1201-2024 GNSS Calibration Trip

Revision History

Revision	Date	Author(s)	Description
1.0	15.05.2024	GT	Created
1.1	07.06.2024	GT	REF DLY modification

Summary

During the 2022 G1 trip, in the Phase 3 of the claibration trip (SIM), the BIPM equipment visted the U.S. Naval Research Laboratory (NRL) which kindly calibrated one of the BIPM receiver (BP2G). This was taken as occasion to also calibrate in relative mode the local NRL equipment with respect to the G1 reference receiver BP21. Since there are some small deviation between the BIPM reference values and other absolute claibrations the relative calibration values is preferred for its use in UTC.

Report

1 Description of Equipment and Operations

1.1 Traveling Equipment

BP2G from the BIPM traveling claibrator was used as traveling equipement. See Table 2 and the report of operations 1201-2024-cv.pdf. The rest of the traveling equipment is described in Annex 1 of the Guidelines. The opening and closing measurments are the same of the ones sued fro Phase 3 of the 100-2022 G1 calibration trip.

1.2 Visited Equipment

See a summary in Table 2. The detailed information on the set-up and the measurements performed is in the report of operations 1201-2024-cv.pdf.

The receiver BP21from the BIPM serves as a reference for the closure.

Table 2: Summary information on the calibration trip

Institute	Status of Equipment	Dates of measurement	BIPM code	RINEX name	Receiver Type
BIPM	Traveling		BP2G	BP2G	Septentrio PolaRx5TR (AC On)
BIPM	Reference	60119-60128	BP21	BP21	Septentrio PolaRx5TR (AC On)
NRL	Visited	60179-60182	RL5B	nrl2	
BIPM	Reference	60314-60320	BP21	BP21	Septentrio PolaRx5TR (AC On)

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 1201-2024-cv.pdf. All code 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 1201-2024-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 BP21is considered to be the reference. The raw code differences between the reference receiver and the traveling ones are presented in Tables 3 4.

Table 3: GPS raw differential results for all pairs (Traveling – Reference) (ns)

Labo	Date	Pair	RDIF(C1)	Unc	RDIF(P1)	Unc	RDIF(P2)	Unc
BIPM	60119-60128	BP2G-BP21	25.28	0.1	25.11	0.1	23.66	0.1
NRL	60179-60182	RL5B-BP2G	191.17	0.1	191.70	0.1	191.75	0.1
BIPM	60314-60320	BP2G-BP21	25.08	0.1	24.94	0.1	23.64	0.1

Table 4: Galileo raw differential results for all pairs (Traveling – Reference) (ns)

Labo	Date	Pair	RDIF(E1)	Unc	RDIF(E5)	Unc
BIPM	60119-60128	BP2G-BP21	25.23	0.1	24.38	0.1
NRL	60179-60182	RL5B-BP2G	191.22	0.1	192.26	0.1
BIPM	60314-60320	BP2G-BP21	25.06	0.1	24.14	0.1

4 Calibration Results

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

$$\Delta SYSDLY_{A-B}(Code) = RAWDIF_{A-B}(Code) + REFDLY_A - REFDLY_B \quad (1)$$

where RAWDIF(Code) is read in Tables 3 4 and where the values REFDLY are in the report of operations 1201-2024-cv.pdf. The ΔSYSDLY values are reported in Tables 5 6 for the pairs Traveling-Reference (section 4.3) and in Table 7 8 for the pairs Visited-Traveling (section 4.3). In the second step one computes ΔSYSDLY (Visited-Reference) for all visited systems.

$$\Delta SYSDLY_{V-R} = \Delta SYSDLY_{T-R} + \Delta SYSDLY_{V-T}. \quad (2)$$

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

$$\Delta INTDLY_{V-R} = \Delta SYSDLY_{V-R} - CABDLY_V + CABDLY_R \quad (3)$$

where the values CABDLY are taken from the report of operations 1201-2024-cv.pdf; Tables 9 10 reports the $\Delta INTDLY_{V-R}$ results for the pairs Visited-Reference (section 4.3). Using assumed $INTDLY_R$ values for the Reference system, Tables 11 12 then reports $INTDLY_V$ for all visited systems (section 4.4).

4.1 Traveling System with Respect to the Reference System

REFDLY values are available from the report of operations 1201-2024-cv.pdf.

Table 5: Computed GPS ΔSYSDLY values for the traveling systems with respect to reference receiver. The misclosures are also indicated. (all values in ns).

Pair	Date	$REFDLY_T$	$REFDLY_R$	Note	C1 (ns)		P1 (ns)		P2 (ns)		P3 (ns)	
					RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY
BP2G-BP21	60119-60128	53.51	43.39		25.28	35.44	25.11	35.27	23.66	33.82	27.36	37.52
BP2G-BP21	60314-60320	53.51	43.39		25.08	35.24	24.94	35.10	23.64	33.80	26.96	37.12
		Miscl.				0.20		0.17		0.01		0.41
BP2G-BP21		Mean				35.34		35.19		33.81		37.32

Results for the traveling systems are reported in Tables 5 6.

4.2 Traveling System with Respect to the Visited Systems

REFDLY values are available from the report of operations 1201-2024-cv.pdf.

Table 6: Computed Galileo ΔSYSDLY values for the traveling systems with respect to reference receiver. The misclosures are also indicated. (all values in ns).

Pair	**Date**	**REFDLY$_T$**	**REFDLY$_R$**	**Note**	**E1 (ns)**		**E5 (ns)**		**E3 (ns)**	
					RAWDIF	**ΔSYSDLY**	**RAWDIF**	**ΔSYSDLY**	**RAWDIF**	**ΔSYSDLY**
BP2G-BP21	60119-60128	53.51	43.39		25.23	35.39	24.38	34.54	26.31	36.47
BP2G-BP21	60314-60320	53.51	43.39		25.06	35.22	24.14	34.30	26.22	36.38
		Miscl.				0.17		0.24		0.09
BP2G-BP21		Mean				35.31		34.42		36.43

Table 7: Computed GPS ΔSYSDLY values for the traveling systems with respect to visited receiver. (all values in ns).

Pair	**Date**	**REFDLY$_V$**	**REFDLY$_T$**	**Note**	**C1 (ns)**		**P1 (ns)**		**P2 (ns)**	
					RAWDIF	**ΔSYSDLY**	**RAWDIF**	**ΔSYSDLY**	**RAWDIF**	**ΔSYSDLY**
RL5B-BP2G	60179-60182	12.28	78.53		191.17	124.92	191.70	125.45	191.75	125.50

4.3 Visited Systems with Respect to Reference System

The Tables 9 10 provide the values obtained by differencing Tables in sub-section (BP21reference) and Tables in sub-section . CABDLY values are taken from the report of operations 1201-2024-cv.pdfand have not been measured during this calibration.

Table 8: Computed Galileo ΔSYSDLY values for the traveling systems with respect to visited receiver. (all values in ns).

Pair	**Date**	**REFDLY$_V$**	**REFDLY$_T$**	**Note**	**E1 (ns)**		**E5 (ns)**	
					RAWDIF	**ΔSYSDLY**	**RAWDIF**	**ΔSYSDLY**
RL5B-BP2G	60179-60182	12.28	78.53		191.22	124.97	192.26	126.01

Table 9: Computed GPS ΔINTDLY values for the visited systems with respect to reference receiver. (all values in ns).

Pair	**Date**	**CABDLY$_V$**	**CABDLY$_R$**	**Note**	**C1 (ns)**		**P1 (ns)**		**P2 (ns)**	
					ΔSYSDLY	**ΔINTDLY**	**ΔSYSDLY**	**ΔINTDLY**	**ΔSYSDLY**	**ΔINTDLY**
RL5B-BP21 via BP2G	2023.6	300.10	140.80		160.27	0.97	160.64	1.34	159.31	0.01

Table 10: Computed Galileo ΔINTDLY values for the visited systems with respect to reference receiver. (all values in ns).

Pair	**Date**	**CABDLY$_V$**	**CABDLY$_R$**	**Note**	**E1 (ns)**		**E5 (ns)**	
					ΔSYSDLY	**ΔINTDLY**	**ΔSYSDLY**	**ΔINTDLY**
RL5B-BP21 via BP2G	2023.6	300.10	140.80		160.28	0.98	160.43	1.13

Table 11: Provisional GPS INTDLY values of Visited systems (all values in ns).

Pair	**Date**	**Note**	**C1** $\mathbf{INTDLY}_v$	**P1** $\mathbf{INTDLY}_v$	**P2** $\mathbf{INTDLY}_v$	**P3** $\mathbf{INTDLY}_v$
RL5B vs BP21	2023.6		31.57	29.74	27.31	33.50

Table 12: Provisional Galileo INTDLY values of Visited systems (all values in ns).

Pair	**Date**	**Note**	**E1** $\mathbf{INTDLY}_v$	**E5** $\mathbf{INTDLY}_v$	**E3** $\mathbf{INTDLY}_v$
RL5B vs BP21	2023.6		31.68	32.03	31.24

4.4 Final INTDLY Values of Visited Systems

Tables 11 12 list INTDLY values of the visited systems. These values based on INTDLY values for BP21(C1=30.6 ns; P1=28.4 ns; P2=27.3 ns; E1=30.7 ns; E5=30.9 ns; BC=30.4 ns; B5=30.3 ns) from 1001-2020, as described in BIPM Technical Memorandum 266.

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.

$$u_{CAL0} = \sqrt{u_a^2 + u_b^2} \tag{4}$$

with the statistical uncertainty ua and the systematic uncertainty ub. (all are 1-sigma). For frequency dependent error the error are estimated for the single channel. In case a values for the ionofree combination can not be directly derived an upper bound considering the most unfavourable correlation is computed as:

$$u_{if} = \sqrt{(\alpha u_1)^2 + (\beta u_2)^2 + 2\alpha\beta min(u_1, u_2)} \tag{5}$$

where α and β are the ionofree coefficients ($\alpha = 2.5457$, $\beta = 1.5457$ for GPS and $\alpha = 2.2606$, $\beta = 1.2606$ for Galileo).
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 13 for GPS, Table 14 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 (e.g. P1, P2 for GPS) so as to compute a value u_{CAL} applicable to P3 links. We choose to compute U_{CAL} using for ub the uncertainty ubSYS of $\Delta\text{SYSDLY}_{V-R}$ from equation 2[1]. Tables 13,14 presents all components of the uncertainty budget along with the uncertainty u_{bSYS} of $\Delta\text{SYSDLY}_{V-R}$ from equation 2 and the resulting uncertainty value U_{CAL}. The values u_{CAL} from Tables 13,14 are applicable either to single frequency code (C1,P1,E1 and BC) or dual-frequency code or PPP links (P3,E3 and B3). Final values of u_{CAL} are consistent with the conventional value of 1.5 ns for dual-frequency links between G1 laboratories, as used in UTC computation. The components in Tables 13, 14 are separated in several categories:

- The u_a value for P3, E3, B3 is conservatively estimated from the linear combination of P1, E1, BC and P2, E5, B5 values. Lower values would be obtained from a statistical analysis of P3,E3,B3 RAWDIF.

- $u_{b,1}$ 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 (see Tables 5,6).

- $u_{b,11}$ and $u_{b,12}$ account for errors in the differential position (Travel – Local). They are conservatively estimated to be 1.5 cm (50 ps) to account for possible sub-nominal behavior of the baseline determination occasionally observed in the DCLRINEX software. The L5,E5 baseline used for Galileo processing is determined from L5,E5 data.

- $u_{b,13}$ 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.

[1] It is somewhat arbitrary to choose SYSDLY to estimate the link accuracy. This reflects the fact that the REFDLY is subject to change e.g. with change of reference clock and that its uncertainty should better be taken into account.

Table 13: Uncertainty contributions.

Unc.	**Value C1/P1 (ns)**	**Value 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	0.6	See text below
Misclosures				
$u_{b,1}$	0.2	0.0	0.4	observed misclosures
Systematic components related to RAWDIF				
$u_{b,11}$	0.05	0.05	0.2	Position error at reference
$u_{b,12}$	0.05	0.05	0.2	Position error at visited
$u_{b,13}$	0.2	0.2	0.8	Multipaths at reference
$u_{b,14}$	0.2	0.2	0.8	Multipaths at visited
Link of the Traveling system to the local UTC(k)				
$u_{b,21}$	0.5	0.5	0.5	REFDLY$_T$(at ref lab)
$u_{b,22}$	0.5	0.5	0.5	REFDLY$_T$(at visted lab)
$u_{b,TOT}$	0.8	0.8	1.4	
Link of the Reference system to its local UTC(k)				
$u_{b,31}$	0.5	0.5	0.5	REFDLY$_R$(at ref lab)
Link of the Visited system to its local UTC(k)				
$u_{b,32}$	0.5	0.5	0.5	REFDLY$_V$(at visited lab)
$u_{b,SYS}$	1.1	1.0	1.6	Components of equation 2
u_{CAL}	1.1		1.7	Composed of u_a and $u_{b,SYS}$

- $u_{b,31}$ 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.

Table 14: Uncertainty contribution.

Unc.	**Value E1 (ns)**	**Value 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	0.5	See text below
Misclosures				
$u_{b,1}$	0.2	0.2	0.1	observed misclosures
Systematic components related to RAWDIF				
$u_{b,11}$	0.05	0.05	0.2	Position error at reference
$u_{b,12}$	0.05	0.05	0.2	Position error at visited
$u_{b,13}$	0.2	0.2	0.7	Multipaths at reference
$u_{b,14}$	0.2	0.2	0.7	Multipaths at visited
Link of the Traveling system to the local UTC(k)				
$u_{b,21}$	0.5	0.5	0.5	REFDLY$_T$(at ref lab)
$u_{b,22}$	0.5	0.5	0.5	REFDLY$_T$(at visted lab)
$u_{b,TOT}$	0.8	0.8	1.3	
Link of the Reference system to its local UTC(k)				
$u_{b,31}$	0.5	0.5	0.5	REFDLY$_R$(at ref lab)
Link of the Visited system to its local UTC(k)				
$u_{b,32}$	0.5	0.5	0.5	REFDLY$_V$(at visited lab)
$u_{b,SYS}$	1.1	1.1	1.4	Components of equation 2
u_{CAL}	1.1		1.5	Composed of u_a and $u_{b,SYS}$