GOBIERNO DE ESPAÑA
MINISTERIO DE DEFENSA
ARMADA ESPAÑOLA
REAL INSTITUTO Y OBSERVATORIO DE LA ARMADA

GNSS CALIBRATION REPORT

G1G2_1014-2017

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Authorized by: BIPM

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

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 GPS receiver relative calibration campaign, which took place between two European NMIs or DIs: SMD (Belgium) and NPL (United Kingdom).

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 1014_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	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.
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.
NPL	National Physical Laboratory, Teddington, UK.
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.
SMD	FPS Economy, Brussels, Belgium.
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.

Acronym	Definition
	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
SMD	Frank Coutereel Tel +32 2 277 91 72 Frank.Coutereel@economie.fgov.be	FPS Economy Directorate-General Quality and Safety National Standards North Gate, Boulevard du Roi Albert II, 16 B- 1000 Brussels, BELGIUM
NPL	Peter Whibberley Tel. +44 20 8943 6746 peter.whibberley@npl.co.uk	National Physical Laboratory Hampton Road Teddington Middlesex TW11 0LW, UK

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	TR	
ROA*	Group 1 reference	MJD: 57784-57789 31/01/17-05/02/17	DICOM GTR50	RO_5	RO_5
ROA	Group 1 reference	MJD: 57855-57859 12/04/17-16/04/17	DICOM GTR50	RO_5	RO_5
SMD	Group 2	MJD: 57869-57874 26/04/17-01/05/17	DICOM GTR50	SD01	SD01
SMD	Group 2	MJD: 57869-57874 26/04/17-01/05/17	PikTime TTS-4	SD21	SMDB
NPL	Group 2	MJD: 57878-57882 05/05/17-09/05/17	DICOM GTR50	NPL1	NPL1
NPL	Group 2	MJD: 57878-57882 05/05/17-09/05/17	DICOM GTR51	NPL2	NPL2
ROA	Group 1 reference	MJD: 57896-57902 23/05/17-29/05/17	DICOM GTR50	RO_5	RO_5

* Measurements of TR using 100 m antenna cable FSJ2-50. This cable was fixed mounted later at SMD to be used by TR during the calibration.

3. THE ROA TRAVELING EQUIPMENT

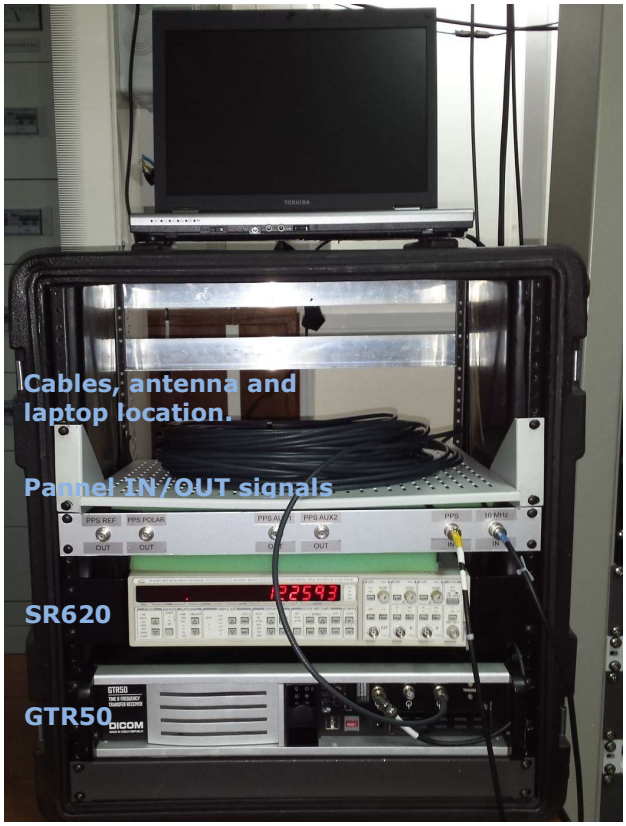
The traveling equipment consists of one shipping box containing the following items:

- 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 (1.9 m)
- 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

We have performed the calibration based on C1 and 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 in particular 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.

The calibration method is basically as follows. 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(C1), INTDLY(P1) and INTDLY(P2) values for the receivers in the visited Labs. The calibration procedure consists of building differential pseudo-ranges for each code C1, P1 and P2 between pairs of receivers in common-clock set-up, which can be easily obtained by using the data collected in C1 and also 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.

At SMD, instead of using the traveling antenna cable (60 m H155), a 100 m FSJ2-50 antenna cable was used. Initially the cable was sent to ROA, to align the TR with this set-up to the reference receiver, and then fixed mounted at SMD to be used by TR during the calibration.

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 we have used an ROA-authored program, in which the common clock differences (CCD) are obtained from the common-view of CGGTTS files. 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, we have obtained the internal delays of 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 , 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, new files have been generated from the RINEX files according to the first paragraph. For the SD01 and NPL2 DICOM receivers all values used are null, since the RINEX files are already corrected by the total delay, so the raw CCD values in Table 5-2 are corrections with respect to the initial internal delay values. For the NPL1 GTR50 receiver all internal values were null at the moment of calibration, because it has not been calibrated since a major repair in 2016, and so its RINEX files were treated as for a standard receiver.

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
SMD	SD01	-29.4	-34.7	-24.1	15.0	392.2
	SD21	-24.26	-24.26	-24.26	19.1	400.6
NPL	NPL1	0	0	0	70.1	251.5
	NPL2	0	0	0	68.6	261.2

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-SD01	6.32	0.04	1.94	0.07	5.63	0.03
TR-SD21	-8.09	0.06	-6.46	0.06	-5.05	0.04
TR-NPL1	34.99	0.05	35.48	0.07	26.74	0.04
TR-NPL2	21.95	0.05	23.91	0.05	23.34	0.06

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 relatively small (below 0.3 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)	-0.02	0.07	-0.01	0.07	0.01	0.06
TR-RO_5 (after the trip)	0.24	0.09	0.28	0.09	0.10	0.10
Misclosure	-0.26		-0.29		-0.09	
Mean	0.13		0.15		0.05	

6. UNCERTAINTY ESTIMATION

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

$$u_{CAL} = \sqrt{u_a^2 + u_b^2} \quad \text{with} \tag{1}$$

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 the 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 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	$u_{b,1}$	0.26	0.29	0.09	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	$u_{b,25}$	0.10	0.10	0.10	TIC nonlinearities at ROA
13	$u_{b,26}$	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 both antennas in the same way, so the time transfer error associated with this factor is quite small.

7. FINAL RESULTS

The results of the calibration campaign G1G2_1014_2017 are summarized in Table 7-1. INTDLY C1 new values have been calculated from (the same for P1 and P2 codes):

$$\text{INTDLY C1 new} = \text{INTDLY C1 old} - \Delta C1(T,V) + \Delta C1(T,R)$$

Table 7-1. Results of the Calibration Campaign G1G2_1014_2017, all values in ns.

Receiver (V)	INTDLY C1 Old	INTDLY P1 old	INTDLY P2 old	ΔC1 (T,V)	ΔP1 (T,V)	ΔP2 (T,V)	ΔC1 (T,R)	ΔP1 (T,R)	ΔP2 (T,R)	REFDLY	CABDLY	INTDLY C1 new	u_{cal} C1	INTDLY P1 new	u_{cal} P1	INTDLY P2 new	u_{cal} P2
SD01	0	0	0	6.32	1.94	5.63	0.13	0.15	0.05	15.0	392.2	-6.2	0.6	-1.8	0.6	-5.6	0.5
SD21*	-24.26	-24.26	-24.26	-8.09	-6.46	-5.05	0.13	0.15	0.05	19.1	400.6	-16.0	0.6	-17.7	0.6	-19.2	0.5
NPL1	0	0	0	34.99	35.48	26.74	0.13	0.15	0.05	70.1	251.5	-34.9	0.6	-35.3	0.6	-26.7	0.5
NPL2	0	0	0	21.95	23.91	23.34	0.13	0.15	0.05	68.6	261.2	-21.8	0.6	-23.8	0.6	-23.3	0.5

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

* The results are valid only as long as the set-up is not changed.

8. ANNEX-A

8.1. CALIBRATION INFORMATION SHEET AT ROA

Laboratory:	ROA
Date and hour of the beginning of measurements:	31.01.2017
Date and hour of the end of measurements:	05.02.2017

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	(407.8 ± 0.3) ns FSJ2-50
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 %

Laboratory:	ROA
Date and hour of the beginning of measurements:	12.04.2017
Date and hour of the end of measurements:	16.04.2017

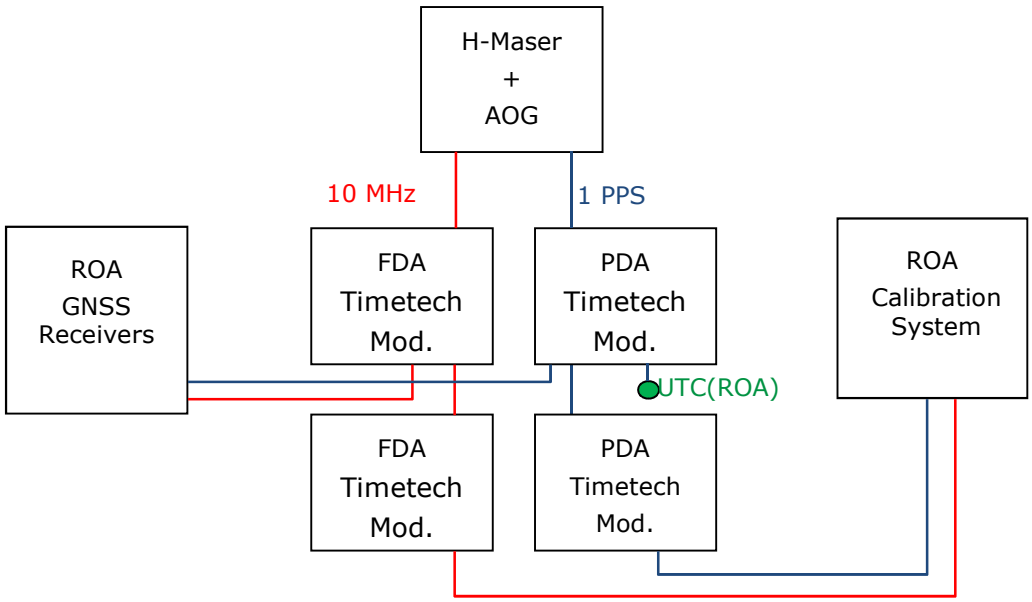
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	RO_5	
• Receiver maker and type: Receiver serial number:	DICOM GTR50 0601012	DICOM GTR50 SN: 0802017
1 PPS trigger level /V:	1 V	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	LMR-400	
Length outside the building /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 SMD

Laboratory:	SMD
Date and hour of the beginning of measurements:	26.04.2017
Date and hour of the end of measurements:	01.05.2017

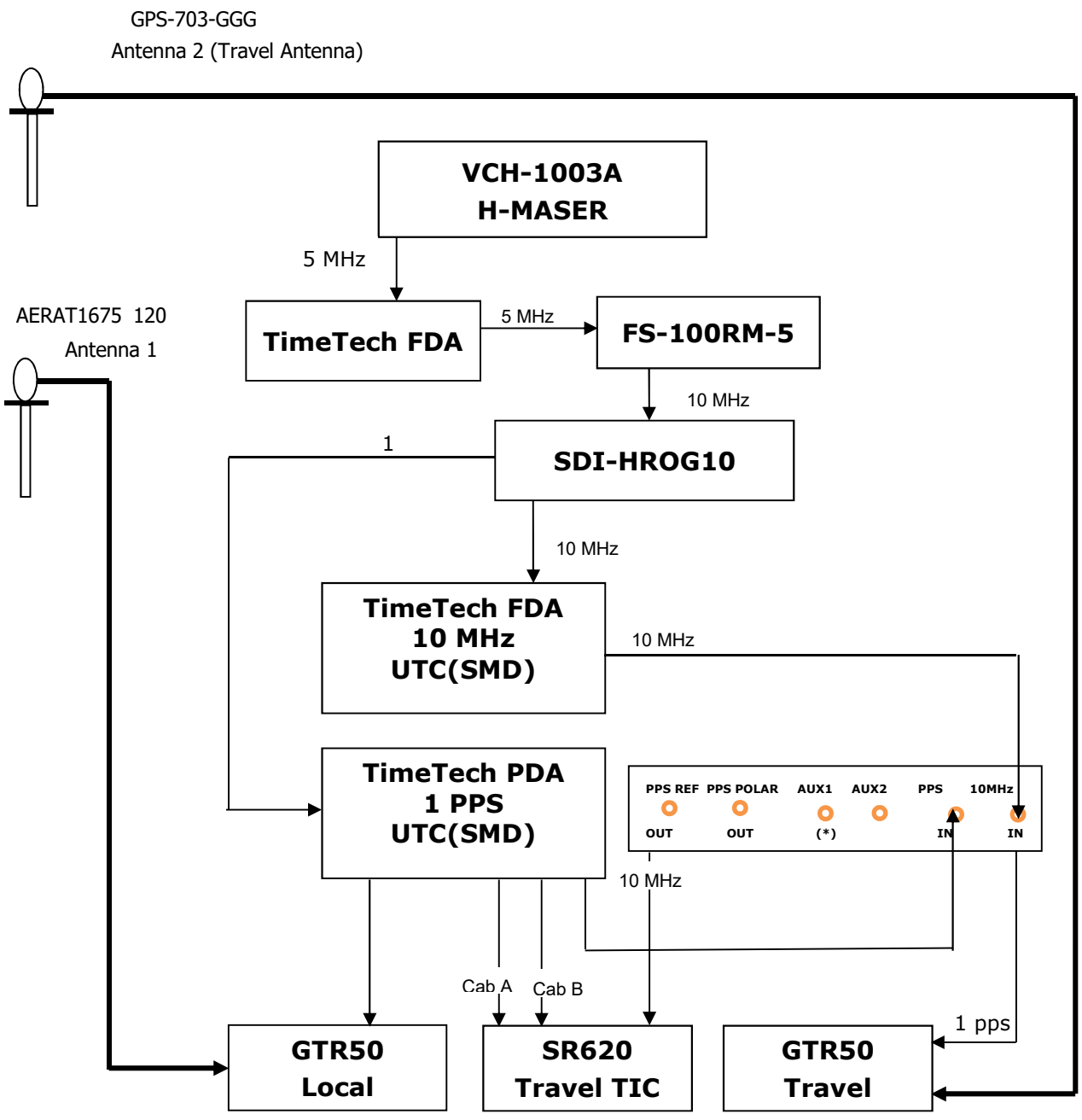
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	SD01	
• Receiver maker and type: Receiver serial number:	GTR50 receiver – Czech SW: 1.7.7 0807182	DICOM GTR50 SN: 0802017
1 PPS trigger level /V:		
• Antenna cable maker and type: Phase stabilised cable (Y/N):	HELIAX® Coaxial Cable - 50-ohm, Foam Dielectric	
Length outside the building /m:	Approximately 100 m	Approximately 16 m
• Antenna maker and type: Antenna serial number:	AERAT1675_120 SPKE 5007	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C		

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	15.20 ns ± 0.1 ns	(9.5 ± 0.1) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		
• Antenna cable delay: Antenna cable type:	392.2 ns ± 0.9 ns	(407.8 ± 0.3) ns FSJ2-50
Splitter delay (if any):		
Additional cable delay (if any):		

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	-34.7 ns (GPS P1), -24.1 ns (GPS P2):
• INT DLY (GLONASS) /ns:	NA
• CAB DLY /ns:	392.2 ns
• REF DLY /ns:	15.0 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	+4022663.64 m
Longitude or Y /m:	+306407.81 m
Height or Z /m:	+4923692.20 m

General information	
• Rise time of the local UTC pulse:	< 3 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(22 ± 0.5) °C
Set humidity value and uncertainty:	(50 ± 10) %

Diagram of the experiment set-up:



(*): travel equipment (signal distribution panel)

Laboratory:	SMD
Date and hour of the beginning of measurements:	26.04.2017
Date and hour of the end of measurements:	01.05.2017

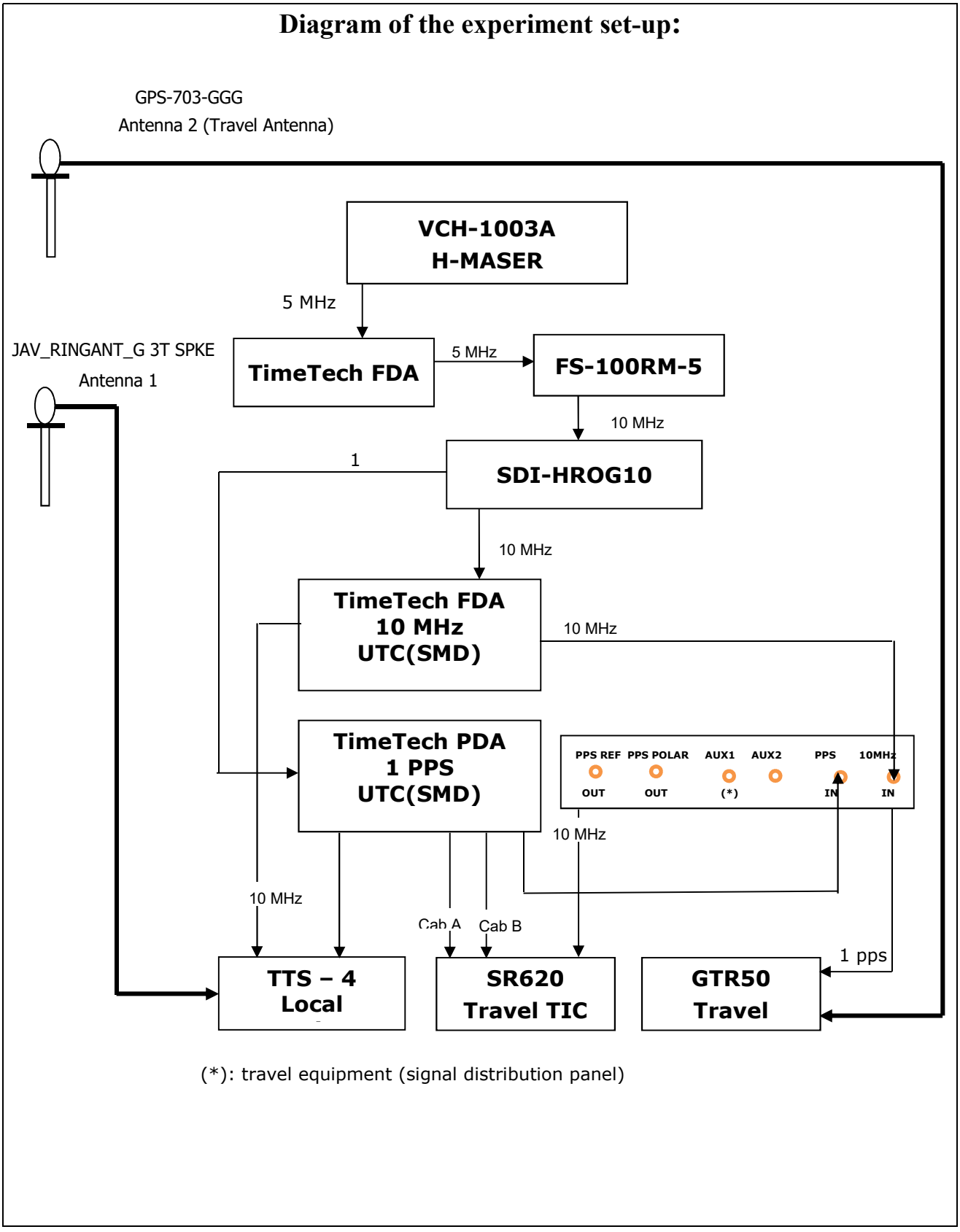
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	SMDB	
• Receiver maker and type: Receiver serial number:	PikTime Systems – Poland, TTS4 (HW:133.32, SW:2.38) 0125	GTR50 receiver SN: 0802017
1 PPS trigger level /V:		
• Antenna cable maker and type: Phase stabilised cable (Y/N):	HELIAX® Coaxial Cable - 50-ohm, Foam Dielectric	FSJ2RK-50, HELIAX® Superflexible, 3/8 in.
Length outside the building /m:	Approximately 100 m	Approximately 100 m
• Antenna maker and type: Antenna serial number:	JAV_RINGANT_G3T NONE 00397	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C		GTR50 receiver SN: 0802017

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	19.10 ns ± 0.2 ns	(9.5 ± 0.1) ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		
• Antenna cable delay: Antenna cable type:	400.60 ns ± 0.9 ns	(407.8 ± 0.3) ns FSJ2-50
Splitter delay (if any):		
Additional cable delay (if any):		

Data used for the generation of CGGTTS files	
• INT DLY (GPS) /ns:	GPS: L1C:-24.26 L2C:-24.26 L1P:-24.26 L2P:-24.26 L5P:-24.26
• INT DLY (GLONASS) /ns:	GLO: L1C:-229.09 L2C:-229.09 L1P:-229.09 L2P:-229.09
• CAB DLY /ns:	400.60 ns
• REF DLY /ns:	19.10 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	+4022663.85 m
Longitude or Y /m:	+306408.71 m
Height or Z /m:	+4923691.92 m

General information	
• Rise time of the local UTC pulse:	< 3 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(22 ± 0.5) °C
Set humidity value and uncertainty:	(50 ± 10) %

Diagram of the experiment set-up:



(*): travel equipment (signal distribution panel)

8.3. CALIBRATION INFORMATION SHEET AT NPL

Laboratory:	NPL
Date and hour of the beginning of measurements:	05.05.2017
Date and hour of the end of measurements:	09.05.2017

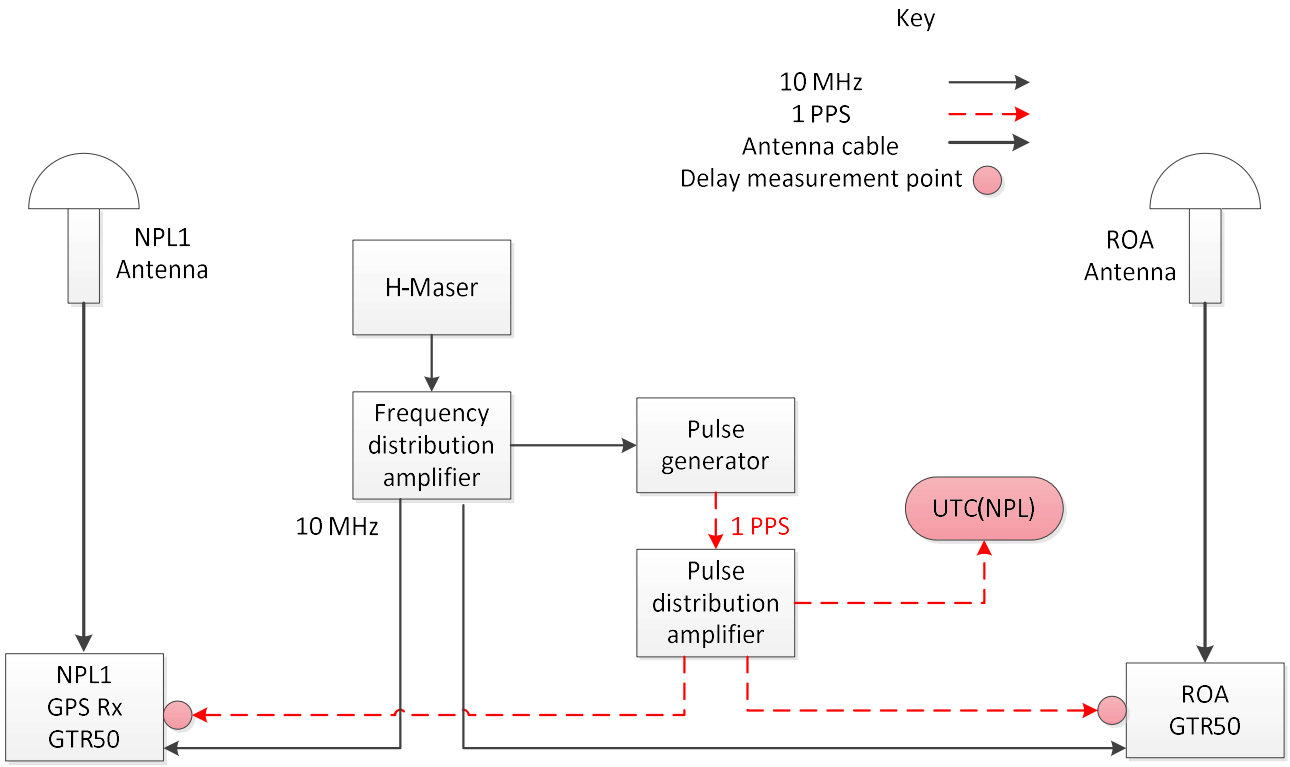
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	NPL1	
• Receiver maker and type: Receiver serial number:	Dicom GTR50 0807183	DICOM GTR50 0802017
1 PPS trigger level /V:	1.00	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Andrew Heliax FSJ1-50A cable Y	
Length outside the building /m:	Approximately 6 m	Approximately 7 m (plus approximately 30 m in a roof space with no temperature control)
• Antenna maker and type: Antenna serial number:	(plus approximately 30 m in a roof space with no T. control) Novatel GPS-702	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C		

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	70.1 ns ± 0.5 ns	60.7 ns ± 0.5 ns
Delay from 1 PPS-in to internal Reference (if different):		
• Antenna cable delay: Antenna cable type:	251.5 ns ± 0.5 ns	263.8 ns ± 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:	
• INT DLY (GLONASS) /ns:	
• CAB DLY /ns:	
• REF DLY /ns:	
• Coordinates reference frame:	
Latitude or X /m:	3985120.38
Longitude or Y /m:	-23893.87
Height or Z /m:	4963240.36

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

Diagram of the experiment set-up:



Laboratory:	NPL
Date and hour of the beginning of measurements:	05.05.2017
Date and hour of the end of measurements:	09.05.2017

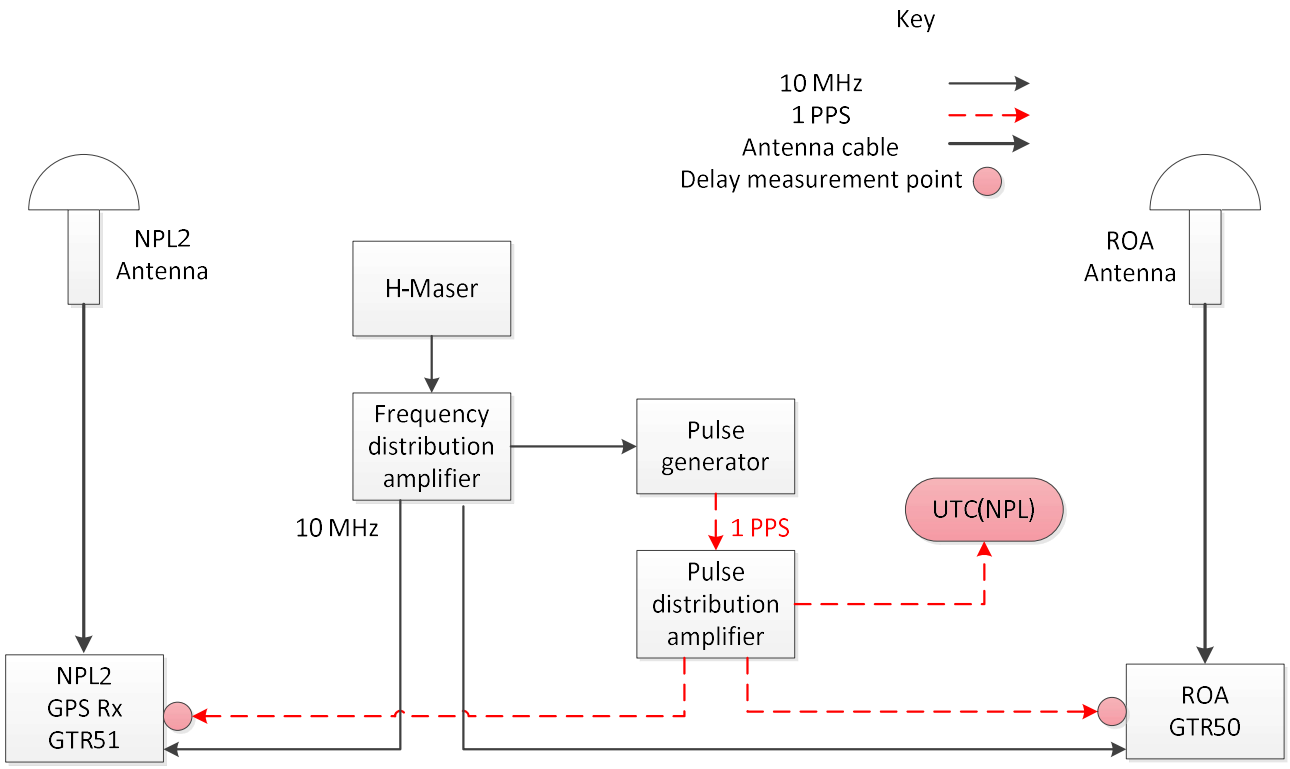
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	NPL2	
• Receiver maker and type: Receiver serial number:	Mesit GTR51 1401406	DICOM GTR50 0802017
1 PPS trigger level /V:	1.0	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	Andrew Heliax FSJ1-50A cable Y	
Length outside the building /m:	Approximately 4 m (plus approximately 30 m in a roof space with no temperature control)	Approximately 7 m (plus approximately 30 m in a roof space with no temperature control)
• Antenna maker and type: Antenna serial number:	Novatel NOV703GGG.R2 NEG13440006	Novatel antenna GPS-703-GGG NEG15300017
Temperature (if stabilized) /°C		

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:	68.6 ns ± 0.5 ns	60.7 ns ± 0.5 ns
Delay from 1 PPS-in to internal Reference (if different):		
• Antenna cable delay: Antenna cable type:	261.2 ns ± 0.5 ns	263.8 ns ± 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:	
• INT DLY (GLONASS) /ns:	
• CAB DLY /ns:	261.2 ns
• REF DLY /ns:	68.6 ns
• Coordinates reference frame:	
Latitude or X /m:	3985120.38
Longitude or Y /m:	-23893.87
Height or Z /m:	4963240.36

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

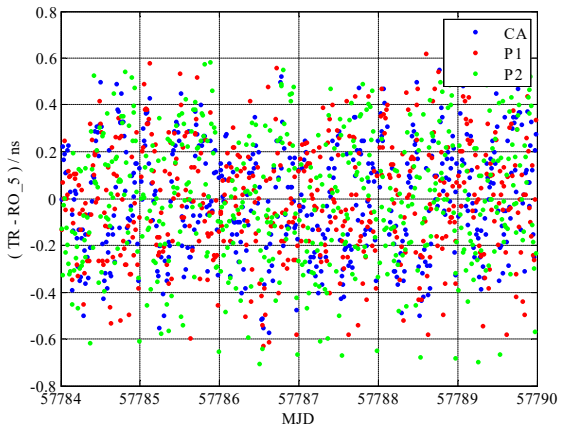
Diagram of the experiment set-up:

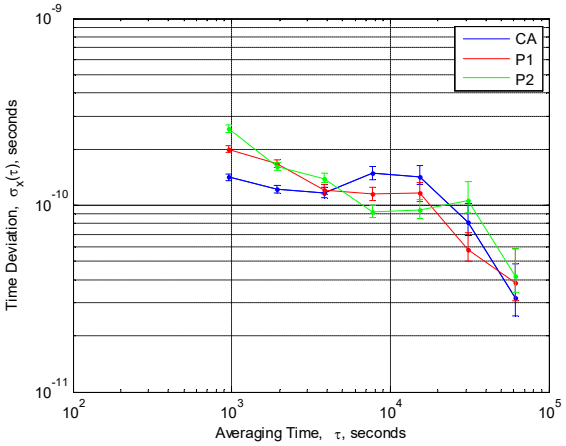


9. ANNEX-B: CCD and TDEV analysis at each Lab

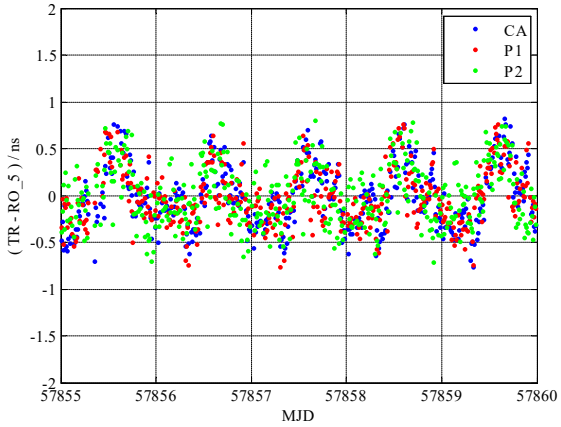
Figure 9-1: CCD (left column) and TDEV (right column) at ROA

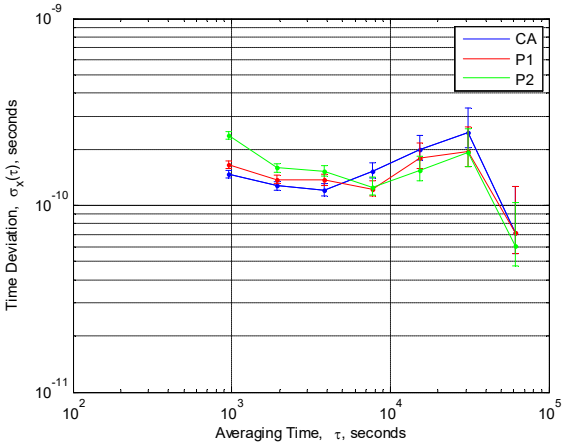
Before de calibration trip (SMD Set-up)



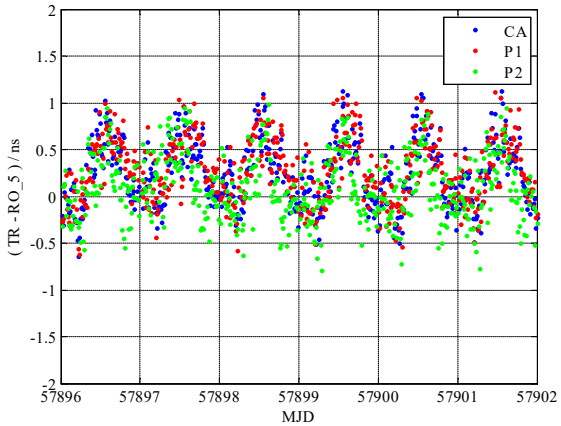


Before de calibration trip (NPL Set-up)





After the calibration trip (NPL Set-up)



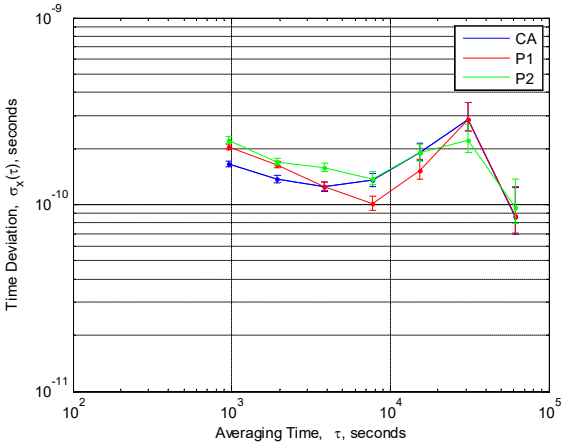
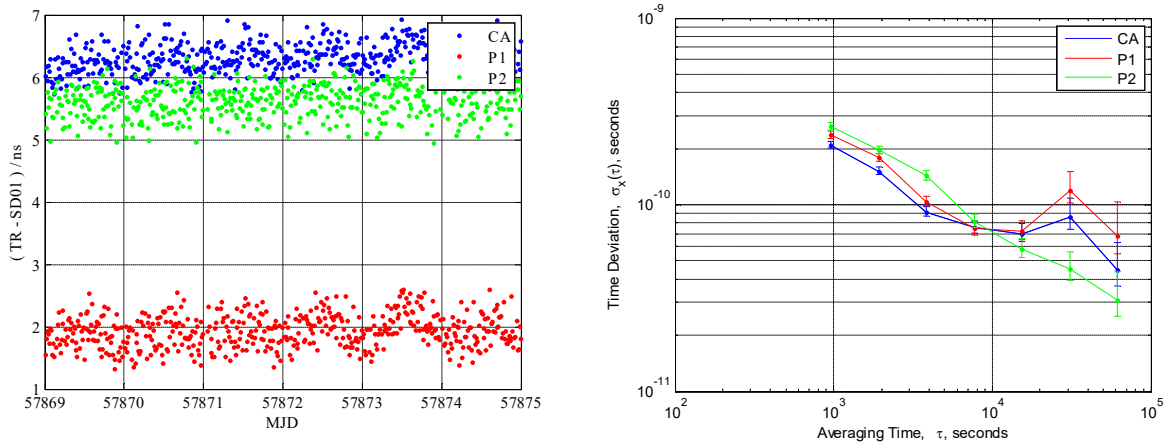


Figure 9-2: CCD and TDEV at SMD



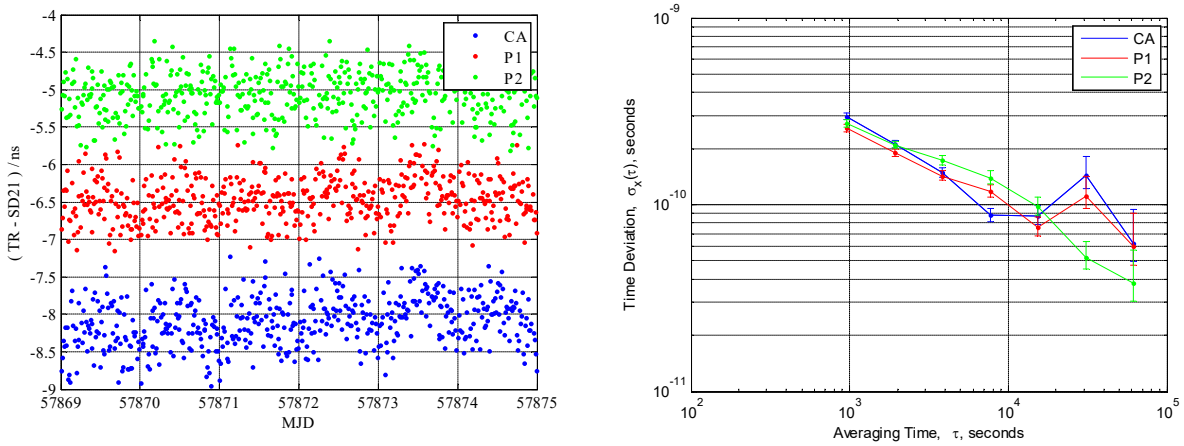
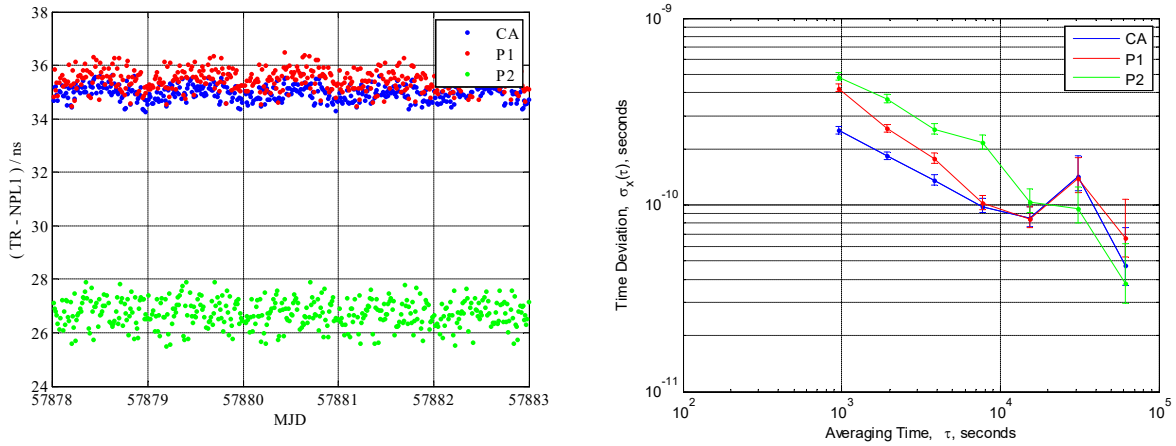
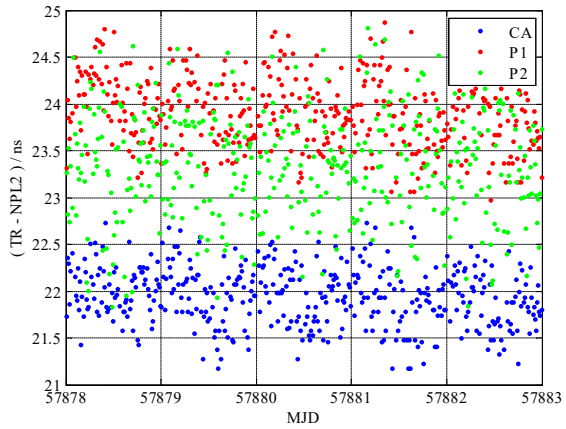
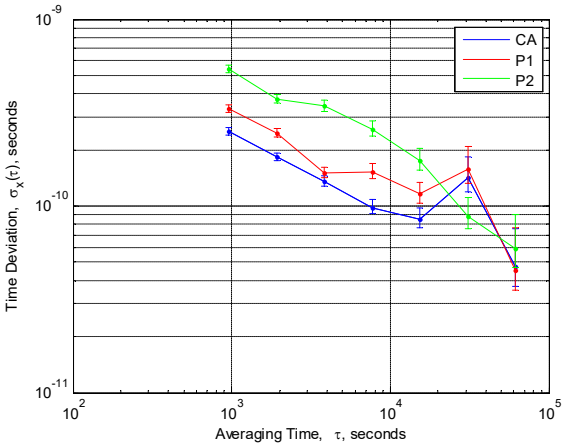


Figure 9-3: CCD and TDEV at NPL




CA
P1
P2
(TR - NPL2) / ns
MJD
25
24.5
24
23.5
23
22.5
22
21.5
21
57878
57879
57880
57881
57882
57883


CA
P1
P2
Time Deviation, σx(τ), seconds
Averaging Time, τ, seconds
10-9
10-10
10-11
102
103
104
105

Acknowledgement

We are grateful to P. Defraigne (ROB) for providing the R2CGGTTS Software, and to Natural Resources Canada (NRCan) for the use of their Precise Point Positioning (PPP) software for positioning computations.

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END OF DOCUMENT