 5.1 and 5.2.

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

Pair	Date	C1	Unc.	P1	Unc.	P2	Unc.	E1	Unc.	E5a	Unc.
MTTI-MTTN	60153-60160	-40.52	0.12	-39.22	0.08	-37.92	0.15	-40.55	0.11	-39.61	0.15

4. CALIBRATION RESULTS

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

$$TOTDLY_R(code) = CABDLY_R\,(code) + INTDLY_R\,(code) - REFDLY_R\,(code) \quad \text{........ (1)}$$

For all reference receiver (MTTI/MTME) and the receiver under calibration (MTTN) use the common clock and frequency reference source UTC(NIMT):

$$RAW_R(code) - TOTDLY_R(code) = RAW_U(code) - TOTDLY_U(code) \quad \text{........ (2)}$$

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

From (1) and (2)

$$TOTDLY_U(code)$$

$$= TOTDLY_R(code) - [RAW_R(code) - RAW_U(code)]$$

$$= CABDLY_U\,(code) + INTDLY_U\,(code) - REFDLY_U\,(code) \quad \text{........ (3)}$$

Or

$INTDLY_U$ (code)

$= TOTDLY_R$ (code) − $RAWDIF_{R\text{-}U}$(code) − $CABDLY_U$ (code)+ $REFDLY_U$ (code) …….. (4)

Where $RAWDIF_{R\text{-}U}$(code) = RAW_R(code) − RAW_U(code).

The CABDLY and REFDLY of MTTN are 250.7 ns and 35.2 ns respectively, from equation (4), the raw calibration of INTDLYs of MTTN are listed in Table 3:

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

	CABDLY	REFDLY	INTDLY				
			C1	P1	P2	E1	E5a
MTTI (ID 1016_2022)	214.7	23.9	12.4	12.2	9.8	12.6	12.4
MTTN	250.7	35.2	28.22	26.72	23.02	28.45	27.31

4.4 Uncertainty

In this section, we use the same method as [1] to determine the uncertainty of INTDLY. 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 $u^2_{P3}=u^2_{P1}+(1.545\times u_{P1-P2})^2$. Uncertainties for the Galileo delays are calculated according to $u^2_{E3}=u^2_{E1}+(1.261\times u_{E1-E5a})^2$. All possible terms to be considered in the sum are to be listed in Table 6.1 and 6.2. Values appear separately for each code (GPS C1, P1, 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 $u_{b,INT}$ of $INTDLY_{MTTN}$ from Eq. (4). Table 5.1 and 5.2 presents all components of the uncertainty budget along with the uncertainty $u_{b.INT}$ of $INTDLY_{MTTN}$ from equation (4) and the resulting uncertainty value u_{CAL}. The items in Table 5 are separated into several categories.

- $u_{b,11}$ and $u_{b,12}$ account for errors in the antenna coordinates. In general, they are estimated to be 3.0 cm (0.1 ns) because the standard uncertainty of the coordinates obtained with the data used for calibration is typically at or below this level. The $u_{b,13}$ and $u_{b,14}$ account for multipath effect. This is difficult to 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 $u_{b,22}$ accounts for the measurement between the reference point of the reference station and the local UTC(k). $u_{b,31} = u_{b,32}$ = 0.5 ns at NIMT, it includes at least one measurement with a TIC. We should note the NIMT did not measure the REFDLY of MTTI this time.
- $u_{b,31}$ and $u_{b,32}$ accounts for the measurement of CABDLY. $u_{b,41} = u_{b,42}$ = 0.5 ns at NIMT, it includes at least one measurement with a TIC. We should note the NIMT did not measure the CABDLY of MTTI this time.

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

Unc.	C1	P1	P2	P1-P2	P3	Description
$u_{a,MTTI-MTTN}$	0.12	0.08	0.15	0.17	0.30	Tdev of RAWDIF of MTTI vs. MTTN
	Systematic components related to RAWDIF					
$u_{b,11}$	0.10	0.10	0.10	0.14	-	Position error at NIMT
$u_{b,12}$	0.20	0.20	0.20	0.28	-	Multipath effect at NIMT
	Link of the Reference system to UTC(NIMT)					
$u_{b,21}$	0.50	0.50	0.50	-		REFDLY of MTTI, did not measure this time
$u_{b,22}$	0.50	0.50	0.50	-	-	REFDLY of MTTN
Antenna cable delays						
$u_{b,31}$	0.50	0.50	0.50	-	-	CABDLY of MTTI, did not measure this time
$u_{b,32}$	0.50	0.50	0.50	-	-	CABDLY of MTTN,
$u_{b,INT}$	1.02	1.02	1.02	0.32	1.14	Components of equation (4)
$u_{CAL0,MTTN}$					1.17	Composed of $u_{a,MTTI-MTTN}$ and $u_{b,INT}$

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

Unc.	E1	E5a	E1-E5a	E3	Description
$u_{a,MTTI-MTTN}$	0.11	0.15	0.19	0.28	Tdev of RAWDIF of MTTI vs. MTTN
Systematic components related to RAWDIF					
$u_{b,11}$	0.10	0.10	0.14	-	Position error at NIMT
$u_{b,12}$	0.20	0.20	0.28	-	Multipath effect at NIMT
	Link of the References to the UTC(NIIMT)				
$u_{b,21}$	0.5	0.5	-	-	REFDLY of MTTI
$u_{b,22}$	0.5	0.5	-	-	REFDLY of MTTN
Antenna cable delays					
$u_{b,31}$	0.5	0.5	-	-	CABDLY of MTTI, did not measure this time
$u_{b,32}$	0.5	0.5	-	-	CABDLY of MTTN
$u_{b,INT}$	1.02	1.02	0.32	1.10	Components of equation (4)
$u_{CAL0,MTTN}$				1.13	Composed of $u_{a,MTTI-MTTN}$ and $u_{b,INT}$

5. The final results for the transferred systems

Table 5.1 Summary of the final results of GPS link

Reference Receiver	Cal_Id	Date		INTDLY/ns		
				C1	P1	P2
MTTI	1016-2022	Oct. 30, 2022		12.4	12.2	9.8
Transferred Reciever	**Cal_Id**	**Date**	**u_{CAL} (P3)/ ns**	**INTDLY/ns**		
				C1	**P1**	**P2**
MTTN			1.2	28.2	26.7	23.0

Table 5.2 Summary of the final results of GAL link

Reference Receiver	Cal_Id	Date		INTDLY/ns	
				E1	E5a
MTTI	1016-2022	Oct. 10, 2022		12.6	12.4
Transferred Receiver	**Cal_Id**	**Date**	**u_{CAL} (E3)/ ns**	**INTDLY/ns**	
				E1	**E5a**
MTTN			1.1	28.5	27.3

ANNEXES

Annex A: Information sheets

Laboratory: NIMT	
Date and hour of the beginning of measurements:	00:00 UTC, 28th JUL, 2023
Date and hour of the end of measurements:	00:00 UTC, 4th AUG, 2023

Information on the system

	Reference:	To be Calibrated:
4-character BIPM code	MTTI	MTTN
● Receiver maker and type: Receiver serial number:	MESIT/GTR55/ 2010010	Septentrio/PolaRx5TR/ 3089903
1 PPS trigger level /V:	1 V	1 V
● Antenna cable maker and type: Phase stabilised cable (Y/N):	Belden/H155PE/N	Belden/RG213/N
Length outside the building /m:	50 m	50 m
● Antenna maker and type: Antenna serial number:	NOV850 NONE/ NMLK20420007H	SEPCHOKE_B3E6_SPKE/ 6139
Temperature (if stabilised) /°C		

Measured delays/ns

	Local:	Travelling:
● Delay from local UTC to receiver 1 PPS-in:	23.9 ns	35.2 ns
Delay from 1 PPS-in to internal Reference (if different):	-	-
● Antenna cable delay:	214.7 ns	250.7 ns
Splitter delay (if any):		(1)
Additional cable delay (if any):		(1)

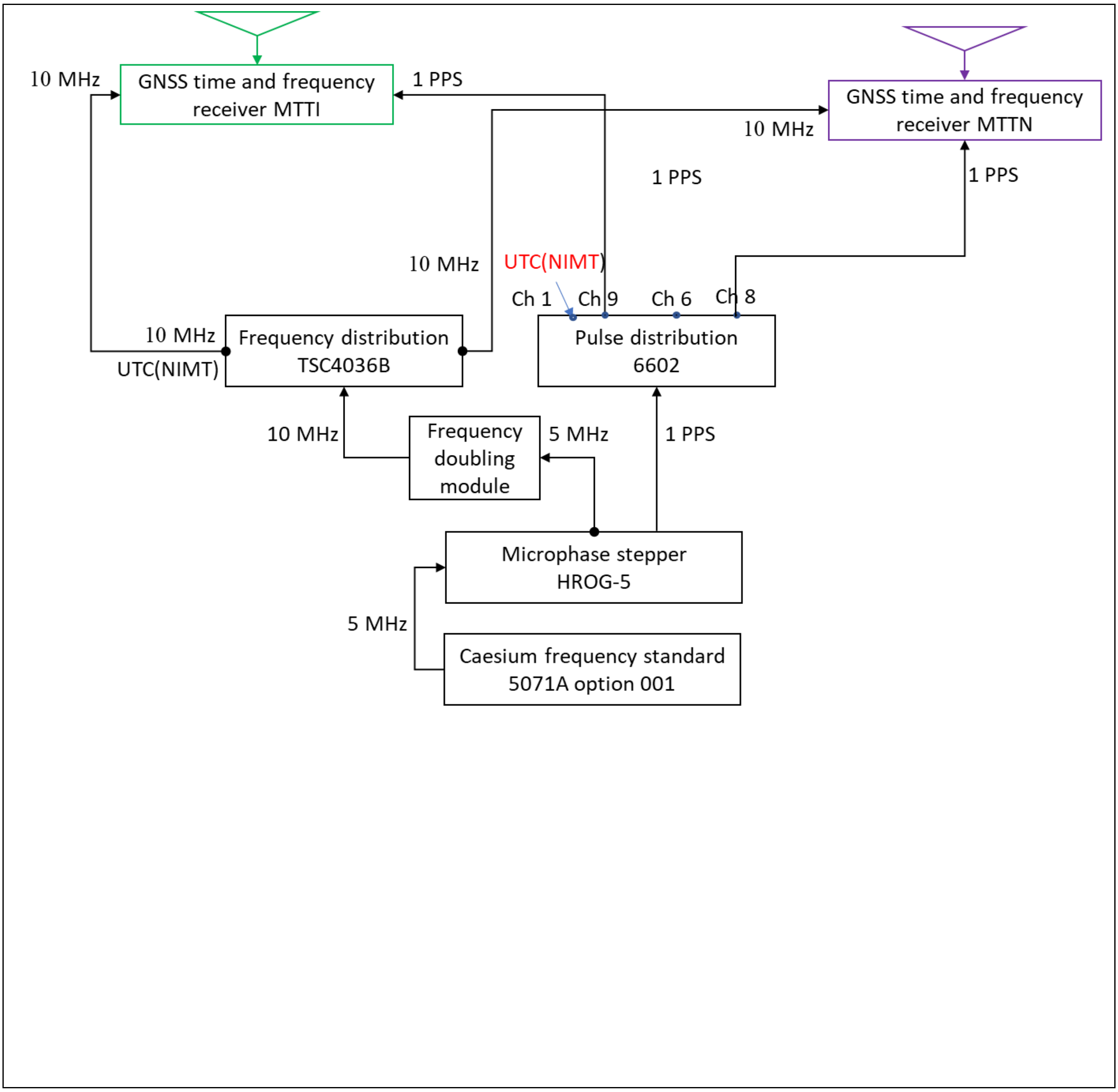
Data used for the generation of CGGTTS files

● INT DLY (GPS) /ns:	-
● INT DLY (GAL) /ns:	-
● CAB DLY /ns:	250.7ns
● REF DLY /ns:	35.2 ns
● Coordinates reference frame:	ITRF2014
Latitude or X /m:	-1150482.6740
Longitude or Y /m:	6080854.9832
Height or Z /m:	1537596.8552

General information

● Rise time of the local UTC pulse:	2 ns
● Is the laboratory air conditioned:	Yes

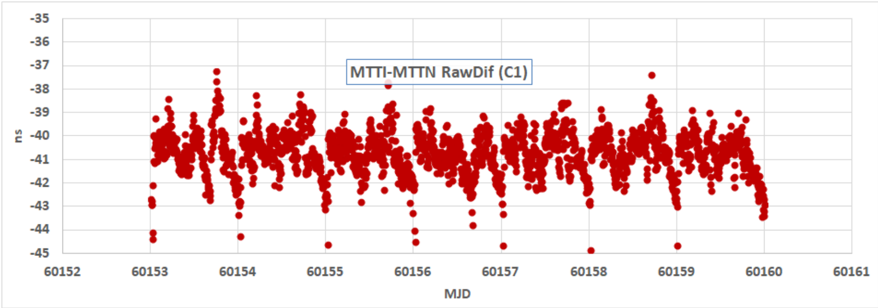
Set temperature value and uncertainty:	(23.0 ± 2.0) °C
Set humidity value and uncertainty:	(50 ± 15) %.RH

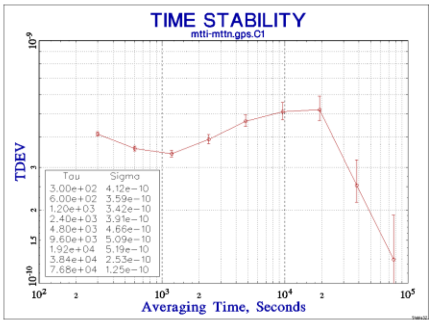


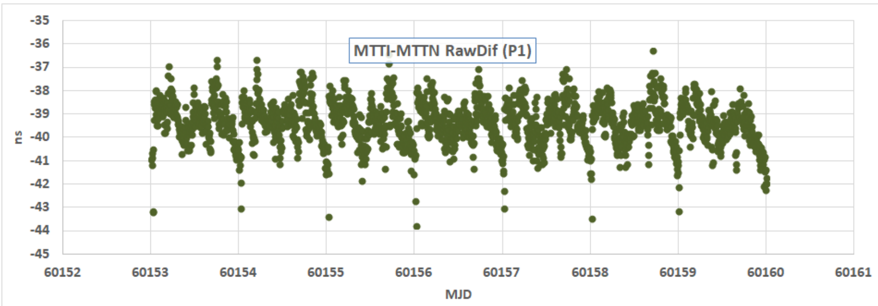
10 MHz
GNSS time and frequency receiver MTTI
1 PPS
GNSS time and frequency receiver MTTN
10 MHz
1 PPS
1 PPS
10 MHz
UTC(NIMT)
Ch 1
Ch 9
Ch 6
Ch 8
10 MHz
Frequency distribution TSC4036B
UTC(NIMT)
Pulse distribution 6602
10 MHz
Frequency doubling module
5 MHz
1 PPS
Microphase stepper HROG-5
5 MHz
Caesium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

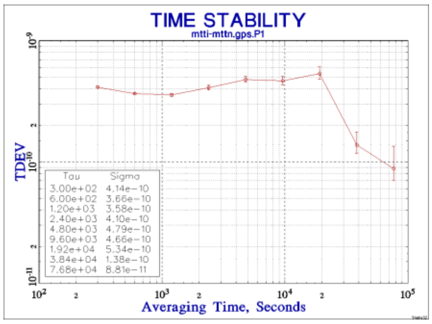
Annex B: Plots of raw data and Tdev analysis

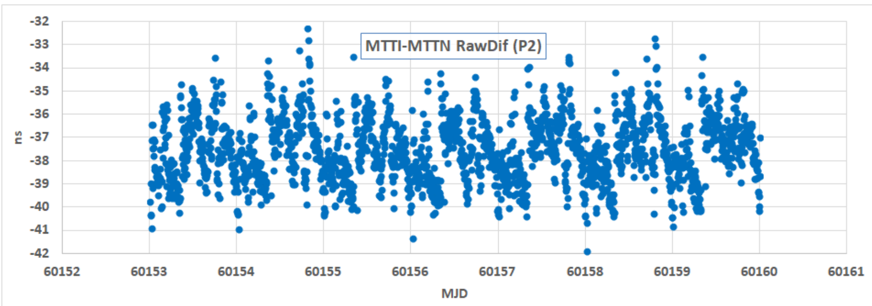
B.1 reference vs. MTTN

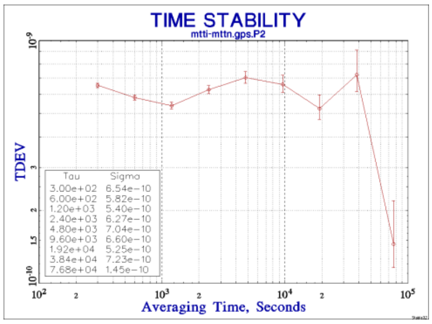


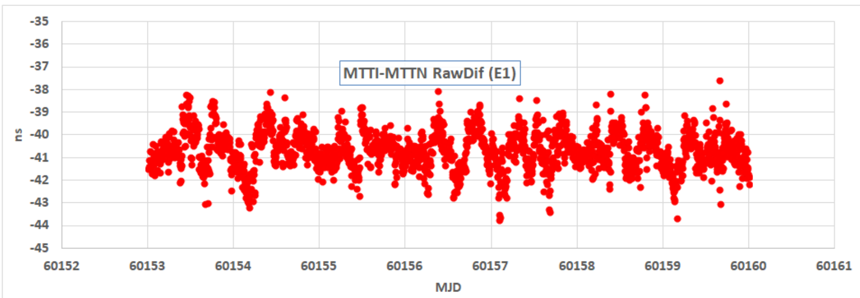


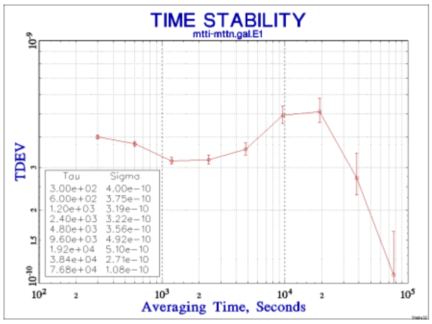


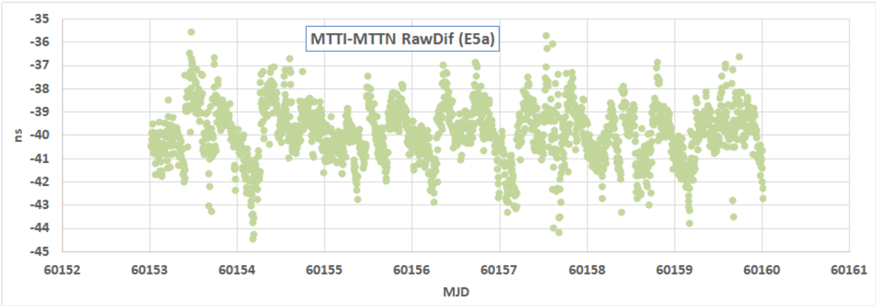


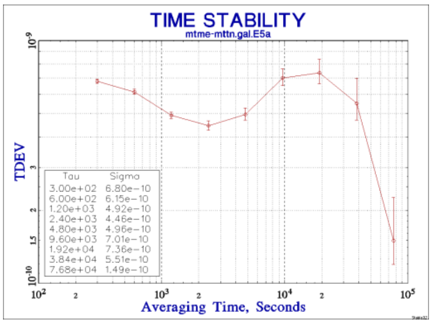









MTTI-MTTN RawDif (E5a)
ns
-35
-36
-37
-38
-39
-40
-41
-42
-43
-44
-45
60152
60153
60154
60155
60156
60157
60158
60159
60160
60161
MJD


TIME STABILITY
mtme-mttn.gal.E5a
TDEV
Tau Sigma
3.00e+02 6.80e−10
6.00e+02 6.15e−10
1.20e+03 4.92e−10
2.40e+03 4.46e−10
4.80e+03 4.96e−10
9.60e+03 7.01e−10
1.92e+04 7.36e−10
3.84e+04 5.51e−10
7.68e+04 1.49e−10
Averaging Time, Seconds

Reference

[1] BIPM "2022 Group 2 GPS calibration trip",

ftp://ftp2.bipm.fr /pub/tai/publication/gnss-calibration/group2/1016-2022

[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

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