2021 Group 2 direct calibration of Kazakhstan (KZ) receiver

Summary

As a COOMET G1 laboratory, VNIIFTRI conducted a direct relative calibration of the GNSS receiver of KZ (Astana, Kazakhstan), 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. KZ receiver was sent to VNIIFTRI where the calibration was performed. SU31 was calibrated by BIPM during Group 1 calibration trip in 2018 and the calibration ID is 1001-2018.

Current G2 calibration follows BIPM guidelines for GNSS calibration (V4.0 05/08/2021). Primary results provided are the visiting 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 5. The internal delays of the receiver 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

See a summary in Table 1. The detailed information on the set-up and the measurements performed is in the report of operations 1202-2021-cv.pdf.

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

Table 1. Summary information on the KZ calibration

Lab	Status of equipment	Dates of measurement	BIPM code	RINEX name	Receiver type
KZ	G2 Visiting		-	KZ04	MESIT GTR55
SU	G1 reference		SU31	SU31	MESIT GTR51

2. Data used

RINEX files have been obtained from all receivers participating to this campaign.

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 1202-2021-cv.pdf. All P1/P2 measurements are indicated with 2 digits numeric precision in order to minimize rounding errors in computing P3 values.

● For the pair (visiting – reference):

- Plots of the data differences and of the statistical analysis (Tdev) are in the report of operations 1202-2021-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 conservative minimum of 0.2 ns.

● Summary tables.

For this report, the VNIIFTRI receiver SU31 is considered to be the reference.

Table 2 Raw differential results for (Visiting – Reference) (ns) receivers at the VNIIFTRI

Lab	Date	Pair	RAW(P1)	Unc	RAW(P2)	Unc	RAW(C1)	Unc
SU	59538-59541	KZ04-SU31	335.30	0.2	333.59	0.2	336.22	0.2

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 the pair (Visiting - Reference), from

$$\Delta SYS_{V\text{-}R}(Code) = RAW_{V\text{-}R}(Code) + REF_V - REF_R \quad (1)$$

where RAW(Code) is read in Table 2 and where the values REF delays are in the report of operations 1202-2021-cv.pdf.

The ΔSYS values are reported in Table 3 for the pair Visiting-Reference (section 4.1).

In the second step one computes ΔINT (Visiting-Reference) for the visiting system:

$$\Delta INT_{V-R} = \Delta SYS_{V-R} - CAB_V + CAB_R \quad (2)$$

where the values CAB delays are taken from the report of operations 1202-2021-cv.pdf;

Table 4 reports the ΔINT_{V-R} results for the pairs Visiting-Reference (section 4.1).

Using assumed INT_R values for the Reference system, Table 5 then reports INT_V for the visiting system (section 4.2).

4.1 Visiting system with respect to the reference system

Table 3. Computed ΔSYS values for the visiting system with respect to SU31 used as a reference

Pair	Date	REF_V	REF_R	P1 (ns)		P2 (ns)		C1 (ns)	
				RAW	ΔSYS	RAW	ΔSYS	RAW	ΔSYS
KZ04-SU31	59538-59541	294.10	193.80*	335.30	629.40	333.59	627.69	336.22	630.32

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

The Table 4 provides the values obtained using CABLY values from the report of operations 1202-2021-cv.pdf and Table 3.

Table 4. Visiting 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
KZ04-SU31	59538-59541	611.50	143.2*	629.40	17.90	627.69	16.19	630.32	18.82

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

4.2 Final INTDLY values of visiting system

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

Table 5. Final INTDLY values of Visiting system 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
KZ04 vs SU31	2021.11	17.90	16.19	18.82

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 (Visiting – Reference) at the epoch of calibration.

$$u_{CAL0} = \sqrt{u_a^2 + u_b^2} \tag{3}$$

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 (Visiting-Reference).

The systematic uncertainty is given by

$$u_b = \sqrt{\sum_n u_{b,n}}, \tag{4}$$

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_{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 6 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} =1.40 ns from Table 6 is applicable to P3/PPP links. The value u_{CAL} =1.25 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 6. Uncertainty contributions

Unc.	**P1/C1 (ns)**	**P2 (ns)**	**P1-P2 (ns)**	**P3 (ns)**	**Description**
u_a	0.2	0.2	0.2	0.34	RAWDIF (visiting-reference)

Systematic components related to RAWDIF					
$u_{b,1}$	0.05	0.05		0.05	Position error at reference
$u_{b,2}$	0.2	0.2	0.3	0.5	Multipaths at reference
Link of the Visiting system to the local UTC(k)					
$u_{b,3}$	0.7	0.7		0.7	REF_V (at ref lab)
Link of the Reference system to its local UTC(k)					
$u_{b,4}$	0.7	0.7		0.7	REF_R (at ref lab)
Antenna cable delay					
$u_{b,5}$	0.5	0.5		0.5	CAB_V
$u_{b,6}$	0.5	0.5		0.5	CAB_R
$u_{b,SYS}$	1.23	1.23		1.32	Components of equation (2)
u_{CAL}	1.25	1.25		1.40	Composed of u_a and $u_{b,SYS}$

The components in Table 6 are separated in several categories:

- $u_{b,1}$ account for errors in the differential position (Visiting – 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.
- $u_{b,2}$ account for multipath. This is difficult to estimate and 0.2 ns is conventionally used, following a discussion in the CCTF working group on GNSS in 2017.
- $u_{b,3}$ account for the measurement between the reference point of the visiting system and the local UTC(k). They include two measurements with a TIC and are taken to be 0.7 ns ($\sqrt{0.5^2 + 0.5^2}$ ns).
- $u_{b,4}$ account similarly for the measurement between the reference point of the local system and the local UTC(k). They include two measurements with a TIC and are taken to be 0.7 ns.
- $u_{b,5}$ and $u_{b,6}$ account for measurement of RF cable delay. These are conservative values.