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Calibration of a sigle frequency GNSS receiver

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Issue 1.1

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1 Summary

1.1 General informations

This Calibration Report released by INRiM is about the relative calibration campaign of a GNSS receivers located at NIST.

It is built according to the Annex 4 of the document “BIPM guidelines for GNSS equipment calibration” [**?**], and contains all the information required by BIPM in the frame of the CCTF Working Group on GNSS. It also contains the uncertainty budget computed according to the Guidelines, which is showing whether the calibrated links used in the frame of the TAI computation would be in line with the conventional values.

1.2 Calibration report changes

This is Issue 1.1 of the Calibration report

2 Acronym list and Reference Documents

2.1 Acronym list

1PPS:	One Pulse per second
ADEV:	Allan deviation, square root of AVAR
AVAR:	Allan variance or two-sample variance
BIPM:	Bureau International des Poids et Mesures, Sèvres, France
CCTF:	Consultative Committee on Time and Frequency
CGGTTS:	CCTF Global GNSS Time Transfer Standard format
CIPM:	Comité International des Poids et Mesures

GLONASS:	Russian GNSS
GNSS:	Global Navigation Satellite System
GPS:	United States of America GNSS
INRiM	Istituto Nazionale di Ricerca Metrologica
MDEV:	Modified Allan deviation, square root of MVAR
MVAR:	Modified Allan variance
NIST:	National Institute of Standards and Technology, United States NMI
NMI:	National Metrology Institute
NRCan:	Natural Resources Canada
OP:	Observatoire de Paris, France
PPP:	Precise Point Positioning
PTB:	Physikalisch-Technische Bundesanstalt, German NMI
RINEX:	Receiver International Exchange format for Geodesy
TDEV:	Time Allan deviation, square root of TVAR
TIC:	Time Interval Counter
TVAR:	Time Allan variance derived from AVAR and MVAR

2.2 Reference Documents.

References

[1] BIPM, "BIPM guidelines for GNSS calibration", V4.0 05/08/2021 at https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/bipmcalibration_guidelines_v40.pdf.

[2] G.D. Rovera, J-M. Torre, R. Sherwood, M. Abgrall, C. Courde, M. Laas-Bourez and P. Uhrich, "Link calibration against receiver calibration: an assessment of GPS time transfer uncertainties", Metrologia 51 (2014) 476-490.

[3] Siccardi M, Abgrall M and Rovera G 2012 About time measurements *European Frequency and Time Forum (EFTF), 2012* pp 379–382.

3 Description of equipment and operations

The relative calibration of the GNSS receivers located at INM (Colombia) was organized by NIST. The reference receiver for this measurement campaign is NIST (BIPM code NISX), a Septentrio PolaRx5 TR multichannel multi-frequencies receiver located in NIST Boulder. This receiver was relatively calibrated by BIPM in the frame of the 1001-2022 G1 calibration campaign.

Table 1 presents a summary of the timetable and of the equipment.

Table 1: Summary information on the calibration trip.

Institute	Status of equipment	MJD of measurement	Receiver type	BIPM code	RINEX name
NIST	Traveling		SEPT POLARX5TR	NB05	NB05
NIST	Group 1 Reference	60888 – 60893	SEPT POLARX5TR	NISX	NIST
NIST	Group 1 Reference	60924 – 60927	SEPT POLARX5TR	NISX	NIST
INM	Group 2	60699 – 60704	NIST-TAI	IC__	IC__

4 Data used

The NIST collected raw data are transformed into RINEX format by using the Septentrio sbf2rin software. The the calibrated receiver only produces C1 CGGTTS data. The calibration is consisting in building differential pseudoranges between pairs of receivers for each code, these differences being corrected by the known reference (REFDLY) and antenna cable (CABDLY) delays when they are available. For each location, the coordinates of the antenna phase centers are especially computed for the calibration period from RINEX files by using the NRCan PPP software. For the INM receiver the antenna coordinate are reported in CGGTTS files.

As conservative estimate, the noise of the C1 common clock differences is obtained from the highest value of the one-sigma error bar of the TDEV at 1 d. In the case there is not enough data to compute a TDEV at 1 d, the upper limit of the last error bar available is considered as noise of the raw differences.

Reference delays are measured against the local time scale UTC(IT) physical reference point at 1 V trigger level. Antenna cable delay is either obtained from dedicated measurements or included in the C1 delay when no value is available for this parameter. In this latter case, the CABDLY value is set to 0 in the parameter file and INT DLYs has to be assumed as SYS DLYs.

5 Results of raw data processing

Table 2 provides a summary of the C1 delays computed from the raw differences between RINEX files. The REFDLY and CABDLY values were either measured on site or taken as known parameter for a given receiving chain. From our point of view, Table 2 is the most comprehensive summary of the calibration campaign.

Table 2: Summary information on GPS receivers delay (all values in ns).

Receiver	Reference	MJD of measurement	REFDLY	CABDLY	C1_DLY	TDEV		
NIST	Ref	60888 – 60893	121.6	275.5	31.0			
NB05	NIST	60888 – 60893	469.7	328.6	33.147	0.046		
NIST	Ref	60924 – 60927	115.3	275.5	31.0			
NB05	NIST	60924 – 60927	437.1	328.6	30.361	0.263		
NB05	Ref	60699 – 60704	101.3	328.6	31.754			
IC__	NB05	60699 – 60704	60.6	176.6	18.9	2.0		

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

Pair	MJD of measurement	Rawdiff C1	TDEV C1						
NB05-NIST	60888 – 60893	292.853	0.045						
NB05-NIST	60924 – 60927	269.339	0.249						
IC__-NB05	60699 – 60704	124.154	6.969						

In addition, the Table 3 is providing the RAWDIF values as required by reference [?]. All the plots of C1 computed delays and of the related TDEV analysis are provided in Annex B. For this particular case where the RINEX files of the calibrated receiver are not available the previous calibration value is already embedded in CGGTTS files and therefore the evaluated C1 internal delay is not the new calibration value but must be added to the one already embedded.

6 Calibration results

6.1 Uncertainty estimation

We provide in this Section an estimation of the uncertainty of the differential calibration for the receiver at INM (Colombia). All the uncertainty budgets have been built according to the reference [1] in order to provide the required u_{CAL0} values. The details on the systematic uncertainties are provided in Annex C.

Table 4: IC__ uncertainty contributions (all values in ns).

Uncertainty	Value C1				Description
u_a(NB05-NIST)	0.1				TDEV(1 d)
u_a(NB05-IC__)	2.0				TDEV(1 d)
u_a	2.0				Visited-reference
Misclosure					
$u_{b,1}$	2.8				Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20				Position error at reference
$u_{b,12}$	0.20				Position error at visited
$u_{b,13}$	0.20				Multipaths at reference
$u_{b,14}$	0.20				Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.50				REFDLY (at ref lab)
$u_{b,22}$	0.50				REFDLY (at visited lab)
Link of the Reference system to its local UTC(k)					
$u_{b,31}$	0.50				REFDLY (at ref lab)
Link of the Visited system to its local UTC(k)					
$u_{b,32}$	0.50				REFDLY (at visited lab)
Antenna cable delays					
$u_{b,41}$	0.0				CABDLY reference
$u_{b,42}$	0.0				CABDLY visit
$u_{b,SYS}$	3.0				Quadratic sum of u_b
u_{CAL0}	3.6				Composed of u_a and $u_{b,SYS}$

7 Final results for the system to calibrate

Table 5: Summary information on receiver delay (all values in ns).

BIPM code	**Rinex name**	**Cal Id**	**Date**	**INTDLY C1/ns**			
Reference system							
NISX	NIST	1001_2022	2024/10/18	31.0			
Visited system(s)							
IC__	IC__	NIST_2025	Sept 2025	18.9			

Table 6: Conservative k=2 expanded uncertainties for all receivers with using NIST as a reference following EURAMET standard (all values in ns).

BIPM code	**Rinex name**	**u(C1)**/ns					
IC__	IC__	7.2					

Table 5 is providing the final results of this calibration campaign, by following the BIPM Guidelines. In addition, Table 6 is providing the computed conservative k = 2 expanded uncertainties in order to be in line with EURAMET recommendations.

Note that the previous calibration value of 26.3 ns is already embedded in CGGTTS files of the IC__ receiver and therefore the evaluated C1 internal delay evaluatd in this repost has to be added to the previous one.

Note also that the uncertainty of the INT DLY values of NIST's fixed receiver NIST which served as the reference is not included.

Annex A - Information Sheet

Laboratory:	**INM Colombia**
Date and hour of the beginning of measurements:	2025-01-24 00:00 (UTC)
Date and hour of the end of measurements:	2025-02-01 23:37 (UTC)

Information on the system		
	Local:	**Traveling:**
4-character BIPM code	**IC__**	
Receiver maker and type: Receiver serial number:	NIST TAI-1 Model: SRI 6004 NIST TAI-1 Serial Number BIPM: 103	SEPTENTRIO PolaRx5TR 4701275
1 PPS trigger level /V:	1 V	
Antenna cable maker and type: Phase stabilized cable (Y/N):		
Length outside the building /m:		
Antenna maker and type: Antenna serial number:	NOVATEL GPS-701-GG Serial: 01017576	SEPTENTRIO PolaNt-X MF.v2 5251
Temperature (if stabilized) /°C		

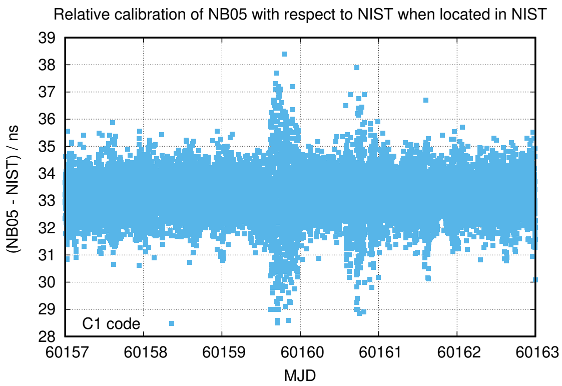
Measured delays /ns		
	Local:	**Traveling:**
Delay from local UTC to receiver 1 PPS-in (X_P)		86.427 ns
Delay from 1 PPS-in to internal Reference (if different): (X_O)		116.158 ns
Antenna cable delay: (X_C)		
Splitter delay (if any):		
Additional cable delay (if any):		

Data used for the generation of CGGTTS files	
INT DLY (or X_R+X_S) (GPS) /ns:	26.3 ns
INT DLY (or X_R+X_S) (Galileo) /ns:	
CAB DLY (or X_C) /ns:	176.6 ns
REF DLY (or X_P+X_O) /ns:	60.6 ns
Coordinates reference frame:	WGS84
X /m:	1743180.352 m
Y /m:	-6116396.744 m
Z /m	513046.768 m

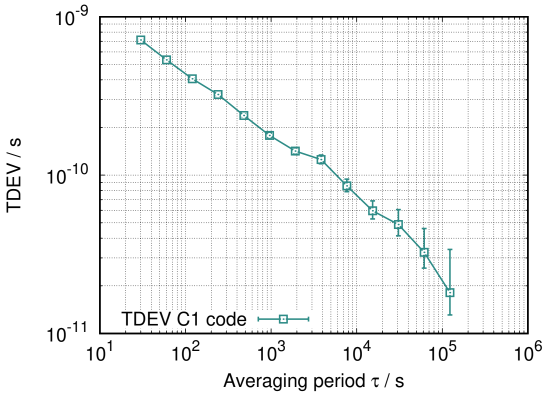
General information	
Rise time of the local UTC pulse:	
Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	21.57 °C with U = 0.21 °C
Set humidity value and uncertainty:	40.82 %HR with U=1.8 %HR

Annex B: Plots of raw data and TDEV analysis

1 Measurements in NIST start of the campaign



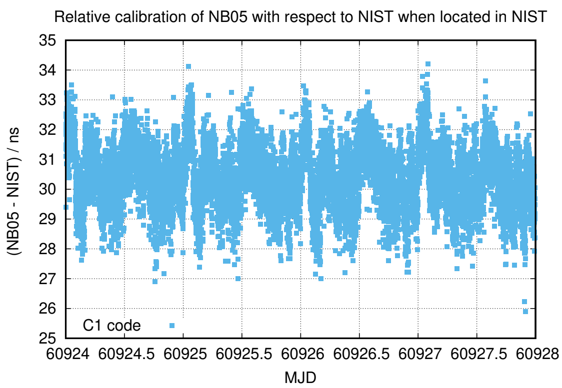
(a) P-code phase differences



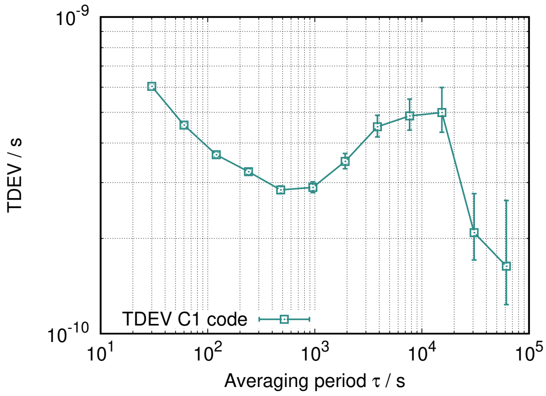
(b) TDEV of P-code delays

Figure 1: Relative calibration of NB05 with respect to NIST from MJD 60888 to in NIST. The C-code phase differences (a) are built from RINEX files. Related TDEV (b) of C-code delays.

2 Measurements in NIST end of the campaign



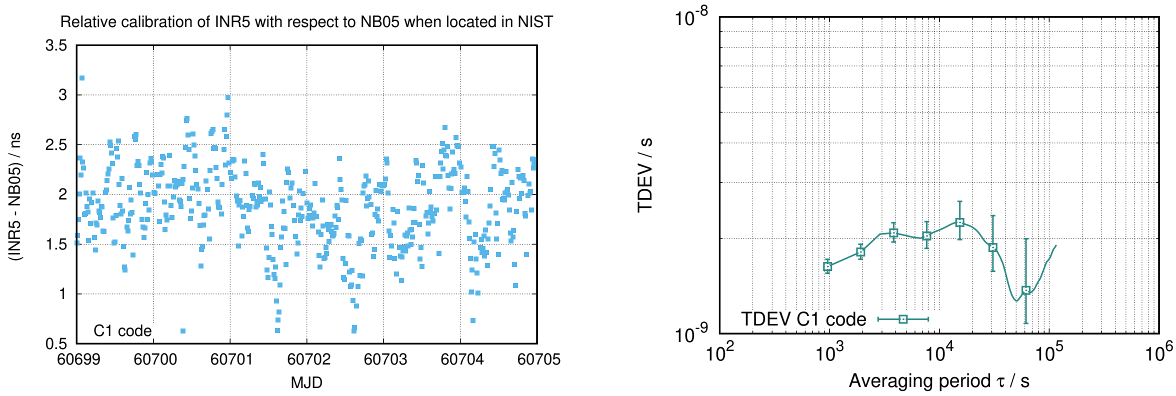
(a) P-code phase differences



(b) TDEV of P-code delays

Figure 2: Relative calibration of NB05 with respect to NIST from MJD 60924 to in NIST. The C-code phase differences (a) are built from RINEX files. Related TDEV (b) of C-code delays.

3 Measurements in IMC Calibration of IC__



(a) C-code phase differences

(b) TDEV of C-code delays

Figure 3: Relative calibration of IC__ with respect to NB05 from MJD 60699 to 60704 in NIST. The C-code phase differences (a) are built from RINEX files. Related TDEV (b) of C-code delays.

Annex C: Uncertainty budget terms

1 Statistical uncertainty

The statistical uncertainty u_a(A-B) for the comparison between two receivers A and B is evaluated by taking the upper limit of the error bar of the TDEV at 61 440 s (close to 1 d) when available, or otherwise the upper limit of the last error bar available. When two traveling receivers are used for the campaign the retained value is the average of the two statistical uncertainty evaluated as above. The statistical uncertainty of the calibration is obtained by the quadratic sum of the uncertainty at reference site and the one at visited site.

$u^2{}_a = u^2{}_a(\text{T-R}) - u^2{}_a(\text{T-V})$

2 Type B uncertainties

- $u_{b,1}$ observed maximum misclosure. This uncertainty component is an estimation of the stability of equipment during the campaign. When a single receiver is traveling the only possible estimation is the classical misclosure. With two traveling receivers it is also possible to estimate the stability of the ensemble during the trip by computing the offset between these receivers when implemented in all sites. The misclosure $u_{b,1}$ we use is the maximum value between the actual misclosure between the start and the end of the campaign and the offset between both traveling equipment
- $u_{b,11}$ position error at reference site. The conventional value agreed at CCTF WG on GNSS is 200 ps.
- $u_{b,12}$ position error at visited site. The conventional value agreed at CCTF WG on GNSS is 200 ps.
- $u_{b,13}$ multipath at reference site. We propose a value of 200 ps. It is in line with the conventional value proposed by the CCTF WG on GNSS.
- $u_{b,14}$ multipath at visited site. Same as above.
- $u_{b,21}$ REFDLY (traveling receiver at reference lab). Uncertainty of the measure of the time difference between the reference point of the traveling receiver and the local UTC(k). The used value is the quadratic sum of a conventional value (200 ps) with the standard deviation of the actual measurement. When the REFDLY is obtained by summing several individual measurement the uncertainty is increased by quadratic sum as required.
- $u_{b,22}$ REFDLY (traveling receiver at visited lab). Same as above.
- $u_{b,TOT}$: Quadratic sum of all previous u_b.
- $u_{b,31}$ REFDLY uncertainty of the reference system to its local UTC(k). Computed as $u_{b,21}$. This term can be set to 0 when the reference has been recently calibrated, the uncertainty of REFDLY being already included in the calibration of the reference receiver.
- $u_{b,32}$ REFDLY uncertainty (at visited lab) of the link of the visited system to its local UTC(k). Computed as $u_{b,21}$. When this delay is measured and the $u_{b,32}$ is taken into account, the local distribution system can be modified afterwards without loosing the calibration.

- $u_{b,41}$ uncertainty of Antenna Cable delay at reference station. Same consideration as for REFDLY above.
- $u_{b,42}$ uncertainty of Antenna Cable delay at visited station. Same consideration as for REFDLY above. When for some reason the Antenna Cable of the traveling system is changed during the campaign $u_{b,42}$ is obtained by the quadratic sum of the uncertainty of the Antenna Cable of the visited station and of the traveling equipment.
- $u_{b,SYS}$: Quadratic sum of all type B uncertainty.
- u_{CAL0}: Quadratic sum of u_a and $u_{b,SYS}$. This uncertainty is for the link between the calibrated receiver and the reference receiver, without taking into account the uncertainty of this reference receiver.