LNE-SYRTE
GNSS station relative calibration report

Transfer of OP71 G1 calibration.

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Issue 1.0

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Content

1. Introduction.

This calibration report released by LNE-SYRTE is about the transfer of Group 1 calibration provided by BIPM for the OP71 station (1001-2020) due to a change of the main unit receiver. Indeed during the 2020 Group 1 calibration campaign, BIPM did calibrate an OP71 ensemble based on a Septentrio PolaRx4TR main unit. But this receiver is suffering many drawbacks today. First, it is proven that this series is exhibiting technical failures during the last few years. We noted at least 4 final failures of such units in French laboratories since 2020, after about 6 to 8 years of operation. Second, its firmware is not upgraded anymore, and this unit remains limited to BDS2 data collection of BeiDou system when the current request at International level is BDS3. Therefore, LNE-SYRTE decided to replace this PolaRx4TR by an updated PolaRx5TR, which firmware allows for tracking all current GNSS signals.

In this report, we call OP71 the PolaRx4TR main unit which had been part of the 1001-2020 BIPM Group 1 calibration and OP70 the Septentrio PolaRx5TR intended to replace the current OP71. During many years, a Septentrio PolaRx3, called OPM6, was implemented in common-clock and common-antenna set-up with OP71, aiming at being a hot backup. At the end of July 2022, OPM6 was put away and replaced by OP70. As can be seen inside this report, we have achieved this way a direct calibration between OP71 and OP70 when implemented in common-clock and common-antenna set-up. This is supposed to lead to only a small augmentation of the uncertainty of the link to the TAI network when switching from OP71 to OP70.

OP71 is also part of the IGS network, for provision of UTC(OP) time scale to the IGS, hence this main unit change will also be documented to IGS when it occurs. Note however that the idea is to change the main unit name of OP70 into OP71 when switching, so that the name of the receiver main unit, of the BIPM G1 station, and of the IGS station remain consistent with each other. In addition, OP71 collected GNSS data are also part of the contractual daily delivery of GNSS CV data to the Galileo Time Service Provider, and a name change of the GNSS unit was already proven to generate many issues in this frame. The PolaRx4TR currently called OP71 will remain as backup to the new PolaRx5TR, carrying the name OP7B until further notice.

The report is built according to the Annex 4 of the document “BIPM guidelines for GNSS equipment calibration”, V4.0 05/08/2021 [1], and contains all the required informations, data, plots and results required by BIPM in the frame of the CCTF Working Group on GNSS. It also contains the uncertainty budget computations according to the Guidelines.

This document contains first a summary of the results obtained for GPS and for Galileo delays. After the list of the acronyms used in the document and of the reference documents, Section 4 describes the equipment and operations during this transfer of calibration. Section 5 provides all informations about data handling and calibration processing. Section 6 provides the calibration results between stations, and Section 7 is devoted to the uncertainty budgets computation. After provision of the resulting delays and related uncertainties of the calibrated stations are provided in Section 8, we propose an analysis of the combined uncertainty of the new G1 GNSS station in Section 9.

Annex A is about the implementation of OP stations and the BIPM Information sheet, and Annex B shows the plots of the raw data together with the related TDEV. Annex C describes all the terms appearing in the uncertainty budgets.

This is Issue 1.0 of this calibration report.

2. Summary of the results.

In this report, we separate the calibrations of GPS or Galileo delays. Table 1 provides a summary of the GPS code delays and uncertainties of OP70 against OP71. Table 2 provides similar results for Galileo codes.

Table 1. Summary of OP70 GPS delays (all values in ns).

Station	**OP70**
Reference	OP71
Measurement period	59819 – 59828
P1-code delay	27.8
Combined uncertainty	0.3
P2-code delay	26.5
Combined uncertainty	0.3
P3 delay	**29.9**
Combined uncertainty	**1.7 [*]**

[*] See Section 9, to be confirmed by BIPM

Table 2. Summary of OP70 Galileo delays (all values in ns).

Station	**OP70**
Reference	OP71
Measurement period	59819 – 59828
E1-code delay	29.9
Combined uncertainty	0.3
E5a-code delay	30.3
Combined uncertainty	0.3
E3 delay	**29.5**
Combined uncertainty	**1.7 [*]**

[*] See Section 9, to be confirmed by BIPM

3. Acronym list and Reference Document.

3.1. 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.
BRDC : Daily compilation by IGS of GNSS broadcast ephemeris.
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.
EURAMET : European association of metrology laboratories.
G1: Group 1 laboratory in the frame of the TAI network.
G2: Group 2 laboratory in any given Regional Metrology Area.
GLONASS: Russian GNSS.
GNSS: Global Navigation Satellite System.
GPS: United States of America GNSS.
IGS: International GNSS Service.
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.
ORB : Observatoire Royal de Belgique, Brussels, Belgium.
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.
TAI: Temps Atomique International.
TDEV: Time Allan deviation, square root of TVAR.
TIC: Time Interval Counter.
TVAR: Time Allan variance, derived from AVAR and MVAR.
UTC: Coordinated Universal Time.
VNA: Vector Network Analyser.

3.2. References.

[1] BIPM Guidelines for GNSS equipment calibration, v4.0, 05/08/2021.

[2] 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] "2020 Group 1 GNSS calibration trip (Cal_Id 1001-2020)", v1.2 / 20210621, Draft Version, BIPM.

4. Description of equipment and operations.

OP71 GNSS station is made of a GNSS receiver Septentrio PolaRx4TR, a short cable to a power splitter, an antenna cable of about 30 m connected to a Leica AR25 antenna located on the roof of the building. OP70 receiver is connected to the same power splitter, antenna cable and antenna by a similar short cable. Both main units are feed by similar 1 PPS and 10 MHz signals coming from the same distributors. All REFDLY delays are measured by using a TIC with respect to the UTC(OP) physical reference point by using the technique described in [2]. Table 3 summarizes the elements according to [1].

Table 3. Summary of equipment and planning of OP71 transfer of calibration.

Institute	**Equipment status**	**MJD of measurement**	**Receiver type**	**BIPM code**	**RINEX name**
OP	Local	59819 – 59828	Septentrio PolaRx5TR	OP70	OP70
OP	G1 reference	59819 – 59828	Septentrio PolaRx4TR	OP71	OP71

5. Data and processing.

All OP collected raw Septentrio binary files (SBF) data are transformed into GNSS RINEX 3 format by using the Septentrio proprietary SBF2RIN software. The calibration is consisting in building differential pseudoranges for each P1- and P2-codes for GPS and for each E1- and E5a-codes for Galileo between pairs of receivers, for which we partly use the R2CGGTTS software developed by P. Defraigne (ORB). These differences are corrected by the known reference delay (REFDLY), as measured at the start of the data collection, and the antenna cable delay (CABDLY) when available.

Reference delays are measured against the local UTC(OP) physical reference point at a 1.0 V trigger level. In this calibration transfer, both main units are connected to the same antenna through a power splitter and two additional small cables. Antenna cable delay CABDLY was obtained from dedicated measurements made some years ago by using a VNA. Since OPM6 and OP71 were connected together to the same antenna cable, and because there was no difference at sub-ns level between both small additional cables, we kept the same CABDLY value for OP70. The potential ps delay difference between the two small additional cables is disregarded: if any, the delay is included in the unit calibration, by considering that the implementation is destined to remain as is over receiver/antenna lifetime. On the other hand, the antenna phase center is exactly the same for both units for all GNSS carriers, and any effect related to the antenna cable is assumed to be the same, disregarding potential differences between PolaRx4 and PolaRx5 to signal attenuation. Moreover, we also assume there is no difference between both units for what concerns multipaths.

For validation purposes, ionosphere-free linear combinations P3 and E3 CGGTTS files are computed by using the R2CGGTTS software provided by P. Defraigne (ORB), and CV are built between pairs of receivers [2].

As conservative estimate, the noise of the P1 and P2 differences and of the E1 and E5a 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 and E3 data is issued from a similar TDEV analysis.

6. Results of data processing.

6.1. GPS delays calibration.

The plots of the GPS codes raw data processing and the related TDEV can be found in Annex B Section 2. Table 4 provides a summary of all the delays involved in the GPS codes calibration.

Table 4. Summary of information on station delays for GPS (all values in ns).

Receiver	Reference	MJD of Measurement	REFDLY	CABDLY	P1DLY	TDEV	P2DLY	TDEV
OP71	1001-2020	59819 – 59828	192.1	128.7	54.900	NC	53.800	NC
OP70	OP71	59819 – 59828	90.7	128.7	27.828	0.016	26.490	0.025

Table 5 provides the mean values of the GPS delays RawDif of OP70 with respect to OP71, according to BIPM Guidelines [1].

Table 5. RawDif of OP70 with respect to OP71 in GPS (all values in ns).

Pair	MJD of measurement	RawDif P1	TDEV	RawDif P2	TDEV
OP70 – OP71	59819 – 59828	- 74.334	0.016	- 74.096	0.025

Table 6 provides the differential GPS delays of OP70 with respect to OP71, according to BIPM Guidelines [1].

Table 6. OP70 with respect to OP71 in GPS (all values in ns).

Pair	MJD of measurement	INTDLY P1	INTDLY P2	P1-P2
OP70 – OP71	59819 – 59828	27.828	26.490	1.338

6.2. Galileo delays calibration.

The plots of the Galileo codes raw data processing and related TDEV can be found in Annex B Section 3. Table 7 provides a summary of all the delays involved in the Galileo codes calibration of OP70 against OP71.

Table 7. Summary of information on station delays for Galileo (all values in ns).

Receiver	Reference	MJD of Measurement	REFDLY	CABDLY	E1 DLY	TDEV	E5a DLY	TDEV
OP71	1001-2020	59819 – 59828	192.1	128.7	55.800	NC	64.900	NC
OP70	OP71	59819 – 59828	90.7	128.7	29.924	0.014	30.277	0.017

Table 8 provides the mean values of the Galileo delays RawDif of OP70 with respect to OP71, according to BIPM Guidelines [1].

Table 8. RawDif of OP70 with respect to OP71 in Galileo (all values in ns).

Pair	MJD of measurement	RawDif E1	TDEV	RawDif E5a	TDEV
OP70 – OP71	59819 – 59828	- 75.530	0.014	- 66.783	0.017

Table 9 provides the differential Galileo delays of OP70 with respect to OP71, according to BIPM Guidelines [1].

Table 9. OP70 with respect to OP71 in Galileo (all values in ns).

Pair	MJD of measurement	INTDLY E1	INTDLY E5a	E1-E5a
OP70 – OP71	59819 – 59828	29.924	30.277	- 0.353

7. Uncertainty budgets.

We provide in this section an estimation of the uncertainty of the differential calibration of OP70 to OP71. 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.

The Type A uncertainty on measured codes is estimated from the high value of the 1 sigma statistical uncertainty of the TDEV(1 d). The Type A uncertainty of the difference between codes is the quadratic sum between both estimations. But the P3 and E3 Type A uncertainty are similarly estimated from the high value of the 1 sigma statistical uncertainty of the related TDEV(1 d). All TDEV plots are in Annex B. Table 10 shows the P3 and E3 computed values related to the TDEV(1 d) for the receiver pair.

Table 10. TDEV(1 d) computed values for P3 and E3 for the receiver pair (all values in ns).

Linear combination	**OP70 – OP71**
P3	0.041
E3	0.040

When required, the GPS P3 result is estimated by applying to the values computed for P1 and P2 the ionosphere-free linear combination formula:

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

Similarly, when required, the Galileo E3 result is estimated by applying to the values computed for E1 and E5a the ionosphere-free linear combination formula:

$$E3 = E1 + 1.261 \times (E1 - E5a)$$

Table 11 and 12 are providing the uncertainty budgets for GPS delays and Galileo delays of OP70 against OP71.

*Table 11. **OP70** uncertainty budget for **GPS** calibrated delays (all values in ns).*

Uncertainty type	P1	P2	P1 - P2	P3	Description
u_a(OP70 - OP71)	0.016	0.025	0.021	0.041	Upper part of statistical uncertainty at 1 d
Type A uncertainties					
u_a	0.016	0.025	0.021	0.041	
Misclosure					
$u_{b,1}$	-	-	-	-	No misclosure here
Systematic components related to RAWDIF					
$u_{b,11}$	0.0	0.0	0.0	0.0	No position error (same antenna)
$u_{b,13}$	0.0	0.0	0.0	0.0	No multipath effect (assumption)
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,TOT}$	0.220	0.220	0.0	0.220	
Link of the reference system to UTC(OP)					
$u_{b,31}$	-	-	-	-	Included in G1 calibration
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	Same antenna cable
Type B uncertainties					
$u_{b,SYS}$	0.220	0.220		0.220	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.221	0.222		**0.224**	Composed of u_a and $u_{b,SYS}$

*Table 12. **OP70** uncertainty budget for **Galileo** calibrated delays (all values in ns).*

Uncertainty type	E1	E5a	E1 - E5a	E3	Description
u_a(OP70 - OP71)	0.014	0.017	0.015	0.040	Upper part of statistical uncertainty at 1 d
Type A uncertainties					
u_a	0.014	0.017	0.015	0.040	
Misclosure					
$u_{b,1}$	-	-	-	-	No misclosure here
Systematic components related to RAWDIF					
$u_{b,11}$	0.0	0.0	0.0	0.0	No position error (same antenna)
$u_{b,13}$	0.0	0.0	0.0	0.0	No multipath effect (assumption)
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,TOT}$	0.220	0.220	0.0	0.220	
Link of the reference system to UTC(OP)					
$u_{b,31}$	-	-	-	-	Included in G1 calibration
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	Same antenna cable
Type B uncertainties					
$u_{b,SYS}$	0.220	0.220		0.220	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.221	0.221		**0.224**	Composed of u_a and $u_{b,SYS}$

8. Final results for the systems to calibrate.

In this Section, we provide the final results of the calibration campaign, based on the uncertainty budgets of Section 7, and according to the BIPM guidelines [1]. In addition, we also provide a conservative k = 2 computation of the uncertainties, according to the EURAMET recommendations.

8.1. GPS delays.

Table 13 provides the final results of the calibration campaign for GPS delays for OP70 against OP71. Table 14 provides the conservative k = 2 expanded uncertainties for all GPS codes in line with EURAMET requirements.

Table 13. Summary GPS informations on the relative calibration (all values in ns).

BIPM code	RINEX name	Cal Id	Date	u_{CAL}(P3)	INTDLY P1	INTDLY P2
Reference system						
OP71	OP71	1001-2020	04/2021	1.5 [*]	54.9	53.8
Local system						
OP70	OP70		09/2022	0.3	27.8	26.5

[*] *Conventional combined uncertainty value for G1 laboratories.*

Table 14. Conservative k = 2 expanded GPS code uncertainties following EURAMET standard (all values in ns).

BIPM code	RINEX name	u(P1)	u(P2)	u(P3)
OP70	OP70	0.5	0.5	0.5

8.2. Galileo delays.

Table 15 provides the final results of the calibration campaign for Galileo delays for all involved stations. Table 16 provides the conservative k = 2 expanded uncertainties for all Galileo codes in line with EURAMET requirements.

Table 15. Summary Galileo informations on the relative calibration (all values in ns).

BIPM code	RINEX name	Cal Id	Date	u_{CAL}(E3)	INTDLY E1	INTDLY E5a
Reference system						
OP71	OP71	1001-2020	04/2021	1.5 [*]	55.8	64.9
Visited systems						
OP70	OP70		09/2022	0.3	29.9	30.3

[*] *Conventional combined uncertainty value for G1 laboratories.*

Table 16. Conservative k = 2 expanded Galileo code uncertainties following EURAMET standard (all values in ns).

BIPM code	**RINEX name**	**u(E1)**	**u(E5a)**	**u(E3)**
OP70	OP70	0.5	0.5	0.5

9. Combined uncertainty of new G1 GNSS station.

9.1. Terms to consider for this computation.

At the end, we have to to apply a combined uncertainty computation inspired from equation (2) given in [1]. The new calibration value has to be computed as follows:

$$u_{CAL}(t) = (u_{CAL0}^2 + u_{AG}^2 + \Delta u_{TC}^2 + \Delta u_{CAL}^2)^{1/2}$$

where u_{CAL0} is the conventional combined uncertainty of G1 calibration of OP71, hence 1.5 ns, u_{AG} is an aging term related to the time elapsed since the OP71 G1 calibration, Δu_{TC} is a transfer of calibration term, estimated by BIPM, and Δu_{CAL} is given by the uncertainty budgets given in Table 11 and 12.

The aging term u_{AG} is computed according to the equation given in [1] as:

$$u_{AG} = \max(c_{AG} \text{ x } \Delta t^{1/2} - 1.0, 0.0)$$

where Δt is in month since the last G1 calibration, and since July 2020 the aging coefficient for GNSS is c_{AG} = 0.4 ns [1], accepting that way a six months calibration agreement without aging. According to [3], the G1 calibration of OP71 took place on April 2021. the transfer of calibration to OP70 took place in end of August / early September 2022, hence Δt = 16, and u_{AG} = 0,6 ns.

The Δu_{TC} has to be estimated by BIPM. In order to help for this determination, we provide here the mean value and standard deviation of the offset between OP71 and OP70, after implementation of calibrated delays in OP70 data, as shown in Figure 1 below for GPS CV and Figure 2 for Galileo CV respectively over the period from early August to mid-October 2022. Note that after calibration of OP70 on OP71, a new firmware was released by Septentrio for PolaRx5TR units. This new firmware was implemented on MJD 59858 without any consequence on the CV between the PolaRx5TR and the PolaRx4TR as can be seen on both plots.

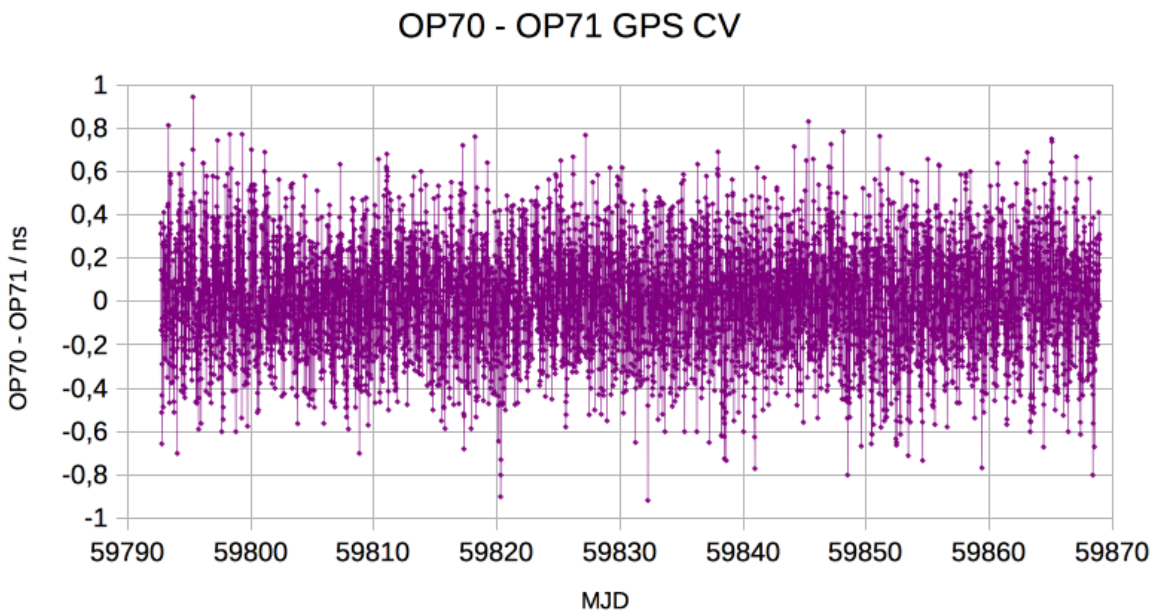


Figure 1. GPS CV between OP70 and OP71 from 1st August to 16 October 2022.

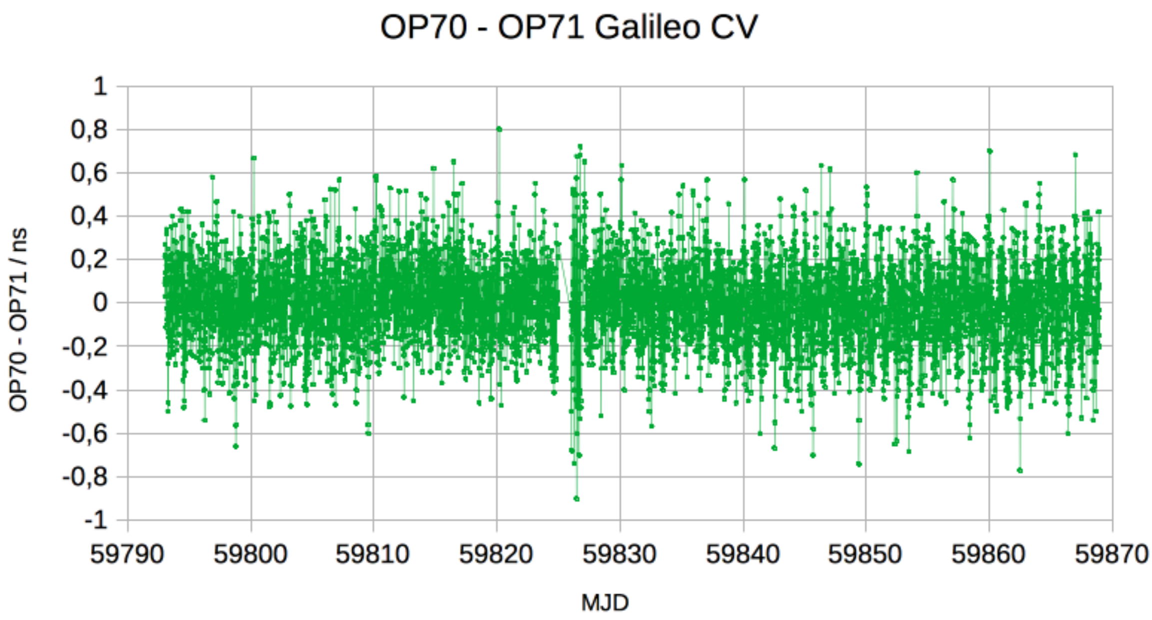


Figure 2. Galileo CV between OP70 and OP71 from 2 August to 16 October 2022.

One can see that the P3 CV between both units remained centered on 0.019 ns over the period, and the E3 CV on – 0.003 ns, hence both stayed very close to 0 as expected from the relative calibration. During this period, the standard deviation was u_{SD}(P3) = 0.243 ns. and u_{SD}(E3) = 0.185 ns, We would like to suggest to BIPM to use these last values as Δu_{TC}, just as we did here below and in Section 1.

Finally, Δu_{CAL} is issued from Table 11 and 12, and it appears that the combined uncertainty of P3 and E3 links is the same, hence Δu_{CAL} = 0.224 ns for GPS as for Galileo time transfer.

9.2. Transfer uncertainty.

We would suggest that there are two possibilities to compute the transfer of calibration for the new G1 combined uncertainty, depending on a choice about Δu_{TC}. Either to use the conservative TDEV at 1 d value which we used for the P3 and E3 uncertainty budgets, as given in Table 10 above, or to use the standard deviation obtained from the plots above in Figures 1 and 2.

When using the TDEV (1 d) statistical uncertainties in Table 10 for Δu_{TC}, combined with the other figures discussed in this Section, we obtain for the new G1 OP71 GNSS station u_{CAL_GPS}(09/2022) = 1.632 ns and $u_{CAL\_Galileo}$(09/2022) = 1.631 ns.

When using u_{SD}(P3) and u_{SD}(E3) as Δu_{TC}, together with the other figures described above, we obtain for the new G1 OP71 GNSS station: u_{CAL_GPS}(09/2022) = 1.649 ns and $u_{CAL\_Galileo}$(09/2022) = 1.641 ns.

We see that in all cases the combined uncertainty to be considered are about 1.7 ns.

11. Appendix.

ANNEX A

Information sheets and implementation of OP stations.

A1. Information sheet OP70-OP71.

Cal Id: Version / Date: 1.0 / 2022-10-17

BIPM Infortion sheet

Laboratory	OP		
Date and hour beginning of measurements	59819		
Date and hour end measurements	59828		
Information on the system			
	Local	**Traveling**	
4-Character BIPM code	OP71		OP70
Receiver maker and type Receiver serial number	Septentrio PolaRx4TR 3009606		Septentrio PolaRx5TR 4701541
1 PPS triger level / V	1.0		1.0
Antenna cable marker and type Phase stabilized cable (Y/N)	Andrew N		Andrew n
Cable length outside building / m	≈ 8		≈ 8
Antenna maker and type Antenna serial number	LEIAR25.R4 725498		LEIAR25.R4 725498
Temperature if stabilized / °C	na		na
Mesured delays / ns			
	Local	**Traveling**	
Delay from local UTC(k) to receiver 1 PPS_IN	See REFDLY below		See REFDLY below
Delay from 1 PPS_IN to internal reference (see Annex 1)	See REFDLY below		See REFDLY below
Antenna cable delay	See CABDLY below		See CABDLY below
Splitter delay	See CABDLY below		See CABDLY below
Additional cable delay	See CABDLY below		See CABDLY below
Data used for the generation of CGGTTS files			
	Local	**Traveling**	
INT DLY (GPS) / ns	P1: 54.9 P2: 53.8	P1: P2:	P1: P2:
INT DLY (Galileo) / ns	E1: 55.8 E5a: 64.9	E1: E5a:	E1: E5a:
CAB DLY / ns	128.7		128.7
REF DLY / ns	192.1		90.7
Coordinate reference frame	ITRF (IGb08)		ITRF (IGb08)
Latitude or X / m	+4202779.90		+4202779.90
Longitude or Y / m	+171370.77		+171370.77
Height or Z / m	+4778660.82		+4778660.82
General Information			
Rise time of local UTC pulse	0.5 ns		
Air conditioning (Y/N)	Y		
Set temperature value and uncertainty	22 ± 2 °C		
Set humidity value and uncertainty	na		

A2. Implementation of OP70 and OP71.

Figure A1 is showing the implementation of OP70 and OP71 stations, connected to the same antenna cable and antenna, in common-clock set-up.

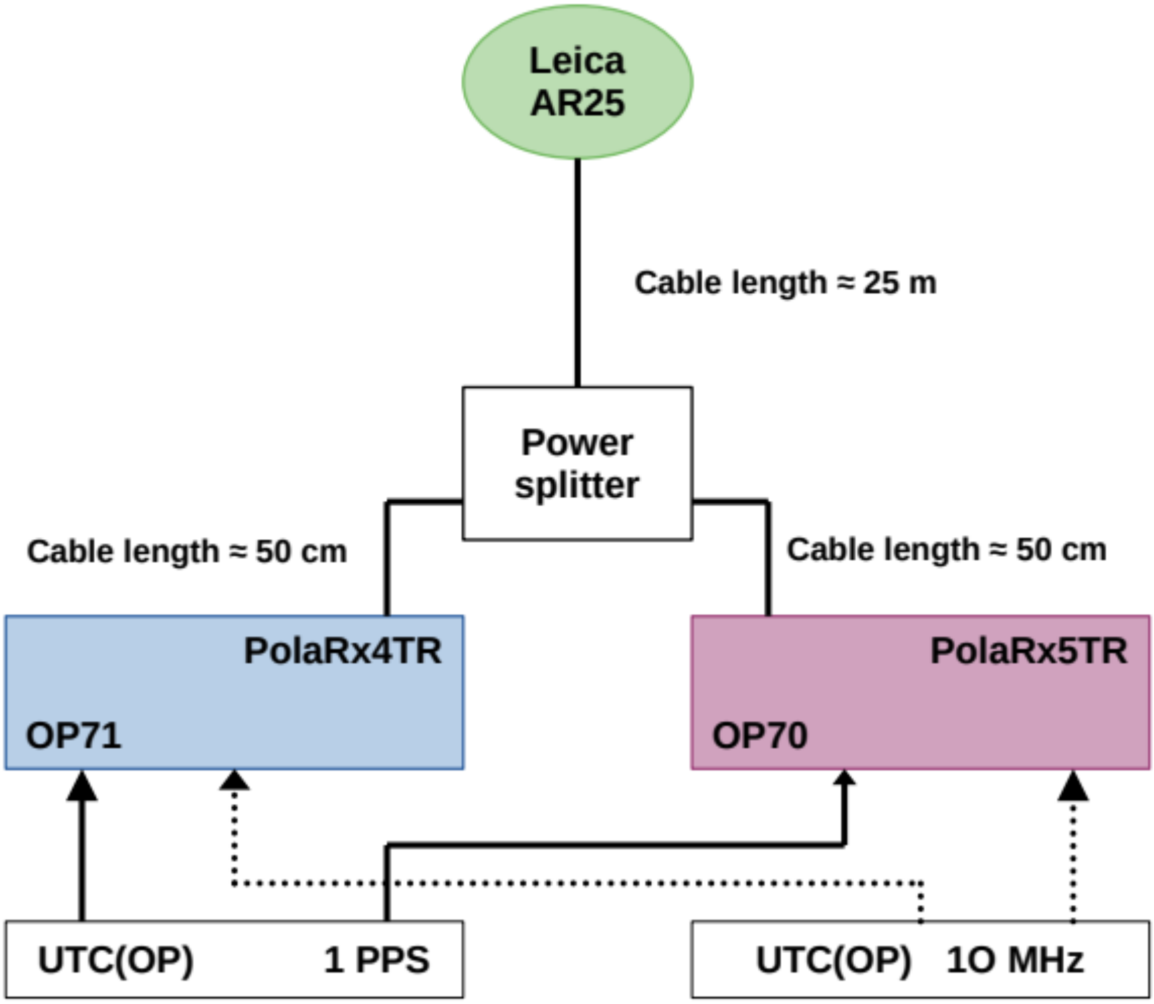


Figure A1. Implementation of OP70 and OP71 in common-antenna and common-clock set-up.

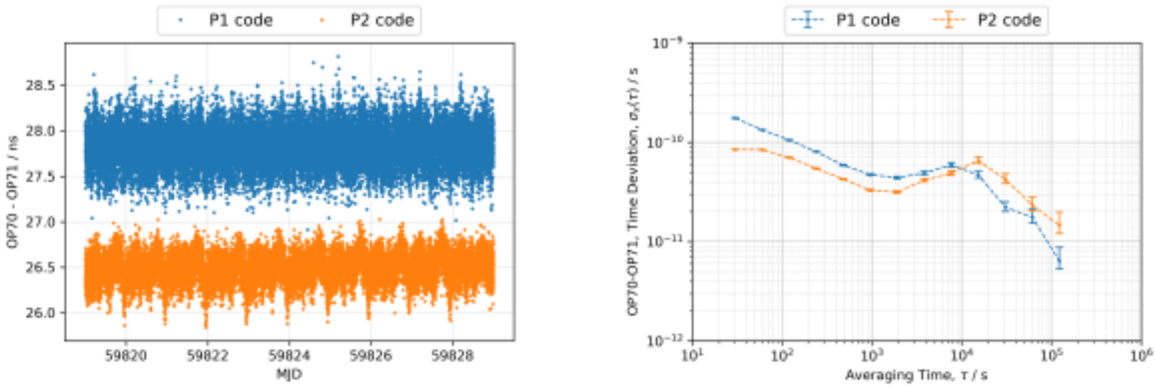
ANNEX B

Raw data and TDEV.

B1. Description of equipment and planning.

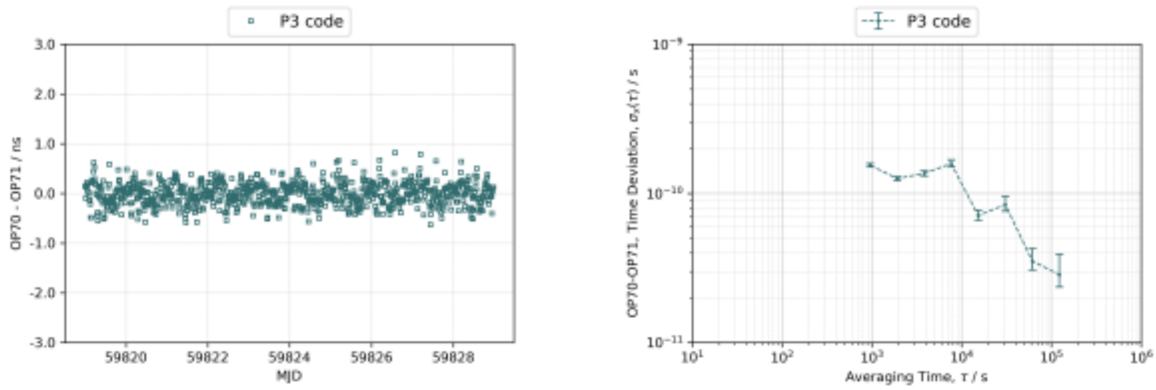
Institute	Equipment status	MJD of measurement	Receiver type	BIPM code	RINEX name
OP	Local	59819 – 59828	Septentrio PolaRx5TR	OP70	OP70
OP	G1 reference	59819 – 59828	Septentrio PolaRx4TR	OP71	OP71

B2. Plots of raw GPS data and TDEV.



(a) P-code phase differences (b) TDEV of P-code delays

Figure 1: Relative calibration of OP70 with respect to OP71



(a) P3 CV after calibration (b) TDEV of P3 CV

Figure 2: P3 CV time difference OP70 with respect to OP71

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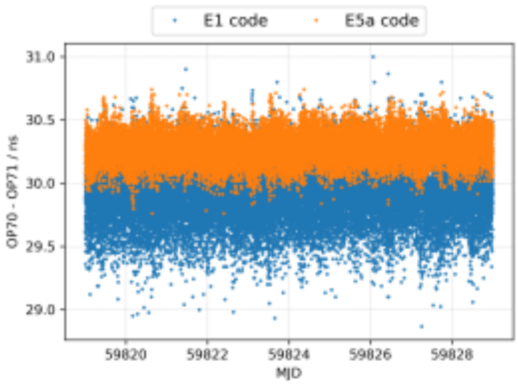
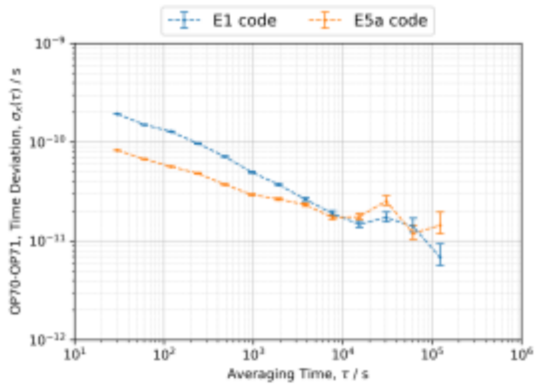
B3. Plots of raw Galileo data and TDEV.

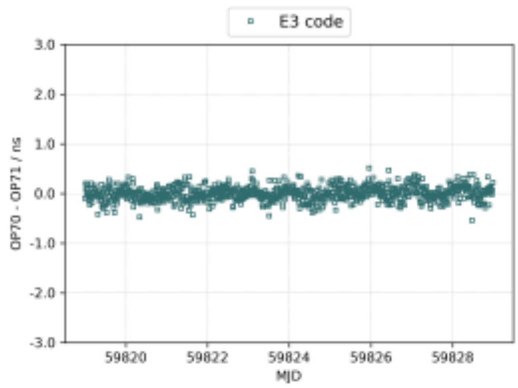


(a) E-code phase differences

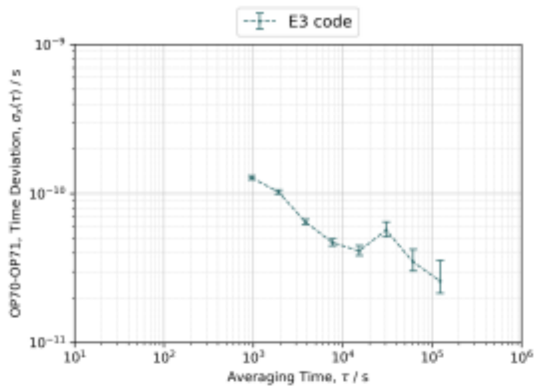


(b) TDEV of E-code delays

Figure 3: Relative calibration of OP70 with respect to OP71



(a) E3 CV after calibration



(b) TDEV of E3 CV

Figure 4: E3 CV time difference OP70 with respect to OP71

ANNEX C

Uncertainty budget terms.

1. Type A uncertainty.

The statistical uncertainty u_a(A-B) for the comparison between two GNSS stations A and B and for each GNSS code is evaluated by computing the upper limit of the error bar of the TDEV at 1 d when possible, or otherwise the upper limit of the last error bar available. The sampling periods of computed calibrated offset usually lead to data available for 61 440 s and 122 880 s averaging periods. The computed u_a is obtained by a linear interpolation at an 86 400 s averaging period. When required, a simple quadratic sum leads to the Type A uncertainty required for an uncertainty budget computation.

2. Type B uncertainty.

Here are the u_b uncertainties taken into account in the uncertainty budget computations, together with the way they are estimated when necessary.

- $u_{b,1}$ observed maximum misclosure. The misclosure $u_{b,1}$ is typically computed between the start and the end of the campaign. But there is no travel, hence no misclosure here.
- $u_{b,11}$ position error at reference site. The position of the center of phase of the antenna is estimated by using the NRCan PPP software. Note that this computation is achieved by using GPS data only. This might lead to a small bias on the phase center of the antenna for Galileo signals. But because both units are sharing the same antenna, this potential bias is disregarded here.
- $u_{b,13}$ multipath at reference site. We assume that when sharing the same antenna and antenna cable, both units are subject to the same effects that are cancelled when computing the differences.
- $u_{b,21}$ REFDLY. Uncertainty of the measure of the time difference between the reference point of the traveling receiver and the local UTC(k). The used value is the quadratic sum of an uncertainty value attributed to the Time Interval Counter (TIC) with the standard deviation of the actual measurement. When the REFDLY is obtained by summing several individual measurement the uncertainty is increased by quadratic sum as required. We use 220 ps as conservative conventional value.
- $u_{b,TOT}$: Quadratic sum of all previous u_b.
- $u_{b,31}$ REFDLY uncertainty of the GNSS reference station to its local UTC(k). This term can be set to 0 when the GNSS reference station has been recently calibrated, the uncertainty of REFDLY being already included in the conventional uncertainty decided by the CCTF WG on GNSS.
- $u_{b,41}$ uncertainty of the antenna cable delay at reference station. Again, the same cable being shared by both units, we assume any residual effects would be cancelled when computing the differences.
- $u_{b,SYS}$: Quadratic sum of all type B uncertainties above.

3. Combined uncertainty.

- u_{CAL0}: Quadratic sum of u_a and $u_{b,SYS}$. This uncertainty is for the link between the calibrated station and the reference station, without taking into account the uncertainty of this reference station.

Note finally that, in our computation, P3 uncertainty values, E3 respectively, are not based on a linear combination of P1 and P2, E1 and E5a respectively, but estimated in a similar way as for P1 and P2, E1 and E5a respectively.

END OF DOCUMENT