





**Calibration Report Cal_Id 1012-2018**

# Calibration of GPS receiver at Bureau Luxembourgeois de Métrologie.

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Issue 1

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## Appendix



# 1 Summary.

## 1.1 General informations.

This Calibration Report released by LNE-SYRTE is about the relative calibration campaign of the GPS receiver located at Bureau Luxembourgeois de Métrologie (BLM, Esch-sur-Alzette, Luxembourg)

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 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. |
| MDEV: | Modified Allan deviation, square root of MVAR. |
| MVAR: | Modified Allan variance. |
| NIST: | National Institute of Standards and Technology, United States NMI. |
| NMI: | National Metrology Institute. |
| NRCan: | National Ressources Canada. |
| OP: | Observatoire de Paris, France. |
| PPP: | Precise Point Positioning. |
| PPS: | Pulse per second. |
| PTB: | Physikalisch Technisches 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 BLM 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. In BLM, the receiver to calibrate was a Septentio PolaRx5TR multi-GNSS receiver called LU01.

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.

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 | 58124 – 58133 | Septentrio PolaRx4TR | OP71 | OP71 |
| OP | Group 1 Reference | 58145 – 58150 | Septentrio PolaRx4TR | OP71 | OP71 |
| LUX | Group 2 | 58135 – 58143 | Septentrio PolaRx5TR | LU01 | LU01 |

# 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 receiver RINEX 2.1 data are provided by BLM. 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 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 | 58124 – 58133 | 191.6 | 128.7 | 55.7 | | 54.4 | |
| OPM7 | OP71 | 58124 – 58133 | 195.5 | 218.6 | 50.989 | 0.032 | 54.266 | 0.034 |
| OPM3 | OP71 | 58124 – 58133 | 195.3 | 218.6 | 49.830 | 0.026 | 53.571 | 0.029 |
| OP71 | Ref | 58145 – 58150 | 191.6 | 128.7 | 55.7 | | 54.4 | |
| OPM7 | OP71 | 58145 – 58150 | 202.5 | 218.6 | 50.714 | 0.037 | 54.157 | 0.037 |
| OPM3 | OP71 | 58145 – 58150 | 202.4 | 218.6 | 49.513 | 0.043 | 53.312 | 0.028 |
| OPM7 | Ref | 58135 – 58143 | 141.3 | 215.8 | 50.852 | | 54.212 | |
| OPM3 | Ref | 58135 – 58143 | 161.0 | 215.8 | 49.671 | | 53.441 | |
| LU01 | OPM7 | 58135 – 58143 | 53.7 | 118.0 | 25.845 | 0.060 | 22.517 | 0.066 |
| LU01 | OPM3 | 58135 – 58143 | 53.7 | 118.0 | 25.834 | 0.062 | 22.540 | 0.063 |

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

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

| Pair | MJD of measurement | Rawdiff P1 | TDEV | Rawdiff P2 | TDEV |
|---|---|---|---|---|---|
| OPM7-OP71 | 58124 – 58133 | -81.289 | 0.032 | -85.866 | 0.032 |
| OPM3-OP71 | 58124 – 58133 | -80.33 | 0.026 | -85.371 | 0.029 |
| OPM7-OP71 | 58145 – 58150 | -74.014 | 0.037 | -78.757 | 0.037 |
| OPM3-OP71 | 58145 – 58150 | -72.913 | 0.043 | -78.012 | 0.028 |
| LU01-OPM7 | 58135 – 58143 | -35.207 | 0.060 | -41.895 | 0.066 |
| LU01-OPM3 | 58135 – 58143 | -14.337 | 0.062 | -21.401 | 0.063 |

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

| Pair | MJD of measurement | INTDLY P1 | INTDLY P2 | P1 -P2 |
|---|---|---|---|---|
| OPM7-OP71 | 58124 – 58133 | 50.989 | 54.266 | -3.277 |
| OPM7-OP71 | 58145 – 58150 | 50.714 | 54.157 | -3.443 |
| misclosure | | 0.275 | 0.109 | 0.166 |
| mean | | 50.8515 | 54.2115 | -3.36 |
| OPM3-OP71 | 58124 – 58133 | 49.830 | 53.571 | -3.741 |
| OPM3-OP71 | 58145 – 58150 | 49.513 | 53.312 | -3.799 |
| misclosure | | 0.317 | 0.259 | 0.058 |
| mean | | 49.6715 | 53.4415 | -3.77 |

## 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-LU01 | 58135 – 58143 | 25.845 | 22.517 | 3.328 |
| OPM3-LU01 | 58135 – 58143 | 25.834 | 22.540 | 3.294 |
| OPM7 to OPM3 | 58135 – 58143 | 0.011 | 0.023 | 0.034 |
| mean | | 25.840 | 22.529 | 3.311 |

## 6.3 Uncertainty estimation.

We provide in this Section an estimation of the uncertainty of the differential calibration for the receiver at BLM. 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: LU01 uncertainty contributions (all values in ns).

| Uncertainty | Value P1 | Value P2 | Value P1-P2 | Value P3 | Description |
|---|---|---|---|---|---|
| $u_a$(OPM7-OP71) | 0.035 | 0.036 | 0.050 | 0.229 | TDEV(1 d) |
| $u_a$(OPM3-OP71) | 0.034 | 0.029 | 0.045 | 0.214 | TDEV(1 d) |
| $u_a$T-R | 0.035 | 0.033 | 0.048 | 0.222 | Average trav-reference |
| $u_a$(OPM7-LU01) | 0.060 | 0.066 | 0.089 | 0.130 | TDEV(1 d) |
| $u_a$(OPM3-LU01) | 0.062 | 0.063 | 0.088 | 0.144 | TDEV(1 d) |
| $u_a$T-V | 0.061 | 0.065 | 0.089 | 0.137 | Average trav-visited |
| $u_a$ | 0.070 | 0.073 | 0.101 | 0.261 | Visited-reference |
| Misclosure | | | | | |
| $u_{b,1}$ | 0.317 | 0.259 | 0.166 | 0.317 | 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) |
| $u_{b,TOT}$ | 0.531 | 0.499 | 0.335 | 0.531 | |
| 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 |
| $u_{b,42}$ | 0.5 | 0.5 | | 0.5 | CABDLY visit |
| $u_{b,SYS}$ | 0.793 | 0.772 | | 0.793 | Quadratic sum of $u_b$ |
| $u_{CAL0}$ | 0.796 | 0.775 | | 0.835 | Composed of $u_a$ and $u_{b,SYS}$ |

# 7 Final results for the system to calibrate.

Table 7 is providing the final results of this calibration campaign, by following the BIPM Guidelines. In addition, Table 8 is providing the computed conservative k = 2 expanded uncertainties in order to be in line with EURAMET recommendations. The BLM calibrated link used in the frame of the TAI computation is in line with the conventional combined uncertainty of 2.5 ns.

Table 7: Summary information on the calibration trip.

| **BIPM code** | **Rinex name** | **Cal Id** | **Date** | $\mathbf{u_{CAL}}$ **(P3)/ns** | **INTDLY P1/ns** | **INTDLY P2/ns** |
|---|---|---|---|---|---|---|
| **R**eference system | | | | | | |
| OP71 | OP71 | 1001-2016 | 2016-12-1 | | 55.7 | 54.4 |
| **V**isited system(s) | | | | | | |
| LU01 | LU01 | 1012-2018 | 2018.1 | 0.9 | 25.840 | 22.529 |

Table 8: 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) |
|---|---|---|---|---|
| LU01 | LU01 | 1.6 | 1.6 | 1.7 |