



Performance Enhancement of NavIC Disciplined Atomic Clock

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**12/30/2019
ICG-14, Bengaluru**

- ❑ 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.

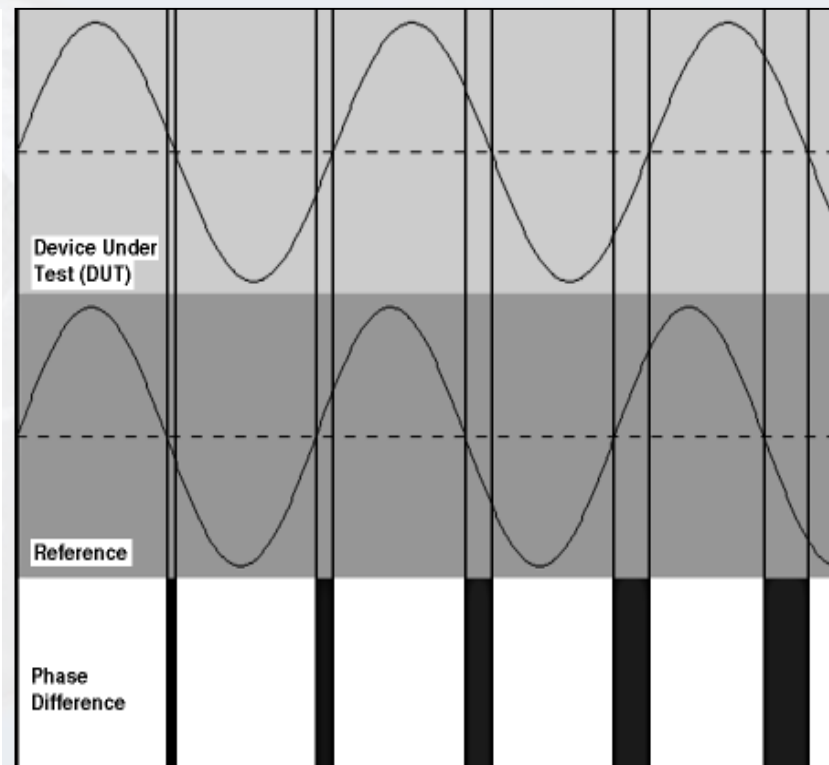
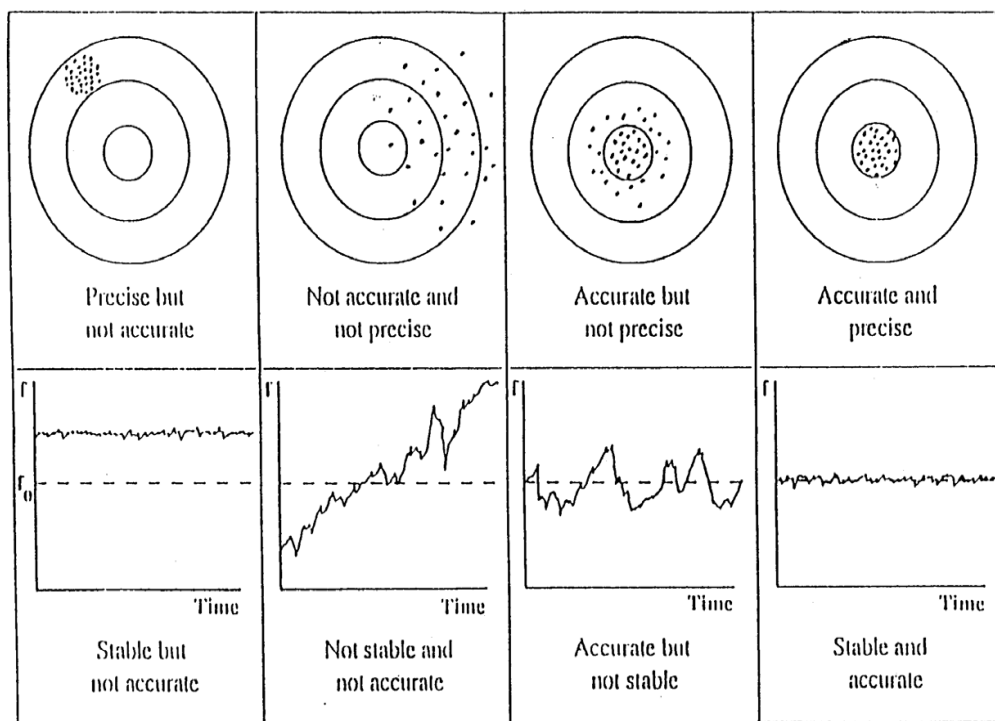
- ❑ The NavIC System Time is being generated at a precise timing laboratory.
- ❑ An ensemble of highly accurate and stable atomic clocks viz. Active Hydrogen Masers and High Performance Cesium Standards.
- ❑ Maintained within 40 ns (2 sigma) with respect to UTC over an yearly period and have stability performance as 5×10^{-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.

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

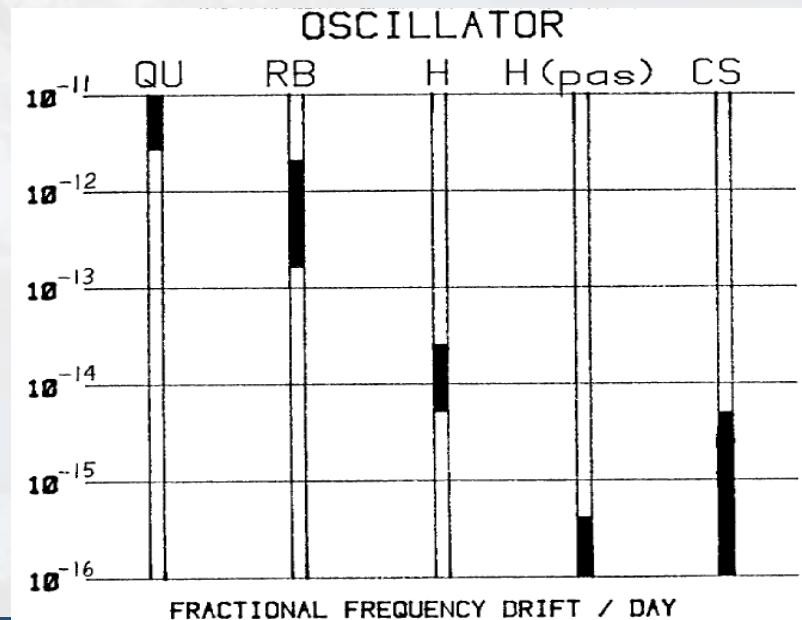
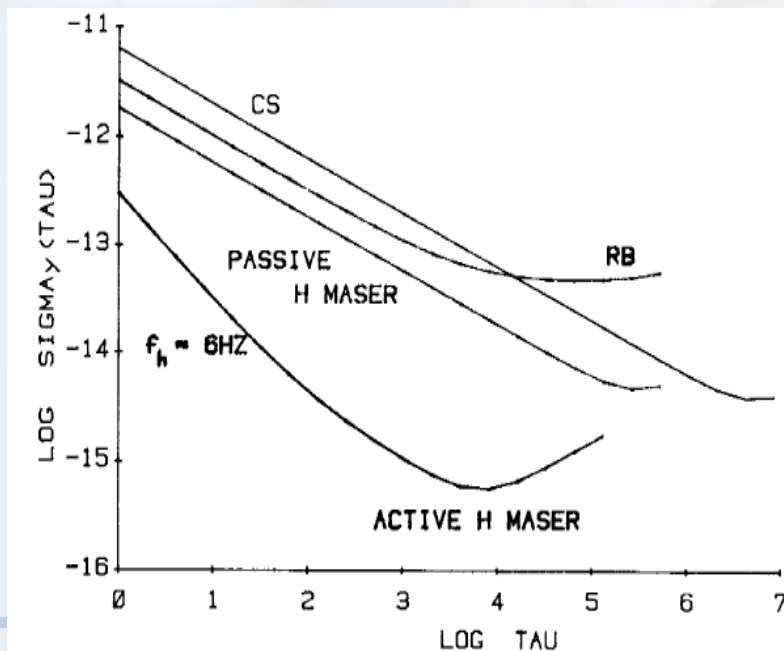
- ❑ Uses an electron transition frequency of atoms.
- ❑ Provides signals with high accuracy and good stability
 - Rubidium Atomic Clocks
 - Cesium Atomic Clocks
 - Hydrogen Masers



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}



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

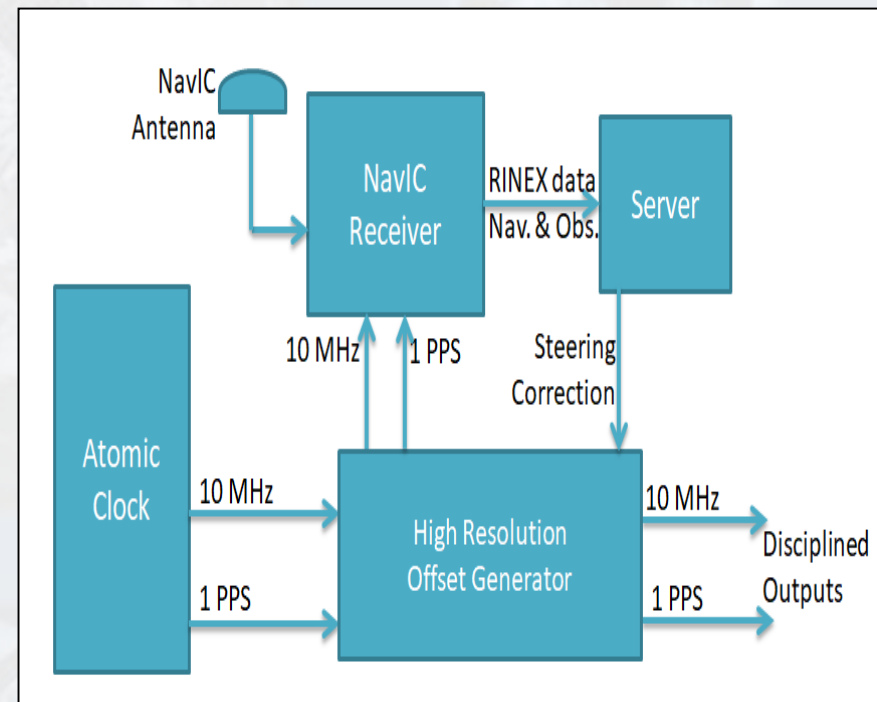
- ❑ Maintains the clock for required accuracy and stability
- ❑ Improves the frequency accuracy without loss the frequency stability

What can be improved by disciplining a clock?

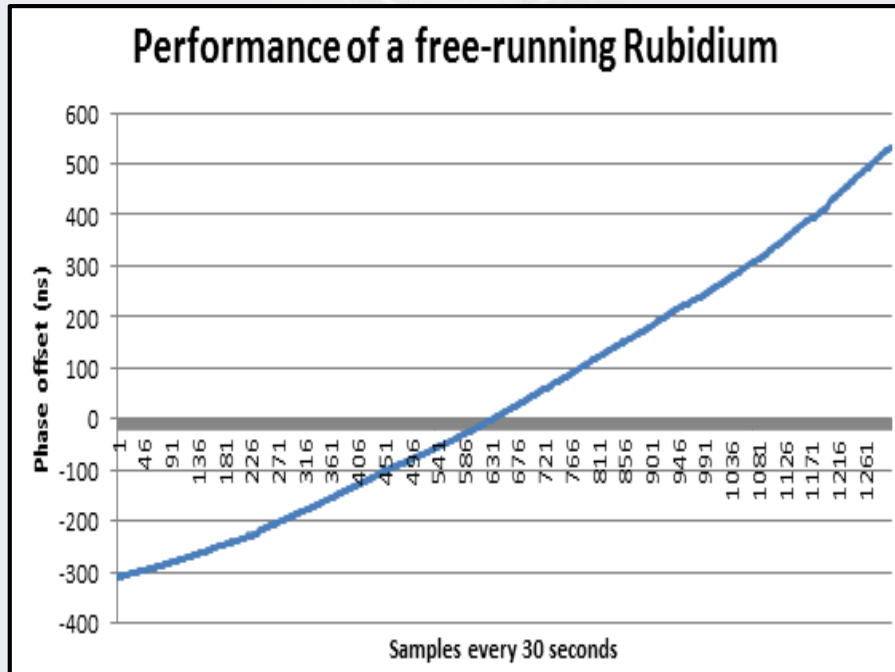
S. No.	Clock	Improvement
1	Oven Controlled Crystal Oscillator (OCXO)	Accuracy & Stability
2	Rubidium atomic Clock	Accuracy & Long term stability
3	Caesium Atomic Clock	Medium term Stability
4	Hydrogen Maser	Accuracy

How to Discipline an oscillator?

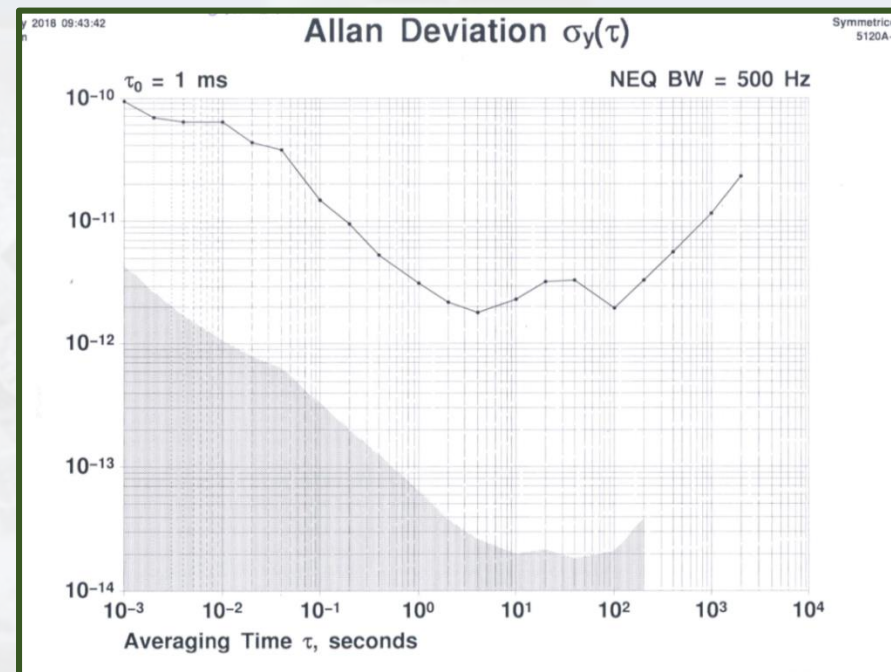
- ❑ Process the raw measurements.
- ❑ Estimate the phase & frequency offsets between the clock & NavIC System Time.
- ❑ Adjust the offset of the clock with respect to NavIC System Time using an optimal steering technique such as LQG.
- ❑ For accuracy,
fast steering at the cost of reduced stability.
-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



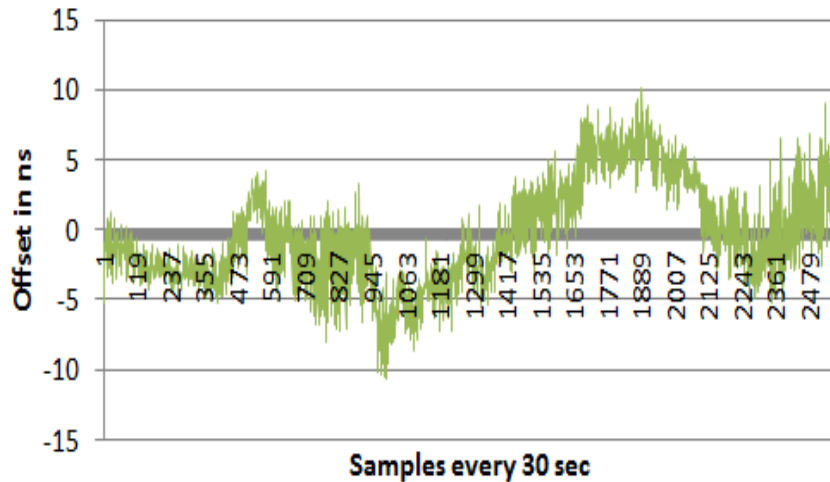
Moved ~850 ns in ~10.5 hrs



2.5e-11 ADEV @ 2000 seconds

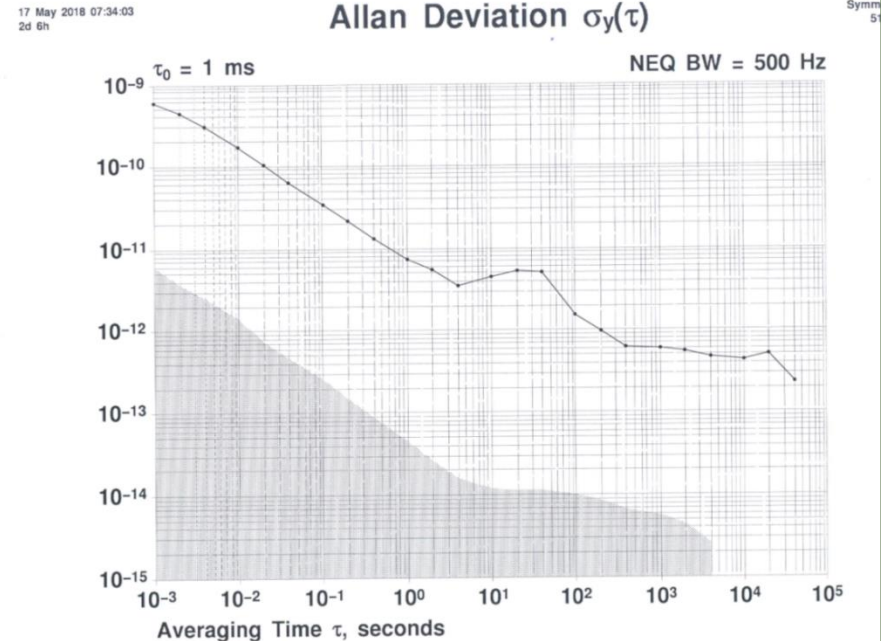
Performance of Rubidium clock (After Disciplining)

**Steering Performance of Rubidium Oscillator
w.r.t. UTC(IRNSS) over a day**



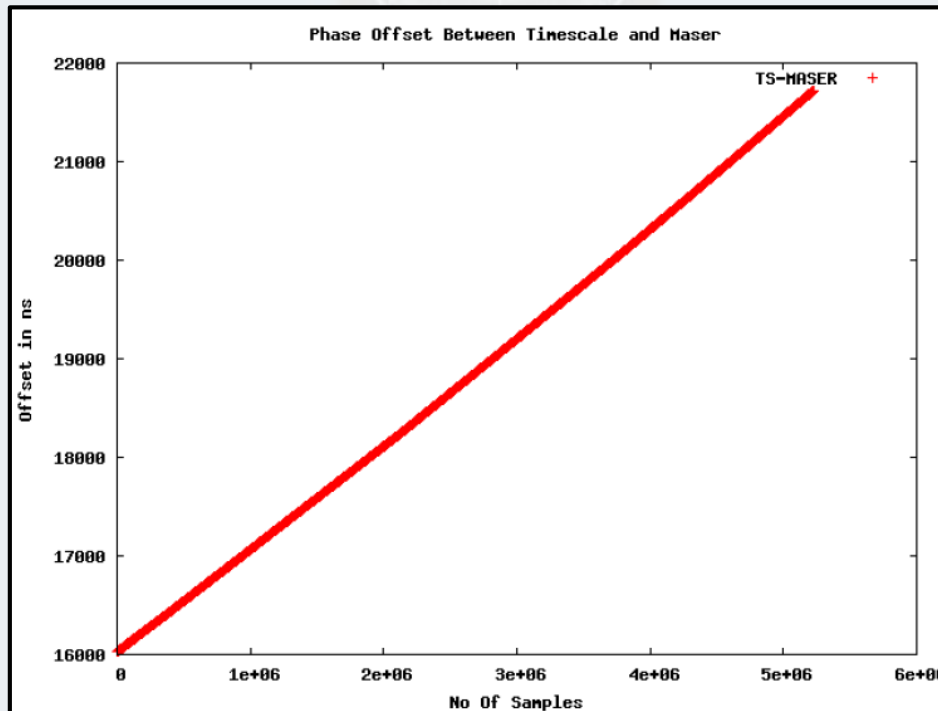
Maintained Within 10 ns over a day

Allan Deviation $\sigma_y(\tau)$

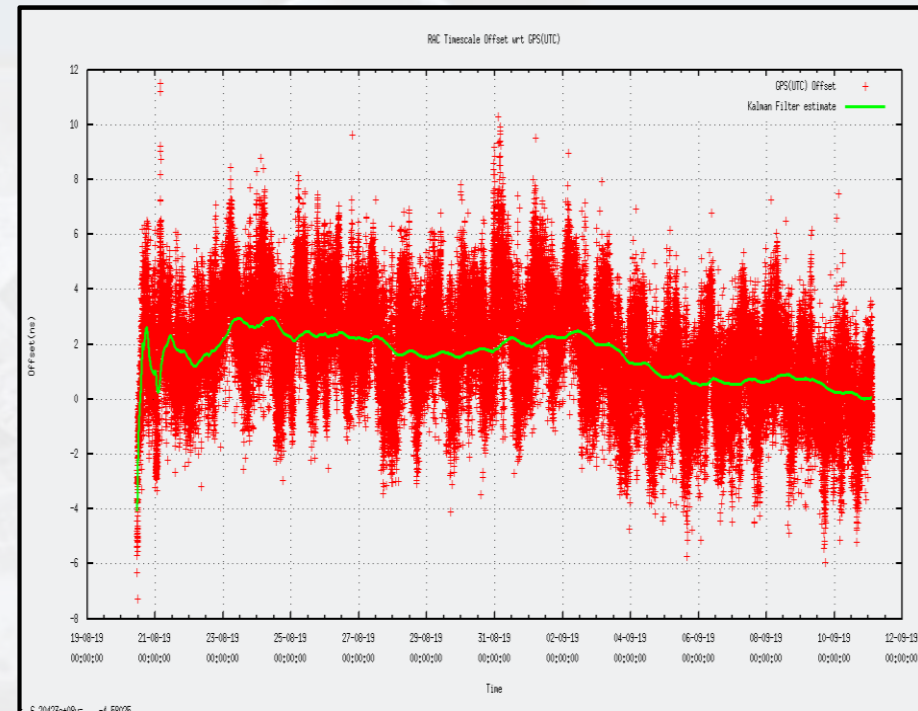


5e-13 ADEV @ 2000 seconds

Performance of Active Hydrogen Maser (Before & After Disciplining)



Drift @ ~120 ns/day
(Before Disciplining)



Maintained Within 4 ns over 20 days
(After Disciplining)

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.

