Calibration Report Cal_ID 1018-2017

Calibration of GPS receivers at Observatoire Royal de Belgique.

September 28, 2017
Issue 1

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Contents

1 Summary.

1.1 General informations.

This Calibration Report released by LNE-SYRTE is about the relative calibration campaign of GPS receivers located at Observatoire Royal de Belgique (ORB).

It is built according to the Annex 4 of the document “BIPM guidelines for GNSS equipment calibration”, V3.2 15/02/2016 [1], 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 that the calibrated links used in the frame of the TAI computation are in line with the conventional combined uncertainty of 2.5 ns.

1.2 Calibration report changes.

This is Issue 1 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, Sèvres, France.

CCTF:	Consultative Committee on Time and Frequency.
CGGTTS:	CCTF Global GNSS Time Transfer Standard format.
CIPM:	Comité International des Poids et Mesures.
GLONASS:	Russian GNSS.
GNSS:	Global Navigation Satellite System.
GPS:	United States of America GNSS.
LNE:	Laboratoire National de Métrologie et d'Essais, French NMI.
LNE-SYRTE:	French designated laboratory in charge of Time and Frequency units.
NMI:	National Metrology Institute.
NRCan:	National Ressources 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 derived from AVAR and MVAR.

2.2 Reference Documents.

[1] BIPM, "BIPM guidelines for GNSS calibration", V3.2 15/02/2016.
[2] Pierre Uhrich 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. Uhrich, "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 GPS receiver located at ORB 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 fall 2016 (#1001-2016).

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 A for all receivers and all locations. Table 1 present a summary of the timetable and of the equipment.

Table 1: Summary information on the calibration trip.

Institute	Status of equipment	MJD of measurement	Receiver type	BIPM code	RINEX name
OP	Traveling		Septentrio PolaRx4TR	OPM7	OPM7
OP	Traveling		Septentrio PolaRx4TR	OPM3	OPM3
OP	Group 1 Reference	57823 – 57832	Septentrio PolaRx4TR	OP71	OP71
OP	Group 1 Reference	57844 – 57850	Septentrio PolaRx4TR	OP71	OP71
ORB	Group 2	57839 – 57843	Septentrio PolaRx4TR	OR1Z	BRUX
ORB	Group 2	57839 – 57843	Septentrio PolaRx4TR	OR4A	ORBA
ORB	Group 2	57841 – 57843	Ashtech Z-XII3T	OR2Z	ZTB1
ORB	Group 2	57841 – 57843	Septentrio PolaRx4TR	OR3Z	ZTB3

4 Data used.

The OP71 collected raw data are transformed into RINEX 2.1 format by using the UNAVCO TEQC software. The same software is also used to convert the raw data of traveling receivers into RINEX 2.1 format. Local receivers RINEX 2.1 data are provided by ORB. The calibration is 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 visited laboratory. 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.

In addition, the Table 3 is providing the RAWDIF values as required by reference [1]. 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.

6.2 Traveling system with respect to the visited systems.

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, computed from the offset to the visited receiver used as pivot. These differences are taken as an indicator of the potential delay deviations of the traveling equipment as implemented in remote sites during the whole 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	57823 – 57832	191.6	128.7	55.7		54.4	
OPM7	OP71	57823 – 57832	250.2	218.6	50.014	0.026	53.543	0.025
OPM3	OP71	57823 – 57832	250.3	218.6	49.525	0.021	53.372	0.027
OP71	Ref	57844 – 57850	191.6	128.7	55.7		54.4	
OPM7	OP71	57844 – 57850	244.9	218.6	49.926	0.027	53.589	0.021
OPM3	OP71	57844 – 57850	244.8	218.6	49.326	0.020	53.281	0.021
OPM7	Ref	57839 – 57843	167.7	218.6	49.970		53.566	
OPM3	Ref	57839 – 57843	167.6	218.6	49.425		53.326	
BRUX	OPM7	57839 – 57843	149.5	237.0	54.533	0.029	51.562	0.035
BRUX	OPM3	57839 – 57843	149.5	237.0	54.555	0.037	51.569	0.034
ORBA	OPM7	57839 – 57843	158.0	149.2	55.144	0.058	55.450	0.020
ORBA	OPM3	57839 – 57843	158.0	149.2	55.168	0.053	55.458	0.016
ZTB1	OPM7	57841 – 57843	58.9	150.0	303.651	0.147	312.419	0.051
ZTB1	OPM3	57841 – 57843	58.9	150.0	303.685	0.167	312.436	0.055
ZTB3	OPM7	57841 – 57843	160.7	147.9	58.329	0.165	58.413	0.161
ZTB3	OPM3	57841 – 57843	160.7	147.9	58.362	0.178	58.425	0.178

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

Pair	MJD of measurement	Rawdiff P1	TDEV	Rawdiff P2	TDEV
OPM7-OP71	57823 – 57832	-25.614	0.026	-30.443	0.026
OPM3-OP71	57823 – 57832	-25.025	0.021	-30.172	0.027
OPM7-OP71	57844 – 57850	-30.826	0.027	-35.789	0.027
OPM3-OP71	57844 – 57850	-30.326	0.020	-35.581	0.021
BRUX-OPM7	57839 – 57843	41.163	0.029	34.596	0.035
BRUX-OPM3	57839 – 57843	41.63	0.037	34.743	0.034
ORBA-OPM7	57839 – 57843	-54.526	0.058	-57.816	0.020
ORBA-OPM3	57839 – 57843	-54.057	0.053	-57.668	0.016
ZTB1-OPM7	57841 – 57843	293.881	0.147	299.053	0.051
ZTB1-OPM3	57841 – 57843	294.36	0.167	299.21	0.055
ZTB3-OPM7	57841 – 57843	-55.341	0.165	-58.853	0.161
ZTB3-OPM3	57841 – 57843	-54.863	0.178	-58.701	0.178

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

Pair	MJD of measurement	INTDLY P1	INTDLY P2	P1 -P2
OPM7-OP71	57823 – 57832	50.014	53.543	-3.529
OPM7-OP71	57844 – 57850	49.926	53.589	-3.663
misclosure		0.088	0.046	0.134
mean		49.97	53.566	-3.596
OPM3-OP71	57823 – 57832	49.525	53.372	-3.847
OPM3-OP71	57844 – 57850	49.326	53.281	-3.955
misclosure		0.199	0.091	0.108
mean		49.4255	53.3265	-3.901

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

Pair	MJD of measurement	INTDLY P1	INTDLY P2	P1 -P2
OPM7-BRUX	57839 – 57843	54.533	51.562	2.971
OPM3-BRUX	57839 – 57843	54.555	51.569	2.986
OPM7 to OPM3	57839 – 57843	0.022	0.007	0.015
mean		54.544	51.566	2.978
OPM7-ORBA	57839 – 57843	55.144	55.450	-0.306
OPM3-ORBA	57839 – 57843	55.168	55.458	-0.29
OPM7 to OPM3	57839 – 57843	0.024	0.008	0.016
mean		55.156	55.454	-0.298
OPM7-ZTB1	57841 – 57843	303.651	312.419	-8.768
OPM3-ZTB1	57841 – 57843	303.685	312.436	-8.751
OPM7 to OPM3	57841 – 57843	0.034	0.017	0.017
mean		303.668	312.428	-8.76
OPM7-ZTB3	57841 – 57843	58.329	58.413	-0.084
OPM3-ZTB3	57841 – 57843	58.362	58.425	-0.063
OPM7 to OPM3	57841 – 57843	0.033	0.012	0.021
mean		58.346	58.419	-0.073

6.3 Uncertainty estimation.

We provide in this Section an estimation of the uncertainty of the differential calibration for the receivers at ORB. 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.

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

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
u_a(OPM7-OP71)	0.026	0.023	0.035	0.119	TDEV(1 d)
u_a(OPM3-OP71)	0.021	0.024	0.032	0.121	TDEV(1 d)
u_aT-R	0.024	0.024	0.034	0.120	Average trav-reference
u_a(OPM7-BRUX)	0.029	0.035	0.045	0.170	TDEV(1 d)
u_a(OPM3-BRUX)	0.037	0.034	0.050	0.122	TDEV(1 d)
u_aT-V	0.033	0.035	0.048	0.146	Average trav-visited
u_a	0.041	0.042	0.059	0.189	Visited-reference
Misclosure					
$u_{b,1}$	0.199	0.091	0.134	0.199	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
$u_{b,13}$	0.05	0.05	0.05	0.05	Multipaths at reference
$u_{b,14}$	0.05	0.05	0.05	0.05	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)
$u_{b,TOT}$	0.471	0.436	0.321	0.471	
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					
$u_{b,41}$	0.2	0.2		0.2	CABDLY reference
$u_{b,42}$	N/A	N/A		N/A	CABDLY visit
$u_{b,SYS}$	0.599	0.572		0.599	Quadratic sum of u_b
u_{CAL0}	0.600	0.573		0.628	Composed of u_a and $u_{b,SYS}$

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

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
u_a(OPM7-OP71)	0.026	0.023	0.035	0.119	TDEV(1 d)
u_a(OPM3-OP71)	0.021	0.024	0.032	0.121	TDEV(1 d)
u_aT-R	0.024	0.024	0.034	0.120	Average trav-reference
u_a(OPM7-ORBA)	0.058	0.020	0.061	0.103	TDEV(1 d)
u_a(OPM3-ORBA)	0.053	0.016	0.055	0.101	TDEV(1 d)
u_aT-V	0.056	0.018	0.059	0.102	Average trav-visited
u_a	0.061	0.030	0.068	0.157	Visited-reference
Misclosure					
$u_{b,1}$	0.199	0.091	0.134	0.199	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
$u_{b,13}$	0.05	0.05	0.05	0.05	Multipaths at reference
$u_{b,14}$	0.05	0.05	0.05	0.05	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)
$u_{b,TOT}$	0.471	0.436	0.321	0.471	
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					
$u_{b,41}$	0.2	0.2		0.2	CABDLY reference
$u_{b,42}$	N/A	N/A		N/A	CABDLY visit
$u_{b,SYS}$	0.599	0.572		0.599	Quadratic sum of u_b
u_{CAL0}	0.602	0.575		0.619	Composed of u_a and $u_{b,SYS}$

Table 8: ZTB1 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
u_a(OPM7-OP71)	0.026	0.023	0.035	0.119	TDEV(1 d)
u_a(OPM3-OP71)	0.021	0.024	0.032	0.121	TDEV(1 d)
u_aT-R	0.024	0.024	0.034	0.120	Average trav-reference
u_a(OPM7-ZTB1)	0.147	0.051	0.156	0.210	TDEV(1 d)
u_a(OPM3-ZTB1)	0.167	0.055	0.176	0.207	TDEV(1 d)
u_aT-V	0.157	0.053	0.166	0.208	Average trav-visited
u_a	0.159	0.058	0.169	0.240	Visited-reference
Misclosure					
$u_{b,1}$	0.199	0.091	0.134	0.199	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
$u_{b,13}$	0.05	0.05	0.05	0.05	Multipaths at reference
$u_{b,14}$	0.05	0.05	0.05	0.05	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)
$u_{b,TOT}$	0.471	0.436	0.321	0.471	
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					
$u_{b,41}$	0.2	0.2		0.2	CABDLY reference
$u_{b,42}$	N/A	N/A		N/A	CABDLY visit
$u_{b,SYS}$	0.663	0.639		0.663	Quadratic sum of u_b
u_{CAL0}	0.682	0.658		0.705	Composed of u_a and $u_{b,SYS}$

Table 9: ZTB3 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
u_a(OPM7-OP71)	0.026	0.023	0.035	0.119	TDEV(1 d)
u_a(OPM3-OP71)	0.021	0.024	0.032	0.121	TDEV(1 d)
u_aT-R	0.024	0.024	0.034	0.120	Average trav-reference
u_a(OPM7-ZTB3)	0.165	0.161	0.231	0.194	TDEV(1 d)
u_a(OPM3-ZTB3)	0.178	0.178	0.252	0.289	TDEV(1 d)
u_aT-V	0.171	0.169	0.240	0.241	Average trav-visited
u_a	0.173	0.171	0.243	0.269	Visited-reference
Misclosure					
$u_{b,1}$	0.199	0.091	0.134	0.199	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
$u_{b,13}$	0.05	0.05	0.05	0.05	Multipaths at reference
$u_{b,14}$	0.05	0.05	0.05	0.05	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)
$u_{b,TOT}$	0.471	0.436	0.321	0.471	
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					
$u_{b,41}$	0.2	0.2		0.2	CABDLY reference
$u_{b,42}$	N/A	N/A		N/A	CABDLY visit
$u_{b,SYS}$	0.599	0.572		0.599	Quadratic sum of u_b
u_{CAL0}	0.623	0.598		0.657	Composed of u_a and $u_{b,SYS}$

7 Final results for the system to calibrate.

Table 10 is providing the final results of this calibration campaign, by following the BIPM Guidelines. In addition, Table 11 is providing the computed conservative k = 2 expanded uncertainties in order to be in line with EURAMET recommendations. The ORB calibrated links used in the frame of the TAI computation are in line with the conventional combined uncertainty of 2.5 ns.

Table 10: Summary information on the calibration trip.

BIPM code	**Rinex name**	**Cal Id**	**Date**	**u_{CAL} (P3)/ns**	**INTDLY P1/ns**	**INTDLY P2/ns**
Reference system						
OPM7	OPM7	1001-2016	2016-12-1		55.7	54.4
Visited system(s)						
OR1Z	BRUX	1018-2017	2017.3	0.628 0.7	54.544	51.566
OR4A	ORBA	1018-2017	2017.3	0.619 0.7	55.156	55.454
OR2Z	ZTB1	1018-2017	2017.3	0.705 0.8	303.668	312.428
OR3Z	ZTB3	1018-2017	2017.3	0.657 0.7	58.346	58.419

Table 11: 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)
OR1Z	BRUX	1.2	1.2	1.3
OR4A	ORBA	1.3	1.2	1.3
OR2Z	ZTB1	1.4	1.4	1.5
OR3Z	ZTB3	1.3	1.2	1.4

8 Acknowlegments.

We acknowlege Pascale Defraigne, Bruno Bertrand and Gérard Petit for support and valuable comments.