Performance Enhancement of NavIC Disciplined Atomic Clock

Anu Arora
Sci./Engr. ‘SD’
Navigation Systems Area
ISRO Telemetry Tracking and Command Network (ISTRAC)
Indian Space Research Organization (ISRO)

12/30/2019
ICG-14, Bengaluru
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.
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

Courtesies: Matsakis, Time & Time Transfer
Comparison of clocks: Accuracy, Stability & Drift

<table>
<thead>
<tr>
<th>Oscillator Type</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven controlled crystal oscillator (OCXO)</td>
<td>$10^{-8}$ (with $10^{-10}$ per g option)</td>
</tr>
<tr>
<td>Small atomic frequency standard (Rb, RbXO)</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>High performance atomic standard (Cs)</td>
<td>$10^{-12}$ to $10^{-11}$</td>
</tr>
<tr>
<td>Hydrogen Maser</td>
<td>$10^{-14}$ to $10^{-13}$</td>
</tr>
</tbody>
</table>

![Graphs showing comparison of clocks](image)

Courtesy: David W. Allan, Clock Characterization Tutorial
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?

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Clock</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oven Controlled Crystal Oscillator (OCXO)</td>
<td>Accuracy &amp; Stability</td>
</tr>
<tr>
<td>2</td>
<td>Rubidium atomic Clock</td>
<td>Accuracy &amp; Long term stability</td>
</tr>
<tr>
<td>3</td>
<td>Caesium Atomic Clock</td>
<td>Medium term Stability</td>
</tr>
<tr>
<td>4</td>
<td>Hydrogen Maser</td>
<td>Accuracy</td>
</tr>
</tbody>
</table>
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 off 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