Earth-Facing Antenna Characterization in a Complex Ground Plane/Multipath Rich Environment

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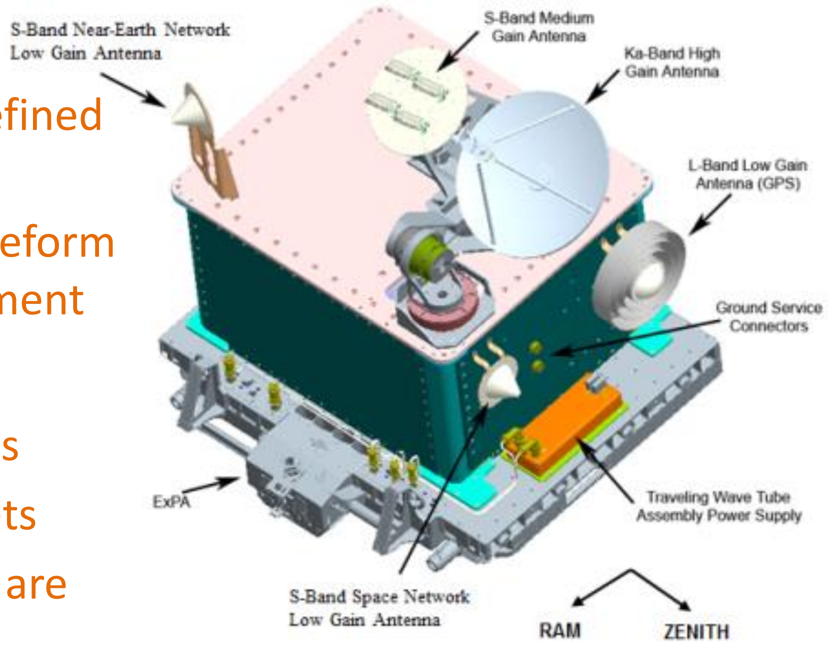
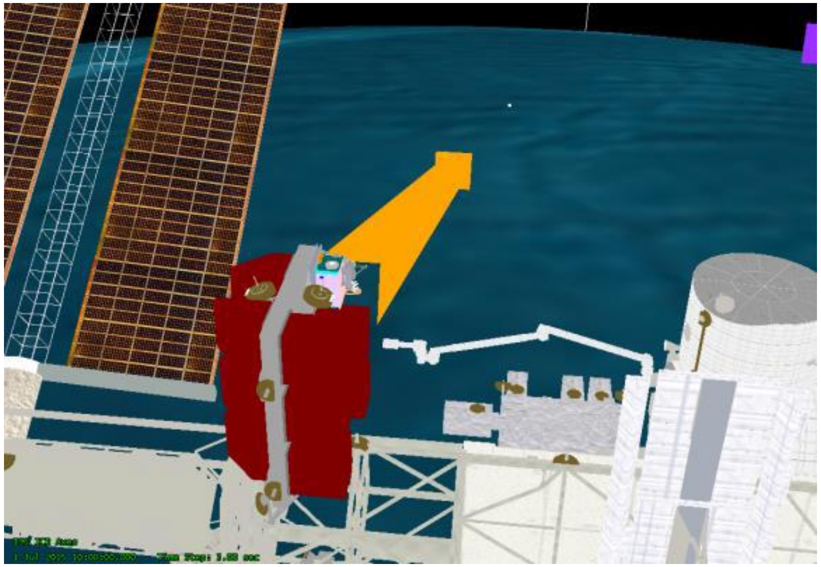
Introduction

- ***Space Communications and Navigation*** (SCaN) Testbed is an experimental communication system installed on the International Space Station (ISS)
  - Developed at NASA's Glenn Research Center (GRC)
  - Launched on July 20, 2012 on HTV-2
- ***SCaN Project Objectives***
  - To investigate the applicability of software defined radios (SDR) to NASA missions
  - To study the operation of SDRs and their waveform applications in an operational space environment
- ***Capabilities***
  - S-Band, Ka-Band, and L-Band communications
  - Communications with space and ground assets
  - Three distinct software-defined radios which are reprogrammable
  - Five distinct antennas



Purpose of Characterization

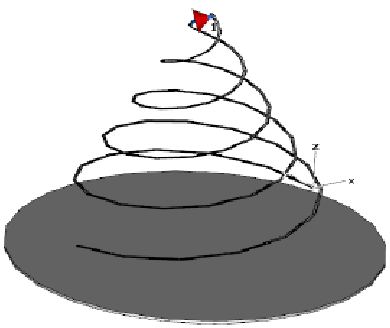
- Post-Installation: it is necessary to characterize each antenna in its operational environment
  - Provide performance expectations to future experimenters
  - Compare pattern to pre-launch testing to check for damage
  - Monitor for future changes to the antenna or the environment



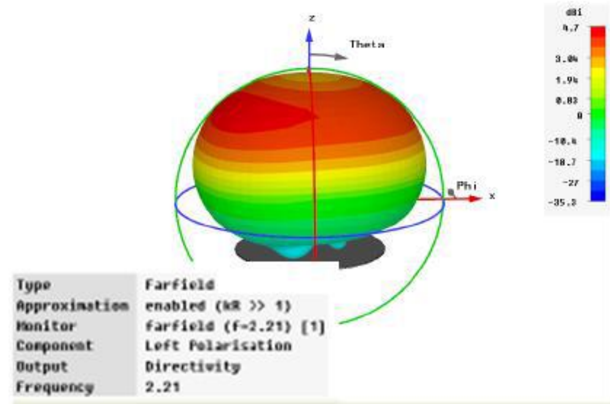
SCAN onboard the ISS with boresight vector for the S-Band Near Earth Network – Low Gain Antenna (NEN-LGA)

Pre-Launch Simulations

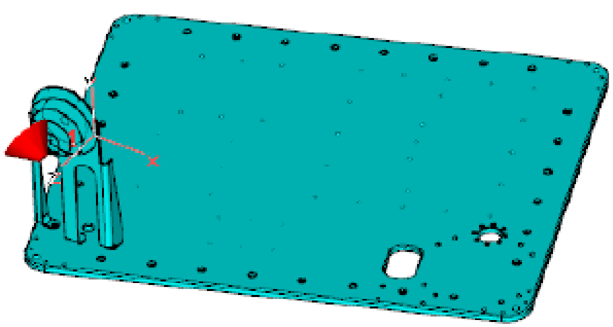
Antenna without complex ground plane



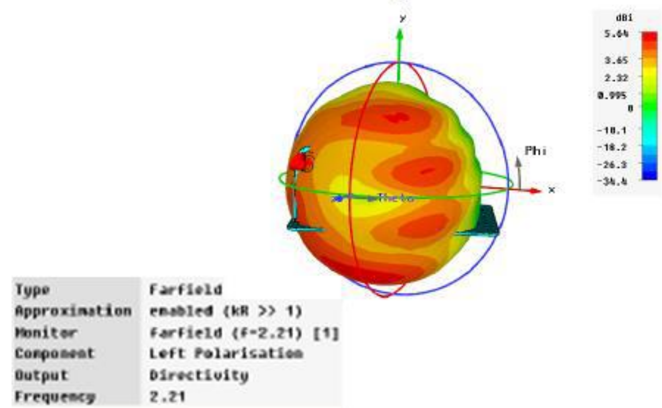
Left Hand Circular Polarization (Co-pol)



Antenna with mounting bracket and starboard radiator



Co-Pol @ 2.21 GHz



Note: Oscillations caused by non-uniform local ground plane

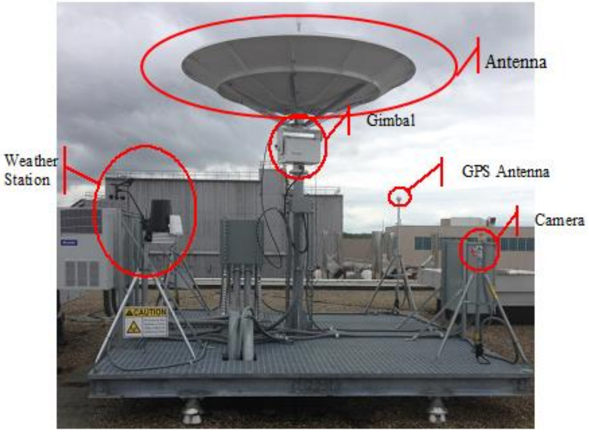
Initial Testing and Issues

- Initial testing planned using the Wallops Ground Station (WGS)
  - Several discrepancies from pre-launch testing
  - Later testing via other satellites determined this was a limitation of WGS, not an antenna issue

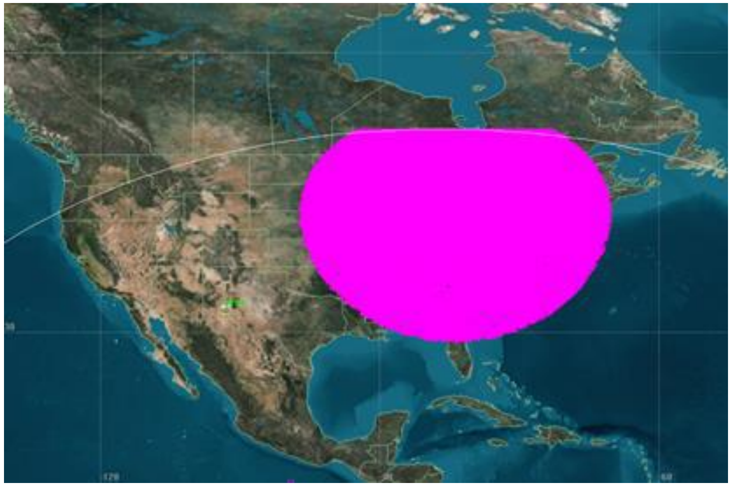
	Uplink	Downlink
General Dynamics (GD) SDR	• Insufficient spectrum • WGS pointing	• C/N0 crude measurements • WGS pointing • Lack of real-time bit flow
Jet Propulsion Laboratory (JPL) SDR	• Lack of JPL power estimator • WGS pointing	• C/N0 crude measurements • WGS pointing • Lack of real-time bit flow

GRC-GS Description

- These issues led to the commissioning of a new S-Band Ground Station (GRC-GS) at the NASA Glenn Research Center
  - Characterizing the NEN-LGA
  - Earth Based Node for Experimental Communications
- Key component of the GRC-GS
  - GRC-GS uses a 2.4m parabolic reflector
  - Elevation over Azimuth gimbal used to track ISS
    - Elevation constraint is 10^{o} over the horizon



- Contact times are limited to 6 minutes every 90 minutes



6 month coverage analysis

Solved for Effective Gain

- Derivation based on several factors
  - Frequency
    - Uplink – 2041.027 MHz or 2106.406 MHz (6 MHz Bandwidth)
    - Downlink – 2216.5 MHz or 2287.5 MHz (5 MHz Bandwidth)
  - Distance and Direction
    - Enter ISS Two Line Element (TLE) information into the Standard General Perturbations Satellite Orbit Model 4 (SGP4)
    - LynxCAT SK toolbox used for the analysis and to command antenna pointing toward ISS
      - Open-loop commanding used to eliminate pattern oscillation noise from injecting alignment errors

$$G_{R\_EFF} = P_R - P_T - G_T - L_{CT} - L_{FSP} - L_{CR}$$

Uplink – Effective Receiver Antenna Gain

- P_T, G_T, and L_{CT} are derived from system testing of the GRC-GS
- P_R is a measurement from the GD SDR
- L_{CR} was a measured value from pre-flight testing
- L_{FSP} is a calculated value from the SCaN Testbed Analysis Tool (STAT)
- L_{ADD} is unknown, cannot be determined independently, and is unique to the link direction

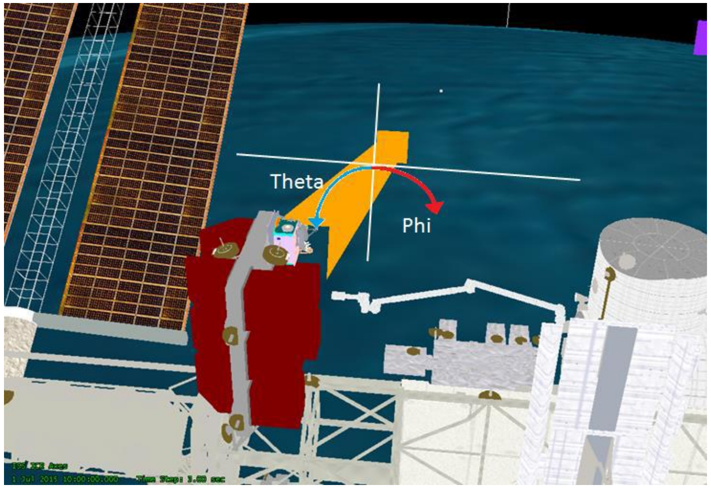
$$G_{T\_EFF} = P_R - P_T - L_{CT} - L_{FSP} - G_R - L_{CR}$$

Downlink – Effective Transmitter Antenna Gain

- P_T and L_{CT} are derived from pre-flight testing
- P_R, G_R, and L_{CR} are derived from system testing of the GRC-GS
- L_{FSP} is a calculated value from STAT
- L_{ADD} is unknown, cannot be determined independently, and is unique to the link direction

Data Processing

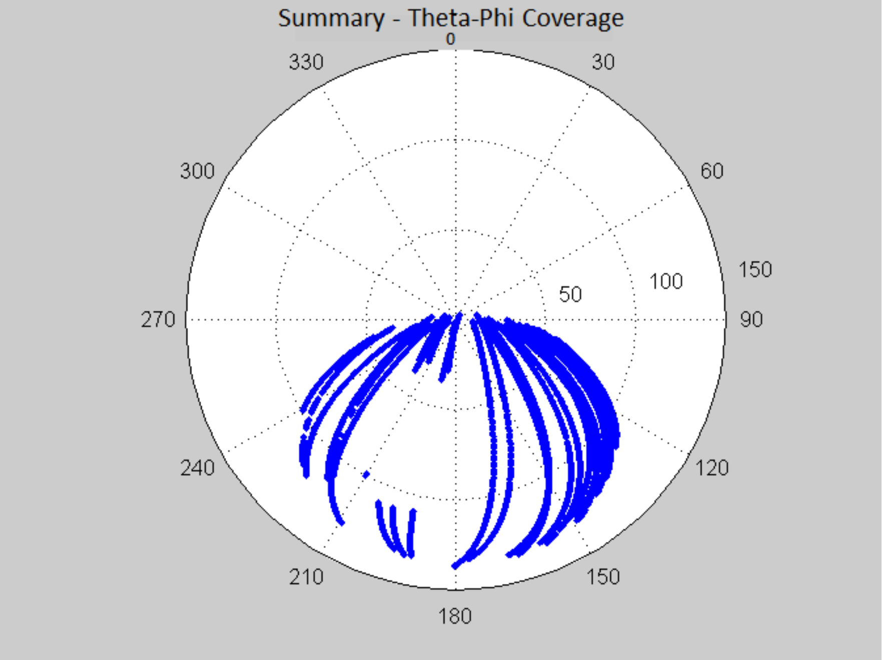
- Telemetry Data taken during events was essential for post processing analysis
  - GRC-GS antenna pointing telemetry logged in LynxCAT SK Toolbox (0.1 s intervals)
  - GRC-GS RF telemetry logged in RF_Monitor (5 second intervals)
  - SCAN Testbed payload telemetry data (1 second intervals)
- The datasets are fed into STAT which performs the calculations from the previous slide
- STAT correlates each calculation with a specific area on the antenna pattern
  - Boresight direction of the antenna limits measurements to one half of the antenna



- Theta-Phi Pattern Coordinate System
  - Theta is the angle off boresight
  - Phi is the angle around boresight

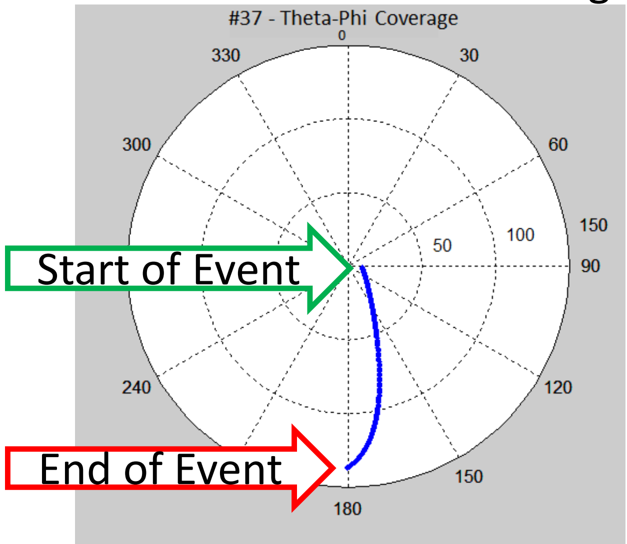
Characterization Events

- Events were split evenly between operating pairs of frequencies
  - Uplink – 2041.027 MHz, Downlink 2216.5 MHz
  - Uplink – 2106.406 MHz, Downlink 2287.5 MHz
- Total of 108 passes
  - 72 – GD SDR
  - 36 – JPL SDR
- Pattern Coverage
  - Phi 90º – 120º (50%)
  - Phi 160º – 200º (10%)

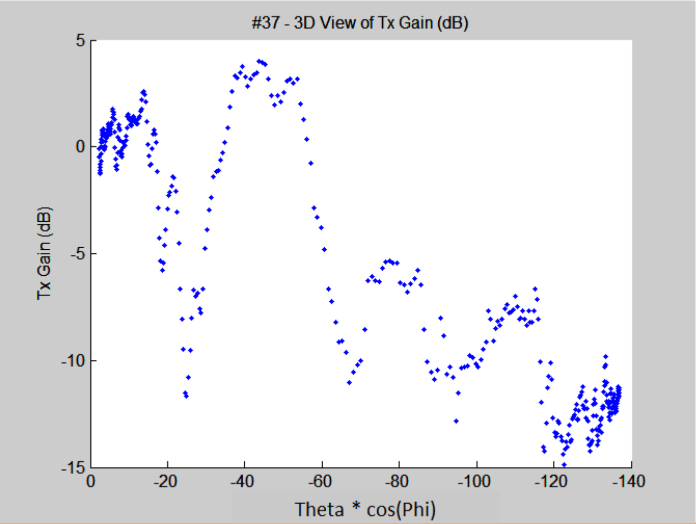


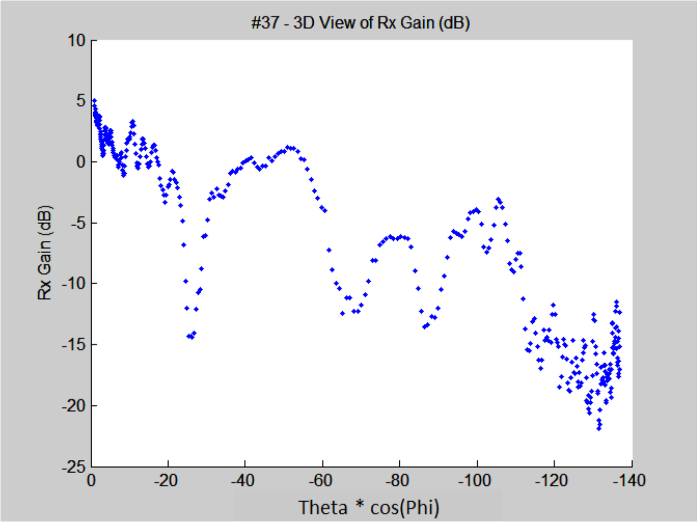
Single-Event Data Example

Antenna Swath Coverage



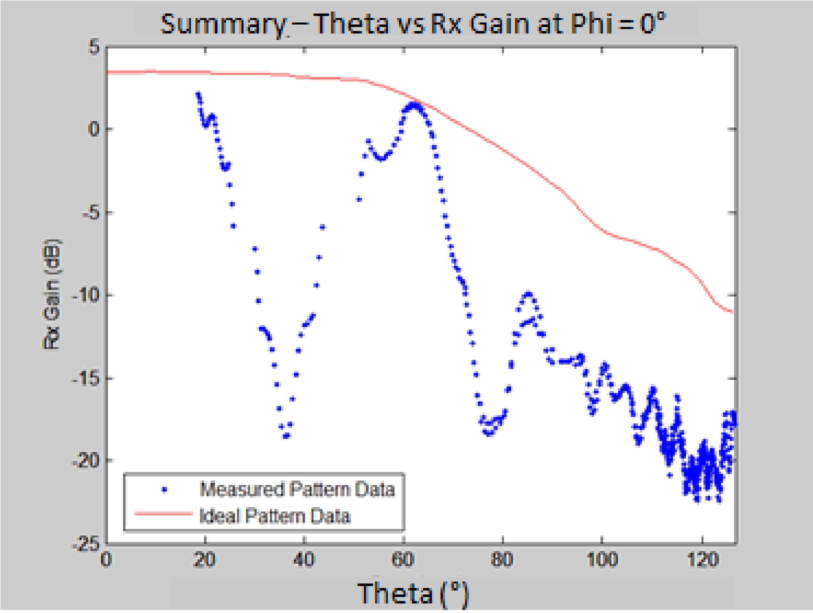
Antenna Pattern Measurements

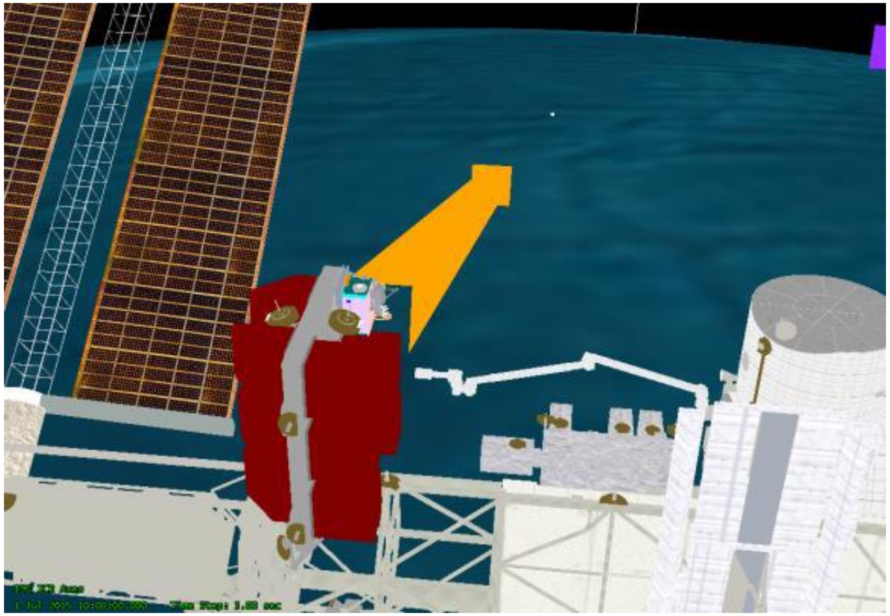




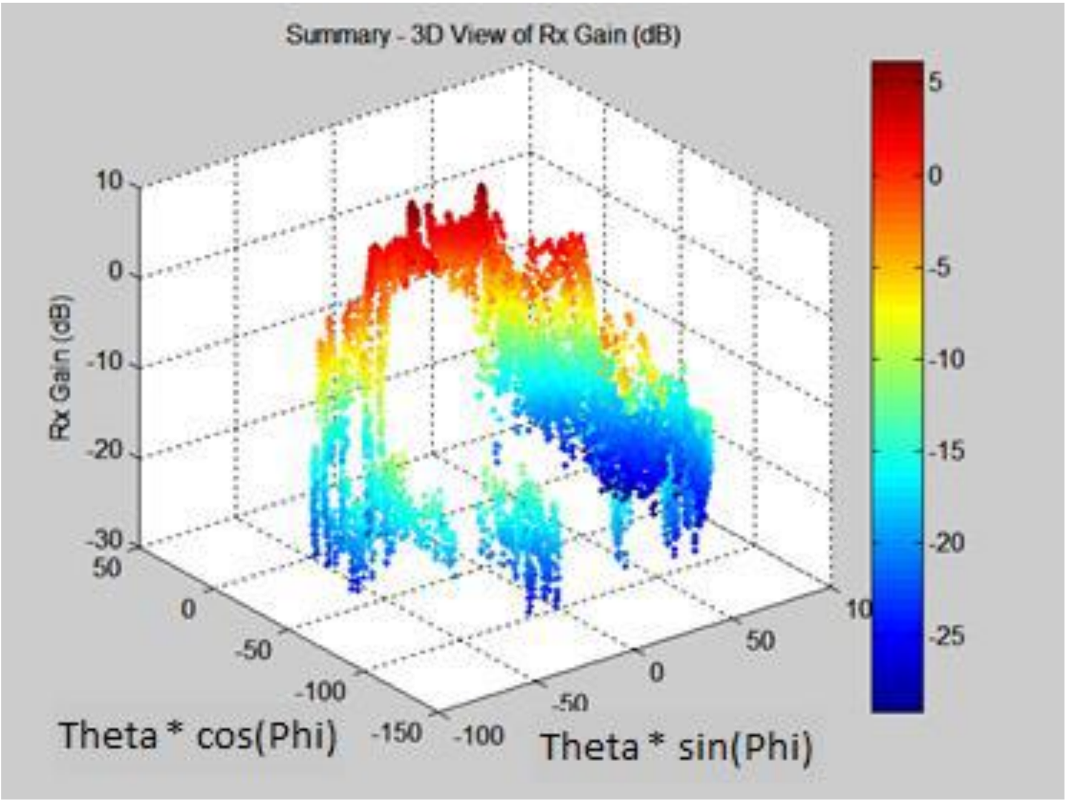
Shadowing Analysis

- Degradation between 20° and 50° Theta correlates with the locations of the ISS Japanese Experiment Module
- Degradation past 70° is due to shadowing and multipath from the ISS structure



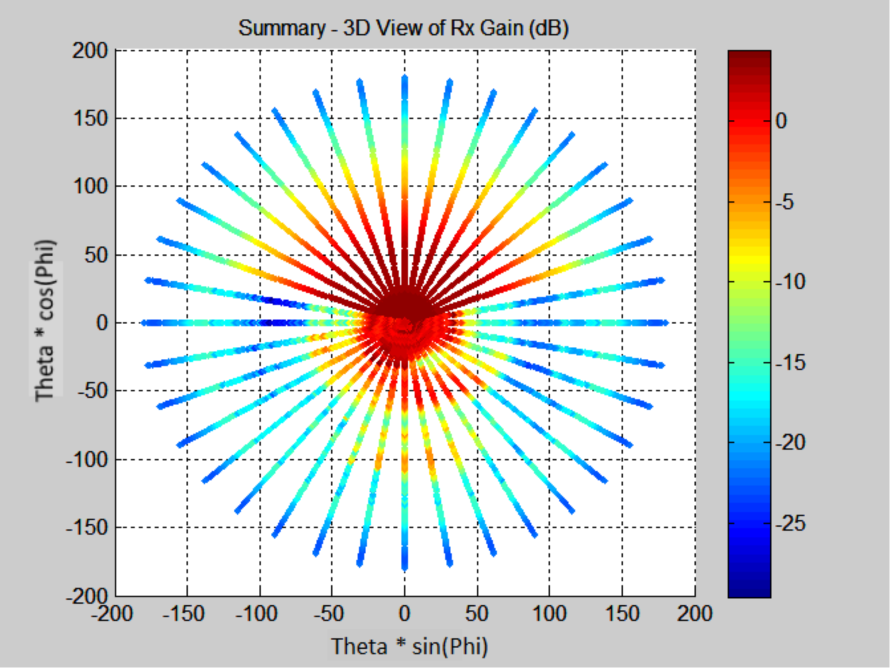


Aggregate Measurement



Producing Final Gain Pattern

- Pattern will be used to create a 3D Model for STAT
  - 1^{o} increments on the Theta axis
  - 10^{o} increments on the Phi axis
- Each pattern is parsed into phi slices and then averaged on the theta axis in 1^{o} sets
  - Smoothing is done over consecutive theta groupings to produce the final phi slice
  - Additional averaging was completed at boresight from the surrounding data as that point should be constant for each phi slice



Conclusions

- The NEN-LGA was characterized despite environmental challenges
  - Shadowing, Multipath, Multiple Frequencies, Link Directions
- Important information for the performance model of the SCAN Testbed
  - Planning and Post Processing
  - Growing adaptive and cognitive radio usage
- Demonstrates the importance of a fully characterized ground node and access to telemetry data

Acknowledgement and References

The authors would like to thank the SCaN Testbed Project for allowing the opportunity to characterize the NEN-LGA with the newly designed, built, and characterized GRC Ground Station. We also would like to thank the SCaN Testbed Mission Operations Team for their early morning and late evening shifts covering operations due to contact times between ISS and NASA GRC.

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Characterization Process

- Antenna Characterization is determined by using the Link budget Equation

$$P_R = P_T + G_T + L_{CT} + L_{FSP} + L_{ADD} + G_R + L_{CR}$$

- P_R is the received power level in units of dBm
- P_T is the transmitted power level in units of dBm
- G_T is the transmitter antenna gain in units of dB
- L_{CT} is the circuit losses on the transmit side between the transmitter and the antenna feed in units of dB
- L_{FSP} is the free space path loss in units of dB
- L_{ADD} is the additional link budget losses not accounted for in (1) such as multipath or shadowing in units of dB
- G_R is the receiver antenna gain in units of dB
- L_{CR} is the circuit loss on the receive side between the antenna feed and the received power level measurement in units of dB

- Derivation based on several factors
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Effective Gain Solutions

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