ESA ESTEC
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands

ABSOLUTE CALIBRATION OF BP27 (INCLUDING BDS-3)

Prepared by	P.Waller, C.Plantard
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EXECUTIVE SUMMARY

After successful absolute calibration campaign of two GNSS receivers chains for the BIPM in 2019 in the ESA/ESTEC Laboratory, a second campaign was conducted in May 2021 on one receiver, in order to include for the first time the Beidou-3 signals (B1C and B2a). While the basic principles and method for the calibration remain the same as in 2019, the equipment and tools had to be updated to handle these new signals. Because no other results for Beidou-3 signals are available, it is not possible to assess their quality level. However they are found to be consistent with other signals and in line with results obtained on another similar receiver (not reported here).

The table below reports the obtained calibration results of the BP27 receiver and associated 1-sigma uncertainties (in ns) for all calibrated signals.

			BP27 (FW 5.4.0)	
	Signal		value	uncert.
GPS	L1C	C1C	11.45	0.48
	L1P	C1W	11.11	0.45
	L2P	C2W	10.49	0.47
	L5Q	C5Q	11.19	0.42
GAL	E1C	C1C	11.56	0.42
	E5Q	C5Q	11.20	0.44
	E7Q	C7Q	7.40	0.43
	E8Q	C8Q	9.18	0.45
	E6C	C6C	7.13	0.47
BDS-2	B1I	C2I	4.51	0.54
	B2I	C7I	7.09	0.53
BDS-3	B1C	C1P	11.29	0.44
	B2A	C5P	11.29	0.52

1. INTRODUCTION

This document reports the results of the absolute calibration campaign conducted on the BIPM GNSS receiver named BP27 in the ESA/ESTEC Laboratory in May 2021.

This calibration campaign was aimed at including for the first time the delays of the Beidou-3 signals (B1C, B2a), in addition to GPS, Galileo and Beidou-2 signals.

The absolute calibration method used during this campaign was the same as reported in [1, 2], with equipment and tools updated to cover the Beidou-3 signals.

All uncertainties in this report are reported as the 1-sigma value.

2. REFERENCES DOCUMENTS

[1]: “Absolute calibration of GNSS timing stations and its applicability to real signals”, E.Garbin et al 2019 Metrologia 56 015010

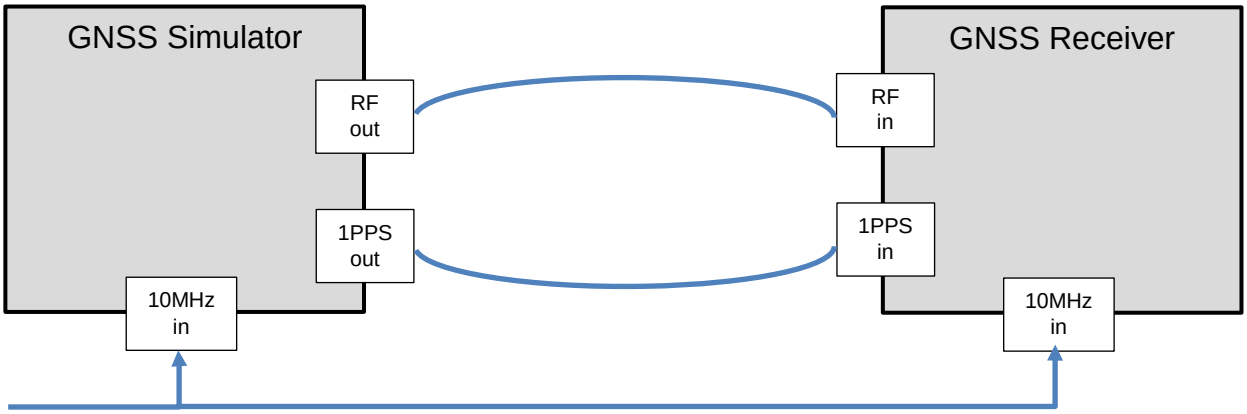
[2]: “Absolute Calibration Report of GNSS Chains for the BIPM”, ESA-TECEFE-TN-015234, July 2019

[3]: “Cross-calibrations of multi-GNSS Receiver Chains”, P.Waller et al, 2019, EFTF-IFCS.

[4]: “Zero-doppler pseudorange biases”, JM.Sleewagen et al., 2018, ION-PTTI

3. RECEIVER CALIBRATION METHOD

The absolute calibration of the GNSS receiver is based on the use of simulated GNSS signals with the very simple set-up as described in the figure below:



The GNSS simulator and receiver under test are both connected to the same external 10MHz frequency reference signal. The antenna port of the receiver is connected to the RF signal generated by the GNSS simulator through high quality coaxial cable. Likewise, the 1pps input of the receiver is connected to the 1pps generated by the GNSS simulator with similar coaxial cable. The GNSS simulator is configured to generate a scenario where all signals from all satellites from all GNSS constellations (except Glonass) are active, and where the ionosphere and troposphere delays, as well as the on-board clock errors are set to zero. For this specific calibration campaign, our GNSS Simulator had to be updated to generate also the Beidou-3 signals (B1C and B2a).

The first step in the measurement is to calibrate the Simulator delays. These are the delays, for each individual GNSS signal, between the rising edge of the first chip of the signal and the rising edge of the 1pps signal, both measured at the end of the cables that will be connected to the receiver. To do so, these two ends of the cables are connected to a wideband – high sampling rate digital oscilloscope that records simultaneously the RF and 1pps signals. While the rising edge of the 1pps signal is easily identified in the data records, a dedicated correlator tool is used to identify the maximum correlation peak of all individual GNSS signals (corresponding to the rising edge of the first chip). This correlator tool has been validated in

several instances (e.g. AD03) and has been updated to process the Beidou-3 B1C and B2a signals.

After the GNSS Simulator has been calibrated, the two ends of the cables are connected to the receiver and the same GNSS Simulator scenario is run. In this configuration, pseudoranges from all simulated satellites in view are collected and recorded in rinex format. The receiver delays for each GNSS signal is then computed by subtracting to the so-obtained pseudoranges the simulated geometrical range and the simulator calibration values, and by adding the delay of the external 1pps signal to the receiver clock ("latching delay").

In practice, to simplify the correlation process for the Simulator calibration, 1 satellite per constellation is simulated in GEO orbit (i.e. zero-Doppler). Stable and repeatable correlation peaks are obtained for all GNSS signals over a typical correlation duration of 4ms. For the receiver calibration, pseudorange measurements are collected over typically several hours which guarantees full stabilisation of the receiver operation. In addition, pseudoranges are collected from all simulated MEO satellites in view (instead of simulated GEO satellites as done in [2]), thereby reducing the pseudorange noise and suppressing possible effects of zero-Doppler PRN-dependant biases [4].

4. RECEIVER CALIBRATION UNCERTAINTY BUDGET

The GNSS receiver absolute calibration is a combination of GNSS Simulator delay measurements, pseudorange measurements and latching delay measurements. The table below summarises the source of errors for those measurements and identify how they have been estimated.

Uncertainty	Type	Description	Value (ps)
Sim_noise	A	Measurement Noise (std over 16 runs/PRNs)	50 to 350
Sim_resol	B	Oscilloscope Resolution (10GSps)	100
Sim_trigger	B	Oscilloscope Trigger error (specs)	15
Sim_config	B	Simulator output power effects (tests)	100
Sim_filter	B	Correlator low-pass filter effects (test)	100
PR_noise	A	Pseudorange Noise (std of the PR differences)	10 to 155
PR_icb	B	Receiver inter-channel biases (test)	10
PR_agc	B	Receiver AGC-dependant biases (test)	100
PR_temp*	B	Thermal effects on receiver (test)	200
LD	A	LD measurement noise (conservative assumption)	40
LD	B	Receiver autocalibration (test)	300
		TOTAL:	**418 to 564**

* only to be considered in case the receiver operates at a significantly different temperature than the one during calibration.

This uncertainty budget is valid for measurements using simulated GNSS signals as described in the previous section. As demonstrated e.g. in [1], additional contributors to this uncertainty budget shall be taken into account when using real GNSS signals.

5. RECEIVER CALIBRATION RESULTS

5.1. Test Conditions

The table below summarises the equipment and environmental conditions of the test campaign.

Simulator	
Type	Dual Spirent TS1140
Item #	117201 and 117200
FW version	V7.01.00
1pps rise time	3ns
Oscilloscope	
Type	Keysight DSOS404A (4GHz, 20GSps)
Serial Number	MY55510163
Trigger level	1V
Samples duration	4ms
Correlator	
Version / date	v5.0 / March 2021
Filter characteristics	20MHz / 45MHz
Receiver	
Type	Septentrio PolaRx5TR
Serial Number / SSID	4701324 / 3046906
FW version	3.2.0 and 5.4.0
Receiver scenario duration	24h
Environment	
Room temperature	22°C ± 2°C
Room Humidity	40% ± 10%

5.2. Stand-alone Receiver

When it was delivered, the BP27 receiver was not updated to the latest firmware version and as a consequence, was not able to track the Beidou-3 signals. It was therefore agreed that a first calibration campaign would be executed with the current firmware (without Beidou-3 signals) and would be repeated after firmware update (with Beidou-3 signals). Such approach allowed to keep track of possible changes in delays due to firmware update. The table below presents the results of these two campaigns:

			BP27			
			FW 3.2.0		FW 5.4.0	
	Signal		value	uncert.	value	uncert.
GPS	L1C	C1C	11.16	0.48	11.45	0.48
	L1P	C1W	10.83	0.45	11.11	0.45
	L2P	C2W	10.19	0.47	10.49	0.47
	L5Q	C5Q	10.90	0.42	11.19	0.42
GAL	E1C	C1C	11.26	0.42	11.56	0.42
	E5Q	C5Q	10.89	0.44	11.20	0.44
	E7Q	C7Q	7.11	0.43	7.40	0.43
	E8Q	C8Q	8.88	0.45	9.18	0.45
	E6C	C6C	6.82	0.47	7.13	0.47
BDS-2	B1I	C2I	4.22	0.54	4.51	0.54
	B2I	C7I	6.79	0.53	7.09	0.53
BDS-3	B1C	C1P			11.29	0.44
	B2A	C5P			11.29	0.52

The table above indicates that the update of the firmware has caused a shift of about 300ps on all the signals.

5.3. Receiver + Antenna Cable

As the receiver has been delivered together with an antenna cable, a splitter and a short cable, another calibration campaign was conducted including this full cable assembly (that was also measured separately). The results obtained are summarised in the table below.

			BP27 + cable		**cable**		**"BP27 + cable" - cable**		Δ BP27	
	Signal		value	uncert.	value	uncert.	value	uncert.	value	uncert.
GPS	L1C	C1C	212.26	0.48	200.78	0.06	11.48	0.48	0.03	0.67
	L1P	C1W	211.88	0.44			11.10	0.44	-0.01	0.63
	L2P	C2W	211.29	0.47			10.51	0.47	0.02	0.66
	L5Q	C5Q	211.98	0.42			11.20	0.43	0.00	0.60
GAL	E1C	C1C	212.37	0.42			11.59	0.42	0.02	0.60
	E5Q	C5Q	211.98	0.44			11.20	0.44	0.00	0.62
	E7Q	C7Q	208.20	0.43			7.42	0.43	0.02	0.61
	E8Q	C8Q	209.95	0.45			9.17	0.45	-0.01	0.63
	E6C	C6C	207.77	0.47			6.99	0.47	-0.14	0.67
BDS-2	B1I	C2I	205.49	0.54			4.71	0.55	0.20	0.77
	B2I	C7I	207.88	0.53			7.10	0.53	0.01	0.75
BDS-3	B1C	C1P	212.11	0.44			11.33	0.44	0.04	0.63
	B2A	C5P	212.08	0.52			11.30	0.52	0.01	0.74

The last columns report the difference between the delays measured on the receiver + cable assembly and the ones measured on the cable and receiver separately. They are found to be in excellent agreement.