Report of calibration of NMISA equipment at the BIPM (Cal_Id 1102-2016)

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Version history
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In August 2016, GNSS equipment owned by the National Metrology Institute of South Africa (UTC acronym ZA) was installed at the BIPM and calibrated against three BIPM permanently installed reference receivers, including BP0R which is included in the Group1 ensemble of reference systems. The method of calibration is the "golden system calibration" which comprises just one period of data taking at the BIPM.

1. Description of equipment and operations

The detailed information on the involved equipment, the installation set-up and the performed measurements is found in the report of operations 1102-2016-cv.pdf. See a summary in Table 1.

The long term stability of the BIPM reference systems is described in the BIPM Technical Memorandum 204 .

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	BIPM reference	57630-57637	BP0R	BP0R	Septentrio PolaRx2eTR
BIPM	BIPM backup ref	57630-57637	BP1J	BP1J	Septentrio PolaRx4TRpro
BIPM	BIPM backup ref	57630-57637	BP1X	BP1X	Dicom GTR51
NMISA	Under test	57630-57637	ZA02	ZA02	Septentrio PolaRx4TRpro

2. Data used

Rinex files have been obtained from all participating receivers.

3. Results of raw data processing

- The raw code differences have been generated by the DCLRINEX procedure (see Guidelines Annex 3).
  During this processing, we noted that the phase measurements of BP0R are corrupted and could not be used to compute the baseline BP0R-ZA02 needed to compute the code differences. To overcome this
  1. we used two other receivers (BP1J and BP1X), which have previously been compared to BP0R, as additional references;
  2. the baseline BP0R-ZA02 was determined as the sum BP0R-BP1J/X (known previously) + BP1J/X-ZA02 (from step 1) and fixed in the DCLRINEX procedure.

- For each pair (BIPM reference – ZA02):
  - Plots of the data differences and of the statistical analysis (Tdev) are in the report of operations 1102-2016-cv.pdf
  - The inferred RAWDIF(P1) and RAWDIF(P2) are taken as the median of the raw differences and shown in Table 2. The associated uncertainties are taken as the floor of the Tdev values, with a minimum of 0.1 ns.

Table 2 Raw differential results for all pairs (BIPM Reference – ZA02) (ns)

Labo	Date	Pair	RAWDIF(P1)	Unc	RAWDIF(P2)	Unc
BIPM	57630-57637	BP0R-ZA02	62.95	0.1	61.19	0.1
BIPM	57634-57637	BP1J-ZA02	-22.04	0.1	-26.14	0.1
BIPM	57630-57637	BP1X-ZA02	-27.77	0.2	-29.27	0.1

4. Calibration results

In the first step, one computes **ΔSYSDLY,** the differences of SYSDLY for all pairs (BIPM Reference – ZA02) from

$\Delta SYSDLY_{R\text{-}V}(Code) = RAWDIF_{R\text{-}V}(Code) + REFDLY_R - REFDLY_V$ (1)

where the subscript R stands for BIPM reference and V for the visiting ZA02, the RAWDIF(Code) are read in Table 2 and where the values REFDLY are in the report of operations 1102-2016-cv.pdf. The **ΔSYSDLY** values are reported in Table 3 for all pairs (BIPM Reference – ZA02).

Table 3. **ΔSYSDLY** for (BIPM Reference – ZA02) (all values in ns)

Pair	Date	$REFDLY_T$	$REFDLY_R$	Note	L1 (ns)		L2 (ns)	
					RAWDIF	ΔSYSDLY	RAWDIF	ΔSYSDLY
BP0R-ZA02	57630-57637	269.0	175.7		62.95	156.25	61.19	154.49
BP1J-ZA02	57634-57637	180.0	175.7		-22.04	-17.74	-26.14	-21.84
BP1X-ZA02	57630-57637	42.6	175.7	*	-27.77	-160.87	-29.27	-162.37

* The value REFDLY=42.6 ns is entered in the receiver BP1X.

In the second step one then computes **ΔINTDLY** for all pairs (ZA02 - BIPM Reference) from

$\Delta INTDLY_{V\text{-}R} = \Delta SYSDLY_{V\text{-}R} - CABDLY_V + CABDLY_R$ (2)

where the values CABDLY are taken from the report of operations 1102-2016-cv.pdf. See Table 4;

Table 4. **ΔSYSDLY** and **ΔINTDLY** for (ZA02 – BIPM Reference) (all values in ns)

Pair	Date	$CABDLY_V$	$CABDLY_R$	Note	L1 (ns)		L2 (ns)	
					ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY
ZA02-BP0R	2016.7	152.6	133.4		-156.25	-175.45	-154.49	-173.69
ZA02-BP1J	2016.7	152.6	128.7		17.74	-6.16	21.84	-2.06
ZA02-BP1X	2016.7	152.6	129.7	*	160.87	137.97	162.37	139.47

* The value CABDLY=129.7 ns is entered in the receiver BP1X.

Finally Table 5 shows the assumed $\mathbf{INTDLY_R}$ values for the BIPM Reference systems and the computed $\mathbf{INTDLY_V}$ for ZA02.

From Table 5, the final INTDLY values for ZA02 are taken as 47.0 ns (L1) and 51.0 ns (L2).

Table 5. **INTDLY$_R$** for the BIPM References and inferred **INTDLY$_V$** for ZA02 (all values in ns)

Pair	Date	Note	L1 (ns)		L2 (ns)	
			INTDLY$_R$	**INTDLY$_V$**	**INTDLY$_R$**	**INTDLY$_V$**
ZA02-BP0R	2016.7		222.60	47.15	224.80	51.11
ZA02-BP1J	2016.7		53.20	47.04	53.10	51.04
ZA02-BP1X	2016.7	*	-4.00	46.87	-1.60	50.77
Mean				**47.0**		**51.0**

* The value CABDLY-REFDLY = 87.1 ns entered in the receiver BP1X is substracted from **ΔINTDLY**.

5 Uncertainty estimation

This section is an exercise to determine the uncertainty of the differential calibration process, here noted u_{CAL0}.
In the actual UTC computation, the calibration uncertainty for an UTC link with such a "golden system" calibration is conventionally taken to be u_{CAL} = 4 ns. This is to account for the difference between the calibration set-up and the actual set-up at the laboratory,.

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

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.

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 6 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 $\Delta SYSDLY_{R-V}$ from equation (1)
Table 6 presents all components of the uncertainty budget along with the uncertainty u_{bSYS} and the resulting uncertainty value u_{CAL0}.

Table 6. 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 (V-R)	0.1-0.2	0.1	0.15-0.2		RAWDIF (visitor-reference)
u_a	0.1-0.2	0.1	0.15-0.2	0.25-0.35	
Systematic components related to RAWDIF					
$u_{b,11}$	0.1	0.1	0.1		Baseline error
$u_{b,13}$	0.3	0.3	0.4		Multipaths
Link to the local UTC(k)					
$u_{b,31}$	0.5	0.5	0		REFDLY$_R$ (at BIPM)
$u_{b,32}$	0.5	0.5	0		REFDLY$_V$ (at BIPM)
$u_{b,SYS}$	0.8	0.8	0.45	1.1	Components of equation (1)
u_{CAL0}				1.1	Composed of u_a and $u_{b,SYS}$

The components in Table 6 are separated in several categories:

- $u_{b,11}$ accounts for errors in the differential position (Travel – Local). L1 and L2 phase centers are independently estimated with standard uncertainties of order 1.5 cm (50 ps) when computing the RAWDIF values. However the baseline uncertainty is here increased to account for the problem encountered with BP0R (see section 3).
- $u_{b,13}$ accounts for multipaths. This is difficult to estimate and has been conventionally and conservatively estimated to be 0.3 ns, independently for P1 and P2.
- $u_{b,31}$ and $u_{b,32}$ account for the measurement between the reference point of the receiver and the local UTC(k) and are taken to be 0.5 ns (see more information in the report of operations 1102-2016-cv.pdf).