



Calibration Report 1014-2019

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## Calibration of GPS receivers in some European laboratory

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Issue 1.1

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## 1 Summary

### 1.1 General informations

This Calibration Report released by LNE-SYRTE is about the relative calibration campaign of GPS receivers located at PTB DLR RISE ROA INRiM.

It is built according to the Annex 4 of the document “BIPM guidelines for GNSS equipment calibration”, V3.2 15/02/2016, and contains all the required information, data, plots and results either required by BIPM in the frame of the CCTF Working Group on GNSS, or by BIPM and EURAMET in the frame of the Group1/Group2 calibration scheme. It also contains the uncertainty budget computation 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. With respect to issue 1.0 the main changes are about the P3 uncertainty computations.

## 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, Sèvres, France
CCTF:	Consultative Committee on Time and Frequency
CGGTTS:	CCTF Global GNSS Time Transfer Standard format
CIPM:	Comité International des Poids et Mesures
DI:	Designated institute
DLR:	Deutsches Zentrum für Luft- und Raumfahrt
GFZ:	Geoforschungszentrum
GLONASS:	Russian GNSS
GNSS:	Global Navigation Satellite System
GPS:	United States of America GNSS
INRiM:	Istituto Nazionale Ricerca Metrologica, Italian NMI
LNE:	Laboratoire National de Métrologie et d'Essais, French NMI
LNE-SYRTE:	French NMI for Time and Frequency units
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
PPS:	Pulse per second
PTB:	Physikalisch-Technische Bundesanstalt, German NMI
RINEX:	Receiver International Exchange format for Geodesy
RISE:	Research Institutes of Sweden, Swedish NMI
ROA:	Real Instituto y Observatorio de la Armada, Spanish DI for Time and Frequency units
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 derived from AVAR and MVAR

## 2.2 Reference Documents

- [1] BIPM, “BIPM guidelines for GNSS calibration”, V3.2 15/02/2016.
- [2] Pierre Urich and David 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 (CD-Rom).
- [3] G.D. Rovera, J-M. Torre, R. Sherwood, M. Abgrall, C. Courde, M. Laas-Bourez and P. Urich, “Link calibration against receiver calibration: an assessment of GPS time transfer uncertainties”, Metrologia 51 (2014) 476-490.

## 3 Description of equipment and operations

The relative calibration of the GPS receiver located at PTB DLR RISE ROA INRiM was organized by LNE-SYRTE with the support of local Colleagues. The reference receiver for this measurement campaign is OP71, a Septentrio PolaRx4 multichannel multi-frequencies receiver located in OP. This receiver was relatively calibrated by BIPM in the frame of a G1 calibration campaign during winter 2018/2019 (#1001-2018).

The traveling equipment was made of two Septentrio PolaRx4 receivers called OPM7 and OPM3, together with a Choke-Ring Ashtech antenna and a 50 m antenna cable.

All the involved equipment are described inside the BIPM information sheets provided in Annex E for all receivers and all locations. Table 1 presents a summary of the timetable and of the equipment.

## 4 Data used

All OP collected raw data are transformed into GPS RINEX 2.11 format by using the UNAVCO TEQC software. Local receivers RINEX 2.1 data are provided by the visited laboratory. The calibration is

Table 1: Summary information on the calibration trip.

Institute	Status of equipment	MJD of measurement	Receiver type	BIPM code	RINEX name
OP	Traveling		Septentrio PolaRx4TR	OPM7	OPM7
OP	Traveling		Septentrio PolaRx4TR	OPM3	OPM3
OP	Group 1 Reference	58509 – 58523	Septentrio PolaRx4TR	OP71	OP71
OP	Group 1 Reference	58681 – 58692	Septentrio PolaRx4TR	OP71	OP71
PTB	Group 2	58534 – 58540	Ashtech Z-XII3T	PT02	PTBB
PTB	Group 2	58534 – 58540	DICOM GTR50	PT07	PT07
PTB	Group 2	58534 – 58540	Septentrio PolaRx4TR	PT09	PT09
PTB	Group 2	58535 – 58540	DICOM GTR51	PT10	PT10
DLR	Group 2	58563 – 58567	Septentrio PolaRx4TR	DL05	OBET
DLR	Group 2	58563 – 58567	Septentrio PolaRx4TR	DL04	UTC4
DLR	Group 2	58563 – 58567	Septentrio PolaRx5TR	DL07	UTC7
DLR	Group 2	58563 – 58567	Septentrio PolaRx5TR	DL08	UTC8
RISE	Group 2	58572 – 58580	Septentrio PolaRx5TR	RIT1	RIT1
RISE	Group 2	58572 – 58580	Javad E_GGD	SP01	SP01
RISE	Group 2	58572 – 58580	Javad E_GGD	SP02	SP02
RISE	Group 2	58572 – 58580	Septentrio PolaRx5TR	SP05	SP05
ROA	Group 2	58586 – 58597	DICOM GTR50	RO_5	RO_5
ROA	Group 2	58586 – 58597	Septentrio PolaRx3ETR	RO_6	RO_6
INRIM	Group 2	58606 – 58611	Septentrio PolaRx4TR	IT10	IENG
INRIM	Group 2	58606 – 58611	Septentrio PolaRx4TR	IT11	GR01
INRIM	Group 2	58606 – 58611	Septentrio PolaRx4TR	IT12	GR02
INRIM	Group 2	58606 – 58611	Septentrio PolaRx5TR	IT13	GR03
INRIM	Group 2	58606 – 58611	Septentrio PolaRx4TR	IT08	INR5
INRIM	Group 2	58606 – 58611	Septentrio PolaRx4TR	IT09	INR6

consisting in building differential pseudoranges for each code P1 and P2 between pairs of receivers, these differences being corrected by the known reference (REFDLY) and antenna cable (CABDLY) delays when 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. The geometric correction between pairs of antenna phase centers for receivers in common-clock set-up is computed by using BRDC files provided by IGS .

As conservative estimate, the noise of the P1 and P2 differences is obtained from the highest value of the one-sigma statistical uncertainty 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 UTC(k) physical reference point at the trigger level currently used in the involved laboratories. 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.

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. This is more especially the case between the two traveling receivers in each location, in order to better assess the stability of this traveling ensemble all over the calibration campaign. We have decided to consider as overestimated value for the traveling equipment stability during the campaign the upper value between the highest misclosure between the start and the end of the campaign on one side and the highest mean offset between the two traveling receivers obtained from CV on the other side.

## 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, 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. Table 2 also includes the P1 and P2 internal delays of traveling equipment as computed against OP71, in average between the start and the end of the campaign, with the related REFDLY when located in remote stations. From our point of view, this table is the most comprehensive summary of the calibration campaign.

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

Receiver	Reference	MJD of measurement	REFDLY	CABDLY	P1_DLY	TDEV	P2_DLY	TDEV
OP71	Ref	58509 – 58523	191.7	128.7	55.2		53.8	
OPM7	OP71	58509 – 58523	254.4	218.6	49.757	0.027	52.856	0.055
OPM3	OP71	58509 – 58523	243.8	218.6	49.197	0.029	52.613	0.058
OP71	Ref	58681 – 58692	191.7	128.7	55.2		53.8	
OPM7	OP71	58681 – 58692	194.5	218.6	49.399	0.020	52.940	0.029
OPM3	OP71	58681 – 58692	203.9	218.6	48.793	0.018	52.715	0.029
OPM7	Ref	58534 – 58540	191.5	218.6	49.578		52.898	
OPM3	Ref	58534 – 58540	180.9	218.6	48.995		52.664	
PTBB	OPM7	58534 – 58540	73.9	301.7	306.062	0.047	321.403	0.062
PTBB	OPM3	58534 – 58540	73.9	301.7	306.289	0.049	321.611	0.065
PT07	OPM7	58534 – 58540	43.5	245.8	-200.643	0.040	-200.779	0.066
PT07	OPM3	58534 – 58540	43.5	245.8	-200.415	0.044	-200.570	0.069
PT09	OPM7	58534 – 58540	182.6	198.7	57.801	0.027	56.959	0.039
PT09	OPM3	58534 – 58540	182.6	198.7	58.028	0.026	57.167	0.040
PT10	OPM7	58535 – 58540	52.0	250.0	-25.009	0.054	-31.503	0.056
PT10	OPM3	58535 – 58540	52.0	250.0	-24.780	0.052	-31.290	0.059
OPM7	Ref	58563 – 58567	219.2	218.6	49.578		52.898	
OPM3	Ref	58563 – 58567	208.6	218.6	48.995		52.664	
OBET	OPM7	58563 – 58567	157.3	524.1	61.518	0.025	58.755	0.056
OBET	OPM3	58563 – 58567	157.3	524.1	61.493	0.032	58.752	0.058

UTC4	OPM7	58563 – 58567	154.8	524.2	62.819	0.026	61.067	0.062
UTC4	OPM3	58563 – 58567	154.8	524.2	62.797	0.031	61.067	0.062
UTC7	OPM7	58563 – 58567	64.9	545.0	36.218	0.022	34.324	0.079
UTC7	OPM3	58563 – 58567	64.9	545.0	36.192	0.031	34.320	0.080
UTC8	OPM7	58563 – 58567	67.8	547.3	38.392	0.021	34.521	0.079
UTC8	OPM3	58563 – 58567	67.8	547.3	38.365	0.030	34.518	0.080
OPM7	Ref	58572 – 58580	163.9	218.6	49.578		52.898	
OPM3	Ref	58572 – 58580	172.8	218.6	48.995		52.664	
RIT1	OPM7	58572 – 58580	0.0	0.0	273.490	0.028	269.625	0.042
RIT1	OPM3	58572 – 58580	0.0	0.0	273.539	0.030	269.692	0.041
SP01	OPM7	58572 – 58580	0.0	0.0	235.467	0.026	250.868	0.045
SP01	OPM3	58572 – 58580	0.0	0.0	235.516	0.025	250.934	0.045
SP02	OPM7	58572 – 58580	0.0	0.0	235.980	0.026	250.032	0.047
SP02	OPM3	58572 – 58580	0.0	0.0	236.029	0.027	250.097	0.046
SP05	OPM7	58572 – 58580	0.0	0.0	201.420	0.079	195.595	0.047
SP05	OPM3	58572 – 58580	0.0	0.0	201.470	0.074	195.662	0.046
OPM7	Ref	58586 – 58597	426.4	218.6	49.578		52.898	
OPM3	Ref	58586 – 58597	435.7	218.6	48.995		52.664	
RO_5	OPM7	58586 – 58597	306.9	91.5	215.143	0.047	215.123	0.063
RO_5	OPM3	58586 – 58597	306.9	91.5	215.167	0.048	215.127	0.061
RO_6	OPM7	58586 – 58597	484.9	82.0	54.331	0.024	53.123	0.036
RO_6	OPM3	58586 – 58597	484.9	82.0	54.354	0.021	53.128	0.036
OPM7	Ref	58606 – 58611	258.7	218.6	49.578		52.898	
OPM3	Ref	58606 – 58611	247.8	218.6	48.995		52.664	
IENG	OPM7	58606 – 58611	483.7	130.5	55.095	0.032	55.409	0.034
IENG	OPM3	58606 – 58611	483.7	130.5	55.057	0.031	55.409	0.028
GR01	OPM7	58606 – 58611	483.8	298.6	57.103	0.048	55.170	0.031
GR01	OPM3	58606 – 58611	483.8	298.6	57.065	0.044	55.167	0.030
GR02	OPM7	58606 – 58611	483.6	0.0	353.827	0.035	353.269	0.027
GR02	OPM3	58606 – 58611	483.6	0.0	353.787	0.037	353.268	0.029
GR03	OPM7	58606 – 58611	210.5	0.0	283.221	0.016	280.476	0.059
GR03	OPM3	58606 – 58611	210.5	0.0	283.181	0.018	280.473	0.061
INR5	OPM7	58606 – 58611	484.1	0.0	310.222	0.026	309.276	0.033
INR5	OPM3	58606 – 58611	484.1	0.0	310.183	0.031	309.275	0.034
INR6	OPM7	58606 – 58611	484.1	130.5	55.768	0.032	55.850	0.030
INR6	OPM3	58606 – 58611	484.1	130.5	55.728	0.029	55.849	0.026

In addition, the Table 3 is providing the raw difference (Rawdiff) values as required by reference [1]. Note that some DICOM receivers are already including all the implemented delays in the RINEX data. Therefore, we are first providing the raw computation results, and then compute additionally the actual INTDLY to be implemented according to Annex D. The actual delays for all the receivers are provided in table 26. All the plots of P1 and P2 computed delays and of the related TDEV analysis are provided in Annex B. The P3 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 Traveling system against reference system

Table 4 is providing the computed internal delays INTDLY P1 and P2 for both traveling receivers OPM7 and OPM3 against the reference receiver OP71 at the start and at the end of the campaign. The mean values are the ones used for the computation of the visited equipment delays.

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

Pair	MJD of measurement	Rawdiff P1	TDEV	Rawdiff P2	TDEV
OPM7-OP71	58509 – 58523	-21.757	0.027	-26.256	0.027
OPM3-OP71	58509 – 58523	-31.797	0.029	-36.613	0.058
OPM7-OP71	58681 – 58692	-81.299	0.020	-86.24	0.020
OPM3-OP71	58681 – 58692	-71.293	0.018	-76.615	0.029
PTBB-OPM7	58534 – 58540	457.184	0.047	469.205	0.062
PTBB-OPM3	58534 – 58540	447.394	0.049	459.047	0.065
PT07-OPM7	58534 – 58540	-75.021	0.040	-78.477	0.066
PT07-OPM3	58534 – 58540	-84.81	0.044	-88.634	0.069
PT09-OPM7	58534 – 58540	-2.777	0.027	-6.939	0.039
PT09-OPM3	58534 – 58540	-12.567	0.026	-17.097	0.040
PT10-OPM7	58535 – 58540	96.313	0.054	86.499	0.056
PT10-OPM3	58535 – 58540	86.525	0.052	76.346	0.059
OBET-OPM7	58563 – 58567	379.34	0.025	373.257	0.056
OBET-OPM3	58563 – 58567	369.298	0.032	362.888	0.058
UTC4-OPM7	58563 – 58567	383.241	0.026	378.169	0.062
UTC4-OPM3	58563 – 58567	373.202	0.031	367.803	0.062
UTC7-OPM7	58563 – 58567	467.34	0.022	462.126	0.079
UTC7-OPM3	58563 – 58567	457.297	0.031	451.756	0.080
UTC8-OPM7	58563 – 58567	468.914	0.021	461.723	0.079
UTC8-OPM3	58563 – 58567	458.87	0.030	451.354	0.080
RIT1-OPM7	58572 – 58580	169.212	0.028	162.027	0.042
RIT1-OPM3	58572 – 58580	178.744	0.030	171.228	0.041
SP01-OPM7	58572 – 58580	131.189	0.026	143.27	0.045
SP01-OPM3	58572 – 58580	140.721	0.025	152.47	0.045
SP02-OPM7	58572 – 58580	131.702	0.026	142.434	0.047
SP02-OPM3	58572 – 58580	141.234	0.027	151.633	0.046
SP05-OPM7	58572 – 58580	97.142	0.079	87.997	0.047
SP05-OPM3	58572 – 58580	106.675	0.074	97.198	0.046
RO_5-OPM7	58586 – 58597	157.965	0.047	154.625	0.063
RO_5-OPM3	58586 – 58597	167.872	0.048	164.163	0.061
RO_6-OPM7	58586 – 58597	-190.347	0.024	-194.875	0.036
RO_6-OPM3	58586 – 58597	-180.441	0.021	-185.336	0.036
IENG-OPM7	58606 – 58611	-307.583	0.032	-310.589	0.034
IENG-OPM3	58606 – 58611	-317.938	0.031	-321.255	0.028
GR01-OPM7	58606 – 58611	-137.575	0.048	-142.828	0.031
GR01-OPM3	58606 – 58611	-147.93	0.044	-153.497	0.030
GR02-OPM7	58606 – 58611	-139.251	0.035	-143.129	0.027
GR02-OPM3	58606 – 58611	-149.608	0.037	-153.796	0.029
GR03-OPM7	58606 – 58611	63.243	0.016	57.178	0.059
GR03-OPM3	58606 – 58611	52.886	0.018	46.509	0.061
INR5-OPM7	58606 – 58611	-183.356	0.026	-187.622	0.033
INR5-OPM3	58606 – 58611	-193.712	0.031	-198.289	0.034
INR6-OPM7	58606 – 58611	-307.31	0.032	-310.548	0.030
INR6-OPM3	58606 – 58611	-317.667	0.029	-321.215	0.026



Table 4: Traveling vs. Reference system (all values in ns).

Pair	MJD of measurement	INTDLY P1	INTDLY P2	P1 -P2
OPM7-OP71	58509 – 58523	49.757	52.856	-3.099
OPM7-OP71	58681 – 58692	49.399	52.940	-3.541
misclosure		0.358	0.084	0.442
mean		49.578	52.898	-3.32
OPM3-OP71	58509 – 58523	49.197	52.613	-3.416
OPM3-OP71	58681 – 58692	48.793	52.715	-3.922
misclosure		0.404	0.102	0.506
mean		48.995	52.664	-3.669

## 6.2 Visited systems with respect the traveling system

Table 5 is providing the computed internal delays INTDLY P1 and P2 for the visited systems by using OPM7 and OPM3 as reference systems. In addition, it also provides the differences between both traveling receivers, allowing for a monitoring of the stability of traveling equipment during the whole campaign.

Table 5: Traveling vs. Visited system (all values in ns).

Pair	MJD of measurement	INTDLY P1	INTDLY P2	P1 -P2
OPM7-PTBB	58534 – 58540	306.062	321.403	-15.341
OPM3-PTBB	58534 – 58540	306.289	321.611	-15.322
OPM7 to OPM3	58534 – 58540	0.227	0.208	0.019
mean		306.175	321.507	-15.332
OPM7-PT07	58534 – 58540	-200.643	-200.779	0.136
OPM3-PT07	58534 – 58540	-200.415	-200.570	0.155
OPM7 to OPM3	58534 – 58540	0.228	0.209	0.019
mean		-200.529	-200.674	0.145
OPM7-PT09	58534 – 58540	57.801	56.959	0.842
OPM3-PT09	58534 – 58540	58.028	57.167	0.861
OPM7 to OPM3	58534 – 58540	0.227	0.208	0.019
mean		57.915	57.063	0.852
OPM7-PT10	58535 – 58540	-25.009	-31.503	6.494
OPM3-PT10	58535 – 58540	-24.780	-31.290	6.51
OPM7 to OPM3	58535 – 58540	0.229	0.213	0.016
mean		-24.895	-31.396	6.501
OPM7-OBET	58563 – 58567	61.518	58.755	2.763
OPM3-OBET	58563 – 58567	61.493	58.752	2.741
OPM7 to OPM3	58563 – 58567	0.025	0.003	0.022
mean		61.505	58.754	2.751
OPM7-UTC4	58563 – 58567	62.819	61.067	1.752
OPM3-UTC4	58563 – 58567	62.797	61.067	1.73
OPM7 to OPM3	58563 – 58567	0.022	0	0.022
mean		62.808	61.067	1.741
OPM7-UTC7	58563 – 58567	36.218	34.324	1.894
OPM3-UTC7	58563 – 58567	36.192	34.320	1.872
OPM7 to OPM3	58563 – 58567	0.026	0.004	0.022
mean		36.205	34.322	1.883
OPM7-UTC8	58563 – 58567	38.392	34.521	3.871
OPM3-UTC8	58563 – 58567	38.365	34.518	3.847
OPM7 to OPM3	58563 – 58567	0.027	0.003	0.024
mean		38.379	34.520	3.859



OPM7-RIT1	58572 – 58580	273.490	269.625	3.865
OPM3-RIT1	58572 – 58580	273.539	269.692	3.847
OPM7 to OPM3	58572 – 58580	0.049	0.067	0.018
mean		273.514	269.659	3.855
OPM7-SP01	58572 – 58580	235.467	250.868	-15.401
OPM3-SP01	58572 – 58580	235.516	250.934	-15.418
OPM7 to OPM3	58572 – 58580	0.049	0.066	0.017
mean		235.492	250.901	-15.409
OPM7-SP02	58572 – 58580	235.980	250.032	-14.052
OPM3-SP02	58572 – 58580	236.029	250.097	-14.068
OPM7 to OPM3	58572 – 58580	0.049	0.065	0.016
mean		236.005	250.065	-14.06
OPM7-SP05	58572 – 58580	201.420	195.595	5.825
OPM3-SP05	58572 – 58580	201.470	195.662	5.808
OPM7 to OPM3	58572 – 58580	0.05	0.067	0.017
mean		201.445	195.629	5.816
OPM7-RO_5	58586 – 58597	215.143	215.123	0.02
OPM3-RO_5	58586 – 58597	215.167	215.127	0.04
OPM7 to OPM3	58586 – 58597	0.024	0.004	0.02
mean		215.155	215.125	0.03
OPM7-RO_6	58586 – 58597	54.331	53.123	1.208
OPM3-RO_6	58586 – 58597	54.354	53.128	1.226
OPM7 to OPM3	58586 – 58597	0.023	0.005	0.018
mean		54.343	53.126	1.217
OPM7-IENG	58606 – 58611	55.095	55.409	-0.314
OPM3-IENG	58606 – 58611	55.057	55.409	-0.352
OPM7 to OPM3	58606 – 58611	0.038	0	0.038
mean		54.919	55.320	-0.401
OPM7-GR01	58606 – 58611	57.103	55.170	1.933
OPM3-GR01	58606 – 58611	57.065	55.167	1.898
OPM7 to OPM3	58606 – 58611	0.038	0.003	0.035
mean		56.965	55.019	1.946
OPM7-GR02	58606 – 58611	353.827	353.269	0.558
OPM3-GR02	58606 – 58611	353.787	353.268	0.519
OPM7 to OPM3	58606 – 58611	0.04	0.001	0.039
mean		353.666	353.135	0.531
OPM7-GR03	58606 – 58611	283.221	280.476	2.745
OPM3-GR03	58606 – 58611	283.181	280.473	2.708
OPM7 to OPM3	58606 – 58611	0.04	0.003	0.037
mean		283.041	280.360	2.681
OPM7-INR5	58606 – 58611	310.222	309.276	0.946
OPM3-INR5	58606 – 58611	310.183	309.275	0.908
OPM7 to OPM3	58606 – 58611	0.039	0.001	0.038
mean		310.001	309.123	0.878
OPM7-INR6	58606 – 58611	55.768	55.850	-0.082
OPM3-INR6	58606 – 58611	55.728	55.849	-0.121
OPM7 to OPM3	58606 – 58611	0.04	0.001	0.039
mean		55.601	55.767	-0.166

### 6.3 Uncertainty estimation

We provide in this section an estimation of the uncertainty of the differential calibration for the receivers located at visited laboratories. 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. Note that we have chosen as  $u_b$  for misclosure the upper values between the actual misclosure between the start and the end of the campaign and the offset between both traveling equipment.

In the calibration process only P1 and P2 delay are estimated, therefore the misclosure for P3 delay is not directly available from the calibration computation. The P3 misclosure is estimated by applying the formula:

$$P3 = P1 + 1.546 \times (P1 - P2)$$

to the misclosure values computed for P1 and for P1-P2.

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

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-PTBB)	0.047	0.062	0.078	0.153	TDEV(1 d)
$u_a$ (OPM3-PTBB)	0.049	0.065	0.081	0.141	TDEV(1 d)
$u_a$ T-V	0.048	0.064	0.080	0.147	Average trav-visited
$u_a$	0.054	0.077	0.094	0.165	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited system to its local UTC(k)					
$u_{b,32}$	0.360	0.360		0.360	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
$u_{b,SYS}$	0.773	0.693		1.357	Quadratic sum of $u_b$
$u_{CAL0}$	0.775	0.695		1.367	Composed of $u_a$ and $u_{b,SYS}$

Table 7: PT07 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-PT07)	0.040	0.066	0.077	0.105	TDEV(1 d)
$u_a$ (OPM3-PT07)	0.044	0.069	0.082	0.106	TDEV(1 d)
$u_a$ T-V	0.042	0.068	0.080	0.105	Average trav-visited
$u_a$	0.048	0.080	0.093	0.129	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.721	0.634		1.333	Composed of $u_a$ and $u_{b,SYS}$

Table 8: PT09 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-PT09)	0.027	0.039	0.047	0.042	TDEV(1 d)
$u_a$ (OPM3-PT09)	0.026	0.040	0.048	0.045	TDEV(1 d)
$u_a$ T-V	0.026	0.040	0.048	0.043	Average trav-visited
$u_a$	0.035	0.059	0.069	0.086	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.330	Composed of $u_a$ and $u_{b,SYS}$

Table 9: PT10 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-PT10)	0.054	0.056	0.078	0.119	TDEV(1 d)
$u_a$ (OPM3-PT10)	0.052	0.059	0.079	0.111	TDEV(1 d)
$u_a$ T-V	0.053	0.057	0.078	0.115	Average trav-visited
$u_a$	0.058	0.071	0.092	0.137	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.721	0.635		1.334	Composed of $u_a$ and $u_{b,SYS}$

Table 10: OBET uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-OBET)	0.025	0.056	0.061	0.077	TDEV(1 d)
$u_a$ (OPM3-OBET)	0.032	0.058	0.066	0.063	TDEV(1 d)
$u_a$ T-V	0.029	0.057	0.064	0.070	Average trav-visited
$u_a$	0.038	0.071	0.081	0.103	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.331	Composed of $u_a$ and $u_{b,SYS}$

Table 11: UTC4 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a(\text{OPM7-OP71})$	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a(\text{OPM3-OP71})$	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a\text{T-R}$	0.024	0.043	0.049	0.075	Average trav-reference
$u_a(\text{OPM7-UTC4})$	0.026	0.062	0.067	0.051	TDEV(1 d)
$u_a(\text{OPM3-UTC4})$	0.031	0.062	0.069	0.064	TDEV(1 d)
$u_a\text{T-V}$	0.028	0.062	0.068	0.057	Average trav-visited
$u_a$	0.037	0.075	0.084	0.094	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.330	Composed of $u_a$ and $u_{b,SYS}$



Table 12: UTC7 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-UTC7)	0.022	0.079	0.082	0.143	TDEV(1 d)
$u_a$ (OPM3-UTC7)	0.031	0.080	0.086	0.155	TDEV(1 d)
$u_a$ T-V	0.026	0.080	0.084	0.149	Average trav-visited
$u_a$	0.035	0.091	0.097	0.167	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.337	Composed of $u_a$ and $u_{b,SYS}$

Table 13: UTC8 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-UTC8)	0.021	0.079	0.082	0.144	TDEV(1 d)
$u_a$ (OPM3-UTC8)	0.030	0.080	0.085	0.145	TDEV(1 d)
$u_a$ T-V	0.026	0.080	0.084	0.144	Average trav-visited
$u_a$	0.035	0.091	0.097	0.162	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.337	Composed of $u_a$ and $u_{b,SYS}$

Table 14: RIT1 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-RIT1)	0.028	0.042	0.050	0.095	TDEV(1 d)
$u_a$ (OPM3-RIT1)	0.030	0.041	0.051	0.106	TDEV(1 d)
$u_a$ T-V	0.029	0.042	0.051	0.101	Average trav-visited
$u_a$	0.038	0.060	0.071	0.126	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.333	Composed of $u_a$ and $u_{b,SYS}$

Table 15: SP01 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-SP01)	0.026	0.045	0.052	0.143	TDEV(1 d)
$u_a$ (OPM3-SP01)	0.025	0.045	0.051	0.141	TDEV(1 d)
$u_a$ T-V	0.026	0.045	0.052	0.142	Average trav-visited
$u_a$	0.035	0.062	0.071	0.161	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.337	Composed of $u_a$ and $u_{b,SYS}$

Table 16: SP02 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-SP02)	0.026	0.047	0.054	0.126	TDEV(1 d)
$u_a$ (OPM3-SP02)	0.027	0.046	0.053	0.129	TDEV(1 d)
$u_a$ T-V	0.026	0.046	0.053	0.128	Average trav-visited
$u_a$	0.035	0.063	0.072	0.148	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.335	Composed of $u_a$ and $u_{b,SYS}$

Table 17: SP05 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-SP05)	0.079	0.047	0.092	0.218	TDEV(1 d)
$u_a$ (OPM3-SP05)	0.074	0.046	0.087	0.231	TDEV(1 d)
$u_a$ T-V	0.076	0.046	0.089	0.225	Average trav-visited
$u_a$	0.080	0.063	0.102	0.237	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.723	0.637		1.348	Composed of $u_a$ and $u_{b,SYS}$

Table 18: RO\_5 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-RO_5)	0.047	0.063	0.079	0.087	TDEV(1 d)
$u_a$ (OPM3-RO_5)	0.048	0.061	0.078	0.087	TDEV(1 d)
$u_a$ T-V	0.048	0.062	0.078	0.087	Average trav-visited
$u_a$	0.054	0.075	0.092	0.115	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.721	0.634		1.332	Composed of $u_a$ and $u_{b,SYS}$



Table 19: RO\_6 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-RO_6)	0.024	0.036	0.043	0.055	TDEV(1 d)
$u_a$ (OPM3-RO_6)	0.021	0.036	0.042	0.044	TDEV(1 d)
$u_a$ T-V	0.022	0.036	0.042	0.050	Average trav-visited
$u_a$	0.033	0.056	0.065	0.090	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.330	Composed of $u_a$ and $u_{b,SYS}$

Table 20: IENG uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-IENG)	0.032	0.034	0.047	0.044	TDEV(1 d)
$u_a$ (OPM3-IENG)	0.031	0.028	0.042	0.063	TDEV(1 d)
$u_a$ T-V	0.032	0.031	0.045	0.053	Average trav-visited
$u_a$	0.040	0.053	0.066	0.092	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.330	Composed of $u_a$ and $u_{b,SYS}$

Table 21: GR01 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-GR01)	0.048	0.031	0.057	0.109	TDEV(1 d)
$u_a$ (OPM3-GR01)	0.044	0.030	0.053	0.101	TDEV(1 d)
$u_a$ T-V	0.046	0.030	0.055	0.105	Average trav-visited
$u_a$	0.052	0.052	0.074	0.129	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.721	0.634		1.333	Composed of $u_a$ and $u_{b,SYS}$

Table 22: GR02 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-GR02)	0.035	0.027	0.044	0.092	TDEV(1 d)
$u_a$ (OPM3-GR02)	0.037	0.029	0.047	0.099	TDEV(1 d)
$u_a$ T-V	0.036	0.028	0.046	0.096	Average trav-visited
$u_a$	0.043	0.051	0.067	0.122	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.333	Composed of $u_a$ and $u_{b,SYS}$

Table 23: GR03 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-GR03)	0.016	0.059	0.061	0.095	TDEV(1 d)
$u_a$ (OPM3-GR03)	0.018	0.061	0.064	0.092	TDEV(1 d)
$u_a$ T-V	0.017	0.060	0.062	0.093	Average trav-visited
$u_a$	0.029	0.074	0.079	0.119	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.332	Composed of $u_a$ and $u_{b,SYS}$

Table 24: INR5 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-INR5)	0.026	0.033	0.042	0.078	TDEV(1 d)
$u_a$ (OPM3-INR5)	0.031	0.034	0.046	0.050	TDEV(1 d)
$u_a$ T-V	0.028	0.034	0.044	0.064	Average trav-visited
$u_a$	0.037	0.055	0.066	0.099	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.331	Composed of $u_a$ and $u_{b,SYS}$

Table 25: INR6 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
$u_a$ (OPM7-OP71)	0.024	0.042	0.048	0.077	TDEV(1 d)
$u_a$ (OPM3-OP71)	0.024	0.044	0.050	0.073	TDEV(1 d)
$u_a$ T-R	0.024	0.043	0.049	0.075	Average trav-reference
$u_a$ (OPM7-INR6)	0.032	0.030	0.044	0.054	TDEV(1 d)
$u_a$ (OPM3-INR6)	0.029	0.026	0.039	0.068	TDEV(1 d)
$u_a$ T-V	0.030	0.028	0.041	0.061	Average trav-visited
$u_a$	0.038	0.051	0.064	0.097	Visited-reference
Misclosure					
$u_{b,1}$	0.404	0.213	0.506	1.186	Observed Max misclosure
Systematic components related to RAWDIF					
$u_{b,11}$	0.20	0.20	0.20	0.20	Position error at reference
$u_{b,12}$	0.20	0.20	0.20	0.20	Position error at visited
$u_{b,13}$	0.20	0.20	0.20	0.20	Multipaths at reference
$u_{b,14}$	0.20	0.20	0.20	0.20	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.220	0.220		0.220	REFDLY (at ref lab)
$u_{b,22}$	0.220	0.220		0.220	REFDLY (at visited lab)
$u_{b,TOT}$	0.648	0.550	0.645	1.290	
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 Visited 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
$u_{b,SYS}$	0.719	0.632		1.327	Quadratic sum of $u_b$
$u_{CAL0}$	0.720	0.633		1.331	Composed of $u_a$ and $u_{b,SYS}$



## 7 Final results for the system to calibrate

Table 26 is providing the final results of this calibration campaign, by following the BIPM Guidelines. Additional computation for Dicom receivers implementing delays in Rinex files is reported in annex D. In addition, Table 27 is providing the computed conservative  $k = 2$  expanded uncertainties in order to be in line with EURAMET recommendations. The PTB DLR RISE ROA INRiM calibrated links used in the frame of the TAI computation are in line with the conventional combined uncertainty of 2.5 ns.

Table 26: Summary information on the calibration trip.

BIPM code	Rinex name	Cal Id	Date	$u_{CAL}$ (P3)/ns	INTDLY P1/ns	INTDLY P2/ns
<b>Reference system</b>						
OP71	OP71	1014-2018	2019-xx		55.2	53.8
<b>Visited system(s)</b>						
PT02	PTBB	1014-2019	2019.2	1.4	306.2	321.5
PT07	PT07	1014-2019	2019.2	1.4	-200.5	-200.7
PT09	PT09	1014-2019	2019.2	1.4	57.9	57.1
PT10	PT10	1014-2019	2019.2	1.4	-24.9	-31.4
DL05	OBET	1014-2019	2019.2	1.4	61.5	58.8
DL04	UTC4	1014-2019	2019.2	1.4	62.8	61.1
DL07	UTC7	1014-2019	2019.2	1.4	36.2	34.3
DL08	UTC8	1014-2019	2019.2	1.4	38.4	34.5
RIT1	RIT1	1014-2019	2019.2	1.4	273.5	269.7
SP01	SP01	1014-2019	2019.2	1.4	235.5	250.9
SP02	SP02	1014-2019	2019.2	1.4	236.0	250.1
SP05	SP05	1014-2019	2019.2	1.4	201.4	195.6
RO_5	RO_5	1014-2019	2019.2	1.4	215.2	215.1
RO_6	RO_6	1014-2019	2019.2	1.4	54.3	53.1
IT10	IENG	1014-2019	2019.2	1.4	54.9	55.3
IT11	GR01	1014-2019	2019.2	1.4	57.0	55.0
IT12	GR02	1014-2019	2019.2	1.4	353.7	353.1
IT13	GR03	1014-2019	2019.2	1.4	283.0	280.4
IT08	INR5	1014-2019	2019.2	1.4	310.0	309.1
IT09	INR6	1014-2019	2019.2	1.4	55.6	55.8

Table 27: Conservative  $k=2$  expanded uncertainties for all receivers with using OP71 as a reference following EURAMET standard (all values in ns).

BIPM code	Rinex name	u(P1)	u(P2)	u(P3)
PT02	PTBB	1.6	1.4	2.8
PT07	PT07	1.5	1.3	2.8
PT09	PT09	1.5	1.3	2.8
PT10	PT10	1.5	1.3	2.8
DL05	OBET	1.5	1.3	2.8
DL04	UTC4	1.5	1.3	2.8
DL07	UTC7	1.5	1.3	2.8
DL08	UTC8	1.5	1.3	2.8
RIT1	RIT1	1.5	1.3	2.8
SP01	SP01	1.5	1.3	2.8
SP02	SP02	1.5	1.3	2.8
SP05	SP05	1.5	1.3	2.8
RO_5	RO_5	1.5	1.3	2.8
RO_6	RO_6	1.5	1.3	2.8
IT10	IENG	1.5	1.3	2.8
IT11	GR01	1.5	1.3	2.8
IT12	GR02	1.5	1.3	2.8
IT13	GR03	1.5	1.3	2.8
IT08	INR5	1.5	1.3	2.8
IT09	INR6	1.5	1.3	2.8

## 8 Acknowledgments

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