Robust GNSS for Timing Applications

57th Meeting of the CGSIC

Portland, Oregon
September 25, 2017

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Robust GNSS timing is critical to infrastructure across numerous industries, and facing a wide range of threats.
Topics

• Septentrio Background
• Keys to Robustness for GNSS Timing
  ➢ Multi-frequency
  ➢ Multi-constellation
  ➢ Anti-jamming
  ➢ Spoof resilience
• Summary
Septentrio Global Resources for Global Positioning

Europe
- **Leuven, Belgium (HQ)**

Americas
- Torrance, California
Asia-Pacific
- Causeway Bay, Hong Kong

* Septentrio corporate offices shown above. Additional dealers are located on 6 continents.

Leuven Institutions
Septentrio – GNSS Technology for Professional and Scientific Applications

Machine Automation
- Marine
- Construction
- Mining
- Logistics
- Agriculture
- Autonomous driving

Survey and Mapping
- Survey
- GIS
- Mobile Mapping
- Unmanned Systems

Timing/Scientific/Reference
- Reference Receivers
- Timing Receivers
- Space Weather

Aerospace/Defense
- Aerospace
- Defense
Septentrio – GNSS Technology for Professional and Scientific Applications

Easy-to-integrate

Reliability
Availability
Accuracy

Technology
Typical Septentrio Product

In-House Developed Baseband ASIC

Flexible Positioning Engine

- DGPS, RTK, PPP
- Multi-sensor
- High Sensitivity
- High update rates

State-of-the-Art RF front-end

- High Linearity
- COTS components

Multi-Frequency
Multi-Constellation
Multi-Antenna
Septentrio GNSS Product Lines – Professional and Scientific

**AsteRx:**
- Machine Control, Marine, Military & UAV segments

**Altus:**
- Survey & GIS

**PolaRx:**
- Government & Research Institutions

**OEM Receiver Boards**

**Smart Antennas**

**Integrated GNSS Receivers**

**Timing, Reference & Iono Monitoring GNSS Receivers**

Septentrio in Confidence
Septentrio GNSS Receivers for Time & Frequency Applications

PolaRx5TR
- Multi-frequency GNSS Time and Frequency Transfer
- High-precision, low-noise measurements
- PPS input internal delay auto-calibration
- Fully compliant with CCTF 4 and 5 (2015), CGGTTS V2E

AsteRx-m2 OEM
- Compact, high-performance
- Ultra-low power multi-frequency GNSS
- Time and frequency synchronization
- For Telecom, First Responders, Military, other OEMs

AIM+ Advanced Interference Mitigation: Most advanced anti-jamming technology, Suppressing the widest variety of interferers
Septentrio Advanced Timing Applications

National Timing Labs
- UTC Contributors

Satellite Laser Ranging
- Time & Frequency sync

Particle Physics
- Neutrino velocity measurement

Graphic from GPS World, May 2017
By Comparing Individual Clocks with GNSS Time, They Can be Compared with Each Other

To compare the atomic clocks used in timing labs around the world, they need to be connected to an accurate GNSS time transfer receiver. This special type of receiver uses an external atomic clock and utilizes two output signals:

- A pulse every second synchronized to UTC (PPS IN) and
- A 10 MHz frequency reference; essentially a sine wave (REF IN)

To reach the nanosecond accuracies required, Septentrio applies its expertise:

- Signal delays in all elements in the setup should be accurately calibrated
- BIPM maintains a set of pre-calibrated travelling receivers as calibration references.
Why Multi-Constellation GNSS?  
More Satellites = Higher Accuracy

SATELLITE AVAILABILITY

➢ Full open-sky conditions can be difficult to attain in urban environments
➢ Ex: Portland, Oregon in open-sky
  GPS max 12 SV
  GPS+GLONASS max 22 SV
  GPS+GLONASS+GALILEO + BEIDOU max 41SV
Why Multi-Constellation GNSS?
More Satellites = Higher Accuracy

ROBUSTNESS

- Even if L1 signal is jammed, other carriers (L2, L5) can still provide a solution
- The use of multi-frequency GNSS equipment allows the calculation and removal of local ionospheric errors

The height of a static PolaRxS receiver with and without scintillation-improved algorithms.
(Supplied by: B. Bougard from data collected as part of the CIGALA project, Brazil)
GNSS RFI Vulnerability: Interference Is Everywhere

- GNSS signals received on the ground are very low power
- Sharing of radio spectrum with other services, some operating at high power (Ligado, Iridium, Inmarsat, Distance Measuring Equipment)

Narrowband
Wideband
Pulsed
Continuous

Unintentional
Intentional (jamming)
In-band
Out of band
Spectral Allocation – United States
Spectral Allocation Challenges

- **VHF Radio Links**: 150 MHz
- **UHF Links**: 400 MHz
- **Cellular**: 800-960 MHz
- **Aircraft Systems**: L5/E5 GNSS, L2 GPS, L2 GLO, E6
- **Radar**
- **Radio Amateurs**
- **Harmonics**
- **Aliasing**

- **4G (Ligado/Docomo)**
- **L-band**
- **B1/L1/G1**
- **Satellite Modems**
- **Cellular**
- **WiFi**

Frequency:
- 1510 MHz
- 1610 MHz
- 1710 MHz
- 2200 MHz
- 2400 MHz

Overlap!
Septentrio AIM+ Advanced Interference Mitigation

Out-of-band

Multiple Demodulators

Separated filtering for all bands

In-band

- 3 notch filters
- Wide band interference mitigation Unit (WIMU)
- Pulse-blanking

* Demod 3 is PolaRx5/AsteRx4 Platform only
Spoofing Threats Must Be Addressed

• Inexpensive software-defined radio spoofers will pose a significant threat to GNSS equipment
  ➢ Just a few hundred dollars
  ➢ Thousands in the field
• By emulating GNSS signals, SDR spoofers convince a receiver that it is somewhere other than its true location
• Septentrio has tested their effectiveness and can now demonstrate how spoofing may be mitigated

Septentrio at ION GNSS+

Session B4: Spectrum: Protection and Optimization
Date: Thursday, Sept. 28, 2017
Time: 1:45 p.m. - 5:30 p.m.
Location: Room B110/B111/B112

Wim de Wilde presentation*
➢ Spoofing Threats: Reality Check, Impact and Cure

*If you do not attend, this paper is available after ION GNSS+
Septentrio Summary for Delivering Robust, Accurate GNSS Timing

- Maximize GNSS signals
- Calculate and resolve ionospheric errors
- Mitigate the effects of narrowband and wideband interference
- Address the threat of spoofing
Questions?
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Appendix
Septentrio Core Technologies for Reliable Accuracy in Challenging Environments

RF front-end & Clock
- Multi-Frequency Multi-Constellation
- High interference immunity
- High stability (biases over temperature)
- COTS or RFIC

SoC, ASIC
- All-in-view multi-frequency multi-constellation
- Fast acquisition
- Built-in interference mitigation (incl. chirp)
- Advanced power management

DSP
- All signals in space (GPS, GLO, GAL, BDS, QZSS)
- multi-path mitigation (wide-band arch., APME)
- Very low measurement noise
- High sensitivity

PVT: Position Velocity & Timing
- Scalable accuracy: sub-meter down to cm
- High reliability
- High availability in challenging environments
- All technologies (SBAS, DGNSS, RTK, PPP, SSR)

Professional and Scientific GNSS applications
## PolaRx5 Product Family: Application-Specific Models

<table>
<thead>
<tr>
<th></th>
<th>PolaRx5 Reference Receiver</th>
<th>PolaRx5S Iono Monitoring</th>
<th>PolaRx5TR Time &amp; Freq Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hardware</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal clock</td>
<td>TCXO</td>
<td>OCXO</td>
<td>TCXO</td>
</tr>
<tr>
<td>REF IN</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>PPS IN</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>External Clock</td>
<td>Frequency only</td>
<td>NO</td>
<td>Frequency and time</td>
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<tr>
<td>Synchronization</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>REF OUT</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>PPS OUT</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td><strong>Software</strong></td>
<td></td>
<td></td>
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<tr>
<td>PPP for seismic</td>
<td>YES</td>
<td>NO</td>
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<td>CGGTTS</td>
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<tr>
<td>ISMR</td>
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<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>IQ Corr</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
</tr>
</tbody>
</table>

Application driven → different hardware & specific software features
All PolaRx5 Family GNSS Receivers provide:

- Track all visible signals (GPS, GLONASS, GALILEO, BEIDOU, IRNSS, QZSS, SBAS)
- High-precision, low-noise measurements
- AIM Best in class interference monitoring and mitigation
- Low and scalable power consumption
- Powerful web interface and logging tools
- Logging up to 24 parallel data records both internally and to an external device
What Accuracy Can Be Achieved with PolaRx5TR?

Accuracy is dependent on the setup...

- Delays due to cable, antenna and receiver front-end require calibration
- Achieve ~1ns accuracy when all delays calibrated

\[ X_{S,i}: \text{delay in antenna for signal i} \]
\[ X_{R,i}: \text{delay in RF section of receiver for signal i} \]
\[ X_{C}: \text{delay in RF cable (including amplifier and splitter)} \]
\[ X_{p}: \text{delay in PPS cable} \]
\[ X_{O}: \text{delay between PPS IN connector and internal receiver time reference (} X_{O} = 0 \text{ on PolaRx5TR when auto-calibration is enabled)} \]
AsteRx-m2 - Key Features

- Best-in-class reliable and scalable position accuracy
- Clock synch functionality = Time synch + frequency synch
- AIM+ unique interference monitoring and mitigation system
- Industry-leading ultra-low power consumption
- All-in-view satellite tracking: multi-constellation, multi-frequency
- Easy to integrate
AsteRx-m2 Features

• Multi-Constellation / Multi-Frequency
  • GPS L1CA, L1P, L2P, L2C, L5, L1C ready
  • GLO L1CA, L2CA, L3
  • BDS B1, B2
  • GAL E1BC, E5a, E5b, E5AltBOC
  • QZSS L1CA, L2C, L5, L1C ready
  • IRNSS L5
  • SBAS L1, L5
  • 2-channel L-band – Terrastar services

• Powerful GNSS capabilities
  • Interference monitoring and mitigation
  • Low latency
  • Up to 100Hz RTK

• Footprint and connectivity backward compatible with AsteRx-m
  • USB device
  • 3 TTL UART
  • PPS out, event marker
  • 1 SDIO (for SD card logging)
**AsteRx-m2 Clock Synchronization**

**CLOCK SYNC = FREQ SYNC + TIME SYNC**

- **Freq Sync**
  Connecting an accurate 10 MHz reference enables your receiver to keep the time accurately

- **Time Sync**
  Sending a time-adjust signal sets the time right after each power cycle

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**Frequency synchronization**

**Frequency and time synchronization**

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[septentrio logo]