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

- Topsoil: 9.4 cm @ 25%, L-Band
- Soil moisture VWC (%): 0 to 50
- Penetration depth (m): 0 to 50
- Soil moisture: 25%
- Frequency bands: 100 MHz, 600 MHz, 1100 MHz, 1600 MHz, 2100 MHz, 2600 MHz, P-Band (260 MHz), L-Band (1.5 GHz)

- Sand: 40%, Clay: 20%, Temperature: 20 °C
Soil P-band Reflectivity

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

Specular reflection

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

$\Gamma$: 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**

“Nearly illiterate men rigged a radio in less than one minute”


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.”

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**

\[ R_{11}(\tau) = \langle x_1^*(t)x_1(t+\tau) \rangle \]

\[ = G_1G_{S,D}C_D \langle a^*(t-\tau_D)a(t-\tau_D+\tau) \rangle + G_1\sigma_1^2 \delta(\tau) \]

**Cross-correlation of channel 1 and 2**

\[ R_{12}(\tau) = \langle x_1^*(t)x_2(t+\tau) \rangle \]

\[ = \sqrt{G_1G_2G_{S,D}G_{E,R}C_D} \langle a^*(t-\tau_D)a(t-\tau_R+\tau) \rangle e^{j\omega(\tau_R-\tau_D)} \]

**Reflectivity:**

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

Reflectivity: 0.65, EIRP: 26 dB
RFI Impacts Estimate

- RFI in sky antenna (channel 1) adds to $R_{11}(0)$, which attenuates estimate by:
  $$\sim \left( \frac{1}{1 + ISR} \right)^2 \quad ISR = \frac{I_D}{C_D}$$

- 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:

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

Reflectivity: 0.65, EIRP: 26 dB
Spectrogram collected near Washington, D.C. shows desired persistent narrowband signals but with significant broadband transient interference.
Spectrogram showing desired persistent narrowband signals with no discernable RFI from undesired signals.
Spectrogram showing desired persistent narrowband signals with potential RFI in band 4.
Spectrogram showing desired narrowband signals with no discernable RFI from undesired signals.
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• Rural spectrum cleaner than Urban spectrum
• Urban spectrum possibly worst case because D.C. area
• Airborne spectrum example appears clean