

2018 Group 1 GNSS calibration trip

Summary

The 2018 visit to Group 1 laboratories is the third Group 1 trip and started in March 2018.

The trip is decomposed into several phases, each enclosed with closure at the BIPM. Some phases may be run in parallel.

- Phase 1 (March-September 2018). BIPM-TL-NICT-NIM-BIPM with the traveling receivers BP1C and BP0U;
- Phase 2 (April-October 2018): BIPM-SU-BIPM with the traveling receivers BP1K;
- Phase 3 (November 2018-February 2019): BIPM-PTB-ROA-OP-BIPM with the traveling receivers BP1C and BP1X;
- Phase 4 (To Be Continued)

Since the 2016 Group 1 trip, results are provided for the GPS codes P1, P2 and C1.

Starting with this phase 3 of 1001-2018, results are also provided for Galileo E1 and E5 codes, as defined in the CGGTTS V2E format (The notation E5 corresponds to E5a).

This report provides intermediate results which are determined with respect to one BIPM receiver.

Final results for all Group 1 receivers are determined in a separate document [BIPM Technical Memorandum 266](#).

Trip 1001-2018: Report of phase 3

1. Description of equipment and operations

1.1 Traveling equipment

- Traveling systems:

Two systems are included in the BIPM traveling calibrator: BP1C and BP1X, see Table 1 and the report of operations [1001-2018-phase3-cv.pdf](#).

The long term stability of the BIPM systems is described in the [BIPM Technical Memorandum 204](#).

- Other traveling equipment:

See Annex 1 of the [Guidelines](#).

1.2 Visited equipment

See a summary in Table 1. The detailed information on the set-up and the measurements performed is in the report of operations [1001-2018-phase3-cv.pdf](#).

The receiver BP1J from the BIPM serves as a reference for the closure, with the receiver BP0R included as a backup system.

Table 1. Summary information on phase 1 of the calibration trip 1001-2018

Institute	Status of equipment	Dates of measurement	BIPM code	RINEX name	Receiver type
BIPM	Traveling		BP1C	BP1C	Septentrio PolaRx3eTR
BIPM	Traveling		BP1X	BP1X	Dicom GTR51
BIPM	BIPM reference	58409-58415	BP1J	BP1J	Septentrio PolaRx4
BIPM	BIPM backup	58409-58415	BP0R	BP0R	Septentrio PolaRx2eTR
PTB	G1 reference	58442-58450	PT02	PTBB	Ashtech Z12T
PTB	G1 backup	58442-58450	PT03	PTBG	Ashtech Z12T
PTB	G1 backup	58442-58450	PT07	PT07	Dicom GTR50
PTB	G1 backup	58442-58450	PT09	PT09	Septentrio PolaRx4TR
PTB	G1 backup	58442-58450	PT10	PT10	Dicom GTR51
ROA	G1 reference	58466-58470	RO_5	RO_5	Dicom GTR50
ROA	G1 backup	58466-58470	RO_6	RO_6	Septentrio PolaRx3TR
ROA	G1 backup	58466-58470	RO_7	RO_7	Septentrio PolaRx4TR
ROA	G1 backup	58466-58470	RO_8	RO_8	Dicom GTR51
ROA	G1 backup	58466-58470	RO_9	RO_9	Septentrio PolaRx4TR
ROA	G1 backup	58466-58470	RO10	RO10	Septentrio PolaRx5
OP	G1 reference	58500-58511	OP02	OPMT	Ashtech Z12T
OP	G1 backup	58500-58511	OP71	OP71	Septentrio PolaRx4TR
OP	G1 backup	58500-58511	OPM9	OPM9	Dicom GTR51
BIPM	BIPM reference	58525-58535	BP1J	BP1J	Septentrio PolaRx4
BIPM	BIPM backup	58525-58535	BP0R	BP0R	Septentrio PolaRx2eTR

2. Data used

Rinex files have been obtained from all receivers participating to this trip.

3. Results of raw data processing

- The raw code differences have been generated by the DCLRINEX procedure (see [Guidelines Annex 3](#)). Each run for a pair of stations generates 3 files (summary .sum, data .dif, plot .pdf). Summary files and plots are available in [1001-2018-phase3-cv.pdf](#). All measurements are indicated with 2 digits numeric precision in order to minimize rounding errors in computing iono-free linear combination values.
- For each pair (traveling – visited) or (traveling – reference):
 - Plots of the data differences and of the statistical analysis (Tdev) are in the report of operations [1001-2018-phase3-cv.pdf](#);
 - For each code, the inferred RAWDIF(code) are taken as the median of the raw differences. The associated uncertainties are taken as the floor of the Tdev values, with a minimum of 0.1 ns.
- Summary tables.

For this report, the BIPM system BP1J is considered to be the reference. However another system (BP0R) is used as a backup and is listed in Table 2.1.

4. Calibration results

In the first step, one computes ΔSYSDLY , the differences of SYSDLY for all pairs (Traveling-Reference) and (Traveling-Visited), from

$$\Delta\text{SYSDLY}_{A-B}(\text{Code}) = \text{RAWDIF}_{A-B}(\text{Code}) + \text{REFDLY}_A - \text{REFDLY}_B \quad (1)$$

where RAWDIF(Code) is read in Table 2 and where the values REFDLY are in the report of operations [1001-2018-phase3-cv.pdf](#).

The ΔSYSDLY values are reported in Table 3 for the pairs Traveling-Reference (section 4.1) and in Table 4 for the pairs Traveling-Visited (section 4.2).

In the second step one computes ΔSYSDLY (Visited-Reference) for all visited systems.

$$\Delta\text{SYSDLY}_{V-R} = \Delta\text{SYSDLY}_{T-R} - \Delta\text{SYSDLY}_{T-V}. \quad (2)$$

One can then compute ΔINTDLY (Visited-Reference) for all visited systems.

$$\Delta\text{INTDLY}_{V-R} = \Delta\text{SYSDLY}_{V-R} - \text{CABDLY}_V + \text{CABDLY}_R \quad (3)$$

where the values CABDLY are taken from the report of operations [1001-2018-phase3-cv.pdf](#);

Tables 5 reports the $\Delta\text{INTDLY}_{V-R}$ results for the pairs Visited-Reference (section 4.3).

Using assumed INTDLY_R values for the Reference system, Table 6 then reports INTDLY_V for all visited systems (section 4.4).

(1) **REFDLY_v** value not measured during calibration.

4.3 Visited systems with respect to reference system

The Table 5 provides the values obtained by differencing Table 3.1 (BP1J reference) and Table 4. CABDLY values are taken from the report of operations [1001-2018-phase3-cv.pdf](#) and have not been measured during this calibration.

(1) Results are changes with respect to values entered in the receiver

5 Uncertainty estimation

In this section, we determine the uncertainty of the differential calibration process i.e. we estimate all components that can affect the accuracy. We determine a value U_{CAL0} that is to be used as the accuracy of all P3/PPP links (Visited – Reference) at the epoch of calibration.

$$u_{CAL0} = \sqrt{u_a^2 + u_b^2}$$

with the statistical uncertainty u_a and the systematic uncertainty u_b . (all are 1-sigma).

The statistical uncertainty u_a originates from RAWDIF (see section 3) and is given by the statistical analysis of the raw code differences for (Traveling-Reference) and (Traveling-Visited).

The systematic uncertainty is given by $u_b = \sqrt{\sum_n u_{b,n}^2}$

where all possible terms to be considered in the sum are listed in Table 7 for GPS and Table 8 for Galileo and some detail on their estimation is provided at the end of this section. Values appear separately for each code and for the difference of the two codes (P1, P2 and P1-P2 for GPS) so as to compute a value u_{CAL} applicable to dual frequency links.

We choose to compute U_{CAL} using for u_b the uncertainty $u_{b,SYS}$ of $\Delta SYSDLY_{V-R}$ from equation (2)¹ Table 7 presents all components of the uncertainty budget along with the uncertainty $u_{b,SYS}$ of $\Delta SYSDLY_{V-R}$ from equation (2) and the resulting uncertainty value U_{CAL} .

Table 7. GPS uncertainty contributions. For all components of u_b , the P3 values are computed as $P1 + 1.545x(P1-P2)$

Unc.	Value C1/P1 (ns)	Value P2 (ns)	Value P1-P2 (ns)	Value P3 (ns)	Description
u_a (T-V)	0.1	0.1			RAWDIF (traveling-visited)
u_a (T-R)	0.1	0.1			RAWDIF (traveling-reference)
u_a	0.15	0.15		0.4	See text below
“Misclosure”					
$u_{b,1}$	0.2	0.2	0.1		observed mis-closure
Systematic components related to RAWDIF					
$u_{b,11}$	0.05	0.05	0.05		Position error at reference
$u_{b,12}$	0.05	0.05	0.05		Position error at visited
$u_{b,13}$	0.2	0.2	0.3		Multipaths at reference
$u_{b,14}$	0.2	0.2	0.3		Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.5	0.5	0		REFDLY _T (at ref lab)
$u_{b,22}$	0.5	0.5	0		REFDLY _T (at visited lab)
$u_{b,TOT}$	0.8	0.8	0.4	1.0	
Link of the Reference system to its local UTC(k)					
$u_{b,31}$	0.5	0.5	0		REFDLY _R (at ref lab)
Link of the Visited system to its local UTC(k)					
$u_{b,32}$	0.5	0.5	0		REFDLY _V (at visited lab)
$u_{b,SYS}$	1.1	1.1	0.4	1.2	Components of equation (2)
u_{CAL}	1.1			1.3	Composed of u_a and $u_{b,SYS}$

¹ It is somewhat arbitrary to choose SYSDLY to estimate the link accuracy. This reflects the fact that the REFIDLY is subject to change e.g. with change of reference clock or distribution so that its uncertainty should be taken into account.

The value $u_{\text{CAL}} = 1.3$ ns from Table 7 is applicable to P3/PPP links. The value $u_{\text{CAL}} = 1.1$ ns is applicable to C1 links. Final values of u_{CAL} are consistent with the conventional value of 1.5 ns for P3/PPP links between G1 laboratories, as used in UTC computation.

Table 8. Galileo uncertainty contributions. For all components of u_b , the E3 values are computed as $E1 + 1.261x(E1-E5)$

Unc.	Value E1 (ns)	Value E5 (ns)	Value E1-E5 (ns)	Value E3 (ns)	Description
u_a (T-V)	0.1	0.1			RAWDIF (traveling-visited)
u_a (T-R)	0.1	0.1			RAWDIF (traveling-reference)
u_a	0.15	0.15		0.4	See text below
“Misclosure”					
$u_{b,1}$	0.2	0.2	0.1		observed mis-closure
Systematic components related to RAWDIF					
$u_{b,11}$	0.05	0.2	0.2		Position error at reference
$u_{b,12}$	0.05	0.2	0.2		Position error at visited
$u_{b,13}$	0.2	0.2	0.3		Multipaths at reference
$u_{b,14}$	0.2	0.2	0.3		Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.5	0.5	0		REFDLY _T (at ref lab)
$u_{b,22}$	0.5	0.5	0		REFDLY _T (at visited lab)
$u_{b,\text{TOT}}$	0.8	0.8	0.5	1.0	
Link of the Reference system to its local UTC(k)					
$u_{b,31}$	0.5	0.5	0		REFDLY _R (at ref lab)
Link of the Visited system to its local UTC(k)					
$u_{b,32}$	0.5	0.5	0		REFDLY _V (at visited lab)
$u_{b,\text{SYS}}$	1.1	1.1	0.5	1.2	Components of equation (2)
u_{CAL}	1.1			1.3	Composed of u_a and $u_{b,\text{SYS}}$

The components in Tables 7 and 8 are separated in several categories:

- u_a (T-V) is larger (0.2 ns) for OP P1 code comparisons. The final u_a value for OP is 0.5 ns for P3. This does not affect the overall uncertainty.
- $u_{b,1}$ accounts for possible variations of the delays of the traveling systems during the trip. This is evaluated on the one hand by the observed misclosure (~ 0.2 ns average for each code, 0.1 ns for P1-P2, see Table 3.1), on the other hand by the observed discrepancies between the results of the two traveling receivers (~ 0.2 ns average for each code, 0.1 ns for P1-P2, see Table 6). The chosen values represent an average of both evaluations.
For Galileo, only one traveling receiver provides data so that only the misclosure is available.
By default, the same values as for GPS have been taken.
- $u_{b,11}$ and $u_{b,12}$ account for errors in the differential position (Travel – Local). In general they are estimated to be 1.5 cm (50 ps) because the standard uncertainty of the differential positioning obtained with the data used for calibration is typically at or below this level.
For Galileo some uncertainty arises from the position of the L5 phase center, which is not determined from the data. An uncertainty of 6 cm (0.2 nc) has been used.
- $u_{b,13}$ and $u_{b,14}$ account for multipaths. This is difficult to estimate and 0.2 ns is conventionally used, following a discussion in the CCTF working group on GNSS in 2017.

- $u_{b,21}$ and $u_{b,22}$ account for the measurement between the reference point of the traveling system and the local UTC(k). They include at least one measurement with a TIC and are taken to be 0.5 ns. Note that lower uncertainties are reported by the participating laboratories: 0.2 ns at PTB, 0.1 ns at ROA, 0.2 ns at OP.
- $u_{b,31}$ and $u_{b,32}$ account similarly for the measurement between the reference point of the local system and the local UTC(k). They include at least one measurement with a TIC and are taken to be 0.5 ns. Note that lower uncertainties are reported by the participating laboratories: 0.1 to 0.2 ns at PTB, 0.3 ns at OP.

Version history

V1.0 2019/03/15: Draft report of phase 3.

V1.1 2020/01/06: Correction of typos in OP receiver names in Table 6.

V2.0 2020/06/20: Inclusion of results of Galileo E1/E5A measurements in Tables 5 and 6. New Table 8 for Galileo uncertainty budget.