REPORT

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Reference
Calibration report 2020:08

BIPM

Relative calibration of GNSS (GPS) receivers at RISE

1. Description of equipment and operations

An internal relative calibration of three GNSS receivers has been performed with respect to a local reference receiver. The reference receiver (SP06) is previously calibrated within CAL_ID 1014-2019. Two of the calibrated receivers (SP01 and SP02) have been calibrated earlier within the same CAL_ID 1014-2019 but due to an antenna change a new calibration was necessary. Receiver SP07 (by RISE suggested BIPM code) has not been calibrated before.

The calibration is performed using measurements of the TOTAL DELAY for each frequency (L1 and L2) with respect to the corresponding, calibrated delays of SP06. Only GPS (codes P1/C1W on L1 and P2/C2W on L2) was calibrated. Table 1 summarizes the receivers involved in the relative calibration as well as the measurement period.

Table 1. Summary information on the calibration

Institute	Status of equipment	Dates of measurements	Receiver type	BIPM code	RISE code	RINEX name
RISE	Calibrated 1014-2019	Reference	PolaRx5TR	SP06	SP06	RIT1
RISE	New antenna	59075-59081	Javad LGGD	SP01	SP01	SP01
RISE	New antenna	59075-59081	Javad LGGD	SP02	SP02	SP02
RISE	Not calibrated	59075-59081	PolaRx5TR	SP07	SP07	RIT2

2. Receiver installations

Table 2 summarizes the receiver installations. The reference clock for all receivers is UTC(SP) 1-PPS and 5/10 MHz sinusoidal signals. The Javad receivers uses 5 MHz and the PolaRx5TR receivers 10 MHz. All receivers are fed from the corresponding antenna via a power splitter indicated in the table by RISE internal name as given in the RISE equipment register. The antenna cable type is given for reference. The fixed antenna coordinates are used when creating CGGTTS data from RINEX data as explained in Section 3.

The mode of operation of the SP06 and SP07 PolaRx5TR receivers is “auto-compensation OFF”.

Table 2. Summary information on receiver installations

Receiver	RISE monument name	Antenna type/ Power splitter	Antenna cable type	Fixed antenna coordinates		
				X	Y	Z
SP06	Pillar 2	LEIAR25.R4 PS14	Andrew Heliax FSJ1-50A	3328988.29	761918.19	5369032.01
SP01	Pillar 1	TRM59800.00 PS1	Andrew Heliax LDF2-50A	3328984.40	761910.47	5369033.95
SP02	Pillar 1	TRM59800.00 PS1	Andrew Heliax LDF2-50A	3328984.40	761910.47	5369033.95
SP07	Pillar1	TRM59800.00 PS1	Andrew Heliax LDF2-50A	3328984.40	761910.47	5369033.95

3. Data used

Data from 2020-08-14 to 2020-08-20 (MJD 59075-59081) were used for the relative calibration. RINEX (ver. 3.03) data were calculated from raw data collected from each receiver with software JPS2RIN (ver. 2.0.137) for the Javad receivers and software SBF2RIN (ver. 11.3.2) for the Septentrio receivers. CGGTTS data were calculated from RINEX data using the software RISEGNSS [1] developed at RISE.

4. Results of raw data processing

Table 3 summarizes the calculated delay differences for each receiver relative to the calibrated reference receiver SP06. The results are presented as the mean difference of the Total Delay for each frequency/code relative to the calibrated values for SP06 (ΔTOTDLY) of CAL_ID 1014-2019. The statistical uncertainty $\mathbf{u_a}$ represented by the rms of the raw data processing, is given for each receiver pair. Annex A shows plots of raw data and Tdev analysis.

Table 3. Summary of the raw calibration results (all values in ns)

Pair	Date	ΔTOTDLY (P1/C1W)	u_{aP1}	ΔTOTDLY (P2/C2W)	u_{aP2}
SP06-SP01	59075-59081	242.7	0.12	251.5	0.13
SP06-SP02	59075-59081	244.1	0.12	250.3	0.15
SP06-SP07	59075-59081	231.6	0.12	228.0	0.08

5. Uncertainty estimation

Table 4 summarizes the statistical uncertainty contributions for ΔTOTDLY for each receiver pair listed in Table 3. The statistical uncertainty $\mathbf{u_a}$ is represented by the RMS of the raw calibration results. These values are also given in Table 3.

Table 4. Statistical uncertainty contributions (all values in ns)

Pair	u_{aP1}	u_{aP2}	Description
SP06-SP01	0.12	0.13	RMS of raw data difference
SP06-SP02	0.12	0.15	RMS of raw data difference
SP06-SP07	0.12	0.08	RMS of raw data difference

Table 5 summarizes the systematic uncertainty that is attributed to the calibration uncertainty of SP06 and the same for all receiver pairs. The total systematic uncertainty is calculated as

$$\mathbf{u_{b,TOT}} = \sqrt{\textstyle\sum_n \mathbf{u_{b,n}^2}}$$

Table 5. Systematic uncertainty contributions (all values in ns)

Uncertainty	Value P1/C1W	Value P2/C2W	Description
$u_{b,1}$	2.5	2.5	Calibrated Total Delay of SP06 (1014-2019)
$u_{b,2}$	0.5	0.5	Aging of SP06 since 2019-03
$\mathbf{u_{b,TOT}}$	2.6	2.6	

6. Calibration results

Table 6 summarizes the calibration results. For reference, the present calibration values from CAL_ID 1014-2919 are given for SP06.

The combined uncertainty $\mathbf{u_{CAL}}$ is calculated as

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

and the TOTDLY for P3 is calculated as P1 + 1.545*(P1-P2).

As the systematic uncertainty $u_{b,TOT}$ dominates u_{CAL}, the combined uncertainty for the TOTDLY (P1, P2, and P3) and for all calibrated receivers given in Table 6 is 2.6 ns.

Table 6. Summary of relative calibration results (all values in ns)

Reference system	**Cal_ID**	**Date**	**TOTDLY (P1/C1W)**	**TOTDLY (P2/C2W)**	**TOTDLY (P3)**
SP06	1014-2019	2019-03	273.5	269.7	279.4
Calibrated system		**Date**	**TOTDLY (P1/C1W)**	**TOTDLY (P2/C2W)**	**TOTDLY (P3)**
SP01		2020-08	242.7	251.5	229.1
SP02		2020-08	244.1	250.3	234.5
SP07		2020-08	231.6	228.0	237.2

References

[1] K. Jaldehag, P. Jarlemark, and C. Rieck, "Further Evaluation of CGGTTS Time Transfer Software, "in Proc. of the 2019 Joint Conference of the IEEE International Frequency Control Symposium and European Frequency and Time Forum (EFTF/IFC), Orlando, Florida, USA, 2019.

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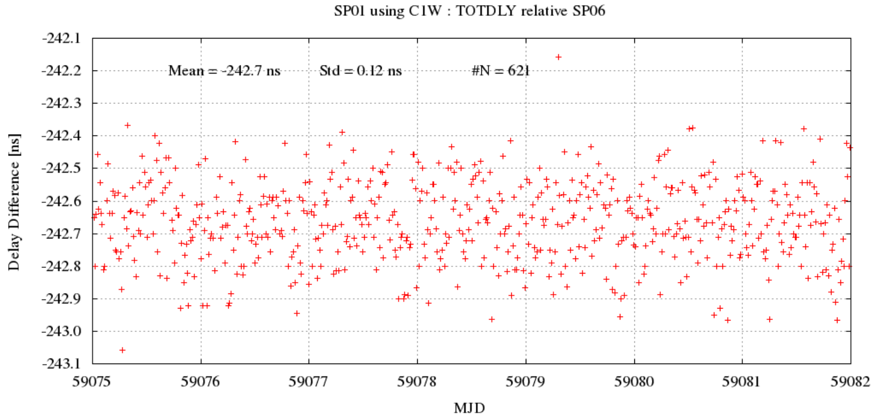
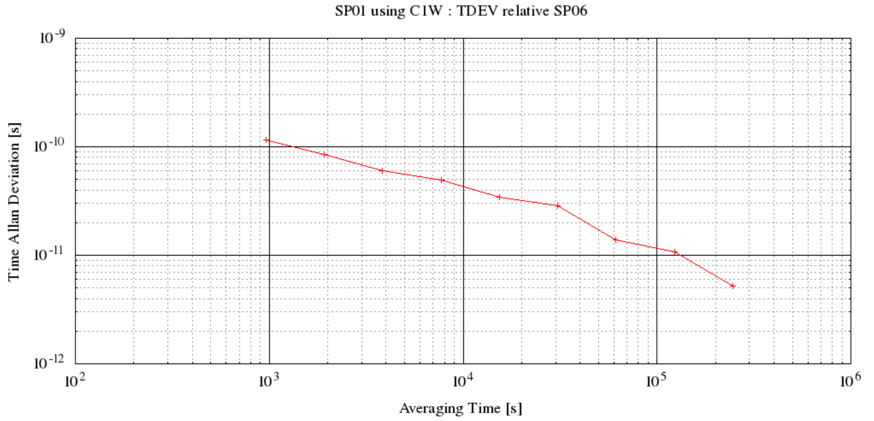
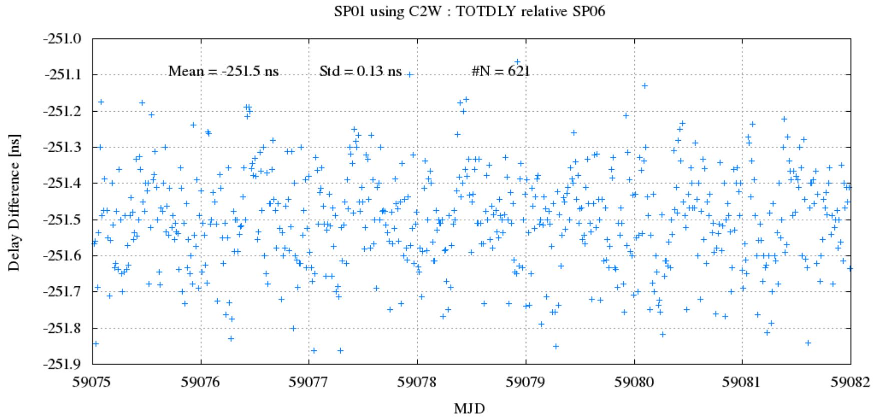
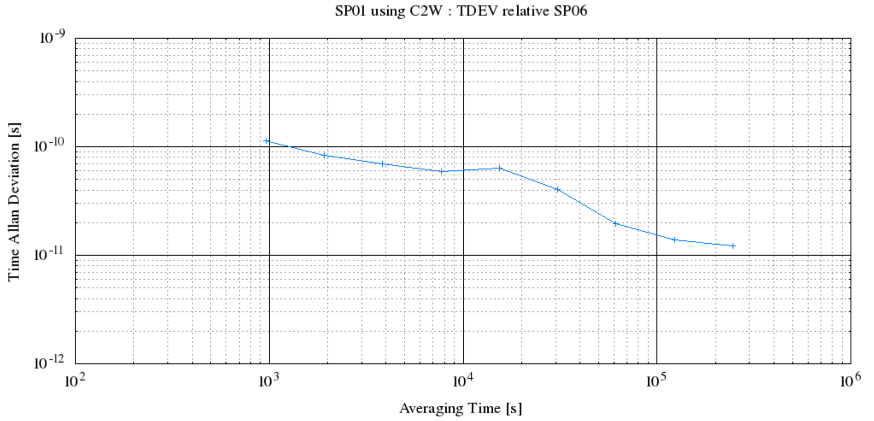
ANNEX A: Plots of raw data and Tdev analysis

SP01

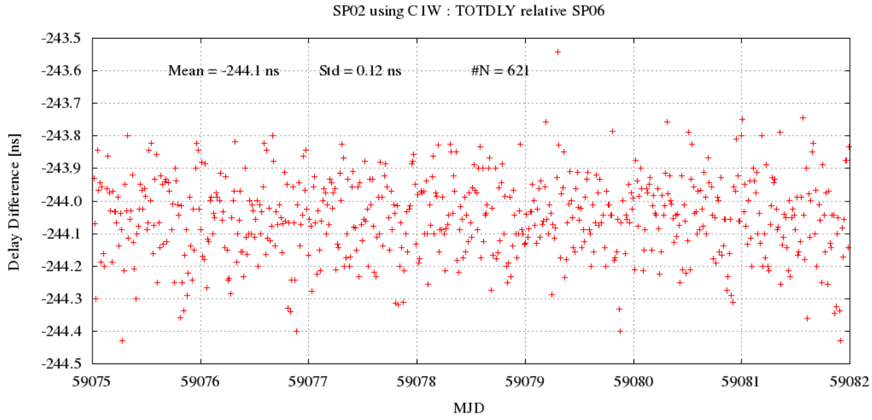

SP01 using C1W : TOTDLY relative SP06
Mean = -242.7 ns
Std = 0.12 ns
#N = 621
Delay Difference [ns]
-242.1
-242.2
-242.3
-242.4
-242.5
-242.6
-242.7
-242.8
-242.9
-243.0
-243.1
59075
59076
59077
59078
59079
59080
59081
59082
MJD

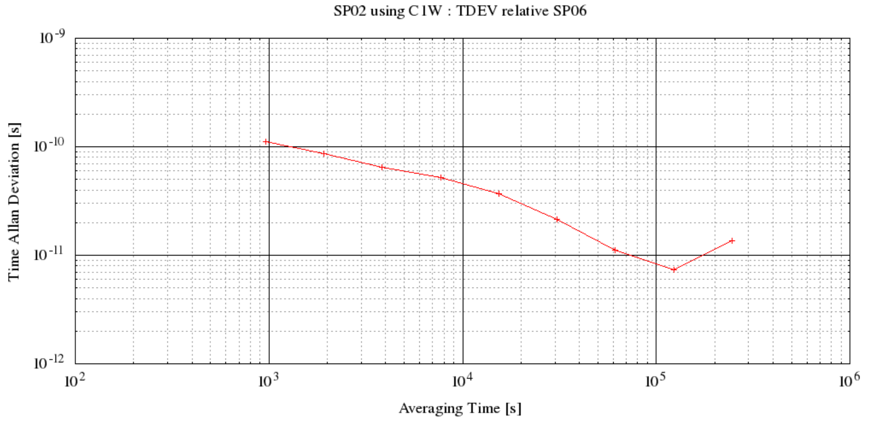

SP01 using C1W : TDEV relative SP06
Time Allan Deviation [s]
10^-9
10^-10
10^-11
10^-12
10^2
10^3
10^4
10^5
10^6
Averaging Time [s]

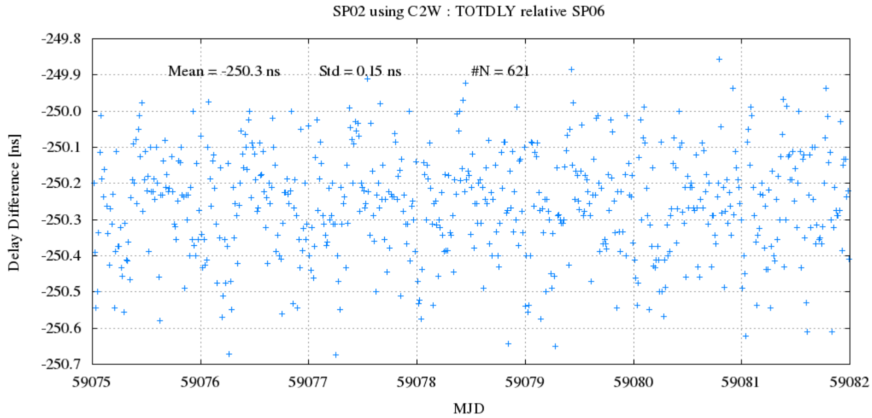

SP01 using C2W : TOTDLY relative SP06
Mean = -251.5 ns
Std = 0.13 ns
#N = 621
Delay Difference [ns]
-251.0
-251.1
-251.2
-251.3
-251.4
-251.5
-251.6
-251.7
-251.8
-251.9
59075
59076
59077
59078
59079
59080
59081
59082
MJD

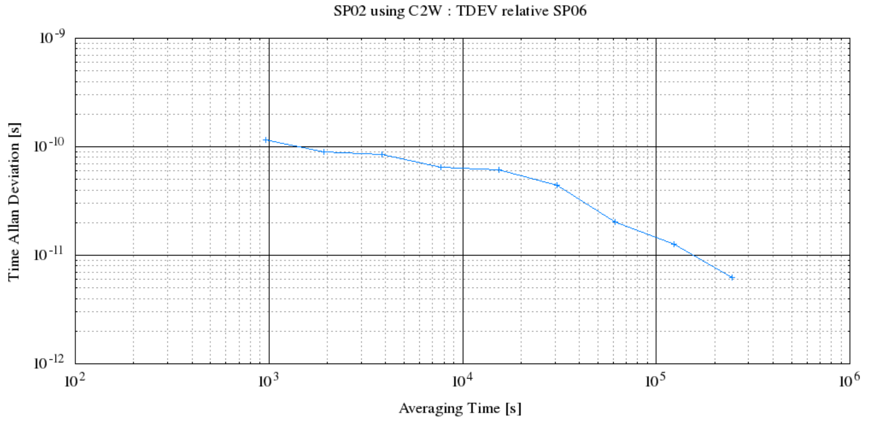

SP01 using C2W : TDEV relative SP06
Time Allan Deviation [s]
10^-9
10^-10
10^-11
10^-12
10^2
10^3
10^4
10^5
10^6
Averaging Time [s]

SP02

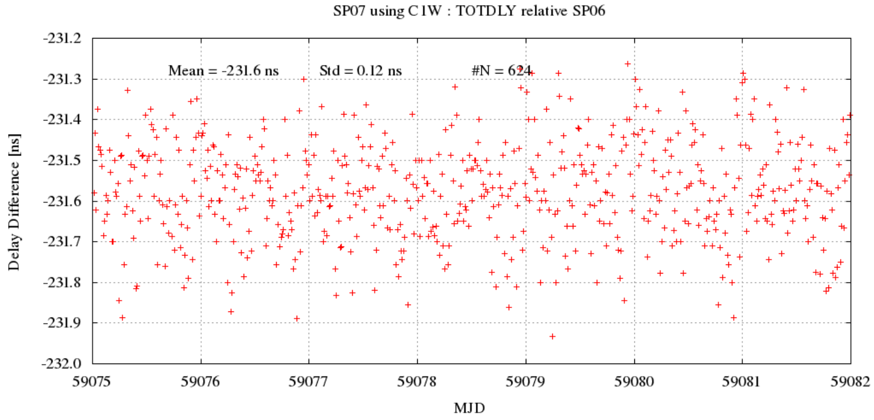

SP02 using C1W : TOTDLY relative SP06
Mean = -244.1 ns
Std = 0.12 ns
#N = 621
Delay Difference [ns]
-243.5
-243.6
-243.7
-243.8
-243.9
-244.0
-244.1
-244.2
-244.3
-244.4
-244.5
59075
59076
59077
59078
59079
59080
59081
59082
MJD

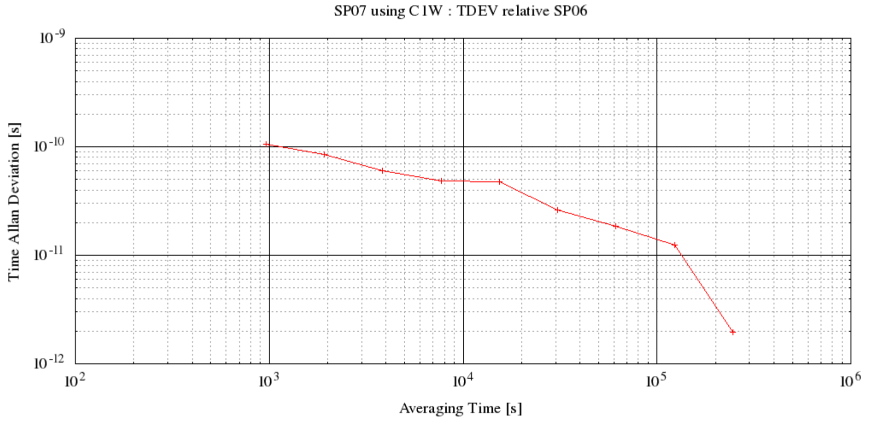

SP02 using C1W : TDEV relative SP06
Time Allan Deviation [s]
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
Averaging Time [s]

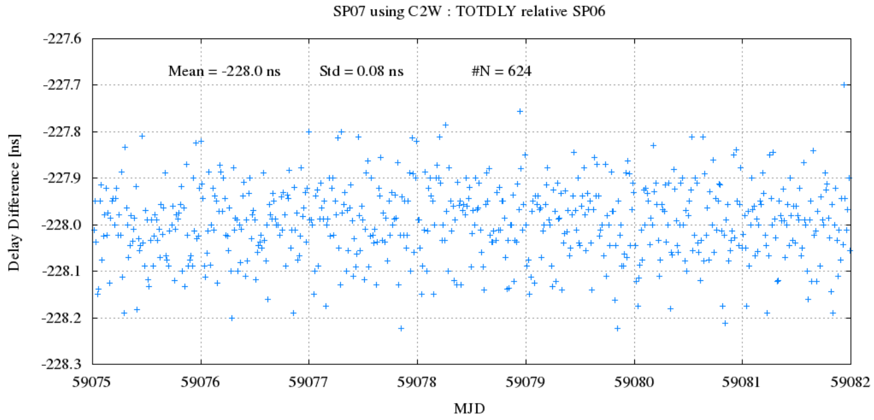

SP02 using C2W : TOTDLY relative SP06
Mean = -250.3 ns
Std = 0.15 ns
#N = 621
Delay Difference [ns]
-249.8
-249.9
-250.0
-250.1
-250.2
-250.3
-250.4
-250.5
-250.6
-250.7
59075
59076
59077
59078
59079
59080
59081
59082
MJD

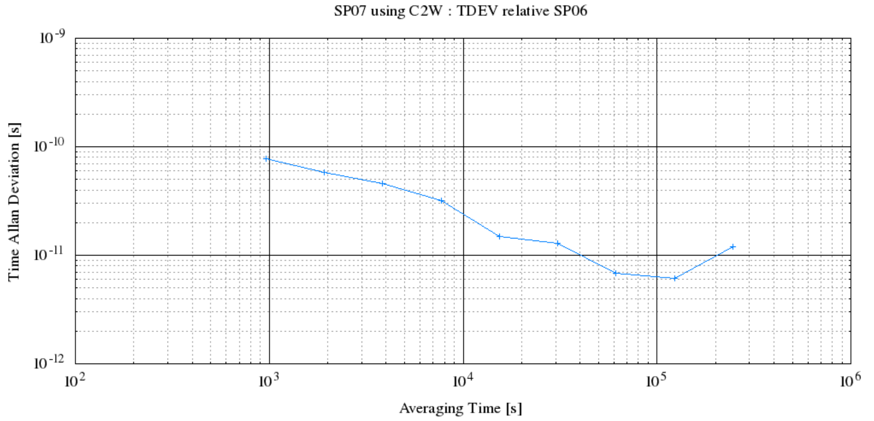

SP02 using C2W : TDEV relative SP06
Time Allan Deviation [s]
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
Averaging Time [s]

SP07


SP07 using C1W : TOTDLY relative SP06
Mean = -231.6 ns
Std = 0.12 ns
#N = 624
Delay Difference [ns]
MJD


SP07 using C1W : TDEV relative SP06
Time Allan Deviation [s]
Averaging Time [s]


SP07 using C2W : TOTDLY relative SP06
Mean = -228.0 ns
Std = 0.08 ns
#N = 624
Delay Difference [ns]
MJD


SP07 using C2W : TDEV relative SP06
Time Allan Deviation [s]
Averaging Time [s]