A Scalable Deployable High Gain Reflectarray Antenna - DaHGR

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MMA Design LLC
MMA Overview

• Facilities in Boulder County Colorado
  – 10,000 SF facility
  – Cleanroom / Flight Lab
  – R&D Lab
  – Machine Shop

• Business Areas
  – Solar Array Systems
  – Deployable Antennas
  – Deployable Apertures and Structures

• Products
  – HaWK High Performance Solar Arrays
  – DaHGR high gain compact antenna
  – CubeSat Systems
  – dragNET De-orbit Modules
Outline

• DaHGR Overview
• What is a Reflectarray?
• Reflectarray Advantages
• DaHGR Performance
• Frequency range and Bandwidth
• Mission Concepts
• DaHGR Heritage/Risk
• Conclusions
DaHGR Overview

- MMA Design has been developing the DaHGR system under IR&D – multiple patents pending
  - Our RF teams have heritage and world class expertise in reflectarray antennas
  - MMA has world class deployable structures technologies and expertise
  - Three DaHGR 1m to 3m antenna programs started in first quarter 2016
- DaHGR is a product that competes with a parabolic wire mesh reflector high gain antenna
  - Small stowed volume
  - Similar area mass with feed included
  - Fewer parts -1/3rd the parts
  - Lower cost -1/3 the cost
- Uses thin film reflectarray antenna and membrane technologies
  - High TRL
  - Leverages MMA’s TRL-9 membrane deployment experience
    - TRL-9 dragNET De-Orbit system and launch restraints
    - TRL-8 FalconSat-7 diffractive membrane deployment
    - Flight heritage standoff boom composite tapes
  - Multiple frequencies up to Ka-band
- Printed reflectarray technology reduces cost and enables >3m² apertures on CubeSats
Deployable High Gain Reflectarray Antenna P- DaHGR

- Deployment Structure Elements
- Stowage Volume 1.5U/m²
- Reflectarray Blanket Assembly
- Vehicle Mounted Feed
What is a Reflectarray?

- First described in the 1960’s
- 1990’s-2000’s inflatable reflectarrays for space

**Reflectarray**
- Collimation over narrow bandwidth (limited by electrical size, radiator properties, number of layers)
- Single or multiple flat surfaces conducive to small stowed volume

**Parabolic Reflector**
- Collimation over infinite bandwidth (limited by surface roughness)
- Precise parabolic profile requires many physical control features limiting stowed volume/size

Reflectarrays support any polarization and high power

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Thin Membrane Reflectarray

Advantages

• Cost
  – Less complex mechanical deployment system
  – Lower parts count
  – Less touch labor to assemble

• Small stowed size
  – 1 m diameter aperture in a 0.1m X 0.1m X 0.12m (1U) volume

• Meeting RMS tolerances with flat membrane surfaces is inherently less difficult than mesh/parabola systems
  – Increasing tension improves surface RMS
  – RMS vs Membrane thickness and tension
• Areal Compaction: approximately \{0.5 to 1.0\} m²/L
• Mass Density: \{1.5 to 1.0\} kg/m² @10m² to \{1.6 to 1.0\} kg/m² @0.78m²
• First mode >1 Hz
• Low CTE structure
• On orbit adjustable feed to reflectarray geometry
Frequency Range and Bandwidth for Small Sats

- Aperture sizes in development span 0.8 m to 5 m diameter
- Lower frequency limited by electrical size conducive to spatial feeding with minimal spillover losses (≈D/λ > 10)
  - D=5m, λ=0.5m, lowest frequency is 0.6 GHz
  - At smaller electrical size, the deployment methods described support constrained feed antenna architectures.
- Highest frequency is limited by features controlling deployed flatness and allowance for Gain and sidelobe degradation
- Reflectarrays are inherently bandwidth limited
Ruze’s Equation for Reflectors

• Active area of research driven primarily by material thickness (membranes and metal).
• Current photogrammetry inspections of surfaces showing better than 35 mil rms.
• Near term work will quantify performance at X-band; we expect Ka band applications to be viable

<0.3 dB @ X-band
< 25 mil RMS

• Initial lab membranes inspected with photogrammetry
Folding Test Setup
Far Field Patterns: Frequency 9.6 GHz
Photogrammetry

- Photogrammetry Results:
  - Unfolded: 0.0323” RMS (Good)
  - Folded: 0.0345” RMS (Good)
  - Crinkled: 0.0492” RMS (Marginal, but acceptable)
Histograms of Flatness

Undisturbed, RMS = 0.0323"

Folded, RMS = 0.0345"

Crinkled, RMS = 0.0492"

Deviation from Ideal Plane (inches)

Deviation from Mean (inches)
# Test Summary

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Test Article</th>
<th>rms (mils)</th>
<th>Directivity (dBi)</th>
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<tr>
<td>Config 01</td>
<td>TA1</td>
<td>32</td>
<td>33.93</td>
</tr>
<tr>
<td>Config 06</td>
<td>TA1</td>
<td>35</td>
<td>33.76</td>
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<tr>
<td>Config 07</td>
<td>TA1</td>
<td>49</td>
<td>33.44</td>
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<tr>
<td>Config 02</td>
<td>TA2</td>
<td>Not measured</td>
<td>33.98</td>
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<tr>
<td>Config 05</td>
<td>TA2</td>
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<td>33.97</td>
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<tr>
<td>Config 08</td>
<td>TA2</td>
<td>Not measured</td>
<td>33.99</td>
</tr>
</tbody>
</table>

- **Low Gain loss**
- **Excellent Repeatability**
Reflectarray Surface Error Loss Budget

<table>
<thead>
<tr>
<th>Reflectarray Losses</th>
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<tbody>
<tr>
<td>Surface dissipative</td>
<td>0.1 dB</td>
<td>full wave analysis with material parameters</td>
</tr>
<tr>
<td>Surface flatness</td>
<td>0.28 dB</td>
<td>Ruze's equation for reflectors. 25 mil rms flatness derived from experiment.</td>
</tr>
<tr>
<td>Folding (Area Loss)</td>
<td>0.20 dB</td>
<td>56 folds, lam/20 peak distortion, 0.25 inch width</td>
</tr>
<tr>
<td>Seams</td>
<td>0 dB</td>
<td>assumed negligible, test coupon planned soon to confirm</td>
</tr>
<tr>
<td>Element phase</td>
<td>0.07 dB</td>
<td>variations due to phase resolution chosen in artwork plus variations due to etch and element to ground plane spacing: total is rms of these three values. Ruze's equation for phased arrays.</td>
</tr>
<tr>
<td>total</td>
<td>0.7 dB</td>
<td></td>
</tr>
</tbody>
</table>

Folding loss estimate consistent with measurement.
Path length variation \((R_n)\) drives bandwidth of the system.
1.0 dB Bandwidth (DaHGR)

Single Facet

Two Facet

Reflectarray Bandwidth

f/D

Reflectarray Bandwidth

f/D

% BW

D/λ

% BW

D/λ

0.5

1

1.5

2

0.5

1

1.5

2

<5% BW

~15% BW

>15% BW

e.g. 4m @ X-band is D/λ=133
Mission Concepts

SAR/SATCOM

SAR with STAP
Aspect Ratios (H/W)>2 supported

Over the Horizon Comms

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DaHGR Heritage/Risk

- Combine two high TRL (9 and 7) to produce a high gain and cost effective antenna
- The deployment system is based on the 14m² Flight heritage dragNet de-orbit system
- Deployable thin film Ka and X band reflectarrays have been built and tested by NASA and its contractors
  - They used inflatables to deploy the array
  - The mechanical system in DaHGR is more robust
Conclusion

• Compared to conventional parabolic antennas-DaHGR is:
  – 1/3 the cost
  – 1/5th the volume
  – 1/3 the parts

• Reflectarrays enable new/expanded missions for SmallSats:
  – Expanded GEO communications
    • 2-4x RF aperture
    • Expanded “real estate” for secondary payloads
  – Enable High resolution SmallSat SAR/SIGINT missions and high capacity communications platforms
  – Launch on ESPA, Minotaur, Pegasus, Taurus, Alasa, etc.

• System TRL-9 expected in next 18-24 months on a CubeSat or other mission