URSI RCRS 2022, IIT (Indore), India, 1-4 December, 2022

Absolute calibration of NavIC reference receiver

Neelu Kasat*(1), Sortur Anand Neelappa (1), F B Singh(1) and M R Raghavendra(1)
(1) ISTRAC-ISRO, Bangalore, India

Abstract

The NavIC (or IRNSS) reference receiver's measurement data is the basis for the generation of orbital parameters of the NavIC satellites. For ensuring accurate orbit determination, the various sources of error in ground segment need to be precisely measured and compensated. The RF/IF delays of the NavIC reference receiver are derived from its absolute calibration. The achieved accuracy level is better than 1ns. In this paper, we also present the impact of Doppler collision on the calibration process of receiver.

1. Introduction

The NavIC (Navigation with Indian Constellation) has its own system time. The difference between NavIC system time (NavIC-ST) and individual satellite clock is used for satellite clock corrections. The Precise Time Facility (PTF) provides an extremely high accurate time base, which can be used to establish the NavIC-ST for the constellation.

The satellite transmit time can be determined by demodulating the received pseudorandom noise (PRN) signal and computing pseudorange from the same. That is

$$T_{TxT} = T_{RLT} - \frac{PR}{C} \quad (1)$$

where T_{TxT} is the time at which the measured phase of the received PRN signal was broadcasted by the satellite, T_{RLT} is the receiver local time (RLT), PR is the measured pseudorange to the satellite and C is the speed of light.

In Eq. (1), the measured pseudorange associates the RLT to the satellite transmit time. This association is further complicated when the RLT is required to be aligned or synchronized with respect to an external time base derived from PTF. To accomplish this, the various radio frequency/intermediate frequency (RF/IF) delays involved from antenna element to that of receiver output should be accurately measured and calibrated.

2. Theory of receiver delay calibration

The computed pseudorange includes a number of errors and delays in addition to the true range between the satellite and the receiver antenna (i.e. geometric range). The computed pseudorange also consists of RF/IF delays from antenna element to the receiver output. The final equation is

$$PR = R + C(\delta t - \delta T) + \delta_{Iono} + \delta_{Trop} + \delta_{Rec} + \epsilon_{Mul} + \epsilon_{AWGN} \quad (2)$$

Here:
R is geometric range from satellite to receiver antenna,
δt is receiver clock error,
δT is satellite clock error,
δ_{Iono} is ionospheric delay,
δ_{Trop} is tropospheric delay,
δ_{Rec} is receiver RF/IF delay.
ϵ_{Mul} is Multipath errors
ϵ_{AWGN} is receiver thermal noise

The computed pseudorange is based on the receiver time base (i.e. receiver 1PPS) whereas the transmitted PRN code signal is based on NavIC-ST. The time base of the generated calibration PRN signal should be same as that of receiver. To minimize the impact of receiver thermal noise, the corresponding carrier-to-noise density ratio (C/No) value should be high enough. If the code phase of the calibration PRN signal is known (i.e. R), then the calibration process becomes the calibration of the PRN signal referenced to a reference 1PPS, and subsequently measuring the time difference between the reference 1PPS and the 1PPS output from receiver being calibrated. [5]

3. Experiment carried out

For lab calibration of the Reference receiver, Spirent Simulator (GSS8000) is used. To ensure, clean RF signal, the simulated scenario had zero ionospheric, tropospheric and multipath errors. Out of 3 RF ports, MON/CAL port of simulator was used for the experiment.

Receiver delay can be divided in 3 components [1,5]:

3.1 1PPS to RF alignment (Tick to Code) [2,3,4]
3.2 1PPS in of simulator to 1PPS out of Receiver (Tick to Tick), and
3.3 Cable delays (RF path)

3.1 1PPS to RF alignment

Experimental setup is shown in Figure 1. The Agilent DSO was used to observe the delay between 1PPS and RF signals. The observation plots are shown in Figure 2 and 3 for NavIC L5 and NavIC S band respectively. The observed values of Tick to Code are consistent across different NavIC PRNs.

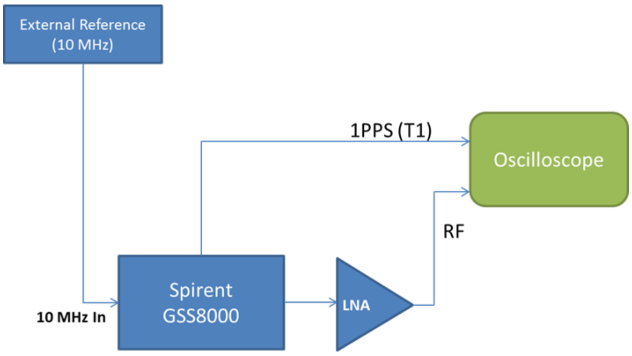

Figure 1. The experimental setup for 1PPS to RF alignment calculation.

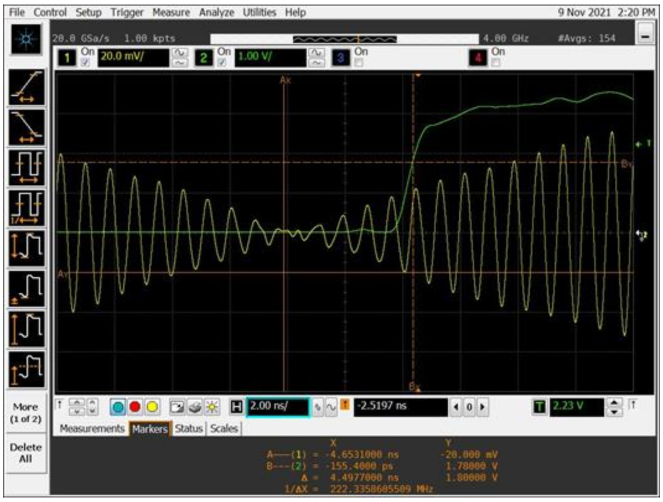

Figure 2. NavIC L5 band observation

Figure 3. NavIC S band observation

Table 1 The below table shows the observations for 1PPS to RF alignment for NavIC L5 and NavIC S bands

Delay Measurements	**IRNSS SPS-L5**	**IRNSS SPS-S**
1PPS Delay (50%) to RF Code Chip Phase Transition	4.4977ns	4.7064ns
Simulator 1PPS Cable Delay	10.227ns	
Simulator RF Path Delay	9.316ns	9.327ns
Tick-to-Code Delay (ΔT_{Ttc}) (will be negative here)	= -(4.4977-(10.227-9.316)) = -3.5867ns	= -(4.7064-(10.227-9.327)) = -3.8064ns

3.2 1PPS in of simulator to 1PPS out of Receiver (Tick to Tick)

Experimental setup is shown in Figure 2. Here, IRNWT represents IRNSS network timing facility or NavIC-system time.

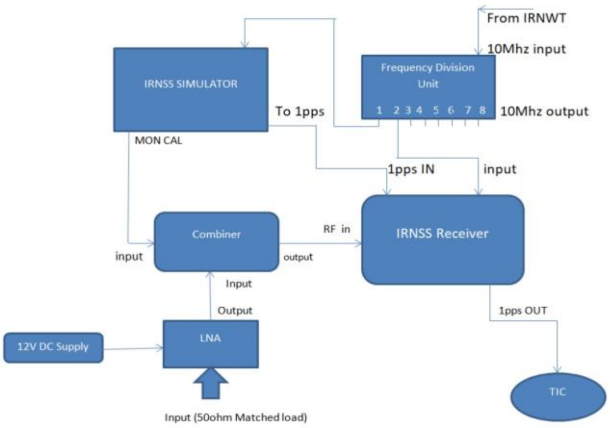

Figure 4 The setup for measurement of tic to tic delay.

Table 2 below shows the observation for one particular receiver

Delay Measurements	**IRNSS SPS-L5**
TIC reading	41.5305ns
1PPS Cable Delay from simulator	10.227ns
1PPS cable delay of receiver	35.813ns
Tic-to-Tic Delay (ΔT_{Ttc})	=41.5305-35.813+10.227 = 15.9445ns

RF path delays were computed using Anritsu Vector network analyzer for the complete frequency band (1.0 to 3.0GHz).

3.3 Computation of absolute delay

The delay formula using above delay values is as follows:

RF/IF Delay = (PSR-GR) (ns) + Tic to Tic (ns) - Tic to Code (ns) - RF path delay (ns) (3)

Here, GR = Geometric range between satellite and receiver under test. Rest of the parameters is explained earlier.

The error budget is given in following table (table 3)

Table 3 The factors impacting accuracy achieved in calibration process is summarized below

Parameters	Uncertainty in measurement (SDEV) (ns)
Measurement noise of receiver	0.1
Tic to Tic uncertainty	0.02
Tic to Code uncertainty	0.1
RF path delay uncertainty	0.2
Total error budget (rms)	0.12

The uncertainty in the calibration result is 0.12ns.

4. Effect of Doppler Collision on calibration

The simulated constellation was a combination of GEO and GSO satellites. The cross correlation effects may lead to Doppler collision which introduces a varying bias in the calibration process. The interesting finding has been explained in following plots. Initially, the simulated scenario had 4 GEO (stationary) satellites with 3 GSO satellites.

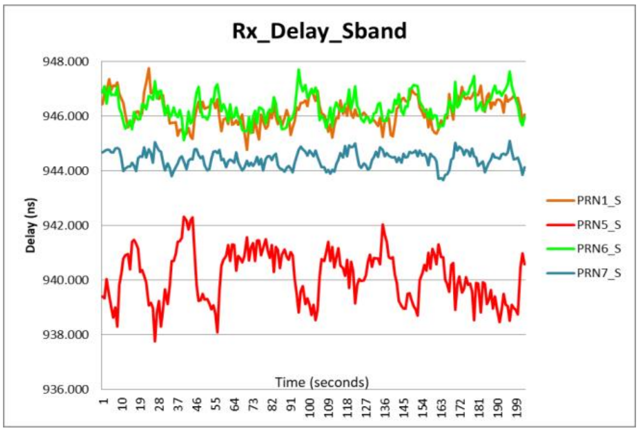

Figure 5 Calculated delay values for S band with Doppler collision (DC)

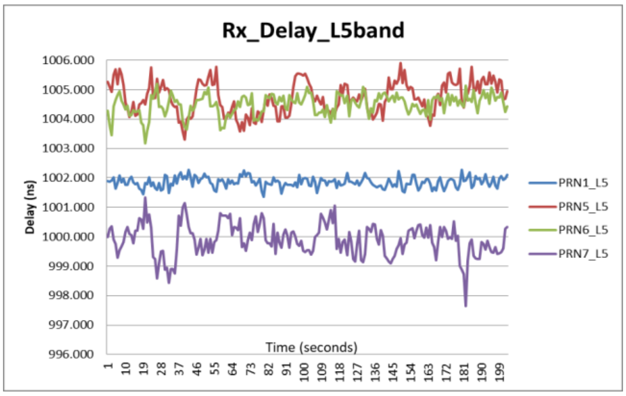

Figure 6 Calculated delay values for L5 band with DC

Impressions of the above exercise:

a. Delay values for individual PRN is varying from 1ns to 4ns (even in short time span)

b. Delay values across PRNs are inconsistent.

The simulated scenario is then modified. The modified simulation has only 1 GEO satellite and 6 GSOs, such that Doppler collision does not exists among any GSO satellites pair also. The delay plots are given below.

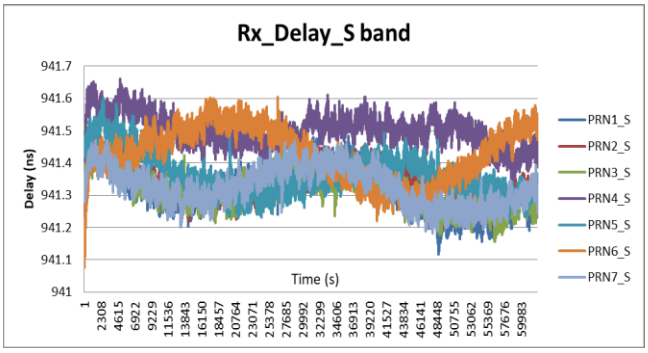

Figure 7 Calculated delay values for S band with no DC

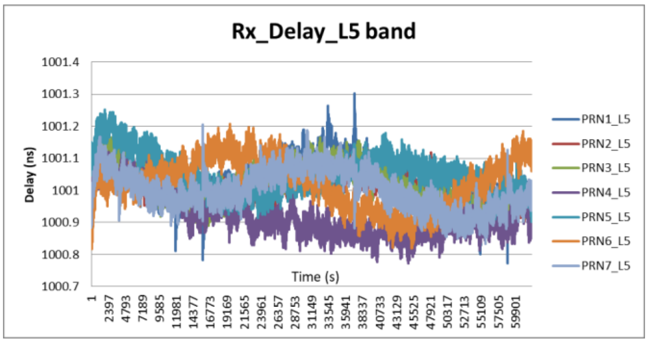

Figure 8 Calculated delay values for L5 band with no DC

Impression with no Doppler collision:

a. Variation in Delay of individual PRN is less than 1ns for 16+hrs data.

b. Delay values are consistent across PRNs.

5. Conclusion

The absolute calibration of the NavIC reference receiver involves precise calibration of NavIC simulator (1pps to RF code alignment), precise measurements of 1PPS in to 1PPS out (Tic to Tic measurement) and RF path delays. The coherent timing signal for the receiver and the simulator was used for the calibration process so as to remove any variations in delay values due to timing signals. The calibration procedure was repeated multiple (four) times on the same receiver for consistent result.

It is seen that the phenomenon of doppler collision has an impact on the receiver measurements and thus, affect the calibration process. It is ensured that the Doppler collision phenomenon is minimized during calibration of the NavIC reference receiver.

6. Acknowledgments

Authors would like to acknowledge Dr B N Ramakrishna, Director, ISTRAC for his guidance and support.

References

[1] B.P.B.Elwischger, S.Thoelert, M.Suess, J.Furthner, "Absolute Calibration of Dual Frequency Timing Receivers for Galileo", European Navigation Conference (ENC), Vienna 2013

[2] A. de Latour, G. Cibiel, J. Dantepal, J.-F. Dutrey, M. Brunet, L. Ries, J.-L. Issler, "Dual frequency absolute calibration of GPS receiver for time transfer".

[3] John Plumb, Kristine M. Larson, Joe White, and Ed Powers, "Absolute Calibration of a Geodetic Time Transfer System", journal of LATEX class files, vol. 1, no. 11, November 2002

[4] J. F. Plumb, J. White, E. Powers, K. Larson, and R. Beard, "Simultaneous absolute calibration of three receivers", 33rd Annual Precise Time and Time Interval (PTTI) Meeting

[5] U. Grunert, S. Thoelert, H. Denks, J. Furthner, "Absolute Calibration of Time Receivers with GPS/Galileo HW Simulator"