Performance Enhancement of NavIC Disciplined Atomic Clock

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Navigation with Indian Constellation (NavIC)

- A Satellite based navigation system realized by ISRO.
- Provides independent position, navigation and timing (PNT) services.
- The space segment consists of a constellation of 7 GSO satellites positioned at different longitudes.
- The ground segment consists of a navigation center linked with a number of one-way and two-way ranging stations and a precise timing facility.
- The user segment consists of variety of users for position and timing requirements.

NavIC System Time Generation & Dissemination

- The NavIC System Time is being generated at a precise timing laboratory.
- An ensemble of highly accurate and stable atomic clocks viz. Active Hydrogen Masers and High Performance Cesium Standards.
- Maintained within 40 ns (2 sigma) with respect to UTC over an yearly period and have stability performance as 5e-15 (ADEV) over a day.
- Disseminated to all the NavIC Satellites and Ground Stations for Orbit Determination and Time Synchronization.
- Broadcasted to the User via NavIC satellites.

Time & frequency Sources for Users

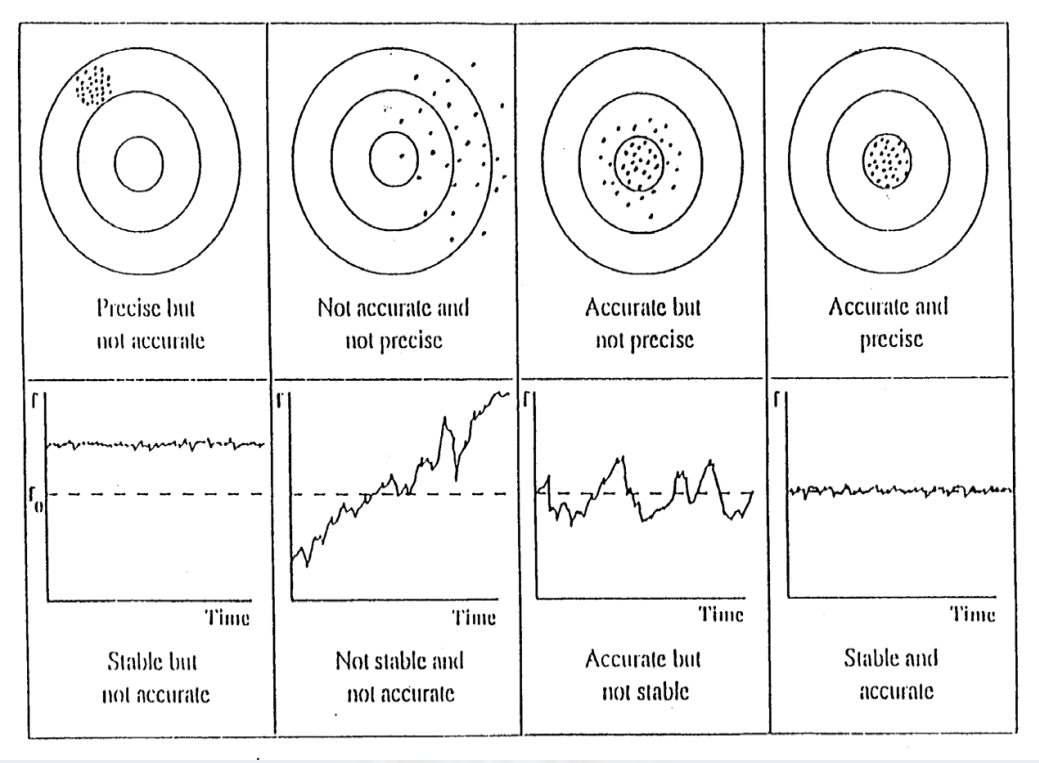
Crystal Oscillator

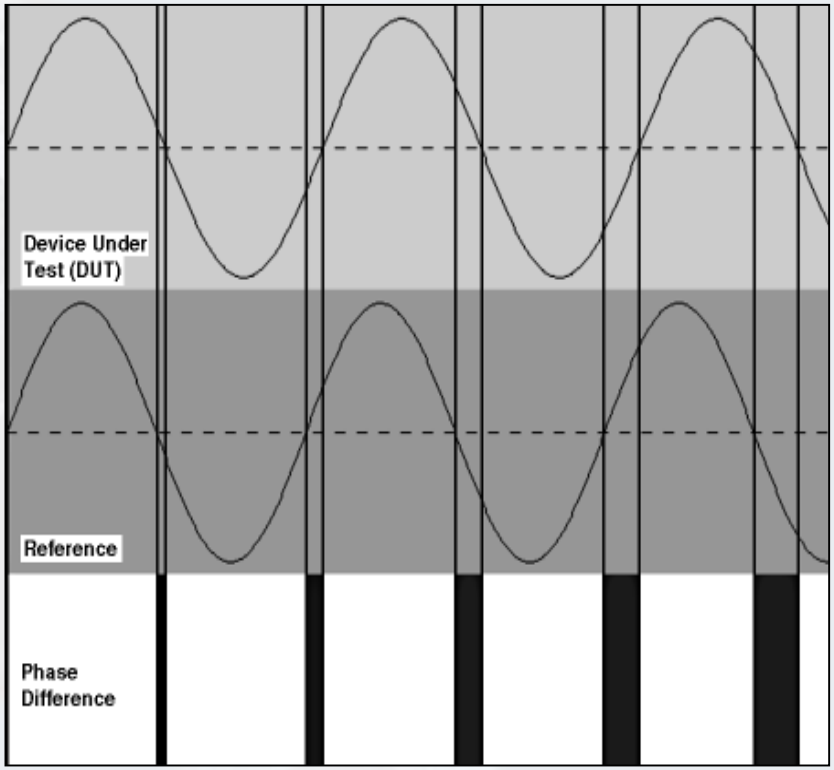
- Uses the mechanical resonance of a vibrating crystal
- Provides signals with low accuracy and poor stability
  - Temperature Compensated Crystal Oscillator (TCXO)
  - Oven Controlled Crystal Oscillator (OCXO)

Atomic Clocks

- Uses an electron transition frequency of atoms.
- Provides signals with high accuracy and good stability
  - Rubidium Atomic Clocks
  - Cesium Atomic Clocks
  - Hydrogen Masers

Characterization of Clock: Accuracy & Stability

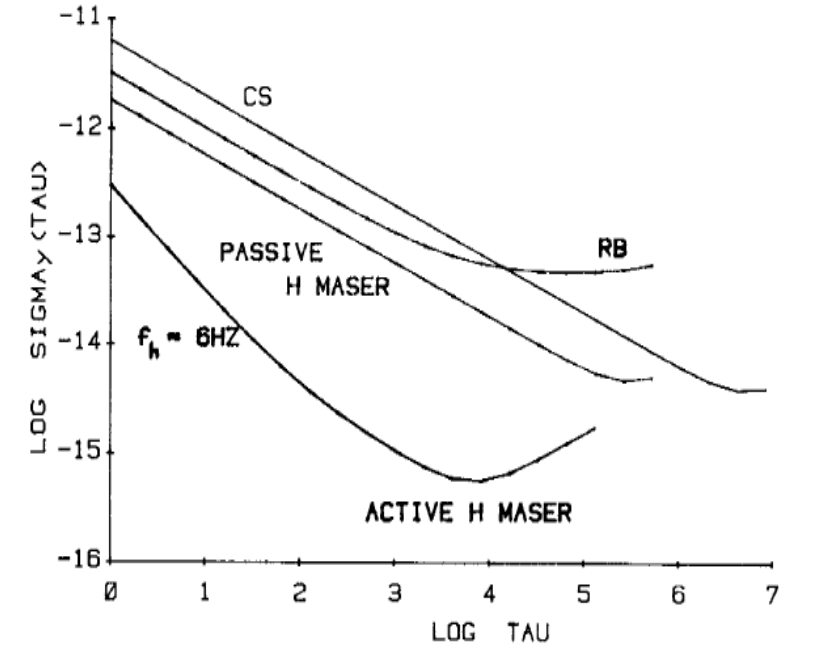


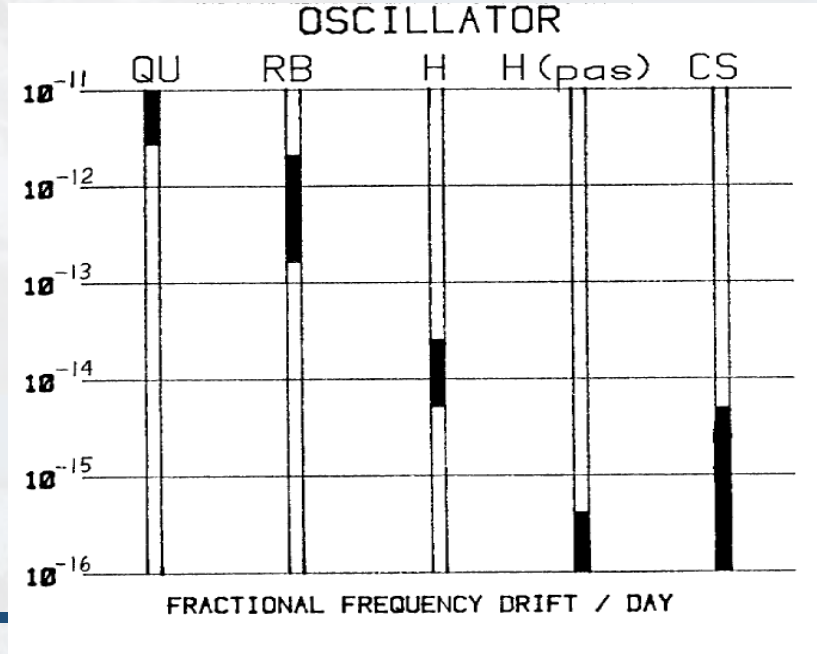


Courtesy: Matsakis, Time & Time Transfer

Comparison of clocks: Accuracy, Stability & Drift

Oscillator Type	Accuracy
Oven controlled crystal oscillator (OCXO)	10^{-8} (with 10^{-10} per g option)
Small atomic frequency standard (Rb, RbXO)	10^{-9}
High performance atomic standard (Cs)	10^{-12} to 10^{-11}
Hydrogen Maser	10^-14 to 10^-13





Courtesy: David W. Allan, Clock Characterization Tutorial

Time and Frequency Requirements

- Many applications require highly accurate and precise timing signals.
- However, some of the applications need highly stable and accurate signals without having to afford a costly atomic clock.
- NavIC offers the means to satisfy such timing requirements on a continuous basis with nanoseconds accuracy.
- Such requirements can be fulfilled using a clock disciplined to the NavIC System time which is highly stable and accurate time.

Disciplining an Oscillator

What is Disciplined Oscillator?

- An oscillators whose frequency is controlled by an external reference signal are known as disciplined oscillators.
- No manual adjustment for time and frequency synchronization.

Why disciplining?

- A free-running clock eventually walks away and therefore must be disciplined using an external reference in order to be accurate with respect to the reference

Key features of disciplining

- Maintains the clock for required accuracy and stability
- Improves the frequency accuracy without loss the frequency stability

What can be improved by disciplining a clock?

S. No.	Clock	Improvement
1	Oven Controlled Crystal Oscillator (OCXO)	Accuracy & Stability
2	Rubidium atomic Clock	Accuracy & Long term stability
3	Caesium Atomic Clock	Medium term Stability
4	Hydrogen Maser	Accuracy

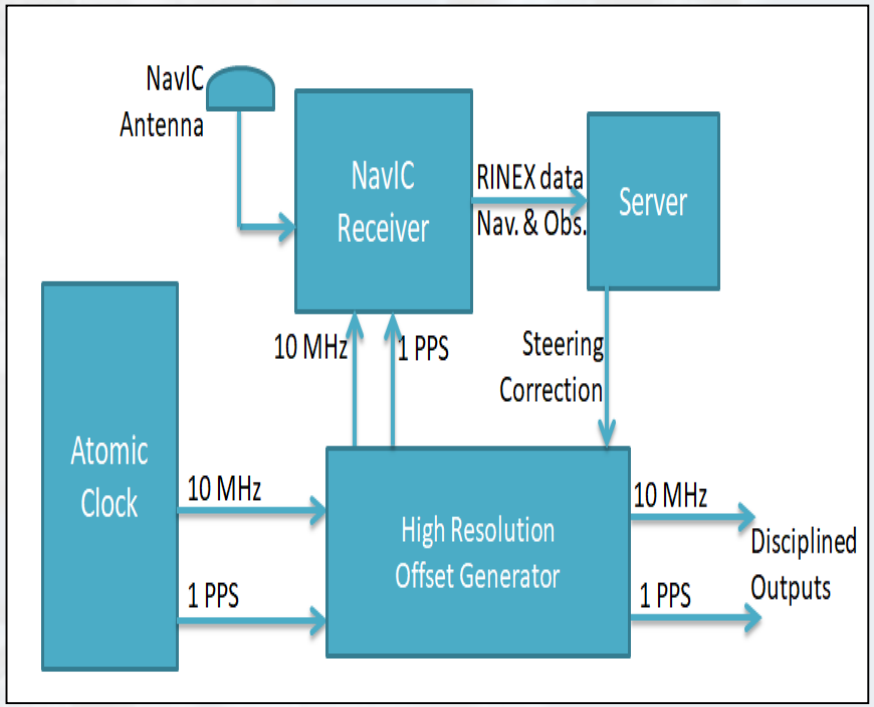
How to Discipline an oscillator?

- Process the raw measurements.
- Estimate the phase & frequency offsets between the clock & NavIC System Time.
- Adjust the offset of the clock with respect to NavIC System Time using an optimal steering technique such as LQG.
- For accuracy,

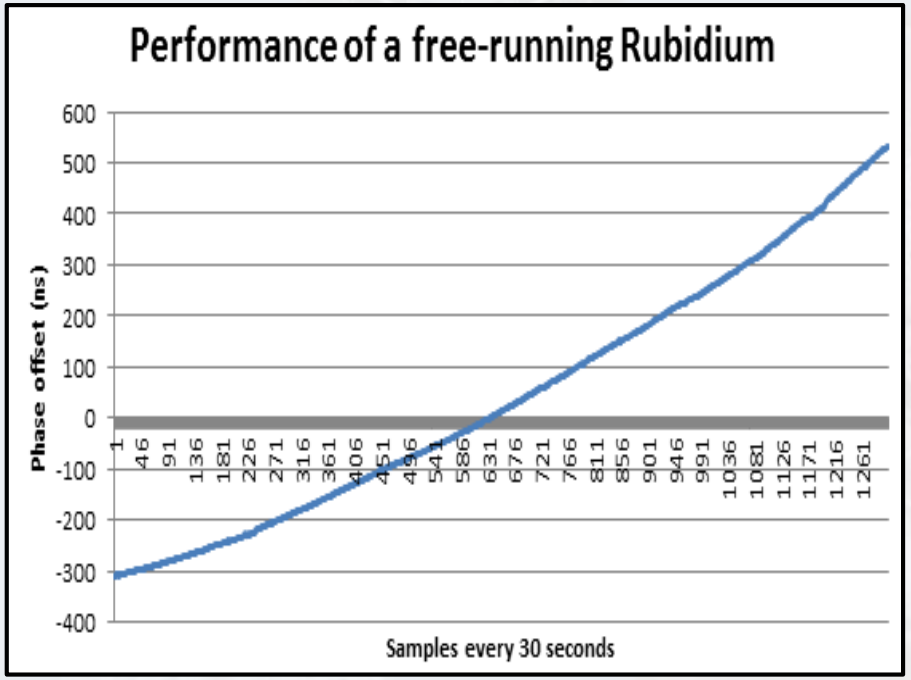
  fast steering at the cost of reduced stability.
- For stability,

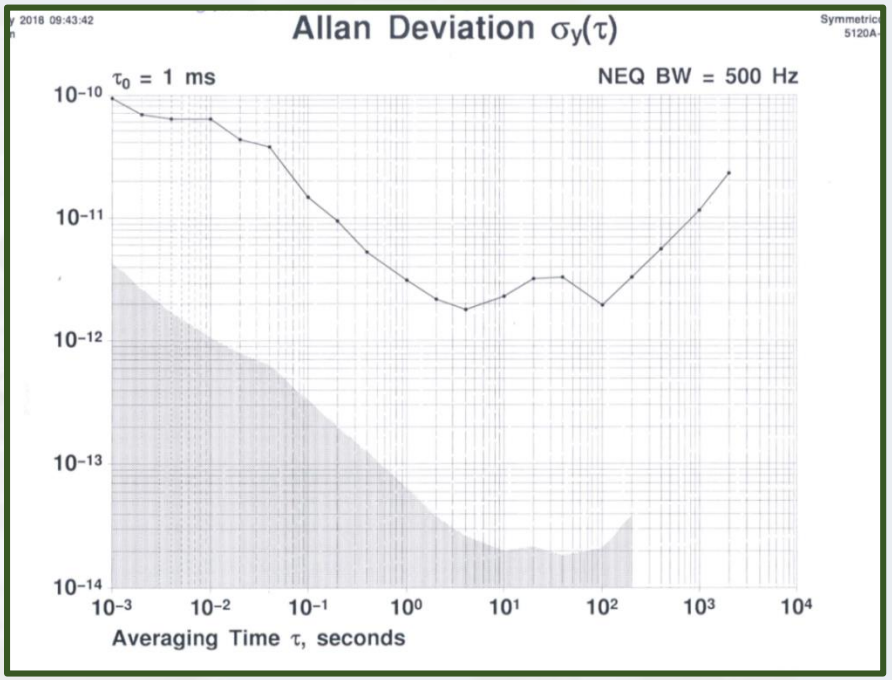
  slow steering at the cost of accuracy.
- For both accuracy and stability,

  trade of between slow & fast correction.



Performance of Rubidium clock (Before Disciplining)

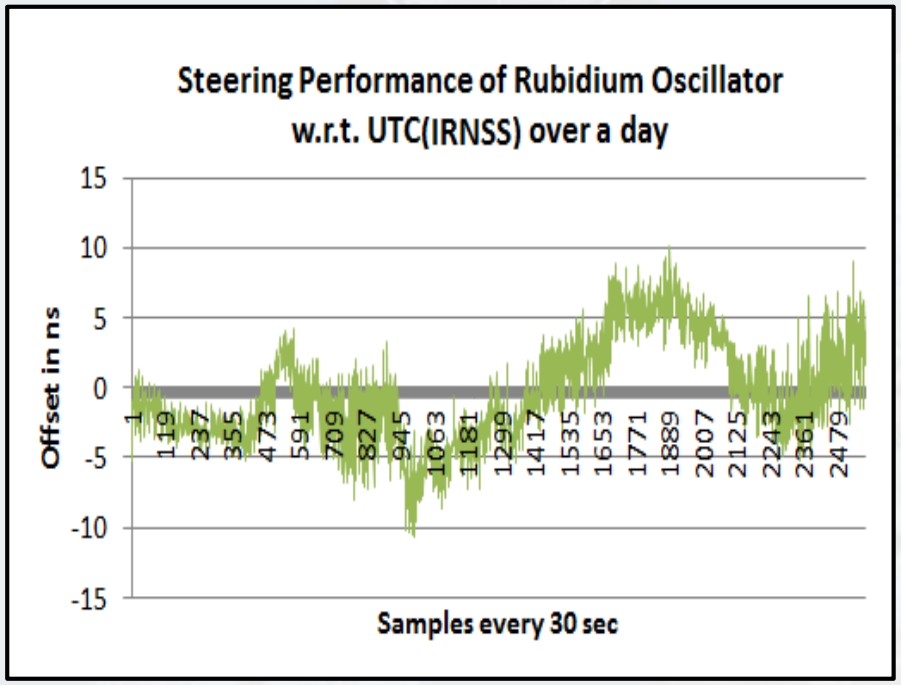


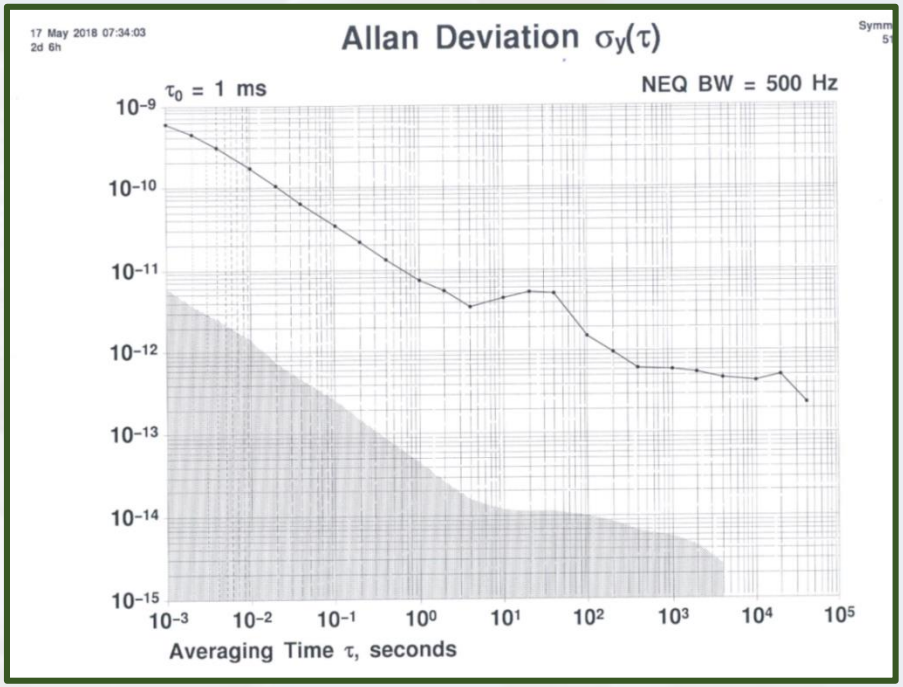


Moved ~850 ns in ~10.5 hrs

2.5e-11 ADEV @ 2000 seconds

Performance of Rubidium clock (After Disciplining)

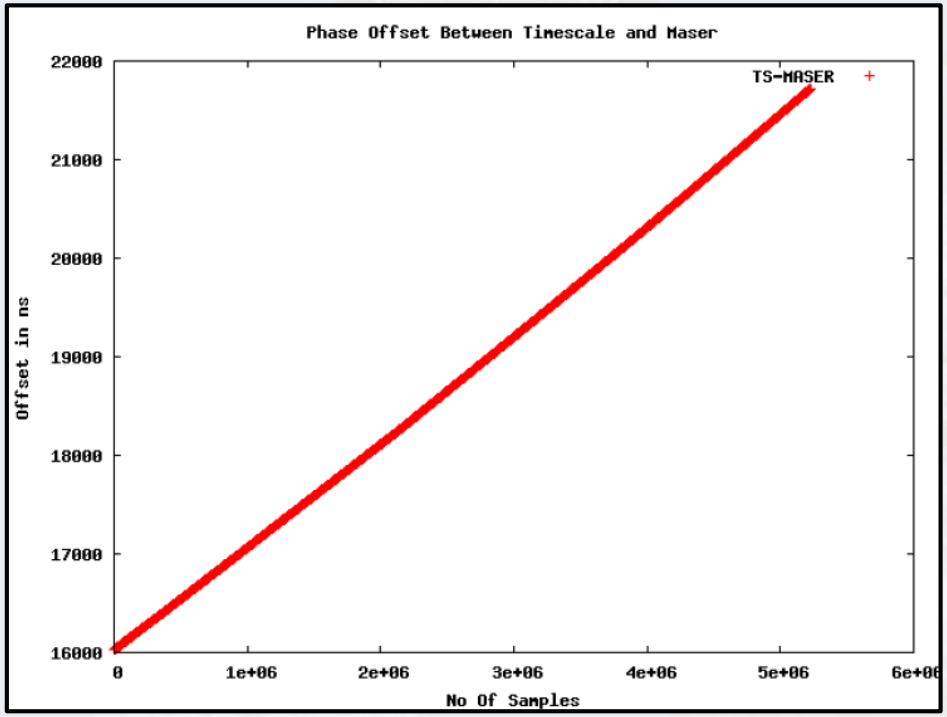




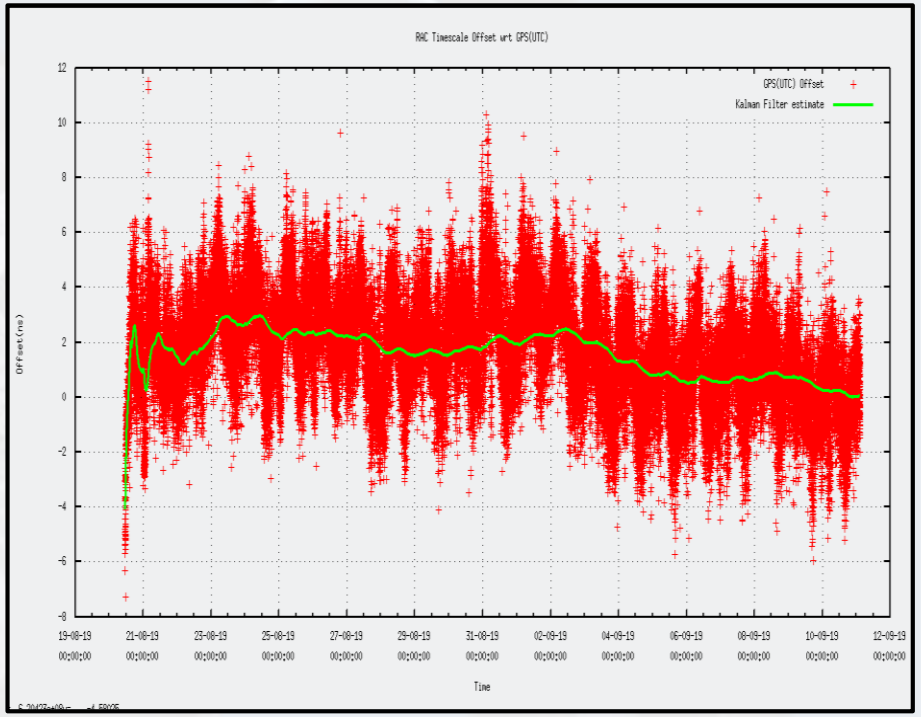
Maintained Within 10 ns over a day

5e-13 ADEV @ 2000 seconds

Performance of Active Hydrogen Maser (Before & After Disciplining)



Drift @ ~120 ns/day
(Before Disciplining)



Maintained Within 4 ns over 20 days
(After Disciplining)

Advantages of NavIC Disciplined Oscillator

Better Performance

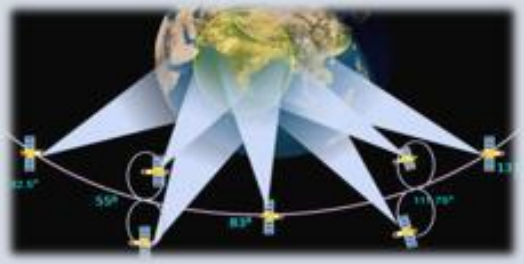
- Capable of maintaining the phase offset of the clock with respect to UTC within a window of 10 ns.
- Improved stability performance (almost two orders) as compared to the free-running clock.

Independence from other constellation

- Disciplining the clock using NavIC signals not only improves the performance but also makes the user independent of other constellation (e.g. GPS) for stable time and frequency signals.

Cost-effectiveness

- Costs much lesser as compared to a high cost atomic clock of similar performance.



Thank You