2021 Group 2 calibration trip to Belarus (BY)

Summary

As a COOMET G1 laboratory, VNIIFTRI conducted a relative calibration of the GNSS equipment of BY (Minsk, Belarus), with respect to the VNIIFTRI receiver SU31, which currently serves as the reference receiver in all GPS dual-frequency time links to VNIIFTRI in the context of realization of TAI. SU31 was calibrated by BIPM during Group 1 calibration trip in 2018 and the calibration ID is 1001-2018. SU31 calibration delays was transferred to traveling receiver (designated as SU05) by relative calibration.

Current G2 calibration trip follows BIPM guidelines for GNSS calibration (V4.0 05/08/2021). Primary results provided are the visited receiver's internal delays for GPS P-code signals on the two frequencies L1 and L2 (INT DLY (P1), and INT DLY(P2)). The delays for the C/A-code signals on L1 were also determined during this campaign using SU31 as the reference.

The final results are included in Table 6. The internal delays of the two receivers involved were determined with an uncertainty of about 1.3 ns for single frequency observations. All uncertainty values reported in this document are 1-σ values.

1. Description of equipment and operation

1.1 Traveling equipment

● Traveling systems:

The traveling system is SU05 – GTR51 receiver, see Table 1 and the report of operations 1020-2021-cv.pdf.

● Other traveling equipment:

None.

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 1020-2021-cv.pdf.

The receiver SU31 (VNIIFTRI G1 reference receiver) serves as a reference for the closure.

Table 1. Summary information on the G2 calibration trip to BY

Lab	Status of equipment	Dates of measurement	BIPM code	RINEX name	Receiver type
SU	Traveling		-	SU05	MESIT GTR51
SU	G1 reference		SU31	SU31	MESIT GTR51
BY	G2 reference		BY46	BY46	PikTime TTS-4
BY	G2 backup		-	BY14	PikTime TTS-5
SU	G1 reference		SU31	SU31	MESIT GTR51

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 software by BIPM. Each run for a pair of stations generates 3 files (summary .sum, data .dif, plot .pdf). Summary files and plots are available in 1020-2021-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 (visited – traveling) or (traveling – reference):

- Plots of the data differences and of the statistical analysis (Tdev) are in the report of operations 1020-2021-cv.pdf;

- The inferred RAW(P1), RAW(P2) and RAW(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 VNIIFTRI receiver SU31 is considered to be the reference.

Table 2.1 Raw differential results for (Traveling – Reference) (ns) receivers at the VNIIFTRI.

Lab	Date	Pair	RAW(P1)	Unc	RAW(P2)	Unc	RAW(C1)	Unc
SU	59475-59480	SU05-SU31	-62.10	0.1	-68.60	0.1	-61.88	0.1
SU	59486-59491	SU05-SU31	-62.07	0.1	-68.55	0.1	-61.83	0.1

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

Lab	Date	Pair	RAW(P1)	Unc	RAW(P2)	Unc	RAW(C1)	Unc
BY	59481-59485	BY46-SU05	19.78	0.1	22.93	0.1	20.97	0.1
BY	59481-59485	BY14-SU05	36.81	0.1	37.55	0.1	37.81	0.1

All RINEX observation files were also processed with VNIIFTRI own software which is similar to DCLRINEX. Both software's delay estimates showed a good agreement within 0.1 ns. So we do not present VNIIFTRI software results here.

4. Calibration results

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

$$\Delta SYS_{A\text{-}B}(Code) = RAW_{A\text{-}B}(Code) + REF_A - REF_B \quad (1)$$

where RAW(Code) is read in Table 2 and where the values REF delays are in the report of operations 1020-2021-cv.pdf.

The ΔSYS values are reported in Table 3 for the pairs Traveling-Reference (section 4.1) and in Table 4 for the pairs Visited-Traveling (section 4.2).

In the second step one computes ΔSYS(Visited-Reference) for all visited systems.

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

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

$$\Delta INT_{V\text{-}R} = \Delta SYS_{V\text{-}R} - CAB_V + CAB_R \quad (3)$$

where the values CAB delays are taken from the report of operations 1020-2021-cv.pdf;

Tables 5 reports the $\Delta INT_{V\text{-}R}$ results for the pairs Visited-Reference (section 4.3).

Using assumed INT_R values for the Reference system, Table 6 then reports INT_V for all visited systems (section 4.4).

4.1 Traveling system with respect to the reference system

Table 3. Computed ΔSYS values for the traveling systems with respect to SU31 used as a reference. The misclosures are also indicated. (all values in ns)

Pair	Date	REF_T	REF_R	P1 (ns)	P2 (ns)	C1 (ns)

				RAW	ΔSYS	RAW	ΔSYS	RAW	ΔSYS
SU05-SU31	59475-59480	193.80	0.00 *	-62.10	131.70	-68.60	125.20	-61.88	131.92
SU05-SU31	59486-59490	193.80	0.00 *	-62.07	131.73	-68.55	125.25	-61.83	131.97
		Misclos.			-0.03		-0.05		-0.05
SU05-SU31		Mean			131.72		125.23		131.95

* – INT, CAB and REF delays are corrected in RINEXes of Reference receiver

4.2 Visited systems with respect to the Traveling system

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

Pair	Date	REF_V	REF_T	P1 (ns)		P2 (ns)		C1 (ns)	
				RAW	ΔSYS	RAW	ΔSYS	RAW	ΔSYS
BY46-SU05	59481-59485	40.77	15.20	19.78	45.35	22.93	48.50	20.97	46.54
BY14-SU05	59481-59485	40.31	15.20	36.81	61.92	37.55	62.66	37.81	62.92

4.3 Visited systems with respect to reference system

The Table 5 provides the values obtained by differencing Table 3.1 (SU31 reference) and Table 4.

CABDLY values are taken from the report of operations 1020-2021-cv.pdf.

Table 5. Visited vs. SU31 Reference (all values in ns)

Pair	Date	CAB_V	CAB_R	P1 (ns)		P2 (ns)		C1 (ns)	
				ΔSYS	ΔINT	ΔSYS	ΔINT	ΔSYS	ΔINT
BY46-SU31 via SU05	59481-59485	144.14	0.00 *	177.05	32.91	173.70	29.56	178.46	34.32
BY14-SU31 via SU05	59481-59485	140.59	0.00 *	193.62	53.03	187.86	47.27	194.84	54.25

* – INT, CAB and REF delays are corrected in RINEXes of Reference receiver

4.4 Final INTDLY values of visited systems

The final INT delay values are based on INTDLY reference values for 1001-2018 calibration campaign of SU31.

Table 6. Final INTDLY values of Visited systems using 1001-2018 reference values for the reference receiver SU31 (all values in ns).

Pair	Date	P1	P2	C1
		INT_V	INT_V	INT_V
BY46 vs SU31	2021.9	32.91	29.56	34.32
BY14 vs SU31	2021.9	53.03	47.27	54.25

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 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 (Visited-Traveling).

The systematic uncertainty is given by

$$u_b = \sqrt{\sum_n u_{b,n}}, \tag{5}$$

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 ΔSYS_{V-R} from equation (2). Table 7 presents all components of the uncertainty budget along with the uncertainty u_{bSYS} of ΔSYS_{V-R} from equation (2) and the resulting uncertainty value U_{CAL}.

The value u_{CAL} =1.47 ns from Table 7 is applicable to P3/PPP links. The value u_{CAL} =1.28 ns is applicable to C1 links.

Note that the uncertainty of the INT delay values of SU31 receiver which served as the reference for the calibration is not included.

Table 7. Uncertainty contributions.

Unc.	**P1/C1 (ns)**	**P2 (ns)**	**P1-P2 (ns)**	**P3 (ns)**	**Description**
u_a (V-T)	0.1	0.1	0.14	0.24	RAWDIF (traveling-visited)
u_a (T-R)	0.1	0.1	0.14	0.24	RAWDIF (traveling-reference)
u_a	0.14	0.14	0.20	0.34	
Misclosure					
$u_{b,1}$	0.2	0.2		0.2	Observed misclosure
Systematic components related to RAWDIF					
$u_{b,2}$	0.05	0.05		0.05	Position error at reference
$u_{b,3}$	0.05	0.05		0.05	Position error at visited
$u_{b,4}$	0.2	0.2	0.3	0.50	Multipaths at reference
$u_{b,5}$	0.2	0.2	0.3	0.50	Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,6}$	0.5	0.5		0.5	REF_T (at ref lab)
$u_{b,7}$	0.5	0.5		0.5	REF_T (at visited lab)
Link of the Reference system to its local UTC(k)					
$u_{b,8}$	0.5	0.5		0.5	REF_R (at ref lab)
Link of the Visited system to its local UTC(k)					
$u_{b,9}$	0.5	0.5		0.5	REF_V (at visited lab)
Antenna cable delay					
$u_{b,10}$	0.5	0.5		0.5	CAB_V
$u_{b,11}$	0.5	0.5		0.5	CAB_R
$u_{b,SYS}$	1.27	1.27		1.43	Components of equation (2)
u_{CAL}	1.28	1.28		1.47	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 represent a more conservative estimate.
- $u_{b,2}$ and $u_{b,3}$ 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.
- $u_{b,4}$ and $u_{b,5}$ 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.
- $u_{b,6}$ and $u_{b,7}$ 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.

- $u_{b,8}$ and $u_{b,9}$ 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.
- $u_{b,10}$ and $u_{b,11}$ account for measurement of RF cable delay. These are conservative values.