GNSS CALIBRATION REPORT

G1G2_1011_2016

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1. INTRODUCTION

1.1. SCOPE OF THE DOCUMENT

In 2014, as result of CCTF recommendation of collaboration between the BIPM and the RMOs for GNSS equipment calibration, some National Metrology Institutes (NMIs) and Designated Institutes (DIs), were selected to be G1 laboratories, to function as regional nodes for the GPS calibrations. The mission of these Labs, once calibrated by BIPM, were to perform new calibration trips between G2 laboratories, under the responsibility of RMOs.

ROA, as EURAMET G1 laboratory, organized this year, a GPS receiver relative calibration campaign, which took place between seven European NMIs or DIs: BIM (Bulgaria), UME (Turkey), BoM (Macedonia), DMDM (Serbia), IMBIH (Bosnia & Herzegovina), INRIM (Italy) and ROA (Spain).

In this campaign was carried out a differential calibration with closure, where the travelling system served as a transfer between all systems visited during the trip and the reference receiver RO_5. This last was calibrated and reported two years ago (Cal_Id=1001-2014 [RD01]), being continuously monitored since.

1.2. DOCUMENT STRUCTURE

The current campaign has been carried out in accordance with ROA calibration procedure and following as much as possible the BIPM guidelines for GNSS calibrations [RD02]. The results will be reported using Cal_Id 1011_2016, and they will provide the visited receivers' internal delays for GPS P1 and P2 code signals on the two carrier frequencies L1 and L2 (INT DLY P1/P2).

Section 1 of this document gives the introduction, the document structure and a document baseline (in terms of applicable and reference documents and used acronyms).

Section 2 reports, the participating laboratories, dates of visits, and GPS receivers involved in this calibration campaign.

Section 3 presents an overview of the travelling equipment specifically prepared for this activity.

Section 4 basically describes the calibration procedure.

Section 5 explains the data processing carried out by our own software and all the necessary tables to get the results.

Section 6 is focused in the uncertainty estimation, in all the terms taken into account for the uncertainty budget.

Section 7 shows the final results, with the new internal delays, as well as all the necessary information to get them.

The report concludes with the Annex-A for each visited receiver, and the Annex-B, which contains all the figures with the common clock differences (CCD), and their respective time instability (TDEV) plots.

1.3. DOCUMENTS

REFERENCES	
RD01	BIPM report 1001-2014 V.1.9 13.07.2016, subject: Initial Group 1 calibration trip.
RD02	BIPM guidelines for GNSS calibration, V3.2, 15/02/2016.
RD03	G. Petit, Z. Jiang, P. Moussay, J. White, E. Powers, G. Dudle, P. Uhrich, 2001, Progresses in the calibration of geodetic like GPS receivers for accurate time comparisons, Proc. 15th EFTF, pp. 164-166.
RD04	P. Defraigne and G. Petit, 2003, Time transfer to TAI using geodetic receivers, Metrologia Vol. 40, pp. 184-188.
RD05	J. Kouba, P. Heroux, 2002, Precise Point Positioning Using IGS Orbit and Clock Products, GPS Solutions, Vol. 5, No. 2, pp. 12-28.
RD06	MODEL SR620 Universal Time Interval Counter, Stanford Research Systems, Revision 2.7 (2006).

1.4. ACRONYMS AND ABBREVIATIONS

Table 1-1: List of Acronyms and Abbreviations

Acronym	Definition
BIPM	Bureau International des Poids et Mesures.
BIM	Bulgarian Institute of Metrology, Sofia, Bulgaria.
BOM	Bureau of Metrology, SkopJe, Macedonia.
CCD	Common clock differences.
CCTF	Consultative Committee for Time and Frequency.
CGGTTS	CCTF Generic GNSS Time Transfer Standard.
CCTF	Consultative Committee for Time and Frequency.
DI	Designated Institute.
DMDM	Directorate of Measures and Precious Metals, Belgrade, Serbia.
EURAMET	The European Association of National Metrology Institutes.
GNSS	Global Navigation Satellite.
GPS	Global Positioning System.
GUM	Glówny Urzad Miar, Central Office of Measures, Warsaw, Poland.
IGS	International GNSS Service.
IMBIH	Institute of Metrology of Bosnia and Herzegovina, Sarajevo, Bosnia and Herzegovina.
INRIM	Istituto Nazionale di Ricerca Metrologica, Torino, Italy.
MJD	Modified Julian Date.
NMI	National Metrology Institute.
ORB	Observatoire Royal Belgique, Brussels, Belgium.
PPP	Precise Point Positioning.
RINEX	Receiver Independent Exchange Format.
ROA	Real Instituto y Observatorio de la Armada, San Fernando, Spain.

Acronym	Definition
R2CGGTTS	RINEX to CGGTTS conversion software, provided by ORB / BIPM.
TDEV	Time Deviation. Is a measure of time stability based on the modified Allan variance.
TIC	Time Interval Counter.
UTC	Coordinated Universal Time.
UME	National Metrology Institute/TÜBITAK Ulusal Metroloji Enstitüsü.
UTC(k)	Version of UTC realized at each of the contributing NMI(k)s.
	CGGTTS specific acronyms
CAB DLY	Field present in the CGGTTS header. It is the group delay inside the antenna cable, including both end connectors.
INT DLY	Field present in the CGGTTS header. It is the code- and frequency-dependent combined electric delay of the GNSS signal inside the antenna and the receiver**.** See also [RD03].
REF DLY	Field present in the CGGTTS header. It is the time offset between the receiver internal clock (or its conventional realization by an external signal) and the local clock at the station. See also [RD03].
REFGPS	Time difference between the reference clock and GPS time, for each satellite at the mid-point of the 13 min track. Receiver delay, cable delay, tropospheric delay and (for one single code) modelled ionospheric delay corrections have been applied.
MSIO	Is the measured ionospheric delay for each satellite at the mid-point of each 13 min track.

2. PARTICIPANTS AND SCHEDULE

Participating laboratories, dates and GPS receivers involved in the calibration campaign are summarized in Table 2-1 and Table 2-2. Nevertheless, a complete information related with the receiver set-up and the signal distribution system have been provided by all Labs (see relevant Annex-A).

Table 2-1: List of participants.

Institute	Point of contact	Postal address
ROA	Héctor Esteban Tel +34 956 54 54 39 hesteban@roa.es	Plaza de las Tres Marinas s/n 11100, San Fernando Spain
BIM	Natasha Tosheva Tel +359 2 9702 795 n.tosheva@bim.government.bg	Bulgarian Institute of Metrology General Directorate "National Centre of Metrology" 52-B, G.M. Dimitrov Blvd. 1040 Sofia, Bulgaria
UME	Mesut Yogun Tel 0090(262) 679 50 00 mesut.yogun@tubitak.gov.tr	TUBITAK UME TUBITAK Gebze Yerleskesi P.K. 54 41470 Gebze/KOCAELI Turkey
BoM	Armin Mirto Tel ++389 2 240 3676 armin.mirto@bom.gov.mk	Bureau of Metrology Bul. Jane Sandanski No. 109A 1000 Skopje R. Makedonija
DMDM	Snezana Renovica Tel +381-11-20 24 407 renovica@dmdm.rs	Directorate of Measures and Precious Metals Mike Alasa 14, 11000 Belgrade, Serbia
IMBIH	Osman Sibonjic Tel: ++ 387 33 568 923 osman.sibonjic@met.gov.ba	Institute of Metrology of Bosnia and Herzegovina Augusta Brauna 2 71 000 Sarajevo Bosnia and Herzegovina
INRIM	Giancarlo Cerretto Tel: +39 011 3919 239/236 g.cerretto@inrim.it	Istituto Nazionale di Ricerca Metrologica Time and Frequency Laboratory Strada delle Cacce 91, 10135 Torino, Italy

Table 2-2: Schedule of the campaign and involved receivers.

Institute	Status of equipment	Dates of measurements	Receiver type	BIPM code	RINEX name
ROA	Traveling		Septentrio PolaRx2	TR01	
			DICOM GTR50	TR02	
ROA	Group 1 reference	MJD: 57431-57436 13/02/16-18/02/16	DICOM GTR50	RO_5	RO_5
BIM	Group 2	MJD: 57448-57452 01/03/16-05/03/16	PikTime TTS-3	BM37	BGB
UME	Group 2	MJD: 57501-57505 23/04/16-27/04/16	PikTime TTS-4	UM01	UME4
BoM	Group 2	MJD: 57518-57523 10/05/16-15/05/16	PikTime TTS-4	MA__	TTS
DMDM	Group 2	MJD: 57529-57533 21/05/16-25/05/16	DICOM GTR50	ZM68	DMDM
IMBIH	Group 2	MJD: 57554-57558 15/06/16-19/06/16	PikTime TTS-4	BH01	BH01
INRIM	Group 2	MJD: 57594-57602 25/07/16-02/08/16	DICOM GTR50	IT__	GTRB
INRIM	Group 2	MJD: 57594-57602 25/07/16-02/08/16	DICOM GTR50	IT2_	GTRI
INRIM	Group 2	MJD: 57594-57602 25/07/16-02/08/16	ASHTECH Z-XII3T	IT1Z	IENG
INRIM	Group 2	MJD: 57594-57602 25/07/16-02/08/16	Septentrio PolaRx4TR	IT5_	INR5
INRIM	Group 2	MJD: 57594-57597 25/07/16-28/07/16	Septentrio PolaRx4TR	IT6_	INR6
ROA	Group 1 reference	MJD: 57615-57619 15/08/16-19/08/16	DICOM GTR50	RO_5	RO_5

3. THE ROA TRAVELING EQUIPMENT

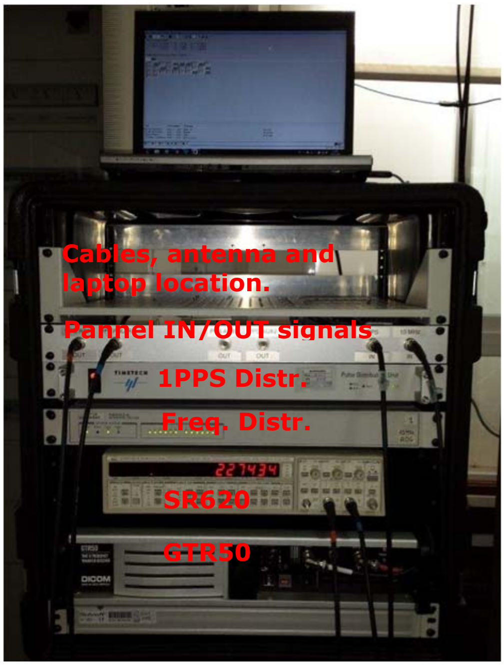
Traveling equipment consists of one shipping box containing the following items:

- 1 Septentrio PolaRx2 receiver SN: 1225
- 1 GTR50 receiver SN: 0802017
- 1 Time Interval Counter (TIC) Stanford SR620 SN: 4060
- 1 Portable PC Toshiba Tecra M9 laptop SN: X7052920H
- 1 Timetech Pulse Distribution Unit (1 Input - 16 Outputs, BNC) SN:0110
- 1 Symmetricom Distribution Amplifier 58502A (1 Input - 12 Outputs, BNC) SN: KR93200171
- 1 Novatel antenna GPS-703-GGG SN: NEG15300017
- 1 GPS Networking GPS Active Antenna Splitter 1X8
- 60 m antenna cable
- 2 BNC cables (1.9 m)
- 1 Ethernet cable
- 1 Frequency attenuator (3 dB)
- 1 Female-female BNC connector
- 1 Screw 20 cm long

As it is shown in the equipment list, two different receivers were used as traveling equipment, in order to detect any anomaly behavior during the calibration campaign in any of the two receivers. We used two short cables and an active antenna splitter to connect both to the same antenna cable and Novatel antenna.

A Time Interval Counter (TIC) was also part of the traveling equipment, aiming at minimizing the systematic uncertainty for cable delay measurements on each site. We also added a PPS distribution amplifier and a frequency distribution amplifier, both with constant output levels independently of the source input level. In this way, we could reproduce the same operating conditions in all laboratories, and we could solve, among others, the problem of providing an erroneous input frequency level to the PolaRx2.

Figure 3-1: Front and rear view of the travelling equipment.



4. CALIBRATION PROCEDURE

Initially we started the calibration based on P3 CGGTTS files. But instead of using the files automatically generated by each particular receiver, we thought that it would be better to generate them from RINEX V.2.1 observation files and the satellite ephemeris BRDC files provided by IGS, according to the TAIP3 processing [RD04] developed by Pascale Defraigne (Royal Observatory of Belgium). This was done to avoid any systematic error induced by the use of a different tropospheric model, and mainly by imprecise antenna positions.

On this latter point, the coordinates of the antenna phase centre at each location have been especially computed for the calibration period from RINEX files by using the NRCan PPP (V 1.05 34613) software [RD05], so the time transfer error caused by this factor is nearly negligible.

Basically the calibration consists on the following. From the known delays of the reference receiver (RO_5) and an average of the traveling receiver delays between the start and the end of the campaign, we can obtain INTDLY(P1) and INTDLY(P2) for the receivers in the visited Labs. As the calibration is consisting in building differential pseudo-ranges for each code P1 and P2 between pairs of receivers in common-clock set-up, they can be easily obtained by using the data collected in P3 CGGTTS files:

$$\gamma = (f_1/f_2)^2 = (77/60)^2$$

$$REFGPS(P1) = REFSYS(P3) + MSIO$$

$$REFGPS(P2) = REFGPS(P3) + \gamma \times MSIO = REFGPS(P3) + 1.647 \times MSIO$$

where *MSIO* are the measured ionospheric delays.

Nevertheless, and due to the interruptions in the TR01 receiver data dumping at the end of calibration, which caused a very low number of CGGTTS observations, we changed the way of processing, to be based in all the observations provided in the RINEX files, that is, using all the GPS satellites in view, at 30 seconds time intervals. Consequently, we have reprocessed all Labs again, and the results discussed further on have been obtained by this new way.

At each laboratory, the traveling equipment implementation and the delay measurements were carried out by local staff according to the calibration procedure prepared by ROA, and this work is acknowledged with appreciation.

5. DATA PROCESSING

For the calculation process we have used a ROA-authored program, in which the common clock differences (CCD) are obtained every 30 seconds for all the satellites in view, by simple differences of pseudo-ranges only corrected for the geometric effect of receivers' and satellites' positions, and the total delay (TOTDLY = INTDLY+CABDLY-REFDLY). For each location, the coordinates of the antenna have been carefully calculated for the calibration period from RINEX V.2.1 files.

As was stated before, from the known delays of the reference receiver RO_5, it has been obtained the internal delays for the receivers at the visited sites. Normally the antenna cable delay (CABDLY) is maintained without any change, and the reference delay (REFDLY) is normally updated, anyway, any variation with respect to the true values, will be assumed by the INTDLY results.

Table 5-1 summarizes the initial delays of receivers at start of calibration. With these values, new files have been generated from RINEX files according to first paragraph. For DICOM receivers all values are null, since RINEX files are already corrected by the total delay, so the raw CCD of Table 5-2 are corrections with respect to the internal initial values.

Table 5-1: Initial delays (in ns) of receivers at start of calibration.

BIPM Acronym	System	INT DLY P1	INT DLY P2	REF DLY	CAB DLY	TOT DLY P3
BIM	BIM	-28.1	-28.1	8.3	147.1	110.7
UME	UM01	0	0	7	139.9	132.9
BOM	MA_5	0	0	3.5	203	199.5
DMDM	ZM68	0	0	0	0	0
IMBH	BH01	0	0	11.1	146.0	134.9
INRIM	GTRB	0	0	0	0	0
	GTRI	0	0	0	0	0
	IENG	305.6	315.6	385.9	136.6	40.9
	INR5	0	0	523.4	0	-523.4
	INR6	0	0	539.6	0	-539.6

Table 5-2: Raw common clock differences, all values in ns.

Pair	RAW ΔP1	TDEV (1 day)	RAW ΔP2	TDEV (1 day)	RAW ΔP3	TDEV (1 day)	P1-P2
TR01-BIM	-13.04	0.07	-26.16	0.04	7.23	0.16	13.12
TR02-BIM	-12.64	0.08	-25.91	0.04	7.86	0.17	13.27
mean	-12.84		-26.04		7.55		13.20
TR01-TR02	**-0.40**		**-0.25**		**-0.63**		**-0.15**
TR01-UME	31.58	0.05	32.31	0.02	30.45	0.12	-0.73
TR02-UME	31.82	0.05	32.34	0.02	31.02	0.12	-0.52
mean	31.70		32.33		30.73		-0.63
TR01-TR02	**-0.24**		**-0.03**		**-0.56**		**-0.21**
TR02-BOM	38.71	0.05	42.60	0.02	32.70	0.11	-3.89
mean	38.71		42.60		32.70		-3.89
TR01-DMDM	-0.34	0.07	-0.59	0.04	0.05	0.13	0.25
TR02-DMDM	-0.15	0.08	-0.51	0.04	0.41	0.20	0.36
mean	-0.25		-0.55		0.21		0.30
TR01-TR02	**-0.19**		**-0.08**		**-0.36**		**-0.11**
TR01-IMBH	21.69	0.09	25.75	0.06	15.42	0.25	-4.06
TR02-IMBH	21.64	0.08	25.55	0.03	15.59	0.19	-3.91
mean	-64.04		-60.05		-70.20		-3.99
TR01-TR02	**0.05**		**0.19**		**-0.18**		**-0.14**
TR01-GTRB	1.52	0.06	1.01	0.03	2.31	0.19	0.51
TR01-GTRI	1.28	0.05	1.35	0.03	1.17	0.17	-0.07
TR01- IENG	-3.30	0.06	-3.49	0.06	-3.01	0.19	0.19
TR01-INR5	-220.51	0.05	-222.52	0.06	-217.40	0.20	2.01
TR01-INR6	-229.38	0.08	-229.37	0.09	-229.40	0.25	-0.01

During the calibration at BOM, there was only one 10 MHz frequency source available, and it was being used by the local receiver, so the calibration was only performed by GTR50 receiver (TR02).

When the traveling box arrived to the last laboratory, at INRIM, the effect of the long trip was evident in the protective case as well as in one connector of the antenna cable. Besides, one internal connector of the power supply of TR02 receiver was loose, leaving it unusable.

Fortunately, it was fixed at its return to ROA. So there was only one receiver at INRIM (TR01), but the behavior was not entirely satisfactory, because it lost several observations, and after one or two days the receiver got stuck. This anomalous behavior persists at this moment at ROA, and after several modifications and changes of antenna, antenna cable, connector, etc., it seems to be related with the receiver itself.

Table 5-3: Closure measurements at ROA, all values in ns.

Pair	RAW ΔP1	TDEV (1 day)	RAW ΔP2	TDEV (1 day)	RAW ΔP3	TDEV (1 day)	P1-P2
TR01-RO_5 (before the trip)	-0.10	0.08	-0.34	0.07	0.27	0.13	0.24
TR01-RO_5 (after the trip)	**-0.20**	0.07	**-1.13**	0.06	1.24	0.12	0.93
misclosure	0.10		0.79		-0.97		-0.69
mean	-0.15		-0.74		0.76		-0.59
TR02-RO_5 (before the trip)	-0.10	0.04	-0.23	0.03	0.10	0.12	0.13
TR02-RO_5 (after the trip)	-0.21	0.03	-0.65	0.02	0.47	0.09	0.44
misclosure	0.11		0.42		-0.37		-0.31
mean	**-0.16**		**-0.44**		0.27		-0.28
TR01-TR02 (before the trip)	0.00	0.07	0.11	0.06	-0.17	0.12	-0.11
TR01-TR02 (after the trip)	0.01	0.03	-0.48	0.02	0.77	0.08	0.49
misclosure	0.01		-0.59		0.94		-0.58

Taking a close loop to the closure measurements, we can observe a normal behavior of TR02 receiver, where the P1-P2 difference has remained relatively constant (0.3 ns), but not in the TR01 receiver, with a P1-P2 variation of around 0.7 ns, that can be correlated with its final anomalous behavior. So we have decided to use the TR02 receiver alone, for all Labs except for INRIM, where TR01 was the only receiver available. We also consider appropriate for TR01 receiver, to use the closure measurements after the trip, when the problem became apparent.

6. UNCERTAINTY ESTIMATION

The overall uncertainty of the INT DLY values obtained as a result of the calibration is given by:

$$u_{CAL} = \sqrt{u_a^2 + u_b^2}\ , \tag{1}$$

with the statistical uncertainty u_a and the systematic uncertainty u_b. The statistical uncertainty is related to the instability of the common clock data collected at each site and collected at ROA when the INT DLY of travelling equipment was determined. The systematic uncertainty is given by:

$$u_b = \sqrt{\sum_n u_{b,n}^2} \tag{2}$$

The contributions to the sum (2) are listed and explained subsequently. In the Table 6-1, we have considered the larger type A uncertainty found at remotes sites, which is quite small, so there is no need to develop it in detail for each Lab. Note that the uncertainty of the INT DLY values of ROA's fixed receiver RO_5, which served as the reference, is not included.

Table 6-1: Uncertainty contributions for the calibration of receiver delays

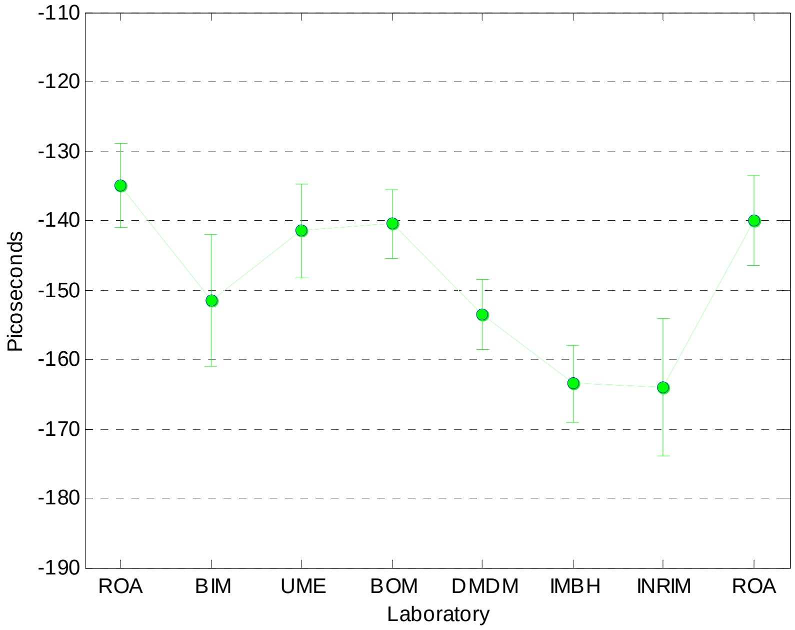
	Uncertainty	Value P1 (ns)	Value P2 (ns)	Value P3 (ns)	Description
1	$u_{a(ROA)}$	0.10	0.10	0.15	CCD uncertainty at ROA, TDEV at τ = 1 day
2	$u_{a(Lab(k))}$	0.10	0.10	0.25	CCD uncertainty at remote Lab, TDEV at τ = 1 day
Result of closure measurement at ROA					
3	$u_{b,1}$	0.10	0.79	0.97	TR01 Misclosure, see Table 5-3.
4	$u_{b,2}$	0.11	0.42	0.37	TR02 Misclosure, see Table 5-3.
Systematic components due to antenna installation					
5	$u_{b,11}$	0.05	0.05	0.10	Position error at ROA
6	$u_{b,12}$	0.05	0.05	0.10	Position error at remote Lab
7	$u_{b,13}$	0.10	0.10	0.30	Multipath at ROA
8	$u_{b,14}$	0.10	0.10	0.30	Multipath at remote Lab
Installation of TR01/02 and visited receivers					
9	$u_{b,21}$	0.20	0.20	0.20	Connection of TR01/02 to UTC(ROA) (REF DLY)
10	$u_{b,22}$	0.20	0.20	0.20	Connection of TR01/02 to UTC(k) (REF DLY)
11	$u_{b,23}$	0.20	0.20	0.20	Connection of receivers at site k to UTC(k) (REF DLY)
12	$u_{b,24}$	0.10	0.10	0.10	TIC nonlinearities at ROA
13	$u_{b,25}$	0.10	0.10	0.10	TIC nonlinearities at remote sites

For each location, the coordinates of the antenna phase centres are especially computed for the calibration period from RINEX files by using the NRCan PPP software. The geometric correction between pairs of antenna phase centres is therefore well determined, and any bias during this calculation affects in the same way to both antennas, so the time transfer error associated to this factor is quite small.

The contribution of TR01 receiver is significantly higher than in TR02, mainly due to the large closure measurements showed by TR01, that can be associated with its final anomalous behavior.

In order to check the stability of SR620 time interval counter, two specific outputs of the travelling PPS distribution unit were measured at each Lab, with the same couple of twin cables. The results are plotted in Figure 6-1, showing a very good performance of TIC during all the campaign, in accordance with the technical specifications [RD06].

Figure 6-1: Control measure of SR620 at each Laboratory.



7. FINAL RESULTS

The results of the calibration campaign G1G2_1011_2016 are summarized in Table 7-1. It contains the designation of visited Lab except at INRIM that is identified by the receiver denomination. INTDLY P1 new (for INR5 and INR6 are SYSDLY) values have been calculated from (the same for P2):

INTDLY P1 new = INTDLY P1 old - ΔP1(T,V) + ΔP1(T,R) + REF DLY new - REF DLY old

Table 7-1. Results of the Calibration Campaign G1G2_1011_2016, all values in ns.

Receiver (V)	INTDLY P1 old	INTDLY P2 old	ΔP1 (T,V)	ΔP2 (T,V)	ΔP1 (T,R)	ΔP2 (T,R)	REFDLY Old	REFDLY New	CABDLY	INTDLY P1 new	u_{cal} P1	INTDLY P2 new	u_{cal} P2	u_{cal} P3	Rec. (T)
BIM	-28.1	-28.1	-12.64	-25.91	-0.16	-0.44	8.3	8.2	147.1	-15.7	0.5	-2.7	0.6	0.8	TR02
UME	0	0	31.82	32.34	-0.16	-0.44	7.0	6.0	139.9	-33.0	0.5	-33.8	0.6	0.8	TR02
BOM	0	0	38.71	42.6	-0.16	-0.44	3.5	11.3	203	-31.1	0.5	-35.2	0.6	0.8	TR02
DMDM	0	0	-0.15	-0.51	-0.16	-0.44	39.7	40.1	212.5	0.4	0.5	0.5	0.6	0.8	TR02
IMBH*	0	0	21.64	25.55	-0.16	-0.44	11.1	11.1	146.0	-21.8	0.5	-26.0	0.6	0.8	TR02
GTRB	0	0	1.52	1.01	-0.2	-1.13	22.3	22.8	131	-1.2	0.5	-1.6	0.9	1.2	TR01
GTRI	0	0	1.28	1.35	-0.2	-1.13	19.3	19.4	210.9	-1.4	0.5	-2.4	0.9	1.2	TR01
IENG	305.6	315.6	-3.3	-3.49	-0.2	-1.13	385.9	384.3	136.6	307.1	0.5	316.4	0.9	1.2	TR01
INR5	0	0	-220.51	-222.52	-0.2	-1.13	523.4	523.2	0	220.1	0.5	221.2	0.9	1.2	TR01
INR6	0	0	-229.38	-229.37	-0.2	-1.13	539.6	539.8	0	229.4	0.5	228.4	0.9	1.2	TR01

T=Travelling receiver V=Visited receiver R=Reference receiver (RO_5) INTDLY P3=2.545 x INTDLY P1–1.545 x INTDLY P2

* Set-up change after the calibration campaign.

8. ANNEX-A

8.1. CALIBRATION INFORMATION SHEET AT ROA

Laboratory:	ROA
Date and hour of the beginning of measurements:	13.02.2016
Date and hour of the end of measurements:	18.02.2016

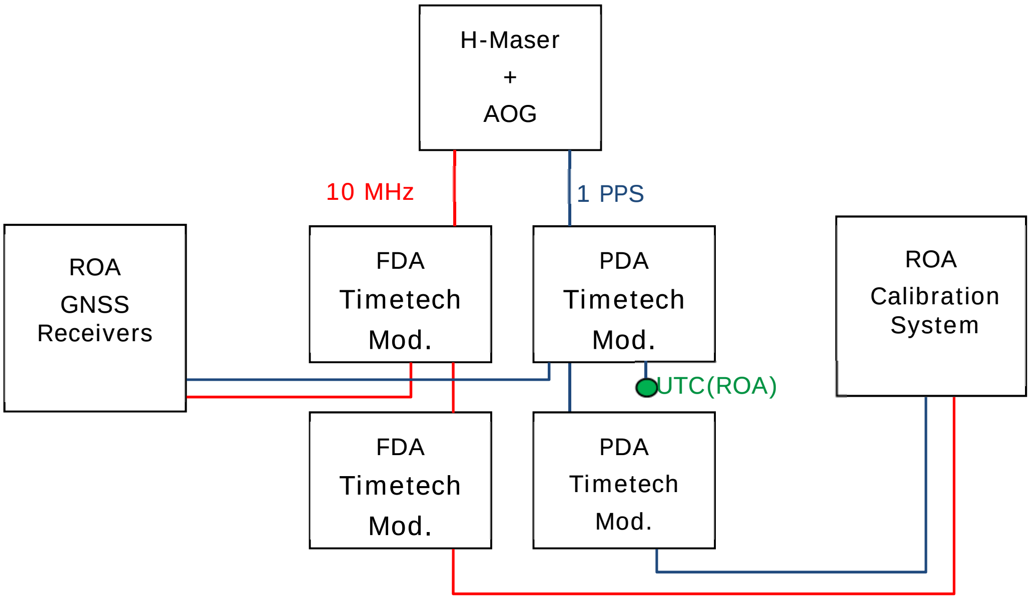
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	RO_5	
• Receiver maker and type: Receiver serial number:	DICOM GTR50 0601012	Septentrio PolaRx2 SN: 1225 DICOM GTR50 SN: 0802017
1 PPS trigger level /V:	1 V	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	LMR-400	
Length outside the building /m:	Approximately 8 m	Approximately 16 m
• Antenna maker and type: Antenna serial number:	LEICA AR25 Choke Ring 725232	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilised) /°C	N	

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	(36.5 ± 0.3) ns	(135.71 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		(236.4 ± 0.3) ns
• Antenna cable delay:	127.5 ns	241.6 ns
Splitter delay (if any):		Y
Additional cable delay (if any):		12.4 ns

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	18.6 ns (GPS P1), 32.6 ns (GPS P2)
• INT DLY (GLONASS) /ns:	N/A
• CAB DLY /ns:	127.50 ns
• REF DLY /ns:	36.50 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	5105510.60 m
Longitude or Y /m:	-555200.98 m
Height or Z /m:	3769791.03 m

General information	
• Rise time of the local UTC pulse:	< 3 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 2) °C
Set humidity value and uncertainty:	< 70 %

Diagram of the experiment set-up:



8.2. CALIBRATION INFORMATION SHEET AT BIM

Laboratory:	BIM
Date and hour of the beginning of measurements:	01.03.2016
Date and hour of the end of measurements:	05.03.2016

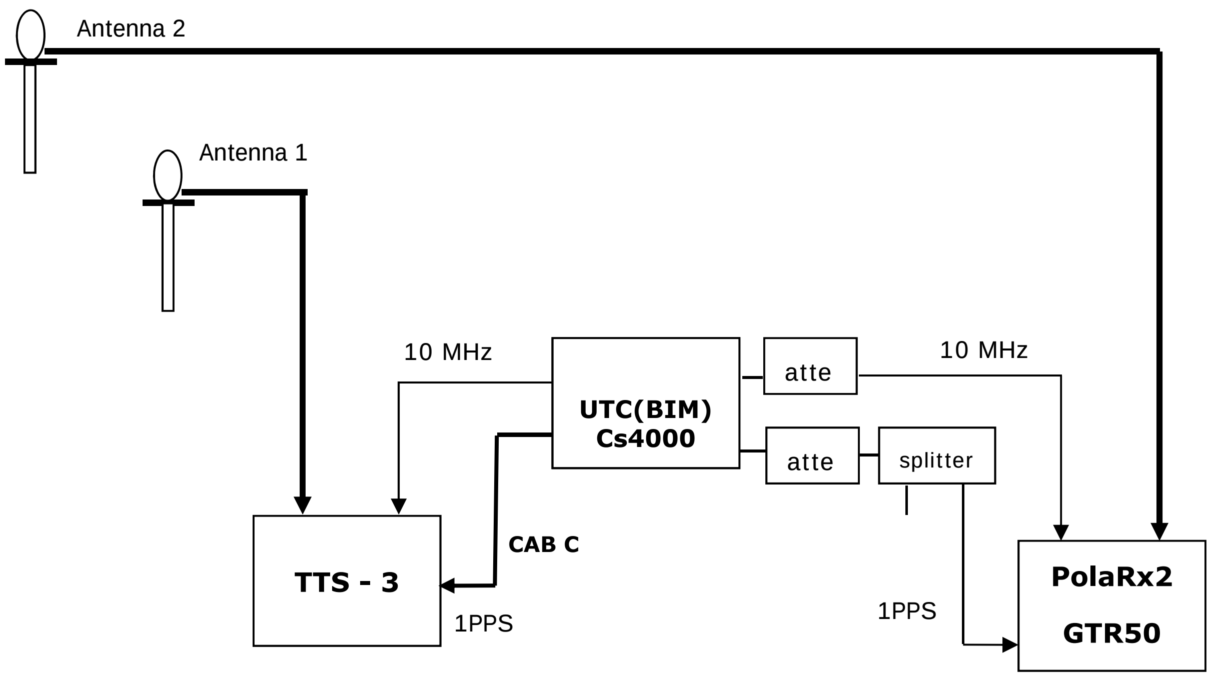
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	BIM	
• Receiver maker and type: Receiver serial number:	PikTime Systems – Poland, TTS3 037	Septentrio PolaRx2 SN: 1225 DICOM GTR50 SN: 0802017
1 PPS trigger level /V:		
• Antenna cable maker and type: Phase stabilised cable (Y/N):		
Length outside the building /m:	Approximately 17 m	Approximately 16 m
• Antenna maker and type: Antenna serial number:	Javad, MarAnt+ MA #4258	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C		

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	(8.2 ± 0.3) ns	(19.29 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		(227.2 ± 0.3) ns
• Antenna cable delay:		241.6 ns
Splitter delay (if any):		Y
Additional cable delay (if any):		12.4 ns

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	-28.10 ns
• INT DLY (GLONASS) /ns:	-117.76 ns
• CAB DLY /ns:	147.10 ns
• REF DLY /ns:	8.3 ns
• Coordinates reference frame:	
Latitude or X /m:	4312767.56 m
Longitude or Y /m:	1862532.98 m
Height or Z /m:	4300603.57 m

General information	
• Rise time of the local UTC pulse:	< 5 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 2) °C
Set humidity value and uncertainty:	(40 ± 10) %

Diagram of the experiment set-up:



8.3. CALIBRATION INFORMATION SHEET AT UME

Laboratory:	UME
Date and hour of the beginning of measurements:	23.04.2016
Date and hour of the end of measurements:	27.04.2016

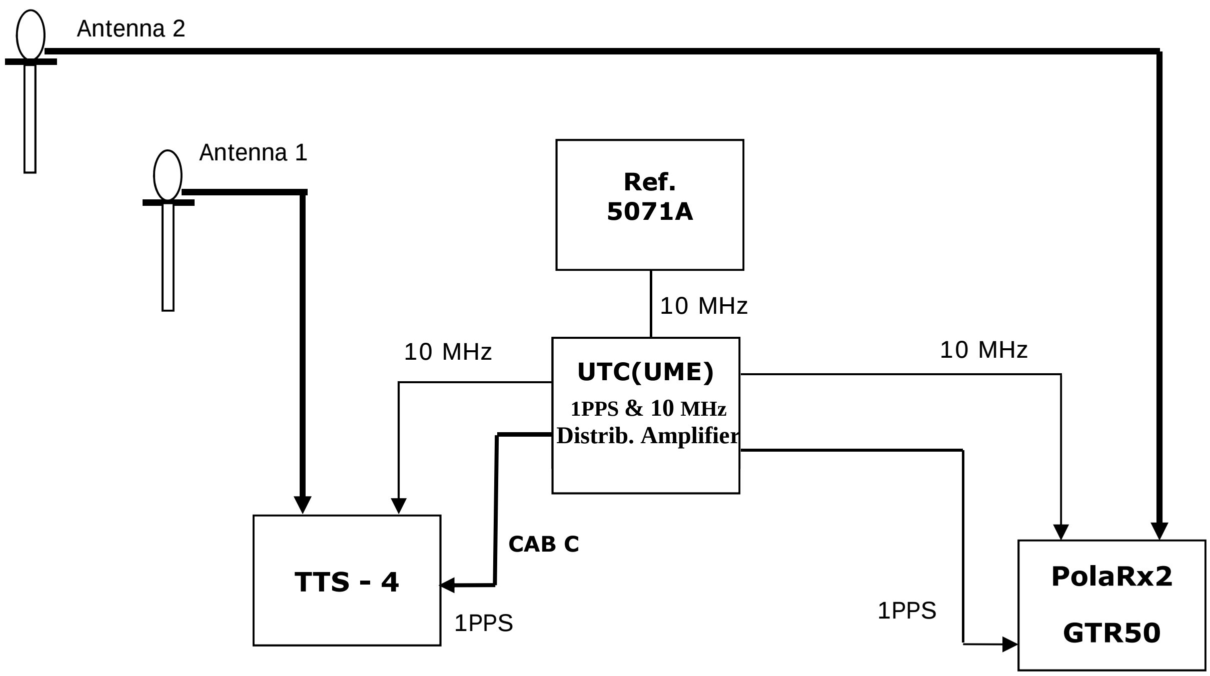
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	UME	
• Receiver maker and type: Receiver serial number:	PikTime Systems – Poland, TTS4 137	Septentrio PolaRx2 SN: 1225 DICOM GTR50 SN: 0802017
1 PPS trigger level /V:		
• Antenna cable maker and type: Phase stabilised cable (Y/N):	FSJ1-50A - 1/4" Andrew Heliax Superflex Coax Cable N	
Length outside the building /m:	Approximately 10 m	Approximately16 m
• Antenna maker and type: Antenna serial number:	Javad, Choke Ring JAV_GRANT-G3T UME	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C		

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	(7.8 ± 0.3) ns	(19.90 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	-1.8 ns	(229.9 ± 0.3) ns
• Antenna cable delay:	139.9 ns	241.6 ns
Splitter delay (if any):		Y
Additional cable delay (if any):		12.4 ns

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	GPS: L1C: -31.31 L2C: 0.00 L1P: 0.00 L2P: 0.00 L5P: 0.00,
• INT DLY (GLONASS) /ns:	GLO: L1C: -232.71 L2C: 0.00 L1P: 0.00 L2P: 0.00
• CAB DLY /ns:	139.91 ns
• REF DLY /ns:	7.0 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	4211630.83 m
Longitude or Y /m:	2377681.42 m
Height or Z /m:	4144465.42 m

General information	
• Rise time of the local UTC pulse:	< 5 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 2) °C
Set humidity value and uncertainty:	(40 ± 10) %

Diagram of the experiment set-up:



8.4. CALIBRATION INFORMATION SHEET AT BOM

Laboratory:	BOM
Date and hour of the beginning of measurements:	10.05.2016
Date and hour of the end of measurements:	15.05.2016

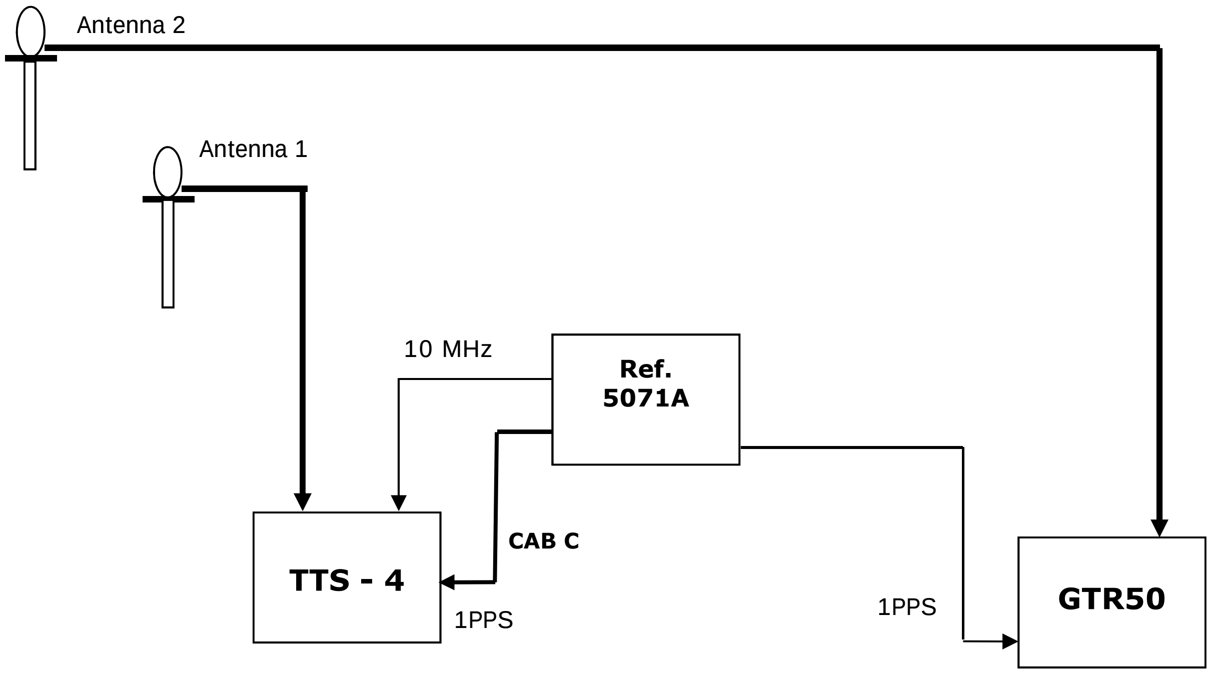
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	BOM	
• Receiver maker and type: Receiver serial number:	PikTime Poland, TTS4 147	DICOM GRT50 SN: 0802017
1 PPS trigger level /V:		
• Antenna cable maker and type: Phase stabilised cable (Y/N):	FSJ1-50A - 1/4" Andrew Heliax Superflex Coax Cable Yes	
Length outside the building /m:	Approximately 60m	Approximately 20 m
• Antenna maker and type: Antenna serial number:	Javad Choke Ring JAV_GRANT-G3T	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C		

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	(8.1 ± 0.3) ns	(18.71 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	3.17 ns	
• Antenna cable delay:	(203 ± 1) ns	241.6 ns
Splitter delay (if any):		
Additional cable delay (if any):		

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	(-23 ± 10) ns
• INT DLY (GLONASS) /ns:	
• CAB DLY /ns:	(203 ± 1) ns
• REF DLY /ns:	8.0 ns
• Coordinates reference frame:	
Latitude or X /m:	+4418914.09 m
Longitude or Y /m:	+1737814.92 m
Height or Z /m:	+4244558.94 m

General information	
• Rise time of the local UTC pulse:	< 5 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 2) °C
Set humidity value and uncertainty:	(40 ± 10) %

Diagram of the experiment set-up:



8.5. CALIBRATION INFORMATION SHEET AT DMDM

Laboratory:	DMDM
Date and hour of the beginning of measurements:	21.05.2016
Date and hour of the end of measurements:	25.05.2016

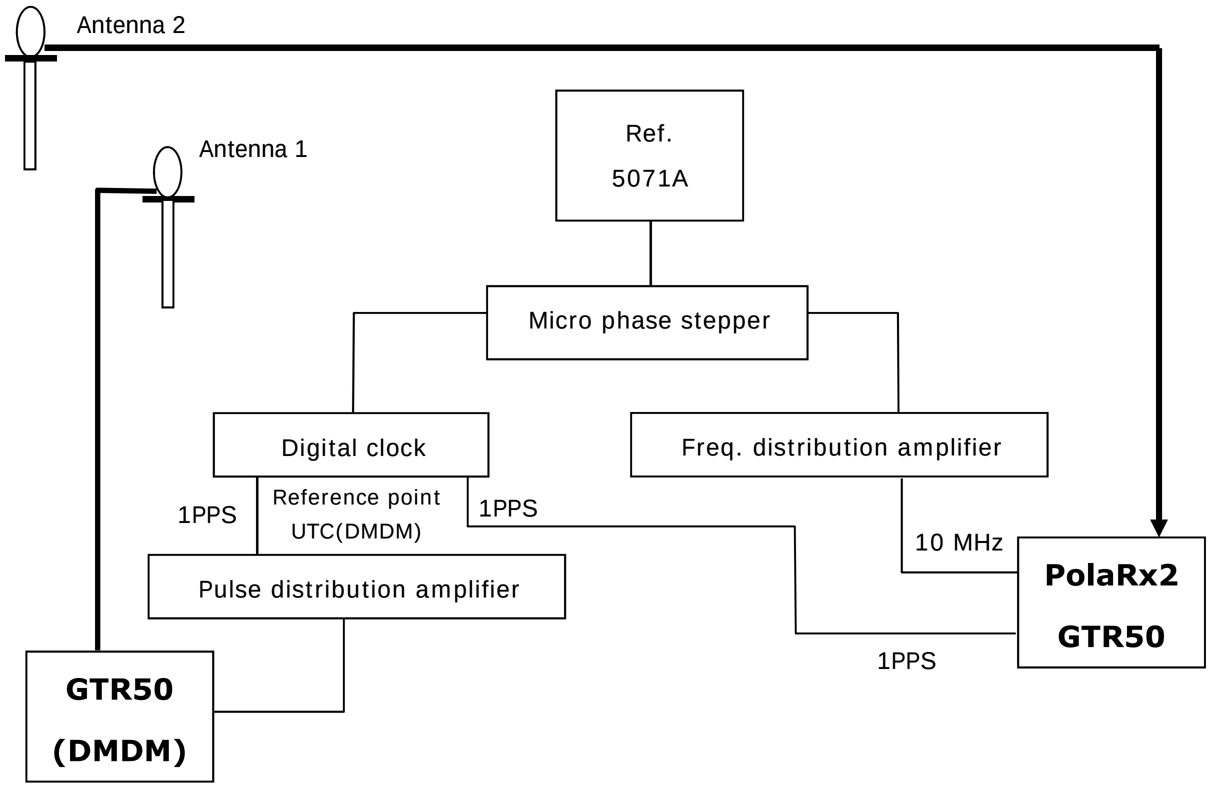
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	DMDM	
• Receiver maker and type: Receiver serial number:	Dicom, GTR50 0905068	DICOM GRT50 SN:0802017 Septentrio PolaRx2 SN: 1225
1 PPS trigger level /V:		
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Andrew Heliax LDF1-50 Y	
Length outside the building /m:	Approximately 25 m	Approximately 25 m
• Antenna maker and type: Antenna serial number:	Novatel antenna GPS-702-GG NAE15430012	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C		

Measured delays /ns		
	Local:	**Traveling:**
• Delay from local UTC to receiver 1 PPS-in:	(40.1 ± 0.3) ns	(19.29 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		(232.3 ± 0.3) ns
• Antenna cable delay:		241.6 ns
Splitter delay (if any):		Y
Additional cable delay (if any):		12.4 ns

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	-35.0 ns (GPS P1), -22.0 ns (GPS P2)
• INT DLY (GLONASS) /ns:	N/A
• CAB DLY /ns:	212.5 ns
• REF DLY /ns:	39.7 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	4245406.08 m
Longitude or Y /m:	1583793.16 m
Height or Z /m:	4473890.87 m

General information	
• Rise time of the local UTC pulse:	< 4 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 0.5) °C
Set humidity value and uncertainty:	(50 ± 10) %

Diagram of the experiment set-up:



8.6. CALIBRATION INFORMATION SHEET AT IMBH

Laboratory:	IMBH
Date and hour of the beginning of measurements:	15.06.2016
Date and hour of the end of measurements:	19.06.2016

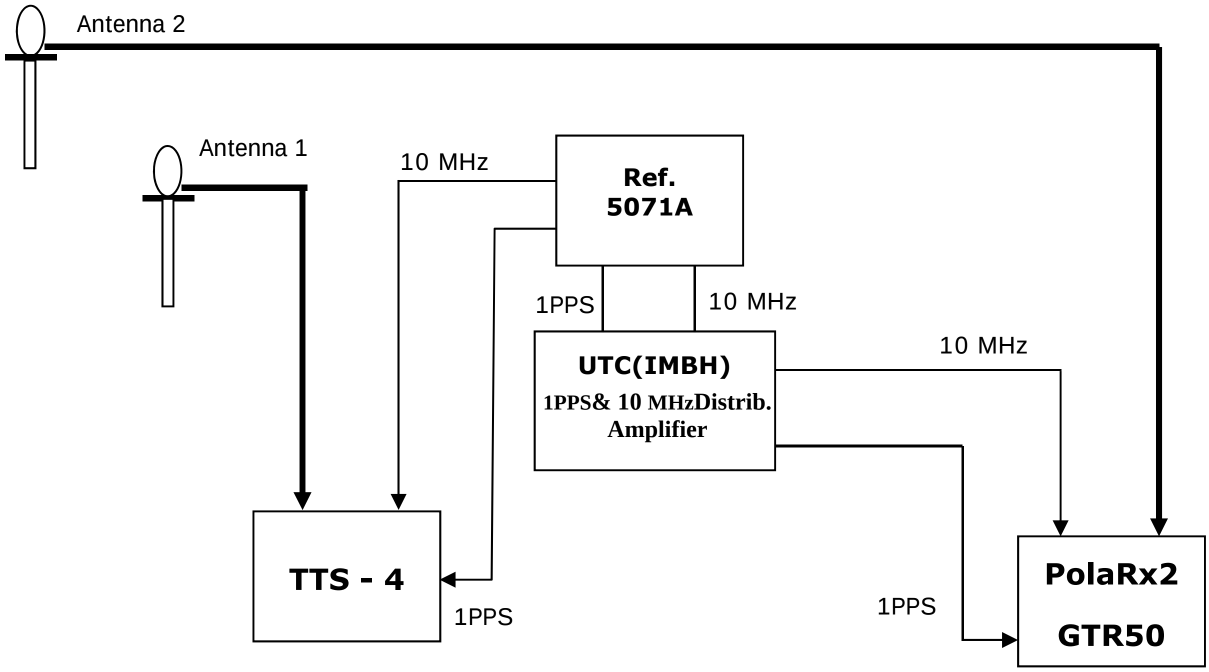
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	IMBH	
• Receiver maker and type: Receiver serial number:	PikTime Systems – Poland, TTS4 142	DICOM GRT50 SN:0802017 Septentrio PolaRx2 SN:1225
1 PPS trigger level /V:		
• Antenna cable maker and type: Phase stabilised cable (Y/N):	FSJ1-50A - 1/4" Andrew HeliaxSuperflex Coax Cable N	
Length outside the building /m:	Approximately 25 m	Approximately 30 m
• Antenna maker and type: Antenna serial number:	Javad, RingAnt-G3T Antenna 00455	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C		

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	(13.7 ± 0.3) ns	(22.68 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	-	(240.0 ± 0.3) ns
• Antenna cable delay:	(144.76 ± 0.50) ns	241.6 ns
Splitter delay (if any):	(368.55 ± 5.00) ps	Y
Additional cable delay (if any):	Attenuator: (856 ± 6) ps	12.4 ns

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	GPS: L1C: -35.65 L2C: 0.00 L1P: 0.00 L2P: 0.00 L5P: 0.00,
• INT DLY (GLONASS) /ns:	GLO: L1C: -244.21 L2C: 0.00 L1P: 0.00 L2P: 0.00
• CAB DLY /ns:	60.33 ns
• REF DLY /ns:	11.08 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	+ 4371185.16 m
Longitude or Y /m:	+ 1454854.92 m
Height or Z /m:	+ 4397063.08 m

General information	
• Rise time of the local UTC pulse:	3.27 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 1) °C
Set humidity value and uncertainty:	(45 ± 10) %

Diagram of the experiment set-up:



8.7. CALIBRATION INFORMATION SHEET AT INRIM

Laboratory:	INRIM
Date and hour of the beginning of measurements:	25.07.2016
Date and hour of the end of measurements:	02.08.2016

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	GTRB	
• Receiver maker and type: Receiver serial number:	DICOM GTR50 1012124	Septentrio PolaRx2 SN:1225
1 PPS trigger level /V:	1 V	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Belden Venlo Holland 2010 50 Ohm low loss H155 PVC N	
Length outside the building /m:	Approximately 10 m	Approximately 25 m
• Antenna maker and type: Antenna serial number:	Novatel NOV702 00455	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C	N/A	

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	22.8 ns	(100.03 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	N/A	(238.2 ± 0.3) ns
• Antenna cable delay:	131 ns	241.6 ns
Splitter delay (if any):	N/A	Y
Additional cable delay (if any):	N/A	12.4 ns

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	-34.5 ns (GPS P1), -21.1 ns (GPS P2)
• INT DLY (GLONASS) /ns:	N/A
• CAB DLY /ns:	131
• REF DLY /ns:	22.30
• Coordinates reference frame:	WGS84 / IGS2000
Latitude or X /m:	45.01497572
Longitude or Y /m:	7.63908853
Height or Z /m:	305.464

General information	
• Rise time of the local UTC pulse:	12.26 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 2) °C
Set humidity value and uncertainty:	(45 ± 5) %

Laboratory:	INRIM
Date and hour of the beginning of measurements:	25.07.2016
Date and hour of the end of measurements:	02.08.2016

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	GTRI	
• Receiver maker and type: Receiver serial number:	DICOM GTR50 0807184	Septentrio PolaRx2 SN:1225
1 PPS trigger level /V:	1 V	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Belden 9273 M17 167-00001 N	
Length outside the building /m:	Approximately 10 m	Approximately 25 m
• Antenna maker and type: Antenna serial number:	Novatel NOV702	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C	N/A	

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	19.4 ns	(100.03 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	N/A	(238.2 ± 0.3) ns
• Antenna cable delay:	210.9 ns	241.6 ns
Splitter delay (if any):	N/A	Y
Additional cable delay (if any):	N/A	12.4 ns

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	-143.5 ns (GPS P1),
• INT DLY (GLONASS) /ns:	-131.5 ns (GPS P2)
• CAB DLY /ns:	N/A
• REF DLY /ns:	210.90
• Coordinates reference frame:	19.30
Latitude or X /m:	WGS84 / IGS2000
Longitude or Y /m:	45.01497092
Height or Z /m:	7.63911372

General information	
• Rise time of the local UTC pulse:	12.26 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 2) °C
Set humidity value and uncertainty:	(45 ± 5) %

Laboratory:	INRIM
Date and hour of the beginning of measurements:	25.07.2016
Date and hour of the end of measurements:	02.08.2016

Information on the system		
	Local:	**Travelling:**
4-character BIPM code	IENG	
• Receiver maker and type: Receiver serial number:	Ashtech (Z-XII3T) RT920010203	Septentrio PolaRx2 SN:1225
1 PPS trigger level /V:	1 V	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	N/A (Not Phase stabilized)	
Length outside the building /m:	Approximately10 m	Approximately25 m
• Antenna maker and type: Antenna serial number:	Ashtech ASH701945C CR5200 10512	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C	N/A	

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	371.72 ns	(100.03 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	12.60 ns	(238.2 ± 0.3) ns
• Antenna cable delay:	136.6 ns	241.6 ns
Splitter delay (if any):	N/A	Y
Additional cable delay (if any):	N/A	12.4 ns

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	305.6 ns (GPS P1),
• INT DLY (GLONASS) /ns:	315.6 ns (GPS P2)
• CAB DLY /ns:	N/A
• REF DLY /ns:	136.6 ns (GPS)
• Coordinates reference frame:	385.90
Latitude or X /m:	WGS84 / IGS2000
Longitude or Y /m:	45.01513403
Height or Z /m:	7.63940783

General information	
• Rise time of the local UTC pulse:	12.26 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 2) °C
Set humidity value and uncertainty:	(45 ± 5) %

Laboratory:	INRIM
Date and hour of the beginning of measurements:	25.07.2016
Date and hour of the end of measurements:	02.08.2016

Information on the system

	Local:	**Travelling:**
4-character BIPM code	INR5	
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx4-TR 3002130	Septentrio PolaRx2 SN:1225
1 PPS trigger level /V:	1 V	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	N/A (Not Phase stabilized)	
Length outside the building /m:	Approximately 5 m	Approximately 25 m
• Antenna maker and type: Antenna serial number:	Septentrio	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C	N/A	

Measured delays /ns

	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	386.72 ns	(100.03 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	136.44 ns	(238.2 ± 0.3) ns
• Antenna cable delay:	0	241.6 ns
Splitter delay (if any):	N/A	Y
Additional cable delay (if any):	N/A	12.4 ns

Data used for the generation of CGGTTS files

• INT DLY (GPS) /ns:	N/A
• INT DLY (GLONASS) /ns:	N/A
• CAB DLY /ns:	N/A
• REF DLY /ns:	N/A
• Coordinates reference frame:	WGS84 / IGS2000
Latitude or X /m:	45.01514847
Longitude or Y /m:	7.63956033
Height or Z /m:	313.222

General information

• Rise time of the local UTC pulse:	12.26 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 2) °C
Set humidity value and uncertainty:	(45 ± 5) %

Laboratory:	INRIM
Date and hour of the beginning of measurements:	25.07.2016
Date and hour of the end of measurements:	28.08.2016

Information on the system

	Local:	**Travelling:**
4-character BIPM code	INR6	
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx4-TR 3102240	Septentrio PolaRx2 SN:1225
1 PPS trigger level /V:	1 V	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	N/A (Not Phase stabilized)	
Length outside the building /m:	Approximately 5 m	Approximately 25 m
• Antenna maker and type: Antenna serial number:	Septentrio	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C	N/A	

Measured delays /ns

	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	404.63 ns	(100.03 ± 0.01) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)	135.12 ns	(238.2 ± 0.3) ns
• Antenna cable delay:	0	241.6 ns
Splitter delay (if any):	N/A	Y
Additional cable delay (if any):	N/A	12.4 ns

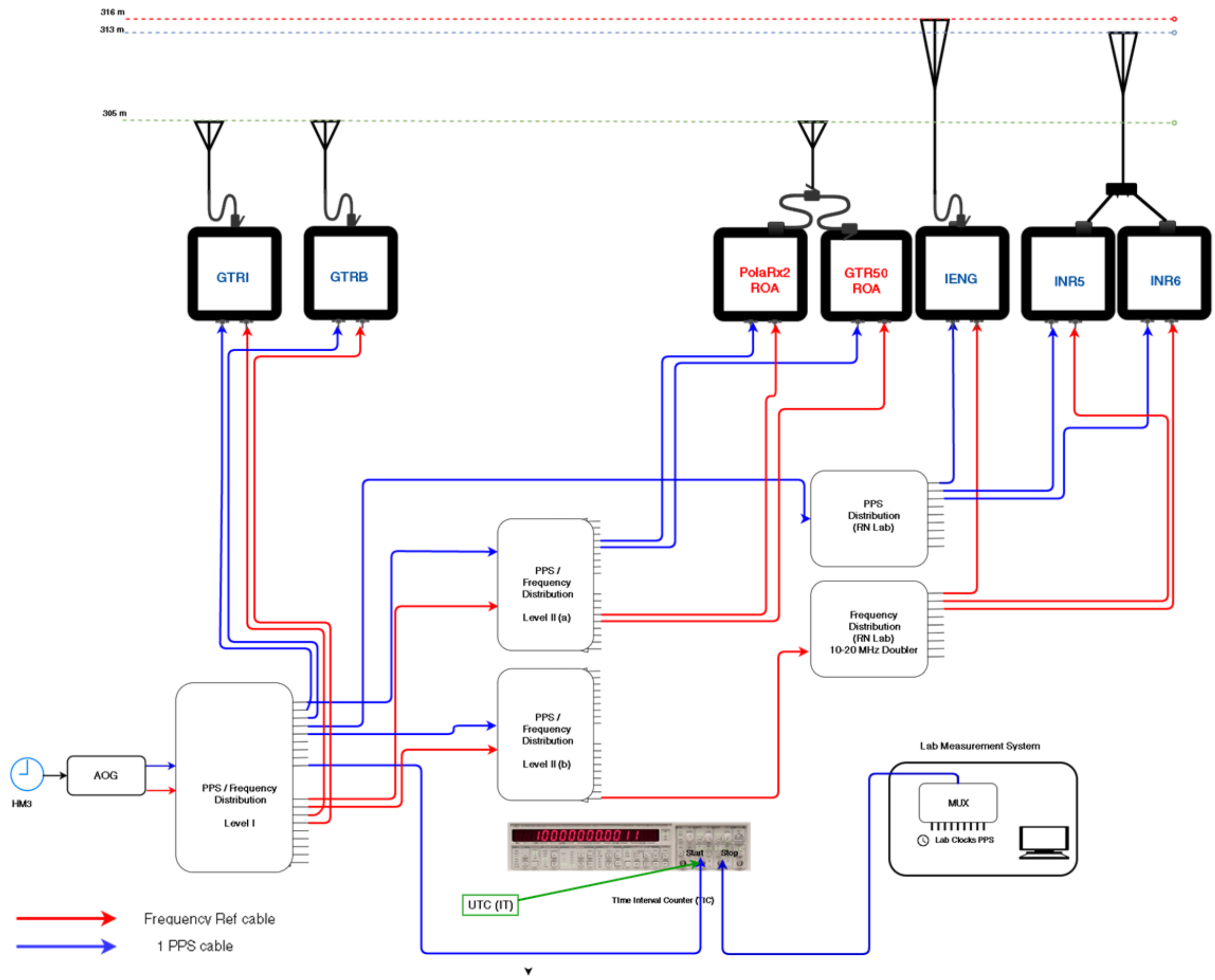
Data used for the generation of CGGTTS files

• INT DLY (GPS) /ns:	N/A
• INT DLY (GLONASS) /ns:	N/A
• CAB DLY /ns:	N/A
• REF DLY /ns:	N/A
• Coordinates reference frame:	WGS84 / IGS2000
Latitude or X /m:	45.01514847
Longitude or Y /m:	7.63956033
Height or Z /m:	313.222

General information

• Rise time of the local UTC pulse:	12.26 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(23 ± 2) °C
Set humidity value and uncertainty:	(45 ± 5) %

Diagram of the experiment set-up:



9. ANNEX-B: CCD and TDEV analysis at each Lab

Figure 9-1: CCD (left column) and TDEV (right column) at ROA before de calibration trip.

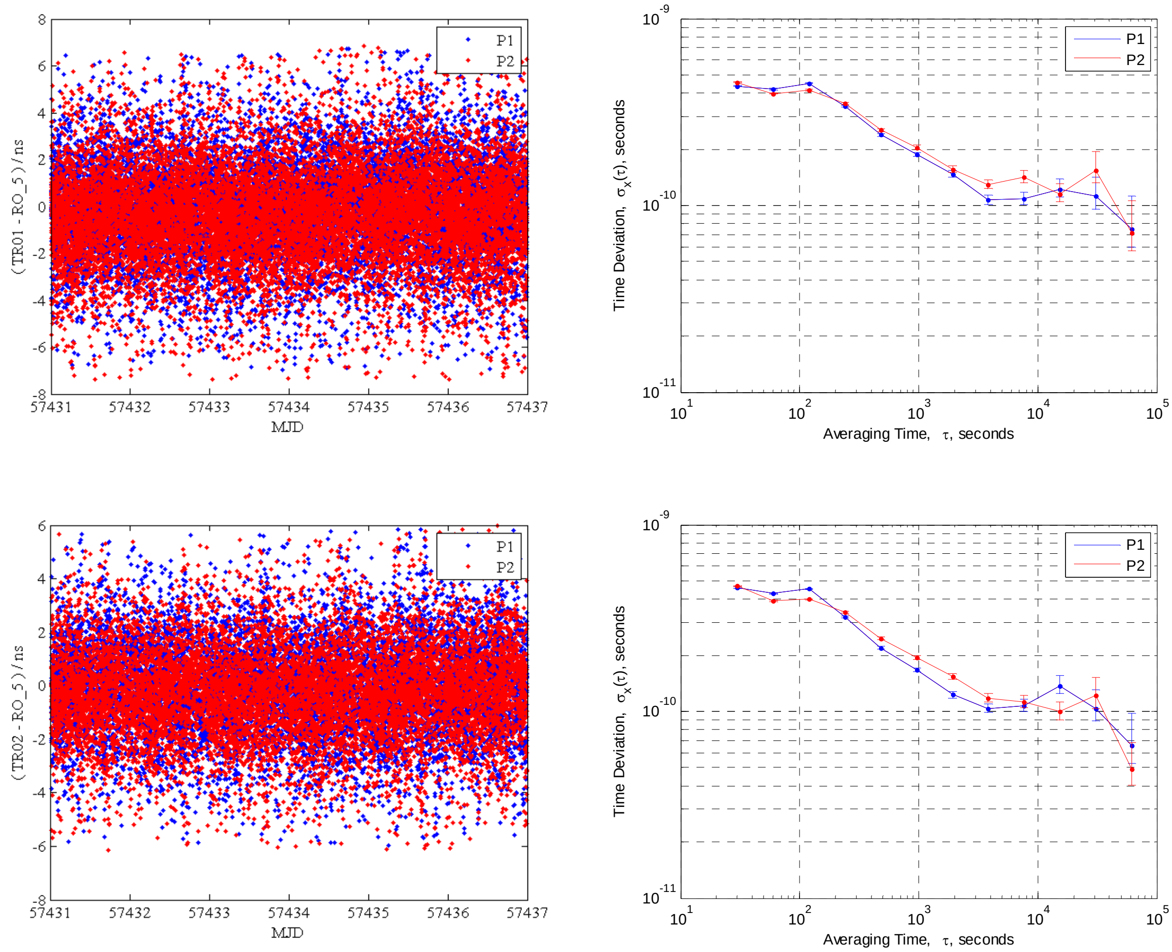
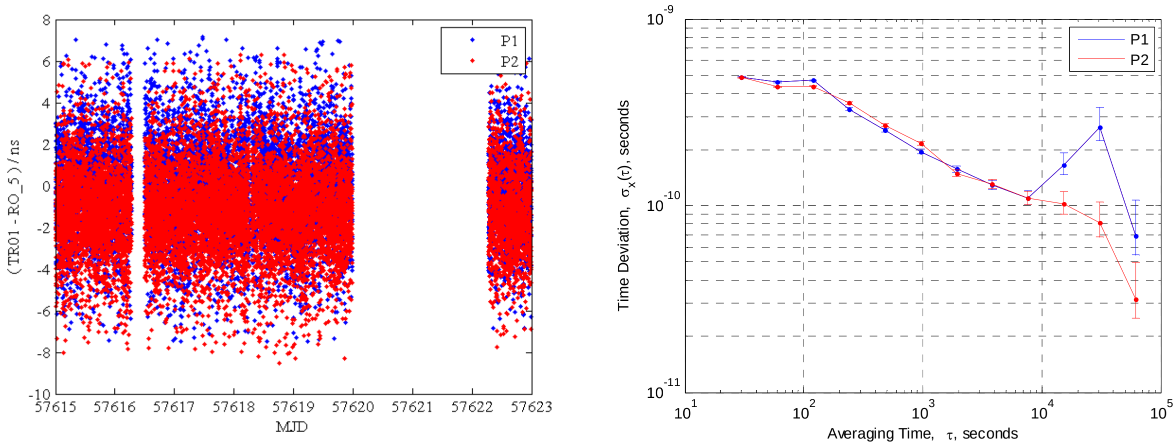


Figure 9-2: CCD (left column) and TDEV (right column) at ROA after de calibration trip.



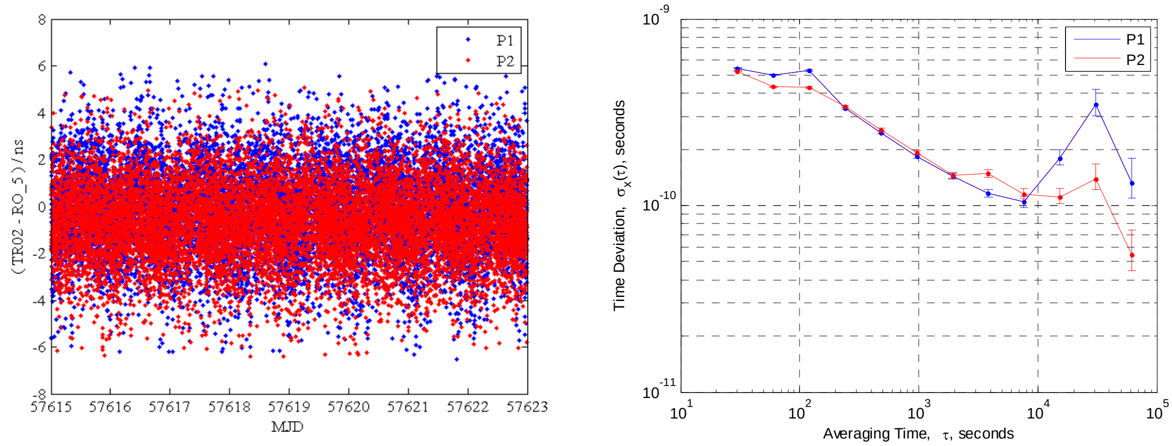


Figure 9-3: CCD and TDEV at BIM

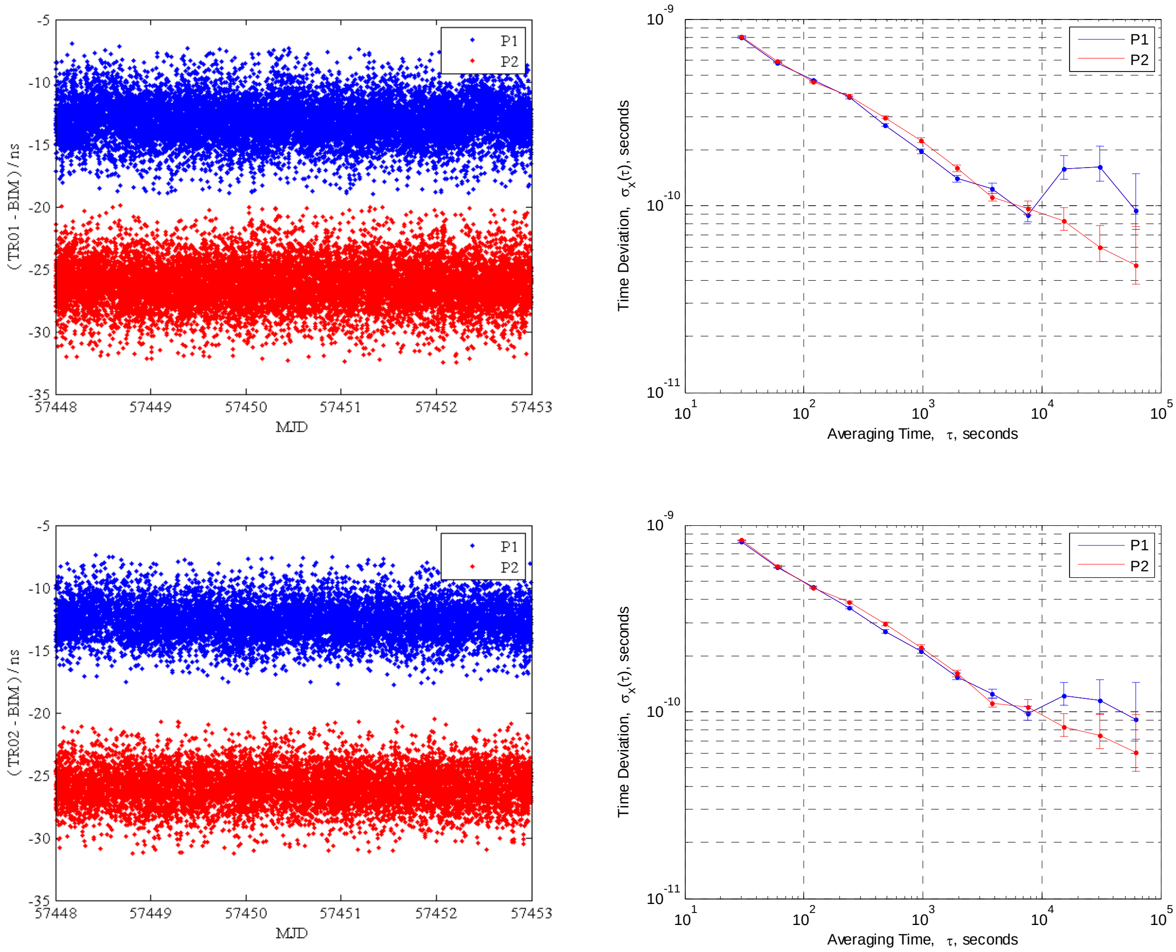


Figure 9-4: CCD and TDEV at UME

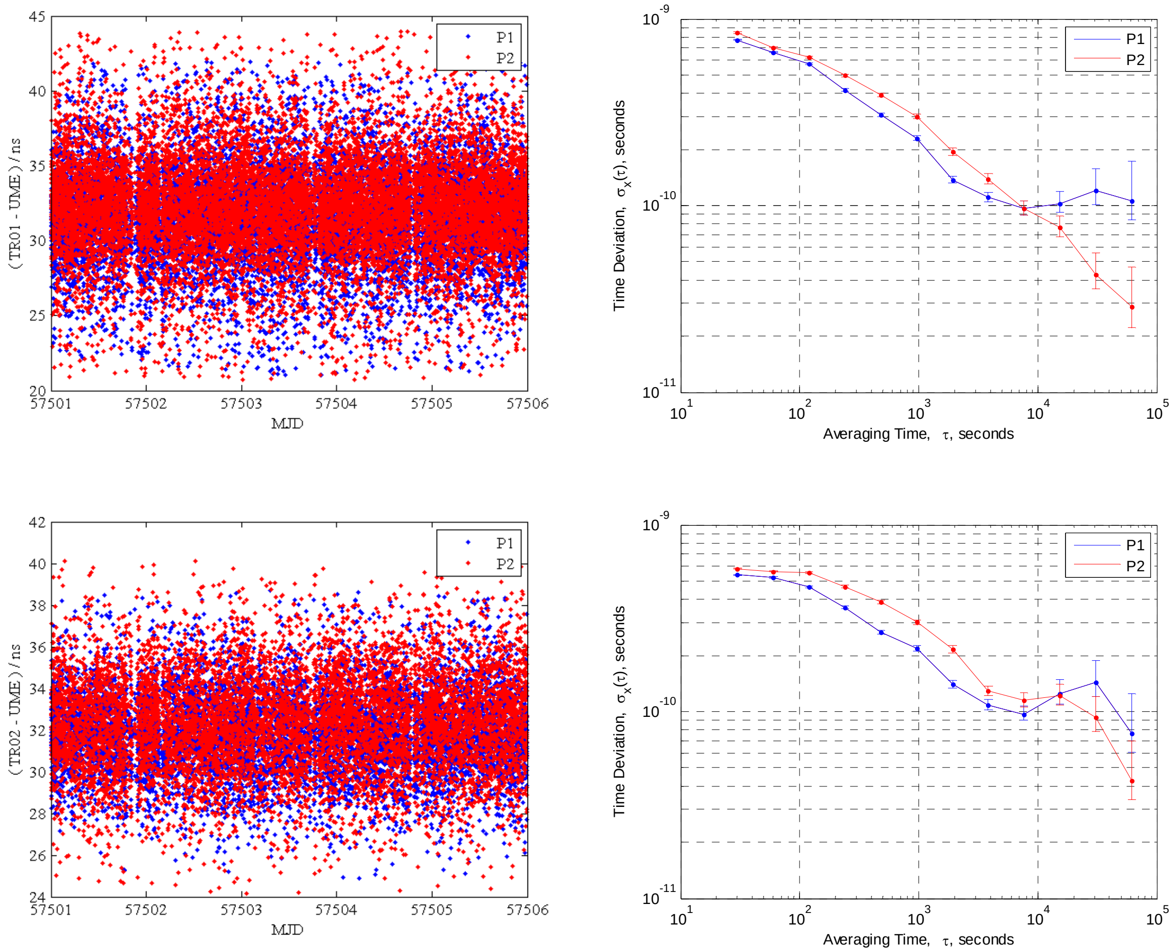


Figure 9-5: CCD and TDEV at BOM

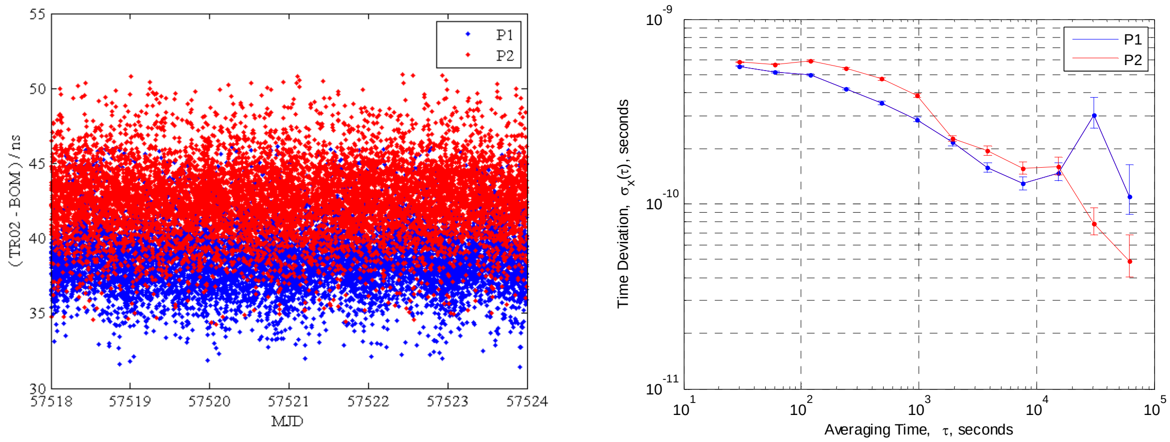


Figure 9-6: CCD and TDEV at DMDM

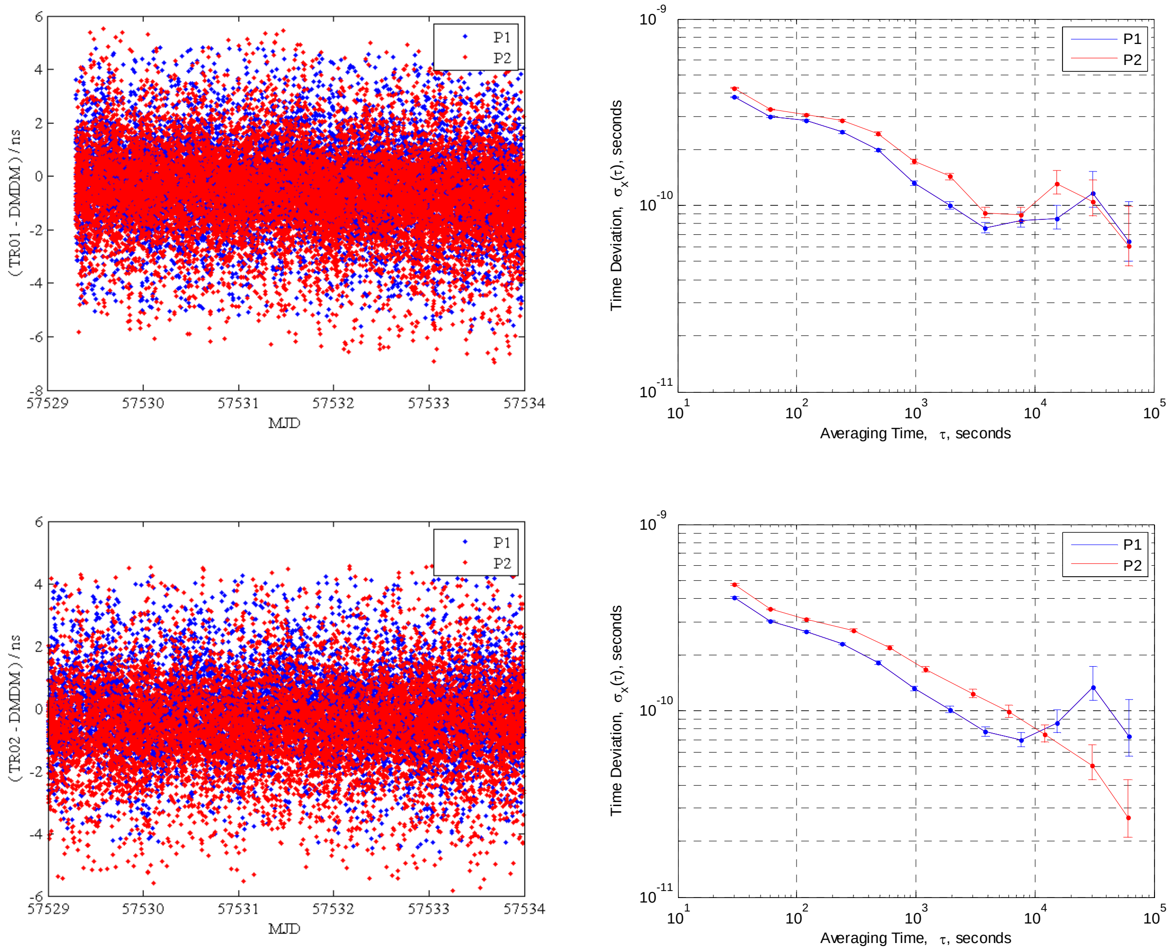
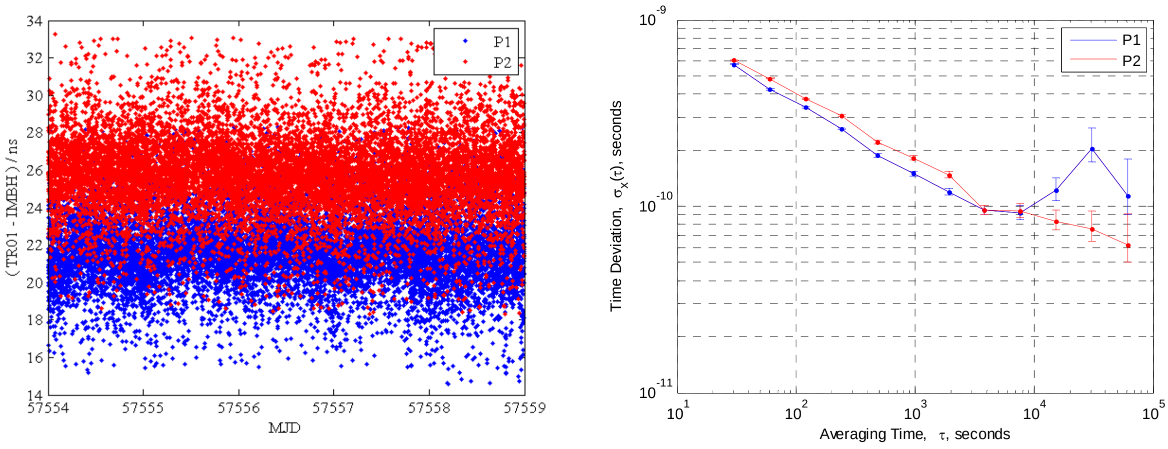
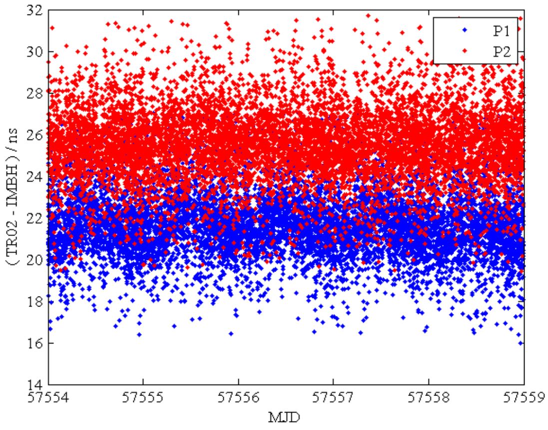


Figure 9-7: CCD and TDEV at IMBH





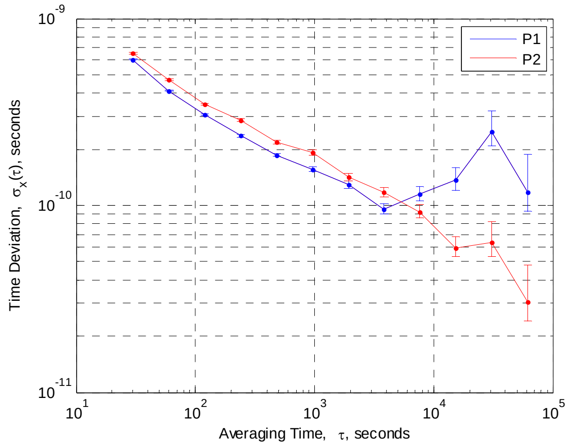
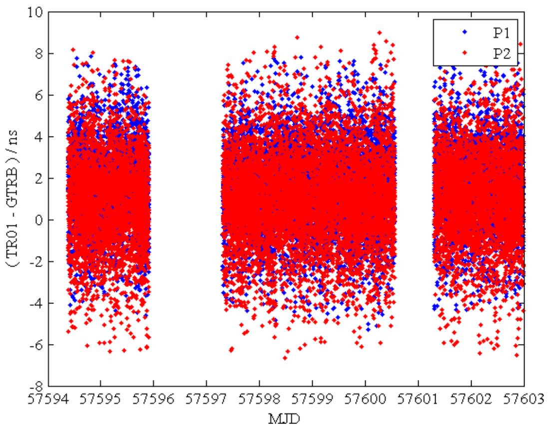
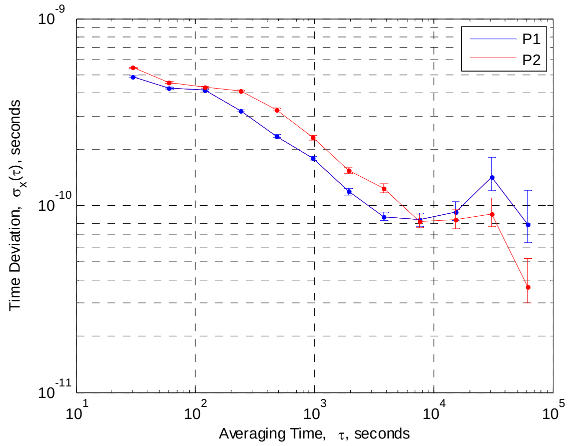
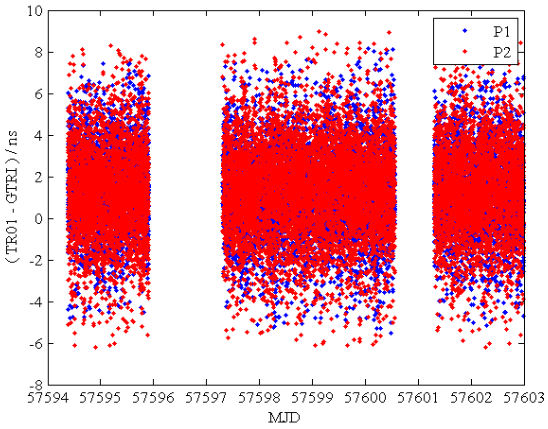
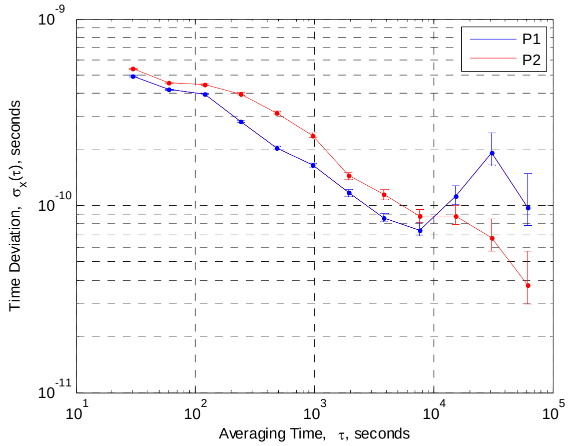


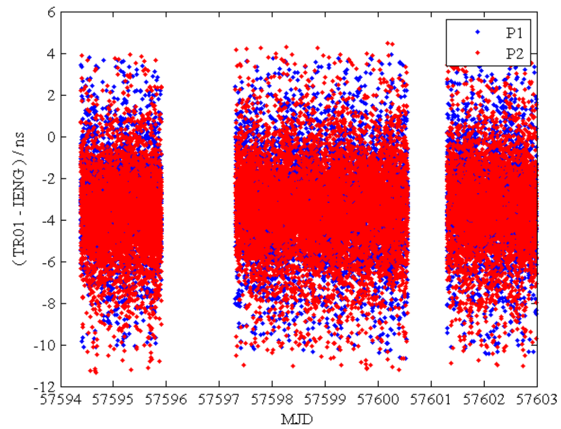
Figure 9-8: CCD and TDEV at INRIM

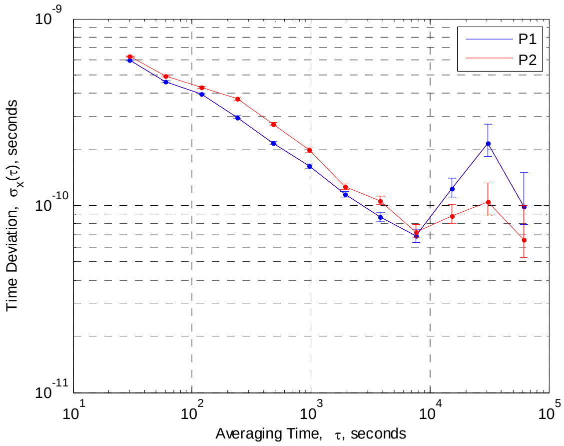


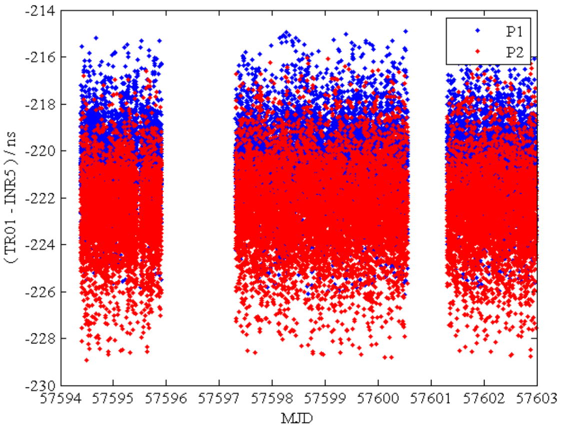


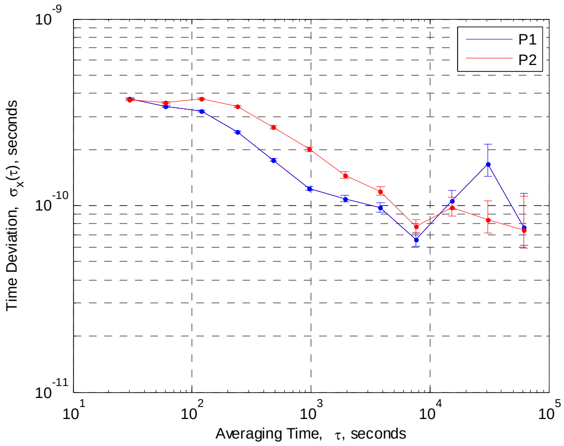


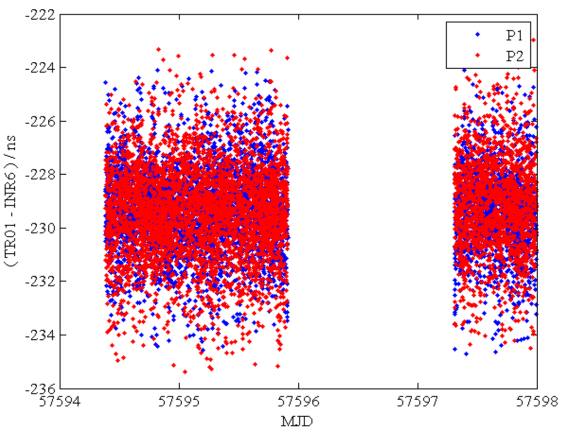


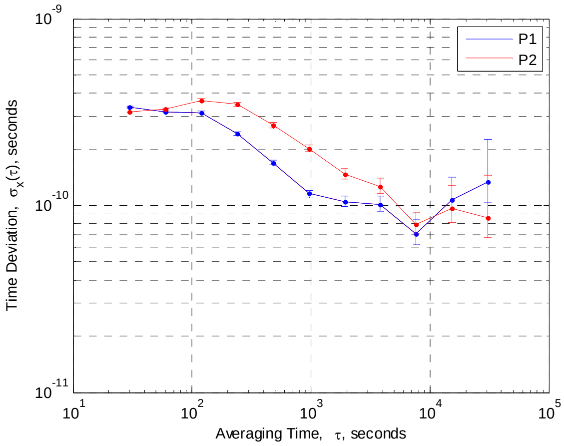

P1
P2
(TR01 - IENG) / ns
MJD


P1
P2
Time Deviation, $\sigma_x(\tau)$, seconds
Averaging Time, τ, seconds


P1
P2
(TR01 - INR5) / ns
MJD


P1
P2
Time Deviation, $\sigma_x(\tau)$, seconds
Averaging Time, τ, seconds


P1
P2
(TR01 - INR6) / ns
MJD


P1
P2
Time Deviation, $\sigma_x(\tau)$, seconds
Averaging Time, τ, seconds

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