Calibration Report #1012-2021

Calibration of CNES and ILNAS GNSS Station by LNE-SYRTE

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Issue 1.0

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Content.

Appendix.

1. Summary.

1.1. General informations.

This calibration report released by LNE-SYRTE is devoted to the relative calibration of the GNSS stations of the French Space Agency CNES and of Institut Luxembourgeois de la Normalisation, de l'Accréditation, de la Sécurité et qualité des produits et services (ILNAS), on behalf of Bureau Luxembourgeois de Métrologie (BLM), by LNE-SYRTE in Observatoire de Paris (OP).

It is built according to the Annex 4 of the document "BIPM guidelines for GNSS equipment calibration", v3.2, 15/02/2016. It contains all the required informations, data, plots and results either required by the BIPM in the frame of the CCTF Working Group on GNSS, or by BIPM and EURAMET in the frame of Group1/Group2 calibration scheme. It also contains the uncertainty budget computation according to the Guidelines, which is showing whether the calibrated link would be in line with the conventional values when used in the frame of the TAI network.

The reference station remained stable enough during the measurement campaign. All calibrated delay uncertainties are in line with the conventional values agreed by CCTF.

1.2. Calibration report changes.

This is Issue 1.0 of the calibration report.

2. Acronym list and reference documents.

2.1. Acronym list.

ADEV:	Allan deviation, square root of AVAR
AVAR:	Allan variance or Two-sample variance
BIPM:	Bureau International des Poids et Mesures
BLM:	Bureau Luxembourgeois de Métrologie
CCTF:	Consultative Committee on Time and Frequency
CGGTTS:	CCTF Global GNSS Time Transfer Standard format
CIPM:	Comité International des Poids et Mesures
CNES:	French Space Agency
CV:	Common-view
Galileo:	European Union GNSS
GFZ:	Geoforschungszentrum, Germany
GLONASS:	Russian GNSS
GNSS:	Global Navigation Satellite System
GPS:	United States of America GNSS
IGS:	International GNSS Service
ILNAS:	Institut Luxembourgeois de la Normalisation, de l'Accréditation, de la Sécurité et qualité des produits et services
LNE:	Laboratoire National de Métrologie et d'Essais, France
LNE-SYRTE:	French designated laboratory in charge of time and frequency units
MDEV:	Modified Allan deviation, square root of MVAR
MVAR:	Modified Allan variance
NC:	Not considered
NMI:	National Metrology Institute
NRCan:	National Resources Canada
OP:	Observatoire de Paris, France
ORB:	Observatoire Royal de Belgique
PPP:	Precise Point Positioning
PPS:	Pulse per second

RINEX: Receiver international exchange format for Geodesy
SYRTE: Systèmes de Référence Temps-espace, OP laboratory where LNE-SYRTE is located
TDEV: Time Allan deviation, square root of TVAR
TIC: Time Interval Counter
TVAR: Time Allan variance

2.2. Reference documents.

[1] BIPM, *BIPM guidelines for GNSS calibration*, V3.2, 15/02/2016.

[2] P. Uhrich and D. Valat, *GPS receiver relative calibration campaign preparation for Galileo In-Orbit Validation*, Proc. Of the 24th European Frequency and Time Forum (EFTF), Noordwijk, The Netherlands, April 2010.

[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 **51** (2014) 476-490.

[4] P Defraigne and G Petit 2015 *Metrologia* **52** G1.

3. Description of equipment and operations.

This relative calibration of the GNSS stations of CNES and ILNAS was organized by circulation of a traveling equipment, the start and the end of the campaign taking place in OP. The traveling equipment was originally made of two Septentrio PolaRx4 receivers, OPM3 and OPM7, plus a small multi-GNSS antenna NovAtel 703-GGG, and the related antenna cables, computer and accessories. It was first implemented in OP in common-clock set-up with the LNE-SYRTE reference station OP71, where the reference time scale signal was UTC(OP). OP71 is currently made of a Septentrio multichannel multi-GNSS PolaRx4, a high quality antenna cable and a Leica AR25 choke-ring antenna. This station was relatively calibrated by BIPM in the frame of the G1 calibration campaign during winter 2018-2019 (#1001-2018). It is also the IGS station OP7100FRA.

The LNE-SYRTE traveling equipment was then implemented in CNES premises in Toulouse, where there was a failure of the power unit of one PolaRx4 receiver, and eventually of OPM7 itself. Therefore, the rest of the campaign being achieved by using OPM3 only, OPM7 is disregarded in the rest of this report. As a third step, the LNE-SYRTE traveling equipment was implemented in ILNAS premises in Luxembourg, before coming back to OP for closure measurements. At CNES, four stations were relatively calibrated: two based on Septentrio PolaRx4 receivers, CS21 and CS22, and two based on PolaRx5 receivers CS23 and CS24. Two stations were relatively calibrated in ILNAS, based on Septentrio PolaRx5 receivers LU01 and LU02. All the involved equipment are described in the BIPM information sheet provided in Annex A. Table 1 presents a summary of the timetable and of the equipment.

Table 1. Summary information of the calibration campaign.

Institute	Status of equipement	MJD of measurement	Receiver type	BIPM code	RINEX name
OP	Traveling	NC – NC	Septentrio PolaRx4TR	OPM3	OPM3
OP	Groupe 1 Reference	59229 – 59238	Septentrio PolaRx4TR	OP71	OP71
OP	Groupe 1 Reference	59293 – 59300	Septentrio PolaRx4TR	OP71	OP71
CNES	Groupe 2	59248 – 59255	Septentrio PolaRx4TR	CS22	CS22
CNES	Groupe 2	59248 – 59255	Septentrio PolaRx4TR	CS21	CS21
CNES	Groupe 2	59250 – 59255	Septentrio PolaRx5TR	CS23	CS23
CNES	Groupe 2	59250 – 59255	Septentrio PolaRx5TR	CS24	CS24
LUX	Groupe 2	59275 – 59284	Septentrio PolaRx5TR	LU02	LU02
LUX	Groupe 2	59275 – 59284	Septentrio PolaRx5TR	LU01	LU01

4. Data and processing.

With OP71, LNE-SYRTE is collecting binary raw data that are transformed daily into RINEX3 data by using the proprietary Septentrio software. LNE-SYRTE received similar RINEX3 data from CNES and from ILNAS. From there, the GPS and Galileo RINEX data can be selected by the OP developed calibration processing software. The calibration consists in building for each GPS P1 and P2 codes and for each Galileo E1 and E5a codes differential offsets between pairs of 30 seconds CGGTTS files generated with the ORB R2CGGTTS software [4]. These differences are corrected by the known reference delay (REFDLY) and antenna cable delay (CABDLY) when available. The coordinates of the antenna phase centres are especially computed for all stations involved for the calibration period from GPS RINEX2 files by using the NRCan PPP software. We assume that the same phase centre is used at antenna level to collect P1 and E1 signals, and that the potential offset between the phase centres used to collect P2 and E5a data is negligible with respect to the final uncertainty obtained for each delay value. The geometric correction between pairs of antenna phase centres for receivers in common-clock set-up is computed by using the consistent BRDC files provided by the IGS.

As a conservative estimate, the noise of the P-code and E-code differences is obtained from the highest value of the one-sigma statistical uncertainty of the TDEV at 1 d, or at a period close to 1 d. In the case where there is not enough data to compute a TDEV at 1 d, the upper limit of the one-sigma statistical uncertainty of the last computed TDEV is considered as the noise. The noise of the P3 or E3 data is issued either from a similar TDEV analysis or from a quadratic sum of the individual code noises.

Reference delays are measured against the local time scale physical reference point: see Annex A for details. Antenna cable delays are either obtained from dedicated measurements carried out in each laboratory, not described in this report, or included in the computed delays when not available.

For validation purposes, P3 or E3 CGGTTS files are computed by using the R2CGGTTS software provided by P. Defraigne (ORB), and CV are built between pairs of receivers. When possible, a direct comparison between the time transfer results after implementation of the calibrated delays and the differences between the involved UTC(k) based on Circular T data is computed.

5. Results of raw data processing.

Table 2 is providing the GPS P1 and P2 delays computed from the raw differences between the RINEX files, together with the REFDLY and CABDLY used for these computations. In addition, Table 3 is providing the raw GPS difference values (Rawdiff) required by [1], and Table 4 is providing the GPS delays of visited system against traveling system. In a parallel way, Table 5, 6 and 7 are providing similar results for Galileo E1 and E5a delays and Galileo differences.

All the plots of P1 and P2 differences, and of E1 and E5a differences are provided in Annex B, together with the related TDEV analysis. The P3 and E3 CV computed by using the results of the calibration and the related TDEV are also made available in Annex B. The ionosphere-free P3 data are obtained from the linear combination: P3 = P1 + 1.546 x (P1 – P2). The ionosphere-free E3 data are obtained from the linear combination: E3 = E1 + 1.261 x (E1 – E5a).

Table 2. Summary information on **GPS** delays (all values in ns).

Receiver	Reference	MJD of Measurement	REFDLY	CABDLY	P1 DLY	TDEV	P2 DLY	TDEV
OP71	Ref	59229 – 59238	191.7	128.7	55.200	NC	53.800	NC
OPM3	OP71	59229 – 59238	204.0	0.0	261.338	0.037	260.764	0.029
OP71	Ref	59293 – 59300	191.7	128.7	55.200	NC	53.800	NC
OPM3	OP71	59293 – 59300	193.7	0.0	261.132	0.057	260.706	0.040
OPM3	Ref	59248 – 59255	157.6	0.0	261.235	NC	260.735	NC
CS21	OPM3	59248 – 59255	157.4	166.2	57.441	0.050	55.763	0.039
CS22	OPM3	59248 – 59255	157.1	176.1	57.096	0.039	55.472	0.040
OPM3	Ref	59250 – 59255	157.6	0.0	261.235	NC	260.735	NC
CS23	OPM3	59250 – 59255	56.8	118.3	31.580	0.061	28.079	0.057
CS24	OPM3	59250 – 59255	57.0	118.5	35.401	0.070	32.052	0.046
OPM3	Ref	59275 – 59284	154.2	0.0	261.235	NC	260.735	NC
LU01	OPM3	59275 – 59284	36.5	118.0	28.168	0.080	24.964	0.094
LU02	OPM3	59275 – 59284	38.6	160.6	31.044	0.049	28.311	0.102

Table 3. Summary of raw **GPS** calibration results (all values in ns).

Pair	MJD of measurement	Rawdiff P1	TDEV	RawDiff P2	TDEV
OPM3-OP71	59229 – 59238	-65.138	0.037	-65.964	0.029
OPM3-OP71	59293 – 59300	-75.232	0.057	-76.206	0.040
CS21-OPM3	59248 – 59255	37.394	0.050	38.572	0.039
CS22-OPM3	59248 – 59255	27.539	0.039	28.663	0.040
CS23-OPM3	59250 – 59255	10.555	0.061	13.556	0.057
CS24-OPM3	59250 – 59255	6.734	0.070	9.583	0.046
LU01-OPM3	59275 – 59284	-2.633	0.080	0.071	0.094
LU02-OPM3	59275 – 59284	-46.009	0.049	-43.776	0.102

Table 4. **GPS** delays of visited system with respect to traveling system (all values in ns).

Pair	MJD of measurement	INTDLY P1	INTDLY P2	P1-P2
OPM3-OP71	59229 – 59238	261.338	260.764	0.574
OPM3-OP71	59293 – 59300	261.132	260.706	0.426
CS21-OPM3	59248 – 59255	57.441	55.763	1.678
CS22-OPM3	59248 – 59255	57.096	55.472	1.624
CS23-OPM3	59250 – 59255	31.580	28.079	3.501
CS24-OPM3	59250 – 59255	35.401	32.052	3.349
LU01-OPM3	59275 – 59284	28.168	24.964	3.204
LU02-OPM3	59275 – 59284	31.044	28.311	2.733

Table 5. Summary information on **Galileo** delays (all values in ns).

Receiver	Reference	MJD of Measurement	REFDLY	CABDLY	E1 DLY	TDEV	E5a DLY	TDEV
OP71	Ref	59229 – 59238	191.7	128.7	55.700	NC	64.200	NC
OPM3	OP71	59229 – 59238	204.0	0.0	261.829	0.049	269.607	0.051
OP71	Ref	59293 – 59300	191.7	128.7	55.700	NC	64.200	NC
OPM3	OP71	59293 – 59300	193.7	0.0	261.721	0.064	269.073	0.069
OPM3	Ref	59248 – 59255	157.6	0.0	261.775	NC	269.340	NC
CS21	OPM3	59248 – 59255	157.4	166.2	58.151	0.061	64.305	0.067
CS22	OPM3	59248 – 59255	157.1	176.1	57.956	0.062	64.804	0.032
OPM3	Ref	59250 – 59255	157.6	0.0	261.775	NC	269.340	NC
CS23	OPM3	59250 – 59255	56.8	118.3	33.310	0.073	30.683	0.061
CS24	OPM3	59250 – 59255	57.0	118.5	36.935	0.075	37.228	0.084
OPM3	Ref	59275 – 59284	154.2	0.0	261.775	NC	269.340	NC
LU01	OPM3	59275 – 59284	36.5	118.0	29.927	0.081	29.583	0.075
LU02	OPM3	59275 – 59284	38.6	160.6	32.669	0.079	30.748	0.054

Table 6. Summary of raw **Galileo** calibration results (all values in ns).

Pair	MJD of measurement	Rawdiff E1	TDEV	RawDiff E5a	TDEV
OPM3-OP71	59229 – 59238	-65.129	0.049	-64.407	0.051
OPM3-OP71	59293 – 59300	-75.321	0.064	-74.173	0.069
CS21-OPM3	59248 – 59255	37.224	0.061	38.635	0.067
CS22-OPM3	59248 – 59255	27.219	0.062	27.936	0.032
CS23-OPM3	59250 – 59255	9.365	0.073	19.557	0.061
CS24-OPM3	59250 – 59255	5.740	0.075	13.012	0.084
LU01-OPM3	59275 – 59284	-3.852	0.081	4.057	0.075
LU02-OPM3	59275 – 59284	-47.094	0.079	-37.608	0.054

Table 7. **Galileo** delays of visited system with respect to traveling system (all values in ns).

Pair	MJD of measurement	INTDLY E1	INTDLY E5a	E1-E5a
OPM3-OP71	59229 – 59238	261.829	269.607	-7.778
OPM3-OP71	59293 – 59300	261.721	269.073	-7.352
CS21-OPM3	59248 – 59255	58.151	64.305	-6.154
CS22-OPM3	59248 – 59255	57.956	64.804	-6.848
CS23-OPM3	59250 – 59255	33.310	30.683	2.627
CS24-OPM3	59250 – 59255	36.935	37.228	-0.293
LU01-OPM3	59275 – 59284	29.927	29.583	0.344
LU02-OPM3	59275 – 59284	32.669	30.748	1.921

6. Uncertainty budgets.

Tables 8, 10, 12, 14, 16 and 18 are providing the uncertainty budgets for the computed internal delays INTDLY P1 and INTDLY P2 (GPS) of the stations CS21, CS22, CS23, CS24, LU01 and LU02, respectively. Tables 9, 11, 13, 15, 17 and 19 are similarly providing the uncertainty budgets for the computed internal delays INTDLY E1 and INTDLY E5a (Galileo) of the stations CS21, CS22, CS23, CS24, LU01 and LU02, respectively. See Annex C for detailed explanations about the different terms.

Important notes.

- In general, the dominant term inside such an uncertainty budget is the misclosure between the start and the end of the campaign of the traveling equipment against the reference station, the traveling station having circulated among the visited laboratories. LNE-SYRTE also pays usually attention to the offset between the two traveling receivers: in the case this offset would surpass the misclosure offset, it would be used as “misclosure” term in the uncertainty budget. But after the failure of OPM7 during the campaign, such a validation was not possible anymore.
- The uncertainty on OP71 antenna cable delay (CABDLY) is not considered here below because it is already taken into account in the BIPM G1 calibration results. These uncertainty budgets below are computed for a G1/G2 calibration scheme.

Generic analysis of uncertainty budgets estimated in the following pages.

- The GPS delay uncertainties are at the state of the art of this technique thanks to a very low deviation from closure of OPM3 during this campaign.

- For Galileo delays, the OPM3 E5a misclosure is significant, about 0.5 ns. This appears to be due to unknown discontinuous issues of E5a signal reception in OP, which were already observed during earlier experiments. The E5a TDEV of CV between OPM3 and OP71 (see Annex B) is indeed exhibiting a significant different behaviour between the start and the end of the campaign, without a clear explanation. On the other hand, when looking at similar comparisons on E1, P1 and P2 TDEV, we note a similar behaviour between the start and the end of the campaign, except for a diurnal term probably due to larger temperature fluctuations at the end of the campaign.

- We computed a highest and a lowest value for the P3 and E3 u_A estimates. The first u_A estimate is computed according to the ionosphere-free linear combination between P1 and P2 estimates and E1 and E5a estimates, respectively. The second one is estimated from the upper value of the TDEV statistical uncertainty at an averaging period of about 1 d. When the offset between both u_A estimates is small, it means that the noise of the P3 or E3 CV is close to the expected white noise modulation. But when there is a significant difference, it means that there are other modulations than white phase noise in the data. This looks to be especially the case for P3 CV against OPM3 of LU01 and LU02, and for E3 CV against OPM3 computed from CS23, CS24, LU01 and LU02 Galileo data. For E3 CV, it is interesting to note that the main units of all these stations are PolaRx5 where OPM3, OP71, CS21 and CS22 are PolaRx4, indicating a potential difference or even an issue in the Galileo tracking. We also recommended to disable the “auto calibration” feature on PolaRx5, hence we assume this effect is coming from another source. Could it come from antennas interferences, or from multipaths, or else? We are having no answer today.

- At the end, we always selected the largest u_A estimates for the computation of a conservative combined uncertainty for the hardware delays.

Table 8. Uncertainty budgets for **GPS** INTDLY of CS21 (all values in ns).

Uncertainty	**Value P1**	**Value P2**	**Value P1 – P2**	**Value P3**	**Description**
u_A(OPM3 – OP71)	0.057	0.040	0.070	0.122/0.120 [1]	TDEV(1 d)
u_A(OPM3 – CS21)	0.050	0.039	0.063	0.109/0.107 [1]	TDEV(1 d)
u_A	**0.076**	**0.056**	**0.094**	**0,164/0.161 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.138**	**0.010**	**0.148**	**0.267 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.448**	**0.426**	**0.451**	**0.503**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.546**	**0.528**	**0.548**	**0.592**	**Quadratic sum of all u_B**
u_{CAL0}	**0.551**	**0.531**	**0.556**	**0.614 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS P3 CV, the misclosure mean value between OPM3 and OP71 is about 29 ps within a combined statistical uncertainty of about 28 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the P3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data on the same line. The second value is the quadratic sum between the second value above for OPM3 – CS21 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is close to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the P3 CV TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 9. Uncertainty budgets for **Galileo** INTDLY of CS21 (all values in ns).

Uncertainty	**Value E1**	**Value E5a**	**Value E1 – E5a**	**Value E3**	**Description**
u_A(OPM3 – OP71)	0.064	0.069	0.094	0.135/0.175 [1]	TDEV(1 d)
u_A(OPM3 – CS21)	0.061	0.067	0.091	0.130/0.140 [1]	TDEV(1 d)
u_A	**0.088**	**0.096**	**0.130**	**0.186/0.224 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.038**	**0.463**	**0.425**	**0.537 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.428**	**0.629**	**0.602**	**0.686**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.529**	**0.702**	**0.678**	**0.753**	**Quadratic sum of all u_B**
u_{CAL0}	**0.536**	**0.709**	**0.690**	**0.787 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS E3 CV, the misclosure mean value between OPM3 and OP71 is about 14 ps within a combined statistical uncertainty of about 21 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the E3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data on the same line. The second value is the quadratic sum between the second value above for OPM3 – CS21 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is equal to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 10. Uncertainty budgets for **GPS** INTDLY of CS22 (all values in ns).

Uncertainty	**Value P1**	**Value P2**	**Value P1 – P2**	**Value P3**	**Description**
u_A(OPM3 – OP71)	0.057	0.040	0.070	0.122/0.120 [1]	TDEV(1 d)
u_A(OPM3 – CS22)	0.039	0.040	0.056	0.095/0.099 [1]	TDEV(1 d)
u_A	**0.069**	**0.057**	**0.090**	**0.155/0.156 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.138**	**0.010**	**0.148**	**0.267 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.448**	**0.426**	**0.451**	**0.503**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.546**	**0.528**	**0.548**	**0.592**	**Quadratic sum of all u_B**
u_{CAL0}	**0.550**	**0.531**	**0.555**	**0.612 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS P3 CV, the misclosure mean value between OPM3 and OP71 is about 29 ps within a combined statistical uncertainty of about 28 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the P3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data on the same line. The second value is the quadratic sum between the second value above for OPM3 – CS22 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is close to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the P3 CV TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 11. Uncertainty budgets for **Galileo** INTDLY of CS22 (all values in ns).

Uncertainty	Value E1	Value E5a	Value E1 – E5a	Value E3	Description
u_A(OPM3 – OP71)	0.064	0.069	0.094	0.135/0.175 [1]	TDEV(1 d)
u_A(OPM3 – CS22)	0.062	0.032	0.070	0.108/0.140 [1]	TDEV(1 d)
u_A	**0.089**	**0.076**	**0.117**	**0.172/0.224 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.038**	**0.463**	**0.425**	**0.537 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.428**	**0.629**	**0.602**	**0.686**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.529**	**0.702**	**0.678**	**0.753**	**Quadratic sum of all u_B**
u_{CAL0}	**0.536**	**0.706**	**0.688**	**0.786 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS E3 CV, the misclosure mean value between OPM3 and OP71 is about 14 ps within a combined statistical uncertainty of about 21 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the E3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data on the same line. The second value is the quadratic sum between the second value above for OPM3 – CS22 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is equal to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 12. Uncertainty budgets for **GPS** INTDLY of CS23 (all values in ns).

Uncertainty	Value P1	Value P2	Value P1 – P2	Value P3	Description
u_A(OPM3 – OP71)	0.057	0.040	0.070	0.122/0.120 [1]	TDEV(1 d)
u_A(OPM3 – CS23)	0.061	0.057	0.083	0.142/0.128 [1]	TDEV(1 d)
u_A	**0.083**	**0.061**	**0.109**	**0.188/0.175 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.138**	**0.010**	**0.148**	**0.267 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.448**	**0.426**	**0.451**	**0.503**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.546**	**0.528**	**0.548**	**0.592**	**Quadratic sum of all u_B**
u_{CAL0}	**0.552**	**0.532**	**0.559**	**0.621 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS P3 CV, the misclosure mean value between OPM3 and OP71 is about 29 ps within a combined statistical uncertainty of about 28 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the P3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data on the same line. The second value is the quadratic sum between the second value above for OPM3 – CS23 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is close to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the P3 CV TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 13. Uncertainty budgets for **Galileo** INTDLY of CS23 (all values in ns).

Uncertainty	Value E1	Value E5a	Value E1 – E5a	Value E3	Description
u_A(OPM3 – OP71)	0.064	0.069	0.094	0.135/0.175 [1]	TDEV(1 d)
u_A(OPM3 – CS23)	0.073	0.061	0.095	0.140/0.250 [1]	TDEV(1 d)
u_A	**0.097**	**0.092**	**0.134**	**0.195/0.305 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.038**	**0.463**	**0.425**	**0.537 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.428**	**0.629**	**0.602**	**0.686**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.529**	**0.702**	**0.678**	**0.753**	**Quadratic sum of all u_B**
u_{CAL0}	**0.538**	**0.708**	**0.691**	**0.812**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS E3 CV, the misclosure mean value between OPM3 and OP71 is about 14 ps within a combined statistical uncertainty of about 21 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the E3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data on the same line. The second value is the quadratic sum between the second value above for OPM3 – CS23 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is equal to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 14. Uncertainty budgets for **GPS** INTDLY of CS24 (all values in ns).

Uncertainty	**Value P1**	**Value P2**	**Value P1 – P2**	**Value P3**	**Description**
u_A(OPM3 – OP71)	0.057	0.040	0.070	0.122/0.120 [1]	TDEV(1 d)
u_A(OPM3 – CS24)	0.070	0.046	0.084	0.148/0.155 [1]	TDEV(1 d)
u_A	**0.091**	**0.062**	**0.110**	**0.193/0.196 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.138**	**0.010**	**0.148**	**0.267 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.448**	**0.426**	**0.451**	**0.503**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.546**	**0.528**	**0.548**	**0.592**	**Quadratic sum of all u_B**
u_{CAL0}	**0.554**	**0.532**	**0.559**	**0.624 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS P3 CV, the misclosure mean value between OPM3 and OP71 is about 29 ps within a combined statistical uncertainty of about 28 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the P3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data on the same line. The second value is the quadratic sum between the second value above for OPM3 – CS24 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is close to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the P3 CV TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 15. Uncertainty budgets for **Galileo** INTDLY of CS24 (all values in ns).

Uncertainty	**Value E1**	**Value E5a**	**Value E1 – E5a**	**Value E3**	**Description**
u_A(OPM3 – OP71)	0.064	0.069	0.094	0.135/0.175 [1]	TDEV(1 d)
u_A(OPM3 – CS24)	0.075	0.084	0.113	0.161/0.259 [1]	TDEV(1 d)
u_A	**0.099**	**0.109**	**0.147**	**0.210/0.313 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.038**	**0.463**	**0.425**	**0.537 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.428**	**0.629**	**0.602**	**0.686**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.529**	**0.702**	**0.678**	**0.753**	**Quadratic sum of all u_B**
u_{CAL0}	**0.538**	**0.710**	**0.694**	**0.815 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS E3 CV, the misclosure mean value between OPM3 and OP71 is about 14 ps within a combined statistical uncertainty of about 21 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the E3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data on the same line. The second value is the quadratic sum between the second value above for OPM3 – CS24 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is equal to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 16. Uncertainty budgets for **GPS** INTDLY of LU01 (all values in ns).

Uncertainty	Value P1	Value P2	Value P1 – P2	Value P3	Description
u_A(OPM3 – OP71)	0.057	0.040	0.070	0.122/0.120 [1]	TDEV(1 d)
u_A(OPM3 – LU01)	0.080	0.094	0.123	0.206/0.128 [1]	TDEV(1 d)
u_A	**0.098**	**0.102**	**0.141**	**0.239/0.175 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.138**	**0.010**	**0.148**	**0.267 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.448**	**0.426**	**0.451**	**0.503**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.546**	**0.528**	**0.548**	**0.592**	**Quadratic sum of all u_B**
u_{CAL0}	**0.555**	**0.538**	**0.566**	**0.638 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS P3 CV, the misclosure mean value between OPM3 and OP71 is about 29 ps within a combined statistical uncertainty of about 28 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the P3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data on the same line. The second value is the quadratic sum between the second value above for OPM3 – LU01 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is close to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the P3 CV TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 17. Uncertainty budgets for **Galileo** INTDLY of LU01 (all values in ns).

Uncertainty	Value E1	Value E5a	Value E1 – E5a	Value E3	Description
u_A(OPM3 – OP71)	0.064	0.069	0.094	0.135/0.175 [1]	TDEV(1 d)
u_A(OPM3 – LU01)	0.081	0.075	0.110	0.161/0.210 [1]	TDEV(1 d)
u_A	**0.103**	**0.102**	**0.145**	**0.210/0.273 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.038**	**0.463**	**0.425**	**0.537 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.428**	**0.629**	**0.602**	**0.686**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.529**	**0.702**	**0.678**	**0.753**	**Quadratic sum of all u_B**
u_{CAL0}	**0.539**	**0.709**	**0.693**	**0.801 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS E3 CV, the misclosure mean value between OPM3 and OP71 is about 14 ps within a combined statistical uncertainty of about 21 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the E3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data on the same line. The second value is the quadratic sum between the second value above for OPM3 – LU01 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is equal to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 18. Uncertainty budgets for **GPS** INTDLY of LU02 (all values in ns).

Uncertainty	**Value P1**	**Value P2**	**Value P1 – P2**	**Value P3**	**Description**
u_A(OPM3 – OP71)	0.057	0.040	0.070	0.122/0.120 [1]	TDEV(1 d)
u_A(OPM3 – LU02)	0.049	0.102	0.113	0.181/0.114 [1]	TDEV(1 d)
u_A	**0.076**	**0.110**	**0.134**	**0.221/0.166 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.138**	**0.010**	**0.148**	**0.267 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.448**	**0.426**	**0.451**	**0.503**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.546**	**0.528**	**0.548**	**0.592**	**Quadratic sum of all u_B**
u_{CAL0}	**0.551**	**0.539**	**0.564**	**0.632 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS P3 CV, the misclosure mean value between OPM3 and OP71 is about 29 ps within a combined statistical uncertainty of about 28 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the P3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the P1 and P1 – P2 data on the same line. The second value is the quadratic sum between the second value above for OPM3 – LU02 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is close to the first value computed here within afew ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the P3 CV TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

Table 19. Uncertainty budgets for **Galileo** INTDLY of LU02 (all values in ns).

Uncertainty	Value E1	Value E5a	Value E1 – E5a	Value E3	Description
u_A(OPM3 – OP71)	0.064	0.069	0.094	0.135/0.175 [1]	TDEV(1 d)
u_A(OPM3 – LU02)	0.079	0.054	0.096	0.145/0.209 [1]	TDEV(1 d)
u_A	**0.102**	**0.088**	**0.135**	**0.198/0.273 [2]**	**Visited – Reference**
Misclosure					
$u_{B,1}$	**0.038**	**0.463**	**0.425**	**0.537 [*]**	**Misclosure on OPM3**
Systematic component related to RAWDIF					
$u_{B,11}$	0.050	0.050	0.050	0.050	Position error at reference site
$u_{B,12}$	0.050	0.050	0.050	0.050	Position error at visited site
$u_{B,13}$	0.200	0.200	0.200	0.200	Multipaths at reference site
$u_{B,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to the local UTC(k)					
$u_{B,21}$	0.220	0.220	0.220	0.220	REFDLY (at reference site)
$u_{B,22}$	0.220	0.220	0.220	0.220	REFDLY (at visited site)
$u_{B,TOT}$	**0.428**	**0.629**	**0.602**	**0.686**	**Quadratic sum of $u_{B,1}$ to $u_{B,22}$**
Link of the reference system to its local UTC(k)					
$u_{B,31}$	0.0	0.0	0.0	0.0	REFDLY (at reference site)
Link of the visited system to its local UTC(k)					
$u_{B,32}$	0.220	0.220	0.220	0.220	REFDLY (at remote laboratory)
Antenna cable delays					
$u_{B,41}$	0.0	0.0	0.0	0.0	CABDLY of reference station
$u_{B,42}$	0.220	0.220	0.220	0.220	CABDLY of visited equipment
$u_{B,SYS}$	**0.529**	**0.702**	**0.678**	**0.753**	**Quadratic sum of all u_B**
u_{CAL0}	**0.539**	**0.707**	**0.691**	**0.801 [3]**	**Quadratic sum of u_A and $u_{B,SYS}$**

[*] Computed from iono-free linear combination. When computed from CGGTTS E3 CV, the misclosure mean value between OPM3 and OP71 is about 14 ps within a combined statistical uncertainty of about 21 ps.
[1] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data. The second value comes from the reading of the upper limit of the one sigma statistical uncertainty of the TDEV at 1 d of the E3 CGGTTS CV.
[2] The first value is the result of the iono-free equation applied quadratically to the E1 and E1 – E5a data on the same line. The second value is the quadratic sum between the second value above for OPM3 – LU02 and the second value above for OPM3 – OP71. It can be easily cross-checked that the quadratic sum of the first values in both lines above is equal to the first value computed here within a few ps. When the second value is not close to the first one within a few ps, it is the signature of some deviation from the expected white phase noise behaviour in the TDEV.
[3] As a conservative estimate, we use the highest u_A result for this P3 uncertainty computation.

7. Final results of the relative calibration.

Table 20 is providing the final results of this relative calibration for GPS delays according to the BIPM guidelines. Table 21 is similarly providing the final results for Galileo delays.
Any calibrated link using one of these stations in the frame of the TAI network is in line with the conventional combined uncertainty of 2.4 ns.
In addition, Table 22 is also providing the computed conservative k = 2 expanded uncertainties for GPS and Galileo delays in order to be in line with EURAMET recommendations.

Table 20. Summary information on the relative calibration of **GPS** delays.

BIPM code	RINEX name	Cal Id	Date	u_{CAL}(P3) / ns	INTDLY P1 / ns	INTDLY P2 / ns
Reference system						
OP71	OP7100FRA	1001-2018	2019.1		55.2	53.8
Visited system						
CS21	CS2100FRA	1012-2021	2021.2	0.7	57.4	55.8
CS22	CS2200FRA	1012-2021	2021.2	0.7	57.1	55.5
CS23	CS2300FRA	1012-2021	2021.2	0.7	31.6	28.1
CS24	CS2400FRA	1012-2021	2021.2	0.7	35.4	32.1
LU01	LU0100LUX	1012-2021	2021.3	0.7	28.2	25.0
LU02	LU0200LUX	1012-2021	2021.3	0.7	31.0	28.3

Table 21. Summary information on the relative calibration of **Galileo** delays.

BIPM code	RINEX name	Cal Id	Date	u_{CAL}(E3) / ns	INTDLY E1 / ns	INTDLY E5a / ns
Reference system						
OP71	OP7100FRA	1001-2018	2019.1		55.7	64.2
Visited system						
CS21	CS2100FRA	1012-2021	2021.2	0.8	58.2	64.3
CS22	CS2200FRA	1012-2021	2021.2	0.8	58.0	64.8
CS23	CS2300FRA	1012-2021	2021.2	0.9	33.3	30.7
CS24	CS2400FRA	1012-2021	2021.2	0.9	36.9	37.2
LU01	LU0100LUX	1012-2021	2021.3	0.9	29.9	29.6
LU02	LU0200LUX	1012-2021	2021.3	0.9	32.7	30.7

Table 22. Conservative k = 2 expended uncertainties following EURAMET standards when using OP71 as reference system (all values in ns).

BIPM code	RINEX name	u(P1)	u(P2)	u(P3)	u(E1)	u(E5a)	u(E3)
CS21	CS2100FRA	1.2	1.1	1.3	1.1	1.5	1.6
CS22	CS2200FRA	1.1	1.1	1.3	1.1	1.5	1.6
CS23	CS2300FRA	1.2	1.1	1.3	1.1	1.5	1.7
CS24	CS2400FRA	1.2	1.1	1.3	1.1	1.5	1.7
LU01	LU0100LUX	1.2	1.1	1.3	1.1	1.5	1.7
LU02	LU0200LUX	1.2	1.1	1.3	1.1	1.5	1.7

8. Comparison of some GPS 2021 delays with 2018 delays.

Because LNE-SYRTE was already in charge in 2018 of G2 GPS delay calibrations for CNES, CS21 and CS22 stations (#1015-2018), and for ILNAS, LU01 station (#1012-2018), it is possible to build from the 2021 results the changes observed between these campaigns. During the same period of time, there were also changes in GPS calibrations between G1 BIPM delays of OP71. Table 23 provides such informations. The combined uncertainties of P3 offsets between both campaigns are about 1.0 ns for CS21 and CS22, and about 1.2 ns for LU01.

Table 23. Comparison of **GPS** delays between 2021 and 2018 (all values in ns).

	OP71 [*]			**CS21**			**CS22**			**LU01**		
	P1 [*]	**P2** [*]	**P3** [*]	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**
#1012/1015-2018	55.7	54.4	57.7	58.5	56.6	61.4	57.9	56.0	60.8	25.8	22.5	34.9
#1012-2021	55.2	53.8	57.4	57.4	55.8	59.9	57.1	55.5	59.6	28.2	25.0	37.1
2021 – 2018	- 0.5	- 0.8	**- 0.3**	- 1.1	- 0.8	**- 1.5**	- 0.8	- 0.5	**- 1.2**	2.4	2.5	**2.2**
Combined uncertainty						1.0			1.0			1.2

[*] The G1 BIPM calibrations of OP71 are #1001-2016 et #1001-2018.

The CS21 and CS22 P3 offsets are staying close to the estimated combined uncertainties, especially when taking into account the change in OP71 P3 delay, even if the CS21 P3 offset is clearly appearing a little large. On the other hand we note that the P3 offset for LU01 station is significantly larger than the estimated combined uncertainty, and this might be related to the change of local clock signal distribution in-between. All offsets are nevertheless in line with the k = 2 expanded uncertainties.

9. Effect of newly calibrated delays against current UTC(k) – UTC(OP).

After application of new calibrated delays, we computed GNSS CV time transfer between each visited GNSS station and OP71, and we compared to the current offset UTC(k) – UTC(OP) as obtained from Circular T over the calibration campaign period. This is giving an idea of the departure of current delays against new ones, and of the potential resulting change to occur when applying the new calibrated delays. It is nevertheless reminded here that UTC – UTC(OP) is based on a TWSTFT link, which uncertainty in the April 2021 BIPM Circular T is estimated at u_B = 1.3 ns.

Each of the following plots is showing the UTC(k) – UTC(OP) offset when using the labelled station in the visited laboratory against OP71 station in OP, after application of newly calibrated delays together with OP computed antenna coordinates. The observed period is corresponding to the data collection period during the calibration campaign on site. In addition, the green dots are showing the UTC(k) – UTC(OP) offset when using the UTC – UTC(k) data published by BIPM in its Circular T.

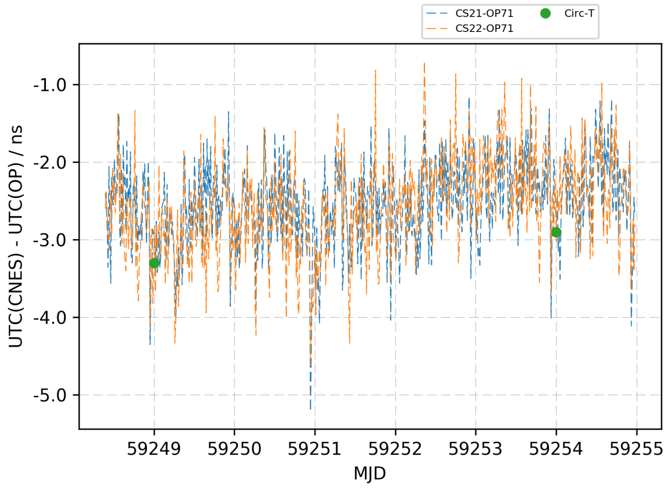


*Figure 1. UTC(CNES) – UTC(OP) computed either from GNSS CV after application of newly calibrated **GPS** delays to CS21 (blue line) and CS22 (orange line) or from Circular T (green dots).*

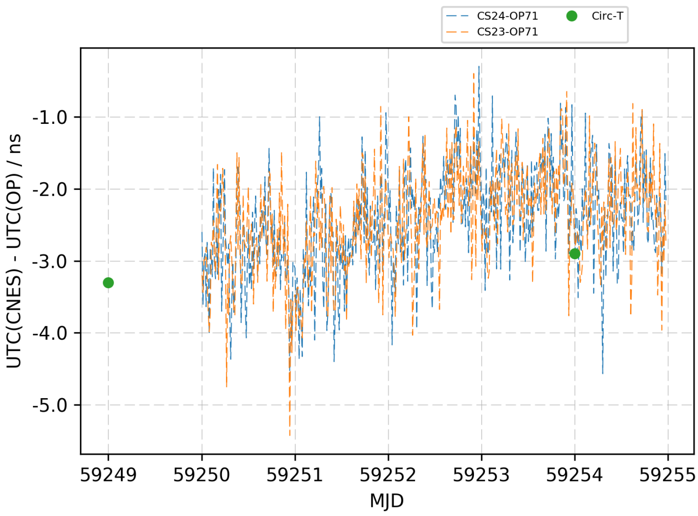
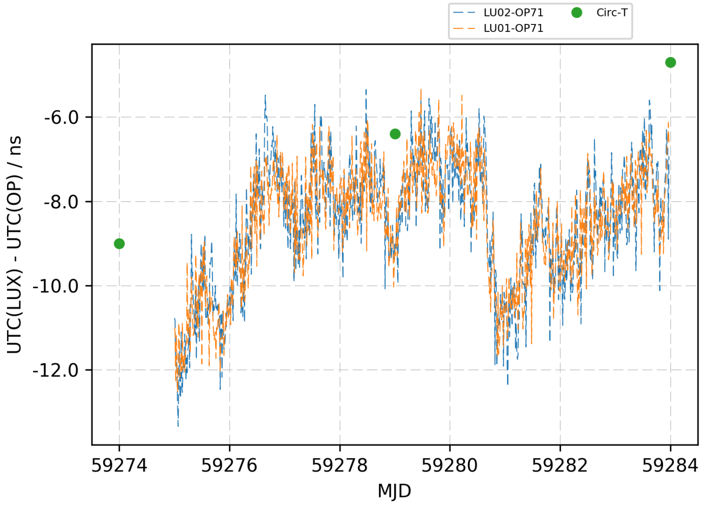
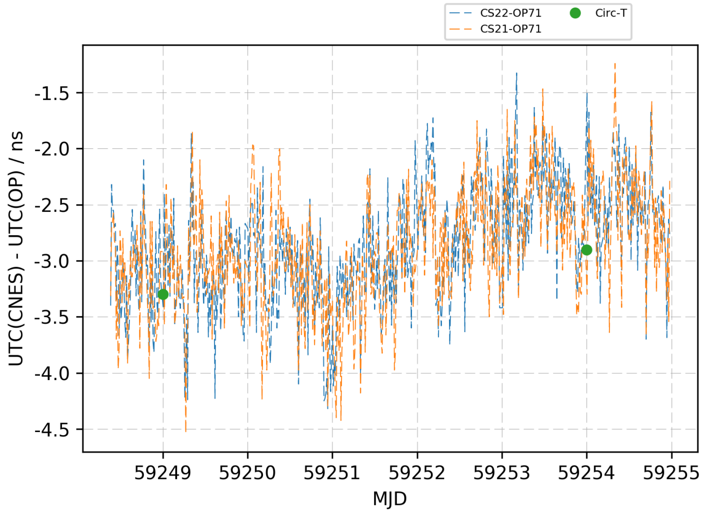


*Figure 2. UTC(CNES) – UTC(OP) computed either from GNSS CV after application of newly calibrated **GPS** delays to CS23 (orange line) and CS24 (blue line) or from Circular T (green dots).*



*<u>Figure 3. UTC(LUX) – UTC(OP) computed either from GNSS CV after application of newly calibrated **GPS** delays to LU01 (orange line) and LU02 (blue line) or from Circular T (green dots).</u>*



*<u>Figure 4. UTC(CNES) – UTC(OP) computed either from GNSS CV after application of newly calibrated **Galileo** delays to CS21 (blue line) and CS22 (orange line) or from Circular T (green dots).</u>*

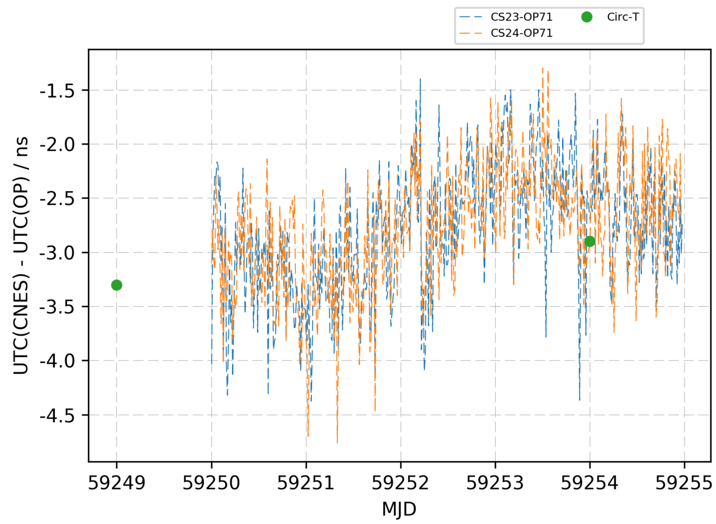


*Figure 5. UTC(CNES) – UTC(OP) computed either from GNSS CV after application of newly calibrated **Galileo** delays to CS23 (blue line) and CS24 (orange line) or from Circular T (green dots).*

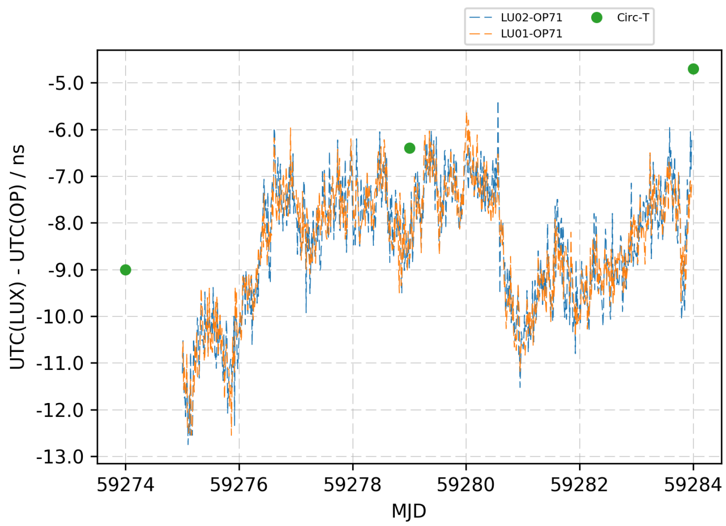


*Figure 6. UTC(LUX) – UTC(OP) computed either from GNSS CV after application of newly calibrated **Galileo** delays to LU01 (blue line) and LU02 (orange line) or from Circular T (green dots).*

From Figures 1 and 2, one can see that the mean offset between the current GPS delays and the new ones would impact the UTC(CNES) departure from UTC by less than 1.0 ns. These results are in line with the conventional combined uncertainty of GPS station inclusion in the TAI network, and this proves that the period of more than two years with respect to the former calibration campaign did not degrade the UTC – UTC(CNES) estimates. From Figures 4 and 5, one can see that the mean offset between the current Galileo delays and the new ones would impact the UTC(CNES) departure from UTC by about 0.5 ns. There is agreement between CNES absolute calibration and this calibration campaign based on Galileo BIPM G1 delays of OP71.

From Figures 3 and 6, one can see that the mean offset between the current GPS or Galileo delays and the new ones would impact the UTC(LUX) departure from UTC by about 2.0 ns or more. This also remains in line with the conventional combined uncertainty of GNSS station inclusion in the TAI network. But these offsets are larger than expected, and should remain under survey during the next calibration campaign.

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