Timing performance and stability characterization of an In house realized NavIC Timing Receiver

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Abstract

Navigation with Indian Constellation (NavIC), also known as Indian Regional Navigation Satellite System (IRNSS), is the Indian regional satellite navigation system. A NavIC Timing receiver is a type of user receiver which realizes NavIC system time on ground by steering its internal oscillator to the NavIC system time. These receivers act as NavIC based time reference. In order to reduce the dependency on other GNSS based timing references, a NavIC Timing receiver has been developed in-house at ISTRAC for use at all ground facilities. This paper provides an assessment of the timing performance and stability characterization of this NavIC Timing receiver.

1 Introduction to NavIC

NavIC, also known as IRNSS is a regional navigation satellite constellation consisting of seven satellites placed in geostationary and geosynchronous orbits (GSO) such that they provide navigation services over the Indian landmass and in the region extending to 1500 kilometer beyond the Indian geopolitical boundary. This system has been realized by the Indian Space Research Organization (ISRO) and has been operational since 2018. Three of the NavIC satellites are in GEO (32.5°E, 83°E and 129.5°E) while four of the satellites are in two geosynchronous orbits having inclination of 29 degrees each. While one of the geosynchronous orbit planes crosses the equator at 55°E longitude, the other geosynchronous orbit crosses the equator at 111.75° E longitude. The NavIC constellation along with the other segments such as the ground segment and the user segment is depicted in Figure 1.

The NavIC ground segment consists of a network of IRNSS Range and Integrity Monitoring Stations (IRIMS) and a network of IRNSS CDMA Ranging stations (IRCDR). While the IRIMS perform one way ranging to the NavIC constellation, the IRCDR stations perform two-way CDMA ranging to the NavIC constellation. Laser ranging of the NavIC constellation is carried out on a best effort basis by the International Laser Ranging Service (ILRS). At the heart of the NavIC ground segment is the ISRO Navigation Centre (INC) which houses the IRNSS Network Timing facility (IRNWT) and also performs the Orbit Determination and Time synchronization (ODTS) of the NavIC constellation. Mode-1 IRIMS are the reference stations which are co-located with IRNWT(s) and receive direct frequency and timing inputs from the timing facility. All other reference stations work in Mode-2 and the reference receivers derive the system time using the broadcast parameters [1].

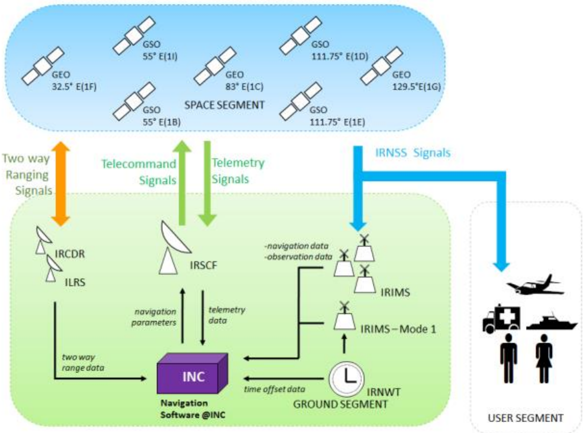

Figure 1: Concept of NavIC Satellite Navigation System

2 NavIC System Time

IRNWT, the Precise Timing Facility established for NavIC, is responsible for the realization, dissemination and maintenance of the NavIC System time which acts as the reference for the entire NavIC network [2]. NavIC system time is generated through a carefully selected ensemble of atomic clocks, such as Cesium atomic frequency standards, Passive Hydrogen Masers and Active Hydrogen Masers [3, 4].

IRNWT is responsible for achieving the following objectives [5, 6]:

a) **Metrological Time keeping**: IRNWT generates a time and frequency signal stable in the longer averaging time (≤ 100000 seconds) and is traceable to national and International standards such as Indian Standard Time (UTC(NPLI)) and hence, Coordinated Universal Time (UTC). The long term frequency stability of IRNWT, measured by Allan Deviation (ADEV) [1, 7], is ≤ 5e-16 ADEV at 100000 seconds averaging time.

b) **Navigation Time keeping**: IRNWT generates a frequency signal which is stable in short and medium averaging times (≥ 1 s to ≤ 10000 s). The short term frequency stability of IRNWT is typically ≤ 8e-14 ADEV at 1 sec and ≤ 1.0e-15 ADEV at 10000 seconds averaging time [1, 8].

Further, NavIC system time is maintained in a way such that it is accurate to within 40 ns (2-sigma) with respect to UTC(NPLI) or Indian Standard Time. this is achieved via time transfer techniques, namely Two-way Satellite Time and Frequency Transfer and GNSS/NavIC based Time transfer.

3 NavIC Timing Receiver

A NavIC Timing receiver is a type of user receiver which realizes NavIC system time on ground by steering its internal oscillator to the NavIC system time. In [1], it has been shown how UTC (NPLI) can be precisely generated at ground using a NavIC timing receiver, without the need of any direct link with NPL, India.
Figure 2 shows the top level block diagram of NavIC Timing receiver [9].

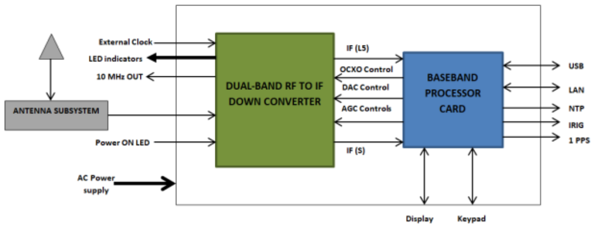

Figure 2: Top level block diagram of NavIC Timing Receiver

The receiver processes the raw pseudoranges to obtain the receiver clock offset with respect to NavIC system time. It them employs a suitable steering algorithm to steer the internal Rubidium oscillator to the NavIC system time such that the difference between the NavIC system time and the time generated by the receiver is better than 40 ns (2σ) for any yearly time interval.

4 Results and Discussion

4.1 Timing performance

To assess the timing accuracy of the realized NavIC Timing receiver, an experiment was designed and Figure 3 shows the experimental setup. The NavIC Timing receiver was installed at the precise timing facility of NavIC ground segment The 1 pulse per second (PPS) output from the timing receiver was compared with the 1PPS output of IRNWT using a Time Interval Counter (TIC).

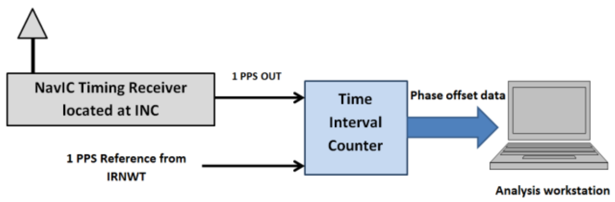

Figure 3: Experimental setup for the Timing accuracy assessment of NavIC Timing Receiver

The measurement uncertainty of the TIC used is less than 1 ns. The phase differences were recorded and corrected for calibration delays. Figure 4 shows the timing accuracy of the receiver.

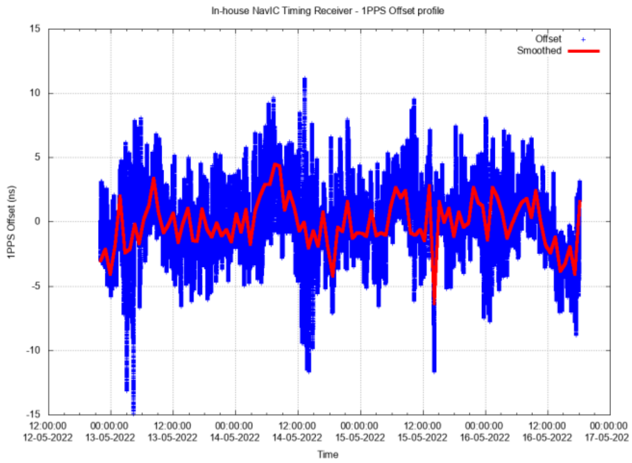

Figure 4: Timing accuracy of NavIC Timing receiver w.r.t NavIC System time

As can be seen from the above figure, the NavIC Timing receiver was able to realize the NavIC system time on ground, to an accuracy of 5 ns, 2-sigma.

4.2 Stability characterization

One of the outputs of NavIC Timing receiver is 10 MHz signal. The stability of the realised 10 MHz frequency is shown in Figure 5.

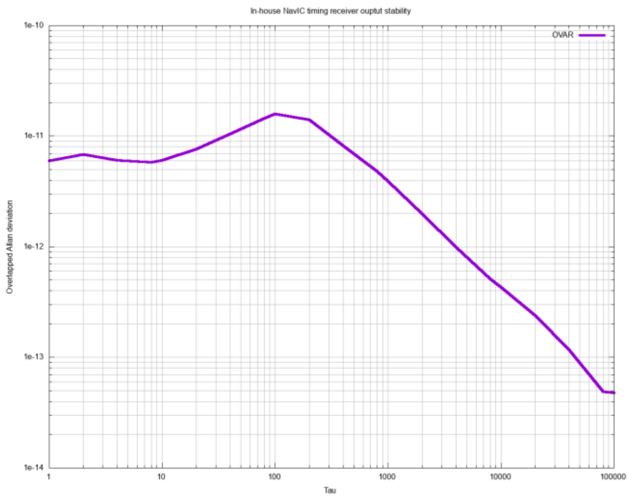

Figure 5: Allan Deviation of 10 MHz output of NavIC timing receiver

The above figure shows that the Allan deviation at 1 day averaging is better than 6e-14. This is an improvement of two orders from the performance offered by a free-running Rubidium (Rb) oscillator. This is because of the fact that the Rb oscillator is being steered to the NavIC system time that is realized by the NavIC timing receiver.

6 References

1. Bhardwajan, A.A., Dakkumalla, S., Arora, A. et al. Navigation with Indian Constellation and its

Applications in Metrology. *MAPAN* **36**, 227-236(2021).https://doi.org/10.1007/s12647-021-00467-9
2. Bhardwajan, A.A., Arora, A., Dakkumalla, S., Ganesh, T.S. and Ramakrishna, B.N. (2019), Challenges in the system engineering of a Precise Timing Facility for NavIC. INCOSE International Symposium, 29: 302-313.
3. A. Arora et al., "An in-house developed Timescale for NavIC PTF," 2019 European Navigation Conference (ENC), Warsaw, Poland, 2019, pp. 1-6, doi: 10.1109/EURONAV.2019.8714190.
4. Anu Arora, D Suresh, Rajath Sadasivan, Aakanksha Avnish Bhardwajan, Manish Chawla, T Subramanya Ganesh, et al., "Design and Development of a Precise Time scale for NavIC", Journal of spacecraft Technology, vol. 28, no. 2, pp. 25-33, July-December 2017.
5. A. Amala Agnes, Anu Arora, Aakanksha Bhardwajan, T Subramanya Ganesh, V Jayaraman and L Srinivasan (2013), System Engineering of a Precise Timing Facility for GNSS Applications, Proceedings of National Conference on Applications and Challenges in Space Based Navigation, Indian Space Research Organization, Bangalore
6. Morante Q (2016), Performance results of the Galileo Precise Timing Facility, IEEE Metrology for Aerospace (MetroAeroSpace) pp 484-488
7. D.W. Allan, "Statistics of atomic frequency standards", Proceedings of the IEEE, Vol. 54, No. 2, 221-231, 1966.
8. Maharana, S., Bhardwajan, A.A., Ganesh, T.S. and Ramakrishna, B.N. (2019), Timescale Ensemble Performance Enhancement through use of Artificial Neural Network. INCOSE International Symposium, 29: 478-488.
9. S. Dakkumalla, R.sadasivan, P.R. Dubey, A.A. Bhardwajan and T.S. ganesh, "Design and realization of NavIC Timing Receiver for precise ground applications, "2021 XXXIVth General Assembly and Scientific Symposium of the International Union of Radio Science (URSI-GASS), 2021, pp.1-3, doi: 10.23919/URSIGASS51995.2021.9560232