G2 Calibration Report for NIST-NRC-NIST: nrc4 and nrca
Cal_Id: 1019-2017

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Abstract

This report is a record of the calibration results of nrc4 and nrca, the site receivers of NRC, and closure measurement of the trip NIST-NRC-NIST. Three sets of data were collected between MJD57948-58013 (July 14, 2017 and September 17, 2017) by simultaneous operation of a pair of co-located GNSS receivers. The purpose of this campaign was to measure the internal delay of the GPS receivers nrc4 and nrca and thereby calibrating the link between NIST and NRC for timing applications. The calibration campaign was initiated by NIST in consultation with NRC for fulfilling the G2 responsibility as per the guidelines set by BIPM [2].

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1 List of Acronyms

Table 1: List of acronyms used in this report.

BIPM	Bureau International des Poids et Mesures, Sèvres, France
CCTF	Consultative Committee on Time and Frequency
CGGTTS	CCTF Global GNSS Time Transfer Standard format
CIPM	Comité International des Poids et Mesures
GNSS	Global Navigation Satellite System
ITRF	International Terrestrial Reference Frame
nb05	NIST-owned GPS traveling system
NIST	National Institute of Standards and Technology
nist	4-letter code of NIST's primary GPS receiver
NRC	National Research Council
nrc4 & nrca	NRC receivers to be calibrated
PPS	Pulse per second
RINEX	Receiver Independent Exchange format
TIC	Time Interval Counter

2 Description of the traveling GNSS receiver

The NIST Traveling System consists of two enclosures containing a rack-mount GPS receiver unit (nb05), a choke-ring antenna and antenna cable, a laptop, a time interval counter and two auxiliary cables (RG223 with BNC connectors) to be used for measuring the REFDLY for the traveling receiver.

The GPS unit nb05 contains a dual-frequency, multi-channel Novatel OEMV Propak-V3 receiver and a NIST-built auxiliary board that conditions the 10MHz and PPS signals to the GPS receiver and measures the time difference between the PPS output and input to the receiver, as well as the time difference between the PPS and 10MHz input signals.

The Novatel GNSS pin-wheel antenna is connected to the receiver with a 50 m long FSJ-50A cable. An HP53132A time interval counter is also provided with nb05.

3 Results

The notation for various delays are consistent with that adopted in the BIPM guidelines[2]. A brief discussion of the various delays and their values for each pair (traveling- and station-receiver) are detailed next, followed by a discussion about computing raw difference of GPS code measurements.

3.1 Computing delays in the measurement setup

The difference of the total delay for a pair of co-located receivers is the sum of the delays incurred in the antenna cable(CABDLY) and the internal delay(INTDLY), minus the time offset at the latching point of the receiver as referenced to a fixed point, usually UTC(k)(REFDLY). The internal delay is comprised of both code- and frequency-dependent delays in the antenna and the receiver.

After accounting for the baseline geometry, the difference in pseudoranges between a pair of receivers, say for P1, is given by

$$\mathrm{RAWDIF(P1)}_{\mathrm{A-B}} = \Delta\mathrm{CABDLY}_{\mathrm{A-B}} + \Delta\mathrm{INTDLY}_{\mathrm{A-B}} - \Delta\mathrm{REFDLY}_{\mathrm{A-B}}, \quad (1)$$

where $\mathrm{RAWDIF(P1)}_{\mathrm{A-B}}$ is the raw difference of pseudorange measurements of two receivers.

$\mathrm{RAWDIF(P2)}_{\mathrm{A-B}}$ is given by using the corresponding set of delays on the right hand side of Eq.(1). The notation for the receivers A and B correspond to the traveling- and station-receiver. $\Delta\mathrm{CABDLY}_{\mathrm{A-B}}$ and $\Delta\mathrm{REFDLY}_{\mathrm{A-B}}$ for nb05(A) and, nrc4/nist and nrca/nist (B) are given in table 2, referenced from Annex 1-3. Note that the delays for nist were revised as a result of the G1 campaign and the changes were implemented on MJD58116.

nb05 setup has provisions to log the REFDLY (both $\mathrm{X_P}$ and $\mathrm{X_O}$) and the procedure is outlined in the operating manual for nb05. Note that in table 2, we provide ΔCABDLY for L1 and L2 because for nb05 the values for CABDLY corresponding to L1 and L2 frequencies were determined separately at NIST. The difference between CABDLY for L1 and L2 are typically of the order of 0.5 ns or less. CABDLY for L1 and L2 are set to the same value if separate measurements are not made available. Schematic of the measurement setup at NRC and that was provided by NRC is given in the secondary information section of this report.

Table 2: REFDLY differences between station and traveling receivers

Pair	MJD	Δ REFDLY(ns)	Δ CABDLY(ns)	
			L1	L2†
nb05-nist	57948-57952	391.37 ± 0.19	-67.90	-68.20
nb05-nrc4	57966-57971	-82.29 ± 0.20	-61.7	-62.0
nb05-nrca	57966-57971	4.73 ± 0.20	-59.7	-60.0
nb05-nist	58009-58013	391.37 ± 0.19	-67.90	-68.20

† L1 may be used instead of L2 for calculating RAWDIF(P2), if L2 are not readily available.

3.2 Computing raw difference of GPS code measurements

The RINEX files for a pair of co-located receivers during the data acquisition period, MJD column in table 2, are processed using a script provided by the BIPM which invokes a call to a fortran executable that solves the baseline between the phase centers of the two antennas from L1 and L2 phase differences[1, 4]. Subsequently, the P1 and P2 pseudorange differences are formed after accounting for the previously computed baseline. For both Novatel NIST station receiver(nist) and traveling receiver(nb05), the RINEX files were corrected for C1P1 bias[3].

The results are given in table 3. The values for ΔINTDLY between a given pair of receivers are computed using Eq.(1) and are given in table 4. IF the RINEX files are not made available a common view difference of two receivers with delays sets to zero may be used in lieu of the raw differences.

Table 3: Raw P1 and P2 differences between station and traveling receivers. The assigned uncertainties are the first minimum of the TDEV.

Pair	MJD	ΔP1(ns)	ΔP2(ns)
nb05-nist	57948-57952	-396.06 ± 0.12	-408.58 ± 0.12
nb05-nrc4	57966-57971	-51.46 ± 0.11	-66.47 ± 0.11
nb05-nrca	57966-57971	-370.25 ± 0.1	-404.28 ± 0.1
nb05-nist	58009-58013	-396.18 ± 0.15	-408.54 ± 0.11

Table 4: INTDLY for receiver(s)

Pair	ΔINTDLY(P1)(ns)	ΔINTDLY(P2)(ns)
nb05-nist$\|_{\text{start}}$	63.17	50.71
nb05-nrc4	-72.05	-87.06
nb05-nrca	-305.82	-339.85
nb05-nist$\|_{\text{end}}$	63.17	50.71
nb05-nist$\|_{\text{average}}$	63.17	50.71
nrc4-nist$\|_{\text{average}}$	135.22	137.77
nrca-nist$\|_{\text{average}}$	368.99	390.56
MISCLOSURE(nb05-nist)	-0.16	0.04

4 Uncertainty estimates

The overall uncertainty of the differential calibration is the uncertainty of the link between two points(labs) over the duration of the calibration. The uncertainties, both statistical and systematic, associated with the GPS constellation and the traveling-receiver drop out. Therefore for a link comprising a pair of locations(labs), say A and B, the total uncertainty is $u_{A-B} = \left(u_A^2 + u_B^2\right)^{1/2}$, where $u_x = \left(u_{x,a}^2 + u_{x,b}^2\right)^{1/2}$, $x \equiv A, B$. $u_{x,a}$ is the total statistical uncertainty that arise due to the fluctuations in the RAWDIF. We have assumed that the total statistical and systematic uncertainties are orthogonal to each other owing to statistical independence. The total uncertainty for each location are given at the end of tables 5 and 6.

The total systematic uncertainty,$u_{x,b}$ have components that are assumed to be statistically independent and hence orthogonal to each other. Therefore, $u_{x,b}$ is equal to the norm of the vector whose components are the various systematic uncertainties. Misclosure is added to the systematic uncertainty at the closure location (NIST). For the RAWDIF, the values for the uncertainty corresponds to the minimum of TDEV. The final result of the link calibration is given in table 7.

Table 5: Uncertainties for the common-clock, co-located measurements of nb05 at NRC

quantity	uncertainty	P1(ns)	P2(ns)
$\text{RAWDIF}_{\text{nb05}-\text{nrc4}}$	u_a	0.11	0.11
$\text{RAWDIF}_{\text{nb05}-\text{nrca}}$	u_a	0.10	0.10
nb05 antenna position	$u_{b,11}$	0.05	
nrc4 antenna position	$u_{b,12}$	0.05	
nrca antenna position	$u_{b,12}$	0.05	
nb05 multipath	$u_{b,13}$	0.10	
nrc4 multipath	$u_{b,14}$	0.10	
nrca multipath	$u_{b,14}$	0.10	
$\text{REFDLY}_{\text{nb05}}$	$u_{b,21}$	0.13	
$\text{REFDLY}_{\text{nrc4}}$	$u_{b,22}$	0.10	
$\text{REFDLY}_{\text{nrca}}$	$u_{b,22}$	0.10	
$\text{CABDLY}_{\text{nb05}}$	$u_{b,31}$	0.10	
$\text{CABDLY}_{\text{nrc4}}$	$u_{b,32}$	0.10	
$\text{CABDLY}_{\text{nrca}}$	$u_{b,32}$	0.10	
$\Delta\text{INTDLY}_{\text{nb05}-\text{nrc4}}$	u_{NRC}	0.29	0.28
$\Delta\text{INTDLY}_{\text{nb05}-\text{nrca}}$	u_{NRC}	0.29	0.27

Table 6: Uncertainties for the common-clock, co-located measurements of nb05 at NIST

quantity	uncertainty	P1(ns)		P2(ns)	
		begin	end	begin	end
$\text{RAWDIF}_{\text{nb05}-\text{nist}}$	u_a	0.12	0.15	0.12	0.11
nb05 antenna position	$u_{b,11}$	0.05			
nist antenna position	$u_{b,12}$	0.05			
nb05 multipath	$u_{b,13}$	0.10			
nist multipath	$u_{b,14}$	0.10			
$\text{REFDLY}_{\text{nb05}}$	$u_{b,21}$	0.14	0.13	0.14	0.13
$\text{REFDLY}_{\text{nist}}$	$u_{b,22}$	0.10	0.05	0.10	0.05
$\text{CABDLY}_{\text{nb05}}$	$u_{b,31}$	0.10			
$\text{CABDLY}_{\text{nist}}$	$u_{b,32}$	0.10			
$\Delta\text{INTDLY}_{\text{nb05}-\text{nist}}$		0.30	0.29	0.30	0.28
$\Delta\text{INTDLY}_{\text{nb05}-\text{nist}}\|_{\text{max}}/\sqrt{2}$		0.22		0.22	
Misclosure/2	$u_{b,1}$	−0.08		0.02	
$\Delta\text{INTDLY}_{\text{nb05}-\text{nist}}$	u_{NIST}	0.22		0.22	

Using the uncertainty estimates from tables 6 and 5 and applying it to the values computed in table 4 the results for ΔINTDLY(P1) and ΔINTDLY(P2) are summarized in table 7. Using the adopted values for the internal delays for nist from the latest BIPM calibration of NIST receiver[6] (also given in Annex A for NIST) along with values from table 7, the inferred internal delays for nrc4 and nrca are given in table 8.

We assigned 0.1 ns for $CABDLY_{nb05}$ as it was measured fairly recently (less than a year). Similarly, a nominal uncertainty of 0.1 ns is assigned for $CABDLY_{nist}$, $CABDLY_{nrc4}$ and $CABDLY_{nrca}$.

Table 7: ΔINTDLY for receiver the link NIST-NRC

Pair	ΔINTDLY(P1) (ns)	ΔINTDLY(P2) (ns)
nrc4-nist	135.22 ± 0.4	137.77 ± 0.4
nrca-nist	368.99 ± 0.4	390.56 ± 0.4

Table 8: INTDLY for receiver nrc4 and nrca

Rcvr	INTDLY(P1) (ns)	INTDLY(P2) (ns)
nrc4	62.4	65.5
nrca	296.2	318.3

5 Secondary information

1. Schematic of the measurement setup at NRC that was provided by NRC.
2. Annex A: Attached separately.
3. Data files: ftp//ftp.nist.gov/pub/pml/688gps/nist_nrc_17.tar.gz

References

[1] ftp://ftp2.bipm.org/pub/tai/publication/gnss-calibration/doc-soft/

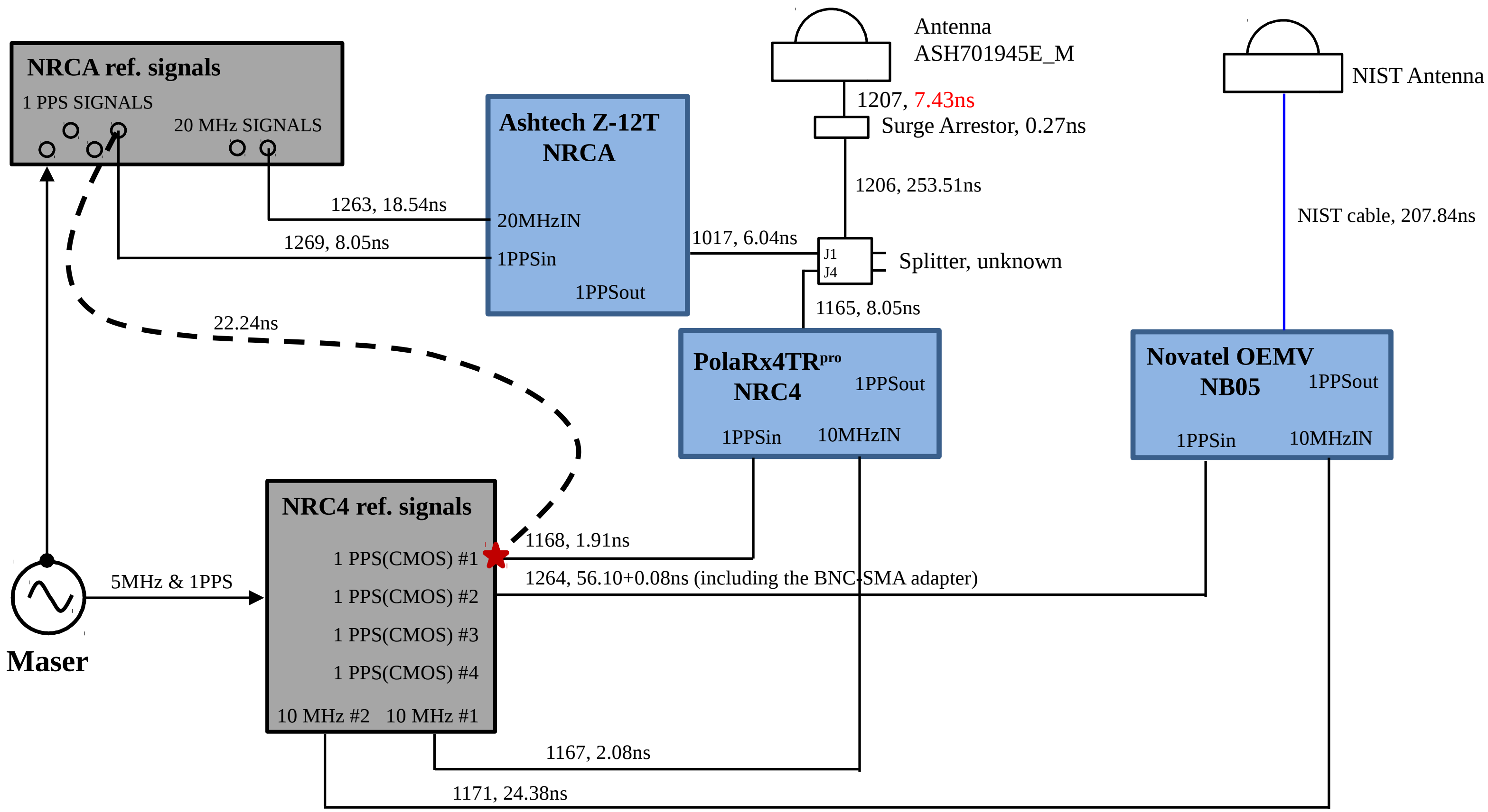
[2] ftp://ftp2.bipm.org/pub/tai/publication/gnss-calibration/guidelines/

[3] ftp://dgn6.esoc.esa.int/CC2NONCC/

[4] http://www.bipm.org/wg/CCTF/WGGNSS/Allowed/BIPM_guidelines_V3/Annex-3_Computation-procedure-Rinex_V2.pdf

[5] P Defraigne and G Petit, Time transfer to TAI using geodetic receivers, Metrologia, vol. 40, no. 4, pp 184, 2003

[6] ftp://ftp2.bipm.org/pub/tai/publication/gnss-calibration/group1/1001-2014/tm243_group1-reference-values_v7.pdf



Schematic setup diagram of the NRC GPS receivers calibration of 1019-2017 trip. The reference signals for the NRC4 and NRCA receivers are from two different signal boxes, both of which are referenced to one of our masers. The reference point of the calibration is the 1pps #1 output of NRC4 reference box (marked as 'red start' in the diagram). The delay between the calibration reference point and the 1pps signal for the NRCA receiver was measured at the connectors (marked as dashed line in the diagram) before and after the calibration as 22.24 ns, 1pps (NRC4) – 1pps (NRCA) = 22.24 ns. The physical cables are represented as the solid lines with the measured delay marked. The corrected delay value of the less counted antenna cable for the calibration of 1017-2016 trip is highlighted in red.

Annex A - Information Sheet

Laboratory:	**NIST**
Date and hour of the beginning of measurements:	195, 2017 00:00:30.00
Date and hour of the end of measurements:	199, 2017 23:59:30.00

Information on the system

	Local:	**Travelling:**
4-character BIPM code	**NIST**	**NB05**
Receiver maker and type: Receiver serial number:	Novatel OEM4-G2 S/N	Novatel OEMV (S/N NAP07270023)
1 PPS trigger level /V:	1	0.5
Antenna cable maker and type: Phase stabilized cable (Y/N):	Andrew FSJ-50A N	Andrew FSJ-50A (cable T1) N
Length outside the building /m:	65	25
Antenna maker and type: Antenna serial number:	Novatel 702	Novatel GPS-703-GGG (S/N NEG08510020)
Temperature (if stabilised) /°C		

Measured delays /ns

	Local:	**Travelling:**
Delay from local UTC to receiver 1 PPS-in (X_P)	86.4 (*)	473.86 ± 0.13 (***)
Delay from 1 PPS-in to internal Reference (if different): (X_O)		3.90± 0.09 (**)
Antenna cable delay: (X_C)	275.5	207.6 (L1), 207.3 (L2)
Splitter delay (if any):	N/A	N/A
Additional cable delay (if any):	N/A	N/A

Data used for the generation of CGGTTS files

• INT DLY (or X_R+X_S) (GPS) /ns:	-72.8 (P1) , -72.3 (P2)
• INT DLY (or X_R+X_S) (GLONASS) /ns:	
• CAB DLY (or X_C) /ns:	275.5
• REF DLY (or X_P+X_O) /ns:	86.4
• Coordinates reference frame:	WGS84
X /m:	-1288398.360
Y /m:	-4721697.040
Z /m	4078625.500

General information

• Rise time of the local UTC pulse:	3 ns
• Is the laboratory air conditioned:	yes
Set temperature value and uncertainty:	
Set humidity value and uncertainty:	

(*) After adopting the values following the most recent BIPM campaign, MJD 56116; (**) averaged over the measurement period (***) 449.75 +24.12(average of before and after)

Annex A - Information Sheet

Laboratory:	National Research Council Canada
Date and hour of the beginning of measurements:	July 29, 2017, 00:00:00
Date and hour of the end of measurements:	Aug 10, 2017, 23:59:30

Information on the system

	Local:	**Travelling:**
4-character BIPM code	NRC4	NB05
• Receiver maker and type:	Septentrio, PolaRx4TRpro	Novatel OEMV
Receiver serial number:	31022286	(S/N NAP07270023)
1 PPS trigger level /V:	1.0 V	0.5
• Antenna cable maker and type:	Andrea, Heliax, LDF2-50	Andrew FSJ-50A (cable T1)
Phase stabilised cable (Y/N):	Y	N
Length outside the building /m:	~ 1.5 m	~ 4 m
• Antenna maker and type:	ASH701945E_M SNOW	Novatel GPS-703-GGG
Antenna serial number:	CR52002205	S/N NEG08510020
Temperature (if stabilised) /°C	-	-

Measured delays /ns

(if needed fill box "Additional Information" below)

	Local:	**Travelling:**
• Delay from local ~~UTC~~ *reference clock* to receiver 1 PPS-in:	1.91 ns	56.25±0.13
Delay from 1 PPS-in to internal Reference (if different):	142.10 ns	5.47±0.06
• Antenna cable delay:	266.29 ns	207.6 ns
Splitter delay (if any):	unknown	N/A
Additional cable delay (if any):	Surge arrester: 0.27 ns	N/A

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:	
Longitude or Y /m:	
Height or Z /m:	

General information

• Rise time of the local UTC pulse:	2.53 ns
• Is the laboratory air conditioned:	YES
Set temperature value and uncertainty:	20.2 ºC ± 0.3 ºC
Set humidity value and uncertainty:	45% ± 2%

BIPM GPS Annex A - Information Sheet

Laboratory:	National Research Council Canada
Date and hour of the beginning of measurements:	July 29, 2017, 00:00:00
Date and hour of the end of measurements:	Aug 10, 2017, 23:59:30

Information on the system

	Local:	**Travelling:**
4-character BIPM code	NRCA	NB05
• Receiver maker and type:	Ashtech, Z12 Metronome 10MB	Novatel OEMV
Receiver serial number:	RT920031101	(S/N NAP07270023)
1 PPS trigger level /V:	1.0 V	0.5
• Antenna cable maker and type:	Andrea, Heliax, LDF2-50	Andrew FSJ-50A (cable T1)
Phase stabilized cable (Y/N):	Y	N
Length outside the building /m:	~ 1.5 m	~ 4 m
• Antenna maker and type:	ASH701945E_M SNOW	Novatel GPS-703-GGG
Antenna serial number:	CR52002205	S/N NEG08510020
Temperature (if stabilised) /°C	-	-

Measured delays /ns

(if needed fill box "Additional Information" below)

	Local:	**Travelling:**
• Delay from local ~~UTC~~ *reference clock* to receiver 1 PPS-in:	30.29 ns	56.25±0.13 ns
Delay from 1 PPS-in to internal Reference (if different):	26.70 ns	5.47±0.06
• Antenna cable delay:	264.28 ns	207.6 ns
Splitter delay (if any):	unknown	N/A
Additional cable delay (if any):	Surge arrester: 0.27 ns	N/A

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:	
Longitude or Y /m:	
Height or Z /m:	

General information

• Rise time of the local UTC pulse:	2.53 ns
• Is the laboratory air conditioned:	YES
Set temperature value and uncertainty:	20.2 ºC ± 0.3 ºC
Set humidity value and uncertainty:	45% ± 2%