ROA CALIBRATION REPORT DUE TO THE MOVE TO NEW THE LABORATORY

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1. INTRODUCTION

On September 15, 2017, new ROA Time Laboratory was inaugurated. The new building is two stories and basement. The labs occupy approximately 200 of the nearly 860 square meters of the new building. This construction is connected to the existing one by a renovated landscape, linking the traditional areas with the modern structure Lab.

All laboratories are equipped with climate and ventilation control. The temperature is maintained at (23 ± 1) °C with relative humidity (45±10) %, so that any room can switch these parameters to the proper performance of a test or proper placed instruments operation.

Two rooms, with a surface area of around 50 square meters, specially designed for atomic clocks, the new development of frequency standards, high precise measurements of phase noise (near the carrier frequency), and short term frequency stability (in terms of the Allan Deviation), are also enclosed inside a Faraday cage or Faraday shield in order to avoid the influence of any outer electromagnetic field.

Each laboratory is equipped with technical flooring (or raised access floor), which provides an elevated structural floor above a solid substrate to the passage of mechanical services, coaxial and fiber optics connections, and wiring that lay underneath.

Power supply is provided in three different ways, in order to ensure an uninterruptible service: AC current from the power company, through uninterruptible power supply (UPS) devices, and 24 VDC supplied by batteries. In case of failure of the AC electric supply, two emergency diesel generators are available.

Finally, the building culminates in a walkable roof, with two separated areas, one prepared for a large number of geodetic GNSS antennas, and the other focused in TWSTFT VSAT antennas. Both of them are open-sky visibility and far away from obstacles that could difficult or reduce the satellite signals. Although it has been initially intended for this kind of systems, in the future it would be feasible for the accommodation of some optical antenna for time and frequency transfer by means of optical links.

1.1. SCOPE OF THE DOCUMENT

In order to proceed with the move of Laboratory, six main steps were carried out:

- Replication of UTC(ROA) at the new Lab.
- Move of clocks to the new standards room. All but one were moved, and the first H-maser and its AOG, which physically materializes UTC(ROA), remain in the old building.
- Move of two GNSS systems and the secondary TWSTFT station, and alignment of the systems to the main links.
- Transfer of UTC(ROA) and remaining time transfer systems. ROA time scale is now materialized by the second H-maser and its AOG in the new Lab.
- Finally, time transfer systems were aligned to the existing one.

1.2. DOCUMENT STRUCTURE

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 equipment move schedule and dates of alignments.

Section 3 briefly describes the calibration procedure.

Section 4 describes the move of UTC(ROA) to the new laboratory, and calibration.

Section 5 explains the GPS recalibrations, including the new Hookup diagram, and the tables with the new internal delays.

Section 6 describes calibration and alignment of ROA01 and ROA02 TWSTFT stations.

Section 7 is focused on the uncertainty estimation, listing all the terms taken into account for the uncertainty budget.

The report concludes with the Annex-A, 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.

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.
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.

Acronym	Definition
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].
	ITU acronyms
ESDVAR	Earth station delay variation (ns), with respect to the earth station delay present at the time of a calibration. All earth station and modem delay changes have to be included.

2. SCHEDULE

The operation schedule shown in Tables 2.1-2.2, was implemented from mid July 2017 to the beginning of June 2018. Nevertheless, the most relevant changes related to the move and calibration of time transfer links were performed during the past month of May.

Table 2.1: Equipment move schedule.

Dates of transfer (MJD)	Equipment	BIPM code
57950	Zen-node (slave)	
58008	5 Cs	
58009	1 H-maser	
58081	PolaRx5TR	RO10
58214	PolaRx4TR (a) PolaRx4TR (b)	RO_7 RO_9
58218	TWSTFT (2)	ROA02
58235	UTC(ROA)	
58235	PolaRx3eTR GTR50 GTR51	RO_6 RO_5 RO_8
58235	TWSTFT (1)	ROA01

Table 2-2: Dates of calibrations/alignments.

Operation	Dates of measurements	Receiver - Lab	Travelling/Reference Receiver - Lab
Calibration of replicated UTC(ROA) (1st Period)	57952-57959	RO_5 - Old	TR01 - Old
	57965-57972	RO_5 - Old	TR01 - New
Recalibration of replicated UTC(ROA) (2nd Period)	58228-58230	RO_5 - Old	TR01 - Old
	58231-58234	RO_5 - Old	TR01 - New
Calibration GPS Phase 1	58227-58233	RO_7 - New RO_9 - New	RO_5 - Old
Calibration GPS Phase 2	58258-58264	RO_5 - New RO_6 - New RO_8 - New RO10 - New	RO_9 - New
Alignment of TW ROA2 to TW ROA1	58227-58233	TW ROA01 - Old	TW PTB05
		TW ROA02 - New	TW PTB05
Alignment of TW ROA1 to TW ROA2	58257-58264	TW ROA01 - New	TW PTB05
		TW ROA02 - New	TW PTB05

3. CALIBRATION PROCEDURE

The replication of UTC(ROA) was feasible by using a pair of ZEN nodes, master and slave. The system was initially tested in the old lab, with different long distance fiber optical cables between nodes, in order to verify the phase delay compensation of the nodes. In a final test, the optical link between the two Labs has been bridged in the new Lab (closed loop old-new-old Lab), and the variation observed, showed in Figure 3.1, was below 150 ps. Moreover, no variation has been observed due to external environmental conditions in the last test.

The GPS CV used for calibration and alignments, has been performed based in P1 and P2 observations from CGGTTS files.

New coordinates of the antenna phase centre have been computed, when required, from RINEX files using the NRCan PPP (V 1.05 34613) software [RD04].

At new laboratory, AOG has been measured at 5 minutes rate, with respect to the replicated UTC(ROA), which is provided by slave ZEN node. A PPS distribution unit, connected with this frequency synthesizer was used to physically define UTC(ROA) on MJD 58235 at new Lab, once the delay between two scales was set to zero.

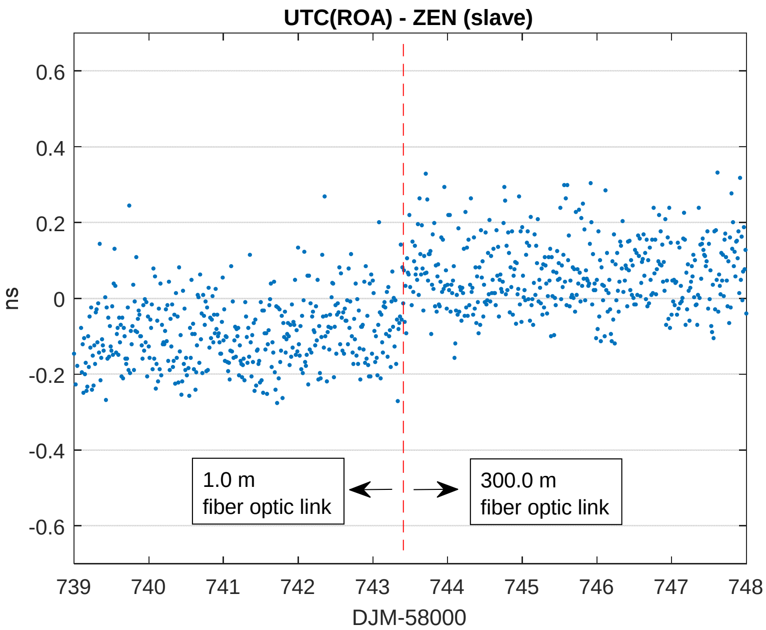


Figure 3-1: CCD at old Lab, after the ZEN node connection change.

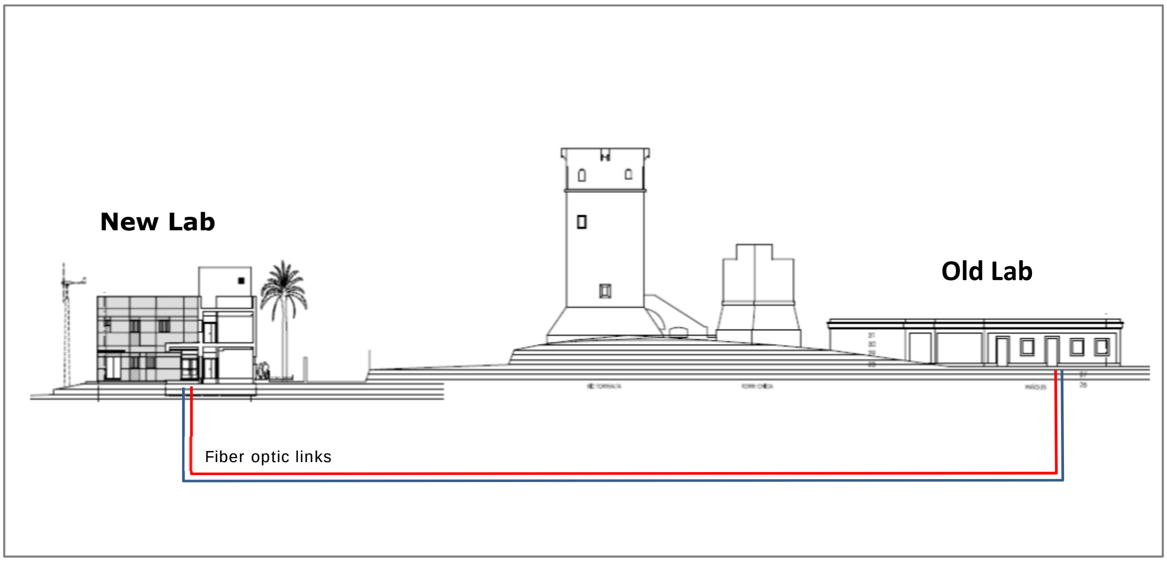


Figure 3-2: ROA situation map of both laboratories, that are separated by 150 meters.

4. GPS DATA PROCESSING FOR UTC(ROA) CHANGE

For the calculation process, the common clock differences (CCD) are obtained from the differential pseudo-ranges for P1 and P2 codes. The reference delay (REF DLY) is the only parameter to take into account in the TR, during the calibration of the replicated UTC(ROA).

Table 4-1: Raw CCD of 1st calibration of replicated UTC(ROA), all values in ns.

Pair	RAW ΔP1	TDEV (1 day)	RAW ΔP2	TDEV (1 day)
RO_5-TR01 (Old Lab)	-0.16	0.10	-2.58	0.10
RO_5-TR01 (New Lab)	-0.33	0.10	-2.65	0.10
Difference	**-0.17**	**-**	**-0.07**	**-**

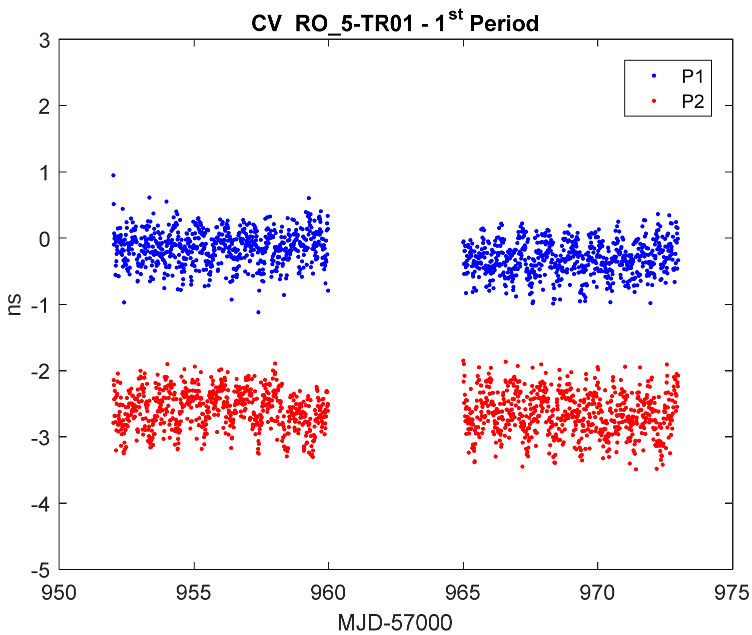


Figure 4-1: P1 and P2 CCD of first calibration of replicated UTC(ROA).

Table 4-2: Raw CCD of 2nd calibration of replicated UTC(ROA), all values in ns.

Pair	RAW ΔP1	TDEV (1 day)	RAW ΔP2	TDEV (1 day)
RO_5-TR01 (Old Lab)	-0.04	0.10	-2.66	0.10
RO_5-TR01 (New Lab)	0.04	0.10	-2.41	0.10
Difference	**0.08**	**-**	**-0.25**	**-**

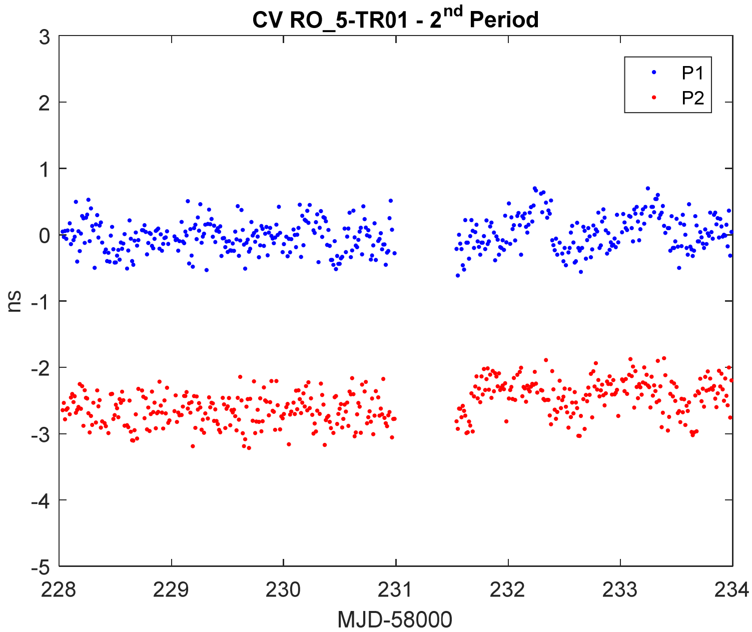


Figure 4-2: P1 and P2 CCD of second calibration of replicated UTC(ROA).

5. RECALIBRATION OF GPS RECEIVERS

The recalibration of GPS receivers was made in two phases. Initially, three receivers were transferred to the new Laboratory (RO_7, RO_9 and RO10), to be used as support for next calibrations, and once UTC(ROA) was moved, the remaining receivers were installed in their definitive position at new laboratory and recalibrated, as shown in the next hookup diagram. Some internal delay values significantly vary from the 2016 Group 1 GPS calibration trip [RD01], due to the update to the real antenna cable delay measurement.

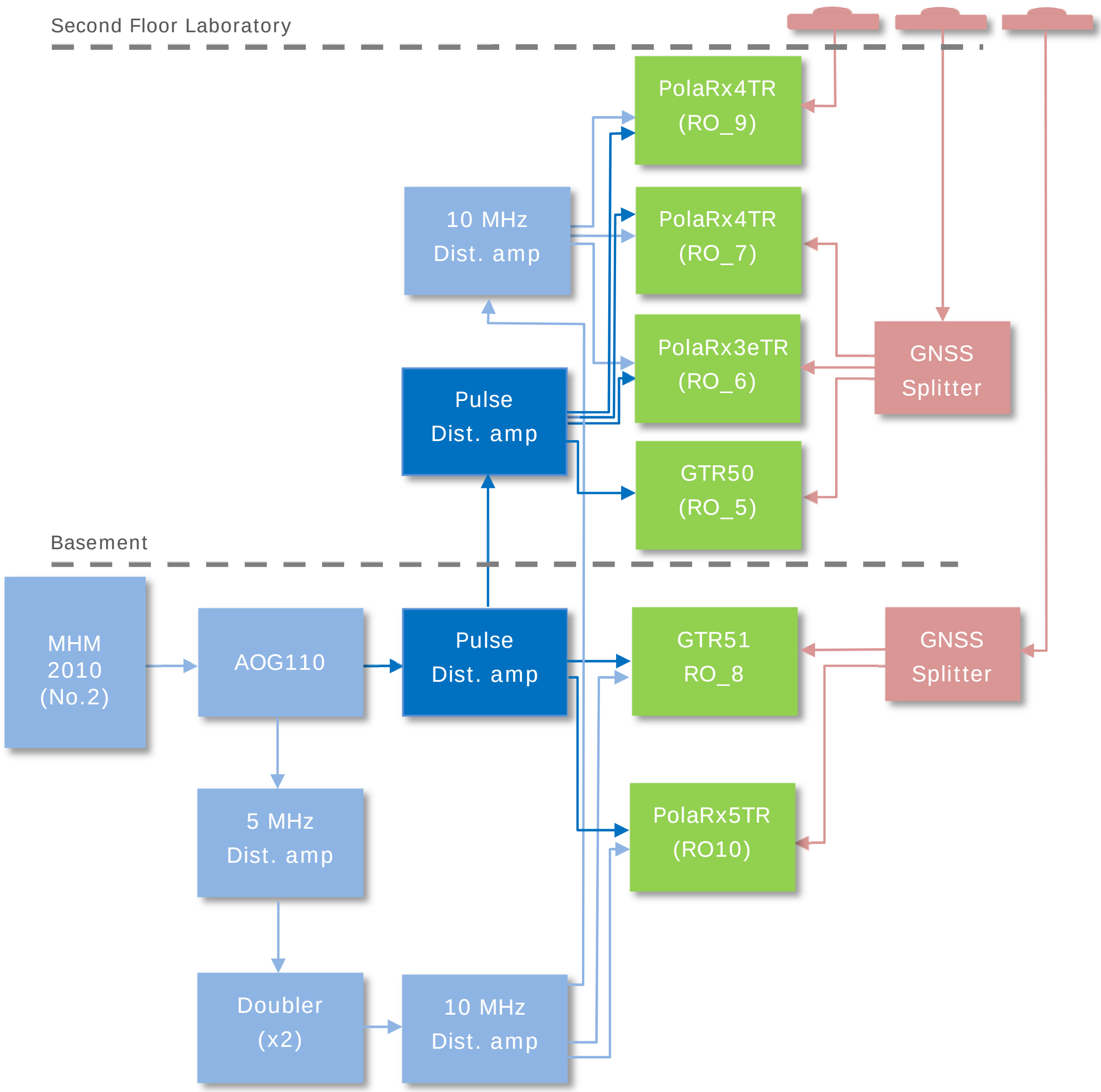


Figure 5-1: Hookup diagram of GNSS receivers.

Receivers C1 INT DLY values, have been calculated from the C1-P1 INT DLY differences obtained in the 2016 Group 1 GPS calibration trip [RD01].

Table 5-1. Recalibration results of ROA receivers, all values in ns.

Receiver	REF DLY	CAB DLY	INTDLY C1	u_{cal} C1	INT DLY P1	u_{cal} P1	INT DLY P2	u_{cal} P2
RO_5	306.6	91.5	8.5	0.7	10.3	0.7	27.3	0.7
RO_6	484.9	82.0	58.1	0.7	56.7	0.7	55.4	0.7
RO_7	452.1	89.9	58.2	0.7	56.9	0.7	55.7	0.7
RO_8	20.4	202.7	-18.9	0.7	-20.8	0.7	-21.1	0.7
RO_9	451.2	59.7	58.3	0.7	57.0	0.7	55.9	0.7
RO10	5.1	204.8	32.4	0.7	31.1	0.7	29.9	0.7

Table 5-2. Detailed information of antenna cable delay, all values in ns.

Receiver	Long low loss cable (LDF1-50)	Signal splitter	Pigtail cable (RG-58)	Total
RO_5	70.0	7	14.5	91.5
RO_6	70.0	7	5.0	82.0
RO_7	70.0	14	5.9	89.9
RO_8	180.5	13	9.2	202.7
RO_9	59.7	-	-	59.7
RO10	180.5	13	11.3	204.8

6. CALIBRATION OF TWSTFT STATIONS

In a similar way to GPS receivers, the move was carried out in two phases. Firstly, TW ROA02 station was installed on the second floor of the new building, and aligned to ROA01, using PTB05 station in odd hours. On MJD 58235, once UTC(ROA) was moved to the Time Laboratory, ROA02 assumed the main role of TW link in even hours. At the same time, ROA01 was installed in its new location, aligned to ROA02, and once again using PTB05 station in odd sessions. Finally, on MJD 58267 at 08:00 UTC, ROA01 station reassumed the operation in even sessions.

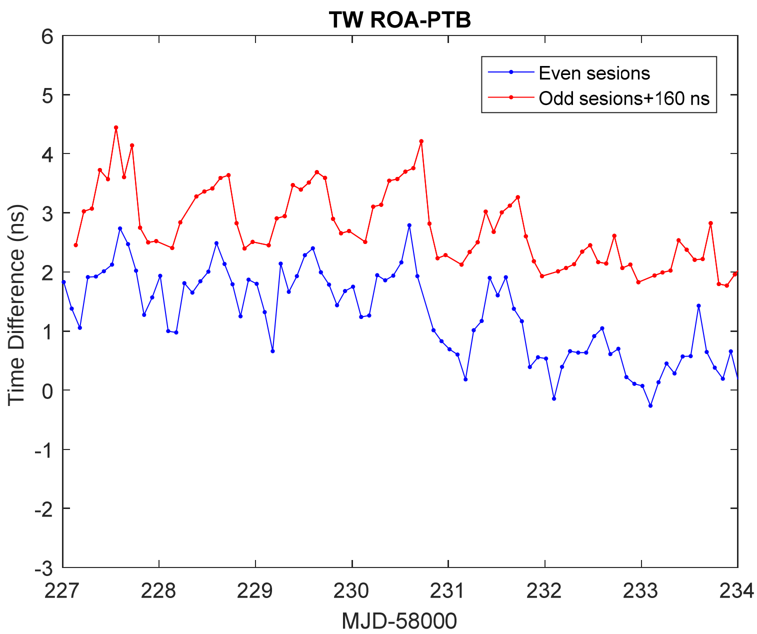


Figure 6-1: TW ROA-PTB results in odd and even hours.

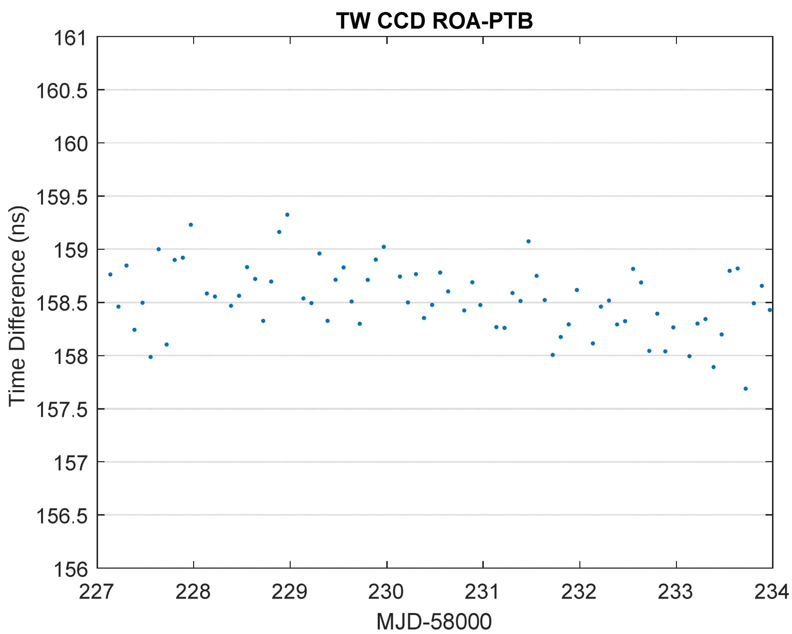


Figure 6-2: TW CCD ROA-PTB between odd and even hours.

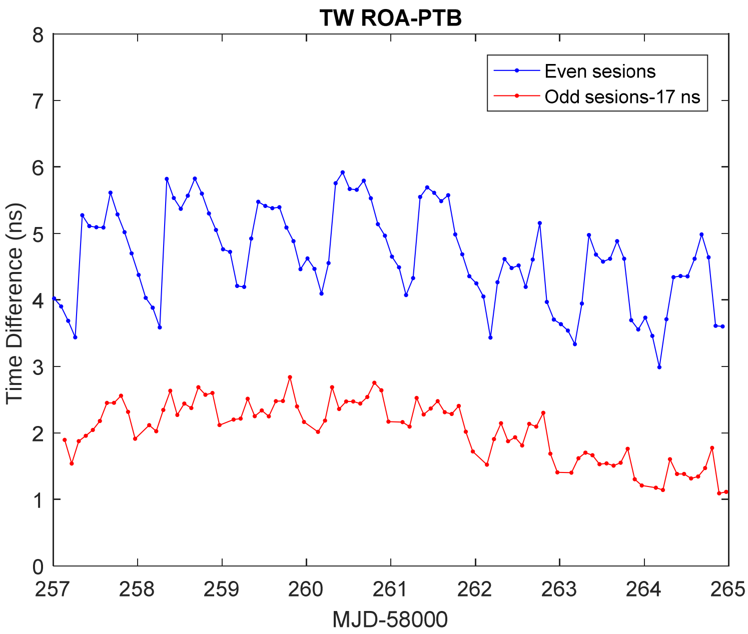


Figure 6-3: TW ROA-PTB results in odd and even hours, at new Lab.

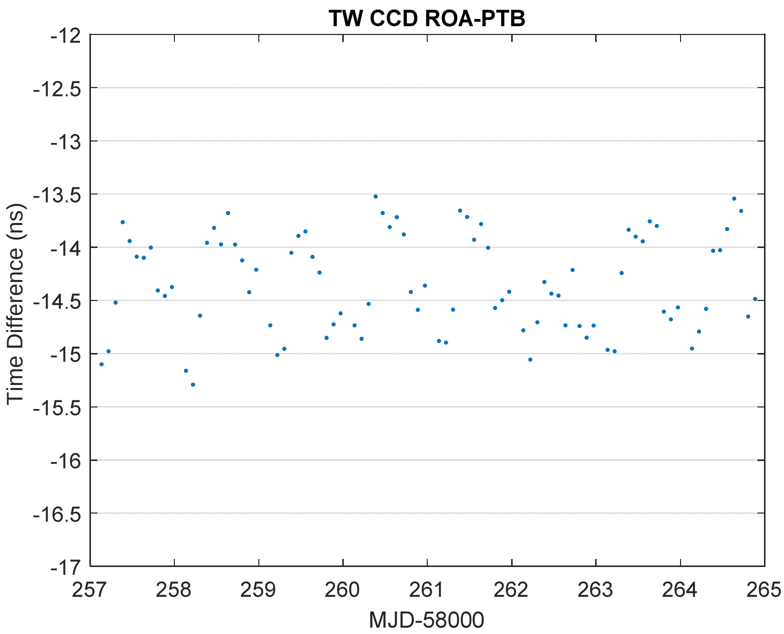


Figure 6-4: TW CCD ROA-PTB between odd and even hours, at new Lab.

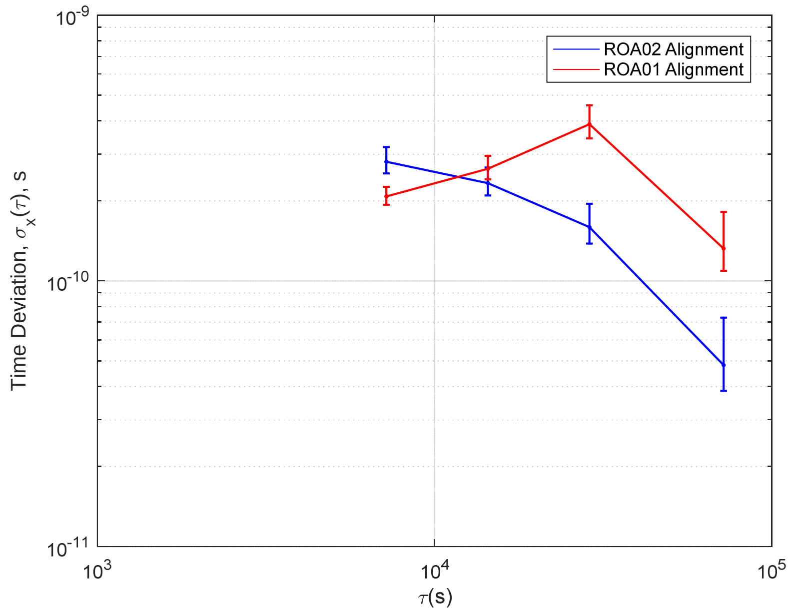


Figure 6-5: Time Deviation of TW CCD ROA-PTB between odd and even hours.

Table 6-1. Recalibration results of TW ROA stations, all values in ns.

Pair (Location)	RAW CCD	TDEV (1 day)	ESDVAR
ROA2-ROA01 (New - Old)	158.55	0.15	**317.10**
ROA2-ROA01 (New - New)	-14.37	0.15	**-28.73**

Figure 6-6: ROA01 and ROA02 stations at new Laboratory.

7. UNCERTAINTY ESTIMATION

The overall uncertainty of the UTC(ROA) change, as well as the uncertainty of the INT DLY values of GNNS receivers, 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. 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 Table **7**-**1**. Note that the uncertainty of the INT DLY values of ROA's fixed receiver, which served as the reference, is not included.

Table 7-1: 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
Systematic components due to antenna installation					
2	$u_{b,11}$	0.05	0.05	0.05	Position error of reference receiver
3	$u_{b,12}$	0.05	0.05	0.05	Position error of second receiver
4	$u_{b,13}$	0.10	0.10	0.10	Multipath at reference antenna
5	$u_{b,14}$	0.10	0.10	0.10	Multipath at second antenna
Installation of RO_5 and JV02 receivers					
6	$u_{b,21}$	0.20	0.20	0.20	Connection of reference receiver to UTC(ROA) (REF DLY)
7	$u_{b,22}$	0.20	0.20	0.20	Connection of second receiver to UTC(ROA) (REF DLY)
8	$u_{b,23}$	0.10	0.10	0.10	TIC nonlinearities at ROA
9	$u_{b,24}$	-	0.25	0.25	Calibrations misclosure of replicated UTC(ROA).

The uncertainty of the INT DLY values of GNNS receivers, is obtained from (1) and larger values of Table 5-1 (0.5 ns), due to the UTC(ROA) change, combined with the GPS alignment result, which generates again the same table, except for the last uncertainty (0.4 ns), that is, the overall uncertainty for GPS receivers have been established in 0.7 ns.

TW link uncertainty has been established by the combination of UTC(ROA) change (0.5 ns), and the two TW alignments carried out (0.22 ns), 0.6 ns in total.

8. ANNEX-A: CCD AND TDEV ANALYSIS

Figure 8-1: CCD (left column) and TDEV (right column). Calibration GPS Phase 1

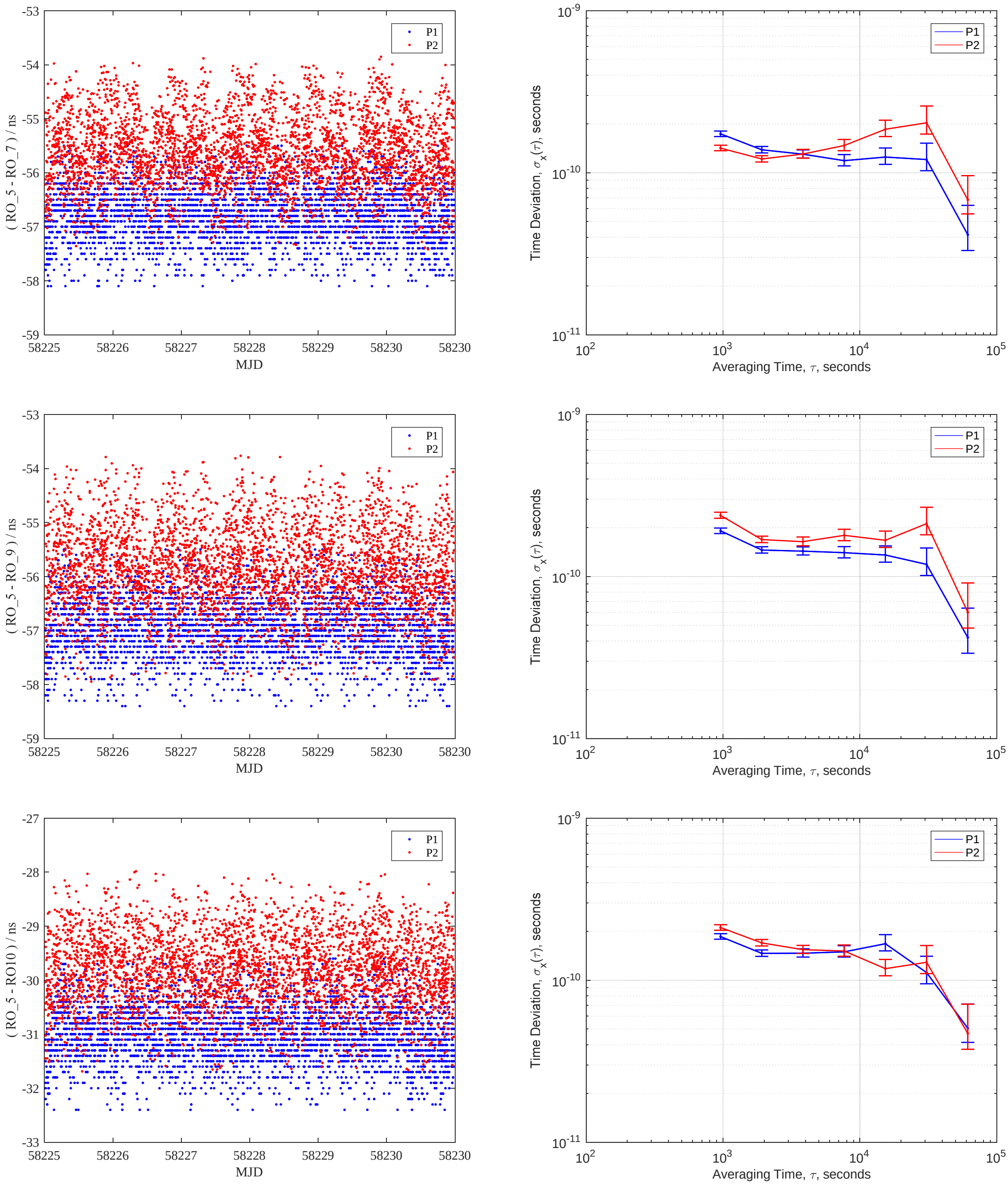
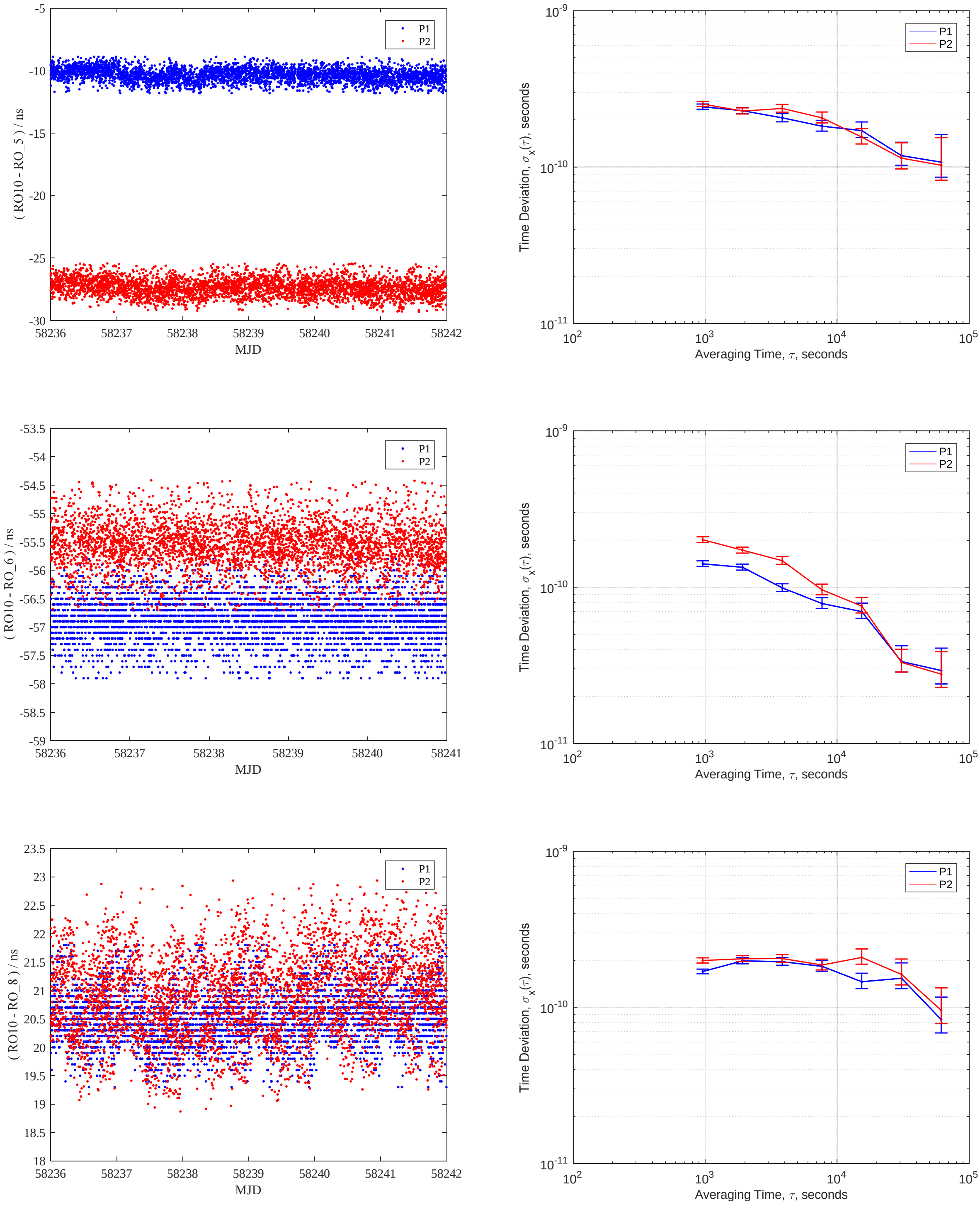


Figure 8-2: Calibration GPS Phase 2



Acknowledgement

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