GNSS CALIBRATION REPORT

G1G2_1201-2020

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Real Instituto y Observatorio de la Armada, San Fernando, Spain, September 2020.

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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 EURAMET G1 laboratory, has organized a new GPS receiver relative calibration this year but, unlike other occasions, the whole SMD station (receiver + antenna + antenna cable) was sent to ROA, to perform a differential calibration without closure, with respect to the ROA reference receiver RO_9, which was previously calibrated and reported last year (Cal_Id=1001-2018 [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 complies as much as possible the BIPM guidelines for GNSS calibrations [RD02]. The results will be reported using Cal_Id 1201_2020, and they will provide the SMD receiver's internal delays for GPS C1, P1 and P2 code signals, as well as E1 and E5a Galileo signals.

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 sent by SMD.

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 1001-2018 V2.0 / 20200620, subject: 2018 Group 1 GPS 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	J. Kouba, P. Heroux, 2002, Precise Point Positioning Using IGS Orbit and Clock Products, GPS Solutions, Vol. 5, No. 2, pp. 12-28.
RD05	PolaRx5TR user manual version 1.1. Applicable to version 5.1 of the receiver firmware, November 30, 2016.

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.
SMD	Belgian National Metrology Institute.
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].

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

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

Institute	Dates of measurements	Status of equipment	Receiver type	BIPM (CGGTTS)	RINEX name
ROA	MJD: 59094-59100 02/09/20-08/09/20	Group 1 reference	Septentrio PolaRx4TR PRO	RO_9	RO_9
		Group 2	Septentrio PolaRx5TR	SD31	SMDC

3. THE SMD TRAVELING STATION

The SMD equipment involved in the calibration:

- 1 PolaRx5TR receiver SN: 4701240
- 1 PolaNt Choke Ring B3/E6 antenna SN: 5264

For calibration purposes only, 16 m (70.3 ns) RG-213 low-loss antenna cable from ROA was used to support this exercise.

Figure 3-1: Choke Ring B3/E6 antenna on the roof of ROA laboratory.

Figure 3-2: PolaRx5TR receiver inside the ROA laboratory.

4. CALIBRATION PROCEDURE

The calibration has been performed based in GPS C1, P1, P2 and Galileo E1, E5a observations provided in the RINEX V.3.0.4 observation files, that is, using all the GPS/Galileo satellites in view, at 30 seconds time intervals. They 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_9), are obtained internal delays code values outlined above for the SMD receiver. The calibration procedure consists on building differential pseudo-ranges for each code between the two receivers in common-clock set-up.

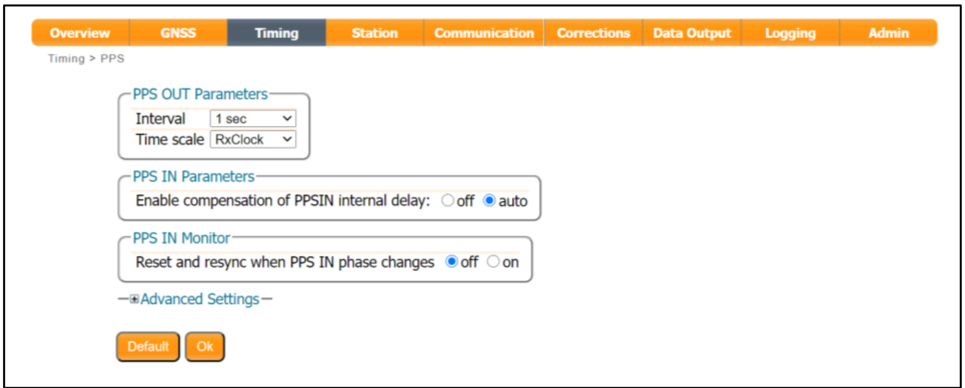
The 10 MHz frequency reference input signal was attenuated to 0.6 Vpp amplitude, in order to enable the ranging from 0.25 Vpp to 1Vpp on 50 ohms load impedance [RD05].

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 (GPS C1, P1, P2 and Galileo E1, E5a). For SMD receiver, the coordinates of the antenna have been carefully calculated from RINEX files for the calibration period.

As was stated before, from the known delays of the reference receiver RO_9 were obtained the internal delays of the PolaRx5TR receiver. The reference delay (REF DLY) was also measured directly from the PPS IN signal, once selected ‘auto’ mode to enable automatic PPS IN internal delay compensation:

Figure 5-1: Auto-compensation PPS IN internal delay mode activated



The receiver was restarted at the beginning and the end of the calibration. After approximately 20 minutes from the start, the internal delay calibration compensation is completed, and the ‘Receiver Messages’ window provides a value for the internal calibration (for information purposes only, not used in the calibration), which were very similar on both occasions:

```
[Wed 2020-09-02 08:56:26] PPS IN: Calibration done. Measurements shifted by 29.81ns.
[Mon 2020-09-07 09:48:24] PPS IN: Calibration done. Measurements shifted by 29.75ns.
```

Table 5-1 and 5-2 summarize the CCD values.

Table 5-1: GPS raw common clock differences, all values in ns.

Pair	RAW ΔC1	TDEV (1 day)	RAW ΔP1	TDEV (1 day)	RAW ΔP2	TDEV (1 day)
RO_9-SMDC	-31.20	0.05	-29.18	0.04	-24.93	0.06

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

Pair	RAW ΔE1	TDEV (1 day)	RAW ΔE5a	TDEV (1 day)
RO_9-SMDC	-31.04	0.05	-32.16	0.04

6. UNCERTAINTY ESTIMATION

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

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

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

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

The contributions to the sum (2) are listed and explained subsequently in Table 6-1. Note that the uncertainty of the INT DLY values of ROA's fixed receiver RO_9, 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	Value E1 ns	Value E5a ns	Description
1	$u_{a(ROA)}$	0.05	0.04	0.06	0.05	0.04	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	0.05	0.05	Position error of RO_9 receiver
3	$u_{b,12}$	0.05	0.05	0.05	0.05	0.05	Position error of SMDC receiver
4	$u_{b,13}$	0.10	0.10	0.10	0.10	0.10	Multipath at RO_9 antenna
5	$u_{b,14}$	0.10	0.10	0.10	0.10	0.10	Multipath at SMDC antenna
Installation of RO_9 and SMDC receivers							
6	$u_{b,21}$	0.50	0.50	0.50	0.50	0.50	Connection of RO_9 to UTC(ROA) (REF DLY)
7	$u_{b,22}$	0.50	0.50	0.50	0.50	0.50	Connection of SMDC to UTC(ROA) (REF DLY)
7	$u_{b,23}$	0.50	0.50	0.50	0.50	0.50	Connection of SMDC to UTC(SMD) (REF DLY)
8	$u_{b,24}$	0.50	0.50	0.50	0.50	0.50	ROA antenna delay used for calibration purposes (ANT DLY)
9	$u_{b,25}$	0.60	0.60	0.60	0.60	0.60	Fixed antenna cable delay at SMDC (ANT DLY)
10	$u_{b,26}$	0.10	0.10	0.10	0.10	0.10	TIC nonlinearities at ROA

7. FINAL RESULTS

The results of the calibration campaign G1G2_1201_2020 are summarized in Table 7-1. INTDLY and associated uncertainty C1 values have been calculated from Table 5.1 and Table 6.1, respectively, rounded to the tenth of a nanosecond (the same for GPS P1, P2 and Galileo E1, E5a codes):

INTDLY C1 = - ∆C1

Table 7-1. GPS calibration results, 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
SMDC	10.1	407.8	31.2	1.2	29.2	1.2	24.9	1.2

Table 7-2. Galileo calibration results, all values in ns.

Receiver	REF DLY*	CAB DLY**	INTDLY E1	u_{cal} E1	INT DLY E5a	u_{cal} E5a
SMDC	10.1	407.8	31.0	1.2	32.2	1.2

* At SMD, in auto-compensation PPS IN internal delay mode operation.
** 100 m HELIAX FSJ2-50 antenna cable calibrated at ROA in 2017 and installed at SMD since then.

8. ANNEX-A

8.1. CALIBRATION INFORMATION SHEET AT ROA

Laboratory:	ROA
Date and hour of the beginning of measurements:	02.09.2020
Date and hour of the end of measurements:	08.09.2020

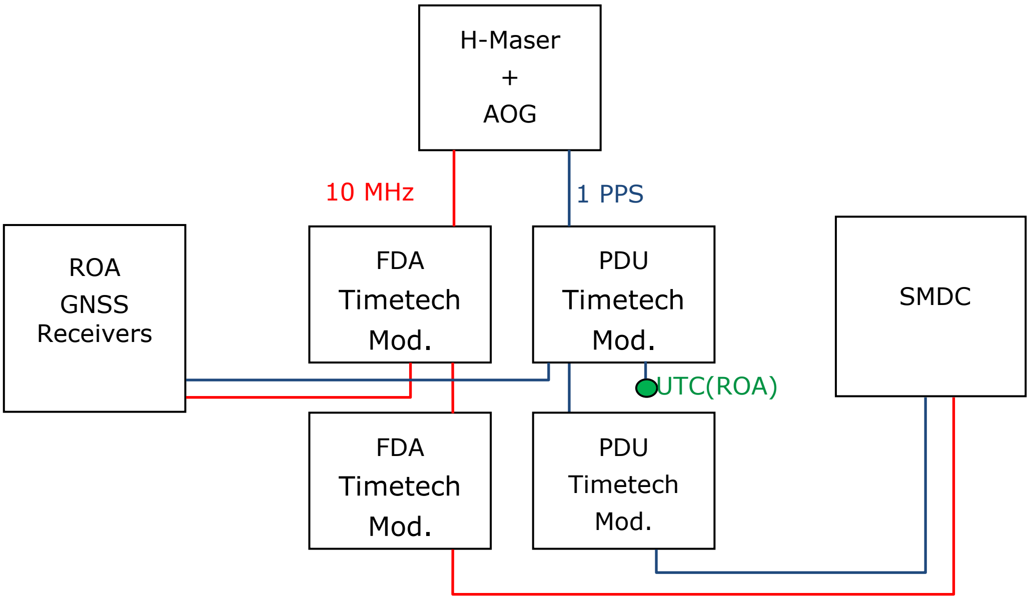
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	RO_9	SMDC
• Receiver maker and type: Receiver serial number:	Septentrio PolaRx4TR PRO 3008013	Septentrio PolaRx5TR 4701439
1 PPS trigger level /V:	1 V	1 V
• Antenna cable maker and type: Phase stabilised cable (Y/N):	LDF1RK-50	RG-213
Length outside the building /m:	Approximately 20 m	Approximately 16 m
• Antenna maker and type: Antenna serial number:	LEICA AR25 726362	PolaNt Choke Ring B3/E6 5764

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in:		287.1 ns
Delay from 1 PPS-in to internal Reference (if different): (see section 2 for details)		
• Delay from local UTC to receiver 1 PPS-out:	451.8 ns	
• Antenna cable delay: Antenna cable type:	59.7 ns	70.3 ns (ROA support cable)

Data used for the generation of RO_9 CGGTTS files	
• INT DLY (GPS) /ns:	56.9 ns (C1) 55.5 ns (P1) 54.4 ns (P2)
• INT DLY (GALILEO) /ns:	56.2 ns (E1) 65.3 ns (E5a)
• CAB DLY /ns:	59.7 ns
• REF DLY /ns:	451.8 ns
• Coordinates reference frame:	ITRF
Latitude or X /m:	5105582.90 m
Longitude or Y /m:	-555191.22 m
Height or Z /m:	3769703.66 m

General information	
• Rise time of the local UTC pulse:	0.5 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	(22 ± 2) °C
Set humidity value and uncertainty:	< 70 %

Diagram of the experiment set-up at ROA:



9. ANNEX-B: CCD and TDEV analysis at ROA

Figure 9-1: GPS common clock differences (CCD) at ROA

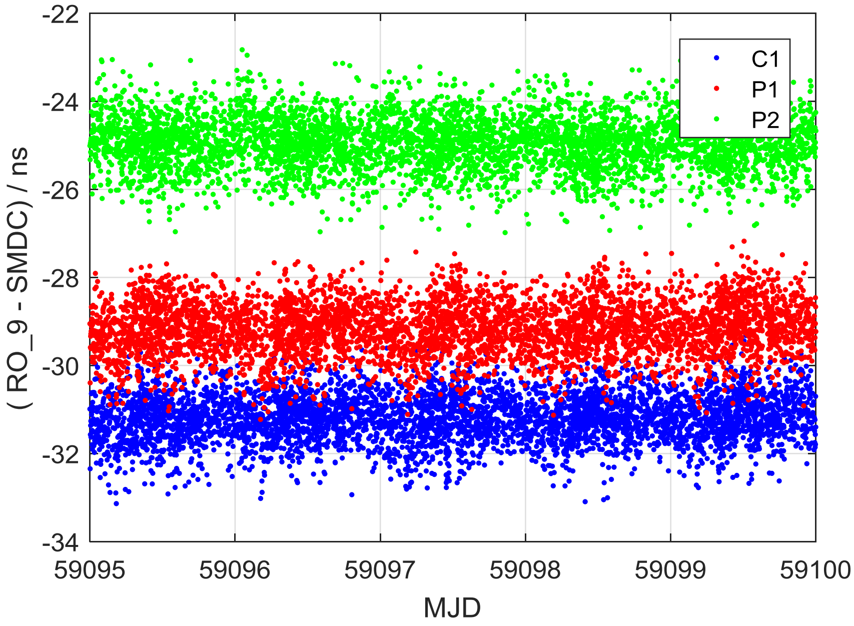


Figure 9-2: GPS time deviation of CCD

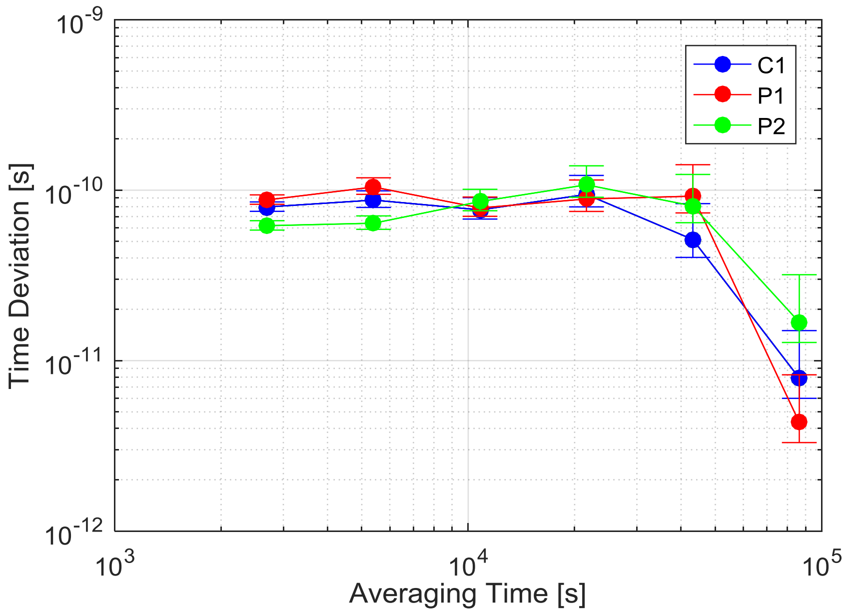


Figure 9-3: Galileo common clock differences (CCD) at ROA

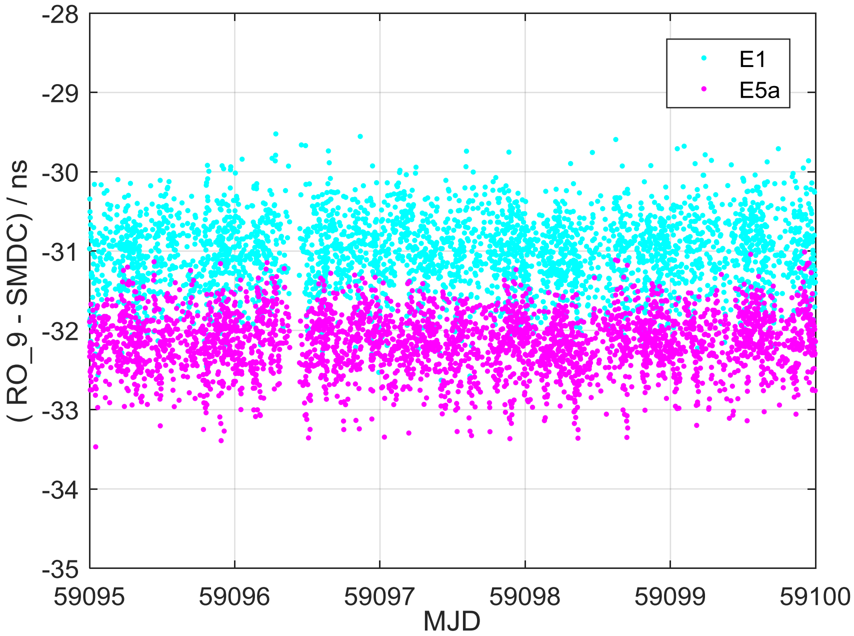
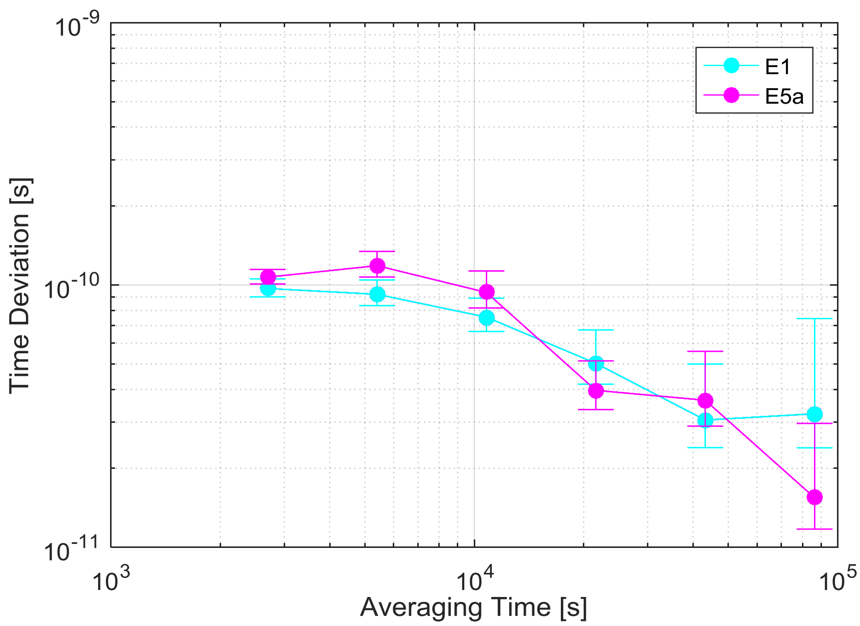


Figure 9-4: Galileo time deviation of CCD



Acknowledgement

We are grateful to Natural Resources Canada (NRCan) for the use of their Precise Point Positioning (PPP) software for positioning computations.

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