

GNSS Calibration Report

CalId: 1101-2025
Page 2 of 16

Contents

1	Methodology	3
2	Ambient and measurement conditions	5
3	Common-clock set up in INTI	6
4	Results	7
4.1	CABDLY and REFDLY measurements	7
4.2	Measurement of rawdifferences	7
4.3	INTDLY determination	9

List of Figures

1	Definition of delays in a receiver station	4
2	Zero baseline / common clock measurement	4
3	Installation of antennas at INTI	5
4	Ambient conditions in INTI clock's room	5
5	UTC(INTI) reference point and 1 PPS signal distribution to GTR50, SIM, and DUT receivers.	6
6	Diagram of the PPS TX technique for the measurement of delays in cables. [6]	7
7	Raw P1, P2 and C1 pseudorange differences A-B between INTI (A) and DUT (B) receiver.	8

List of Tables

1	Acronyms used in this report	3
2	REFDLY, CABDLY and their differences between receivers, in nanoseconds with $k = 1$ coverage factor.	7
3	Median of $RAWDIF_{A-B}$ between receivers, in nanoseconds. See figure 7 and text.	8
4	$\Delta INTDLY$ for INTI and DUT. See table 3 and 2	9
5	Uncertainty assigned for each station, $k=1$	9
6	Results of calibration: INTDLY values, with $k = 1$ uncertainties.	10

List of Acronyms

GNSS Calibration Report

CalId: 1101-2025
Page 3 of 16

CABDLY	Delay in the antenna cable
DUT	Device Under Test
CGGTTS	Common GNSS Generic Time Transfer Standard
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
INTDLY	Internal delay of GNSS receiver
INTI	Instituto Nacional de Tecnología Industrial
ONBA	Observatorio Naval de Buenos Aires
PPS	Pulse per second
REFDLY	Delay of the cable between the reference point and the PPS-in connector of a receiver
RINEX	Receiver Independent Exchange
TDEV	Time deviation
UTC	Coordinated Universal Time

Table 1: Acronyms used in this report

1 Methodology

INTI conducted the calibration of a GNSS receiver relative to INTI's primary receiver, which currently serves as the reference receiver in dual-frequency time links for the realization of UTC(INTI)

The device under test (DUT, the receiver from ONBA) was calibrated over a 10-day interval by comparison with the INTI reference receiver, both operating on a common-clock referenced to UTC(INTI).

For this configuration, one commercial cesium clock provides the time reference of 1 PPS (Pulse Per Second) and the 10 MHz reference frequency.

The current campaign followed as much as possible the documents *BIPM guidelines for GNSS calibration* [1] and *How to get GNSS calibration for UTC(k) laboratories* [2]

The following text describes the definition of the several delays involved in a receiver calibration.

1. **INTDLY** The sum $X_R + X_S$ represents the "INT DLY" field in the CGGTTS header: X_R represents the receiver hardware delay, between a reference point whose definition depends on the receiver type and the internal time reference of the measurements. X_S represents the antenna delay, between the phase center and the antenna cable connector at the antenna body. We distinguish the two quantities for the two GPS frequencies, f1 and f2.

The following terms are considered frequency independent, i. e. no distinction is made for f1 and f2.

2. **CABDLY** The sum $X_C + X_D$ represents the "CAB DLY" field in the CGGTTS header. X_C corresponds to the delay of the long cable from the antenna to the input connector at either the antenna splitter or the receiver body directly. If a splitter is installed, X_D corresponds to the delay of the splitter and the small cable up to the receiver body. For a simple set-up with just an antenna cable, $X_D = 0$.
3. **REFDLY** The sum $X_P + X_O$ represents the "REFDLY" field in the CGGTTS header. X_P corresponds to the delay of the cable between the laboratory reference point for local UTC and the 1 PPS-in connector of the receiver. X_O is the delay between the PPS IN connector and the internal receiver time reference. (X_O was set to zero in the DUT receiver by enabling internal autocompensation)

INTDLY, CABDLY and REFDLY are depicted in figure 1, for the particular case of the DUT of the present report.

The INTI reference system consist of a DICOM GTR50 receiver unit, S/N 1203120 and a Novatel GPS-702 Antenna, S/N NAE11480028. The calibration certificate of the system is identified as 1014-2021 and can be consulted at <https://webtai.bipm.org/database/calib.html?calid=1014-2021>. This calibration of INTI system was part of a "Group 2" calibration campaign organized by NIST during the year 2021.

GNSS Calibration Report

CalId: 1101-2025
Page 4 of 16

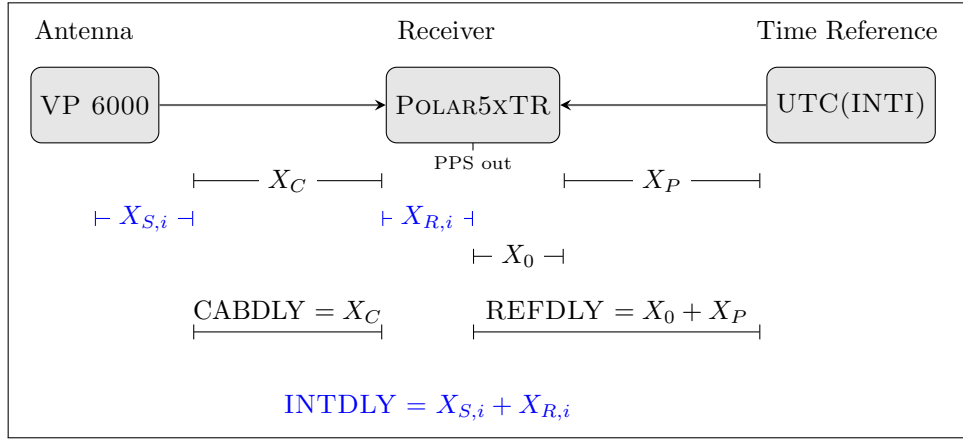


Figure 1: Definition of delays in a receiver station

The difference of the total delay for a pair of co-located receivers is the sum of the delays incurred in the antenna cable (CABDLY) and the internal delay (INTDLY), minus the time offset at the latching point of the receiver as referenced to a fixed point, usually UTC(k)(REFDLY). The internal delay is comprised of both code- and frequency-dependent delays in the antenna and the receiver. After accounting for the baseline geometry, the difference in pseudoranges between a pair of receivers, say for P1, is given by

$$RAWDIF(P1)_{A-B} = \Delta CABDLY_{A-B} + \Delta INTDLY_{A-B} - \Delta REFDLY_{A-B} \quad (1)$$

where $RAWDIF(P1)_{A-B}$ is the raw difference of pseudorange measurements of two receivers. Similarly for C1 and P2, $RAWDIF(C1/P2)_{A-B}$ is given by using the corresponding set of delays on the right hand side of Eq.(1). The configuration of the measurement is depicted in Figure 2.

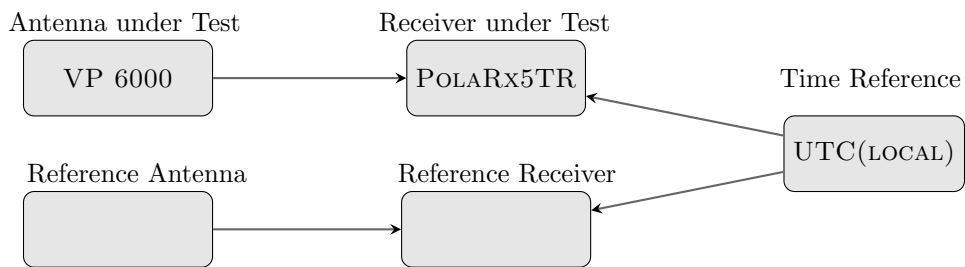


Figure 2: Zero baseline / common clock measurement

GNSS Calibration Report

CalId: 1101-2025
Page 5 of 16

2 Ambient and measurement conditions

Figure 3 illustrates the installation of the GNSS antennas on the roof of the INTI time laboratory during the calibration campaign. The DUT antenna was mounted in a different section of the building due to accessibility and length of cable constraints. The resulting baseline was approximately 10 m.



Figure 3: Installation of antennas at INTI

Ambient conditions (temperature, humidity, and pressure) were monitored in the clocks room during the calibration period (Figure 4). The temperature was controlled by an air conditioning system.

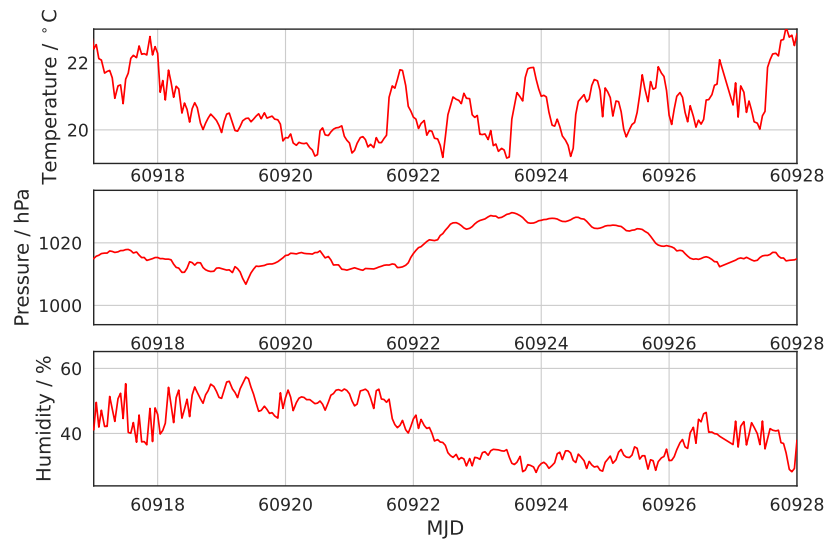


Figure 4: Ambient conditions in INTI clock's room

GNSS Calibration Report

CalId: 1101-2025
 Page 6 of 16

3 Common-clock set up in INTI

For the common-clock measurement, the installation of the receivers is depicted in figure 5. The trigger level of all PPS signals was set to 1 V. The rise time of the pulses was 1.4 ns.

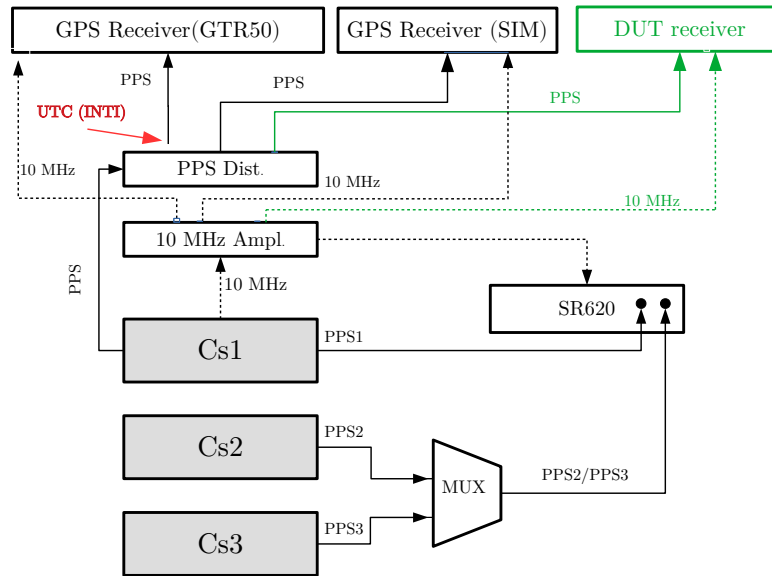


Figure 5: UTC(INTI) reference point and 1 PPS signal distribution to GTR50, SIM, and DUT receivers.

The DUT receiver (ONBB) was configured to apply the internal compensation, so that $X_0(PolaRx5TR) = 0$ ns during the measurement.

The 10 MHz and PPS cables used for the DUT receiver are those intended for its operation once returned to ONBA.

GNSS Calibration Report

CalId: 1101-2025
Page 7 of 16

4 Results

4.1 CABDLY and REFDLY measurements

The differences $\Delta CABDLY_{A-B}$ and $\Delta REFDLY_{A-B}$ for INTI(A) and ONBA (B) receivers are given in Table 2, referenced from Annexes at the end of this report. The measurement technique for the cable delays was the one described in [3] as *1 PPS TX technique*. A diagram of the measurements is shown in Figure 6. The 1 PPS TX measurement is performed by inserting a test cable in a test setup, and by evaluating the delay change before and after the insertion. The hardware setup is made of a 1 PPS source and distributor and two arbitrary cables.

The mean and standard deviation of 100 measurements were computed.

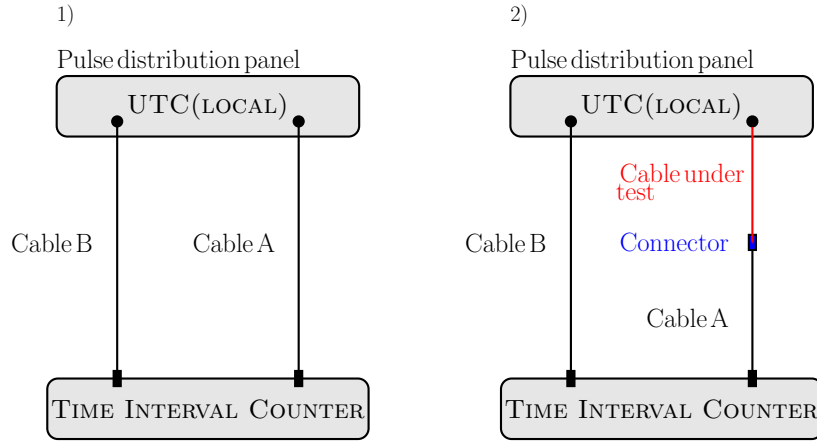


Figure 6: Diagram of the PPS TX technique for the measurement of delays in cables. [6]

REFDLY(GTR)	REFDLY(ONBB)	CABDLY(GTR)	CABDLY(ONBB)	$\Delta REFDLY$	$\Delta CABDLY$
8.0 ± 0.1	41.1 ± 0.1	129.3 ± 0.1	80.6 ± 0.1	-33.1 ± 0.1	48.7 ± 0.1

Table 2: REFDLY, CABDLY and their differences between receivers, in nanoseconds with $k = 1$ coverage factor.

4.2 Measurement of rawdifferences

The RINEX files from the two co-located receivers, collected over a 10-day measurement period (corresponding to the MJD range in Table 3), were processed using two independent methods.

First, the *dclrinex* software provided by the BIPM was employed to calculate the rawdifferences between the two receivers, using L1 and L2 phase differences [5].

Second, the measurements were processed with the GNSS_cal_tools software developed at INTI [6] (Figure 7), using the baseline computed with the PPP service provided by the Canadian Geodetic Survey.

The median results from both processing methods show excellent agreement at the 0.1 nanosecond level. Time Deviation was used as the metric to estimate measurement noise.

Table 3 shows the results of the measurements.

GNSS Calibration Report

CalId: 1101-2025
Page 8 of 16

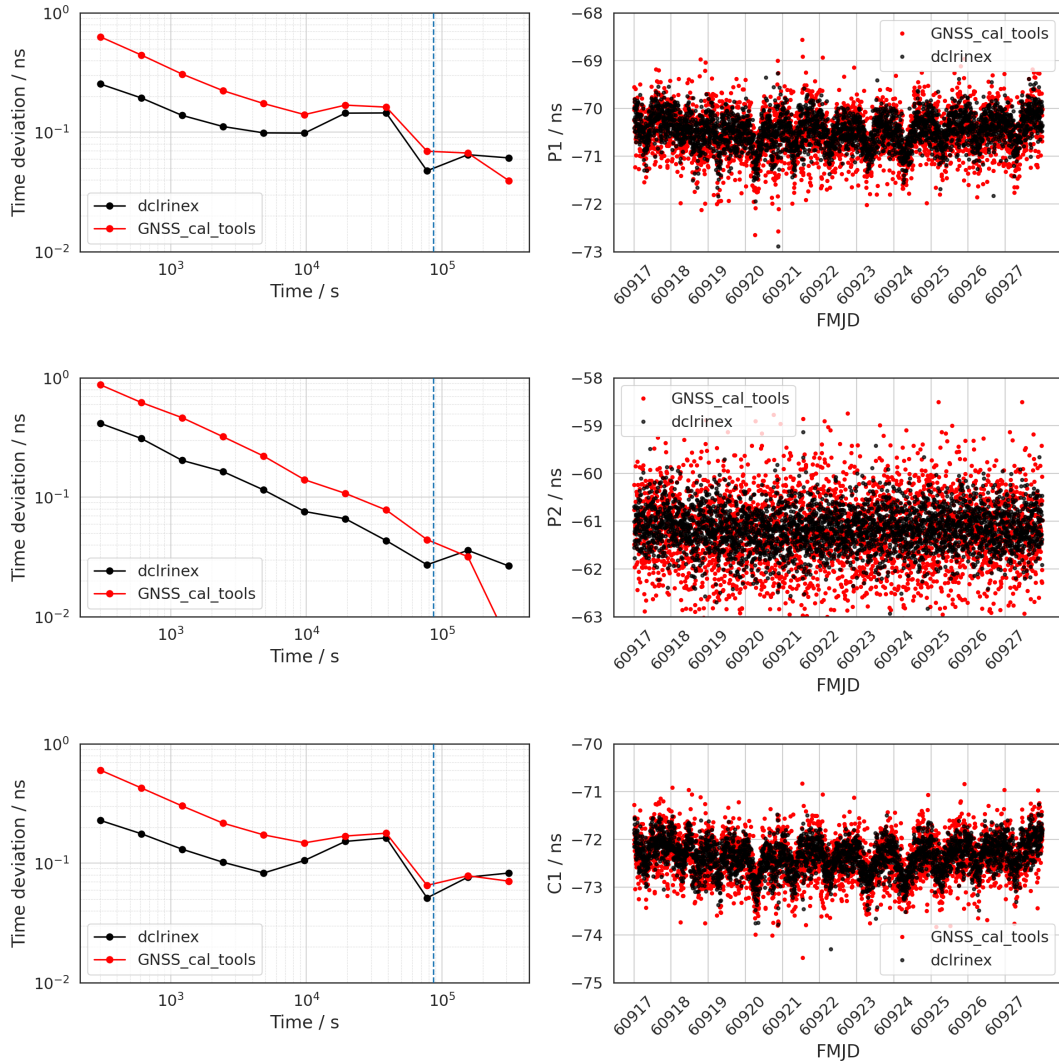


Figure 7: Raw P1, P2 and C1 pseudorange differences A-B between INTI (A) and DUT (B) receiver. Results obtained with the use of the softwares dclrinex and GNSS_cal_tools applied to the RINEX output of both receivers, combined with the AllanTools 2019.9 python library for calculating Allan deviation and related statistics. The blue dashed line indicates the position for $\tau = 1$ day.

Pair A-B	MJD	RAWDIF(P1)	RAWDIF(P2)	RAWDIF(C1)
INTI-ONBA	60917-60927	-70.4	-61.2	-72.3

Table 3: Median of RAWDIF_{A-B} between receivers, in nanoseconds. See figure 7 and text.

GNSS Calibration Report

CalId: 1101-2025

Page 9 of 16

4.3 INTDLY determination

The values of $\Delta INTDLY(P1, P2, C1)$ were obtained from the results of the rawdifferences and the cable delays, applying equation 1.

Pair A-B	MJD	$\Delta INTDLY(P1)$	$\Delta INTDLY(P2)$	$\Delta INTDLY(C1)$
INTI-ONBA	60917-60927	-30.95	-21.66	-32.84

Table 4: $\Delta INTDLY$ for INTI and DUT. See table 3 and 2

IT IS IMPORTANT TO NOTICE THAT THE RINEX FILES GENERATED BY THE GTR50 RECEIVER ARE ALREADY CORRECTED FOR INTDLY, CABDLY AND REFDLY.

The combined uncertainty u of the INTDLY values is given by:

$$u = \sqrt{u_a^2 + u_b^2}$$

with u_a the statistical uncertainty u_b and the systematic uncertainty [8]. The statistical uncertainty is related to the instability of the common clock data collected at INTI. In this kind of calibrations, u_a is estimated by the value of TDEV($\tau = 1$ day).

The TDEV plots show marginal values at one day of integration time, therefore, a value of 0.1 ns is assigned as a conservative estimate of u_a for C1, P1 and P2 differences. The systematic uncertainty is given by

$$u_b = \sqrt{\sum_n u_{b,n}^2 + u_{ref}^2}$$

u_{ref}^2 depicts the uncertainty in the reference receiver as detailed in circular T for the calibration period. i.e., the ageing term is included [9] [10].

Systematic and statistical uncertainties are assigned as given in Table 5.

Quantity	unc type	value / ns
RAWDIF(P1)	u_a	0.1
RAWDIF(P2)	u_a	0.1
RAWDIF(C1)	u_a	0.1
INTI antenna position	$u_{b,11}$	0.05
ONBA antenna position	$u_{b,12}$	0.05
INTI multipath	$u_{b,13}$	0.2
ONBA multipath	$u_{b,13}$	0.2
REFDLY _{GTR}	$u_{b,21}$	0.1
REFDLY _{ONBB}	$u_{b,22}$	0.1
CABDLY _{GTR}	$u_{b,31}$	0.1
CABDLY _{ONBB}	$u_{b,32}$	0.1
INTDLY _{GTR}	u_{ref}	3.5

Table 5: Uncertainty assigned for each station, k=1.

The combined uncertainty given in Table 6 is obtained by combining uncorrelated (assumed) uncertainties in quadrature.

GNSS Calibration Report

CalId: 1101-2025
Page 10 of 16

Receiver model and S/N	Antenna model and S/N	INTDLY(P1)	INTDLY(P2)	INTDLY(C1)
PolaRx5TR, 4701591	VP 6000, 33-605000-01-01	(30.9 ± 3.5) ns	(21.7 ± 3.5) ns	(32.8 ± 3.5) ns

Table 6: Results of calibration: INTDLY values, with $k = 1$ uncertainties.

GNSS Calibration Report

CalId: 1101-2025

Page 11 of 16

References

- [1] https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/bipmcalibration_guidelines_v40.pdf
- [2] <https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/How-to-get-calibration-March2024.pdf>
- [3] Rovera, D., Abgrall, M., Uhrich, P., & Siccaldi, M. (2015, April). Techniques of antenna cable delay measurement for GPS time transfer. In 2015 Joint Conference of the IEEE International Frequency Control Symposium & the European Frequency and Time Forum (pp. 239-244). IEEE.
- [4] Rovera, G. D., Siccaldi, M., Römisch, S., & Abgrall, M. (2019). Time delay measurements: estimation of the error budget. *Metrologia*, 56(3), 035004.
- [5] <ftp://ftp2.bipm.org/pub/tai/publication/gnss-calibration/doc-soft/>
- [6] https://github.com/diegoluna1980/GNSS_cal_tools
- [7] BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, and OIML. Evaluation of measurement data — An introduction to the “Guide to the expression of uncertainty in measurement” and related documents. Joint Committee for Guides in Metrology, JCGM 104:2009. https://www.bipm.org/documents/20126/2071204/JCGM_104_2009.pdf/19e0a96c-6cf3-a056-4634-4465c576e513
- [8] JCGM 100:2008: Evaluation of measurement data — Guide to the expression of uncertainty in measurement https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6
- [9] <https://webtai.bipm.org/ftp/pub/tai/Circular-T/cirt/cirt.434>
- [10] https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.6.pdf

Annex A - Information Sheet

(to be repeated for each calibrated system)

Laboratory:	INTI	
Date and hour of the beginning of measurements:	MJD 60917, 00:00 UTC	
Date and hour of the end of measurements:	MJD 60927, 23:59 UTC	
Information on the system		
	Local:	Travelling:
4-character BIPM code	INTI	ONBB
• Receiver maker and type:	DICOM GTR50	Septentrio PolaRx5TR
Receiver serial number:	1203120	4701591
1 PPS trigger level /V:	1	1
• Antenna cable maker and type:	BELDEN VENLO	RFS Linha kmp RGC-58, Celular
Phase stabilised cable (Y/N):	N	N
Length outside the building /m:	~5m	~15m
• Antenna maker and type:	Novatel, GPS-702	Tallysman, Veraphase 6000
Antenna serial number:	NAE11480028	33-605000-01-01
Temperature (if stabilised) /°C	-	-
Measured delays /ns		
Please tick the correct box depending on the receiver (1)		
	Local:	Travelling:
	REF point is PPSIN ☒	REF point is PPSIN ☒
• Delay from local UTC to receiver 1 PPS-in (REFDLY):	(8,0 ± 0,1) ns	(41,1 ± 0,1) ns
• Optional Delay from local UTC to receiver 1 PPS-Out:	-	-
	REF point is PPSOUT ☐	REF point is PPSOUT ☐
• Delay from local UTC to receiver 1 PPS-Out (REFDLY):	-	-
• Optional Delay from local UTC to receiver 1 PPS-in:	-	-
	REF point. TTS 4/5 ☐	REF point. TTS 4/5 ☐
• Delay from local UTC to receiver 1 PPS-in:	-	-
• Delay from 1 PPS-in to 10 MHz input receiver:	-	-
• Computed 1PPS frequency offset correction:	-	-
• Computed REFDLY by the receiver:	-	-
	(Not to be filled)	REF point is calibration point ☐
• Delay from local UTC to traveling box calibration point:	(Not to be filled)	
	Other case ☐	Other case ☐
Please describe measurements and final REFDLY value		
• Antenna cable delay:	(129,3 ± 0,1) ns	(80,6 ± 0,1) ns
Splitter delay (if any):	-	-(2)

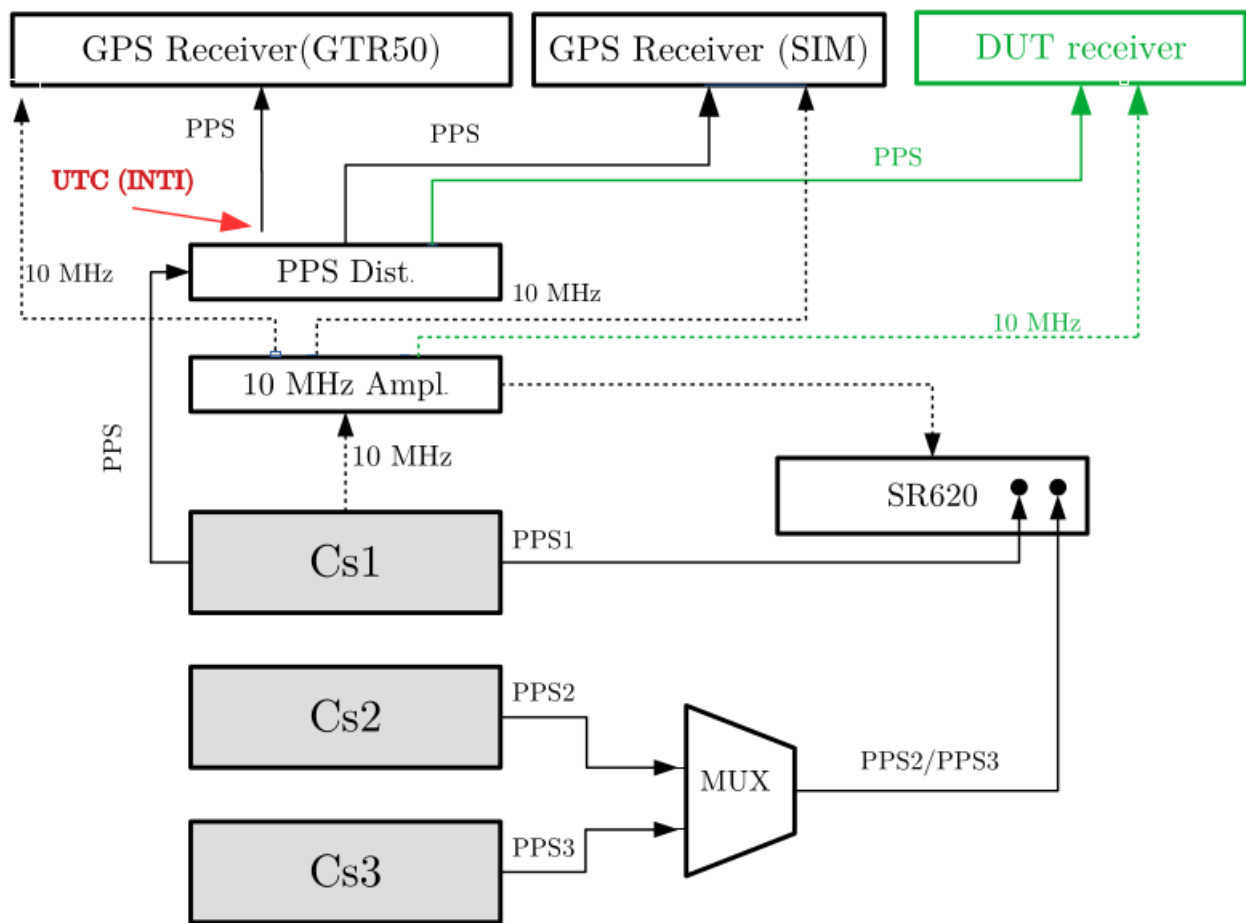
Additional cable delay (if any):	-	- (1)
Data used for the generation of CGGTTS files Complete this section only if CGGTTS-format data were used for the calibration. Please fill with the parameter values as configured in the receiver at the time of calibration		
• INT DLY (GPS) /ns:	--	
• INT DLY (Galileo) /ns:	--	
• INT DLY (BDS) /ns:	--	
• INT DLY (GLONASS) /ns:	--	
• CAB DLY /ns:	--	
• REF DLY /ns:	--	
• Coordinates reference frame:	--	
Latitude or X /m:	--	
Longitude or Y /m:	--	
Height or Z /m:	--	
General information		
• Rise time of the local UTC pulse:	(1,4 ± 0,1)ns	
• Is the laboratory air conditioned:	Yes	
Set temperature value and uncertainty:	(21 ± 2) °C	
Set humidity value and uncertainty:	-	

(1) Typical cases:

- REF point is PPSIN: Mesit GTR receivers, Piktime TTS3, Polarx5 with autocompesation mode activated
- REF point is PPSOUT: Septentrio Polarx3, Polarx4, Polarx5 Polarx5 with no autocompesation mode activated. (For all Septentrio receivers PPSOUT must be RxClock). Novatel OEM4, OEM5 or OEM6 (Please check the documentation to configure the receivers accordingly)
- REF point for TTS 4/5 receivers: Piktime TTS4, TTS5
- REF point can be the calibration point for some G1 calibration box. Please refer to the G1 instructions.

(2) For a trip with closure, not needed if the traveling equipment is used in the same set-up throughout.

Diagram of the experiment set-up:



Log of Events / Additional Information :

--



INTI

Instituto
Nacional
de Tecnología
Industrial



Ministerio de Economía
Argentina

Secretaría de Industria
y Desarrollo Productivo

GNSS Calibration Report

CalId: 1101-2025
Page 16 of 16

END OF DOCUMENT