Calibration Report Cal_Id 1018_2022

Calibration transfer of GNSS receivers in INRiM
GPS and Galileo internal delays

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Issue 1.1

Prepared by: G. D. Rovera, T. T. Thai, A. Perucca

INRiM
Strada delle cacce 91, 10135, Torino

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1 Summary

1.1 General informations

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

It is built according to the Annex 4 of the document “BIPM guidelines for GNSS equipment calibration” [1], 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. This calibration transfer is necessary due to the change of the receiver of the IENG station from Septentrio PolaRX-4 to Septentrio PolaRX-5.

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
NMI:	National Metrology Institute
NRCan:	National Ressources 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

[2] G. D. Rovera, M. Siccardi, S. Römisch, and M. Abgrall, “Time delay measurements: estimation of the error budget,” *Metrologia*, vol. 56, p. 035004, may 2019.

[3] 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*, vol. 51, no. 5, p. 476, 2014.

[4] D. Rovera, M. Abgrall, P. Uhrich, and M. Siccardi, “Techniques of antenna cable delay measurement for gps time transfer,” in *Frequency Control Symposium the European Frequency and Time Forum (FCS), 2015 Joint Conference of the IEEE International*, pp. 239–244, April 2015.

3 Description of equipment and operations

The relative calibration of the GNSS receivers located at INRIM was organized by INRiM. The reference receiver for this measurement campaign is INR5, a Septentrio PolaRx4 TR multichannel multi-frequencies receiver located in INRiM. This receiver was relatively calibrated by OP in the frame of a G2 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
INRiM	Calibrated Receiver	60126 – 60131	Septentrio PolaRx5TR	IT07	IENG
INRiM	Group 2 Reference	60126 – 60131	Septentrio PolaRx4TR	IT08	INR5

4 Data used

The INR5 collected raw data are transformed into RINEX format by using the Septentrio sbf2rin software. The same software is also used to convert to RINEX format the raw data of the calibrated receiver. 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.

As conservative estimate, the noise of the P1 and P2 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. The noise of P3 data is issued from a similar TDEV analysis.

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 P1 and P2 delays 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.

For validation purposes, P3 CGGTTS files are computed by using the R2CGGTTS software provided by P. Defraigne (ORB), and CV are built between pairs of receivers.

5 Results of raw data processing

Table 2 provides a summary of the P1 and P2 delays computed from the raw differences between RINEX files, while Table 3 provides the same summary for E1 and E5a delays, together with the REFDLY and CABDLY used for these computations. 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 Table 3 are 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	P1_DLY	TDEV	P2_DLY	TDEV
INR5	Ref	60126 – 60131	483.9	0.0	309.0		308.5	
IENG	INR5	60126 – 60131	372.7	130.5	26.815	0.039	27.402	0.049

Table 3: Summary information on Galileo receivers delay (all values in ns).

Receiver	Reference	MJD of measurement	REFDLY	CABDLY	E1_DLY	TDEV	E5a_DLY	TDEV
INR5	Ref	60126 – 60131	483.9	0.0	309.9		320.3	
IENG	INR5	60126 – 60131	372.7	130.5	29.080	0.029	31.003	0.041

Table 4: Summary information on raw GPS calibration results (all values in ns).

Pair	MJD of measurement	Rawdiff P1	TDEV	Rawdiff P2	TDEV
IENG-INR5	60126 – 60131	40.485	0.039	39.398	0.049

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In addition, the Table 5 is providing the RAWDIF values as required by reference [1]. All the plots of P1 and P2, E1 and E5a computed delays and of the related TDEV analysis are provided in Annex B.

Table 5: Summary information on raw Galileo calibration results (all values in ns).

Pair	MJD of measurement	Rawdiff E1	TDEV	Rawdiff E5a	TDEV
IENG-INR5	60126 – 60131	39.120	0.029	47.957	0.041

The P3 and E3 CV computed by using the results of the calibration and the related TDEV analysis are also made available in Annex B.

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 INRIM. 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. Here is presented only the GPS uncertainty budget, but the same holds for Galileo replacing P1,P2 and P3 with E1,E5a and E3

Table 6: IENG uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
u_a(IENG-INR5)	0.1	0.1	0.141	0.1	TDEV(1 d)
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths
Link of the Reference system to its local UTC(k)					
$u_{b,31}$	0.220	0.220		0.220	REFDLY (at ref lab)
Link of the Calibrated system to its local UTC(k)					
$u_{b,32}$	0.220	0.220		0.220	REFDLY (at visited lab)
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	CABDLY reference
$u_{b,42}$	0.0	0.0		0.0	CABDLY visit
Total uncertainty					
$u_{b,SYS}$	0.419	0.419		0.419	Quadratic sum of u_b
u_{CAL0}	0.431	0.431		0.431	Composed of u_a and $u_{b,SYS}$

7 Final results for the system to calibrate

Table 7 is providing the final results of this calibration campaign, by following the BIPM Guidelines. In addition, Table 8 is providing the computed conservative k = 2 expanded uncertainties in order to be in line with EURAMET recommendations. Note that the uncertainty of the INT DLY values of INRiM's fixed receiver INR5 which served as the reference is not included.

Table 7: Summary information on the calibration trip.

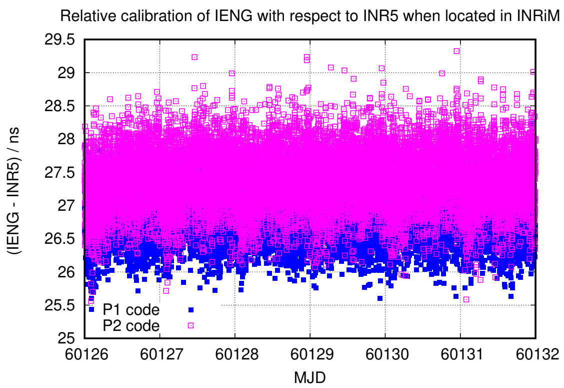
BIPM code	**Rinex name**	**Cal Id**	**Date**	**INTDLY P1/ns**	**INTDLY P2/ns**	**INTDLY E1/ns**	**INTDLY E5a/ns**
Reference system							
IT10	INR5	1018_2022	2022/08/26	309.0	308.5	309.9	320.3
Visited system(s)							
IT07	IENG	1018_2022	June 2023	26.8	27.4	29.1	31.0

Table 8: Conservative k=2 expanded uncertainties for all receivers with using INR5 as a reference following EURAMET standard (all values in ns).

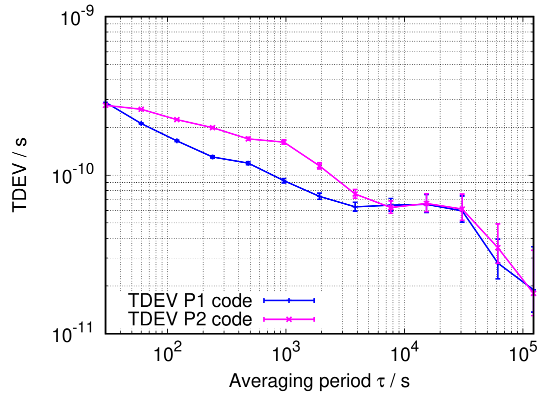
BIPM code	Rinex name	u(P1)	u(P2)	u(P3)	u(E1)	u(E5a)	u(E3)
IT07	IENG	0.9	0.9	0.9	0.9	0.9	0.9

Annex B: Plots of raw data and TDEV analysis

1 Measurements in INRiM

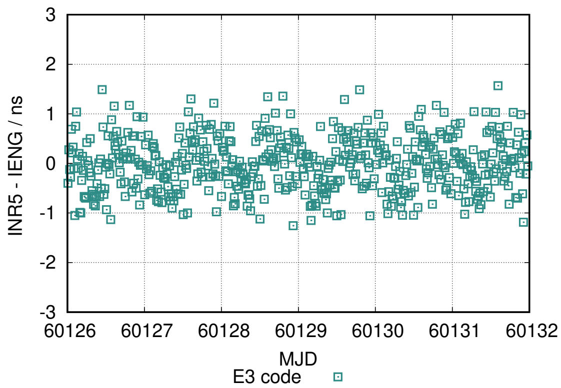


(a) P-code phase differences

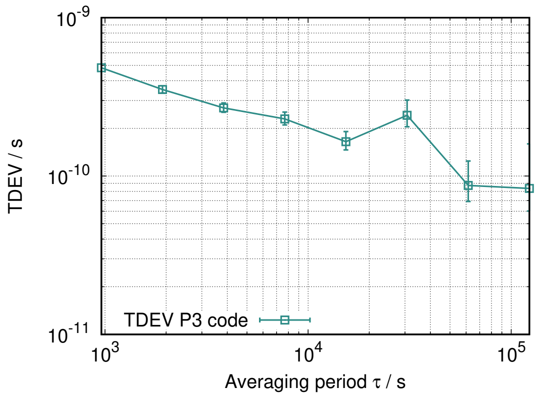


(b) TDEV of P-code delays

Figure 1: Relative calibration of IENG with respect to INR5 from MJD 60126 to 60131 in INRiM. The P-code phase differences (a) are built from RINEX files, in blue for P1, and in lilac for P2. Related TDEV (b) of P-code delays.

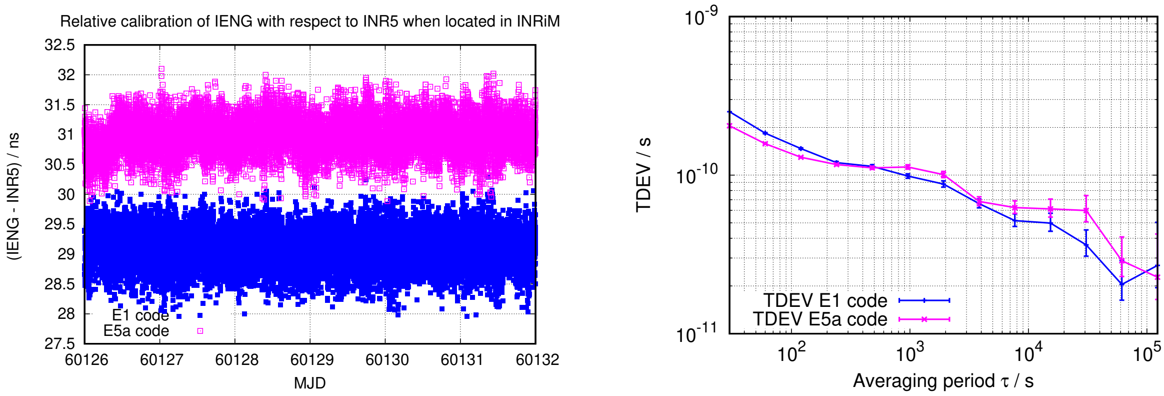


(a) P3 CV after calibration



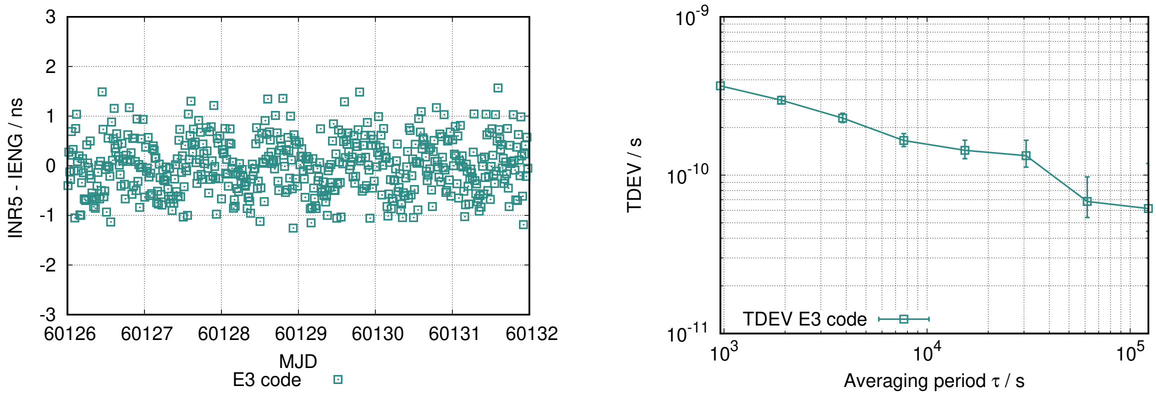
(b) TDEV of P3 CV

Figure 2: P3 CV time difference (a) of IENG with respect to INR5 from MJD 60126 to 60131 in INRiM. Related TDEV (b) of P3 CV.



(a) E-code phase differences (b) TDEV of E-code delays

Figure 3: Relative calibration of IENG with respect to INR5 from MJD 60126 to in INRiM. The E-code phase differences (a) are built from RINEX files, in blue for P1, and in lilac for E5. Related TDEV (b) of E-code delays.



(a) P3 CV after calibration (b) TDEV of P3 CV

Figure 4: E3 CV time difference (a) of IENG with respect to INR5 from MJD 60126 to 60131 in INRiM. Related TDEV (b) of E3 CV.

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.