PNT Activities at NASA Glenn Research Center

National Aeronautics and Space Administration

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Glenn Research Center

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Author Acknowledgements

Thank you to the following contributors and collaborators

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NASA HQ (United States)	Jim Miller Greg Mann	A.J. Oria

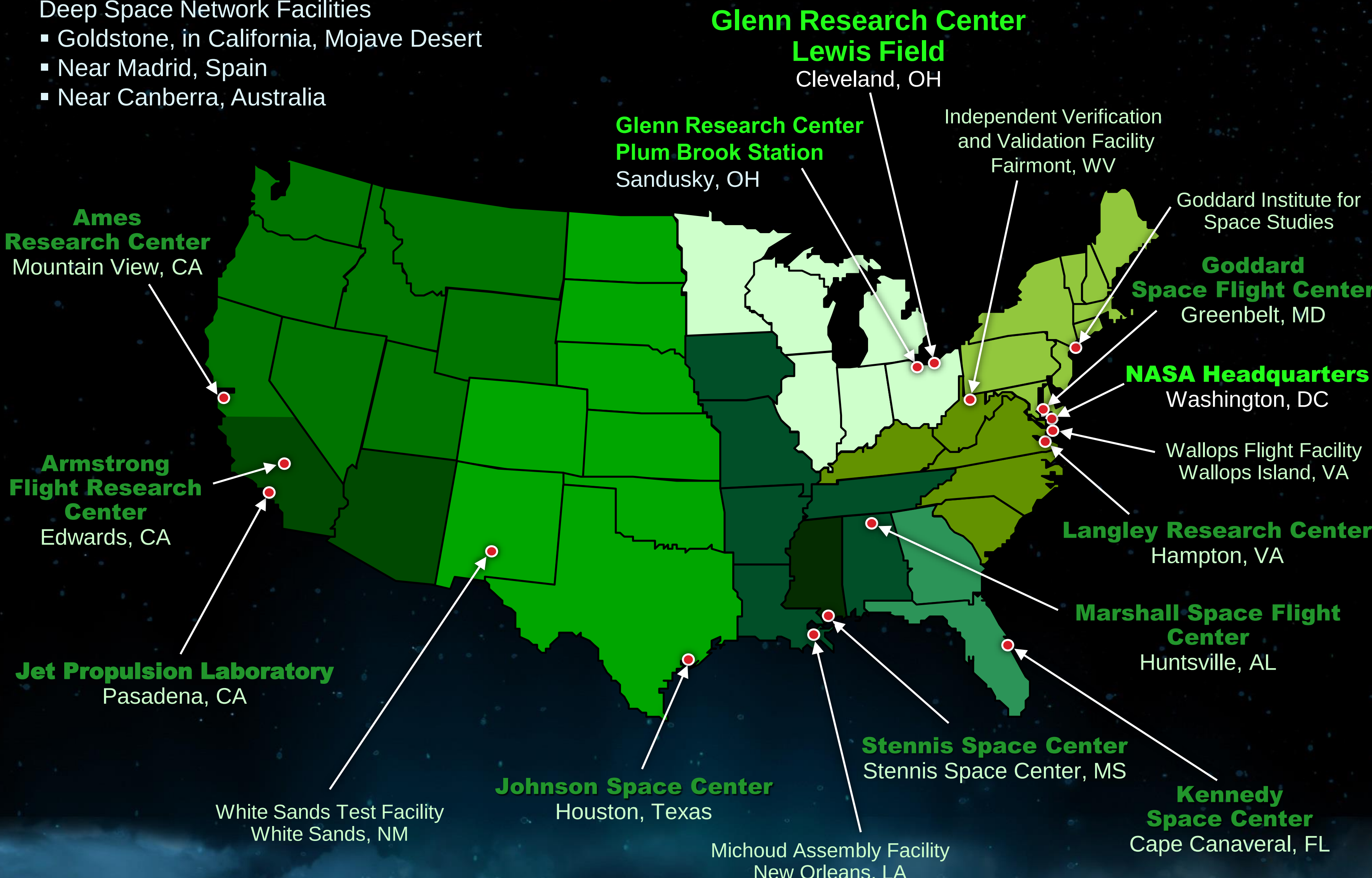
Agenda

- NASA/Glenn Research Center
- International Committee on Global Navigation Satellite system, Working Group “B”
- Galileo Receiver on ISS (GARISS)
- CIF on GPS

NASA/GLENN RESEARCH CENTER

NASA Centers and Installations

Deep Space Network Facilities
- Goldstone, in California, Mojave Desert
- Near Madrid, Spain
- Near Canberra, Australia



Glenn Campuses

Lewis Field (Cleveland)

- 350 acres
- 1491 civil servants and 1476 contractors

Plum Brook Station (Sandusky)

- 6500 acres
- 21 civil servants and 89 contractors

as of 9/2016

SCaN Program Office (MSC) at GRC

SPACE COMMUNICATIONS AND NAVIGATION

- Business Management
- Policy and Strategic Communications
  - Positioning, Navigation and Timing (PNT)
- Systems Engineering and Standards
- Network Services
- Advanced Comm and Nav Technology
- Spectrum Policy and Planning

Communications and Intelligent Systems Division (LC)

Communications and Intelligent Systems Division (LC)

Chief: Dawn C. Emerson

Deputy Chief: Dr. Felix Miranda

Comm Sr. Technologist: Dr. Bob Romanofsky

Architectures, Networks and Systems Integration Branch

LCA/Denise Ponchak

Intelligent Control and Autonomy Branch

LCC/Dr. Sanjay Garg

Advanced High Frequency Branch

LCF/Dave Buchanan

Information and Signal Processing Branch

LCI/Gene Fujikawa

Optics and Photonics Branch

LCP/Dr. George Baaklini

Smart Sensors and Electronics Systems Branch

LCS/Dr. Larry Matus

INTERNATIONAL COMMITTEE ON GLOBAL NAVIGATION SATELLITE SYSTEM, WORKING GROUP “B”(ICG WG-B)

ICG WG-B Action Group on GNSS SSV

International Committee on
Global Navigation Satellite Systems

- Action group on GNSS SSV was formed within WG-B in order to:
  - Establish an Interoperable GNSS Space Service Volume (SSV)
  - Promote the relevance of SSV for users and to the service providers
  - Identify SSV support of every service provider for the benefit of users and receiver manufacturers
  - Harmonize and deepen the mutual understanding on SSV
  - Perform simulations for agreed reference missions in order to demonstrate advantages of an interoperable GNSS SSV
  - Generation of a booklet as a reference for all parties interested in the GNSS SSV
- Work of the Action Group is supported by all GNSS service providers

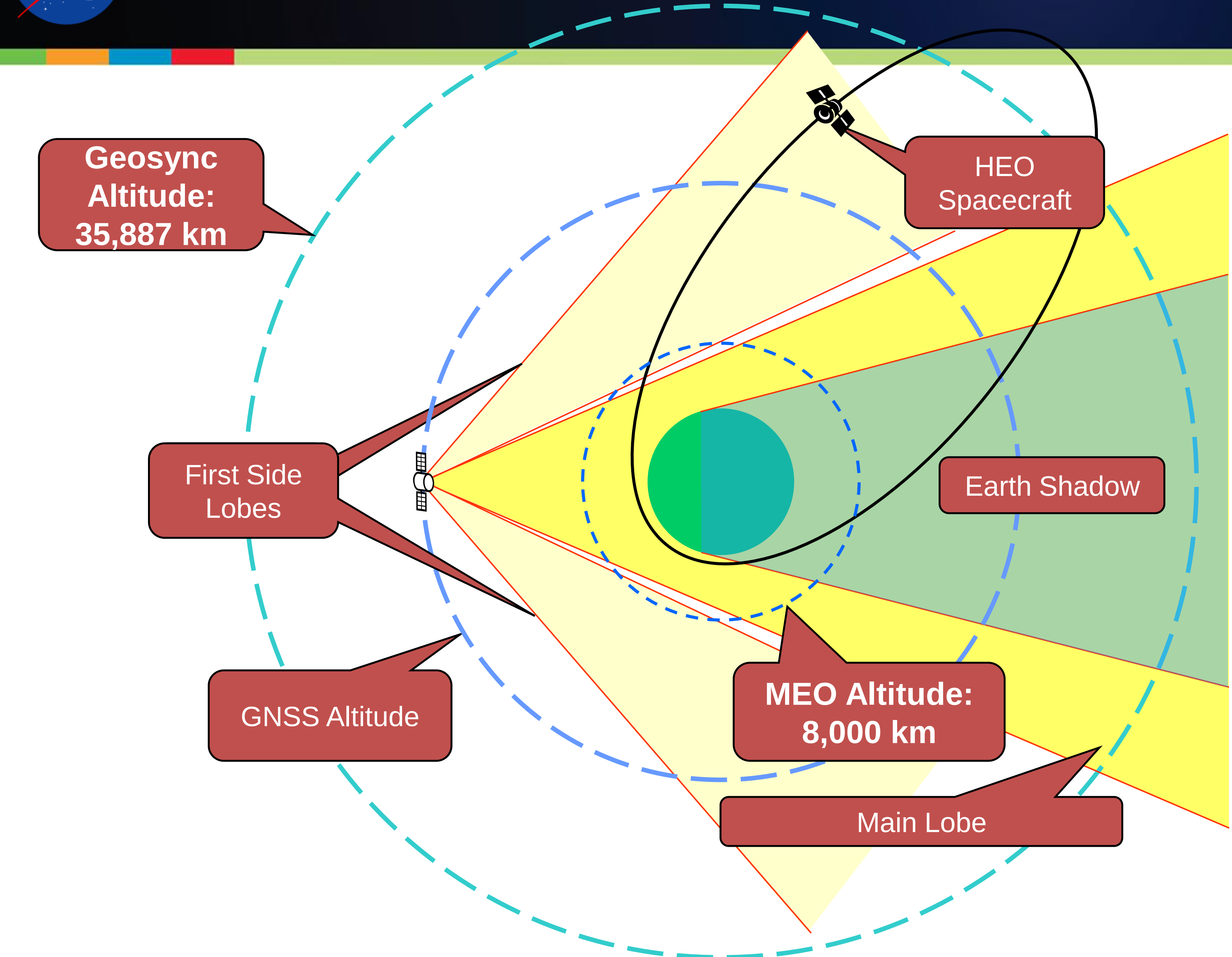
European Space Agency

Established Definition of SSV

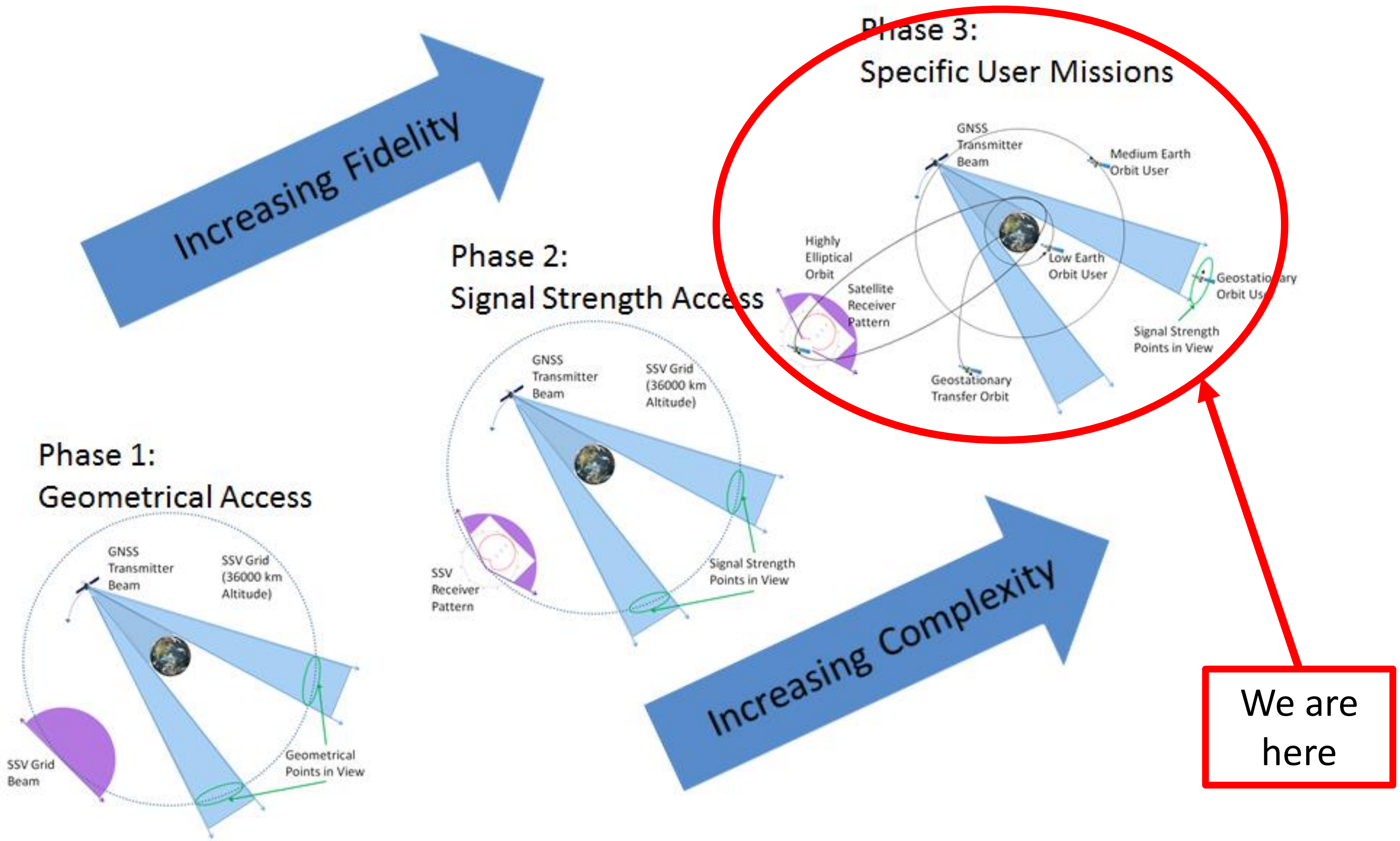
The GNSS Space Service Volume (SSV) is the region of space extending to approximately the geostationary altitude (or even beyond) where terrestrial GNSS performance standards may not be applicable. The SSV defines GNSS system performance for space users by specifying at least three parameters:

1. Pseudorange Accuracy
2. Received Power and
3. Signal Availability

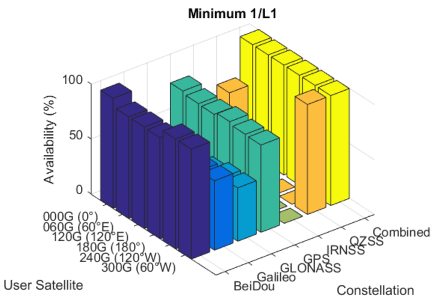
Reception Geometry for GNSS Signals in Space

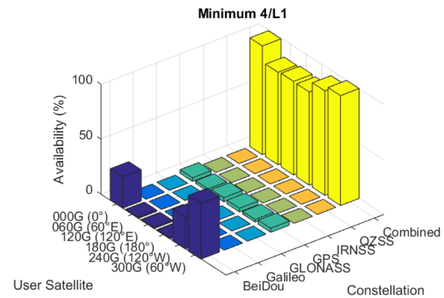


ICG WG-B Analysis Roadmap

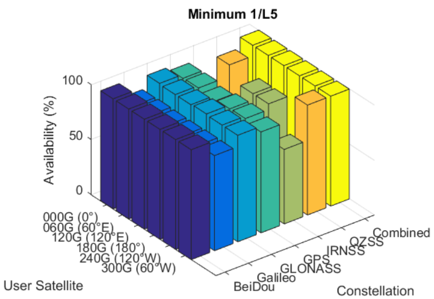


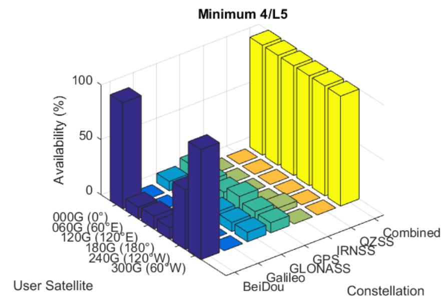
Phase 3 Analysis Products





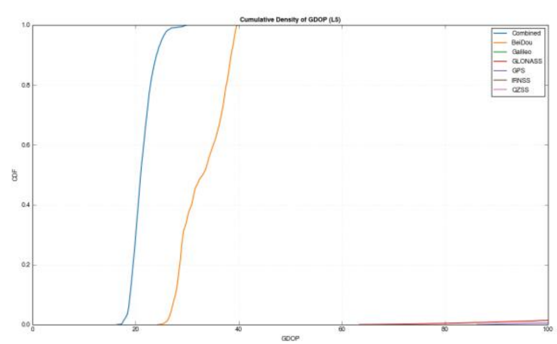
Availability

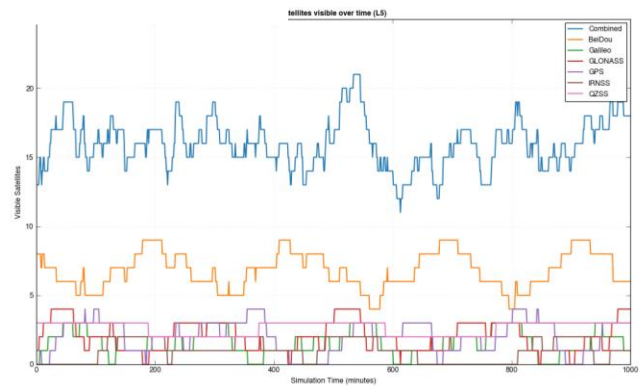




Visibility

DoP





Space Service Volume Characteristics

Medium Earth Orbit (MEO)

•3,000-8000 km
•Four GNSS signals typically available; One-meter orbit accuracies
•Wide range of received GNSS signal strength
•GNSS signals received from NADIR and Zenith direction
•Signals over the limb of the Earth become increasingly important

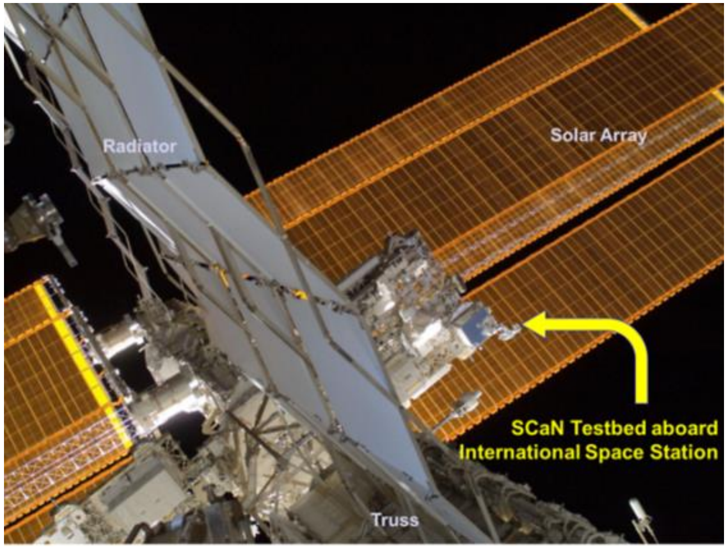
High Earth Orbit/Geosynchronous Earth Orbit (HEO/GEO)

•8,000-36,000 km
•Nearly all GNSS signals received over the limb of the Earth
•Users will experience periods when no satellites are available
•User will highly benefit from interoperable GNSS SSV for availability
•Will require specially designed high sensitivity receivers
•Properly designed receiver should be capable of tens to hundreds of meters accuracy with performance depending upon GNSS signal availability, receiver sensitivity and clock stability

GALILEO RECEIVER FOR THE ISS (GARISS)

The GARISS Project (2014 - present)

- Initial discussions at International GNSS Service meeting (mid-2014)
  - Feasibility assessment and interest from ESA and NASA
  - Agreed to pursue an international agreement and export control license
- **GARISS** (**GA**lileo **R**eceiver for the **I**SS) project formulation (mid-2016)
  - An element of the overall ESA-NASA cooperation
  - Main objective is the development of a Galileo and GPS multi-constellation waveform (software and firmware)
- GARISS Project Plan
  - Design and development of the Galileo/GPS waveform for SCaN Testbed (L5/E5a)
  - Qualification and test the Galileo/GPS waveform using engineering models of the SCaN Testbed available on the ground
  - Perform in-orbit experimentation
    - Receive performance
    - Precise Orbit Determination (POD)



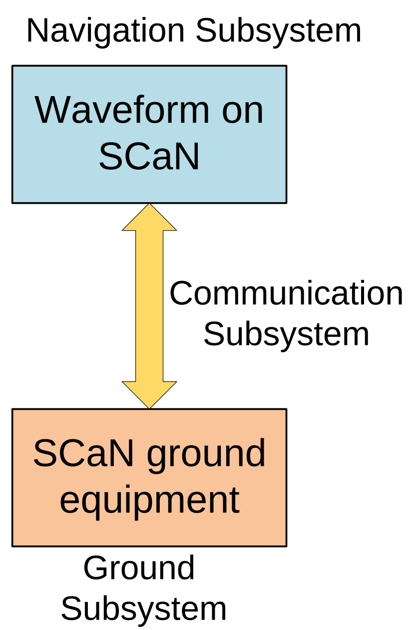
GARISS Design Considerations

- **High Level Mission Concepts**
  - Support for multi-constellation GPS and Galileo
  - Collection and performance assessment of Galileo and GPS raw measurements (Pseudo-range, carrier phase, etc.) in space
  - Computation of positioning in space (Position, Velocity and Time) and assessment of its performance
  - Warm start acquisition aiding from ground via file upload
  - Time aiding from ISS avionics interface
  - Focus on the L5/E5a band

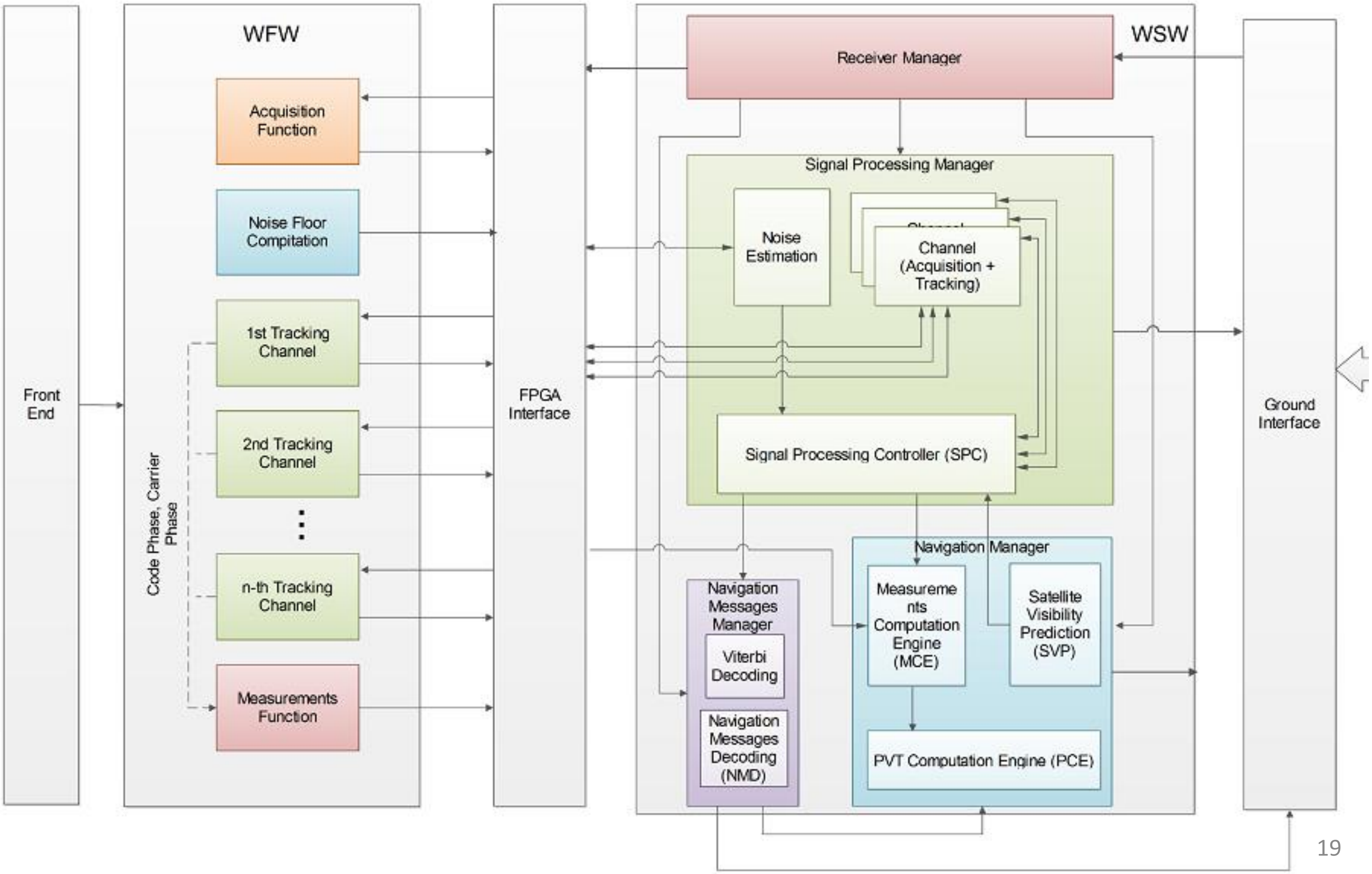
- **System Design Concepts**
  - Communication subsystem and ground support operations
  - Navigation subsystem (waveform)

L1/L5 Trade Off

L5 PROS	L5 CONS
Better Power Budget	Less LOS
Better Code/Carrier accuracy	Lower PVT Availability
New Concept for Space Test	Higher FPGA resources



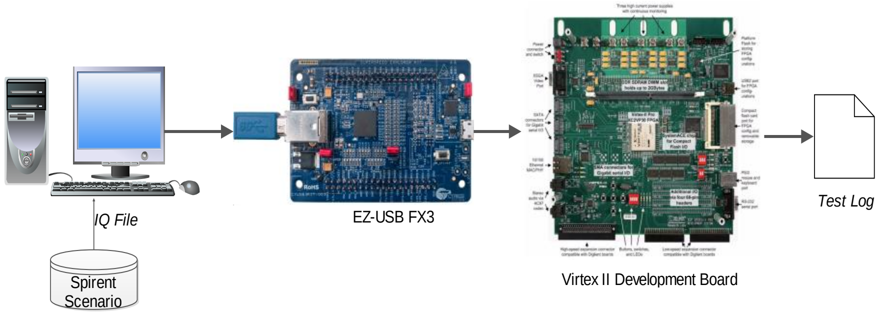
GARISS Waveform Architecture



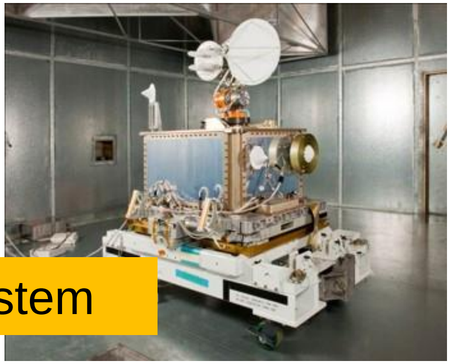
GARISS: Verification and Validation

<u>Three stages of testing</u>

- Unit level testing at Qascom
  – Firmware: Xilinx XC2VP30 FPGA Dev Board
  – Software: STRS framework on Dev PC
  – L-Band Signals: IQ values stored in a file generated by a Spirent constellation simulator; loaded to FPGA board
  – *Unable to test interactions between software and firmware*
- Integration testing at NASA GRC
  – Leverages JPL SDR breadboard, part of the Experiment Development System (EDS), along with LVDS signal simulators
  – Leverages JPL SDR engineering model, part of the Ground Integration Unit (GIU), along with "live sky" signals and RF simulation
- On-orbit flight testing on ISS
  – SCaN Testbed flight system



JPL radio EDS with RF subsystem

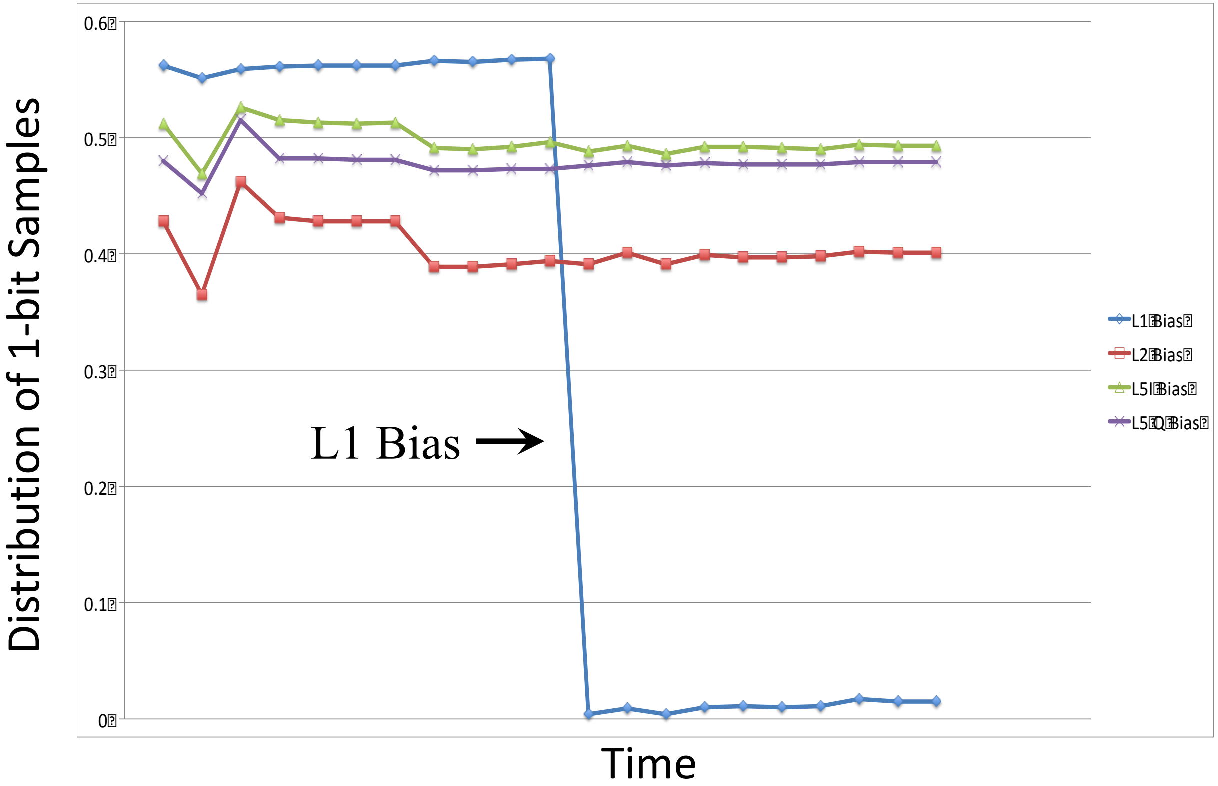


Flight System

Early Setback: Hardware Degradation (late-2014)

- SCaN Testbed L1 channel bias shifted significantly in late 2014
  - Appears to be a hardware failure affecting only L1 band
  - No options for in-space repair of the condition
  - Degradation has continued to worsen through 2017

- SCaN Testbed L2 and L5 channels remain nominal



GARISS: Status, Conclusions, and Path Forward

Status

- CDR occurred 2 March 2017
  - Firmware development is at **45% complete**; beginning tests with simulated IQ samples
  - Software development is at **75% complete**.
- Platform integration is **just-now starting**

Path Forward

- GARISS will develop a multi-constellation Galileo/GPS receiver for the ISS
- GARISS leverages the STRS development framework, making the software portable
- The direct use of L5/E5a is innovative and requires multi-constellation satellite coverage (Space Service Volume) to be most effective

On-orbit experimentation is anticipated in the later half of 2017

ADVANCED TERRAIN IMAGING WITH GPS SIGNALS

Advanced terrain imaging with GPS signals

Objective

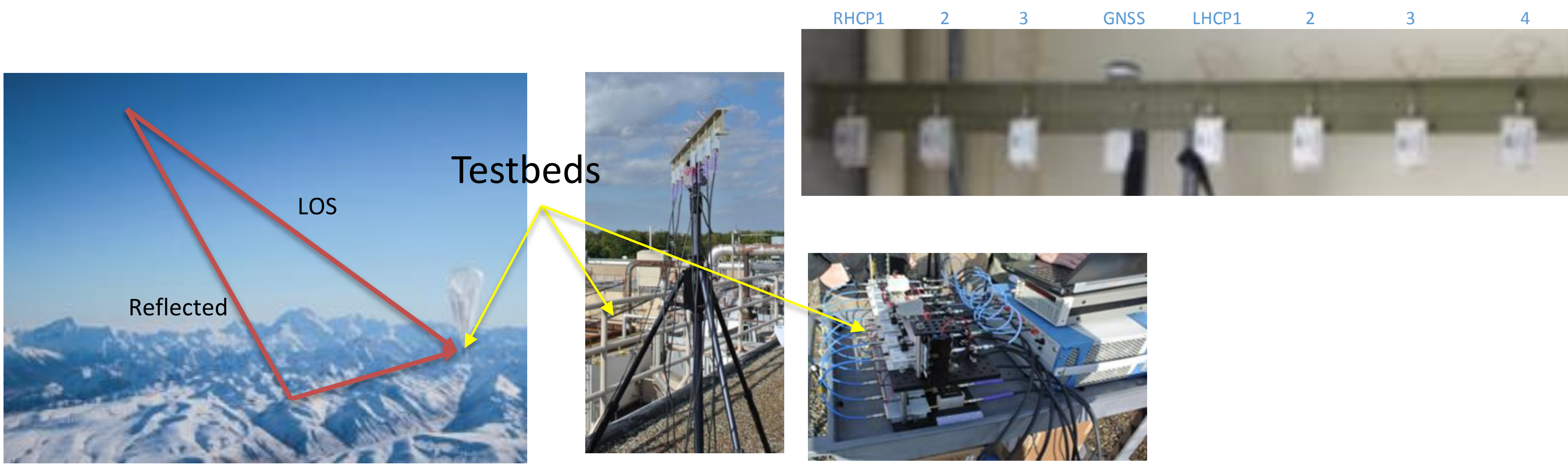
- **Identify advanced methods and processing for combined communicating/sensing paradigm using high bandwidth GPS L5 signals**

Challenges:

- **Limited dynamic range and PAPR for comms gear, bi-static geometries**

Key Innovations/enabling technologies and phenomena

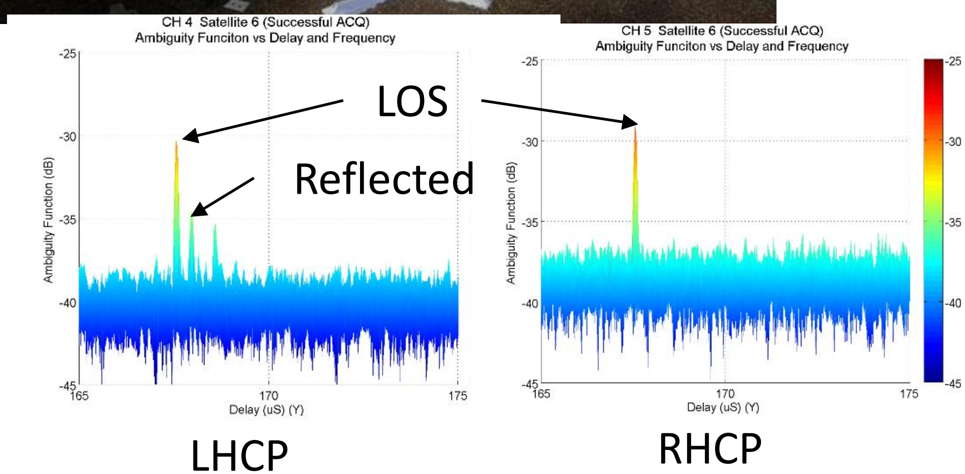
- **SDR, forward scatter, spatial diversity (array antenna) , polarization diversity, stable clock**



Combined sensing/communicating systems for resource constrained platforms such as drones, planetary spacecraft or rovers

L5 Data collection and analysis

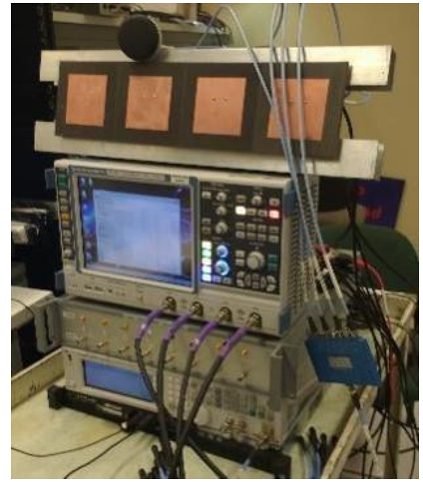
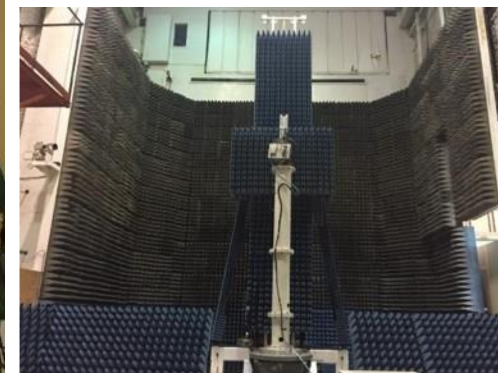
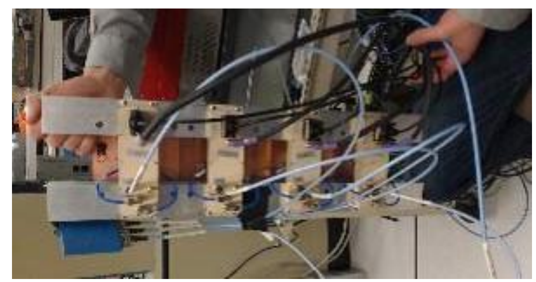
- Assembled a breadboard eight element linear array
  - LHCP(4) and RHCP(3) cloverleaf antennas, + broadside commercial L5 GNSS antenna
  - RF chain (per channel): 3 LNAs + L5 Filter, limiters, ø-stable cables
  - Agilent 9703A 8 channel VNA with simultaneous sampling
- Cuts through delay/Doppler map indicate consistent detection about 0.4μs from main (LOS) peak for LHCP channels, not present for RHCP channels.



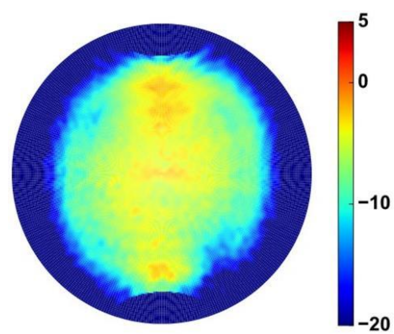
Advanced test-bed

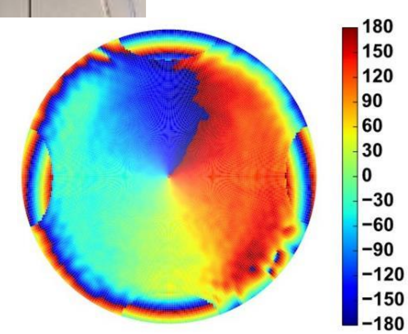
Progress

- Fabricated, tested two 4-element dual-polarization L5 arrays
- Fabricated, tested 10 RF boards
- Completed Testbed software/firmware ‘main program’
- Completed a short single static data collection and detected GPS L5 signals
- Performed near-field scans of both arrays in GRC B7—volumetric beam patterns in gain and phase

Ready to go with server, RF boards, antenna array. Next step is to collect static and flight data, analyze static data





THANK YOU FOR YOUR ATTENTION!