**Calibration Report**
**BIPM Calibration Reference: XXXX-2016**

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# Relative calibration of CNES link to TAI via GPS receiver CS22.

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June 10, 2016.
Issue 1

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# Content

# 1. Summary.

## 1.1. General informations.

This Calibration Report released by LNE-SYRTE is about the relative calibration of one CNES GPS receiver, which took place in April 2016.

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.

Note however that, due to the fact the traveling equipment is the one being calibrated, this calibration report is written down accordingly, and is not exactly in line with the current issue of the guidelines. In particular, the misclosure could only be estimated from CGGTTS CV mean offset between the CNES receiver and the OP reference receiver when using the calibrated internal delays for CNES data processing.

## 1.2. Timetables.

Calibration campaign: April 8-13, 2016 (MJD 57485-92)
Draft 0 of the report: May 31, 2016.
Issue 1 of the report: June 10, 2016.
Transmission to BIPM: June 15, 2016.

## 1.3. 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.
CNES: Centre National d'Études Spatiales, French Space Agency.
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.

In the frame of the future inclusion of UTC(CNES) inside BIPM Circular T, and following a request by CNES to calibrate one GPS receiver, LNE-SYRTE and CNES agreed that one Septentrio PolaRx4 belonging to CNES, together with is antenna, would travel to Paris to be implemented in OP.

The reference receiver for this measurement campaign is OPMT, an Ashtech Z-XII3T multichannel multi-frequencies receiver located in OP, which is also the basis of the IGS station OPMT. This receiver was relatively calibrated by BIPM since 98 on a regular basis. The last BIPM calibration was achieved as the first Group1 calibration trip, which results were made available in Summer 2015. The resulting OPMT internal delays were implemented on July 30 2015 (MJD 57233).

The traveling equipment was made of one Septentrio PolaRx4 receiver called CS22, together with an AEROANTENNA antenna. It was agreed that OP would provide the antenna cable used in Paris. This antenna cable delay should then be taken into account for the implementation back to CNES where one local cable would be used instead.

All the involved equipment is described inside the BIPM information sheets provided in Annex A for all receivers and both locations. Here follows a summary Table.

Table 1. Summary information of the calibration trip.

| Institute | Status of equipment | Dates of measurement | Receiver type | BIPM code | RINEX name |
|---|---|---|---|---|---|
| OP | Group 1 | 57485-57492 | Ashtech ZXII3-T | OPMT | OPMT |
| CNES/OP | Group 2/Traveling | 57485-57492 | Septentrio PolaRx4 | CS22 | CS22 |

## 4. Data used.

The OPMT collected raw data are transformed into RINEX 2.1 format by using the UNAVCO TEQC software. The traveling receivers collected raw data are transformed into RINEX 2.1 format by using the Septentrio proprietary software. 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. The coordinates of the antenna phase centers are especially computed for the calibration period from RINEX files by using the NRCan PPP software, and precise orbits provided by IGS are used to compute an accurate geometric correction between pairs of antenna phase centers for receivers in common-clock set-up.

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 TDEV of the largest possible averaging period is considered as noise of the raw differences.

Reference delays are measured against the local UTC(OP) physical reference point according to the OP double weighting technique. Antenna cable delay is obtained from dedicated measurements.

For validation purposes, P3 CGGTTS files are computed by using the R2CGGTTS software provided by P. Defraigne (ROB), and CV are built between pairs of receivers. Without a given “closure” to be computed, because the receiver to be calibrated is also the traveling one, we have decided to consider as misclosure value the mean offset between the traveling and the reference receivers obtained from CGGTTS CV after application of the calibrated internal delays. The noise of P3 data is issued from a TDEV analysis similarly as above.

## 5. Results of raw data processing.

The first Table here provides a summary of the P1 and P2 delays (INTDLY) computed from the P-code differences between RINEX files, corrected for satellite signal geometrical path differences, 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. From our point of view, this Table is the most comprehensive summary of the calibration campaign.

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

| Receiver | Reference | Dates of measurements | REFDLY | CABDLY | INTDLY P1 | Unc. | INTDLY P2 | Unc. |
|---|---|---|---|---|---|---|---|---|
| OPMT | | 57485-57492 | 155.95 | 156.5 | 310.10 | | 321.65 | |
| CS22 | OPMT | 57485-57492 | 240.6 | 204.8 | 60.3 | 0.06 | 66.4 | 0.07 |

The plots of P1 and P2 computed delays and of the related TDEV analysis are provided in Annex B. In addition, the next table here is providing the RAWDIF values as required by reference [1].

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

| Pair | Dates | Rawdiff P1 | Unc. | Rawdiff P2 | Unc. |
|---|---|---|---|---|---|
| CS22-OPMT | 57485-57492 | - 286.15 | 0.06 | - 291.60 | 0.07 |

The CGGTTS P3 CV computed by using these results of the calibration and the related TDEV analysis are also made available in Annex B.

# 6. Calibration results.

## 6.1. Calibrated system against reference system.

The following Tables are providing the computed internal delays INTDLY P1 and P2 for CS22 against OPMT together with other parameters and computations.

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

| Pair | Date | $CABDLY_{CS22}$ | $CABDLY_{OPMT}$ | ΔINTDLY (P1) | ΔINTDLY (P2) |
|---|---|---|---|---|---|
| CS22 - OPMT | 57485-57492 | 204.8 | 156.5 | - 249.8 | - 255.25 |

Table 5. Traveling vs Reference system ΔSYSDLY (all values in ns).

| Pair | Date | $REFDLY_{CS22}$ | $REFDLY_{OPMT}$ | L1 | | L2 | |
|---|---|---|---|---|---|---|---|
| | | | | RAWDIF | ΔSYSDLY | RAWDLY | ΔSYSDLY |
| CS22-OPMT | 57485-57492 | 240.6 | 155.95 | - 286.15 | - 201.5 | - 291.60 | - 206.95 |

## 6.2. Uncertainty estimation.

We provide in this Section an estimation of the uncertainty of the differential calibration for the receiver CS22 against OPMT. The uncertainty budget has 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 ub for misclosure the mean offset between CS22 and OPMT in CGGTTS CV after application of the calibrated delays. This is certainly not a conservative value, but we are having no other means for this calibration, which was achieved without a traveling transfer equipment. We obtain below 0.9 ns for P3 uncertainty uCAL0 for CS22, in line with the conventional uncertainty of 2.5 ns to appear in Circular T for GPS links of Group 2 laboratories.

Table 6. Uncertainty contributions.
Value $u_a$(P3) is computed from: [P1 + 1.545 x (P1 - P2)].

| Unc. | Value P1 (ns) | Value P2 (ns) | Value P1-P2 (ns) | Value P3 (ns) | Description |
|---|---|---|---|---|---|
| $u_a$(T-R) | 0.06 | 0.07 | | | TDEV(1 d) |
| $u_a$ | 0.06 | 0.07 | 0.09 | 0.15 | |
| Misclosure | | | | | |
| $u_{b,1}$ | | | | 0.02 | Mean CV offset |
| Systematic components related to RAWDIF | | | | | |
| $u_{b,11}$ | 0.05 | 0.05 | 0.05 | 0.05 | Position error (ref) |
| $u_{b,12}$ | 0.05 | 0.05 | 0.05 | 0.05 | Position error (trav) |
| $u_{b,13}$ | 0.05 | 0.05 | 0.05 | 0.05 | Multipaths (ref) |
| $u_{b,14}$ | 0.05 | 0.05 | 0.05 | 0.05 | Multipaths (trav) |
| Link of the Traveling system to local UTC(k) | | | | | |
| $u_{b,21}$ | 0.220 | 0.220 | | 0.220 | REFDLY(trav) |
| Link of the Reference system to its local UTC(k) | | | | | |
| $u_{b,31}$ | 0.360 | 0.360 | | 0.360 | REFDLY(ref) |
| Antenna cable delays | | | | | |
| $u_{b,41}$ | 0.5 | 0.5 | | 0.5 | CABDLY(ref) |
| $u_{b,42}$ | 0.5 | 0.5 | | 0.5 | CABDLY(trav) |
| | | | | | |
| $u_{b,SYS}$ | | | | 0.83 | |
| | | | | | |
| $U_{CAL0}$ | | | | 0.84 | Quadratic sum of $u_a$ and $u_{b,SYS}$ |

Due to the absence of true misclosure, the resulting uncertainty is lower than what is usually obtained. Note that this uncertainty is only valid for the link between CNES and the TAI network. For a comparison between this calibration and another one for this receiver CS22, either relative or absolute, the uncertainty budget might be computed differently.

## 7. Final results for the system to calibrate.

The next Table provides a summary of the calibration results for CS22 receiver.

Table 7. Summary information on the calibration trip.

| Reference system | Cal Id | Date | | INTDLY P1 / ns | INTDLY P2 / ns |
|---|---|---|---|---|---|
| OPMT | 1001-2014 | 2013-03 | | 310.10 | 321.65 |
| Visited system | Cal Id | Date | $u_{CAL}$(P3) / ns | INTDLY P1 / ns | INTDLY P2 / ns |
| CS22 | XXXX-2016 | 2016-04 | 0.9 | 60.3 | 66.4 |

The resulting P3 uncertainty, even if underestimated due to the specific calibration campaign, is in line with the conventional Group 2 laboratory uncertainty of 2.5 ns for the TAI network.

# ANNEXES.

**Annex A. BIPM information sheets.**
**Annex B. Plots of raw data and TDEV analysis.**
**Annex C. Details on the systematic uncertainties.**

**Annex A. BIPM information sheets.**

**BIPM Information Sheet**

| | | |
|---|---|---|
| Laboratory | Observatoire de Paris | |
| Date and hour start of measurements | 2016-04-08 (MJD 57485) | |
| Date and hour end of measurements | 2016-04-13 (MJD 57492) | |
| **Information on the system** | | |
| | **Local** | **Traveling** |
| 4-character BIPM code | OPMT | CS22 |
| Receiver maker and type<br>Receiver serial number | Ashtech ZXII3-T<br>S/N: 02942 | Septentrio PolaRx4<br>S/N: 3008022 |
| 1 PPS trigger level /V | 1.0 | 1.0 |
| Antenna cable maker and type<br>Phase stabilized cable (Y/N) | Andrews SFGXX<br>No | Andrews (?)<br>No |
| Cable length outside building /m | ≈ 10 | ≈ 25 |
| Antenna maker and type<br>Antenna serial number | TSA 3S-02-TSADM<br>0019 | AEROANTENNA<br>AERAT2775_43<br>S/N : 5614 |
| Temperature if stabilized /°C | 75 °F | N/A |
| **Measured delays / ns** | | |
| | **Local** | **Traveling** |
| Delay from local UTC(k) to receiver 1 PPS_IN | 155.9 ns | 103.85 ns |
| Delay from 1 PPS_IN to internal reference | Included above | 136.73 ns |
| Antenna cable delay | 156.5 ns | 204.8 ns |
| Splitter delay | Included above | N/A |
| Additional cable delay | Included above | N/A |
| **Data used for the generation of CGGTTS files** | | |
| | **Local** | **Traveling** |
| INT DLY (GPS) /ns | 310.2 (P1) 321.6 (P2) | 60.3 (P1) 66.4 (P2) |
| INT DLY (GLONASS) /ns | N/A | N/A |
| CAB DLY /ns | 156.5 | 204.8 |
| REF DLY /ns | 155.9 | 240.6 |
| Coordinate reference frame | ITRF | ITRF |
| Latitude or X /m | 4202777.36 | 4202781.42 |
| Longitude or Y /m | 171368.19 | 171369.26 |
| Height or Z /m | 4778660.47 | 4778658.89 |
| **General information** | | |
| Rise time of local UTC pulse | 0.5 ns | |
| Air conditioning (Y/N) | yes | |
| Set temperature value and uncertainty | 22 ± 1 °C | |
| Set humidity value and uncertainty | 50 ± 10 % | |

**Annex B. Plots of raw data and TDEV analysis.**

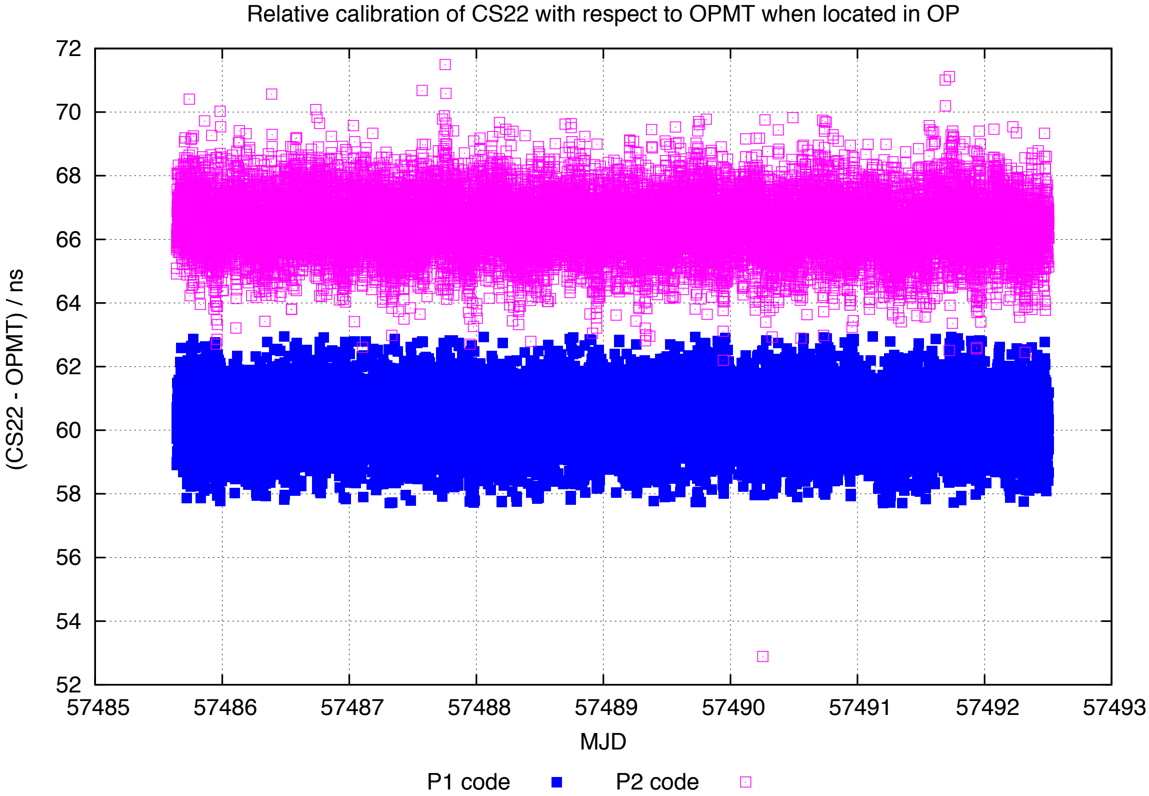


Figure B_1. P1- and P2-code delays of CS22 receiver against OPMT.

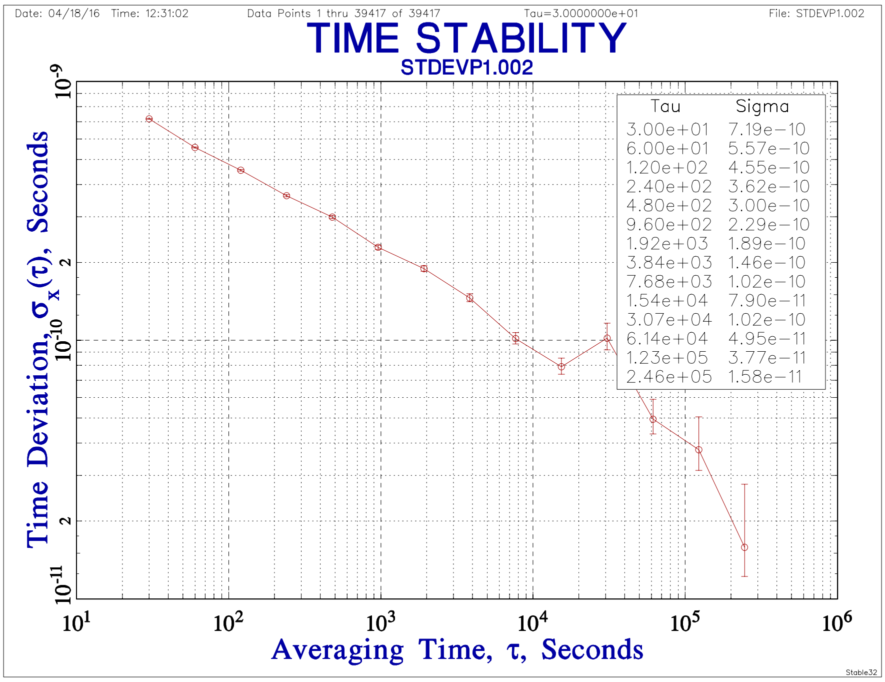


Figure B_2. TDEV for P1 differences between CS22 and OPMT.

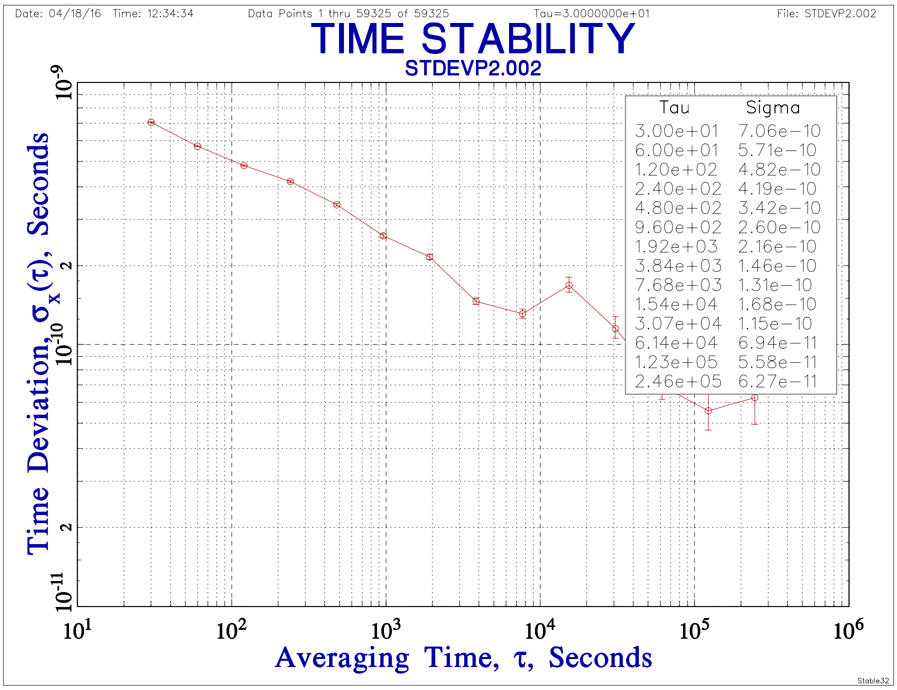


Figure B_3. TDEV for P2 differences between CS22 and OPMT.

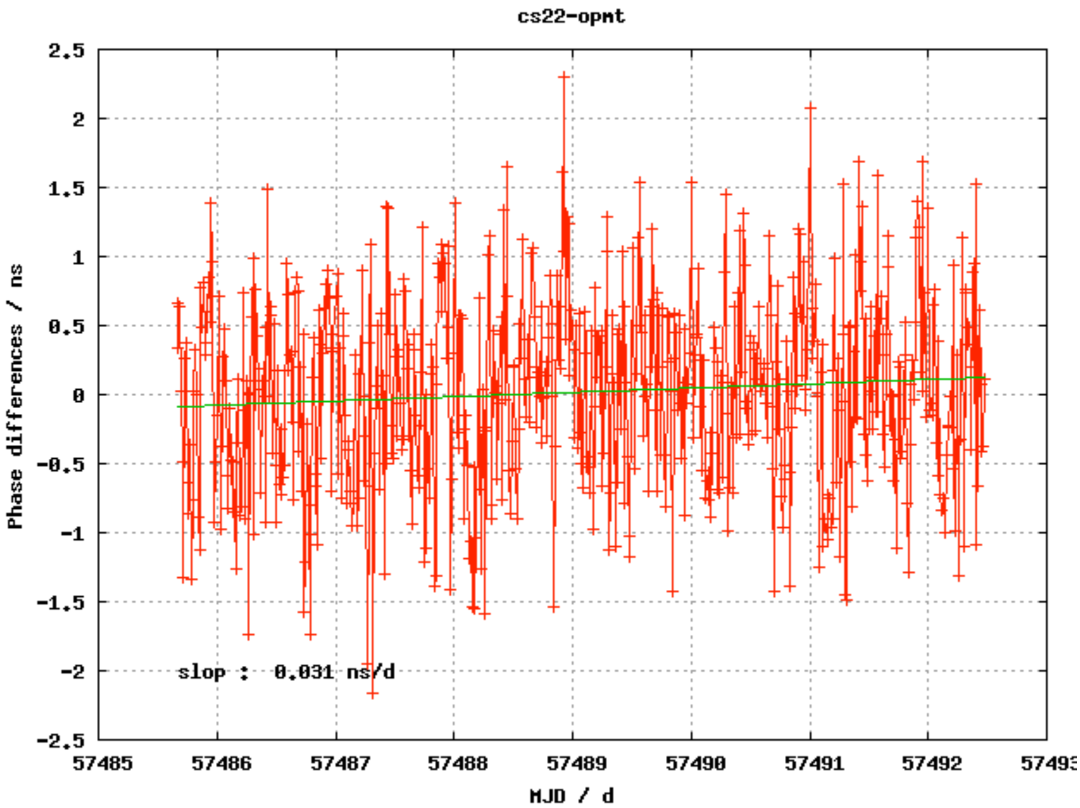


Figure B_4. CGGTTS P3 CV between OPMT and CS22 when implemented in OP in common-clock set-up after application of the CS22 calibrated delays.

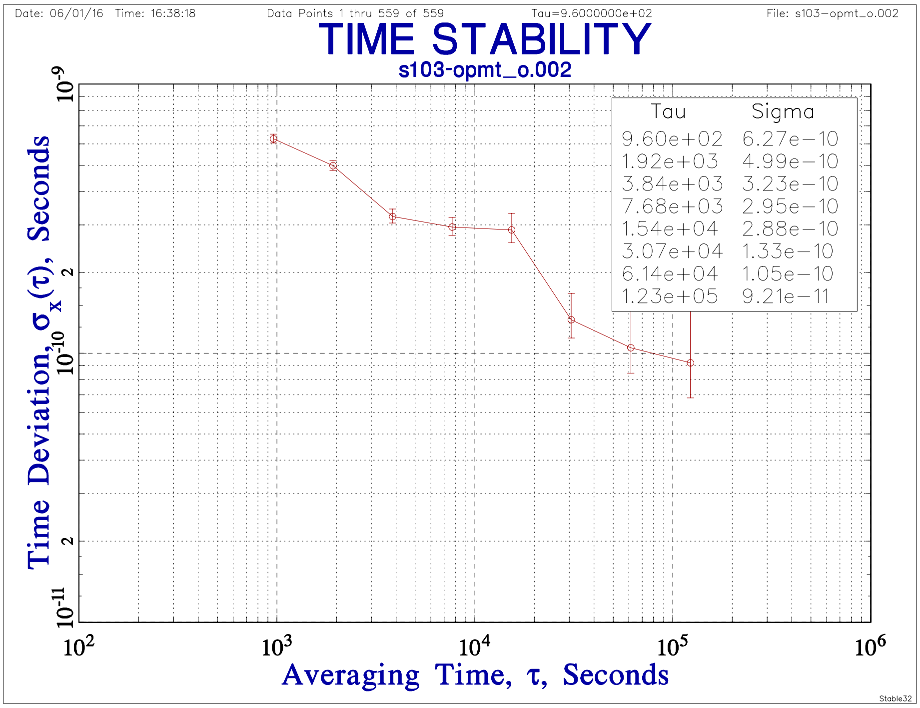


Figure B_5. TDEV of CGGTTS P3 CV between CS22 and OPMT.

**Annex C. Details on the systematic uncertainties.**

**Annex C. Details on the systematic uncertainties.**

We provide here a detailed description of the systematic uncertainties as they are appearing inside the uncertainty budgets provided in the calibration report.

- All $u_a$(ReceiverA-ReceiverB) are based on a TDEV analysis. We choose TDEV(1 d) values as the upper limit of the statistical uncertainty of the TDEV computed for the averaging period the closest to 1 d, which is depending on the available set of data. Clearly, except when the set of data is not consistent over the measurement interval, these values are not a limiting factor in the uncertainty budgets.

- The $u_b$ misclosure appearing in the uncertainty budget is only based on the P3 CV offset between the traveling equipment CS22 and the reference equipment OPMT, after application of the CS22 calibrated delays. This misclosure is usually estimated from the traveling transfer equipment instability during the campaign.

- The $u_b$ uncertainty on the position error is estimated according to the accuracy of the PPP solution computed by using the NRCan software together with IGS products. We have chosen an $u_b$ of about 50 ps for these lines of the uncertainty budgets.

- The $u_b$ uncertainty on multipaths is an arbitrary estimate. We do not have any knowledge about papers describing the optimal way to compute such an estimate.

- About the REFDLY measurements for Septentrio receivers, we assume from past experience that delays based on a TIC by applying the double-balance technique can be measured within an uncertainty of about 200 ps. In addition, we take into account the noise of such data (called "Jitter" on a SR620 TIC), which is added quadratically. By considering 90 ps for Septentrio PPS_OUT data as typical value, we obtain for Septentrio REFDLY value an $u_b$ estimate of about 220 ps.

- For Ashtech ZXII3-T receivers, we have to consider two measurements for the REFDLY computation. First the PPS_IN cable delay measurement based on a TIC and assuming a negligible noise (typically below 10 ps), which leads to a figure of about 200 ps. Second the 20 MHz to PPS_IN additional delay, which is measured by using an oscilloscope, within an uncertainty of about 300 ps. By computing the quadratic sum of both values, we obtain for Ashtech REFDLY value an $u_b$ estimate of about 360 ps.

- By considering the simplest technique for antenna cable delay measurement, which would be based on a 1 PPS signal and a TIC, we assume an $u_b$ estimate of about 0.5 ns.

These choices or assumptions are most probably leading to a conservative uncertainty budget for the relative calibration of GPS receivers, except for the misclosure. Note that this computation, aiming at a validation of the conventional Group2 uncertainty for the link between CNES and the TAI network, is achieved without considering any additional uncertainty estimates on the reference receiver delays.

**END OF DOCUMENT**