Development of Low-profile Antennas for CubeSats

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Outline

- Background
- Approaches
  - Transparent Antenna Designs (2.4 GHz)
  - Non-transparent Designs (434 MHz)
- Results
- Conclusions and Future Work
Current small satellites use commercially available monopole (whip) antennas.

A lot of emphasis on miniaturization and power consumption, less focused on antennas.

Replace monopoles with low profile antennas based on microstrip technology.

434 MHz and 2.4 GHz are targeted center frequencies.
Approaches

- Design transparent antennas to go on *top* of the solar panels on the CubeSat (for the higher frequency bands).

- Design non-transparent antennas that will cover the face of the CubeSat and go *below* the solar panels on the CubeSat (for the 434 MHz band).
Preliminary Transparent Designs

- Meshed design
  - Rectangular Grid
  - Silver epoxy conductor
  - Quartz substrate
    - 2.25 mm thickness
    - $\varepsilon_r = 3.9$
Preliminary Transparent Designs

- **ITO Patch Antenna**
  - Indium Tin Oxide (ITO) is a transparent metal.
  - It can be deposited onto glass or quartz substrates.
Preliminary Transparent Designs

- **Slatted-Ring Resonator Antenna**
  - Uses open space inside rectangular ring to achieve transparency.
  - Metal strips are added to control the center frequency.
  - RO4533
  - $\varepsilon_r = 3.3$
  - 8.3 x 19.5 cm
Preliminary Results: Comments

- Meshed antenna: Good transparency, good impedance match, reasonable efficiency, slightly offset $f_0$.
  - Recommendation: Pursue for further designs.

- ITO antenna: Good transparency for thin films, more difficult to match, lower efficiency.
  - Recommendation: ITO designs have a lower efficiency for the same level of transparency; we therefore prefer to use meshed designs.

- Slatted Ring Resonator: Has a low transparency.
  - Recommendation: Not ideal as a transparent antenna.
Study of Mesh Antenna Surface Impedance

- Analyze $Q$ factor of patch cavity.
- Include only conductor loss in the model.
- Use a cavity model that has PEC on bottom and PMC on the sides.

$$Q = \left( \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sp}} + \frac{1}{Q_{sw}} \right)^{-1}$$

$$Q = Q_c = \left( \frac{\eta_0}{2} \right) \mu_r \left[ \frac{k_0 h}{R_s / 2} \right]$$

Extract the surface impedance $R_s$ from $Q_c$. 
Study of Mesh Antenna Surface Impedance

2.4 GHz

<table>
<thead>
<tr>
<th>Metal</th>
<th>Surface Resistance [$\Omega$/sq.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid copper</td>
<td>0.0127</td>
</tr>
<tr>
<td>Silver mesh</td>
<td>0.0513</td>
</tr>
</tbody>
</table>

Note: The silver mesh design has a transparency of 85%.

**Conclusion:** The surface resistance increases by roughly a factor of 4, but it is still low enough to make a good antenna:

- Solid copper patch: $e_r = 85\%$
- Silver mesh patch: $e_r = 80\%$
2.45 GHz LP Meshed Design

E-plane

H-plane
2.45 GHz LP Meshed Design

E-plane

H-plane
Improved Designs

- 2.4 GHz
- Linear and Circular Polarization
2.4 GHz LP Results

-20 dB at 2.4 GHz

$S_{11}$ vs. frequency

42.8 + j2.4 Ω

Impedance vs. frequency
2.4 GHz CP Results

Axial Ratio = 2

(should be possible to improve by adjusting feed network)
434 MHz Design

- Try a different approach than transparency.
- Make antenna large enough to cover most of the entire CubeSat face.
- The solar panels go on top of the antenna (the antenna is not transparent).
- Use a variation of a PIFA variation to miniaturize in the resonant dimension.
- Use a C-notch for improvement of bandwidth.
- RO6002
  - $\varepsilon_r = 2.94$.
  - $h = 120$ mils (thicker substrate used for BW).
- Final dimensions: 7.1 x 29 cm
$S_{11}$ at 434 MHz: -47 dB
Impedance: $52.12 + j8.82 \, \Omega$
434 MHz Design
434 MHz Design

Fabricated Antennas
ITO Design

- ITO is lossy: the film must be thin to maintain transparency.
- A 50 nm film has a 85% transparency.
- The skin depth is about 16.8 um at 2.4 GHz (the film thickness is therefore much less than skin depth).
- The sheet resistance of a 50 nm film is 50 Ω/sq.
- The sheet resistance is too high to obtain good impedance results (see next two slides).
ITO Results

- Input impedance results (HFSS) were obtained by using a patch with a hypothetical sheet resistance ranging from 1 to 10 Ω.
ITO Results

Results: (2.3 GHz)

- 1 Ω sheet impedance
- 5 Ω sheet impedance
- 10 Ω sheet impedance

![Graphs showing impedance vs. frequency for 1 Ω, 5 Ω, and 10 Ω sheet impedances at 2.3 GHz.](image-url)
Meshed designs are better than ITO designs for making transparent antennas (higher efficiency for the same transparency).

Linearly-polarized meshed designs successfully designed and fabricated at 2.4 GHz.

Circularly-polarized meshed designs successfully designed at 2.4 GHz, awaiting fabrication.

Non-transparent 434 MHz antenna successfully designed and fabricated, awaiting testing.
Future Work

- NASA testing (electrical, thermal, vibration) for 434 MHz antenna.
- NASA testing for 2.4 GHz LP antenna.
- Fabricate and testing of 2.4 GHz CP antenna.
- Explore dual-band possibilities and other frequency bands (e.g., GPS).
Thank You!

[Logo: smallSATELLITE AIAA/Utah State University]