# 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**

Science

Telecommunications

ns

Energy

µs

Financial

ms

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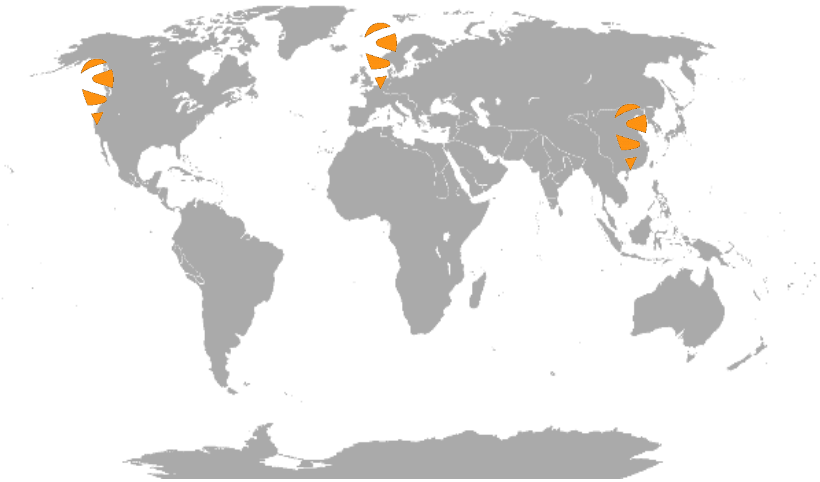
# Topics

- Septentrio Background
- Keys to Robustness for GNSS Timing
  - Multi-frequency
  - Multi-constellation
  - Anti-jamming
  - Spoof resilience
- Summary

# Septentrio Global Resources for Global Positioning



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


Europe

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

Americas

- Torrance, California

Asia-Pacific

- Causeway Bay, Hong Kong

***Leuven Institutions***

imec
aspire invent achieve


KATHOLIEKE UNIVERSITEIT
LEUVEN

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# Septentrio – GNSS Technology for Professional and Scientific Applications

## Machine Automation

Marine

Construction

Mining

Logistics

Agriculture

Autonomous driving

## Survey and Mapping

Survey

GIS

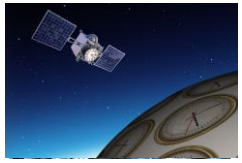
Mobile Mapping

Unmanned Systems

## Timing/Scientific/Reference

Reference Receivers

Timing Receivers



Space Weather

## Aerospace/Defense

Aerospace

Defense

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# Septentrio – GNSS Technology for Professional and Scientific Applications


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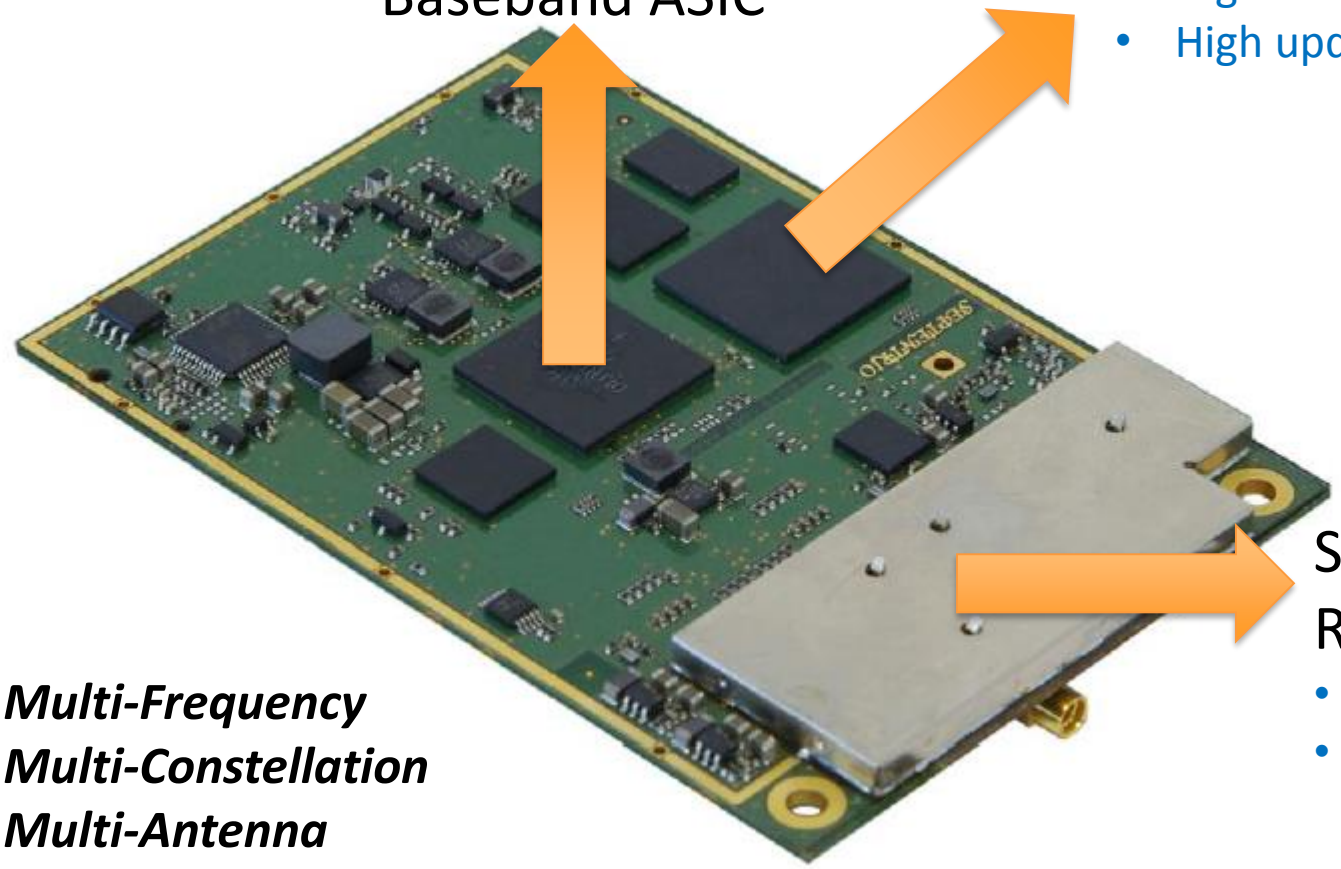
# Typical Septentrio Product

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***

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# 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 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**

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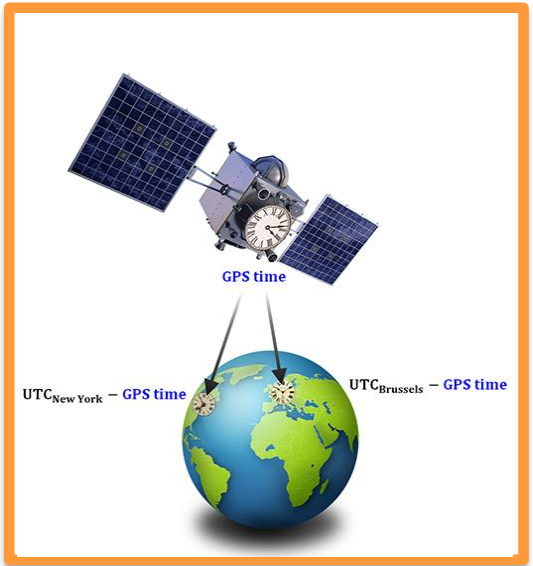
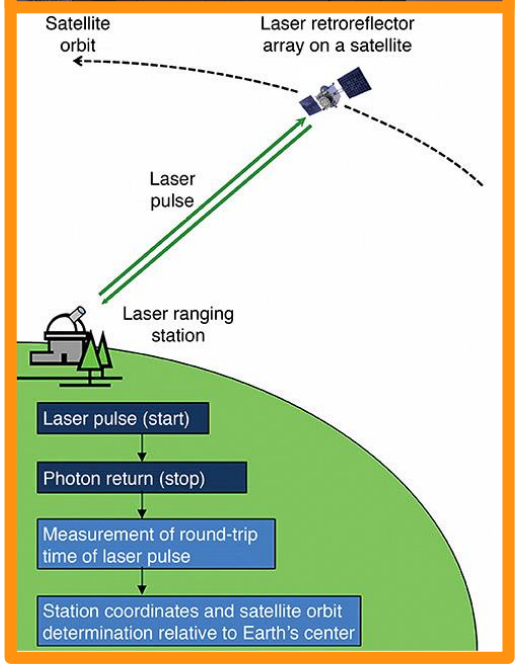
**AIM+ Advanced Interference Mitigation:** Most advanced anti-jamming technology, Suppressing the widest variety of interferers

# Septentrio Advanced Timing Applications

## National Timing Labs
- UTC Contributors




## Satellite Laser Ranging
- Time & Frequency sync


Graphic from GPS World, May 2017

## Particle Physics
- Neutrino velocity measurement

Photo fro, INFN

# 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

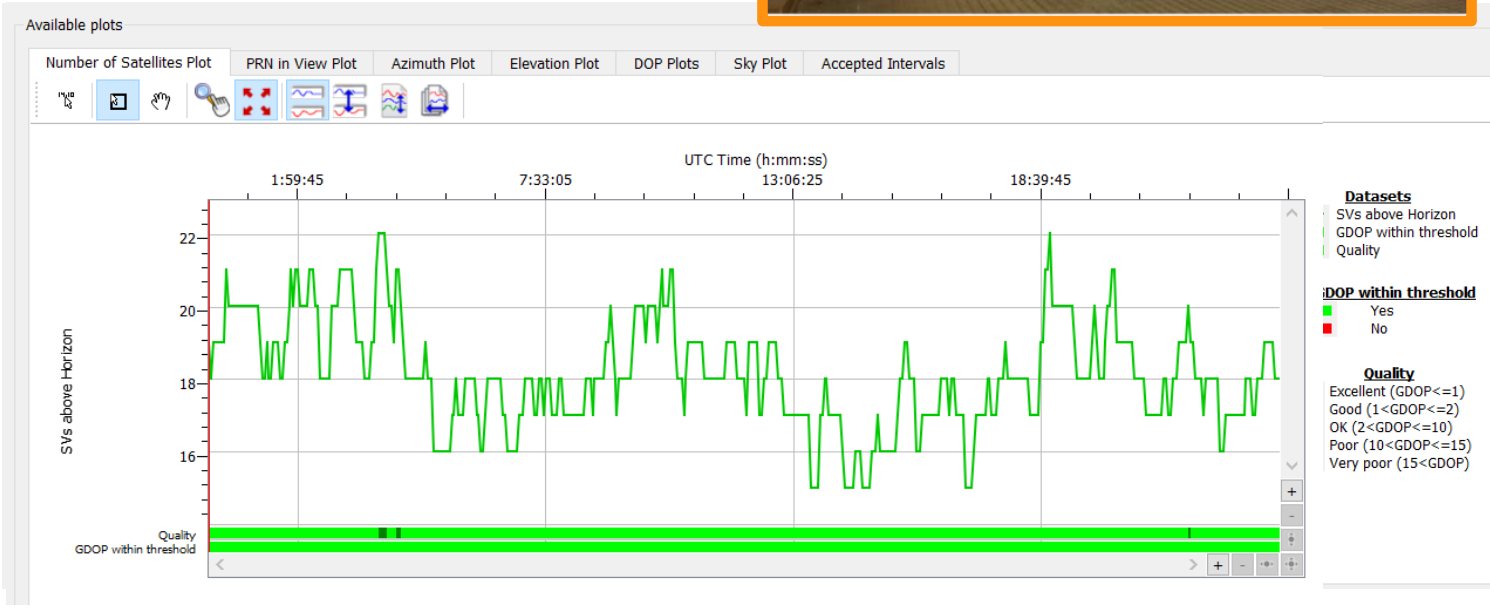
### SATELLITE AVAILABILITY

- 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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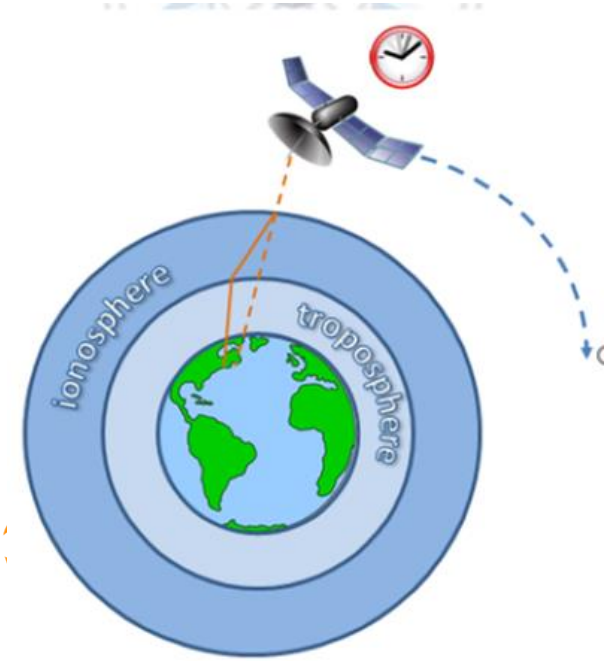
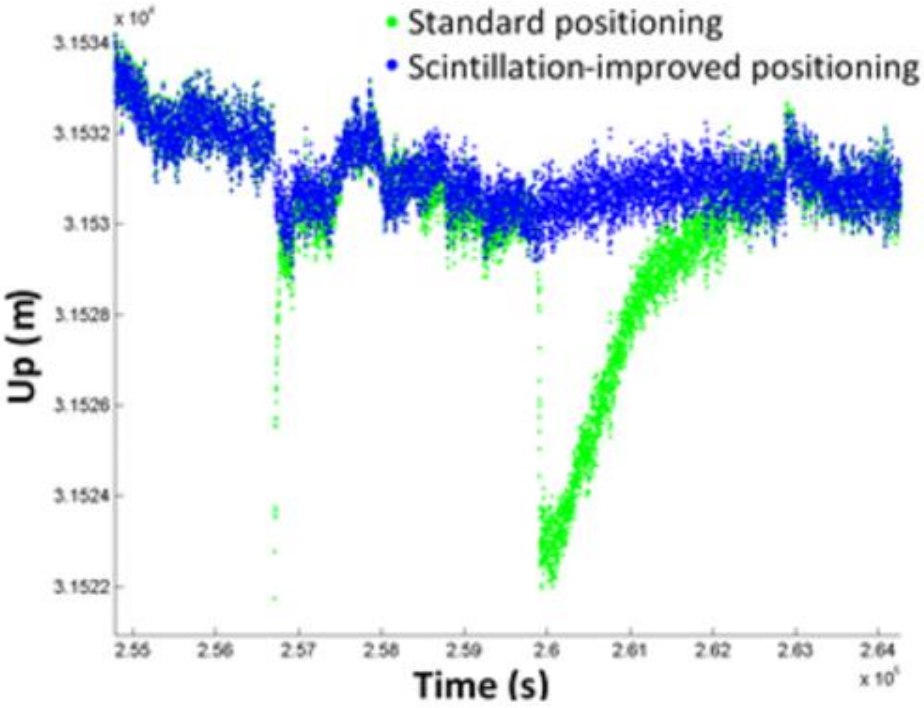
# Why Multi-Constellation GNSS?
## More Satellites = Higher Accuracy

**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

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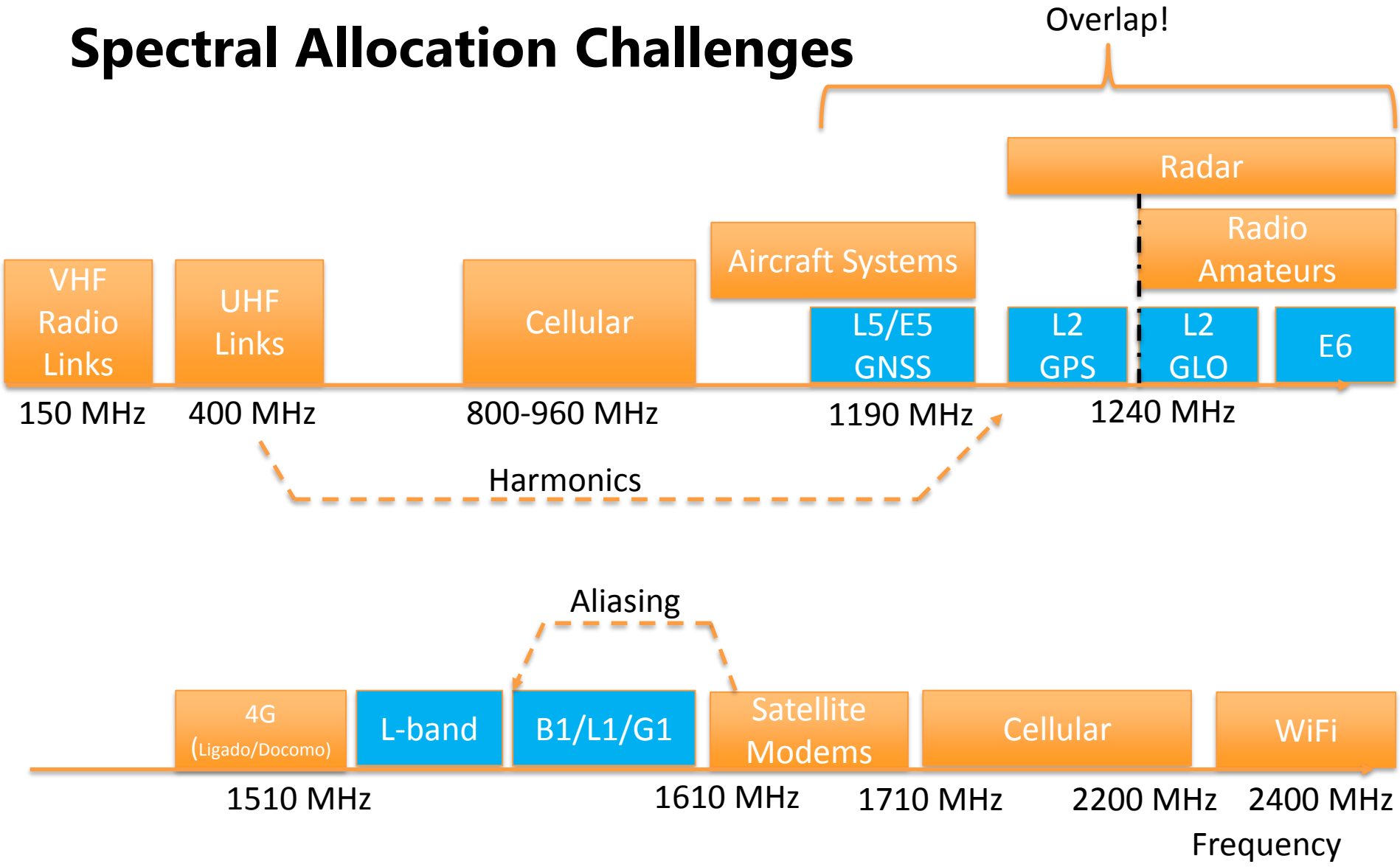
# Spectral Allocation – United States


# Spectral Allocation Challenges

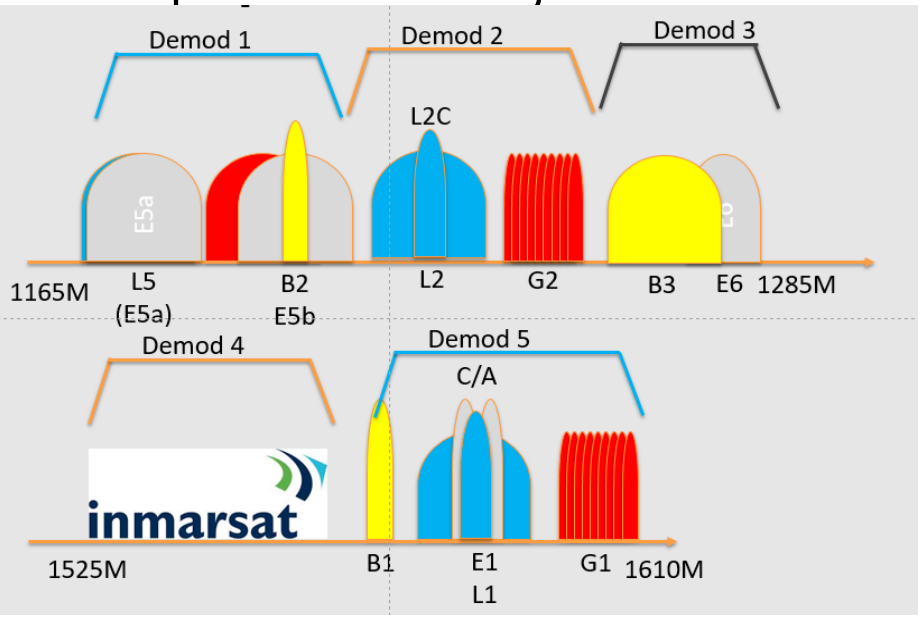


# Septentrio AIM+ Advanced Interference Mitigation

## Out-of-band

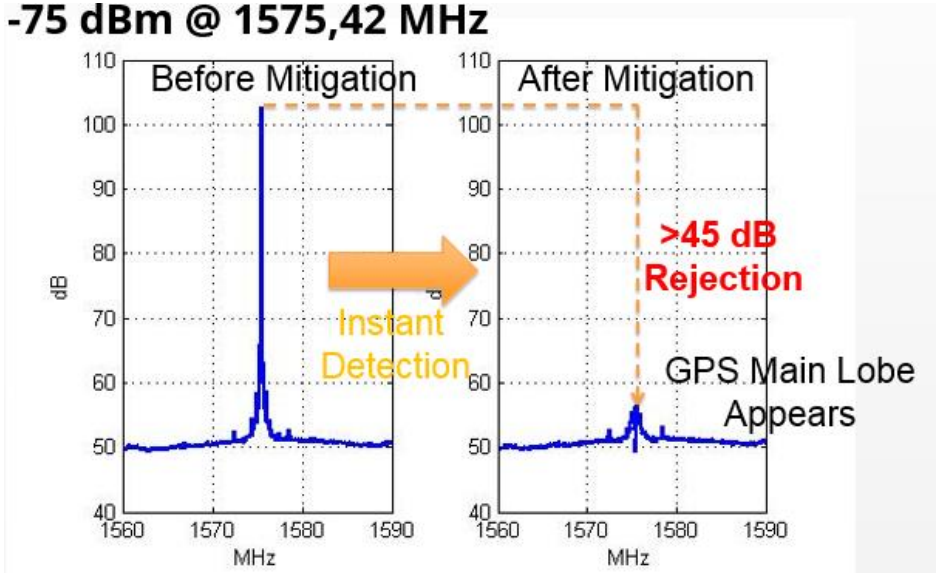
Multiple Demodulators

Separated filtering for all bands




## In-band

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

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* 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+

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# Septentrio Summary for Delivering Robust, Accurate GNSS Timing

- Maximize GNSS signals
- Calculate and resolve ionospheric errors
- Mitigate the effects of narrowband and wideband intereference
- Address the threat of spoofing

# Questions?

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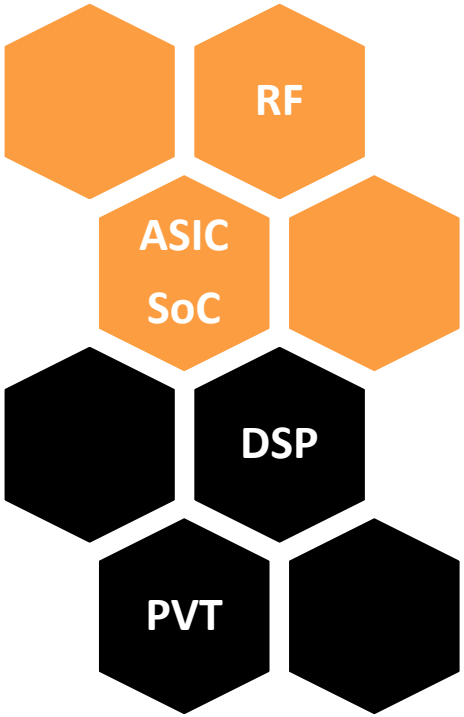
# Appendix

# Septentrio Core Technologies for Reliable Accuracy in Challenging Environments




Professional and Scientific GNSS applications

**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)

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# PolaRx5 Product Family: Application-Specific Models

| | | PolaRx5<br>Reference Receiver | PolaRx5S<br>Iono Monitoring | PolaRx5TR<br>Time & Freq Transfer |
|---|---|---|---|---|
| Hardware | Internal clock | TCXO | **OCXO** | TCXO |
| | REF IN | **YES** | NO | **YES** |
| | PPS IN | NO | NO | **YES** |
| | External Clock Synchronization | **Frequency only** | NO | **Frequency and time** |
| | REF OUT | **YES** | **YES** | **YES** |
| | PPS OUT | **YES** | **YES** | **YES** |
| Software | PPP for seismic | **YES** | NO | NO |
| | CGGTTS | NO | NO | **YES** |
| | ISMR | NO | **YES** | NO |
| | IQ Corr | NO | **YES** | NO |

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Application driven → different hardware & specific software features

# PolaRx5TR


**Timing specific specs:**

- Code-carrier bias 0 by design
- Inter-frequency code bias <10 ns
- Inter-system code bias in common carrier <2ns
- Code measurements <0.5 ns
- Phase measurements < 5 ps
- PPS in delay calibration precision 20 ps

**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

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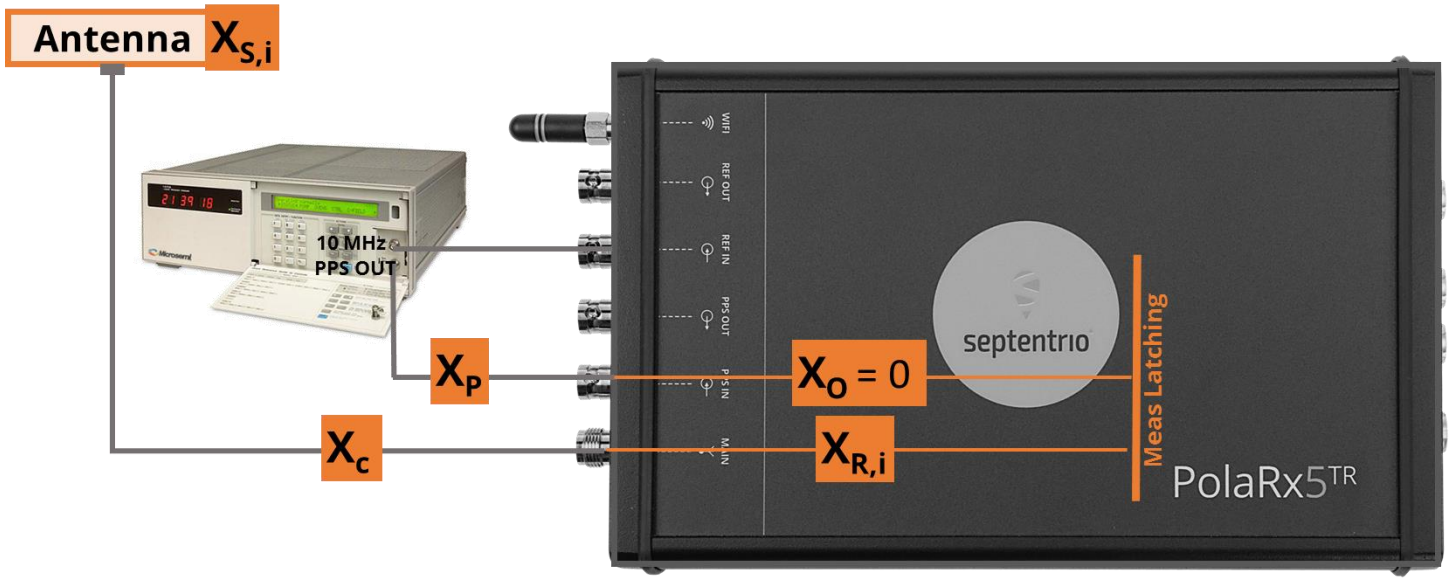
# What Accuracy Can Be Achieved with PolaRx5TR?




Accuracy is dependent on the setup…

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

$X_{S,i}$: delay in antenna for signal i
$X_{R,i}$: delay in RF section of receiver for signal i
$X_C$: delay in RF cable (including amplifier and splitter)
$X_P$: delay in PPS cable
$X_O$: delay between PPS IN connector and internal receiver time reference ($X_O$ = 0 on PolaRx5TR when auto-calibration is enabled)

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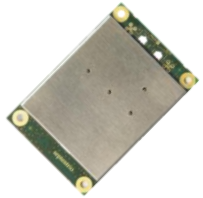
# AsteRx-m2 - Key Features



- 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

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# 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)

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# AsteRx-m2 Clock Synchronization

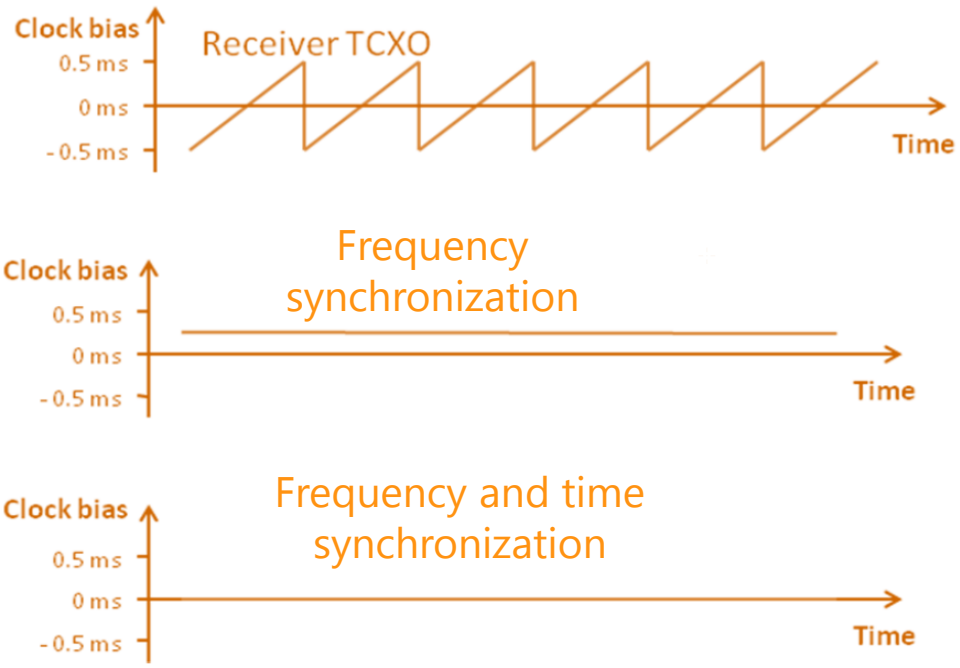
**CLOCK SYNC = FREQ SYNC + TIME SYNC**

## ➢ Freq Sync

Connecting an accurate 10 MHz reference enqbles 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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