Signals of Opportunity Airborne Demonstrator (SoOp-AD)

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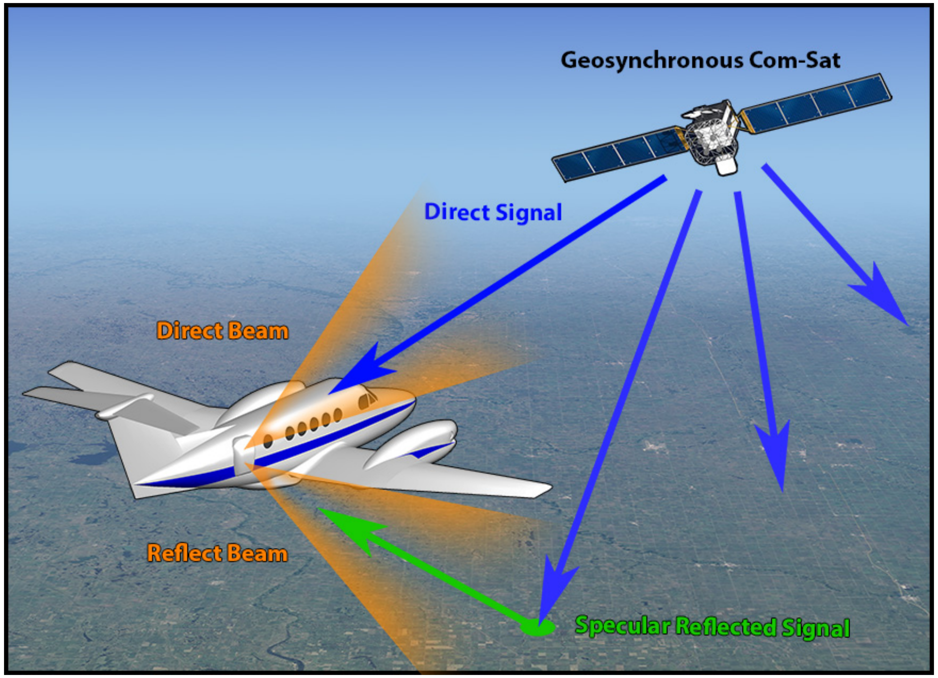
PURDUE UNIVERSITY NASA HARRIS®

Outline

- Overview
- Project Team
- Science Background and Motivations
- P-Band Signal Details
- Instrument Architecture
- Measurement Simulation
- Next Steps

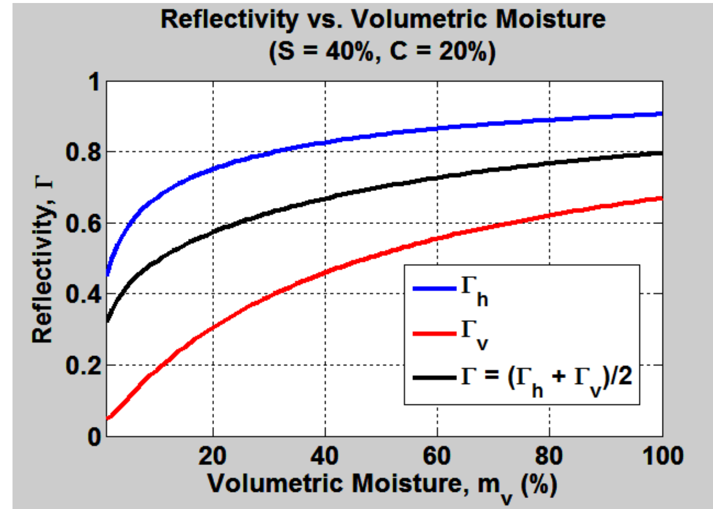
Measurement Overview

P-Band Reflectometry



We propose to measure Root Zone Soil Moisture (RZSM) through cross-correlation of direct and reflected P-Band geosynchronous communication satellite signals.

Basis of Measurement



Expected Performance

Parameter	SoOp Airborne	SoOp Spaceborne
Resolution*	100m	870m
Antenna Size	75 x 75 cm	75 x 75 cm
Sensing Depth	0-30cm	0-30cm
Sensing Precision**	$0.04m^3/m^3$	$0.04m^3/m^3$

*Specular Reflection Assumed

**SMAP Requirement

Project Team

- Purdue University

  Simulation, Retrieval Algorithms, Requirements Def.
  - PI: Jim Garrison (Assoc. Prof)
  - Georges Stienne (Post-doc)
  - Yao-Cheng “Zenki” Lin (PhD candidate)
- NASA GSFC

  Systems Engineering, RF Design, Aircraft Integration
  - Co-I: Jeff Piepmeier (555)
  - Co-I: Joe Knuble (555)
  - Ken Hersey (AS&D)
  - Cornelus Du Toit (AS&D)
  - Co-I: Alicia Joseph (617)
- Harris (Formerly Exelis, Inc)

  Digital Receiver Design
  - George Alikakos
  - Co-I: Steve O’Brien
- Langley Research Center

  Aircraft Operations
  - Bruce Fisher
- Dr. Stephen Katzberg – Consultant

  Scattering Model, Signal Processing

Scientific Motivation

- Root Zone Soil Moisture (RZSM):
  - Water in top ~meter of soil
  - Critical link between surface hydrology and deeper process
  - Drainage and absorption by plant roots
  - Connection between near-term precipitation and long-term availability of fresh water
- Biomass: a related measurement
  - Carbon storage in vegetation – key part of CO_2 balance
  - Raw material and source of 9-13% of World's energy

Current Sensing Limitations

- L-Band
  - L-band (SMAP) penetrates only few cm of soil
  - Saturation at L-band limits the ability to sense soil moisture through vegetation
  - RZSM from SMAP Level 4 model
- P-Band Radar
  - Difficult to find allocation in heavily utilized spectrum
  - ESA-BIOMASS cannot operate in North America or Europe due to interference with Space Object Tracking Radar
  - RFI
  - Expensive from space

SoOp-AD Solution

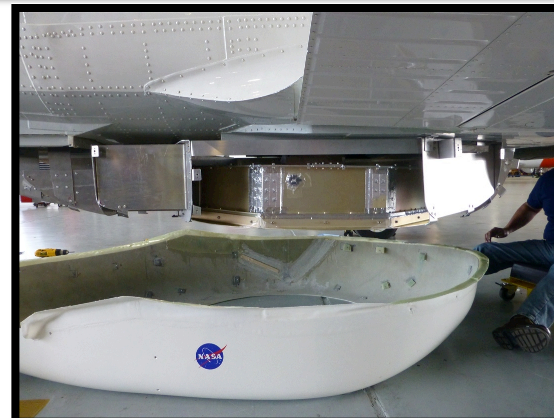
- **We propose to use the principles of reflectometry and reflected SATCOM signals to measure RZSM.**
  - Reutilizing active transmitters with forward scattering presents strong signals even at orbital altitudes.
  - Specular reflection provides good resolution with small antennas.
  - Not limited to protected frequency bands and potentially more resilient to RFI.
  - SoOp-AD will first measure RZSM from an aircraft.
  - P-Band and S-Band (XM Radio) will be investigated.

- SoOp-AD will use geostationary P-Band SATCOM systems
  - 225-420MHz allocation for government use, SoOp-AD will focus on 240-270MHz band: 18 25KHz channels, 20 5KHz channels.
  - Continuous use by US since 1978, follow-on systems planning legacy support
  - SoOp-AD method measures correlation of direct and reflected signals - does not require demod / decode of the transmission. Can work with any noise-like signal source!

SoOp-AD Project Highlights

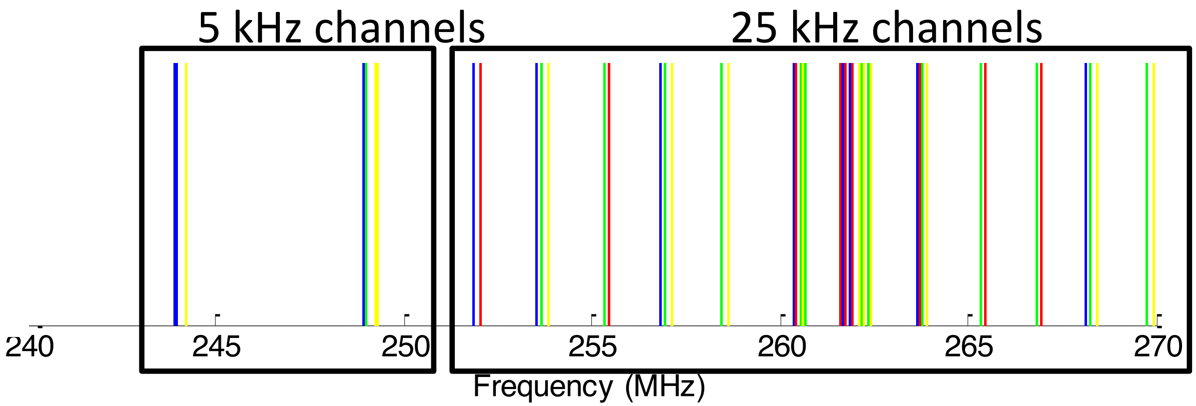
- IIP Timeline
  - Awarded in April ’14.
  - Subsystem I&T at GSFC this summer.
  - Science flights in Fall of ‘16.

- Instrument
  - Antennas: Patch, Dual Linear Pol, Null Steering
  - Receivers: Standard P-Band Receivers w/ internal calibration. S-Band receiver for XM Radio included. Brassboard and compact card.
  - Digital System: FPGA based. 7TB Storage: 1 hour of raw data or many days of processed data.
  - Two aircraft racks: 12U Total

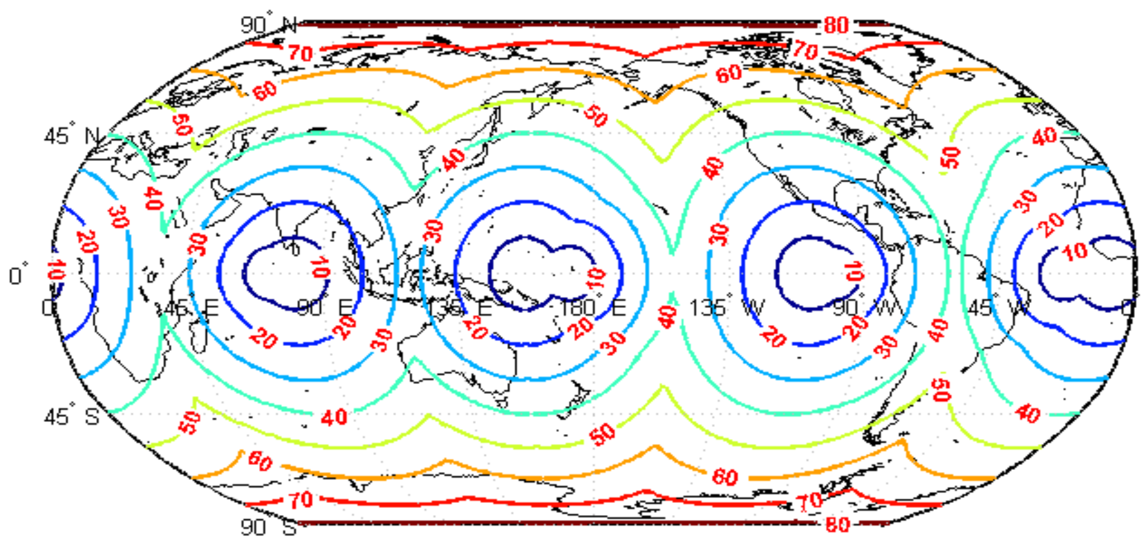


- Aircraft Campaign
  - Flying on NASA Langley B200.
  - Co-Flying with SLAP instrument (GSFC’s Active / Passive L-Band).
  - Science flights over the St. Joseph’s Watershed.

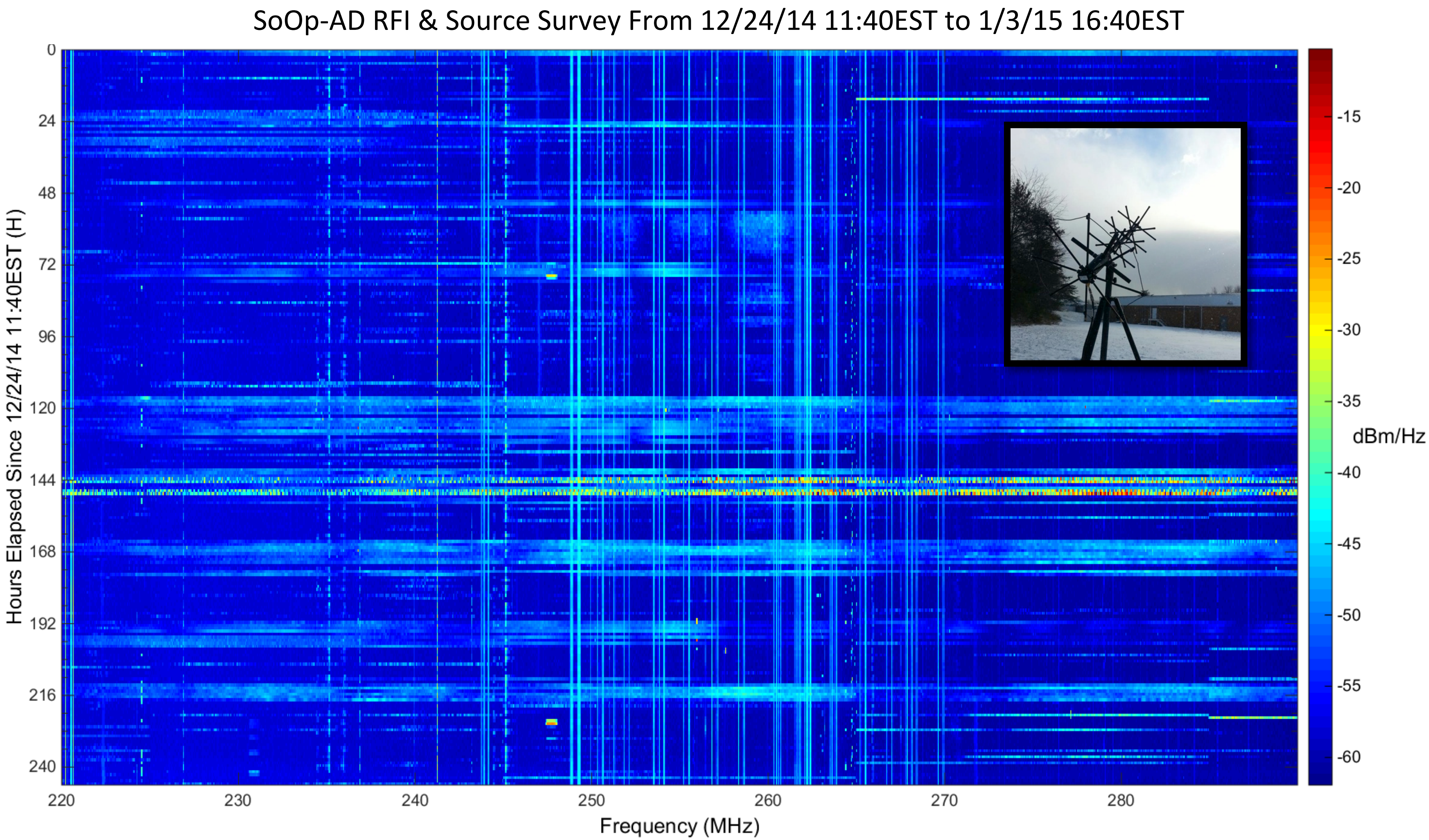
Signal Bands and Coverage



Incidence Angle for Geostationary Sources used by SoOp-AD.



Measured Signal Details & RFI

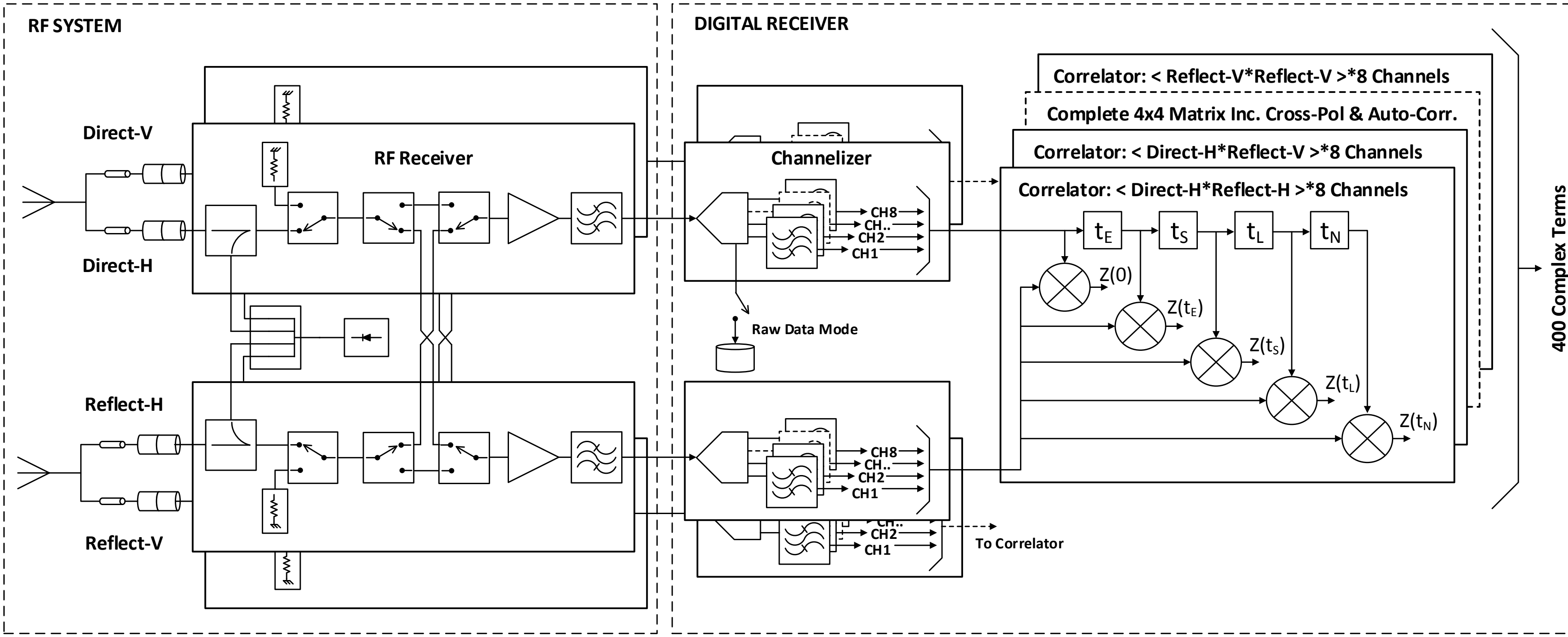


Waterfall spectrum measured at GSFC over 11 days. Note persistence of SATCOM signals and broad-band RFI.

Direct Signal Link Budgets

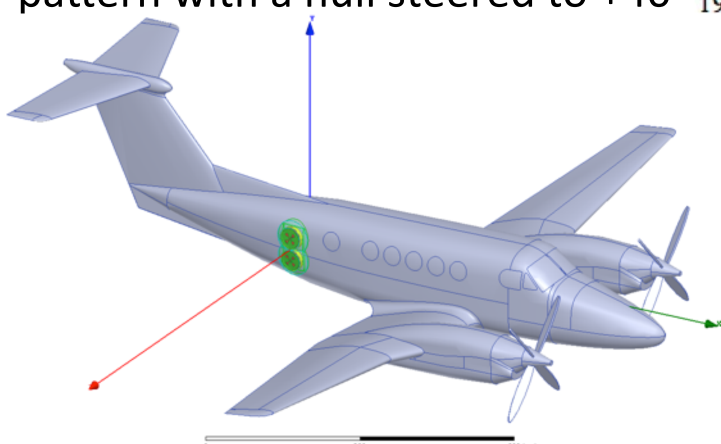
	P-Band		S-Band (XM-Radio)	
EIRP	26dBW (14dBW Measured)		68dBW	
Frequency	240-270MHz		2332.5-2345.0 MHz	
Bandwidth	25 kHz		1.886 MHz	
Longitude	-99.2°	-105.6°	-85°	-105°
Distance	38128km	38512km	37447km	38474km
Path loss	-172dB	-173dB	-191dB	-192dB
Atmospheric loss	-1dB			
Sky-view antenna gain	7dB			
Sky-view antenna noise	145K			
Pre-switch noise	212K			
Post-switch noise	350K			
SNR	**15.7dB (3.7dB)**	**15.6dB (3.6dB)**	**20.1dB**	**19.8dB**

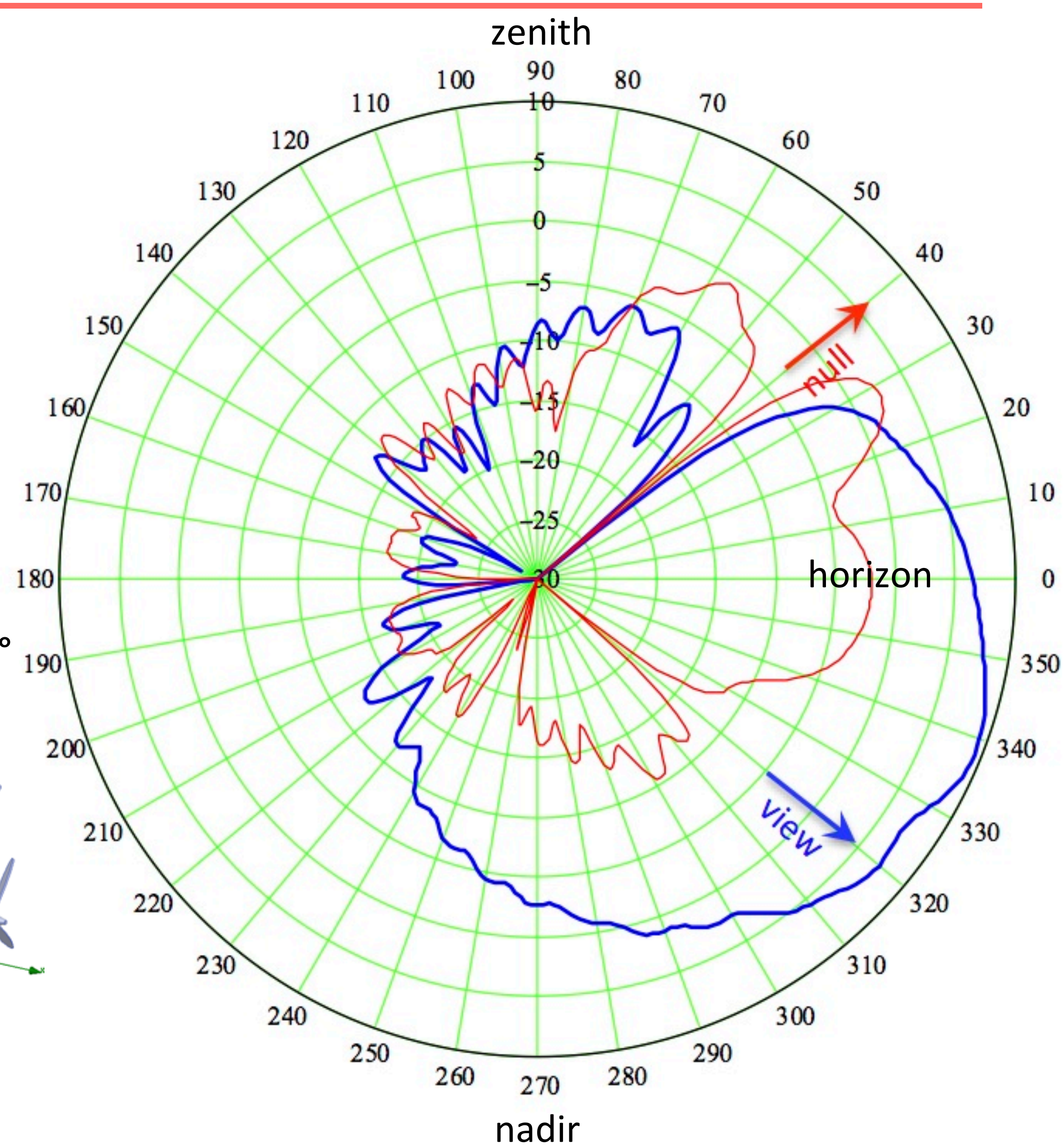
SoOp-AD System Architecture



Antenna System Considerations

- Direct-to-Reflect isolation is driving requirement – But not in orbit!
- Using "Smart Antenna" to steer a null as necessary in post-processing.
- Simulation: Earth View Beam
  - Co-pol (blue): LHCP
  - X-pol (red): RHCP
- Results simulate a post-processed pattern with a null steered to +40°



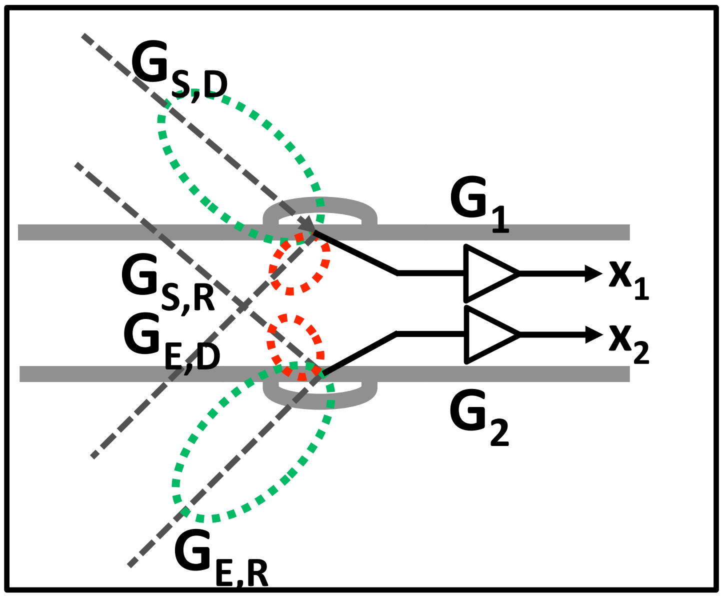


Measurement Simulation

- Purpose:
  - Science requirement flow-down to technology requirements
  - Error budget
  - First generation retrieval algorithms
- Two Methods: Synthetic (IF) Signal Generator (forward model) and Extended Kalman Filter (inverse estimator)
- Evaluate Error Sources against $0.04 m^3/m^3$ Precision Req.
  - SNR
  - RFI
  - Direct signal leakage into reflect antenna (easier in orbit!)
  - Multiple Satellite Interference
  - Antenna Pattern Knowledge
  - Aircraft Position & Attitude Knowledge
  - Number of correlation delays
  - Terrain Height Fluctuation
  - Uncertainty in Receiver Gain and Offset

Modelling Details

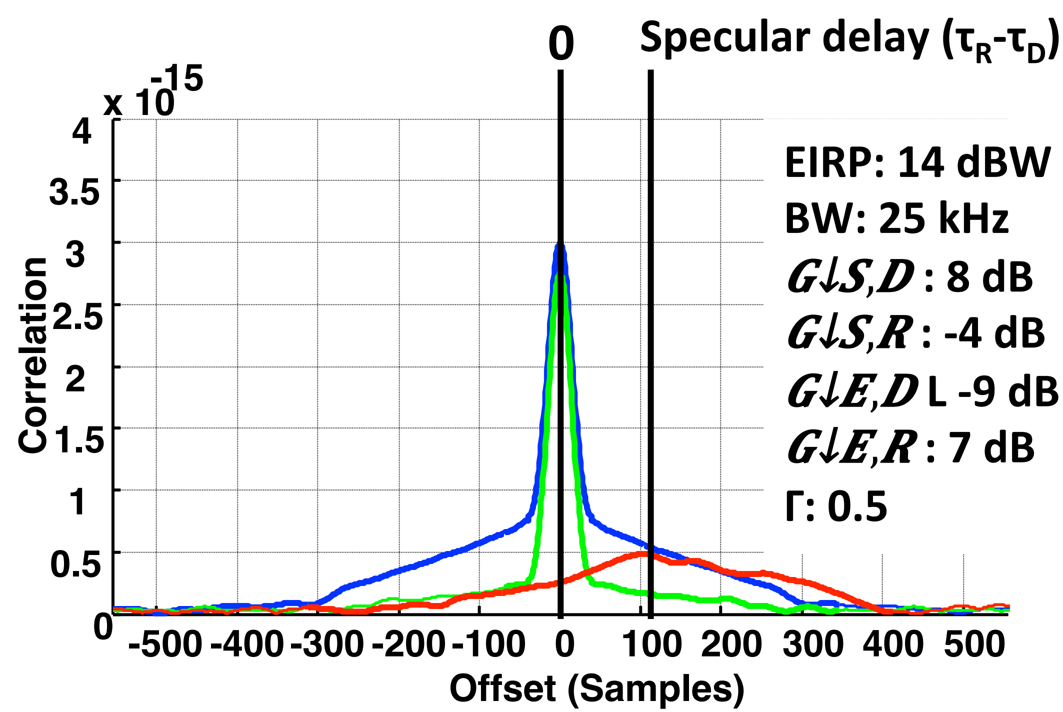
Measuring **Γ** from $\mathbf{x_1}$ and $\mathbf{x_2}$



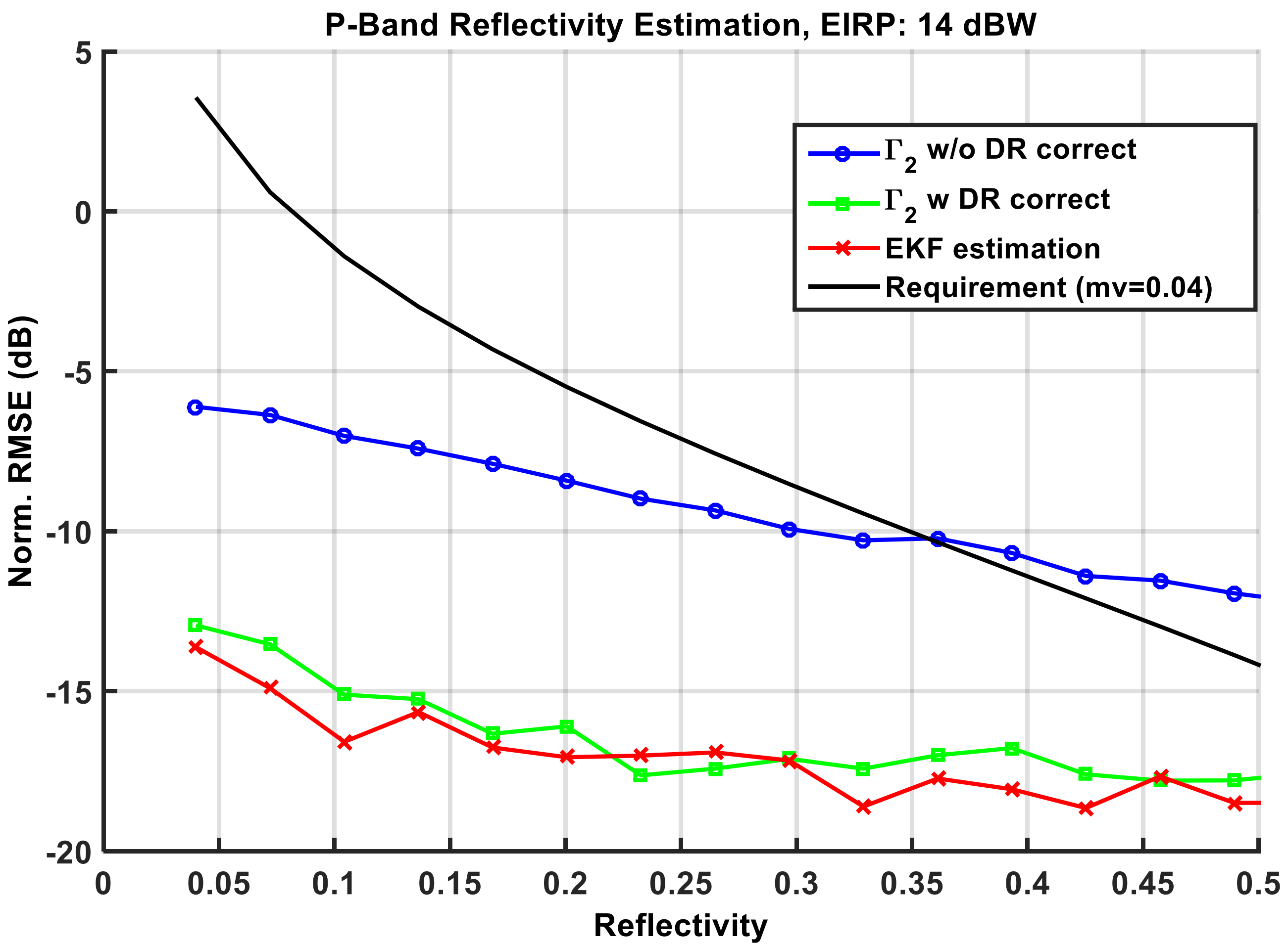
- $\mathbf{G_{S,R}}$ and $\mathbf{G_{E,D}}$ are error sources, estimated with forward model and EKF.
- Ratio of $\mathbf{G_1}$ and $\mathbf{G_2}$ measured with cal system.
- $\mathbf{G_{S,D}}$ and $\mathbf{G_{E,R}}$ are known given aircraft position and antenna patterns

Measurements are made on samples of Z_{11} (autocorrelation of channel 1), Z_{22} (autocorrelation of channel 2) and Z_{12} (cross-correlation between channel 1 and channel 2)

Simulated Forward Model Correlation Result



Current Modelling Results



We believe we will meet requirements with margin.

Next Steps

- Continue Model Refinement
- Perform I&T at GSFC this Summer
- Field campaign using a tower
- Aircraft Campaign in Fall of 2016