Potential Radio Frequency Interference in the GPS L5 band for Radio Occultation Measurements

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Overview

- Radio Occultation Overview (RO)
- DME/TACAN Station Architecture
- Mountain Top RO Mission
- Potential Radio Frequency Interference (RFI) from DME/TACAN Stations
- ISS Data Analysis
- Conclusions

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Radio Occultation (RO) Components

- RO satellite in Low Earth Orbit (LEO) receives a GPS signal from a GPS (or GLONASS) satellite in Medium Earth Orbit (MEO)
- The delay in signal propagation from the signal that passes through the atmosphere is analyzed with remote sensing techniques to infer properties about the intervening atmosphere.
  - This requires geometry where the GPS satellite is ascending from or descending behind Earth's horizon

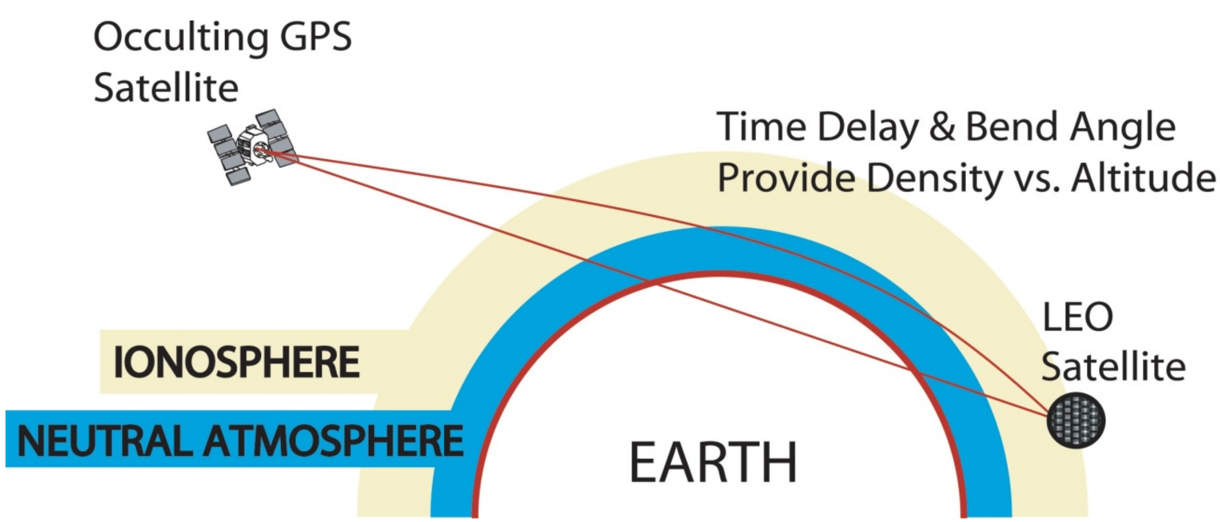
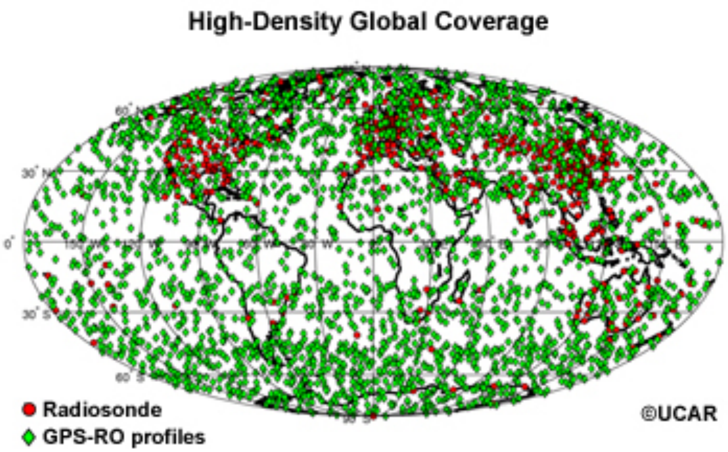


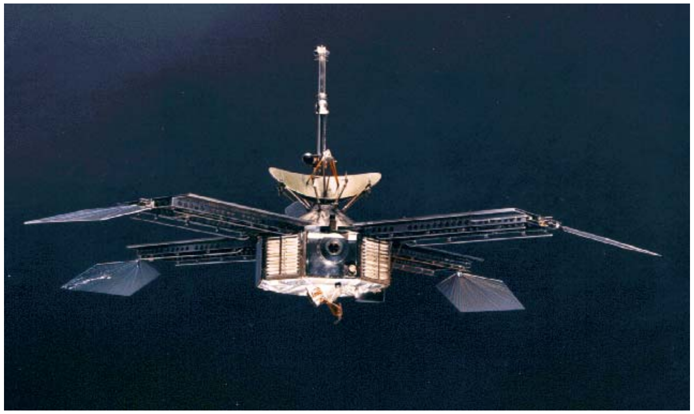
Image created by Erin Griggs

RO Applications

- Interplanetary occultations
- Climate studies
  - Spatial and temporal averaging to detect long term trending
- Meteorology
  - Temperature, pressure, and water vapor measurements
  - Assimilation of RO products into numerical weather prediction models



GPS RO, Global Coverage, http://www.planetiq.com/gps-ro-101/



Mariner IV, Source: NASA JPL, http://www.jpl.nasa.gov/missions/details.php?id=5900

Previous Occultation Missions

Modified TurboRogue GPS receiver [1]

BlackJack receiver [2]

Integrated GPS and Occultation Receiver (IGOR) [2]

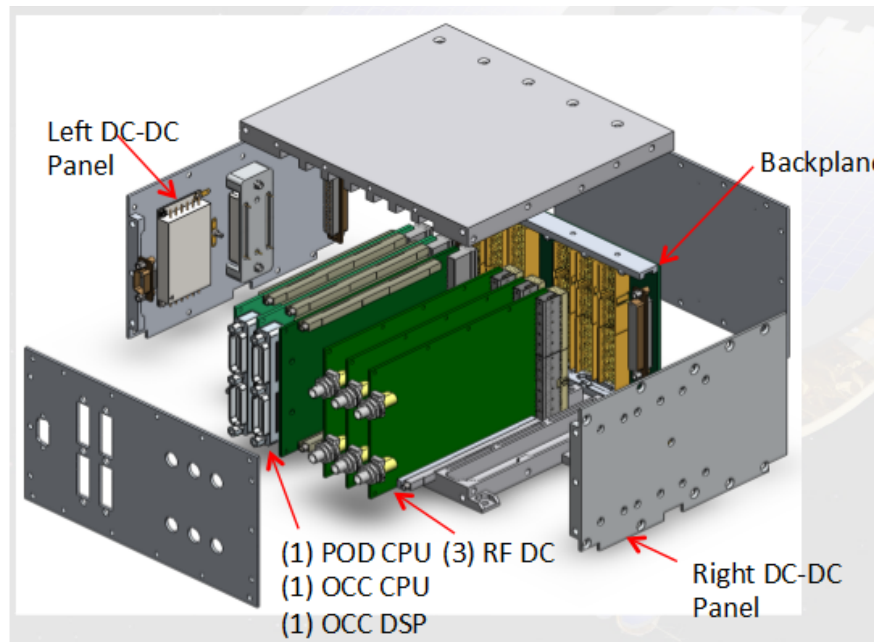
GNSS Receiver for Atmospheric Sounding (GRAS) [3]

GPS/MET (1995)	SAC-C (2001)	CHAMP (2001)	COSMIC/ FORMOSAT-3 (2006)	GRACE (2006)	Metop-A (2006)	TerraSAR -X (2007)	TanDEM-X (2010)	Metop-B (2012)

[1] Kursinski et al., 1997, [2] Wickert et al., 2009, [3] Luntama et al., 2008

Future GNSS Radio Occultation: TriG

- COSMIC-2/ FORMOSAT-7
- Next generation Radio Occultation receiver
- Capable of tracking GPS CA, L1 and L2 semi-codeless, L2C, and L5
- Support for GLONASS, Galileo and BeiDou, in development
- Supports 1-16 antennas
- POD capable (cm level positioning, mm/sec level velocity)



Source: Mannucci et al, 2012

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Distance Measuring Equipment (DME) and TACAN

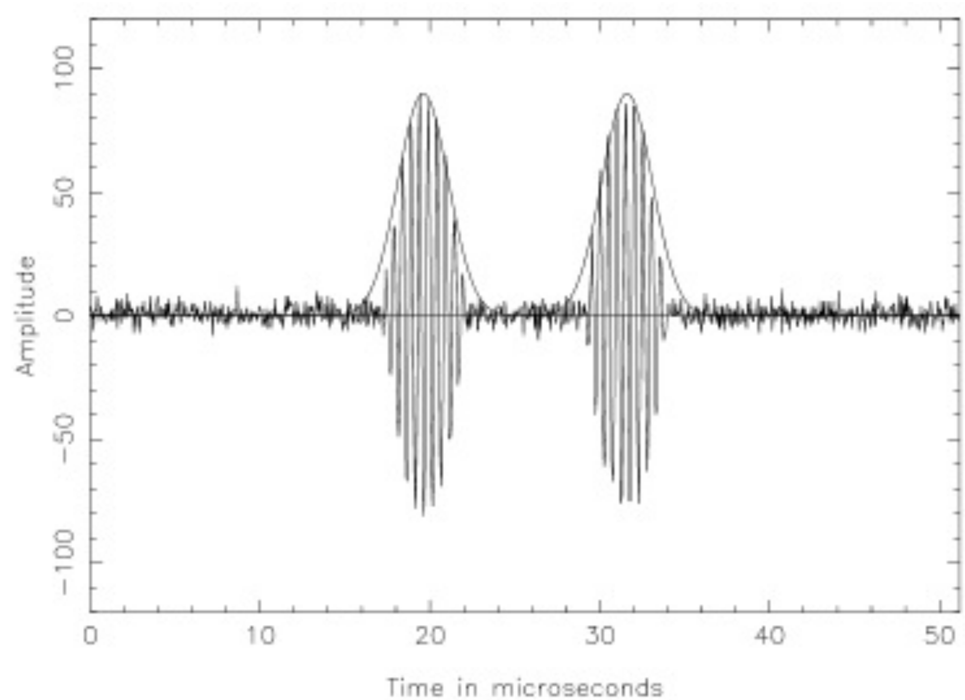
- Airborne interrogator and ground-based transponder used for measuring aircraft distance
- Over 1000 DME stations within the United States, Western Europe is also heavily populated
- Some of these ground stations operate as a Tactical Air and Navigation System (TACAN)
  - Primarily used for military aircraft
  - Higher powered compared to DME

D-VOR/DME ground station. http://upload.wikimedia.org/wikipedia/commons/f/fe/D-VOR_PEK.JPG

Potential Interference: 203 of DME ground stations transmit within +/-10 MHz of the GPS L5 band centered at 1176.45 MHz

DME Signal Characteristics

- Transmitted in pulse pairs
  - Pulse width of 7 µs
  - Pulse period of 12 µs
- Up to 2700 pulse pairs per second (4.32% duty cycle)
  - High Power: 1000 W
  - Low Power: 100 W



- TACAN
  - Up to 3600 pulse pairs per second
  - Power ranges cyclically up to 3500 W

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Mountain Top RO Mission

- Pikes Peak: this elevated vantage point provides similar geometric aspects of RO from LEO
  - Vertical profiling capability, although disturbances to signal are not as dramatic as space-based experiments
  - Ample collection opportunities
- Mountain-based and airborne RO experiments performed in literature
  - Lulich et. al, Olsen et. al, Hu et. al, Aoyama et. al

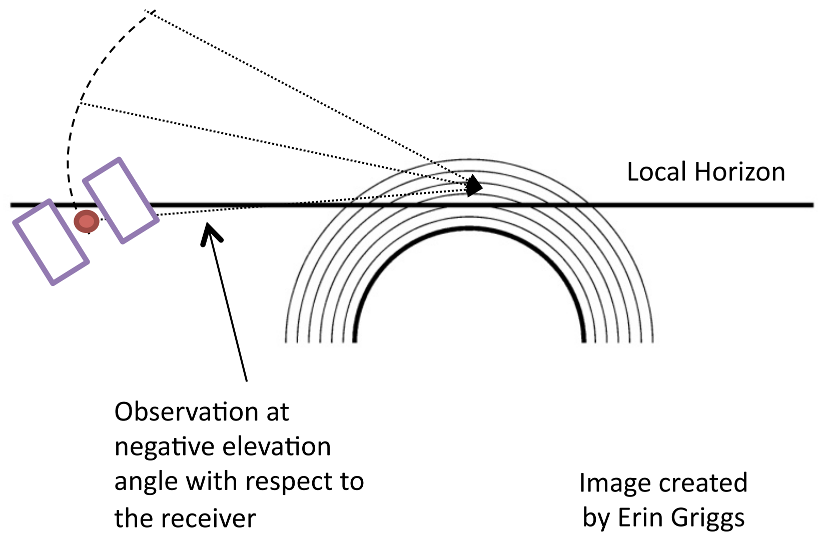
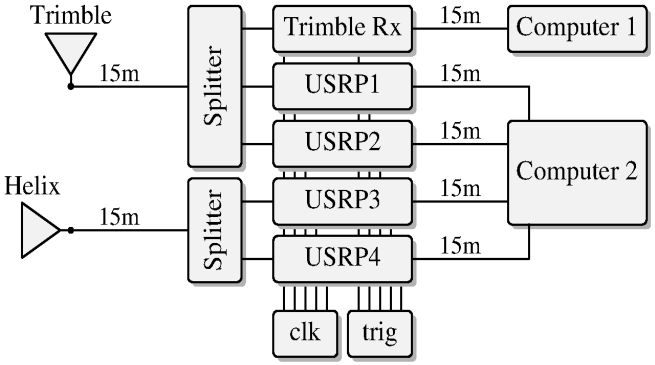


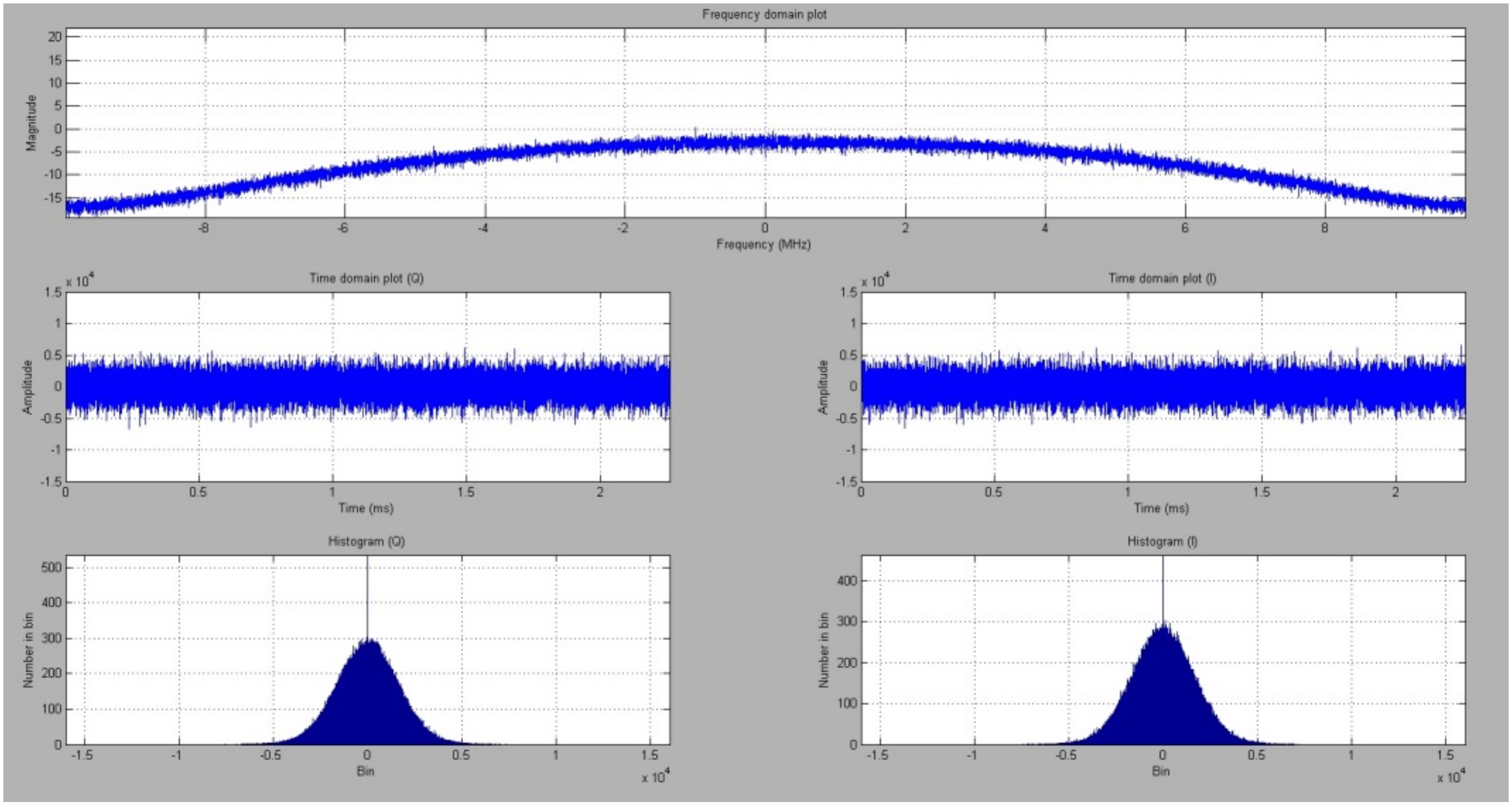
Image created by Erin Griggs

Hardware Setup and Data Collection

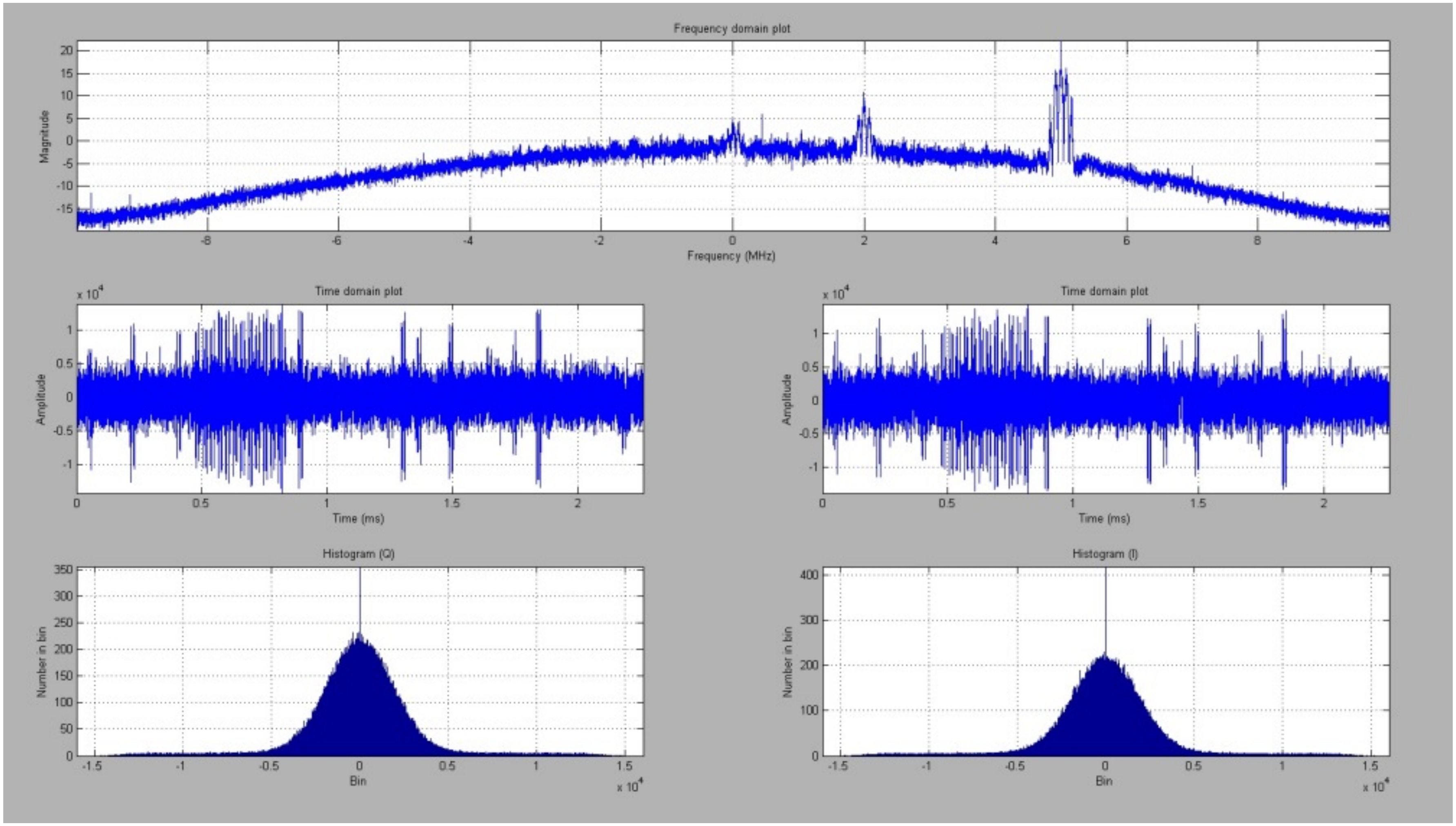
- Two antennas
  - Helix (horizontal) and Trimble dish (hemispherical)
- Four RF front-ends
  - Dual-frequency IF data from each antenna
- One Trimble NetR9
  - Verification of position and available constellation
- PRNs 1 and 17 chosen for fast setting geometries
- L1, L2, and L5 data gathered



Hemispherical Antenna (directed at Zenith)

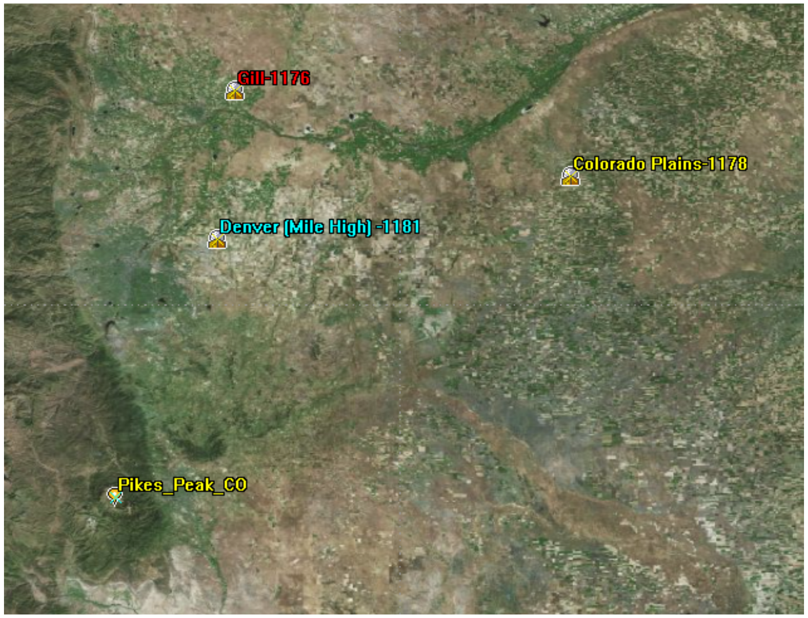


Helix Antenna (directed at PRN 1)



Nearby DME Stations to Pikes Peak

- For PRN 1, the antenna is oriented 38 degrees in Azimuth from North
  - Such an orientation points antenna towards three nearby DME stations to the northeast



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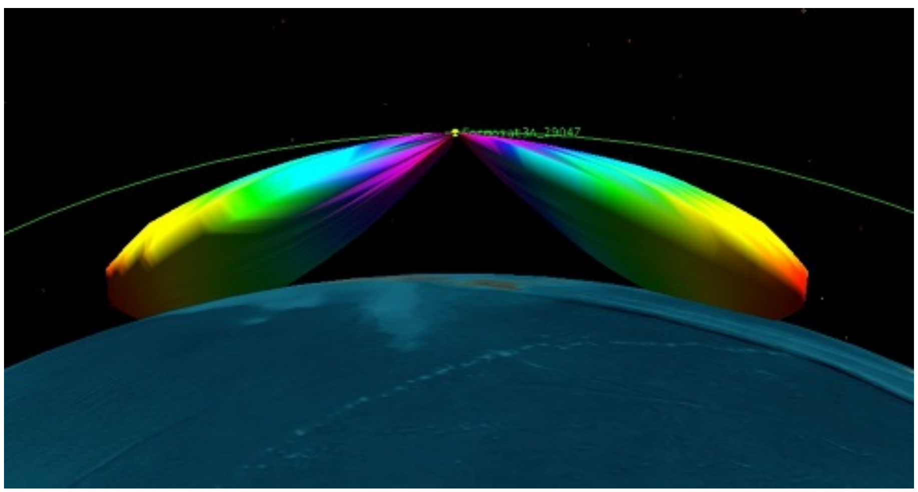
Gain Patterns of GPS RO and DME Antennas

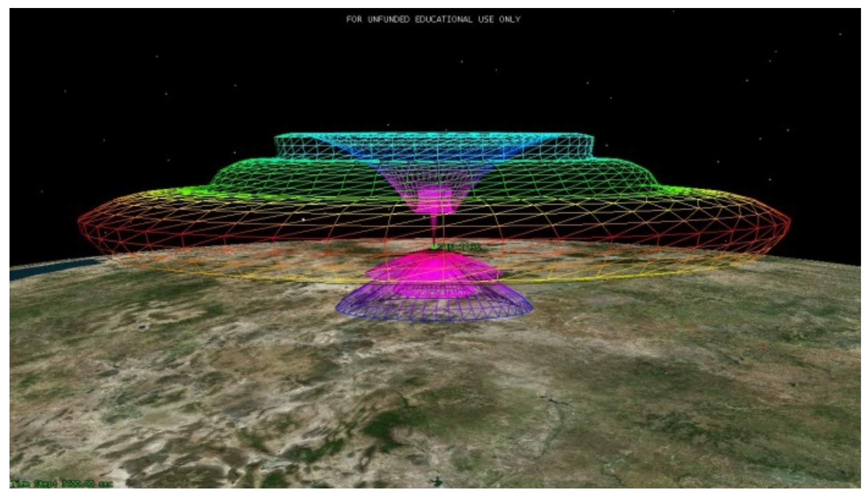
RO Receiver

- Peak Gain: +10dBi
- Elevation: -27.4˚
- Beamwidth: 1.6˚

DME Transmitter

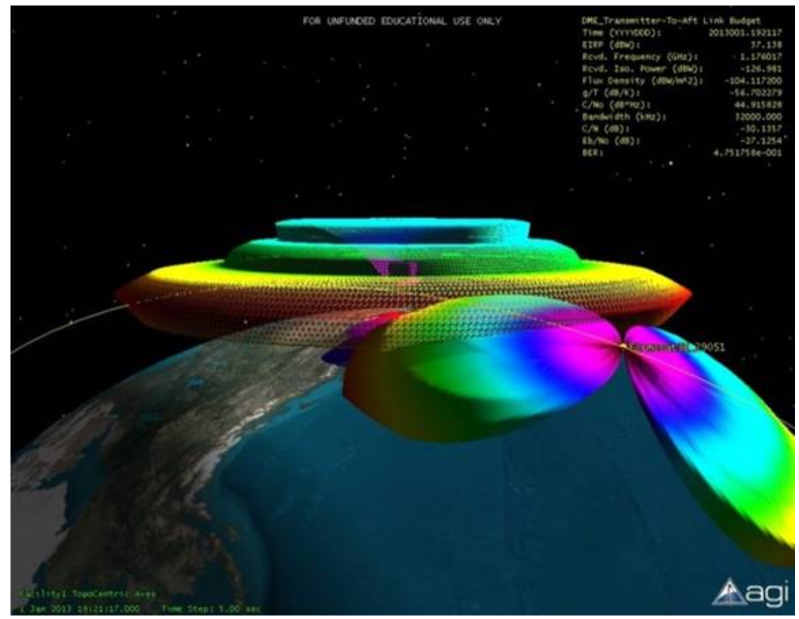
- Peak gain: +9dBi
- Elevation: 4.0˚
- Beamwidth: 6.0˚





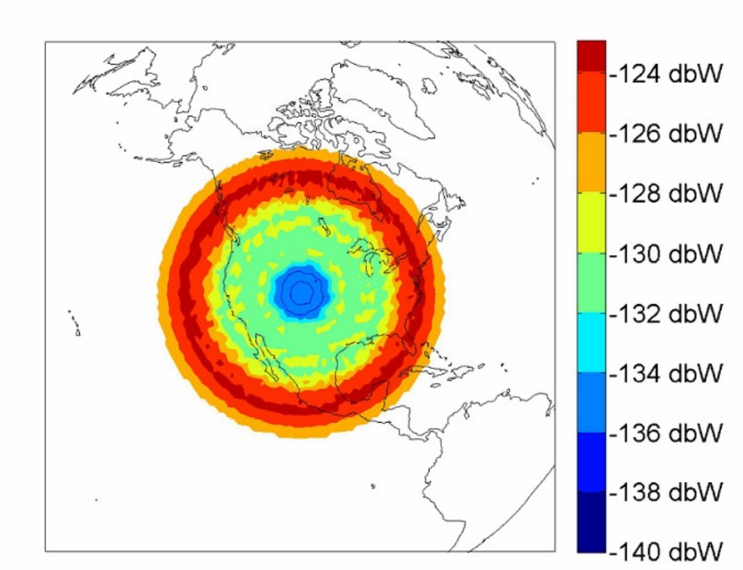
Potential Conflict

- L5 is known to co-exist with DME/TACAN
- Unclear interference environment for space-based GPS L5 receivers
- Similar orientation of gain patterns between RO receiver antenna and DME antenna
- RO receiver will witness large number of DME stations while orbiting over US and Western Europe



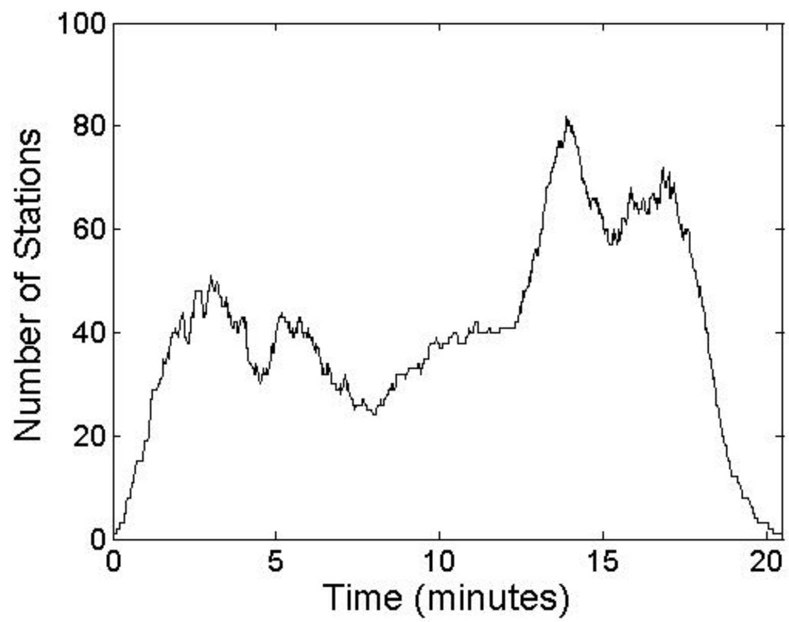
Received Power Level

- Systems Tool Kit (STK) scenario
- Single DME station located in Denver
- Formosat-3 FM4 satellite (Altitude ~ 800 km)
- Maximum received power: -123 dBW



Number of Stations

- STK simulation including 203 relevant DME stations
- Formosat-3 FM4 transits across Unites States
- Maximum of 82 stations witnessed with received power levels above -125 dBW



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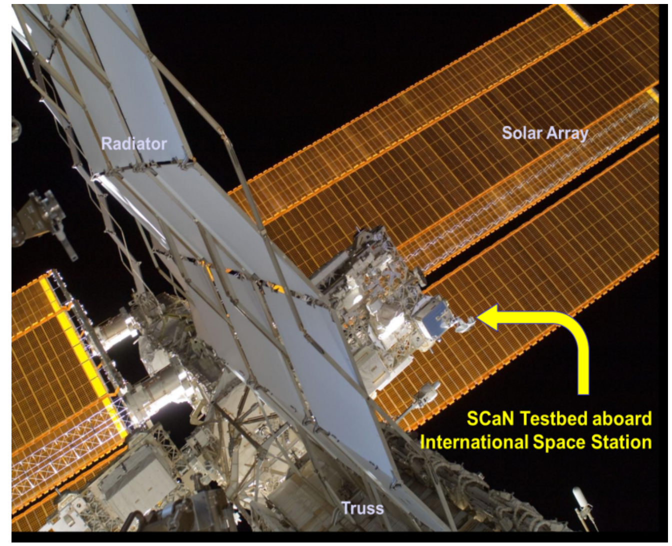
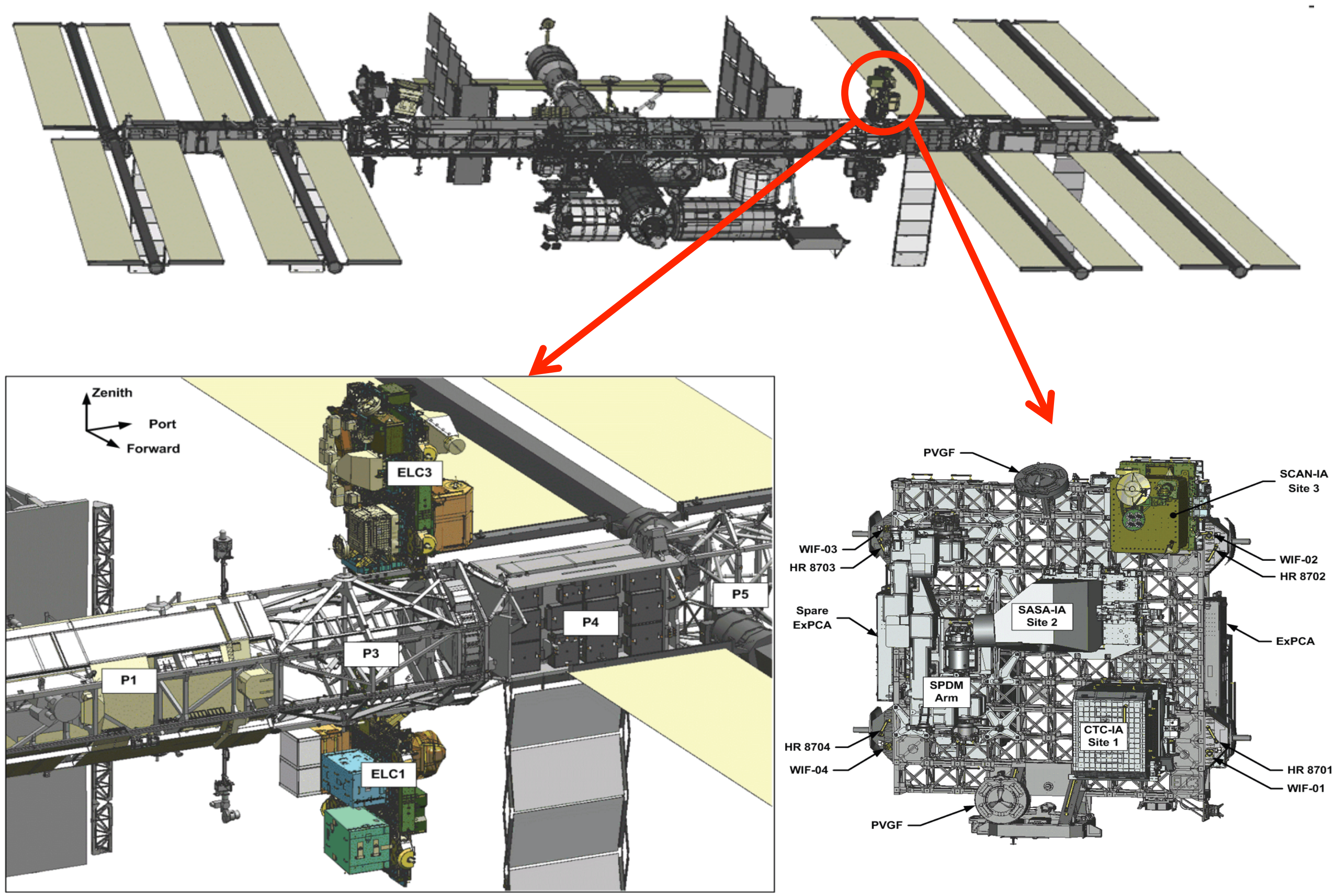
Assessing DME/TACAN RFI using ISS Data

- ISS SCaN Testbed receiver collects GPS signals from orbiting GPS satellites
- GPS L1 and L5 signals are analyzed using GNSS SDR code
  - 19 sections of ISS data from 2013, each 40 ms long

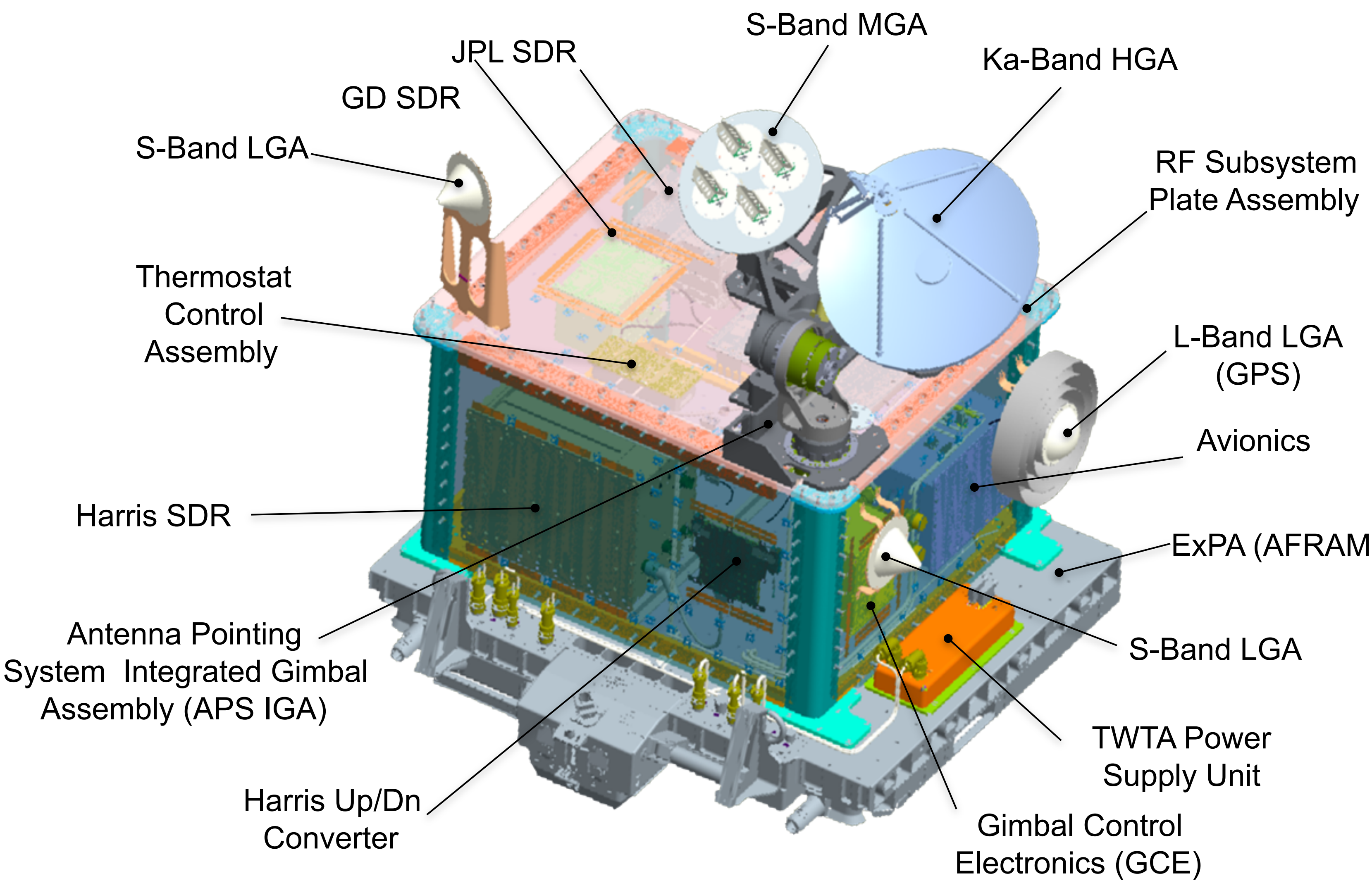


http://www.nasa.gov/sites/default/files/scan_testbed_2.png

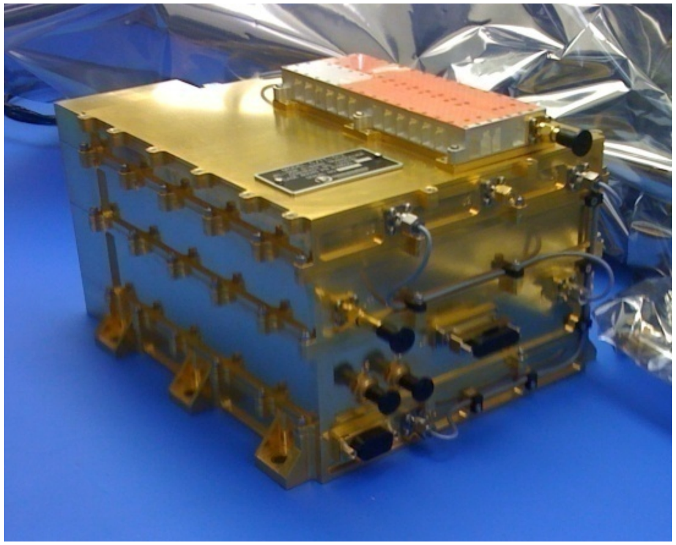
SCaN Testbed Location on ISS



SCaN Receiver Payload



JPL Software Defined Radio Details



Specifications

28.2 L x 20.6 W x15.5 H cm
6.6 kg
15 W Rx (typical)
+ 2 W (GPS)
+ 65W Tx S-band

STRS Operating Environment
- RTEMS OS – POSIX interface
- In memory file system
- All open source

Digital Processing
- 66 MHz SPARC V8
- 128 MByte SDRAM + 512 MByte Flash
- 2x Xilinx Virtex II 3Mgate FPGAs
- SDRAM and Flash on each FPGA

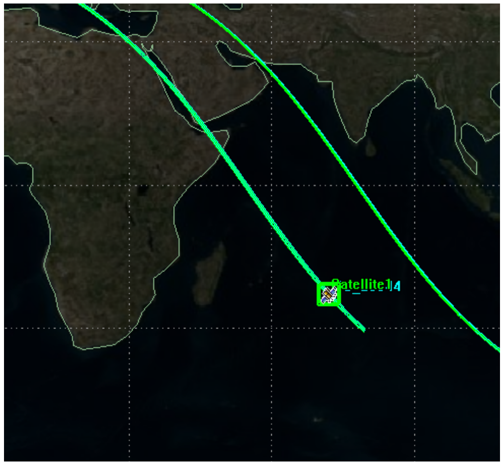
Control and Data Interfaces
- MIL-STD-1553B
- 2 SpaceWire Links (ECSS-E-50-12C)

Full Duplex S-band RF module
- Tx: 2.2-2.3 GHz, 5-10W output
  - 2 x 10bit, 50 MSPS DAC (I/Q)
- Rx: 2.025-2.12 GHz, 11 MHz BW, 2.5dB NF
  - 12 bit, 50 MSPS ADC

GPS Receive Sampler
- L1,L2,and L5

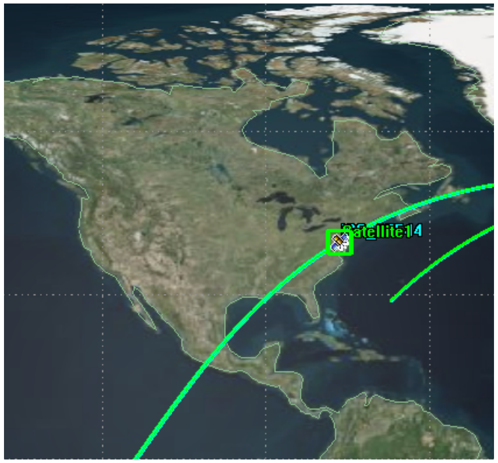
ISS Locations and Data Sets

- Locations generated from historic ISS TLE data
- Focus on data sets nav11, nav19, nav3:
  - Each data set contains L1 and L5 signals
  - The ISS at nav11 is over New England, where there are many DME stations
  - The ISS at nav9 and nav3 is over the ocean and should experience very little DME interference



ISS location during nav19

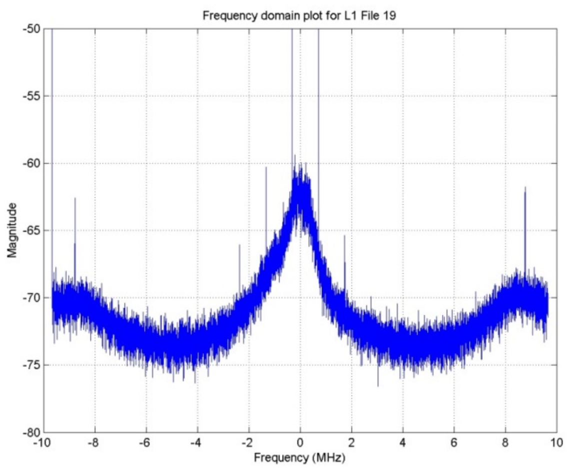
ISS location during nav3



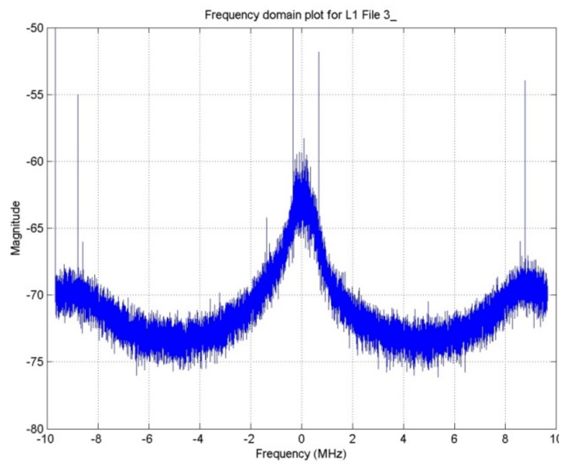
ISS location during nav11

Frequency Spectrums for L1 signals

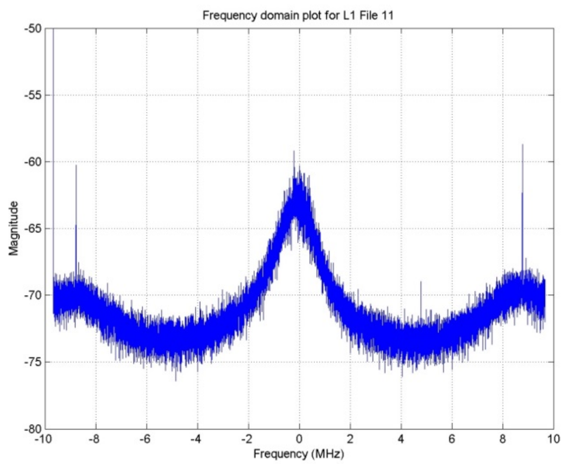
nav19 (Indian Ocean)



nav3 (Pacific Ocean)



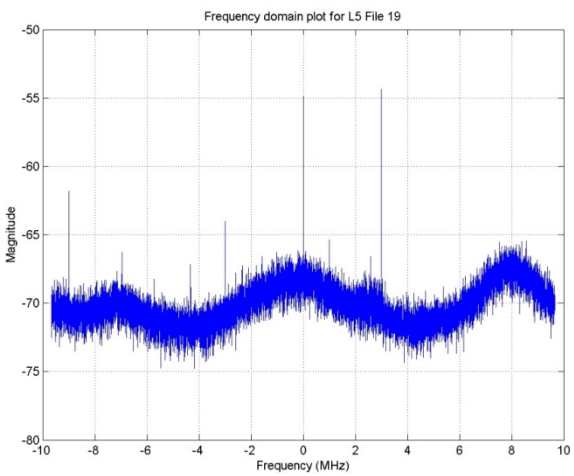
nav11 (New England)



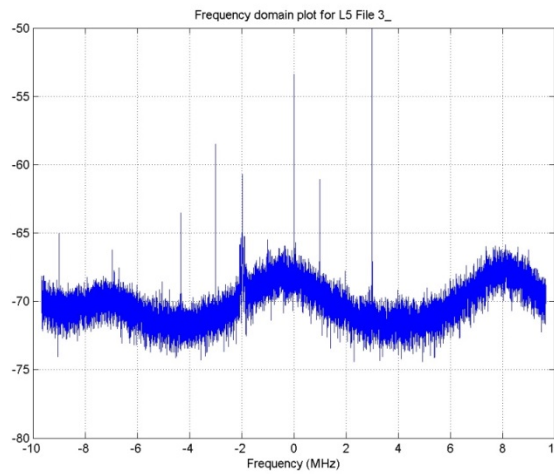
- L1 dataset used as control
  - Do not expect to witness DME interference

Frequency Spectrums for L5 signals

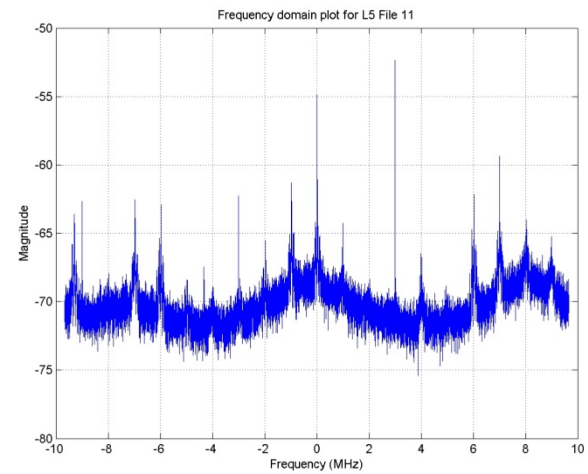
nav19 (Indian Ocean)



nav3 (Pacific Ocean)



nav11 (New England)



- DME interference visible in nav3 and nav11 datasets
  - Interference highest during flight over New England

Conclusions and Next Steps

- Terrestrial receivers experience DME signal interference
- The ISS receiver detects DME signal interference in the L5 frequency band
  - Antenna pattern of ScaN Testbed receiver is needed
  - The geometry between the ISS and the transmitting GPS satellites has yet to be analyzed
- Request for extended lengths L1/L5 SCaN data records
- Further investigate RO receiver saturation levels and the impact of high number of interfering DME stations
- Compare L1 and L5 Signal to Noise Ratios in different environments (DME "rich" and DME "vacuum")