Initial Group 1 calibration trip (Cal_Id 1001-2014)

Several visits of the BIPM equipment 'B3TS' to Group 1 laboratories have been carried out between April 2013 and September 2014 to carry out tests of the equipment. These visits were successful and it was decided to consider them as the start of the initial Group 1 calibration trip.
Because the set-up of the B3TS was not constant in all visits, the trip is actually separated in several phases:

- Phase 1 (March-April 2013). BIPM-OP-BIPM with the two traveling receivers BP0T and BP0U;
- Phase 2 (April 2013-September 2014). BIPM-PTB-BIPM-TL-BIPM-NMIJ-NICT-BIPM-NIM-BIPM-ROA-BIPM with the two traveling receivers BP1C and BP0U;

The starting session (at BIPM) for the second phase corresponds to the closing session of the first phase.

- Phase 3 (September 2014-November 2015). BIPM-SU-BIPM with the traveling receiver BP1K;
- Phase 4 (January-June 2015). BIPM-NIST-USNO-BIPM-OP-BIPM-PTB-BIPM with the two traveling receivers BP1C and BP0U.

Trip 1001-2014: Report of phase 3

1. Description of equipment and operations

1.1 Traveling equipment

- Traveling systems:

The traveling system is BP1K, a TTS4, see Table 1 and the report of operations 1001-2014-Phase3-cv.pdf .
The long term stability of the system 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 on the measurements performed is in the report of operations 1001-2014-Phase3-cv.pdf .

Table 1. Summary information on phase 3 of the calibration trip 1001-2014

Institute	Status of equipment	Dates of measurement	BIPM code	RINEX name	Receiver type
BIPM	Traveling		BP1K	BP1K	Piktime TTS-4 S/N 136
BIPM	BIPM reference	57001-57006	BP0R	BP0R	Septentrio PolaRx2eTR
SU	G1 reference	57183-57188	SU19	SU19	Piktime TTS-4 S/N 119
SU	G1 reference	57196-57200	SU19	SU19	Piktime TTS-4 S/N 119
BIPM	BIPM reference	57332-57337	BP0R	BP0R	Septentrio PolaRx2eTR

2. Data used

Rinex files have been obtained from all receivers participating to this trip.
They are available in G:\calib\Group1\1001-2014\cv\

CGGTTS files have also been collected and used in an alternate computation, following the procedure described in BIPM Technical Memorandum 212 (insert link) (G. Petit, "Computation and report of the results of GPS P3 differential calibration of geodetic receivers", BIPM TM.212, November 2012). This computation provides results which are equivalent to those presented here, within the measurement uncertainty (0.1 ns), and are not explicitly reported.

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). All files are available in G:\calib\Group1\1001-2014. 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 1001-2014-Phase3-cv.pdf;
  - The inferred RAWDIF(P1) and RAWDIF(P2) 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 BP0R is considered to be the reference.

Table 2.1 Raw differential results for all pairs (Traveling – Reference) (ns)

Labo	Date	Pair	RAWDIF(P1)	Unc	RAWDIF(P2)	Unc
BIPM	56897-56902	BP1K-BP0R	-27.18	0.1	-31.90	0.1
BIPM	57332-57337	BP1K-BP0R	-14.73	0.2	-19.60	0.1

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

Labo	Date	Pair	RAWDIF(P1)	Unc	RAWDIF(P2)	Unc
SU	57183-57188	BP1K-SU19	77.36	0.1	73.29	0.1
SU	57196-57200	BP1K-SU19	77.19	0.1	73.17	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 Table 2 and where the values REFDLY are in the report of operations1001-2014-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.

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

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 1001-2014-Phase3-cv.pdf;
Tables 5 reports the $\mathbf{\Delta SYSDLY_{V\text{-}R}}$ and $\mathbf{\Delta INTDLY_{V\text{-}R}}$ 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 provides the values $\mathbf{\Delta SYSDLY_{T\text{-}R}}$ computed with (1) from RAWDIF(Code) in Table 2 and from the values REFDLY in the report of operations 1001-2014-Phase3-cv.pdf.

Table 3. Traveling vs. Reference system (all values in ns)

Pair	Date	$\mathbf{REFDLY_T}$	$\mathbf{REFDLY_R}$	Note	L1 (ns)		L2 (ns)	
					RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**
BP1K-BP0R	56897-56902	45.2	270.6		-27.18	-252.63	-31.90	-257.35
BP1K-BP0R	57332-57337	51.4	288.8		-14.73	-252.13	-19.60	-257.00
		Misclosure				**0.50**		**0.35**
BP1K-BP0R		Mean				**-252.38**		**-257.18**

4.2 Traveling system with respect to the visited systems

Table 4 provides the values $\Delta SYSDLY_{T-V}$ computed with (1) from RAWDIF(Code) in Table 2 and from the values REFDLY in the report of operations 1001-2014-Phase3-cv.pdf.

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

Pair	Date	$REFDLY_T$	$REFDLY_V$	Note	L1 (ns)		L2 (ns)	
					RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY
BP1K-SU19	57183-57188	201.7	194.5		77.36	84.61	73.29	80.54
BP1K-SU19	57196-57200	201.4	194.5		77.19	84.14	73.17	80.12

4.3 Visited systems with respect to reference system

Table 5 provides the values the $\Delta SYSDLY_{V-R}$ and $\Delta INTDLY_{V-R}$ obtained by differencing Tables 3 and 4. CABDLY values are taken from the report of operations 1001-2014-Phase3-cv.pdf.

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

Pair	Date	$CABDLY_V$	$CABDLY_R$	Note	P1		P2	
					ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY
SU19-BP0R via BP1K	2015.4	48.2	133.4		-337.01	-251.78	-337.74	-252.51
SU19-BP0R via BP1K	2015.5	48.2	133.4		-336.54	-251.31	-337.32	-252.09

4.4 Provisional INTDLY values of visited systems

Table 6 lists provisional INTDLY values of the visited systems using BIPM standard reference values for BP0R (**L1=221.5 ns; L2=224.5 ns**).
Final INTDLY values will be based on a reference computed after the completion of phases 1 and 2 of the trip 1101-2014. This reference is provided in TM243_Group1-reference-values_V6.pdf.
Final INTDLY values are reported in the global report of the trip 1001-2014 available here.

Table 6. Provisional INTDLY values of Visited systems using BIPM reference values for the reference systems BP0R (all values in ns)

Pair	Date	P1	P2
		$INTDLY_V$	$INTDLY_V$
SU19 wrt BP0R via BP1K	2015.4	-30.28	-28.01
SU19 wrt BP0R via BP1K	2015.5	-29.81	-27.59
Mean	2015.5	-30.0	-27.8

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_{CAL0} applicable to P3 links.
We choose to compute u_{CAL0} 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_{CAL0}.

The value u_{CAL0} =1.5 ns from Table 7 is applicable to all P3 links between participating systems.

Table 7. Uncertainty contributions. Values P3 are computed as P1 + 1.545x(P1-P2)

Unc.	Value P1 (ns)	Value P2 (ns)	Value P1-P2 (ns)	Value P3 (ns)	Description
u_a (T-V)	0.1-0.2	0.1-0.2	0.15-0.3		RAWDIF (traveling-visited)
u_a (T-R)	0.1	0.1	0.15		RAWDIF (traveling-reference)
u_a	0.15-0.2	0.15-0.2	0.2-0.35	0.35-0.6	
Misclosure					
$u_{b,1}$	0.1	0.4	0.3		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
$u_{b,13}$	0.3	0.3	0.4		Multipaths at reference
$u_{b,14}$	0.3	0.3	0.4		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)
$u_{b,TOT}$	0.9	0.9	0.6	1.3	
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	0.6	1.4	Components of equation (2)
u_{CAL0}				1.5	Composed of u_a and $u_{b,SYS}$

The components in Table 7 are separated in several categories:

[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.

- $u_{b,1}$ accounts for the mis-closure between the reference measurements; it is proposed to take the full mis-closure as $u_{b,1}$ even though the mis-closure may be partly accounted for by other components of the table. The value reported here is for the BP0U traveling system.
- $u_{b,11}$ and $u_{b,12}$ account for errors in the differential position (Travel – Local). L1 and L2 phase centers are independently estimated when computing the RAWDIF values. All position uncertainties are estimated to be 1.5 cm (50 ps). The statistical uncertainty of the differential positioning is typically below this level.
- $u_{b,13}$ and $u_{b,14}$ account for multipaths. This is difficult to estimate and could be conventionally defined.
- $u_{b,21}$ 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, even though reported uncertainties may be lower (see below).
- $u_{b,31}$ 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, even though reported uncertainties may be lower (see below).

Specific features relative to the uncertainties of local measurements (see 1001-2014-Phase3-cv.pdf: for some details on the measurements):

- At BIPM, $u_{b,21}$ and $u_{b,31}$ are not larger than 0.5 ns.
- At SU, $u_{b,22}$ for BP1K and $u_{b,32}$ have been taken to be also 0.5 ns.