2020 Group 1 GNSS calibration trip

Summary

The 2020 visit to Group 1 laboratories is the fourth Group 1 trip and started in June 2020.
The trip is decomposed into several phases, each enclosed with closure at the BIPM. Some phases may be run in parallel.

- Phase 1 (June-December 2020). BIPM-NICT-TL-BIPM with the traveling receivers BP1J and BP25;
- Phase 1b (June-December 2020). BIPM-NIM-BIPM with the traveling receivers TS03 and TS04;
- Phase 2 (February-June 2021), BIPM-ROA-PTB-OP-BIPM with the traveling receivers BP1J and BP25.
- Phase 3 (October 2021-January 2022), BIPM-NIST-USNO-BIPM with the traveling receivers BP1J and BP25.
- Phase 4 (October 2021-September 2022), BIPM-SU-BIPM with the traveling receivers BP2D and BP25.

Due to the COVID situation, restrictions in shipping made it impossible to carry out Phase 1 with the three APMP laboratories in the same trip. Taking advantage of the presence of two NIM receivers at the BIPM, a specific trip was organized, described under Phase 1b.
Since phase 3 of the 2018 Group 1 trip, results are provided for the GPS codes P1, P2 and C1 and the Galileo E1 and E5a codes.
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 1001-2020: Report of phase 4

1. Description of equipment and operations

1.1 Traveling equipment

- Traveling systems:

One system is included in the BIPM traveling calibrator: BP2D, see Table 1 and the report of operations 1001-2020-phase4-cv.pdf.

- 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 1001-2020-phase4-cv.pdf.

The receiver BP21 from the BIPM serves as a reference for the closure.

Table 1. Summary information on phase 3 of the calibration trip 1001-2020

Institute	**Status of equipment**	**Dates of measurement**	**BIPM code**	**RINEX name**	**Receiver type**
BIPM	Traveling		BP2D	BP2D	DICOM (MESIT) GTR55
BIPM	BIPM reference	59512 -59519	BP21	BP21	Septentrio PolaRx5TR (AC On) (1)
SU	G1	59545-59553	SU19	SU19	PikTime TTS-4
SU	G1	59554-59562	SU52	SU52	Septentrio PolaRx5TR (AC On) (1)
SU	G1	59554-59562	SU22	SU22	PikTimeTTS-4
SU	G1	59563-59574	SU04	SU04	DICOM (MESIT) GTR51
SU	G1	59545-59553	SU31	SU31	DICOM (MESIT) GTR51
BIPM	BIPM reference	59828 -59834	BP21	BP21	Septentrio PolaRx5TR (AC On) (1)

(1) Because it is estimated that the Auto-compensation mode of the Septentrio PolaRx5 impacts its INTDLY value at the level of 0.5 ns, the mode is indicated in Table 1.

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 1001-2020-phase4-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 1001-2020-phase4-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 BP21 is the reference.

Table 2.1 Raw differential results for all pairs (Traveling – Reference) (ns) at the BIPM.

Labo	Date	Pair	RDIF(P1)	Unc	RDIF(P2)	Unc	RDIF(C1)	Unc	RDIF(E1)	Unc	RDIF(E5)	Unc
BIPM	59512-59519	BP2D-BP21	20.16	0.1	24.41	0.1	18.74	0.1	18.51	0.1	22.95	0.1
BIPM	59828-59834	BP2D-BP21	14.48	0.1	19.00	0.1	13.10	0.1	12.88	0.1	17.15	0.1

Table 2.2 Raw differential results for all pairs (Traveling – Visited) (ns)

Labo	Date	Pair	RDIF(P1)	Unc	RDIF(P2)	Unc	RDIF(C1)	Unc	RDIF(E1)	Unc	RDIF(E5)	Unc
SU	59545-59553	SU19-BP2D	-9.17	0.1	-10.90	0.1	-8.21	0.1	-7.79	0.1	3.22	0.1
SU	59545-59553	SU31-BP2D	-10.48	0.1	-15.26	0.1	-9.38	0.1	-7.89	0.1	-17.29	0.1
SU	59554-59562	SU22-BP2D	-31.06	0.1	-35.49	0.1	-30.01	0.1	-28.53	0.1	-37.43	0.1
SU	59554-59562	SU52-BP2D	-10.72	0.1	-17.25	0.1	-9.33	0.1	-9.12	0.1	-15.88	0.6
SU	59563-59574	SU04-BP2D	-24.73	0.1	-31.78	0.1	-23.66	0.1	-22.13	0.1	-33.66	0.2

4. Calibration results

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

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

where RAWDIF(Code) is read in Table 2 and where the values REFDLY are in the report of operations 1001-2020-phase4-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.

$$\Delta SYSDLY_{V\text{-}R} = \Delta SYSDLY_{T\text{-}R} - \Delta SYSDLY_{T\text{-}V.} \qquad (2)$$

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

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

where the values CABDLY are taken from the report of operations 1001-2020-phase4-cv.pdf;
Tables 5 reports the **$\Delta INTDLY_{V\text{-}R}$** 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).

4.1 Traveling system with respect to the reference system

REFDLY values are available from the report of operations 1001-2020-phase4-cv.pdf.

Table 3.1. Computed ΔSYSDLY values for the traveling systems with respect to BP21 used as a reference. The misclosures are also indicated. (all values in ns).

Pair	Date	$REFDLY_t$	$REFDLY_r$	Note	P1 [ns]		P2 [ns]		C1 [ns]		E1 [ns]		E5 [ns]	
					RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY
BP2D-BP21	59512-59519	43.37	43.30		20.16	20.23	24.41	24.48	18.74	18.81	18.51	18.58	22.95	23.02
BP2D-BP21	59828-59834	48.42	43.30		14.48	19.60	19.00	24.12	13.10	18.22	12.88	18.00	17.15	22.27
		Misclos.				0.32		0.18		0.30		0.29		0.37
BP2D-BP21		Mean				19.92		24.30		18.51		18.29		22.65

Results for the traveling systems are reported in Table 3.1.

4.2 Traveling system with respect to the visited systems

REFDLY values are available from the report of operations 1001-2020-phase4-cv.pdf.

Table 4. Traveling vs. Visited systems (all values in ns)

Pair	Date	$REFDLY_t$	$REFDLY_v$	Note	P1 [ns]		P2 [ns]		C1 [ns]		E1 [ns]		E5 [ns]	
					RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY
SU19-BP2D	59545-59553	194.00	193.90		-9.17	-9.27	-10.90	-11.00	-8.21	-8.31	-7.79	-7.89	3.22	3.12
SU31-BP2D	59545-59553	194.00	193.90		-10.48	-10.58	-15.26	-15.36	-9.38	-9.48	-7.89	-7.99	-17.29	-17.39
SU22-BP2D	59554-59562	135.40	135.50		-31.06	-30.96	-35.49	-35.39	-30.01	-29.91	-28.53	-28.43	-37.43	-37.33
SU52-BP2D	59554-59562	135.40	134.80		-10.72	-11.32	-17.25	-17.85	-9.33	-9.93	-9.12	-9.72	-15.88	-16.48
SU04-BP2D	59563-59574	266.30	259.00		-24.73	-32.03	-31.78	-39.08	-23.66	-30.96	-22.13	-29.43	-33.66	-40.96

4.3 Visited systems with respect to reference system

The Table 5 provides the values obtained by differencing Table 3.1 (BP21 reference) and Table 4. CABDLY values are taken from the report of operations 1001-2020-phase4-cv.pdf and have not been measured during this calibration.

Table 5. Visited vs. BP21 Reference (all values in ns)

Pair	Date	$CABDLY_v$	$CABDLY_r$	Note	P1 [ns]		P2 [ns]		C1 [ns]		E1 [ns]		E5 [ns]	
					ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY
SU19-BP21 via BP2D	2021.9	122.40	140.80		10.64	29.04	13.30	31.70	10.21	28.61	10.40	28.80	25.76	44.16
SU31-BP21 via BP2D	2021.9	143.20	140.80		9.34	6.94	8.94	6.54	9.03	6.63	10.30	7.90	5.26	2.86
SU22-BP21 via BP2D	2021.9	122.60	140.80		-11.05	7.15	-11.09	7.11	-11.39	6.81	-10.14	8.06	-14.68	3.52
SU52-BP21 via BP2D	2021.9	149.10	140.80		8.59	0.29	6.45	-1.85	8.58	0.28	8.57	0.27	6.17	-2.13
SU04-BP21 via BP2D	2022.0	122.50	140.80		-12.11	6.19	-14.78	3.52	-12.44	5.86	-11.14	7.16	-18.31	-0.01

4.4 Provisional INTDLY values of visited systems

Table 6 lists INTDLY values of the visited systems.
These values are provisional and based on INTDLY values for BP21 (P1=28.4 ns; P2=27.3 ns; C1=30.6 ns, E1=30.7 ns, E5=30.9 ns) from 1001-2018, as described in BIPM Technical Memorandum 266. Final INTDLY values will be based on minimizing changes between 1001-2018 and 1001-2020, as described in BIPM Technical Memorandum 266, and will be reported in the global report of the trip 1001-2020 available here.

Table 6. Provisional INTDLY values of Visited systems using 1001-2018 reference values for the reference systems BP21 (all values in ns).

Pair	Date	Note	P1	P2	C1	E1	E5
			$INTDLY_v$	$INTDLY_v$	$INTDLY_v$	$INTDLY_v$	$INTDLY_v$
SU19-BP21 via BP2D	2021.9		57.44	59.00	59.21	59.50	75.06
SU31-BP21 via BP2D	2021.9		35.34	33.84	37.23	38.60	33.76
SU22-BP21 via BP2D	2021.9		35.55	34.41	37.41	38.76	34.42
SU52-BP21 via BP2D	2021.9		28.69	25.45	30.88	30.97	28.77
SU04-BP21 via BP2D	2022.0		34.59	30.82	36.46	37.86	30.89

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 (e.g. P1, P2 and P1-P2 for GPS) so as to compute a value u_{CAL} applicable to P3 links.
We choose to compute U_{CAL} using for u_b the uncertainty u_{bSYS} of $\Delta SYSDLY_{V-R}$ from equation (2)[1]
Table 7 presents all components of the uncertainty budget along with the uncertainty u_{bSYS} of $\Delta SYSDLY_{V-R}$ from equation (2) and the resulting uncertainty value U_{CAL}.

The value u_{CAL} =1.4 ns from Tables 7 and 8 is applicable to dual-frequency code or PPP links. The value u_{CAL} =1.2 ns is applicable to C1/E1 links. 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.

Table 7. 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
Systematic components related to RAWDIF					
$u_{b,11}$	0.1	0.1	0.1		Position error at reference
$u_{b,12}$	0.1	0.1	0.1		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)
$u_{b,TOT}$	1.0	1.0	0.5	1.2	Values SU
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)
$u_{b,SYS}$	1.2	1.2	0.5	1.4	Components of equation (2)
u_{CAL}	1.2			1.4	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 REFDLY is subject to change e.g. with change of reference clock and that its uncertainty should better be taken into account.

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
Systematic components related to RAWDIF					
$u_{b,11}$	0.1	0.1	0.1		Position error at reference
$u_{b,12}$	0.1	0.1	0.1		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)
$u_{b,TOT}$	1.0	1.0	0.5	1.2	Values SU
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)
$u_{b,SYS}$	1.2	1.2	0.5	1.4	Components of equation (2)
u_{CAL}	1.2			1.4	Composed of u_a and $u_{b,SYS}$

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

- The u_a value for P3 is conservatively estimated from the linear combination of P1 and P2 values. Lower values would be obtained from a statistical analysis of P3 RAWDIF.
- $u_{b,11}$ and $u_{b,12}$ account for errors in the differential position (Travel – Local). They are conservatively estimated to be 3 cm (100 ps) while the uncertainty in the baseline determination by the DCLRINEX software should be lower. The L5 baseline used for Galileo processing is determined from L5 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 since no specific uncertainty was reported by the participating laboratories.
- $u_{b,31}$ 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 since no specific uncertainty was reported by the participating laboratories.

Version history

V1.0 2022/10/04: Draft report of phase 4.
V1.1 2023/03/09: Corrigendum: SU04 REFDLY and CABDLY values.