Status of the Signals of Opportunity
Airborne Demonstrator (SoOp-AD)

Purdue University

Simulation, Retrieval Algorithms, Requirements Def.
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Scattering Model, Signal Processing

https://ntrs.nasa.gov/search.jsp?R=20160007684 2017-12-10T00:42:53+00:00Z
We plan to measure Root Zone Soil Moisture (RZSM) through cross-correlation of direct and reflected P-Band geosynchronous communication satellite signals.

**Expected Performance**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SoOp Airborne</th>
<th>SoOp Spaceborne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution*</td>
<td>100m</td>
<td>870m</td>
</tr>
<tr>
<td>Antenna Size</td>
<td>75 x 75 cm</td>
<td>75 x 75 cm</td>
</tr>
<tr>
<td>Sensing Depth</td>
<td>0-30cm</td>
<td>0-30cm</td>
</tr>
<tr>
<td>Sensing Precision**</td>
<td>0.04m³/m³</td>
<td>0.04m³/m³</td>
</tr>
</tbody>
</table>

*Specular Reflection Assumed

**SMAP Requirement**
SoOp-AD Solution

• SoOp-AD will use geostationary P-Band SATCOM systems
  – 225-420MHz allocation for government use, SoOp-AD will focus on 240-270MHz band: 18 x 25-kHz channels, 20 X 5-kHz 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.
Comparison to Conventional Methods

• 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 assimilation product

• 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 Project Highlights

• IIP Timeline
  – Awarded in April ’14.
  – System I&T at GSFC is underway.
  – 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
  – Digital System: FPGA based. 7TB Storage for raw and/or correlation data
  – Two aircraft racks: 12U Total

• Aircraft Campaign
  – 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.
Waterfall spectrum measured at GSFC over 11 days. Note persistence of SATCOM signals and broad-band RFI.
SoOp-AD System Architecture

Reflectometry:

\[
\Gamma_2 = \left( \frac{\tilde{Z}_{12}(\tau_{RD})}{\tilde{Z}_{11}(0) - G_1 \sigma_1^2} \right)^2 \frac{G_1}{G_2} \frac{G_{S,D}}{G_{E,R}}
\]
Spectrum from SoOp-AD

Raw Data Mode

ESTF June 14-16, 2016
“Auto” Example: \((V_{\text{Sky}}, V_{\text{Sky}^*})\)

Diagram:

```
    +--------+      +--------+      +--------+      +--------+      +--------+
   |        |      |        |      |        |      |        |      |        |
   | V_{Sky} |      | tau1   |      | tau2   |      | tau3   |      | tau4   |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      | tau1   |      | tau2   |      | tau3   |      | tau4   |
   |         |      |        |      |        |      |        |      |        |
   |         |      | tau1   |      | tau2   |      | tau3   |      | tau4   |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      | Corr_1 |      | Corr_2 |      | Corr_3 |      | Corr_4 |
   |         |      | (0 Lag)|      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
   |         |      |        |      |        |      |        |      |        |
```

Digital Complex Correlator
• Correlators have programmable 4 lags + 0
• 300-kHz noise detection bandwidth
• Test: 0, 1, 2 and 10 us (400 us not shown)
“Cross” Example: (V_Sky, V_Gnd*)

V_Sky

V_Gnd

* Negative Delay

* Negative Delay

6/15/2016

SoOp-AD (IIP-13-0076) Second Annual Review
SoOp-AD Cross-Correlator Verification

- AWG QPSK waveform into V&H inputs

0 delay

22 us delay

Cross Corr 3 (ev_eh) Delay 1 (1200 mS)

- Thru (1200 mS)
- Swap (1200 mS)
- Ref (300 mS)
- Noise (300 mS)

Cross Corr 3 (ev_eh) Delay 2

- Thru (1200 mS)
- Swap (1200 mS)
- Ref (300 mS)
- Noise (300 mS)
Technology Development: Antennas

• Antenna radome design for B200 aircraft
Technology Development: Antennas

P-band antenna design

Aperture coupled patch antenna element
Antenna System Considerations

- Direct-to-Reflect isolation is driving requirement – But not in orbit!
- Using two-element interferometer to synthesize a two-element array with null steering 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°
Technology Development: Antenna Radome

- Radome designed and fabricated.
- Test-fit Successful.
- Awaiting test flight
Next Steps

• Ground Testing
• Aircraft Safety Test
• Aircraft Campaign in Fall of 2016