GNSS CALIBRATION REPORT

PT15 TRANSFER CALIBRATION

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Time Dissemination
Working Group

Authorized by: BIPM

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REFERENCES

REFERENCES	
RD01	**2022 Group 1 GNSS calibration trip (CAL_ID 1001-2022)**
RD02	**BIPM guidelines for GNSS calibration, V3.0, 02/04/2015**
RD03	**BIPM Procedure for computing raw difference of GNSS code measurements for geodetic receivers, dclrinex software version 3.1, April 2021**
RD04	**J. Kouba, P. Heroux, 2002, *"Precise Point Positioning Using IGS Orbit and Clock Products",* GPS Solutions, Vol. 5, No. 2, 12-28**
RD05	**W. Lewandowski, C. Thomas, 1991, *"GPS Time transfers,"* Proc. IEEE, Vol. 79, No. 7, 991-1000**
RD06	**P. Defraigne and G. Petit, "CGGTTS-Version 2E: an extended standard for GNSS time transfer", Metrologia 52 (2015) G1**
RD07	**D. A. Howe and N. Schlossberger, "Characterizing Frequency Stability Measurements Having Multiple Data Gaps", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. 69, No. 2 (2022)**
RD08	**BIPM Template for calibration report to the BIPM, V3.1, 29/08/2015**

ACRONYMS

ACRONYMS	
BIPM	**Bureau International des Poids et Mesures, Sèvres, France**
CAB DLY	**Antenna Cable Delay**
CGGTTS	**CCTF Generic GNSS Time Transfer Standard**
DCLRINEX	**Differential calibration software using the pseudoranges directly read from the RINEX files, software was provided by the BIPM**
EURAMET	**The European Association of National Metrology Institutes**
IGS	**International GNSS Service**
INT DLY	**Internal Signal Delay**
GNSS	**Global Navigation Satellite System**
PPP	**Precise Point Positioning**
PTB	**Physikalisch-Technische Bundesanstalt, Braunschweig, Germany**
REF DLY	**Reference Delay**
RINEX	**Receiver Independent Exchange Format**
R2CGGTTS	**RINEX-to CGGTTS conversion software, provided by ORB / BIPM**
TDEV	**Time Deviation**
TIC	**Time Interval Counter**

RESULTS OF RAW DATA PROCESSING

1.1. OVERVIEW

The raw code differences of the pairs of co-located receivers during the data acquisition period are generated using the DCLRINEX software. The stated raw calibration results are taken as the median of the raw differences. The associated uncertainties are derived from the TDEV at 50000 s. The default value of 0.1 ns is chosen if the measured TDEV is less than 0.1 ns.

Table 1-1 Summary information on the raw calibration results for GPS signals (all values in ns)

Pair	Date	RAWDIF	Unc.	Code
PT15-PT13	60519 - 60528	48.97	0.1	P1
PT15-PT13	60519 - 60528	44.57	0.1	P2
PT15-PT13	60519 - 60528	49.99	0.1	C1
PT15-PT13	60519 - 60528	50.43	0.1	E1
PT15-PT13	60519 - 60528	43.56	0.1	E5a

1.2. COMMON-CLOCK SET-UP IN PTB

For “CC1”, PT15 was operated for 9 days at PTB. The installation of the receivers in PTB is depicted in Figure 1-1 for PPS signals and in Figure 1-2 for 5 MHz (and 10 MHz) signals.

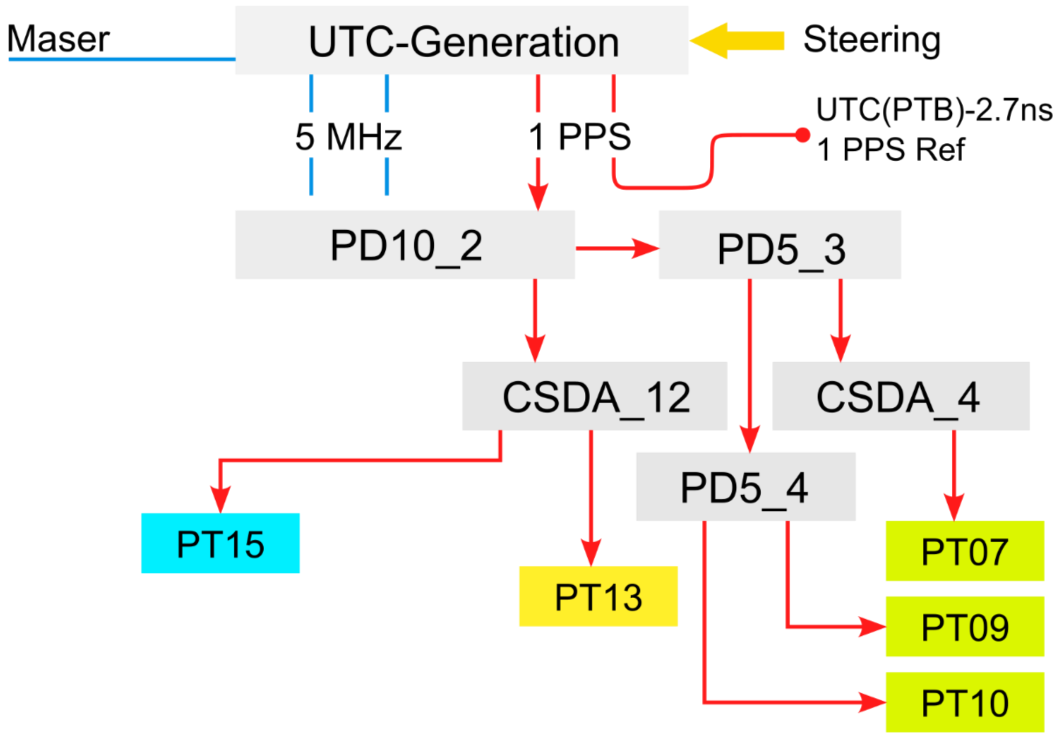

Figure 1-1 UTC(PTB) reference point and 1 PPS signal distribution to PT13, PTBM, and other receivers; PD10 stands for pulse distributor, CSDA stands for clock signal distribution amplifier

A clarification may be helpful regarding the 1 PPS REF point. When measuring with a TIC the time difference between Port A = UTC(PTB), and Port B = 1 PPS REF, then the result is +2.7 ns. Figure 1-3 illustrates the installation of GNSS antennas on the roof of the PTB time laboratory (clock hall) during CC1.

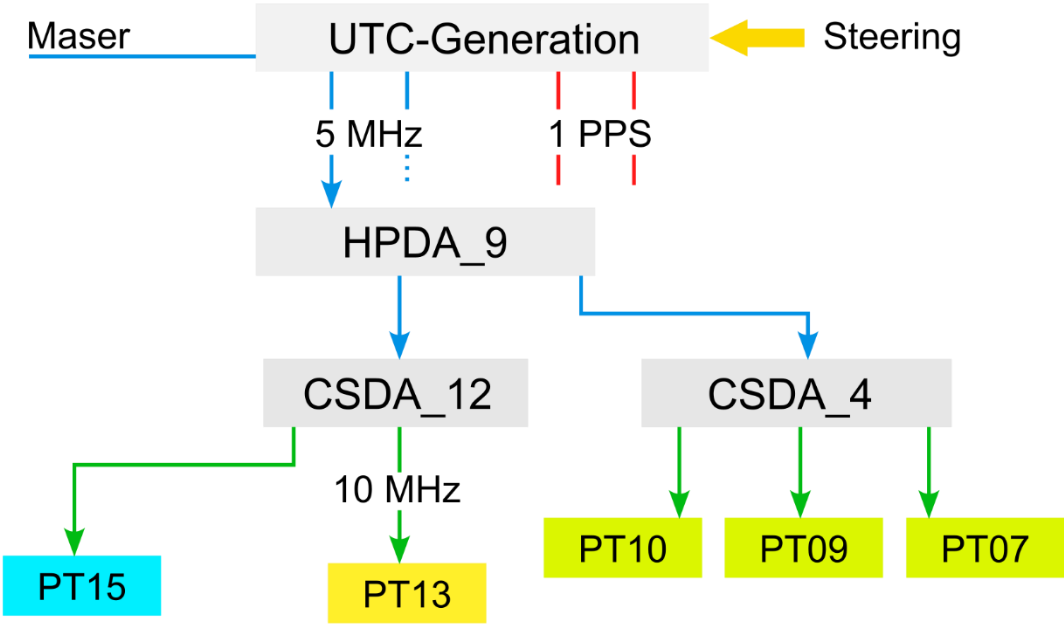

Figure 1-2 UTC(PTB) signal distribution (5 MHz, 10 MHz) to PT13, PTBM, and other receivers

HPDA stands for High-precision distribution amplifier (for rf frequencies)

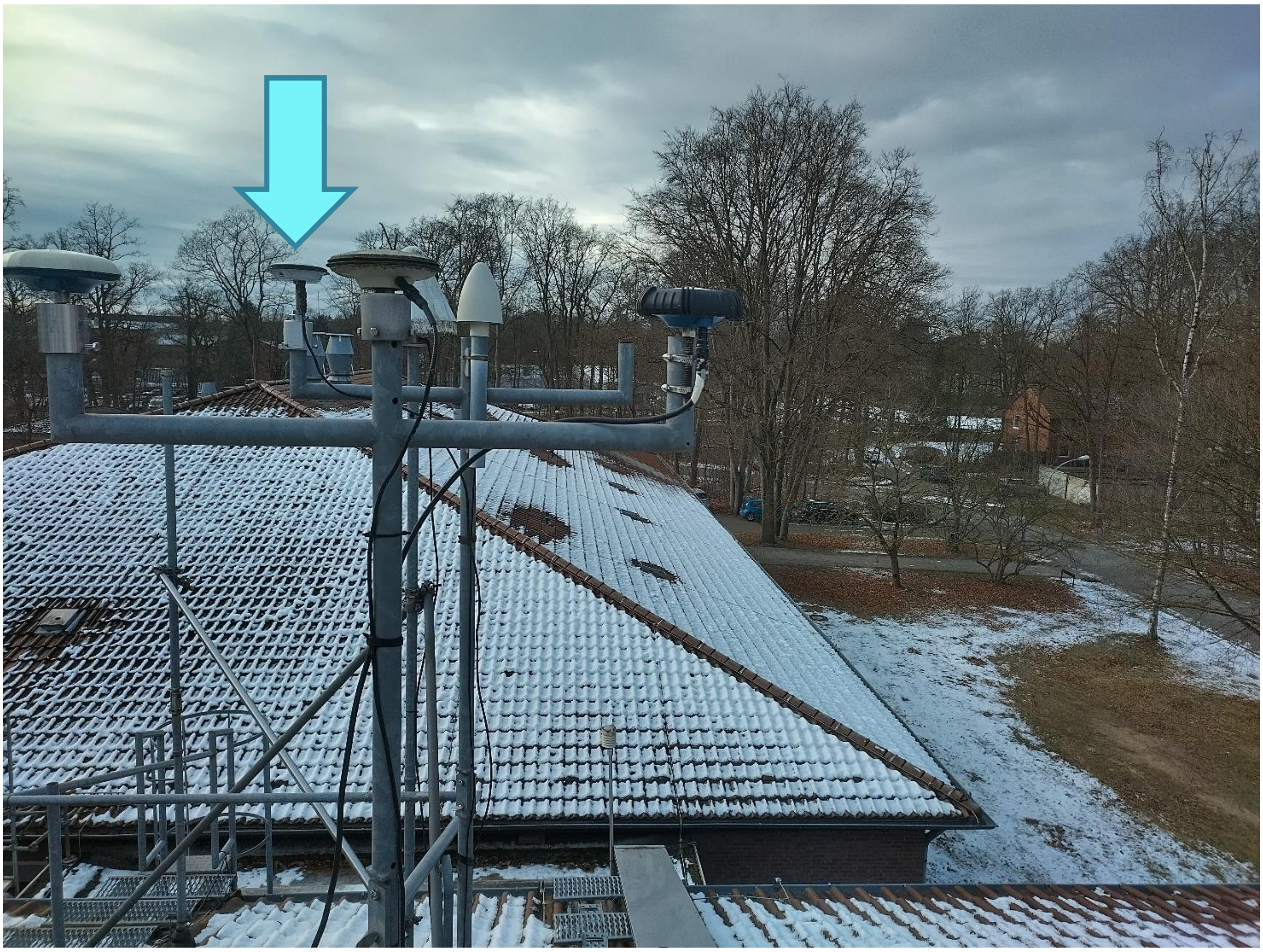

Figure 1-3 Installation of GNSS antennas at PTB, PT15 antenna is highlighted by the blue arrow

The period 60306 to 60528 (9 days) was chosen to determine the initial PT15 INT DLY values. The results of the comparison with PT13 as the reference are shown in Figure B-1. The figures show the raw code differences and the corresponding TDEVs. The numerical results are given in Table 1-1.

2. CALIBRATION RESULTS

2.1. PT15 WITH RESPECT TO THE REFERENCE SYSTEM

Table 2-1 Calibration results T vs. G (all values in ns)

Pair	Date	REF DLY$_V$	REF DLY$_G$	RAW DIF	ΔSYS DLY$_{V-G}$	Code
PT15-PT13	60519 - 60528	10.98	56.2	48.97	3.75	P1
PT15-PT13	60519 - 60528	10.98	56.2	44.57	-0.65	P2
PT15-PT13	60519 - 60528	10.98	56.2	49.99	4.77	C1
PT15-PT13	60519 - 60528	10.98	56.2	50.43	5.21	P1
PT15-PT13	60519 - 60528	10.98	56.2	43.56	-1.66	P2

2.2. INT DLY UNCERTAINTY EVALUATION

Table 2-2 Uncertainty contributions for the calibration of receiver delays (GPS), all values in ns

	Uncertainty	Value f1	Value f2	Value f1-f2	Value f3	Description
1	u_a (PTB)	0.1	0.1	0.14		CC measurement uncertainty at PTB, TDEV max.
2	u_a (GPS)	0.1	0.1	0.14	0.24	
Systematic components due to antenna installation						
3	$u_{b,11}$	0.2	0.2	0	0.20	Multipath at PTB
4	$u_{b,12}$	0.1	0.1	0.14	0.28	Position error at PTB
Installation of PTBM and visited receivers						
5	$u_{b,21}$	0.2	0.2	0	0.20	Connection of PT15 to UTC(PTB) (REF DLY)
6	$u_{b,24}$	0.1	0.1	0	0.10	TIC nonlinearities at PTB
Antenna cable delay						
7	$u_{b,31}$(PTB)	0.5	0.5	0	0.50	Uncertainty estimation for the PTBM CAB DLY when installed at PTB
Total						
8	$u_{b,INT}$ (GPS)	0.77	0.77	0.32	0.91	
9	$u_{CAL,0}$ (GPS)				0.95	

Table 2-3 Uncertainty contributions for the calibration of receiver delays (Galileo), all values in ns

	Uncertainty	Value f1	Value f2	Value f1-f2	Value f3	Description
1	u_a (PTB)	0.1	0.1	0.14		CC measurement uncertainty at PTB, TDEV max.
2	u_a (Galileo)	0.1	0.1	0.14	0.24	
Systematic components due to antenna installation						
3	$u_{b,11}$	0.2	0.2	0	0.20	Multipath at PTB
4	$u_{b,12}$	0.1	0.1	0.14	0.28	
Installation of PTBM and visited receivers						
5	$u_{b,21}$	0.2	0.2	0	0.20	Connection of PT15 to UTC(PTB) (REF DLY)
6	$u_{b,24}$	0.1	0.1	0	0.10	TIC nonlinearities at PTB
Antenna cable delay						
7	$u_{b,31}$(PTB)	0.5	0.5	0	0.50	Uncertainty estimation for the PTBM CAB DLY when installed at PTB
Total						
8	$u_{b,INT}$ (Galileo)	0.78	0.78	0.35	0.89	
9	$u_{CAL,0}$ (Galileo)				0.92	

3. FINAL RESULTS FOR PT15

The results of the calibration are summarized in Table 3-1. INT DLY values for the golden reference receiver PT13 were determined in 2021 [RD01]. The uncertainty values are taken from Table 2-2. The final INT DLY values are listed in Table 2-1.

Table 3-1 Summary of final results for GPS links, all values in ns

Reference system	Cal_Id	Date		INT DLY	Code
PT13	1001-2022	60054		30.96	P1
PT13	1001-2022	60054		28.50	P2
PT13	1001-2022	60054		33.60	C1
PT13	1001-2022	60054		33.19	E1
PT13	1001-2022	60054		33.05	E5a
Visited system	**Cal_Id**	**Date**	**u_{CAL} (P3)**	**INT DLY**	**Code**
PT15	1001-2022	60529	0.9	34.9	P1
PT15	1001-2022	60529	0.9	28.1	P2
PT15	1001-2022	60529	0.9	38.6	C1
PT15	1001-2022	60529	0.9	38.6	E1
PT15	1001-2022	60529	0.9	31.6	E5a

ANNEXES

ANNEX A: BIPM CALIBRATIOIN INFORMATION SHEETS
ANNEX B: PLOTS OF RAW DATA AND TDEV ANALYSIS

. ANNEX A: BIPM CALIBRATION INFORMATION SHEETS

Common clock measurement at PTB

Laboratory:	**PTB**
Date and hour of the beginning of	2022-03-19 0:00 UTC (MJD 59657)
Date and hour of the end of	2022-03-24 24:00 UTC (MJD 59662)

Information on the system		
	Reference:	**DUT:**
4-character BIPM code	**PT13**	**PT15**
Receiver maker and type: Receiver serial number:	PolaRx5TR (5.2.0) S/N 470 1292	GTR55 2312001
1 PPS trigger level /V:	1	1
Antenna cable maker and type: Phase stabilised cable (Y/N):	ECOFLEX 15plus	LMR-400
Length outside the building /m:	approx. 25	Approx.25
Antenna maker and type: Antenna serial number:	LEICA AR25 726333, Calib Geo++ 18.08.2015	NOV850 NMLK22480015P
Temperature (if stabilised) /°C		

Measured delays /ns		
	Reference:	**DUT:**
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	9.59 ± 0.1 (#)	10.98
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	46.63 ± 0.1 (#)	NA
Antenna cable delay: (X_C) / ns	205.7	205.5
Splitter delay (if any):	N/A	NA

Data used for the generation of CGGTTS files				
	Reference:		**DUT**	
☐ INT DLY (or X_R+X_S) (GPS) /ns:	30.96 (P1), 28.5 (P2), 33.6 (C1) (*)		0.0 for all	
☐ INT DLY (or X_R+X_S) (GALILEO) /ns:	33.19 (E1), 33.05 (E5a) (*)		0.0 (E1) 0.0 (E5a)	
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:				
☐ CAB DLY (or X_C) /ns:	205.7		208.7	
☐ REF DLY (or X_P+X_O) /ns:	56.2		44.3	
☐ Coordinates reference frame:	ITRF (*)		ITRF	
X /m:	+3844059.86 (***)	Mast P10	+ 3844063.42 (**)	Mast P4
Y /m:	+709661.56 (***)		+ 709658.80 (**)	
Z /m	+5023129.87 (***)		+ 5023127.41 (**)	

General information	
☐ Rise time of the local UTC pulse:	3 ns
☐ Is the laboratory air conditioned:	Yes

Set temperature value and uncertainty:	23.0 °C, peakt-to-peak variations 0.3° C

Notes:

(#) Local measurements repeated on occasion of campaign 1001-2020.

(*) values based on G1 calib 1001-2022 [RD01]

(**) APC determined using NRCan PPP free software [RD03]

(***) values provided by BIPM via Mail 2019-08-07

ANNEX B: PLOTS OF RAW DATA AND TDEV ANALYSIS

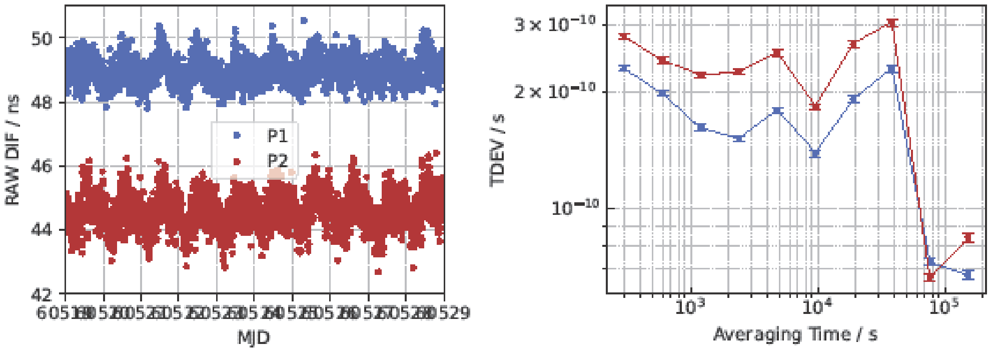

Figure B-1 Left: Raw code differences between V and G for GPS signals during CC1, ΔP1 (blue) and ΔP2 (red) Right: TDEV of the raw code differences.

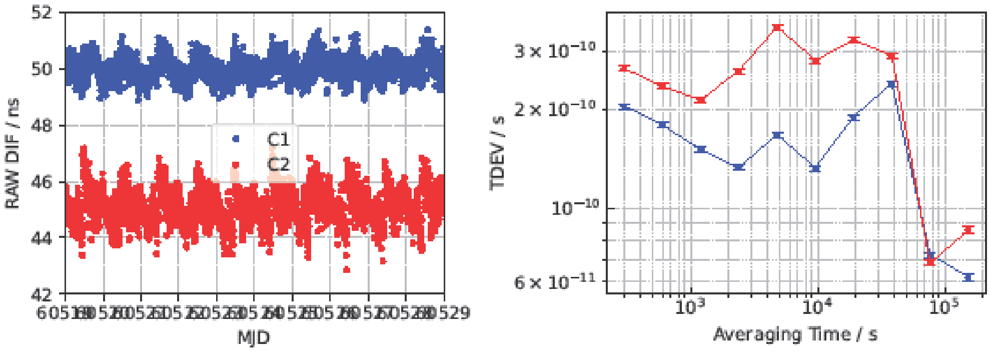

Figure B-2 Left: Left: Raw code differences between V and G for GPS signals, ΔC1 (blue) and ΔPC (red) Right: TDEV of the raw code differences.

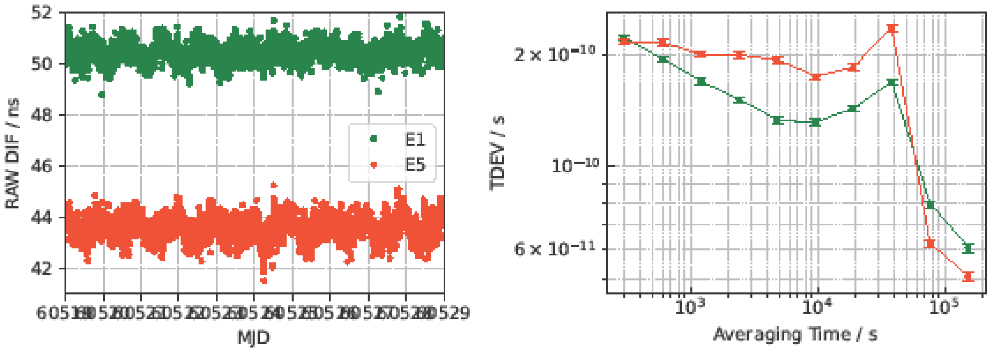

Figure B-3 Left: Left: Raw code differences between V and G for Galileo signals, ΔE1 (green) and ΔE5 (orange) Right: TDEV of the raw code differences.

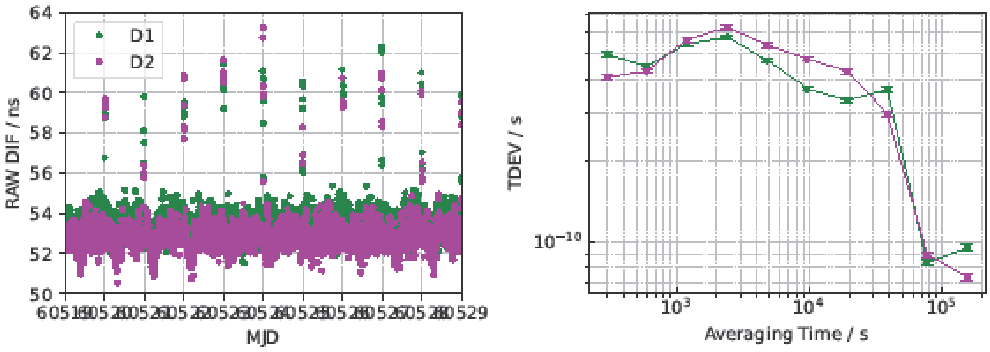

Figure B-4 Left: Left: Raw code differences between V and G for GLONASS signals, ΔD1/C1 (green) and ΔD2/C2 (purple) Right: TDEV of the raw code differences.

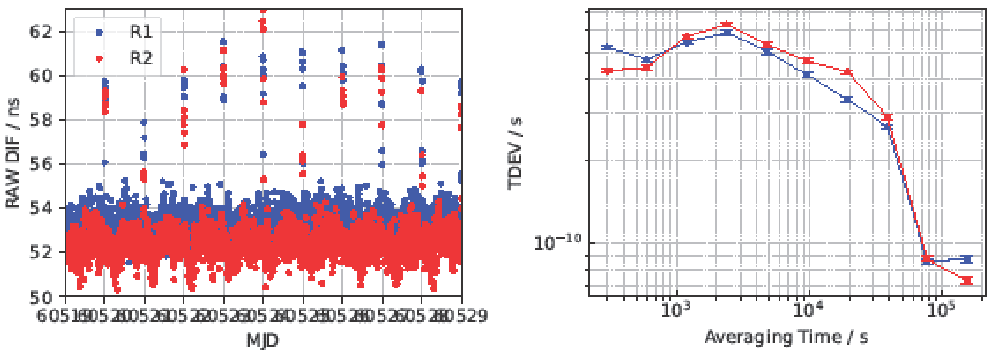

Figure B-5 Left: Left: Raw code differences between V and G for GLONASS signals, ΔR1/P1 (blue) and ΔR2/P2 (red) Right: TDEV of the raw code differences.

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