The Need for a Robust Precise Time and Frequency Alternative to Global Navigation Satellite Systems

North American Synchro Phasor Initiative Meeting
October 2012
Atlanta, Georgia

Mitch Narins
Chief Systems Engineer – Navigation Programs
Federal Aviation Administration
Summary (Starting with the end in mind)

- Time is an important Global Navigation Satellite System (GNSS)* product, often overlooked
  - GNSS Time users greatly outnumber all other users
- GNSS is vulnerable; GNSS is vulnerable!
- There are robust alternatives – but there is a need to identify and incorporate them into operations that ensure safety and security and to mitigate significant economic impact
- Precise Time is particularly important to certain ground based and airborne “discriminating” users
- For many applications authentication is as important as accuracy
- Today’s status quo may not/will not be an acceptable alternative in the future as GNSS services continue to proliferate and support more and more critical operations

*The Global Positioning System is the US’ GNSS
The Definition of **Robust**

ro·bust, *adj*, [rō-ˈbəst, ˈrō-(ˌ)bəst]
a: strong and healthy; having or exhibiting strength or vigorous health.
b: (of an object) strongly formed or sturdy in construction.
c: (of a process, system, organization, etc.) able to withstand or overcome adverse conditions.

. . . so let’s agree that **Robust** Precise Time and Frequency is the provision of precise time and frequency services that are **strong, sturdy, and able to withstand or overcome adverse conditions.**
What are Adverse Conditions?

- Interference
  - Intentional/Unintentional
  - Predictable/Unpredictable
  - Manmade/Environmental
  - Crude/Sophisticated (Jamming/Spoofing)
  - Widespread/Localized

- Dependent on the Position, Navigation, and Timing (PNT) System (both xmtr and rcvr)
  - High power/low power
  - Line-of-sight/ground wave
  - Designed robustly/Engineered for a sunny day

- Both suppliers and users of PNT services need to recognize the potential for real-world adverse conditions and plan design, and equip accordingly

The world is changing…The world has changed
Commercially Available GPS Jammer
(so called “Personal Privacy Device”)
… and a few more “Personal Privacy Devices”

- **Mini Jammer**
  - $110 on Ebay

- **The Jammer Store**
  - $69

- **GPS&GSM**
  - $335 on Ebay
  - $40 on GPS&GSM, www.chinavasion.com
  - $83 on GPS&GSM, www.Tayx.co.uk
  - $55 on Ebay
  - $152 on Ebay

---

FAA

Next GEN
“Super HOT New Cigarette Case
Cell Phone Jammer”

• **Features**
  - Power supply: Rechargeable Li-battery
  - Effective Radius: 5m
  - Dimension: 90x50x15mm
  - Energy Consumption: 33dbm
  - Accessories: AC Adapter/Car Adapter

• **Specifications**
  - Jamming Signal Frequency:
    * CDMA: 869-880MHZ
    * GSM: 925-960MHZ
    * DCS: 1805-1930MHZ
    * 3G: 2110-2170MHZ

~ $99
The Problem

- GNSS-provided precise time and frequency is not robust
- Many users are not aware of the importance of time/frequency in system operations and that they derive it from GNSS
- Time and Frequency supports many critical infrastructure applications
<table>
<thead>
<tr>
<th>Critical Infrastructure/Key Resource Sector</th>
<th>Uses GPS Timing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Communications Sector</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Emergency Services Sector</td>
<td>No</td>
</tr>
<tr>
<td>3. Information Technology Sector</td>
<td>No</td>
</tr>
<tr>
<td>4. Banking &amp; Finance Sector</td>
<td>No</td>
</tr>
<tr>
<td>5. Healthcare &amp; Public Health Sector</td>
<td>No</td>
</tr>
<tr>
<td>6. Energy/Electric Power and Oil &amp; Natural Gas SubSector</td>
<td>No</td>
</tr>
<tr>
<td>7. Nuclear Sector</td>
<td>No</td>
</tr>
<tr>
<td>8. Dams Sector</td>
<td>No</td>
</tr>
<tr>
<td>9. Chemical Sector</td>
<td>No</td>
</tr>
<tr>
<td>10. Critical Manufacturing</td>
<td>No</td>
</tr>
<tr>
<td>11. Defense Industrial Base Sectors</td>
<td>No</td>
</tr>
<tr>
<td>12. Postal &amp; Shipping Sector</td>
<td>No</td>
</tr>
<tr>
<td>13. Transportation Sector</td>
<td>No</td>
</tr>
<tr>
<td>14. Government Facilities Sector</td>
<td>No</td>
</tr>
<tr>
<td>15. Commercial Facilities Sector</td>
<td>No</td>
</tr>
<tr>
<td>16. National Monuments and Icons Sector</td>
<td>Yes</td>
</tr>
<tr>
<td>17. Agriculture and Food Sector</td>
<td>Yes</td>
</tr>
<tr>
<td>18. Water and Wastewater Sector</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Summary
15 of the 18 CIKR Sectors have some degree of GPS timing usage.
Power Grid Requirements

- **Minimum PMU requirement** for time synchronization = 26 µs;
  - Corresponds to a phase error of 0.57 ° at the 60 Hz AC line frequency
  - Per [IEEE C37.118.2-2011](http://example.com) “Standard for Synchrophasor Data Transfer for Power Systems”
- The *desired* accuracy is 1 µs
  - Corresponds to a phase error of 0.022 °

Why Alternate Position, Navigation, and Timing (PNT)?

- Homeland Security Presidential Directive-7 (HSPD-7) establishes a national policy to identify, prioritize, and protect *critical infrastructure and services*. Requires use of alternate means (“a back-up”) if GPS services are being used for safety or security or to prevent significant economic impact.
- FAA recognizes the need to maintain operations within the National Airspace System (NAS).
- Other Critical Infrastructure/Key Resource sectors also have real time and continuity of operations requirements.
- For many waiting for the source of the interference to be located and turned off is not an acceptable alternative.
National Airspace System (NAS) Alternatives

• Today
  ✪ The majority of aircraft flying in the NAS have non-GPS alternatives that ensure safety [e.g., Very High Frequency Ominidirectional Range (VOR), Instrument Landing System (ILS), etc.]
  ✪ The FAA maintains a non-GNSS dependent ground based infrastructure

• Future
  ✪ NAS capacity and efficiency improvements will rely on GNSS services
  ✪ The FAA is exploring alternate position, navigation, and timing means to maintain safety and security and minimize economic impact in the event of a GNSS outage
National Airspace System Precise Time Requirements

- Multi-lateration
- RNAV/RNP
- Power Grid Sync
- Network Time Sync
- 3-mile Separation Assurance
- Asterix Time Stamping
- Automation Data Stamping
- RVR Data Stamping
- Sensor Fusion
- Weather Data Stamping

- GPS
- Cs
- PTP
- NTP
- WWVB

- 1 ns
- 1 μs
- 1 ms
- 1 s

- Automation
- Surveillance
- Navigation
- Communications
- Weather
- Power
- Flight/Manual Activities

FAA

NextGEN
Sources of Time and Frequency

- **GPS**
  - 10 ns Time Accuracy
  - $1 \times 10^{-13}$ Frequency Stability

- **ITS* (NTP)**
  - 10 ms Time Accuracy
  - $1 \times 10^{-7}$ Frequency Stability

- **ITS* (PTP)**
  - 0.1 ms Time Accuracy
  - $1 \times 10^{-9}$ Frequency Stability

- **Cesium (Cs) Clock**
  - 10 ns Time Accuracy
  - Cannot Recover Time Independently
  - $1 \times 10^{-13}$ Frequency Stability

- **Rubidium (Rb) Clock**
  - 10 μs Time Accuracy
  - Cannot Recover Time Independently
  - $5 \times 10^{-11}$ Frequency Stability

- **WWVB**
  - 0.1 – 15 ms Time Accuracy
  - $1 \times 10^{-10} - 1 \times 10^{-12}$ Frequency Stability

*Internet Time Service
Sources of Time and Frequency

- **Loran-C**
  - 100 ns Time Accuracy
  - $1 \times 10^{-11}$ Frequency Stability

- **eLoran**
  - 50 ns Time Accuracy
  - $1 \times 10^{-11}$ Frequency Stability

- **Future HP/LF Groundwave??**
  - ?? ns
  - $1 \times 10^{-11}$ Frequency Stability
### Today’s Alternate Time and Frequency Sources

- **Temperature Controlled Crystal Oscillators (TCXO)**
- **Network Time Protocol (NTP)**
- **Oven Controlled Crystal Oscillators (OCXO)**
- **Rubidium Clocks (Rb)**
- **Cesium Clocks (Cs)**

<table>
<thead>
<tr>
<th>Source</th>
<th>Frequency Accuracy</th>
<th>Time Uncertainty at One Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCXO</td>
<td>$1 \times 10^{-6}$</td>
<td>86.4 ms</td>
</tr>
<tr>
<td>NTP</td>
<td>$1 \times 10^{-6}$ - $1 \times 10^{-8}$</td>
<td>86.4 ms - 864μs</td>
</tr>
<tr>
<td>OCXO</td>
<td>$1 \times 10^{-7}$ - $1 \times 10^{-10}$</td>
<td>8.6ms – 8.6μs</td>
</tr>
<tr>
<td>Rb</td>
<td>$5 \times 10^{-9}$ - $5 \times 10^{-12}$</td>
<td>432μs – 432ns</td>
</tr>
<tr>
<td>Cs</td>
<td>$1 \times 10^{-13}$</td>
<td>10 ns</td>
</tr>
<tr>
<td>GPS</td>
<td>$1 \times 10^{-13}$</td>
<td>10 ns</td>
</tr>
</tbody>
</table>

**Increasing Precision**
The Challenge of Robust Time Transfer

- Precision
- Authentication
Alternative 1
Robust Satellite-Based Sources: GEOs, MEOs, and LEOs
Robust Space-Based Time Transfer

Enabler:
Beam Steering Antenna
Time Transfer RX
Commercially Available Controlled Reception Pattern Antennas (CRPA)

- Mitigate Radio Frequency Interference
- Provides Anti-Jam Performance
Alternative 2
Robust Wireless Ground-Based Sources
Ground Based Wireless Time Networks

WWVB
0.2-15 milliseconds

?? Alternate PNT ??

Loran, eLoran, Future HP/LF GW
???-100 nanoseconds
Alternative 3
Robust Wire-Based Sources
Internet Time Services

• **ITS* (NTP)**
  - 10 ms Time Accuracy
  - $1 \times 10^{-7}$ Frequency Stability

• **ITS* (PTP)**
  - 0.1 ms Time Accuracy
  - $1 \times 10^{-9}$ Frequency Stability

- **ITS Timing Performance Limitations**
  - Use of Ethernet connections
  - Use of different lines for incoming and outgoing traffic
    - Line length differences result in timing errors
    - Errors that increase over distance cannot be corrected
  - When implemented on a wide area network (WAN) such as the Internet, where the path delays are highly variable and uncontrolled, PTP accuracy becomes similar to NTP (i.e., milliseconds)
Summary
Summary (again)

- Time is an important Global Navigation Satellite System (GNSS)* product, often overlooked
  - GNSS Time users greatly outnumber all other users
- **GNSS is vulnerable; GNSS is vulnerable!**
- There are robust alternatives – but there is a need to identify and incorporate them into operations that ensure safety and security and to mitigate significant economic impact
- Precise Time is particularly important to certain ground based and airborne “discriminating” users
- For many applications authentication is as important as accuracy
- Today’s status quo may not/will not be an acceptable alternative in the future as GNSS services continue to proliferate and support more and more critical operations

*The Global Positioning System is the US’ GNSS
Questions