Concept Design of a Multi-Band Shared Aperture Reflectarray/Reflector Antenna

IEEE Phased Array Systems & Technology Symposium

October 19, 2016

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This work was funded through the Instrument Incubator Program (IIP) through NASA’s Earth Science and Technology Office (ESTO)
Agenda

• Mission Objectives
• Radar Concept
• Subscale Antenna Verification
• Shared-Aperture Antenna Design Trades
• AESA Line Feeds & T/R Modules
• Summary
Science Motivations

- Clouds & precipitation are among the greatest sources of uncertainty in climate change prediction.

- Multi-frequency imaging Doppler radar is critical for improved climate understanding.

- Mission Motivation:
  - **ACE**: 2007 Decadal Survey Aerosol Cloud Ecosystem calls for a dual-frequency radar (Ka/W band)
  - **CaPPM**: Cloud and Precipitation Process Mission concept requires a tri-frequency radar (Ku/Ka/W)
Tri-Band Radar Concept for ACE & CaPPM

- **Ka-band AESA line feed**
- **Ku-band AESA line feed**
- **Reflector/Reflectarray**
- **Ku/Ka-band cross-scanning W-band fixed nadir & compatible with cross-scanning**

**Ka-band (35.5 GHz)**

**W-band (94 GHz)**

- **W-band RF Tx/Rx**
- **Ka-band AESA CTL**
- **RF Frequency Conversion**
- **RF LO**
- **IF**
- **Clock & Ref**
- **Tx Waveforms**
- **Waveform Generation**

**Ku-band (13.6 GHz)**

**IF LO**

- **I/O Interface**
- **SBC Processor**
- **Power Module**
- **Master Oscillator & LO Module**
- **Waveform Generation**
- **IF Frequency Conversion**
- **Digital Receiver & Processor**

**Radar Electronic Unit (REU)**

**Cross-Track Direction** (Scanning & Nadir Beams)

**Along-Track Direction** (Radar movement)
Science Objectives Are Closely Tied to the Antenna Design and Associated Trades

Various antenna parameters must be balanced to meet mission objectives...

<table>
<thead>
<tr>
<th>Radar Parameter</th>
<th>Antenna Parameter/Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Resolution</td>
<td>Aperture Size</td>
</tr>
<tr>
<td>Vertical Resolution</td>
<td>Tx Pulse Width</td>
</tr>
<tr>
<td>Field of Regard</td>
<td>Beam Steering</td>
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<tr>
<td>Polarimetry</td>
<td>Dual-Polarization</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Size, Radiated Power, Efficiency, Noise Figure</td>
</tr>
<tr>
<td>Data Diversity</td>
<td>Multi-Band Antenna</td>
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<tr>
<td>Doppler Vel. Accuracy</td>
<td>Aperture Size</td>
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<tr>
<th>Parameters</th>
<th>CaPPM</th>
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</thead>
<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>13.48</td>
</tr>
<tr>
<td>Orbit Altitude (km)</td>
<td></td>
</tr>
<tr>
<td>Transmitter</td>
<td>SSPA</td>
</tr>
<tr>
<td>Tx Peak Power (W)</td>
<td>2000</td>
</tr>
<tr>
<td>Antenna Size (m)</td>
<td>3.0x2.3</td>
</tr>
<tr>
<td>PRF (Hz)</td>
<td>4700</td>
</tr>
<tr>
<td>Vertical Res.(m)</td>
<td>250</td>
</tr>
<tr>
<td>Horizontal Res.(m)</td>
<td>5.0x4.0</td>
</tr>
<tr>
<td>Cross-track Swath (km)</td>
<td>250</td>
</tr>
<tr>
<td>Nadir MDZ (dBZ)</td>
<td>1.0</td>
</tr>
<tr>
<td>Swath MDZ (dBZ)</td>
<td>4.0</td>
</tr>
<tr>
<td>Doppler Vel. Accuracy (m/s)</td>
<td>1.0</td>
</tr>
<tr>
<td>Polarization Option</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Efficient Shared-Aperture Antenna Design

- Sharing the same primary reflector is the only practical tri-band solution
- Cassegrain optics with parabolic cylinder main reflector
- Beams:
  - Cross-track scanning enabled by AESA line feeds
  - Fixed nadir beam enabled by beam waveguide feed & reflectarray surface
A Subscale Antenna Validated the Efficient, Dual-Band Shared Aperture Concept

Subscale Antenna

Ka Line Array

Beam steering replicated by swapping among scanned, fixed beam feeds

35.5 GHz Scanned Pattern

94 GHz Pattern

Pattern are shown in the vicinity of the main beam
Demonstration of the Subscale Antenna During Flight Tests

94 GHz Radar Measurements

Sub-scale antenna in CRS canister in ER-2 tail cone

ER-2

W-Band Feed Horn

Feed Support Structure

Composite Reflector

Passive Ka-band Feed Array (includes azimuth manifold)
Tri-Frequency Antenna Trade Study

Rich Trade Space
Enables tailoring for particular frequency and/or requirements

<table>
<thead>
<tr>
<th>1A</th>
<th>1B</th>
<th>2A</th>
<th>2B</th>
<th>3A</th>
<th>3B</th>
<th>3C</th>
<th>3D</th>
<th>3E</th>
<th>3F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defocused Ku, Focused Ka, W on main.</td>
<td>Focused Ku, Focused Ka via RA on sub., W on RA on main.</td>
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<td>Focused Ku, Focused Ka via RA on sub., W on RA on main.</td>
<td>Separate RA for Ku/Ka &amp; W on both subs.</td>
</tr>
</tbody>
</table>

Trade Study Summary
- Assessed 10 candidate architectures (3 classes)
- Down selected primary candidates
- Evaluated & traded various AESA and T/R module design approaches (Ku, Ka, & W-band)
- Explored usage of reflectarrays for aperture sharing
- Down selected to 1B, 2B, 3B shown below

RA = reflectarray

Surface Types
Acts as solid reflector
Acts as a reflectarray/FEA

Feeds Reflector

W, Ka, Ku
Performance Example of a 7 m² Ka/W Shared Aperture Design

Ka-Band

One-Way Pattern

Two-Way Pattern Cut

W-Band

One-Way Pattern

Two-Way Pattern Cut
Ka Module Development & Component Testing Demonstrates Key Technology

- **Optimized for:**
  - High radar sensitivity
  - Very low DC power
  - Compact size

- **Fab & Test Completed:**
  - GaN HPA MMIC
  - LNA Switch MMIC
  - T/R MMIC
  - Integrated circulator
  - Gate/Control ASIC
Design Space Explored for Dual/Tri-Band AESA Line Feeds

• There are multiple approaches:
  1. Individual line feeds (Ku, Ka, W)
  2. Wide-band line feed (e.g., Ku-Ka)
  3. Interleaved line feeds (e.g., Ku/Ka)

• Trades: Efficiency, complexity, cost, packaging, TRL

• Displaced feeds from focal line cause pattern aberrations
  – Effects: Gain, beam pointing, side lobes

• Reflectarray surface can be used to correct a defocused feed
  – Can achieve co-aligned beam pointing

Example of Displaced Ku Feed

- 2.7" displacement from focal line
Overview of the Four Main Modes of Operation

1. **Module 1D Scanning Radar Puled Mode**
   - 1.65uS
   - 1.65uS
   - 0 to 80uS
   - 167 to 250uS
   - Switch Between Rx Co- & Cx-pol
   - Duty Cycle held at 1.56%

2. **Module Head Count Mode (Health Check)**
   - Antenna Beam Patterns
     - Rx Pattern – Individual Module
     - Tx Pattern – Individual Module
     - Rx Pattern – All Modules
     - Tx Pattern – All Modules

3. **Telemetry – Metadata Modes**
   - Temp, Current, Voltage
   - Phase and Amplitude Control Read-back
     - Serial phase shift and attenuator commands are read back to beam steering control unit

4. **Power Up/Down Modes**
   - Standby
     - TR Module powered up without TR pulsing
   - All OFF Power Down
     - “Zero” DC current draw

**Other Modes Under Consideration**
- Mutual Coupling Across Module Radiators
- Receive Noise Power Check at IF Receiver
Management of Tolerances & Errors is Critical to Maintain Low Sidelobes

• Low 2-way side lobes are critical to minimize effects of an earth ground return

• Primary AESA error contributions:
  – Component variability
  – Device resolution
  – Failures

• Leveraging range tuning & in-the-field techniques to maintain low side lobes
Summary

• Dual- & tri-band radar concepts were developed in support of the CaPPM & ACE missions

• Careful aperture sharing permits efficient tri-band operations
  – Proven reflectarray surface allows for efficient, co-alignment of beams

• Highly leveraged development work on the Ka T/R module

• Down selected to leading candidates within each of the three radar capabilities categories

• Developed multiple point designs that meet mission objectives
THE VALUE OF PERFORMANCE.

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