**RNSS Timescale Description**

**NavIC**

**Reference Document:**

[1] Indian Regional Navigation Satellite System Signal-in-Space ICD for Standard Positioning Service, Version 1.1, August 2017

[2] NavIC Signal-in-Space ICD for Standard Positioning Service in L1 Frequency, Version 1.0, August 2023

**Definition of the System**

1. **System timescale:** NavIC System Time

2. **Generation of System Timescale:**

   Master clock generated using ensemble of atomic frequency standards located at precise timing facility of ISRO Navigation Centre (INC)

3. **Is the system timescale steered to a reference UTC timescale?**

   Yes

   **a. To which reference timescale?**

   UTC(NPLI)

   **b. Whole second offset from reference timescale?**

   As specified in Section 5.7 of [1] and Section 5.6 of [2], NavIC System Time start epoch shall be 00:00 UT on Sunday August 22nd 1999. At the start epoch, NavIC System Time shall be ahead of reference timescale UTC(NPLI)by 13 leap seconds. Since start epoch, five leap seconds have been inserted till 2023. NavIC System Time is currently ahead of UTC by 18 seconds as on January, 2024.

   **c. Maximum offset (modulo 1s) from reference timescale?**

   The offset between NavIC System Time and UTC(NPLI) shall be less than 40 nanoseconds for 95% of any period of 1 year.

4. **Corrections to convert from satellite to system timescale?**

   Yes.

   **If yes:**

   **a. Type of corrections given; include statement on relativistic corrections**

   The clock bias, drift and drift rate as quadratic coefficients broadcast as part of the NavIC navigation message. The expression for relativistic correction is given in Appendix A of [1] and Appendix B of [2]. Computation of relativistic corrections is described in 4d.

**b. Specified accuracy of corrections to system timescale**

The specified error for both satellite position and satellite clock in the NavIC constellation is within 2.3 m.

**c. Location of corrections in broadcast messages**

Subframe 1 of the NavIC navigation broadcast message for L5 and S as described in Section 6.1.1 of [1] and Subframe 2 of the NavIC navigation broadcast message for L1 signal as described in Section 6.1.1 of [2].

**d. Equations to correct satellite timescale to system timescale**

$$a_{f0} + a_{f1}(t - t_{oc}) + a_{f2}(t - t_{oc})^2 + \Delta t_r$$

The polynomial coefficients $a_{f0}$, $a_{f1}$and $a_{f2}$ are the clock bias, drift and drift rate, $t_{oc}$ is the clock data reference time in seconds, and $\Delta t_r$ is the relativistic correction term in seconds and is given by:

$$\Delta t_r = Fe\sqrt{A}\, sin\, E_k$$

The orbit parameters $(e, A, E_k)$ used here are defined in Appendix B of [1] and Appendix A of [2]

where F is a constant given by

$$F = \frac{-2\sqrt{\mu}}{c^2}$$

$\mu$ = Earth's Universal gravitational parameter

$c$ = Speed of light

$e$ = Eccentricity

$A$ = Semi-major axis

$E_k$= Eccentric anomaly

**5. Corrections to convert from system to reference UTC timescale? If yes:**

Yes

**a. Type of corrections given**

Quadratic coefficients and leap second terms.

The following parameters relate NavIC time to UTC(NPLI):
1. NavIC time to UTC(NPLI) bias, drift and drift rate coefficients
2. Current/past leap second count.
3. Current/future leap second count.
4. Reference time and week number for message
5. Reference time and week number for leap second insertion

Section 6.1.3.7 and 6.2.8 of [1], Section 6.1.3.5 and 6.2.2.7 of [2]

**b. Specified accuracy of corrections to reference timescale**

40 nanoseconds (95 %). This is the accuracy of the UTC(NPLI) offset data in the broadcast navigation message portion of the SPS SIS which relates NavIC system time to UTC(NPLI).

**c. Location of corrections in broadcast messages**

Message type 26 broadcast on Subframe 3 and Subframe 4 of the NavIC navigation broadcast message, 6.1.3.7 and 6.2.8 of [1]
Message type 17 broadcast on Subframe 3 of the NavIC L1 band navigation broadcast message. Section 6.1.3.5 and 6.2.2.7 of [2]

**d. Equations to correct system timescale to reference timescale**

Appendix F of [1]

$$\Delta t_{UTC(NPLI)} = \Delta t_{LS} + A_0 + A_1\left(t_E - t_{0t} + 604800\,(WN - WN_{0t})\right) + A_2\left(t_E - t_{0t} + 604800\,(WN - WN_{0t})\right)^2$$

Appendix F of [2]

$$\Delta t_{UTC(NPLI)} = \Delta t_{LS} + A_0 + A_1\left(t_E - t_{ug} + 604800\,(WN - WN_{ug})\right) + A_2\left(t_E - t_{ug} + 604800\,(WN - WN_{ug})\right)^2$$

$\Delta t_{LS}$ = delta time due to leap seconds

$A_0$, $A_1$, $A_2$ = Bias, drift and drift rate of NavIC system time relative to UTC(NPLI)

$t_E$ = NavIC time as estimated by the user

$t_{0t}$ /$t_{ug}$= Reference time for UTC(NPLI) offset data

$WN$ = Current week number

$WN_{0t}$ / $WN_{ug}$ = Reference week number for UTC(NPLI) offset data

**6. Specified stability of system timescale**

Part of the overall specification as mentioned in 5b.

**7. Specified stability of reference timescale**

Not specified

**8. Specified stability of satellite clocks**

5e-14 at 10000 s.

**9. Availability of System to GNSS Time Offset (GGTO)**

Yes

**a. Systems for which corrections are given?**

Can support up to 8 GNSS systems. Currently available for GPS and GLONASS.

**b. Type of GGTO corrections given**

Quadratic coefficients broadcast on the L5, S signal and linear coefficients on the L1 signal. NavIC System Time can be related to GPS, GLONASS using the following parameters available in Message Type 9& 26 of the L5 and S signal broadcast and Message Type 17 of the L1 signal broadcast navigation messages:

1. Bias, drift and drift rate coefficient of NavIC time scale relative to GNSS time scale ($A_0$, $A_1$, $A_2$)
2. Time data reference time of week ($t_{0t}$)
3. Time data reference week number ($WN_{ot}$)
4. GNSS ID

**c. Stated accuracy of GGTO correction, if available**

Accuracy of GGTO corrections to other GNSS systems are dependent on each system's time scales predictability which is estimated through time transfer. NavIC realizes the offset w.r.t other constellations with an uncertainty better than 10ns.

**d. Location of corrections in broadcast messages**

As specified in Subframe 3/4, Message type 9& 26 of the L5 and S broadcast signal and Message Type 17 on Subframe 3 of the L1 signal.

**e. Equations used for GGTO message**

Appendix F of [1]

$$t_{GNSS} = t_E - (A_0 + A_1\big(t_E - t_0 + 604800\,(WN - WN_{ot})\big) + A_2\big(t_E - t_0 + 604800\,(WN - WN_{ot})\big)^2)$$

Appendix F of [2]

$$t_{GNSS} = t_E - (A_{0gnss} + A_{1gnss}\left(t_E - t_{ug} + 604800\left(WN - WN_{ug}\right)\right)$$

$A_0$, $A_1$, $A_2$ = Bias, drift and drift rate of NavIC system time relative to GNSS system time

$t_E$ = NavIC time as estimated by the user

$t_0$ /$t_{ug}$ = Reference time for GNSS offset data

$WN$ = current week number

$WN_{0t}$ /$WN_{ug}$= Reference week number for GNSS offset data

**Describe the details of the system, i.e., locations of system and reference timescale clocks, generation of timescales, and other details.**

ISRO Navigation Centers (INC) are located at Bangalore and Lucknow, India. These facilities house the necessary infrastructure for overall clock and orbit estimation processes.

The NavIC System Time is generated from an ensemble of Hydrogen MASERs and Cesium atomic clocks located at the INCs. The NavIC timescale is steered to UTC(NPLI) using time transfer links and maintained within 40 ns relative to UTC(NPLI), usually better than 10 ns.

The oscillator frequencies onboard the NavIC satellites have been offset from their nominal values in order to account for special and general relativistic effects with respect to ground-based observers so that the received frequencies at the Earth's surface are consistent with terrestrial time (e.g., UTC), assuming mean nominal NavIC orbital elements.

**Describe how the timescale transfers from the reference timescale to the system timescale and finally to the satellites. Include the nominal rate of SV updates.**

NavIC System Time offset with respect to UTC(NPLI) is estimated from TWSTFT measurements and is used to steer the NavIC System Time. NavIC satellite clock offsets with respect to NavIC System Time is modelled from range measurements generated at the reference station co-located with INCs. The estimated satellite clock model is nominally updated at least once per day.

**If any other pertinent details exist concerning the generation and realization of system and/or reference time, include them as well.**

NavIC System Time is realized by simultaneous S and L5 band pseudorange observations used in a linear combination to remove the 1st order ionospheric propagation delay, according to [1]. Users of the L1 NavIC signals or single band users must account for the inter-signal biases and total group delay to obtain the broadcast NavIC Time consistently.

The corrections of inter-signal biases are described in Section 6.2.1.5 of [1] and Appendix C of [2].