2018 Group 1 GPS 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-xxxx): BIPM-PTB-ROA-OP-BIPM with the traveling receivers BP1C and BP1X;
- Phase 4 (To Be Continued)

Since the second Group 1 trip, results are provided for the GPS codes P1, P2 and C1.
This report provides intermediate results which are determined with respect to one BIPM receiver.
Final results for all three codes for all Group 1 receivers are determined in a separate document BIPM Technical Memorandum 266.

Trip 1001-2018: Report of phase 2

1. Description of equipment and operations

1.1 Traveling equipment

- Traveling systems:

The traveling system is BP1K, see Table 1 and the report of operations 1001-2018-phase2-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-phase2-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 1001-2016

Institute	Status of equipment	Dates of measurement	BIPM code	RINEX name	Receiver type
BIPM	Traveling		BP1K	BP1K	Piktime TTS4
BIPM	BIPM reference	58214-58220	BP1J	BP1J	Septentrio PolaRx4
BIPM	BIPM backup	58214-58220	BP0R	BP0R	Septentrio PolaRx2eTR
SU	G1 reference	58264-58272	SU19	SU19	Piktime TTS4
SU	G1 backup	58264-58272	SU31	SU31	Dicom GTR51
SU	G1 backup	58264-58272	SUCL	SUCL	Dicom GTR51
BIPM	BIPM reference	58410-58418	BP1J	BP1J	Septentrio PolaRx4
BIPM	BIPM backup	58410-58418	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-phase2-cv.pdf. All P1/P2 measurements are indicated with 2 digits numeric precision in order to minimize rounding errors in computing P3 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-phase2-cv.pdf;
  - The inferred RAWDIF(P1), RAWDIF(P2) and RAWDIF(C1) 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.

Table 2.1 Raw differential results for all pairs (Traveling – Reference) (ns) for three reference receivers at the BIPM. Measurements for the local backup BP0R are also included.

Labo	Date	Pair	RAWDIF(P1)	Unc	RAWDIF(P2)	Unc	RAWDIF(C1)	Unc
BIPM	58214-58220	BP1K-BP1J	52.68	0.1	50.52	0.1	53.22	0.1
BIPM	58410-58418	BP1K-BP1J	52.69	0.1	50.51	0.1	53.15	0.1
BIPM	58214-58220	BP0R-BP1J	71.83	0.1	74.27	0.1	73.60	0.1
BIPM	58410-58418	BP0R-BP1J	72.07	0.1	74.01	0.1	73.90	0.1

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

Labo	Date	Pair	RAWDIF(P1)	Unc	RAWDIF(P2)	Unc	RAWDIF(C1)	Unc
SU	58264-58272	BP1K-SU19	58.23	0.1	54.30	0.1	58.19	0.1
SU	58264-58272	BP1K-SU31	-116.46	0.1	-118.61	0.1	-115.75	0.1
SU	58264-58272	BP1K-SUCL	-117.31	0.1	-119.93	0.1	-116.65	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

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

where RAWDIF(Code) is read in Table 2 and where the values REFDLY are in the report of operations 1001-2018-phase2-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.

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

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

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

where the values CABDLY are taken from the report of operations 1001-2018-phase2-cv.pdf;
Tables 5 reports the $\mathbf{\Delta INTDLY_{V\text{-}R}}$ results for the pairs Visited-Reference (section 4.3).
Using assumed $\mathbf{INTDLY_R}$ values for the Reference system, Table 6 then reports $\mathbf{INTDLY_V}$ for all visited systems (section 4.4).

4.1 Traveling system with respect to the reference system

Table 3.1. Computed ΔSYSDLY values for the traveling systems with respect to BP1J 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)	
					RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY
BP1K-BP1J	58214-58220	49.7	181.6		52.68	-79.19	50.52	-81.35	53.22	-78.65
BP1K-BP1J	58410-58418	49.7	181.6		52.69	-79.21	50.51	-81.39	53.15	-78.75
		Misclos.				0.02		0.04		0.10
BP1K-BP1J		Mean				-79.20		-81.37		-78.70

Results for the local backup BP0R vs. BP1J are shown in Table 3.2. The misclosure for this pair is an indicator of the relative instabilities of two receivers.

Table 3.2. Computed ΔSYSDLY values for the local backup with respect to BP1J used as a reference. All values in ns

Pair	Date	$REFDLY_T$	$REFDLY_R$	Note	P1 (ns)		P2 (ns)		C1 (ns)	
					RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY
BP0R-BP1J	58214-58220	284.0	181.5		71.83	174.33	74.27	176.77	73.60	176.10
BP0R-BP1J	58410-58418	283.8	181.6		72.07	174.27	74.01	176.21	73.90	176.10
		Misclos.				0.06		0.56		0.00
		Mean				174.30		176.49		176.10

4.2 Traveling system with respect to the visited systems

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

Pair	Date	$REFDLY_T$	$REFDLY_V$	Note	P1 (ns)		P2 (ns)		C1 (ns)	
					RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY
BP1K-SU19	58264-58272	220.8	194.5		58.23	84.58	54.30	80.65	58.19	84.54
BP1K-SU31	58264-58272	220.8	207.5		-116.46	-103.16	-118.61	-105.31	-115.75	-102.45
BP1K-SUCL	58264-58272	220.8	207.5		-117.31	-104.01	-119.93	-106.63	-116.65	-103.35

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-phase2-cv.pdf.

Table 5. Visited vs. BP1J Reference (all values in ns)

Pair	Date	$CABDLY_V$	$CABDLY_R$	Note	P1 (ns)		P2 (ns)		C1 (ns)	
					ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY
SU19-BP1J via BP1K	2018.4	48.2	128.7		-163.78	-83.25	-162.02	-81.49	-163.24	-82.71
SU31-BP1J via BP1K	2018.4	143.2	128.7		23.96	9.46	23.94	9.44	23.75	9.25
SUCL-BP1J via BP1K	2018.4	128.2	128.7		24.81	25.31	25.26	25.76	24.65	25.15
BP0R-BP1J		133.4	128.7		174.30	169.60	176.49	171.79	176.10	171.40

4.4 Final INTDLY values of visited systems

Because this phase 2 of 1001-2018 was conducted in parallel of phase 1, the final INTDLY values are based on INTDLY reference values for BP1J determined from phase 1 (P1=53.0 ns; P2=52.6 ns; C1=54.4 ns), as described in BIPM Technical Memorandum 266. The final INTDLY values are reported in Table 6.

Table 6. Final INTDLY values of Visited systems using 1001-2018 reference values for the reference systems BP1J (all values in ns).

Pair	Date	Note	P1	P2	C1
			$INTDLY_V$	$INTDLY_V$	$INTDLY_V$
SU19 vs. BP1J	2018.4		-30.25	-28.89	-28.31
SU31 vs. BP1J		(1)	-1.84	-2.26	-0.65
SUCL vs. BP1J		(1)	-0.99	-0.94	0.25

(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 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) 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 $\Delta SYSDLY_{V\text{-}R}$ from equation (2)[1] Table 7 presents all components of the uncertainty budget along with the uncertainty u_{bSYS} of $\Delta SYSDLY_{V\text{-}R}$ from equation (2) and the resulting uncertainty value U_{CAL}.

The value u_{CAL} =1.4 ns from Table 7 is applicable to P3/PPP links. The value u_{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.

[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 or distribution and that its uncertainty should better be taken into account.

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	
"Misclosure"					
$u_{b,1}$	0.3	0.3	0.2		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	0.5	1.1	
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	0.5	1.3	Components of equation (2)
u_{CAL}	1.1			1.4	Composed of u_a and $u_{b,SYS}$

The components in Table 7 are separated in several categories:

- $u_{b,1}$ accounts for possible variations of the delays of the traveling systems during the trip. This is evaluated by the observed misclosure (< 0.1 ns for each code and for P1-P2,). The chosen values represents a more conservative estimate.
- $u_{b,11}$ 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.
- $u_{b,13}$ 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.
- $u_{b,31}$ 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.

Version history
V1.0 2018/11/15: Draft report of phase 2.