The Radio Frequency Environment at 240-270 MHz with Application to Signal-of-opportunity Remote Sensing

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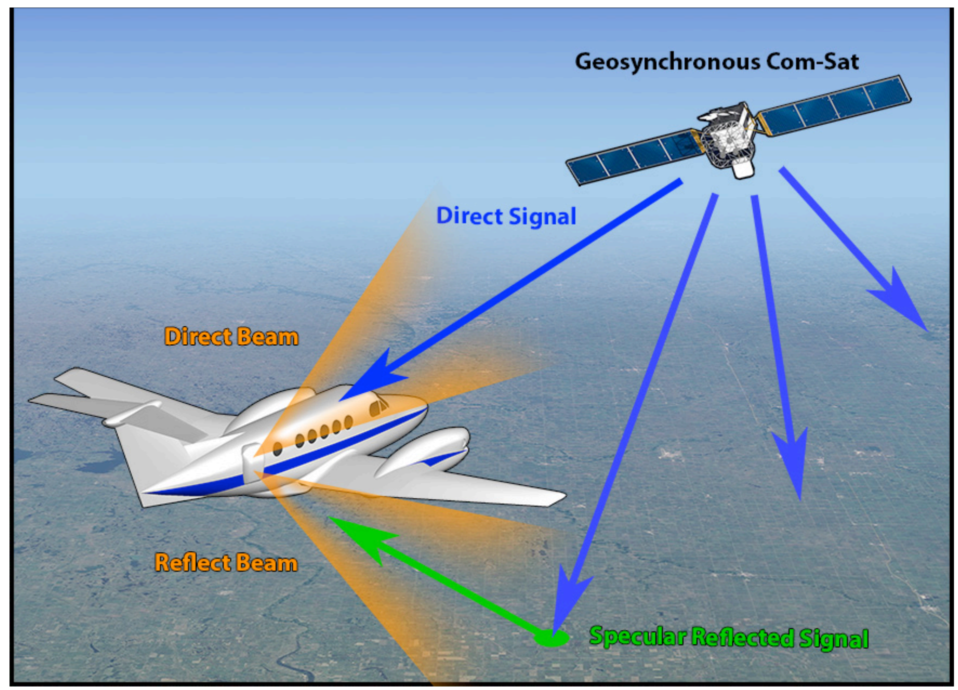
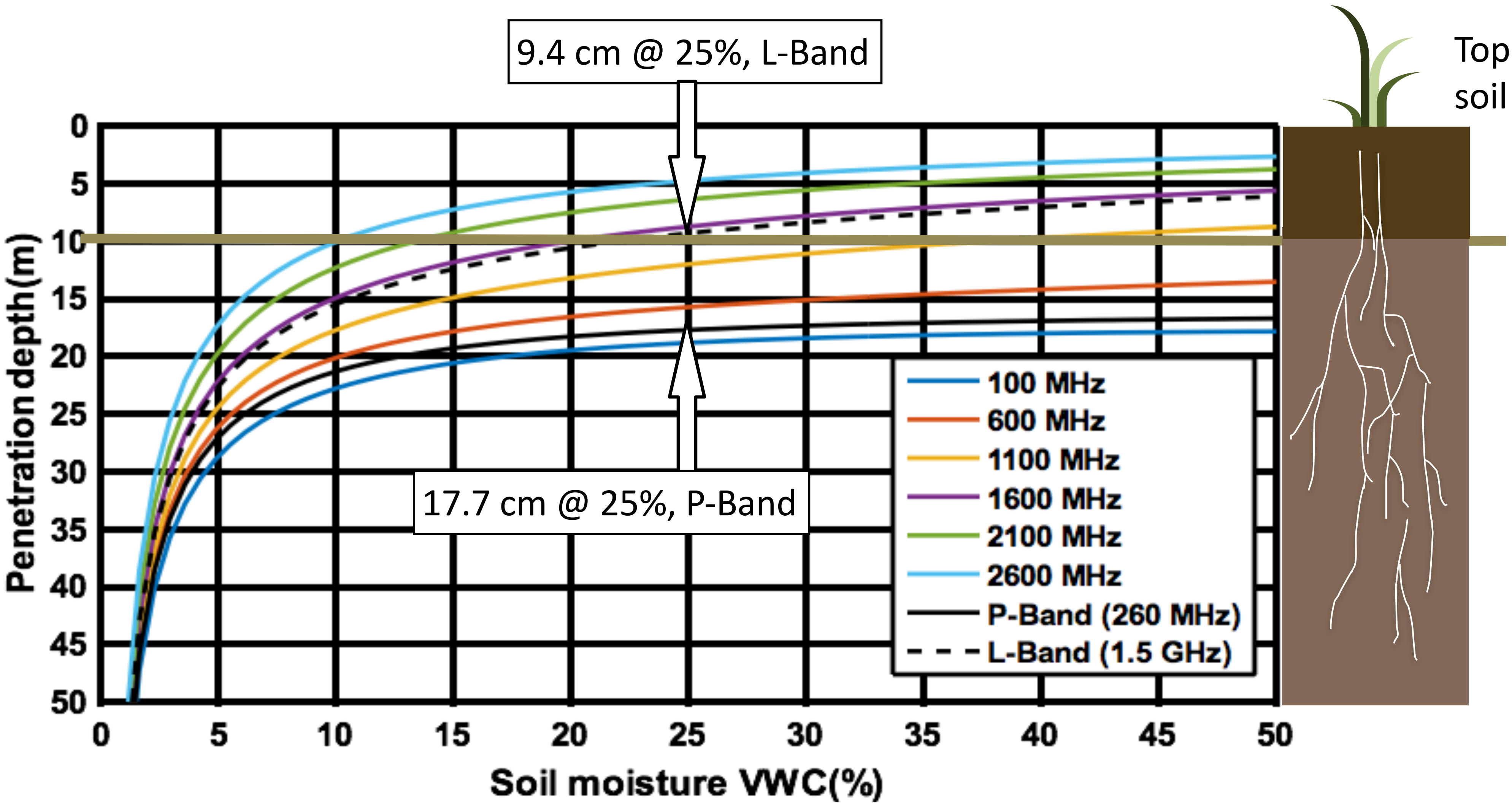
Outline

- P-band, Soil Moisture, and SoOp
- SoOp-AD and Results
- RFI Effects in SoOp
- Spectrum Observations
- Conclusions



Importance of Sensing < 500 MHz



Sand: 40%, Clay: 20%, Temperature: 20 ^{o}C

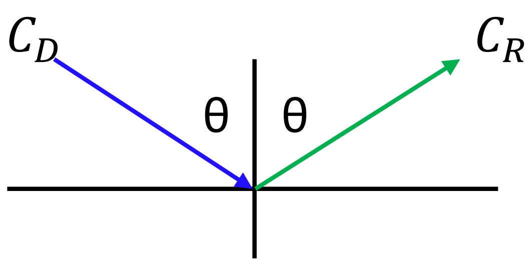
Soil P-band Reflectivity

Assumption:

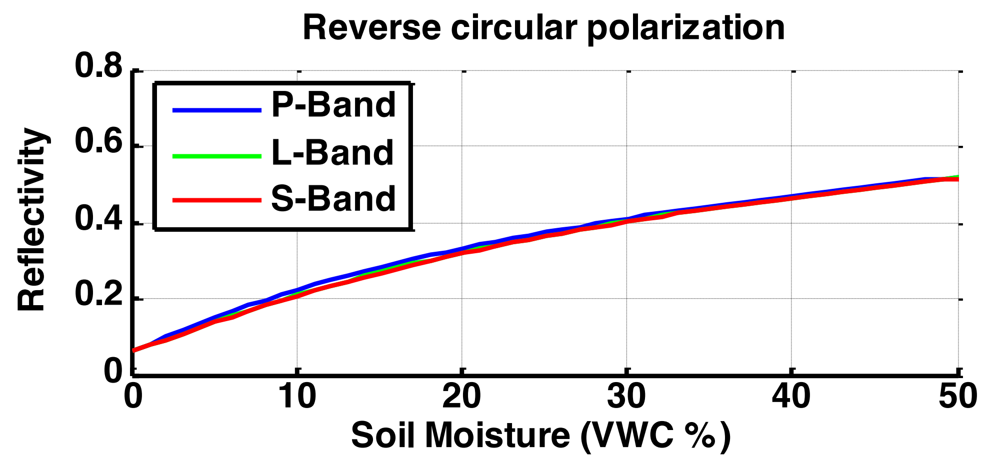
1. Flat specular reflection
2. Single layer and media
3. No vegetation effect

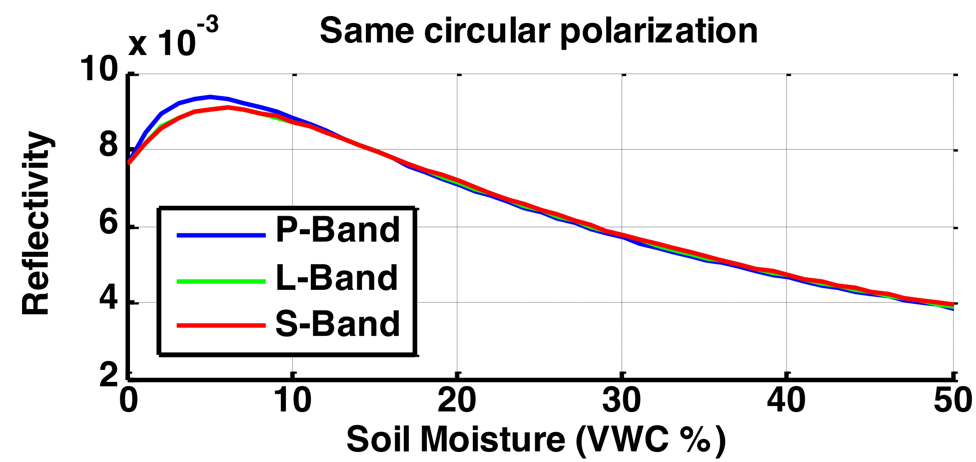
Specular reflection

$$\Gamma = \frac{C_R}{C_D}$$



Γ: Reflectivity
C_D: Carrier power for direct signal
C_R: Carrier power for reflected signal





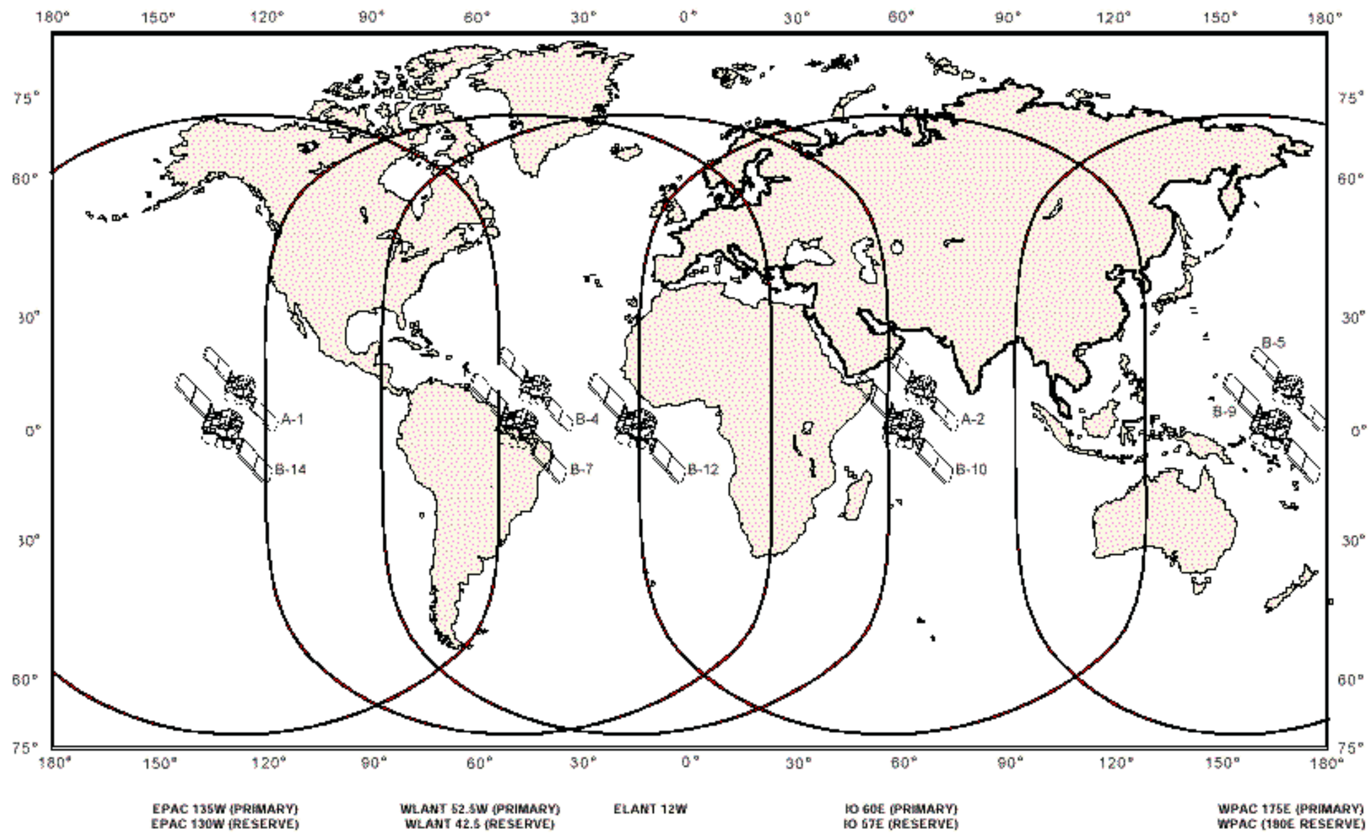
P-band Signals of Opportunity (SoOp)

- Re-utilization of existing transmissions (e.g. potential RFI ***sources***)
- No transmit permission required (re: ESA's Biomass)
- Bands allocated for Space-Earth communications
- High power, forward scatter -> High SNR/smaller antenna
- Resolution set by signal bandwidth or Fresnel zone

P-band SoOp offers opportunity to measure deeper soil moisture from space at low cost

Sources for P-band SoOp

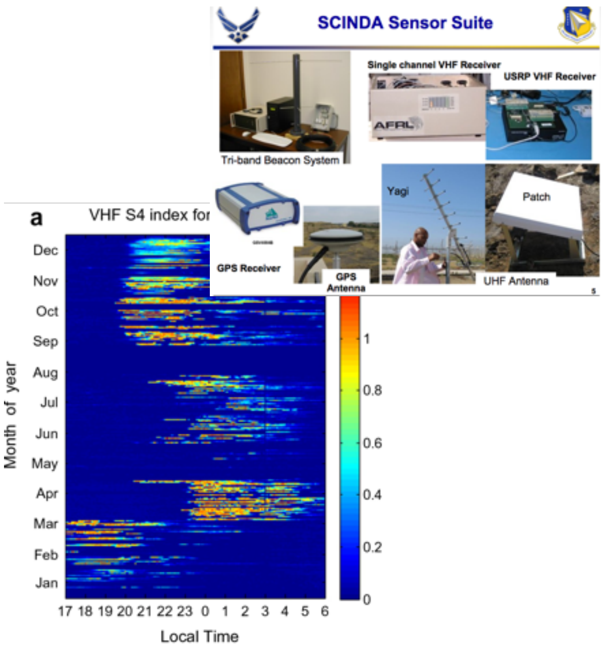
- **225–420 MHz** allocation for defense/government use
- Continuous use by US & Others since 1978 (FLTSATCOM)
- Planned utilization through 2024



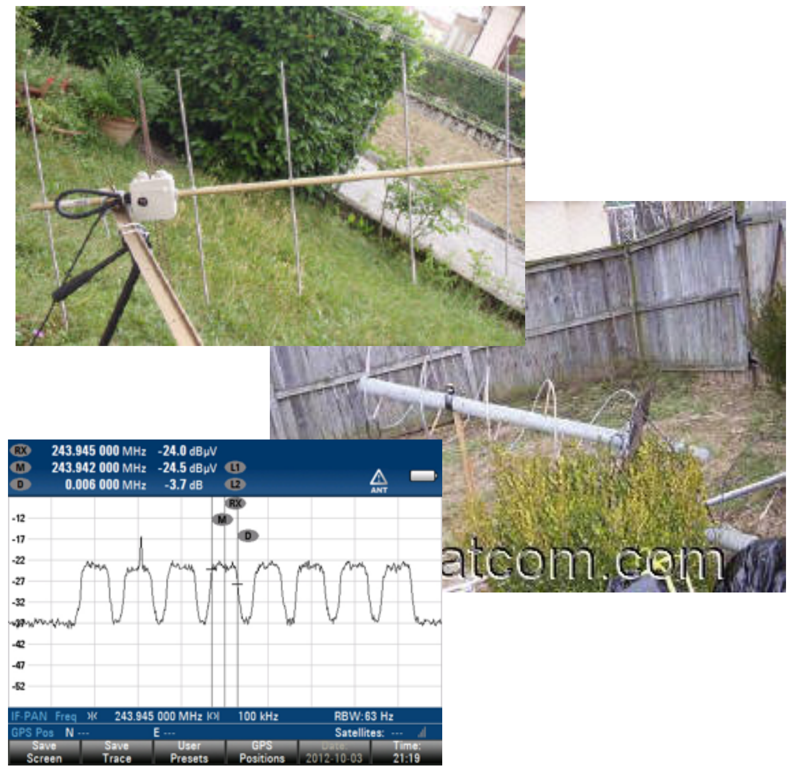
Narrowband Signals

- Multiple Low bandwidth (5, 25 KHz) digital channels.
- Well documented and (supposedly) easy to receive by:

Ionospheric Researchers **Hobbyists** **Pirates**



[Olwendo, et al. *Adv. Space Research* 51 (2013), DOI: . 10.1016/j.asr.2012.12.017]



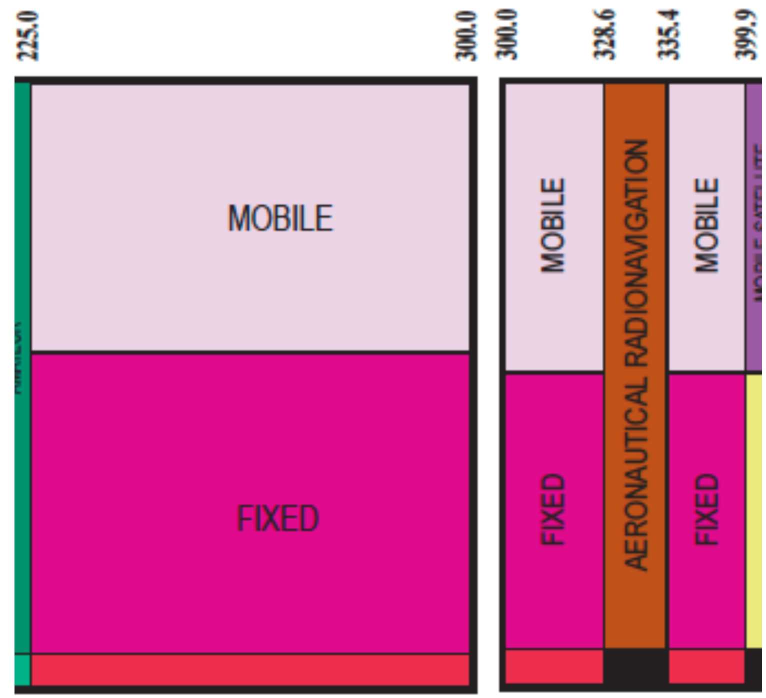
[www.uhf-satcom.com, www.crypto.com]

"Nearly illiterate men rigged a radio in less than one minute" [*Wired*, April 20, 2009]

P-Band Allocation

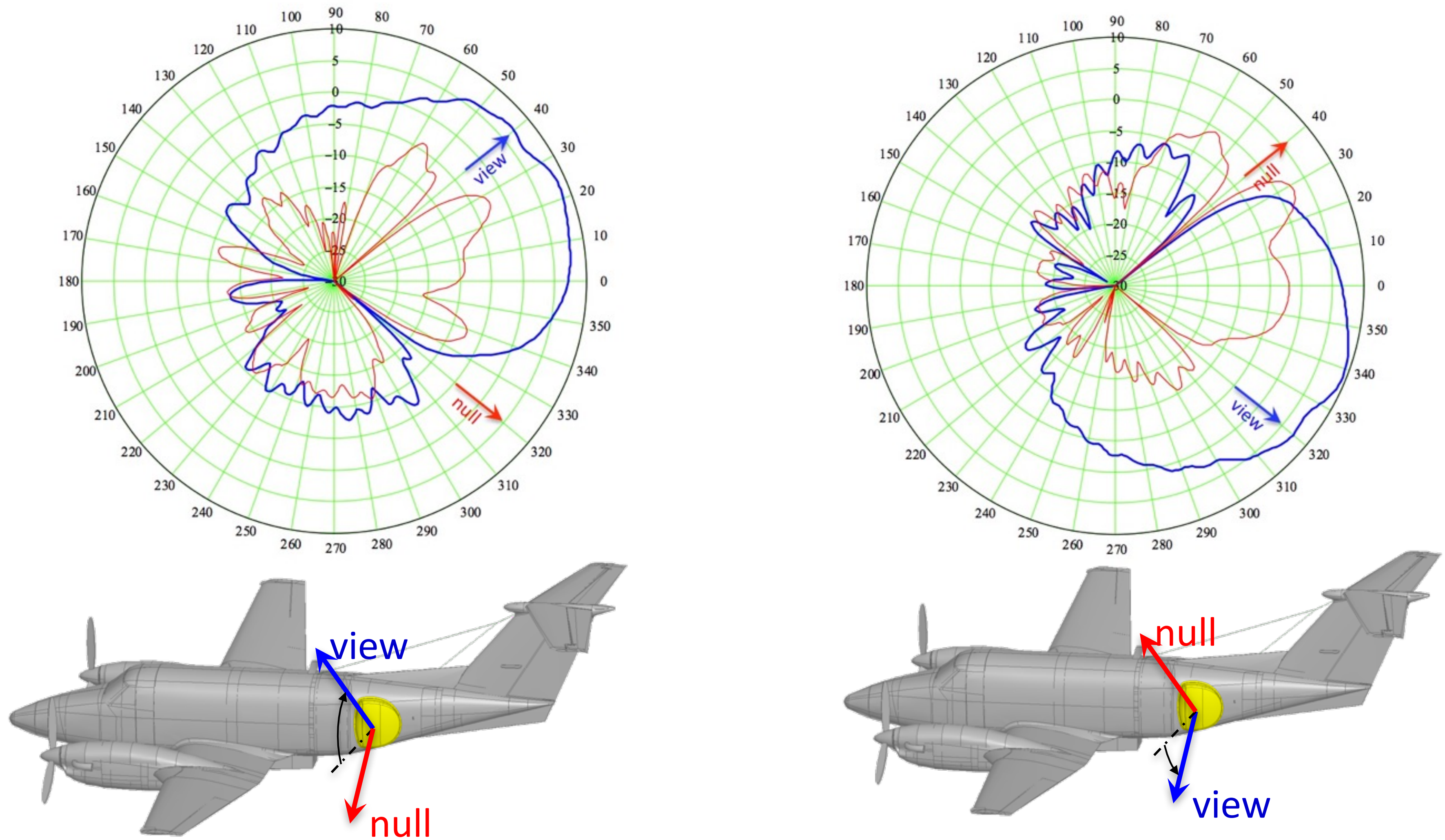
Wide government use:

> "The band 225-328.6 MHz is used for a diverse array of land-based, airborne, maritime, and satellite radio communications services by the military forces, National Guard units, Federal Aviation Administration (FAA), Coast Guard (CG), National Aeronautics and Space Administration (NASA), Department of Energy (DOE), and other Federal agencies. Tactical and non-tactical mobile communications, mobile-satellite communications, and air traffic control communications are the most prevalent uses."



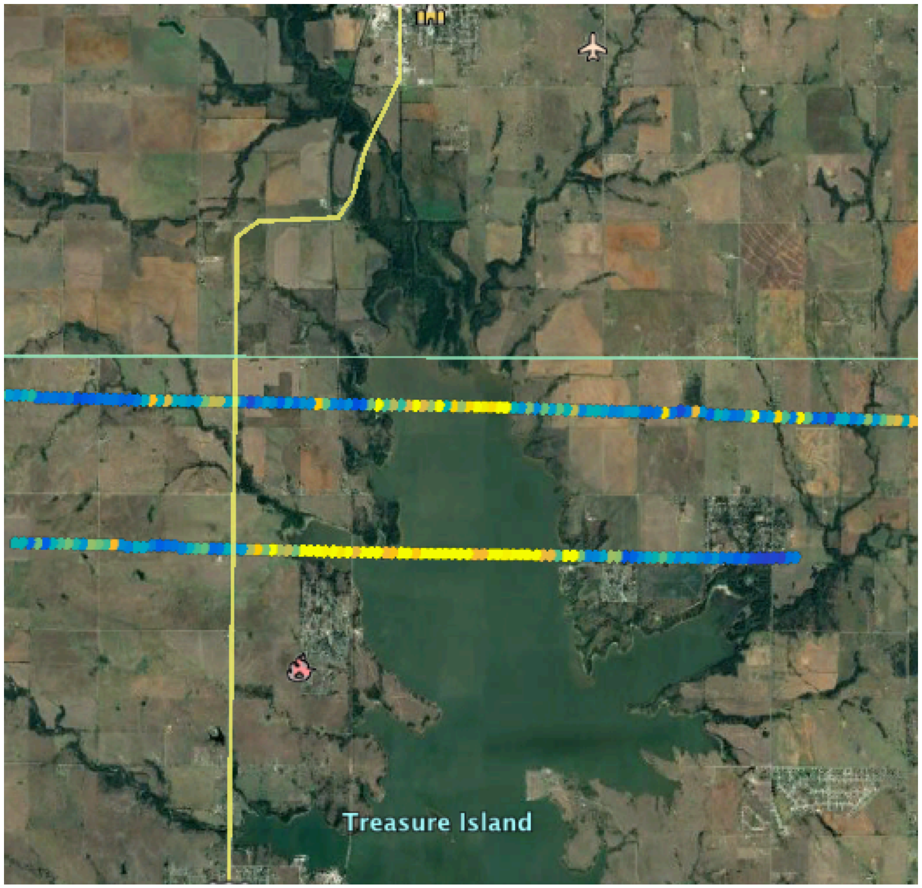
Federal Government Spectrum Compendium, December 16, 2015. National Telecommunications and Information Administration [Online.] https://www.ntia.doc.gov/print/other-publication/2015/federal-government-spectrum-compendium

Signals of Opportunity Airborne Demonstrator (SoOp-AD)

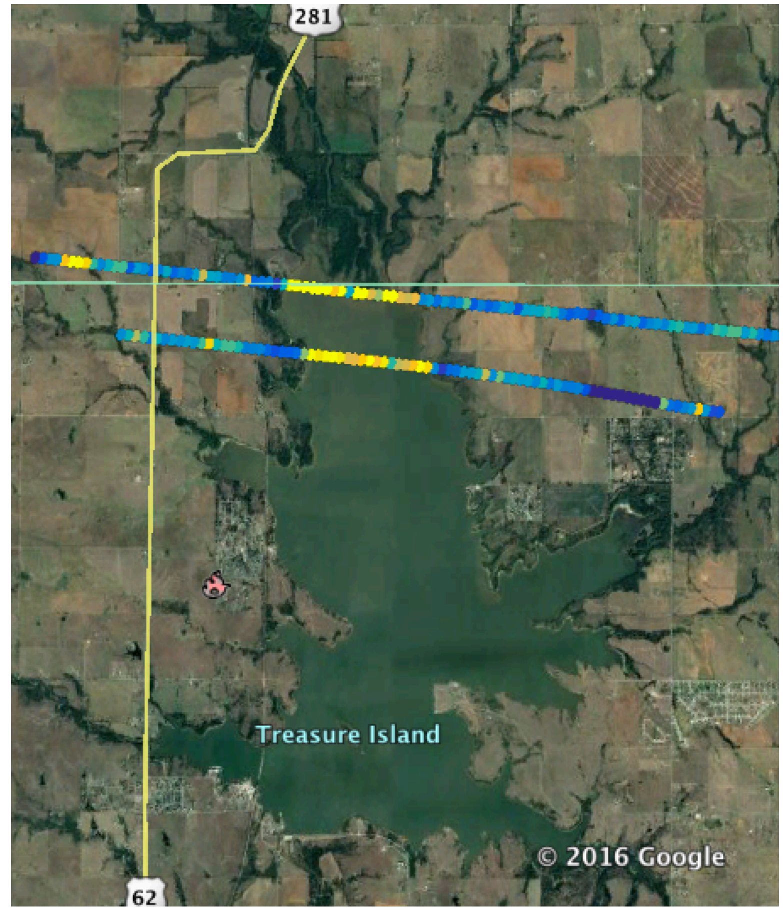


First Look at Data: Antenna Null-Steering and Adjustment

- Lake Ellsworth Overflights



Science Flight 3 (10/22)



Science Flight 5 (10/25)

Estimating Reflectivity

Auto-correlation of channel 1

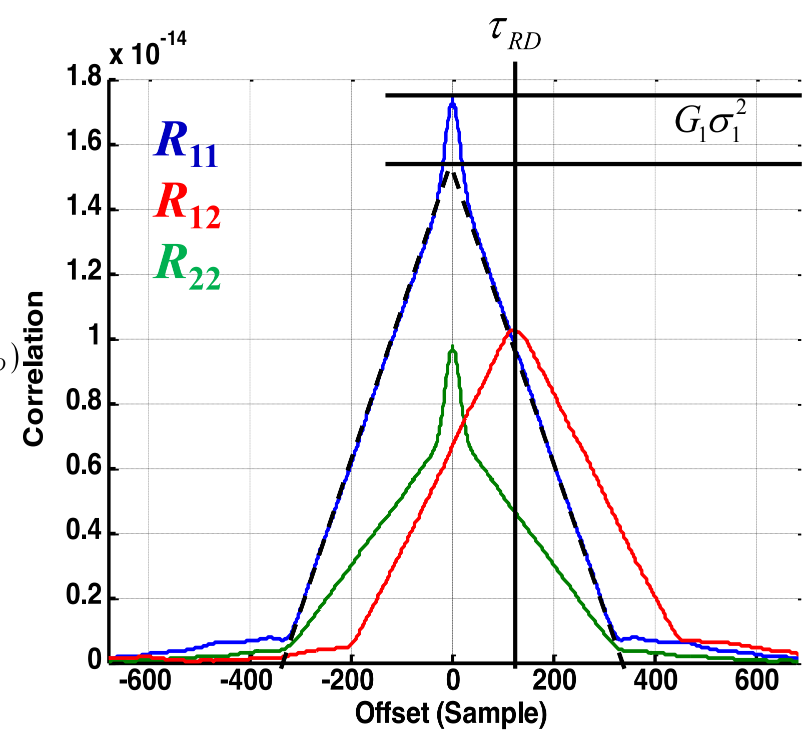
$$R_{11}(\tau) = \langle x_1^*(t) x_1(t+\tau) \rangle$$
$$= G_1 G_{S,D} C_D \langle a^*(t-\tau_D) a(t-\tau_D+\tau) \rangle + G_1 \sigma_1^2 \delta(\tau)$$

Cross-correlation of channel 1 and 2

$$R_{12}(\tau) = \langle x_1^*(t) x_2(t+\tau) \rangle$$
$$= \sqrt{G_1 G_2 G_{S,D} G_{E,R} \Gamma} C_D \langle a^*(t-\tau_D) a(t-\tau_R+\tau) \rangle e^{j\omega(\tau_R-\tau_D)}$$

Reflectivity:

$$\frac{R_{12}(\tau_{RD})}{R_{11}(0) - G_1\sigma_1^2} = \sqrt{\frac{G_2 G_{E,R}}{G_1 G_{S,D}}} \sqrt{\Gamma} e^{j\omega\cdot\tau_{RD}}$$



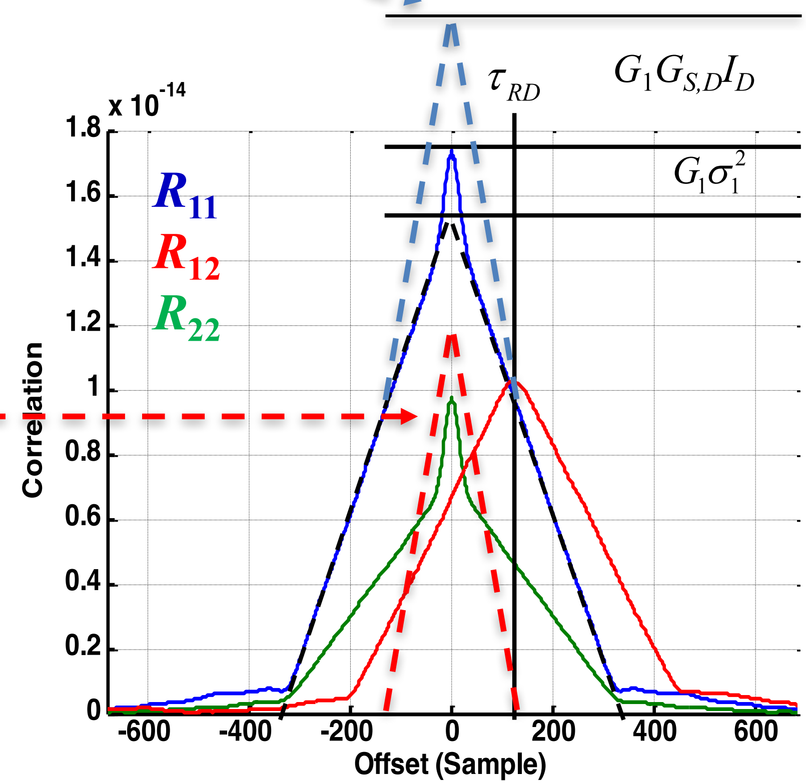
Reflectivity: 0.65, EIRP: 26 dB

RFI Impacts Estimate

- RFI in sky antenna (channel 1) adds to $R_{11}(0)$, which attenuates estimate by:

$$\sim\left(\frac{1}{1+ISR}\right)^2 \qquad ISR=\frac{I_D}{C_D}$$

- RFI in Earth antenna increases noise
- RFI in both antennas adds to R_{12}
  - Systematic addition or subtraction, else
  - Increase noise if $\tau_{RD} \gg 1/BW_I$

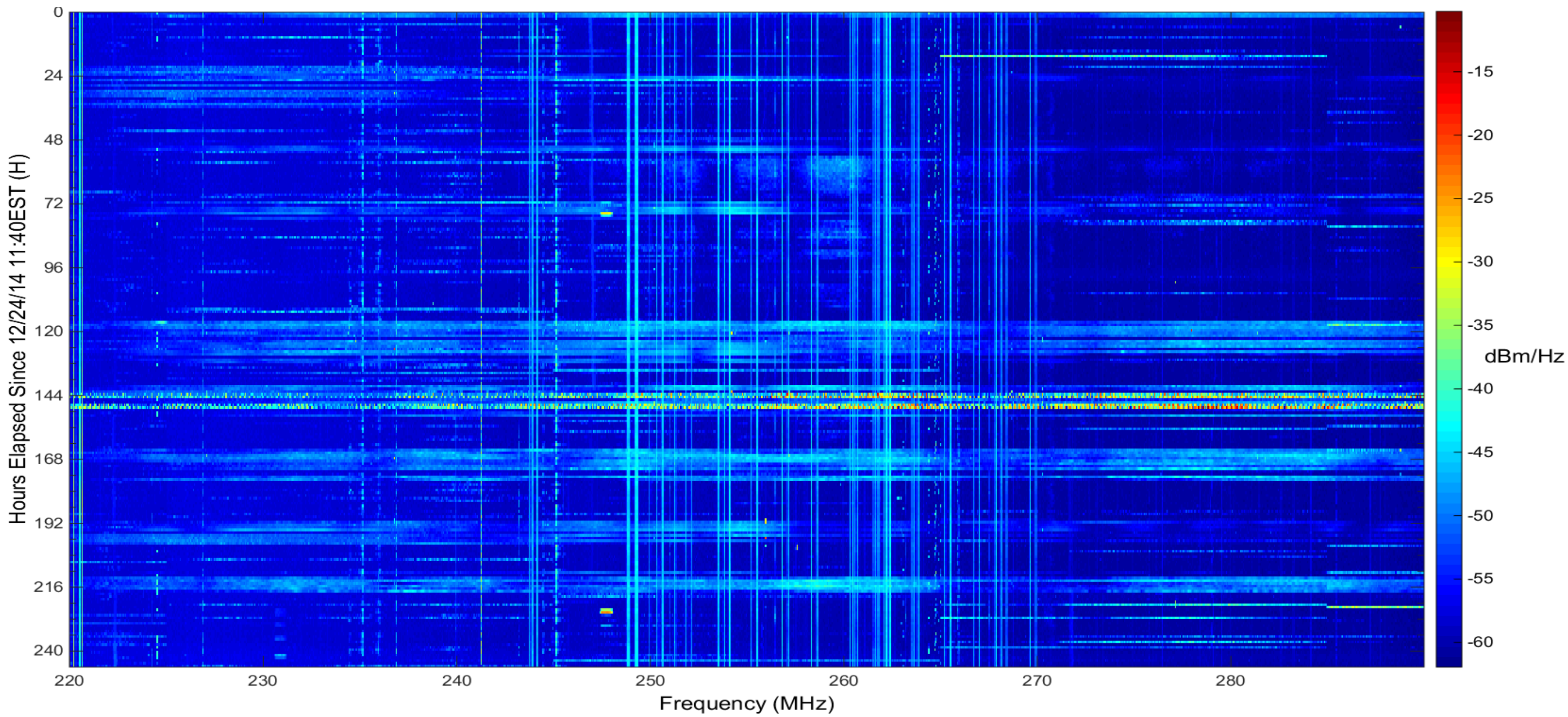


Reflectivity: 0.65, EIRP: 26 dB

Reflectivity:

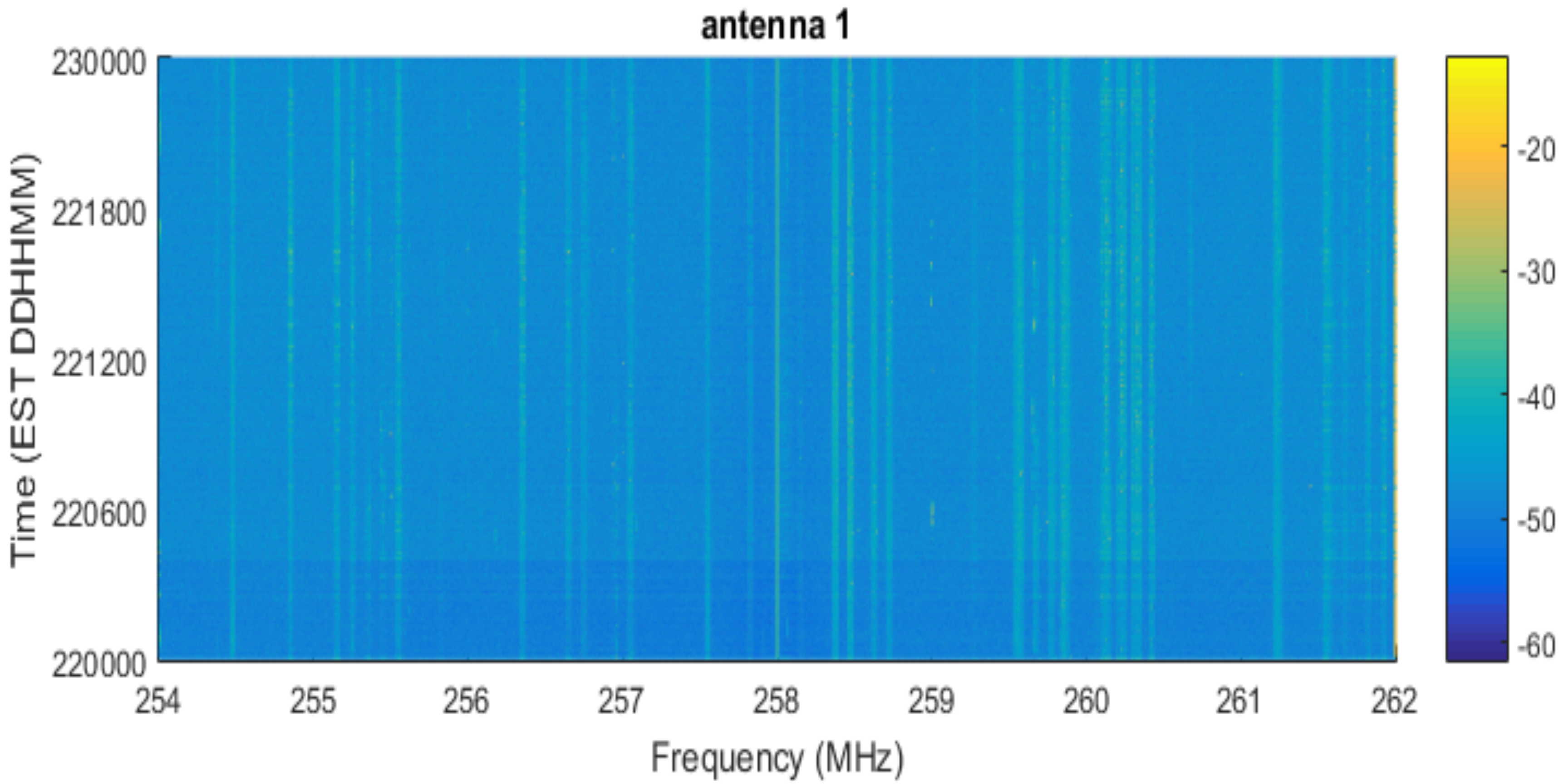
$$\frac{R_{12}(\tau_{RD})}{R_{11}(0)-G_1\sigma_1^2}=\sqrt{\frac{G_2G_{E,R}}{G_1G_{S,D}}}\sqrt{\Gamma}e^{j\omega\cdot\tau_{RD}}$$

Urban Local Spectrogram



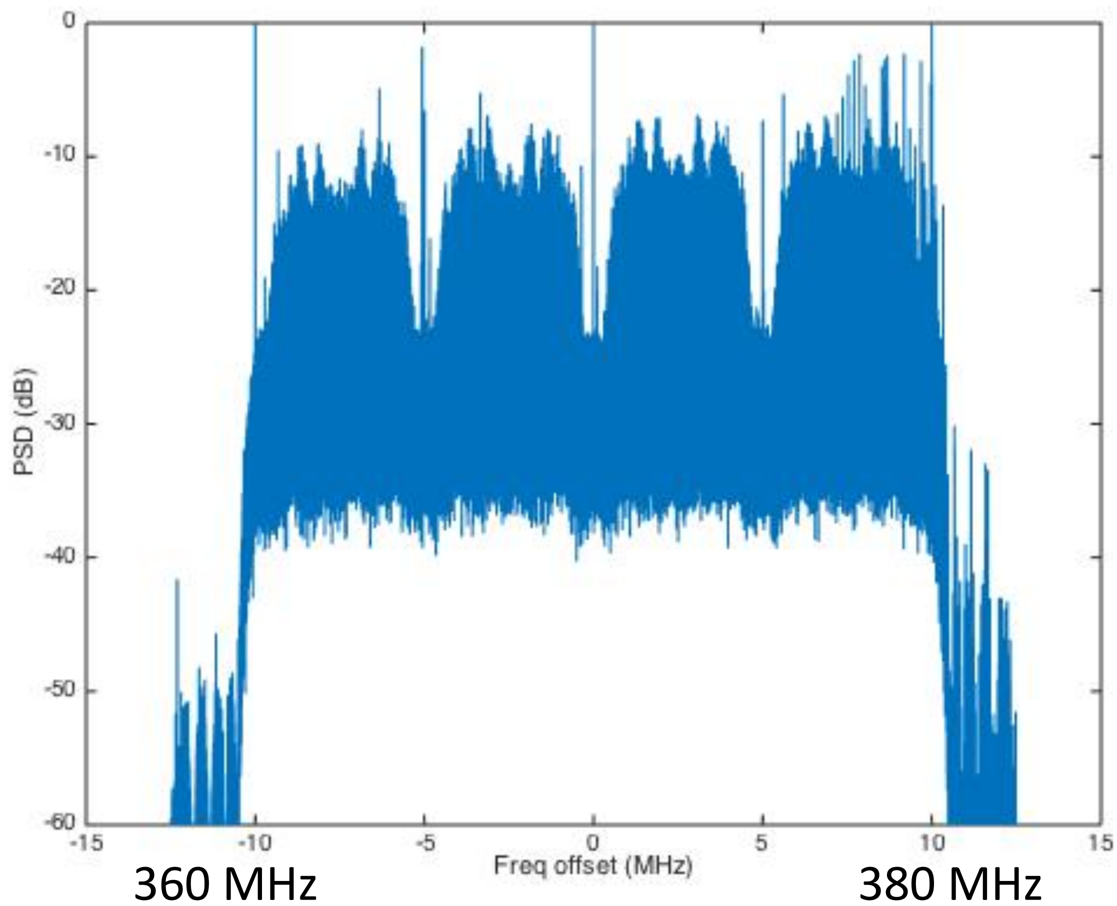
Spectrogram collected near Washington, D.C. shows desired persistent narrowband signals but with significant broadband transient interference.

Rural Local Spectrum 1



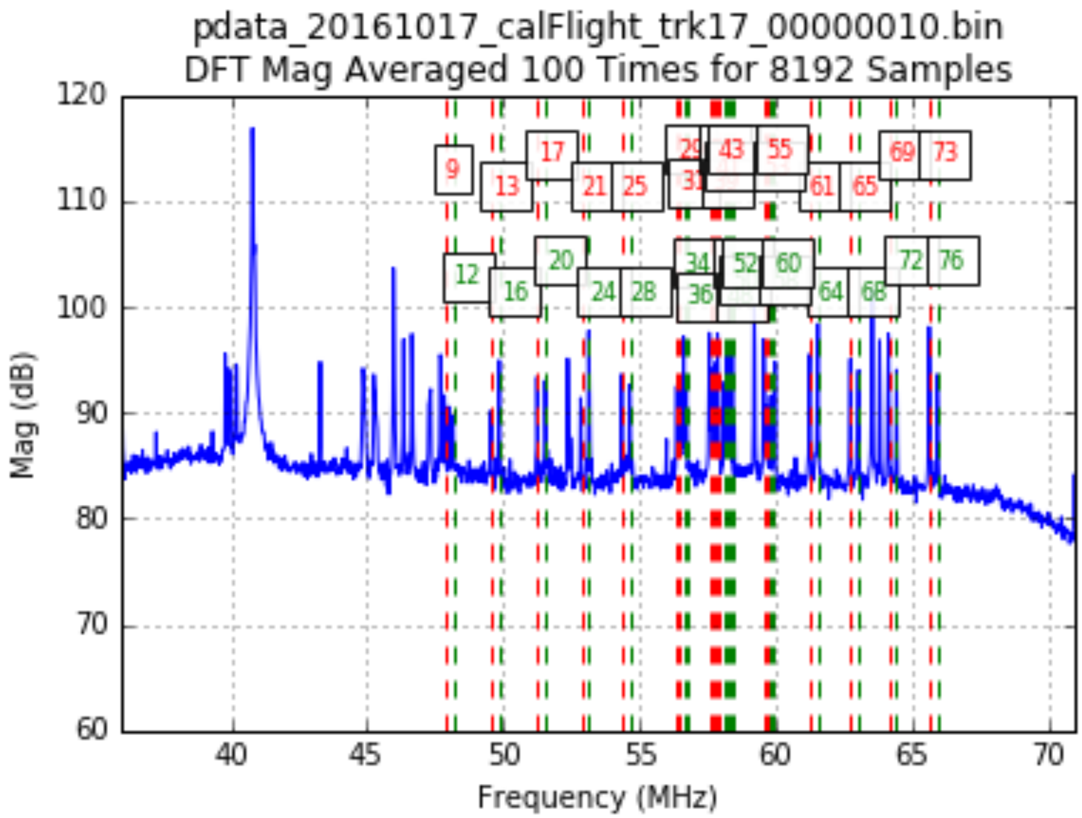
Spectrogram showing desired persistent narrowband signals with no discernable RFI from undesired signals.

Rural Local Spectrum 2



Spectrogram showing desired persistent narrowband signals with potential RFI in band 4.

Airborne Spectrum



230 MHz 270 MHz

Spectrogram showing desired narrowband signals with no discernable RFI from undesired signals.

Acknowledgements

- This work was funded under NASA Grant NNX14AE80G (2013 Instrument Incubator Program).
- USDA (Michael Cosh) provided valuable assistance with utilizing the Little Washita ARS Micronet data.

Discussion

- Rural spectrum cleaner than Urban spectrum
- Urban spectrum possibly worst case because D.C. area
- Airborne spectrum example appears clean