GNSS CALIBRATION REPORT

G1G2_1020-2017

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1. INTRODUCTION

1.1. SCOPE OF THE DOCUMENT

In 2014, as a result of a 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 the BIPM, is to perform new calibration trips between G2 laboratories, under the responsibility of the RMOs.

ROA, as a EURAMET G1 laboratory, has this year organized a new GPS receiver relative calibration campaign, which took place between two European NMIs or DIs: SASO (Saudi Arabia) and ROA (Spain).

In this campaign a differential calibration with closure was carried out, in which the travelling system served as a transfer standard between all systems visited during the trip and the reference receiver RO_5. This last was calibrated and reported last year (Cal_Id=1001-2016 [RD01]), and has been continuously monitored since then.

1.2. DOCUMENT STRUCTURE

The current campaign has been carried out in accordance with ROA calibration procedures and follows as much as possible the BIPM guidelines for GNSS calibrations [RD02]. The results will be reported using Cal_Id 1020-2017, and they will provide the visited receivers' internal delays for GPS C1, 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 acronyms used).

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 briefly describes the calibration procedure.

Section 5 explains the data processing carried out by ROA using its own software and includes all the necessary tables to present the results.

Section 6 is focused on the uncertainty estimation, listing 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 information needed to obtain them.

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

1.3. DOCUMENTS

REFERENCES	
RD01	BIPM report 1001-2016 V1.2 / 20170210, subject: 2016 Group 1 GPS calibration trip (Phase 2).
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	J. Kouba, P. Heroux, 2002, Precise Point Positioning Using IGS Orbit and Clock Products, GPS Solutions, Vol. 5, No. 2, pp. 12-28.
RD05	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.
CCD	Common clock differences.
CCTF	Consultative Committee for Time and Frequency.
CGGTTS	CCTF Generic GNSS Time Transfer Standard.
DI	Designated Institute.
EURAMET	The European Association of National Metrology Institutes.
GNSS	Global Navigation Satellite System.
GPS	Global Positioning System.
IGS	International GNSS Service.
MJD	Modified Julian Date.
NMI	National Metrology Institute.
PPP	Precise Point Positioning.
RINEX	Receiver Independent Exchange Format.
ROA	Real Instituto y Observatorio de la Armada, San Fernando, Spain.
R2CGGTTS	RINEX to CGGTTS conversion software, provided by ORB / BIPM.
SASO	Saudi Standards, Metrology and Quality Organization.
TDEV	Time Deviation, Which is a measure of time instability based on the modified Allan variance.
TIC	Time Interval Counter.
UTC	Coordinated Universal Time.
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.

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	Real Observatorio de la Armada Plaza de las Tres Marinas s/n 11100, San Fernando Spain
SASO	Khalid S Al-Dawood Tel +966 11 2529711 k.dawood@saso.gov.sa	Saudi Standards, Metrology and Quality Organization Riyadh - Al Muhammadiyah PO. B 3437 Riyadh 11471 Kingdom of Saudi Arabia

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		DICOM GTR50	TR01	
ROA	Group 1 reference	MJD: 58044-58048 18/10/17-22/10/17	DICOM GTR50	RO_5	RO_5
SASO	Group 2	MJD: 58080-58089 23/11/17-02/12/17	PikTime TTS-4	SA00	SAS0
SASO	Group 2	MJD: 58080-58089 23/11/17-02/12/17	PikTime TTS-4	SA01	SAS1
ROA	Group 1 reference	MJD: 58110-58116 23/12/17-29/12/17	DICOM GTR50	RO_5	RO_5

3. THE ROA TRAVELING EQUIPMENT

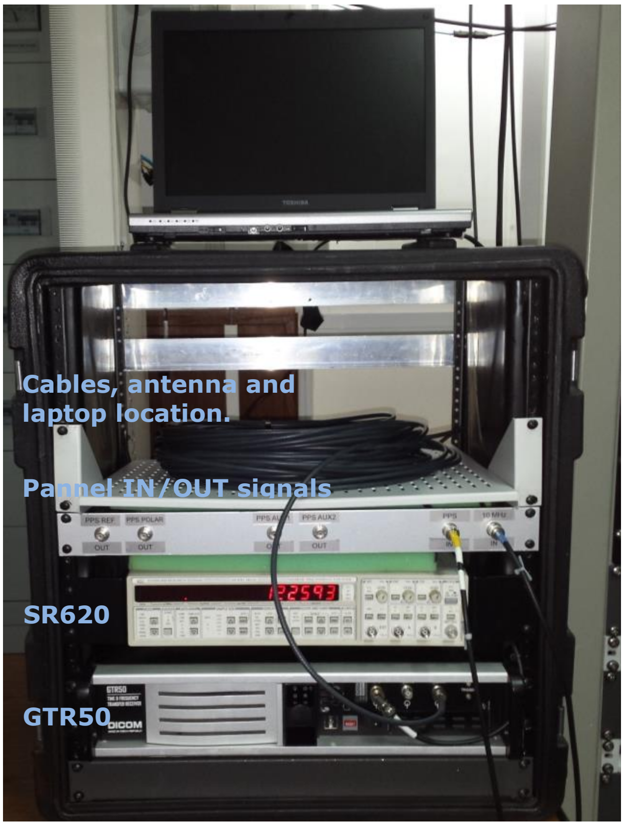
The traveling equipment consists of one shipping box containing the following items:

- 1 GTR50 receiver SN: 0802017
- 1 Time Interval Counter (TIC) Stanford SR620 SN: 4060
- 1 Portable PC Toshiba Tecra M9 laptop SN: X7052920H
- 1 Novatel antenna GPS-703-GGG SN: NEG15300017
- 60 m H155 antenna cable
- 2 BNC cables (10 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, only one receiver was included in the traveling equipment. We used a direct antenna cable to connect the GTR50 and the 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.

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



4. CALIBRATION PROCEDURE

The calibration has been performed based in C1, P1 and P2 observations provided in the RINEX V.2.1 observation files, that is, using all the GPS satellites in view, at 30 seconds time intervals. We have also used the satellite ephemeris BRDC files provided by IGS.

The coordinates of the antenna phase centre have been especially computed for the calibration period from RINEX files by using the NRCan PPP (V 1.05 34613) software [RD04], so the time transfer error caused by this factor is nearly negligible.

The calibration method is basically as follows. From the known delays of the reference receiver (RO_5), we have obtained INTDLY(C1), INTDLY(P1) and INTDLY(P2) values for the SASO receivers. The calibration procedure consists on building differential pseudo-ranges for each code C1, P1 and P2 between the two receivers in common-clock set-up.

At each laboratory, the traveling equipment set-up 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 it has been used an ROA-authored program, in which the common clock differences (CCD) are obtained from the differential pseudo-ranges for each code C1, P1 and P2. For SASO receivers, 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, we have obtained the internal delays of the receivers at the visited site. Normally the antenna cable delay (CABDLY) is maintained without any change and the reference delay (REFDLY) is normally updated, and any variations from the true values of these parameters will be included in the INTDLY results.

Table 5-1 summarizes the initial delays of the receivers at the start of calibration. Using these values, CCD have been accordingly modified.

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

BIPM Acronym	System	INT DLY C1	INT DLY P1	INT DLY P2	REF DLY	CAB DLY
SASO	SAS0	-36.10	0	0	29.36	139.96
	SAS1	-34.35	0	0	29.70	143.38

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

Pair	RAW ΔC1	TDEV (1 day)	RAW ΔP1	TDEV (1 day)	RAW ΔP2	TDEV (1 day)
TR-SAS0	-10.16	0.05	27.30	0.06	29.54	0.04
TR-SAS1	-9.81	0.04	25.82	0.06	29.20	0.07

Taking a close look at the closure measurements in Table 5-3, we can observe normal behavior of the TR receiver, where the C1, P1 and P2 variations have remained small (below 0.1 ns).

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

Pair	RAW ΔC1	TDEV (1 day)	RAW ΔP1	TDEV (1 day)	RAW ΔP2	TDEV (1 day)
TR-RO_5 (before the trip)	-0.01	0.06	0.00	0.07	0.00	0.04
TR-RO_5 (after the trip)	0.02	0.05	-0.02	0.05	0.03	0.05
Misclosure	-0.03		0.02		-0.03	
Mean	0.01		-0.01		0.02	

6. UNCERTAINTY ESTIMATION

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

$$u_{CAL} = \sqrt{u_a^2 + u_b^2}\ , \qquad (1)$$

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 the travelling equipment was determined. The systematic uncertainty is given by:

$$u_b = \sqrt{\sum_n u_{b,n}^2} \qquad (2)$$

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 C1(ns)**	**Value P1 (ns)**	**Value P2 (ns)**	**Description**
1	$u_{a(ROA)}$	0.10	0.10	0.10	CCD uncertainty at ROA, TDEV at τ = 1 day
2	$u_{a(Lab(k))}$	0.10	0.10	0.10	CCD uncertainty at remote Lab, TDEV at τ = 1 day
Result of closure measurement at ROA					
3	$u_{b,1}$	0.10	0.10	0.10	TR Misclosure, see Table 5-3.
Systematic components due to antenna installation					
4	$u_{b,11}$	0.05	0.05	0.05	Position error at ROA
5	$u_{b,12}$	0.05	0.05	0.05	Position error at remote Lab
6	$u_{b,13}$	0.10	0.10	0.10	Multipath at ROA
7	$u_{b,14}$	0.10	0.10	0.10	Multipath at remote Lab
Installation of TR and visited receivers					
8	$u_{b,21}$	0.20	0.20	0.20	Connection of TR to UTC(ROA) (REF DLY)
9	$u_{b,22}$	0.20	0.20	0.20	Connection of TR to UTC(k) (REF DLY)
10	$u_{b,23}$	0.20	0.20	0.20	Connection of reference receiver to UTC(ROA) (REF DLY)
11	$u_{b,24}$	0.20	0.20	0.20	Connection of receivers at site k to UTC(k) (REF DLY)
12	$u_{b,25}$	0.30	0.30	0.30	TIC nonlinearities at ROA
13	$u_{b,26}$	0.30	0.30	0.30	TIC nonlinearities at remote sites

7. FINAL RESULTS

The results of the calibration campaign G1G2_1020_2017 are summarized in Table 7-1. INTDLY C1 new values have been calculated from (the same for P1 and P2 codes):

$$\text{INTDLY C1 new} = \text{INTDLY C1 old} - \Delta C1(T,V) + \Delta C1(T,R) + \text{Ref Dly Old} - \text{Ref dly New}$$

Table 7-1. Results of the Calibration Campaign G1G2_1020_2017, all values in ns.

Receiver (V)	INT DLY C1 old	INT DLY P1 old	INT DLY P2 old	ΔC1 (T,V)	ΔP1 (T,V)	ΔP2 (T,V)	ΔC1 (T,R)	ΔP1 (T,R)	ΔP2 (T,R)	REF DLY old	*REF DLY new	CAB DLY	INT DLY C1 new	u_{cal} C1	INT DLY P1 new	u_{cal} P1	INTDLY P2 new	u_{cal} P2
SAS0	-36.10	0	0	-10.16	27.30	29.54	0.01	-0.01	0.02	29.36	29.47	139.96	-25.8	0.6	-27.2	0.6	-29.4	0.6
SAS1	-34.35	0	0	-9.81	25.82	29.20	0.01	-0.01	0.02	29.70	29.90	143.38	-24.4	0.6	-25.7	0.6	-29.1	0.6

T=Travelling receiver V=Visited receiver R=Reference receiver (RO_5)

* See annex-A (pages 15 and 16) for the detailed analysis.

8. ANNEX-A

8.1. CALIBRATION INFORMATION SHEET AT ROA

Laboratory:	ROA
Date and hour of the beginning of measurements:	18.10.2017
Date and hour of the end of measurements:	22.10.2017

Information on the system

	Local:	**Travelling:**
4-character BIPM code	RO_5	
• Receiver maker and type: Receiver serial number:	DICOM GTR50 0601012	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	(122.5 ± 0.1) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		
• Antenna cable delay: Antenna cable type:	127.5 ns	(263.8 ± 0.3) ns H155
Splitter delay (if any):		
Additional cable delay (if any):		

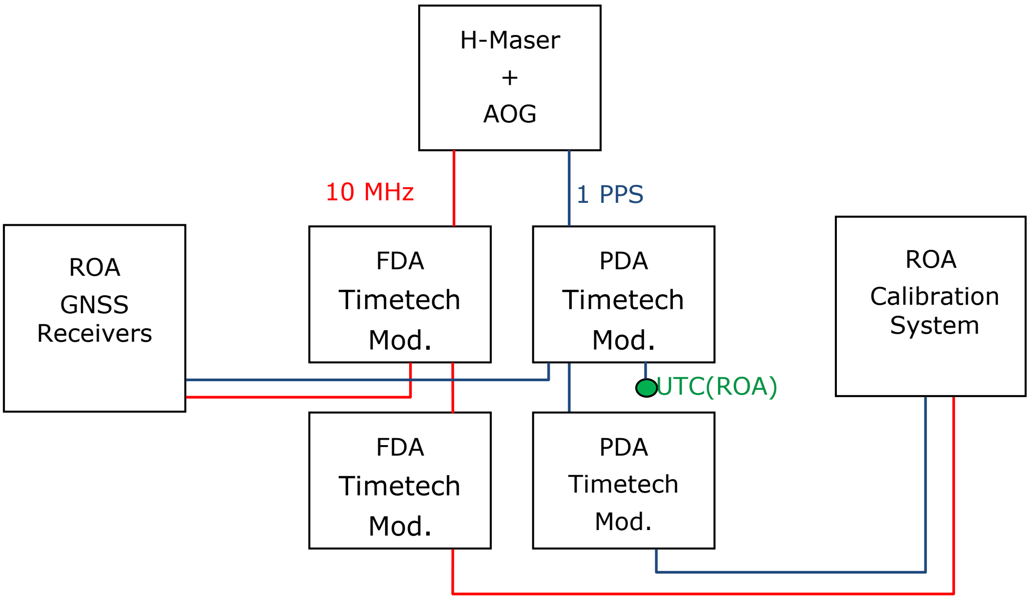
Data used for the generation of CGGTTS files

• INT DLY (GPS) /ns:	18.6 ns (GPS C1) 18.5 ns (GPS P1) 32.7 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 SASO

Laboratory:	SASO Saudi Arabia, Riyadh
Date and hour of the beginning of measurements:	21.11.2017
Date and hour of the end of measurements:	30.11.2017

Information on the system

	Local:	**Travelling:**
4-character BIPM code	SAS0	TR01
• Receiver maker and type: Receiver serial number:	PikTime Poland, TTS4 0135	Dicom GTR50 SN:0802017
1 PPS trigger level /V:		
• Antenna cable maker and type:	FSJ1-50A - 1/4" Andrew Heliax Superflex Coax Cable	H155
Length outside the building /m:	Approximately 10 m	Approximately 20 m
• Antenna maker and type: Antenna serial number:	Javad, Choke Ring JAV_GRANT-G3T 631	Novatel antenna GPS-703-GGG Approximately 20 m

Measured delays /ns

	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in (*A*):	(23.62 ± 0.03) ns	(6.3 ± 0.3) ns
• 1 PPS-in to Frequency offset:	44.15 ns	
• 1 PPS-in to Frequency Correction (*B*): (Provided by receiver)	-5.85 ns	
• Total delay (*A* - *B*): (CGGTTS REF DLY value)	**29.47 ns**	
• Antenna cable delay:	139.96 ns	
Additional cable delay (if any):	No	

Data used for the generation of CGGTTS files

• INT DLY (GPS) /ns:	GPS: L1C:-36.10 L2C:0.00 L1P:0.00 L2P:0.00 L5P:0.00
• INT DLY (GLONASS) /ns:	GLO: L1C:0.00 L2C:0.00 L1P:0.00 L2P:0.00
• CAB DLY /ns:	139.96 ns
• REF DLY /ns:	29.36 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	+3980085.14 m
Longitude or Y /m:	+4214609.88 m
Height or Z /m:	+2652790.26 m

General information

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

Laboratory:	SASO Saudi Arabia, Riyadh
Date and hour of the beginning of measurements:	21.11.2017
Date and hour of the end of measurements:	30.11.2017

Information on the system

	Local:	**Travelling:**
4-character BIPM code	SAS1	TR01
• Receiver maker and type: Receiver serial number:	PikTime Poland, TTS4 0138	Dicom GTR50 SN:0802017
1 PPS trigger level /V:		
• Antenna cable maker and type:	FSJ1-50A - 1/4" Andrew Heliax Superflex Coax Cable	H155
Length outside the building /m:	Approximately 10 m	Approximately 20 m
• Antenna maker and type: Antenna serial number:	Javad, Choke Ring JAV_GRANT-G3T 634	Novatel antenna GPS-703-GGG Approximately 20 m

Measured delays /ns

	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in (*A*):	(23.62 ± 0.03) ns	(6.3 ± 0.3) ns
• 1 PPS-in to Frequency offset:	43.72 ns	
• 1 PPS-in to Frequency Correction (*B*): (Provided by receiver)	-6.28 ns	
• Total delay (*A* - *B*): (CGGTTS REF DLY value)	**29.90 ns**	
• Antenna cable delay:	143.38 ns	
Additional cable delay (if any):	No	

Data used for the generation of CGGTTS files

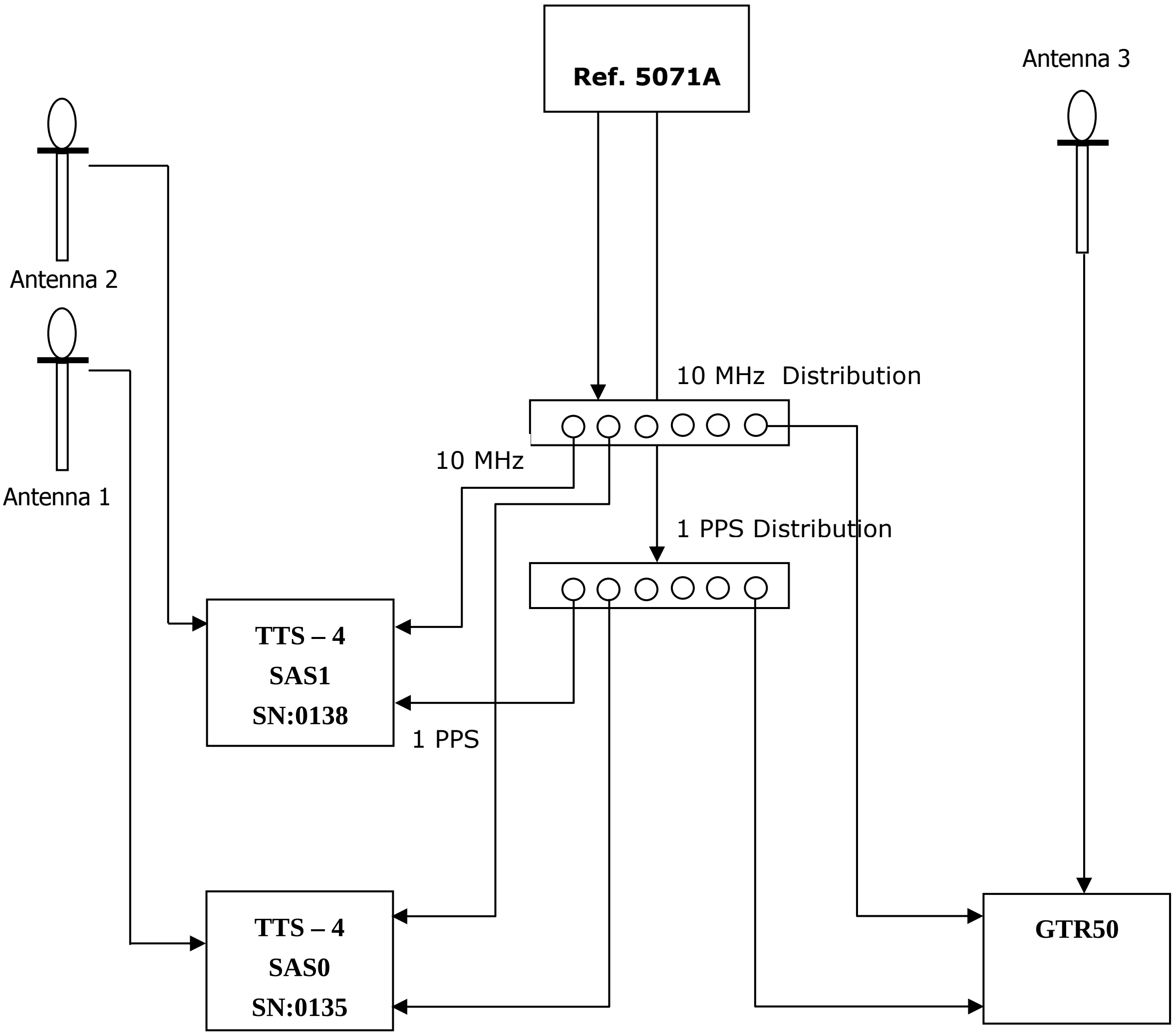
• INT DLY (GPS) /ns:	GPS: L1C:-34.35 L2C:0.00 L1P:0.00 L2P:0.00 L5P:0.00
• INT DLY (GLONASS) /ns:	GLO: L1C:-244.38 L2C:0.00 L1P:0.00 L2P:0.00
• CAB DLY /ns:	143.38 ns
• REF DLY /ns:	29.70 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	+3980086.16 m
Longitude or Y /m:	+4214607.65 m
Height or Z /m:	+2652792.25 m

General information

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

Diagram of the experiment set-up:

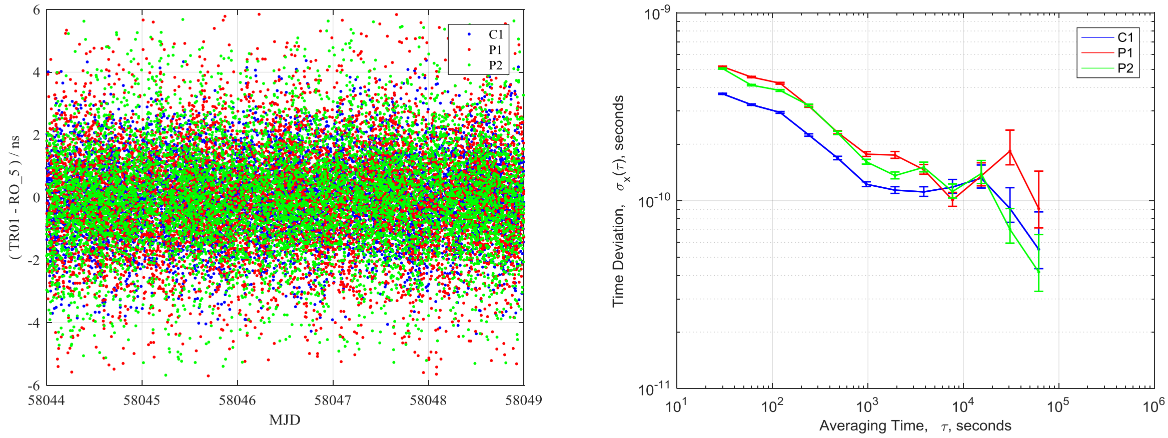
Link to the local UTC of both receivers and Antenna positions



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



After the calibration trip

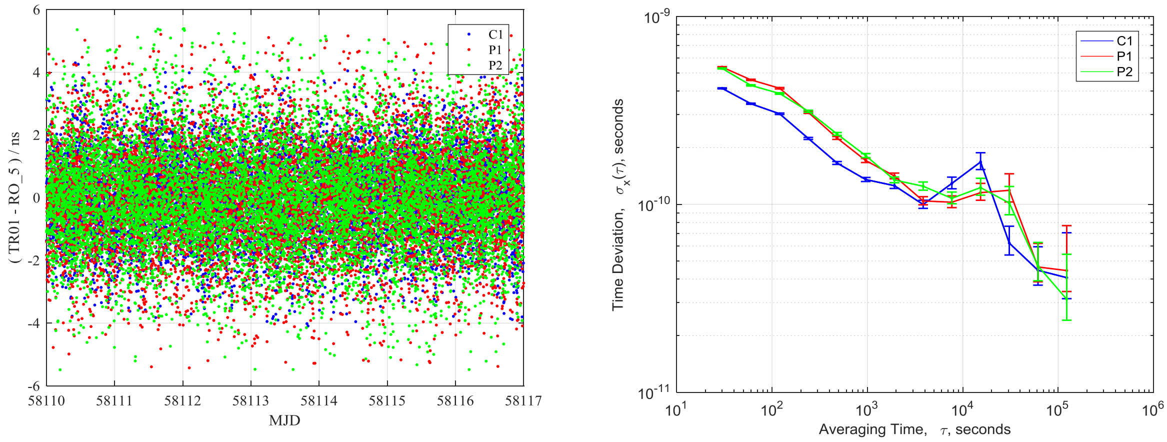
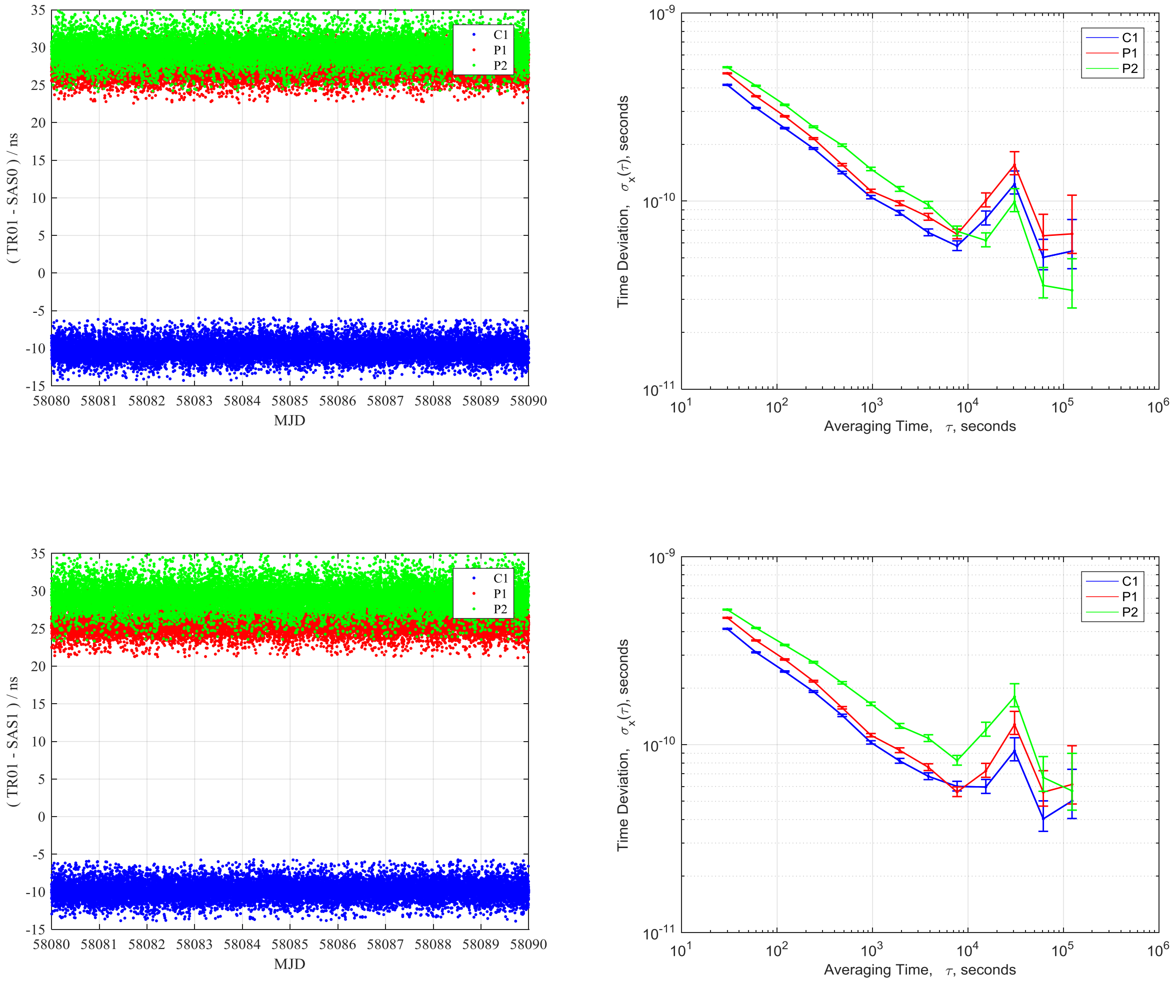


Figure 9-2: CCD and TDEV at SASO



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END OF DOCUMENT