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Calibration of GPS receivers at Centre National d'Études Spatiales (CNES)

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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 Centre National d'Études Spatiales.

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.

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
CNES:	Centre National d'Études Spatiales
GFZ:	Geoforschungszentrum
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
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
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 the GPS receiver located at CNES 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 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 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

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	58260 – 58266	Septentrio PolaRx4TR	OP71	OP71
OP	Group 1 Reference	58315 – 58322	Septentrio PolaRx4TR	OP71	OP71
CNES	Group 2	58284 – 58298	Septentrio PolaRx4TR	CS21	CS21
CNES	Group 2	58284 – 58298	Septentrio PolaRx4TR	CS22	CS22

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.

In addition, the Table 3 is providing the raw difference (Rawdiff) 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 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

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	58260 – 58266	191.6	128.7	55.7		54.4	
OPM7	OP71	58260 – 58266	242.7	218.6	49.917	0.034	53.406	0.026
OPM3	OP71	58260 – 58266	242.5	218.6	49.302	0.037	53.206	0.022
OP71	Ref	58315 – 58322	191.6	128.7	55.7		54.4	
OPM7	OP71	58315 – 58322	242.9	218.6	50.128	0.023	53.538	0.026
OPM3	OP71	58315 – 58322	242.6	218.6	49.448	0.022	53.217	0.026
OPM7	Ref	58284 – 58298	145.1	218.6	50.023		53.472	
OPM3	Ref	58284 – 58298	144.9	218.6	49.375		53.212	
CS21	OPM7	58284 – 58298	149.0	166.2	58.585	0.087	56.682	0.040
CS21	OPM3	58284 – 58298	149.0	166.2	58.509	0.086	56.581	0.039
CS22	OPM7	58284 – 58298	149.0	176.1	57.949	0.033	56.097	0.032
CS22	OPM3	58284 – 58298	149.0	176.1	57.872	0.033	55.996	0.032

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

Pair	MJD of measurement	Rawdiff P1	TDEV	Rawdiff P2	TDEV
CS21-OPM7	58284 – 58298	-47.738	0.087	-53.09	0.040
CS21-OPM3	58284 – 58298	-47.366	0.086	-53.131	0.039
CS22-OPM7	58284 – 58298	-38.474	0.033	-43.775	0.032
CS22-OPM3	58284 – 58298	-38.103	0.033	-43.816	0.032

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

Pair	MJD of measurement	INTDLY P1	INTDLY P2	P1 -P2
OPM7-OP71	58260 – 58266	49.917	53.406	-3.489
OPM7-OP71	58315 – 58322	50.128	53.538	-3.41
misclosure		0.211	0.132	0.079
mean		50.0225	53.472	-3.4495
OPM3-OP71	58260 – 58266	49.302	53.206	-3.904
OPM3-OP71	58315 – 58322	49.448	53.217	-3.769
misclosure		0.146	0.011	0.135
mean		49.375	53.2115	-3.8365

traveling receivers, allowing for a monitoring of the stability of traveling equipment during the whole campaign.

When applying these delays for computing CGGTTS P3 CV between CS21, respectively CS22, and OPM3 and OPM7, we note an unexpected diurnal term of significant amplitude. In addition the diurnal of CS21 seems larger by a factor of about 2 compared to the diurnal of CS22.

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

Pair	MJD of measurement	INTDLY P1	INTDLY P2	P1 -P2
OPM7-CS21	58284 – 58298	58.585	56.682	1.903
OPM3-CS21	58284 – 58298	58.509	56.581	1.928
OPM7 to OPM3	58284 – 58298	0.076	0.101	0.025
mean		58.547	56.632	1.915
OPM7-CS22	58284 – 58298	57.949	56.097	1.852
OPM3-CS22	58284 – 58298	57.872	55.996	1.876
OPM7 to OPM3	58284 – 58298	0.077	0.101	0.024
mean		57.910	56.047	1.863

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.

Table 6: CS21 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
u_a(OPM7-OP71)	0.029	0.026	0.039	0.072	TDEV(1 d)
u_a(OPM3-OP71)	0.029	0.024	0.038	0.074	TDEV(1 d)
u_aT-R	0.029	0.025	0.038	0.073	Average trav-reference
u_a(OPM7-CS21)	0.087	0.040	0.096	0.193	TDEV(1 d)
u_a(OPM3-CS21)	0.086	0.039	0.094	0.193	TDEV(1 d)
u_aT-V	0.086	0.040	0.095	0.193	Average trav-visited
u_a	0.091	0.047	0.102	0.206	Visited-reference
Misclosure					
$u_{b,1}$	0.211	0.132	0.135	0.211	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)
$u_{b,TOT}$	0.549	0.524	0.422	0.549	
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
$u_{b,SYS}$	0.631	0.609		0.631	Quadratic sum of u_b
u_{CAL0}	0.638	0.616		0.664	Composed of u_a and $u_{b,SYS}$

Table 7: CS22 uncertainty contributions (all values in ns).

Uncertainty	Value P1	Value P2	Value P1-P2	Value P3	Description
u_a(OPM7-OP71)	0.029	0.026	0.039	0.072	TDEV(1 d)
u_a(OPM3-OP71)	0.029	0.024	0.038	0.074	TDEV(1 d)
u_aT-R	0.029	0.025	0.038	0.073	Average trav-reference
u_a(OPM7-CS22)	0.033	0.032	0.046	0.083	TDEV(1 d)
u_a(OPM3-CS22)	0.033	0.032	0.046	0.091	TDEV(1 d)
u_aT-V	0.033	0.032	0.046	0.087	Average trav-visited
u_a	0.044	0.041	0.060	0.114	Visited-reference
Misclosure					
$u_{b,1}$	0.211	0.132	0.135	0.211	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)
$u_{b,TOT}$	0.549	0.524	0.422	0.549	
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
$u_{b,SYS}$	0.631	0.609		0.631	Quadratic sum of u_b
u_{CAL0}	0.633	0.611		0.641	Composed of u_a and $u_{b,SYS}$

7 Final results for the system to calibrate

Table 8 is providing the final results of this calibration campaign, by following the BIPM Guidelines. In addition, Table 9 is providing the computed conservative k = 2 expanded uncertainties in order to be in line with EURAMET recommendations. The CNES calibrated links used in the frame of the TAI computation are in line with the conventional combined uncertainty of 2.5 ns.

Table 8: 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						
OP71	OP71	1001-2016	2016-12-1		55.7	54.4
Visited system(s)						
CS21	CS21	1015-2018	2018.6	0.7	58.5	56.6
CS22	CS22	1015-2018	2018.6	0.7	57.9	56.0

Table 9: 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)
CS21	CS21	1.3	1.3	1.4
CS22	CS22	1.3	1.3	1.3