Recent Developments in Small Satellite Antenna Technology

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Outline

- Demand for CubeSat Antennas
- The CubeSat Antenna Design Challenge
- Types of CubeSat Antenna
- Low Gain / Proximity Antennas
- High Gain Antennas
  - Reflectors
  - Reflectarrays
  - Slot Arrays
  - Antenna / Solar Array Integration
  - Membrane Antennas
- Conclusion

Demand for CubeSat Antennas

- CubeSats are complex instruments!
  - Telecom, Imaging, Radar, Radiometer, etc.
- Key telecom requirements
  - High speed data downlink
    - Driven by imaging, high resolution instruments, etc.
    - Deep space exploration
  - Proximity communications links
    - Layered comm links, constellations, formation flyers

High Speed Telecom *Demands*

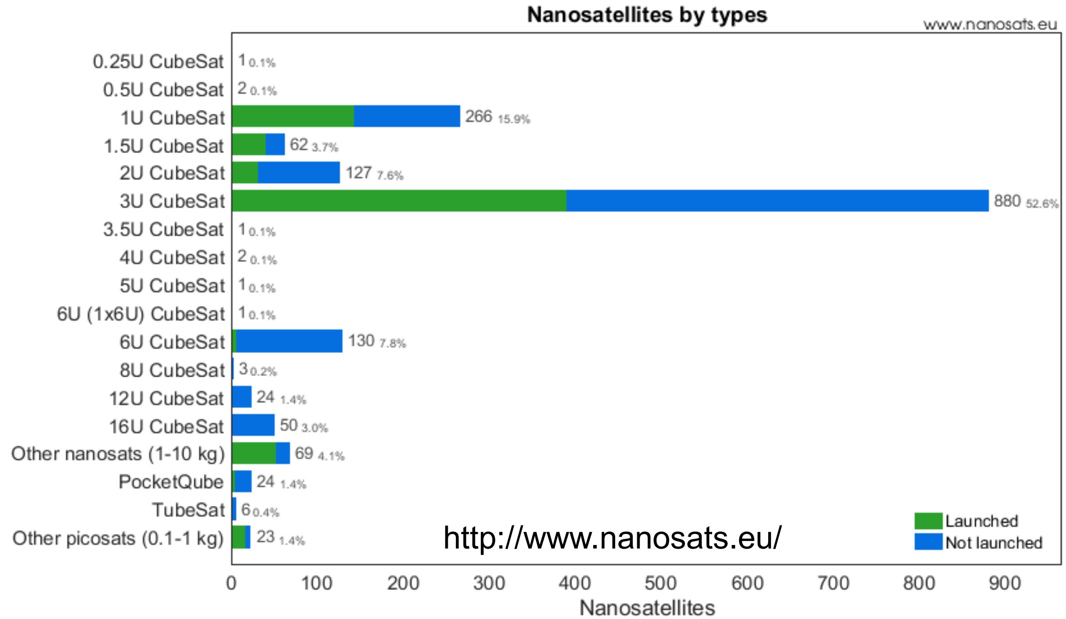
- HIGH POWER RF
  - Limited by solar cell area
  - Creates thermal issues
  - Compete with payload for power!
- HIGH GAIN ANTENNA
  - Requires large antenna aperture
  - Must be deployable
  - Competes with payload for stowage volume

CubeSat Antenna Design Challenge

- Stowage Volume → **Deployable!**
  - Stowage efficiency
  - Surface accuracy
  - Antenna efficiency
  - Development time
  - Cost
- Mass
- Cost
- Adaptable
  - Rapid Development
  - Multiple bus / payload
  - Custom beam pointing
- Environmental

Antenna Stowage Volume

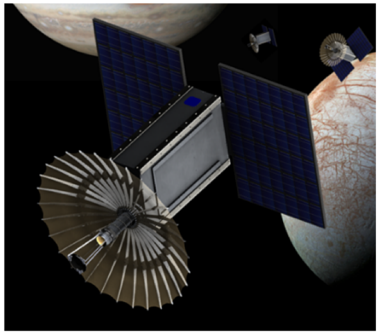
- Most CubeSats are 3U
  - Trend is to bigger…
- Limited space for subsystems
  - Payload
  - Avionics
  - Power
  - Attitude control
  - Telecom
  - GPS
  - Propulsion



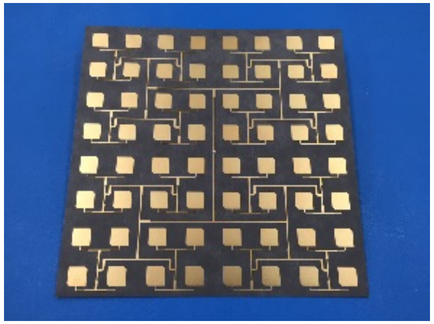
http://www.nanosats.eu/

No room left for antenna!

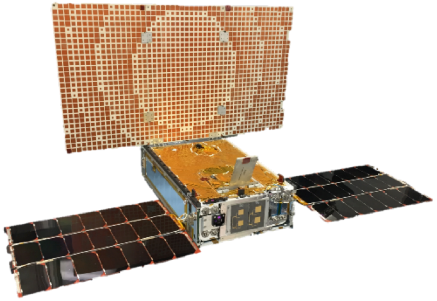
Types of CubeSat Antennas



Reflector Antennas

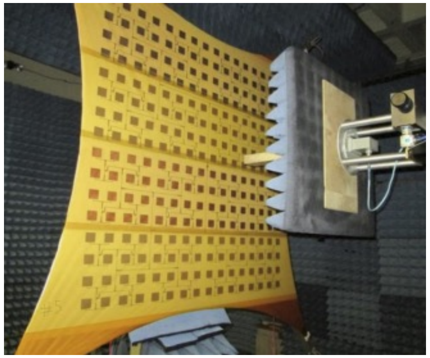


Planar PCB Antennas



Reflectarray Antennas

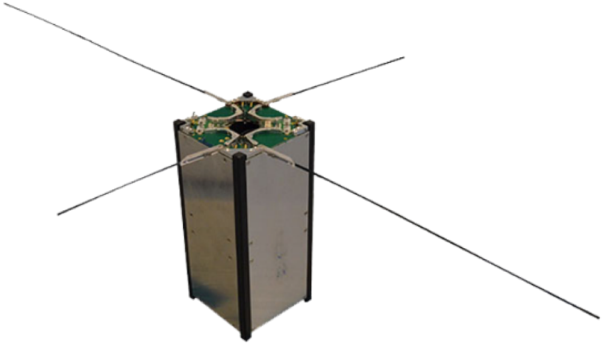
CubeSat Antenna Designs



Membrane Antennas

Warren, et.al. Proc. 29th AIAA Conf. Small Sat, 2015

Horn and Slot Antennas



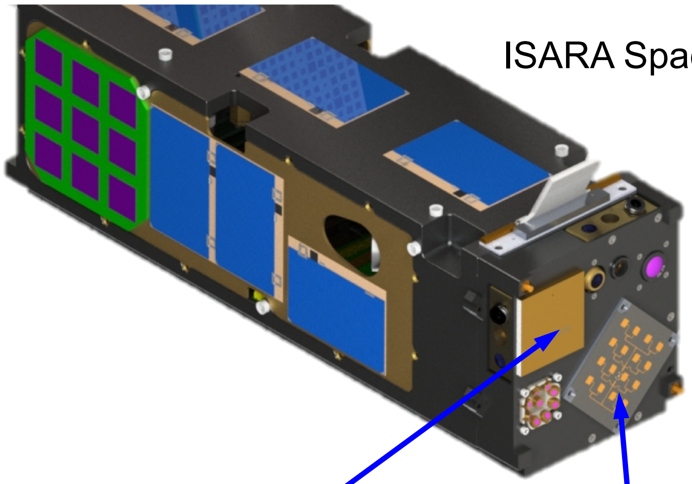
Wire Antennas

www.cubesatshop.com/product/dipole-antenna-system/

Low Gain Proximity Antennas

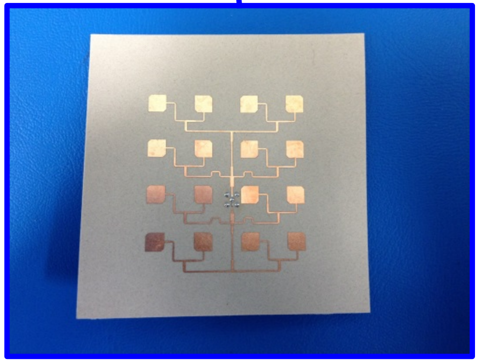
Current State-of-the-Art

- Antenna types
  - Wire antenna
  - Patch antennas
  - Small horns or slots
- Even low gain may require deployment



ISARA Spacecraft

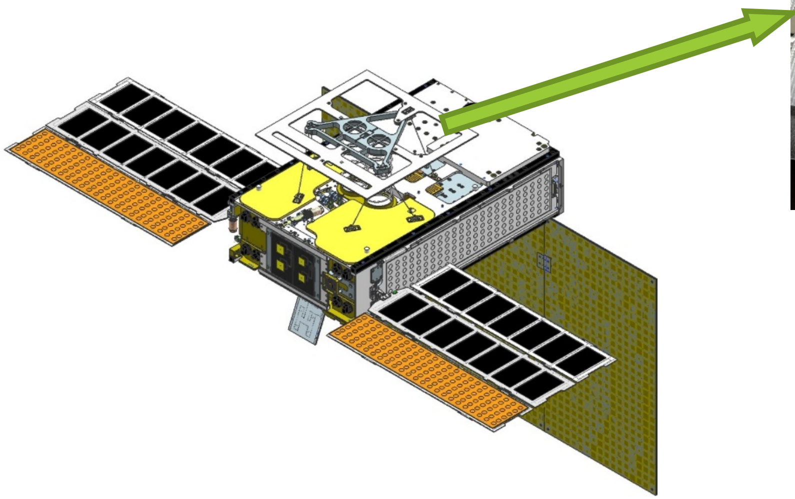
UHF Telecom Patch Antenna
Aerospace Corp.

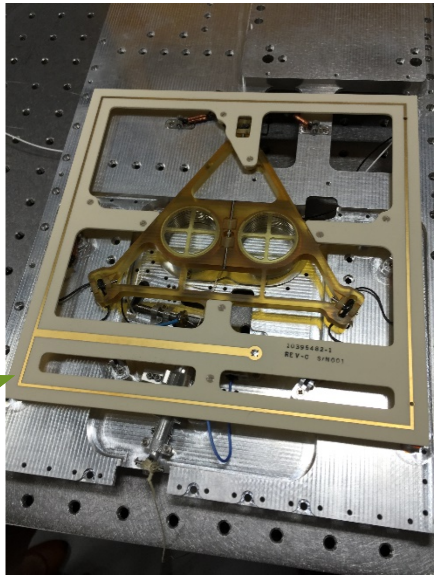


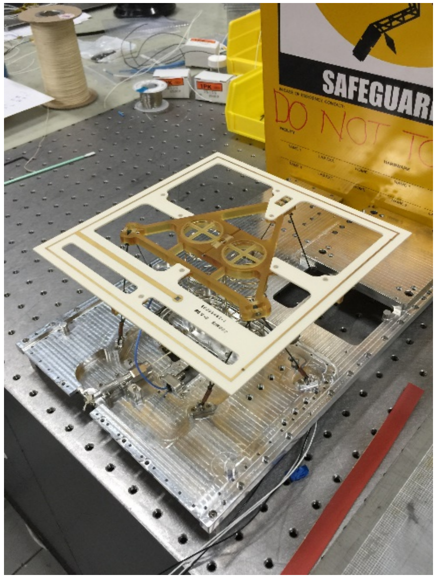
Medium Gain Antenna
M. Radway, JPL

UHF Loop Antenna

- Example from MarCO
  - Required: circular pol UHF + unique coverage
  - 3U bus – no room!
  - Fits between s/c and launch rails







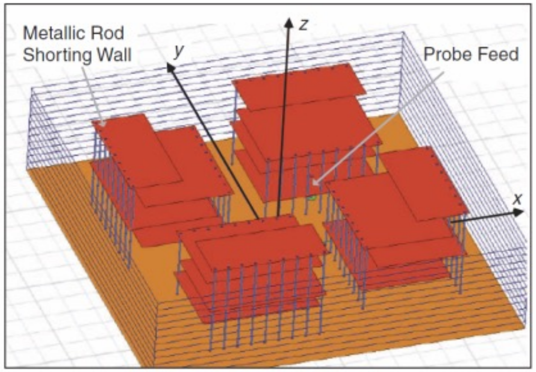
Stowed *Deployed*

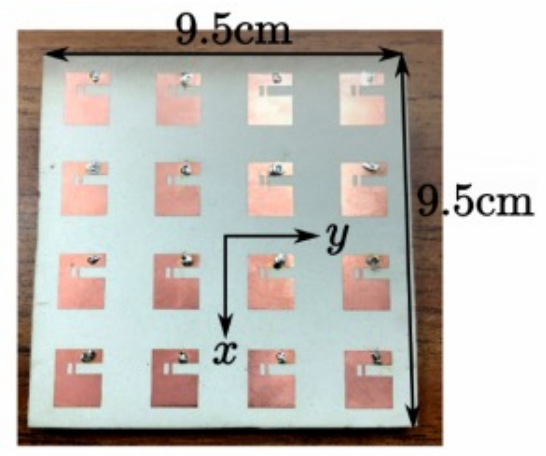
E. Decrossas, Jet Propulsion Laboratory

Low Gain Proximity Antennas

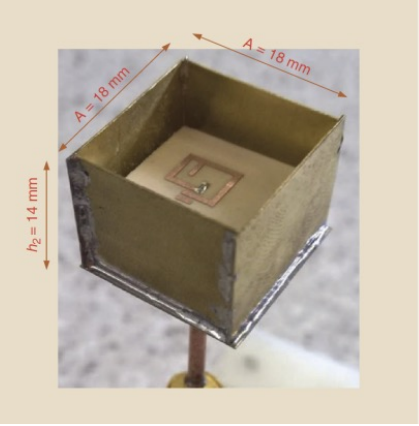
Next Generation

- Exotic Radiators
  - Half E-shape patch
  - Folded Shorted Patch
  - Monofilar Square Spiral

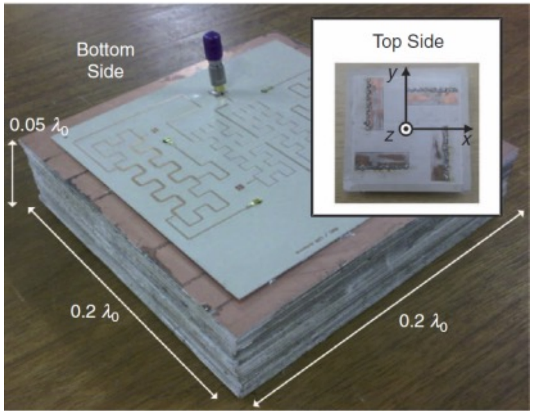




Half E-Patch
J. Kovitz, et. al., IEEE-APS
Aug. 2015

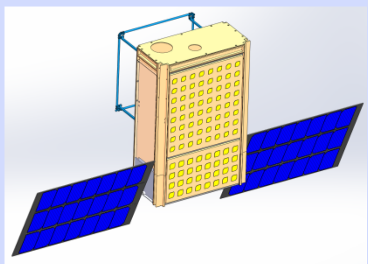
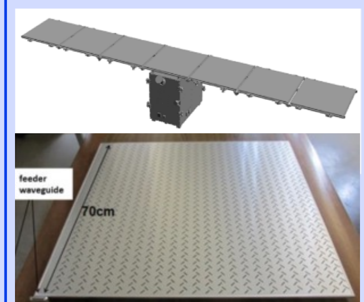
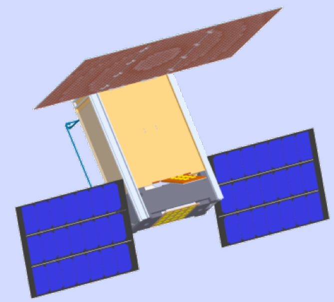
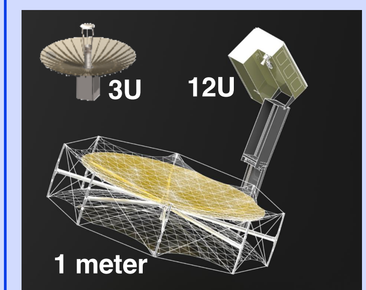


Monofilar Square Spiral
Q. Luo, et. al., IEEE-APS Mag.
April 2017



Folded Shorted Patch
S. Podilchak, et. al., IEEE-APS Mag.
April 2017

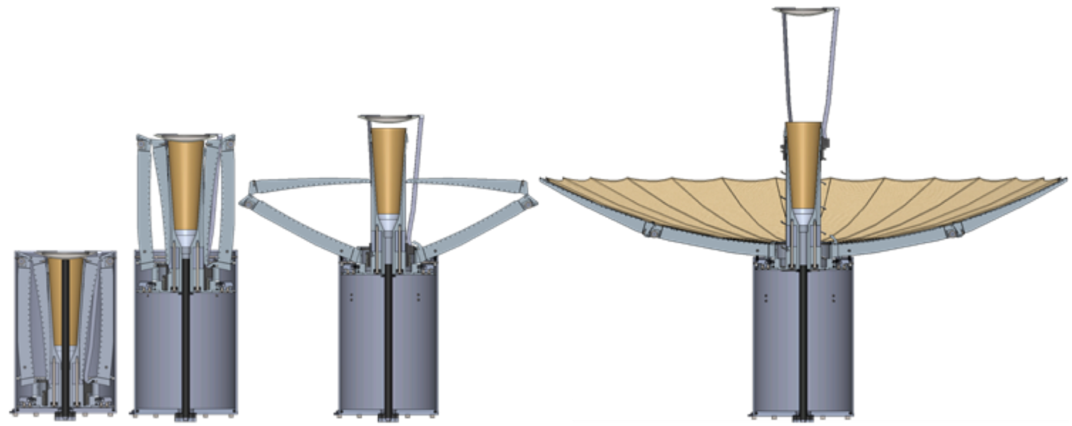
High TRL SmallSat HGA Technologies

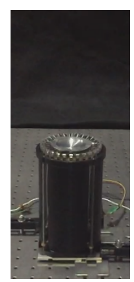
	Single Layer Patch Array	Parallel Plate Slot Array	Folded Panel Reflectarray	Mesh Reflector
				
Size Scalability	Limited by feed loss	Limited by feed loss, stowage, mass	Limited by number of panels that can stow.	Excellent
Bandwidth	< 3% typical	Narrow < 3%	< 3% typical	Large (feed limit)
	10% is possible		10% is possible	
Sidelobes	Controllable	Medium	Low	Medium
Stowage efficiency	Medium-High	Medium	Excellent	Poor-medium
Deploy Complexity	Panel interconnects	Panel interconnects	Simple spring hinge	Complex mechanism
Deploy Reliability	No issue	Medium / High (TBC)	High	Medium / High (TBC)
Cost	Low	Medium (TBC)	Low	Medium (TBC)
Technology Readiness Level	9 (single panel)	4-5 (est)	9	6+ (50 cm KaPDA)
	4 (multi-panel deploy)			4 (1.0 m KaTENna)

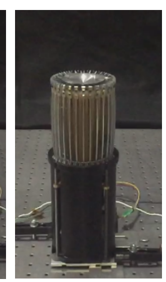
Reflector Antennas

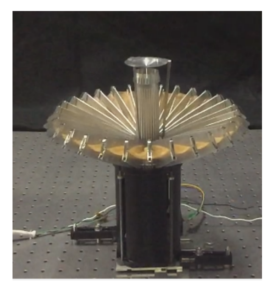
Current Flight Antenna

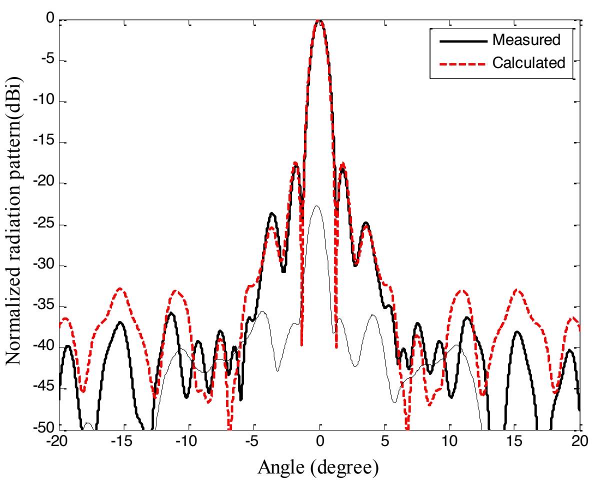
- KaPDA/RainCube
  - 50 cm diameter
  - Stows in 1.5 U
  - Ka-Band (32/36 GHz)
  - 42.6 dB Gain
  - *Scheduled for launch!*









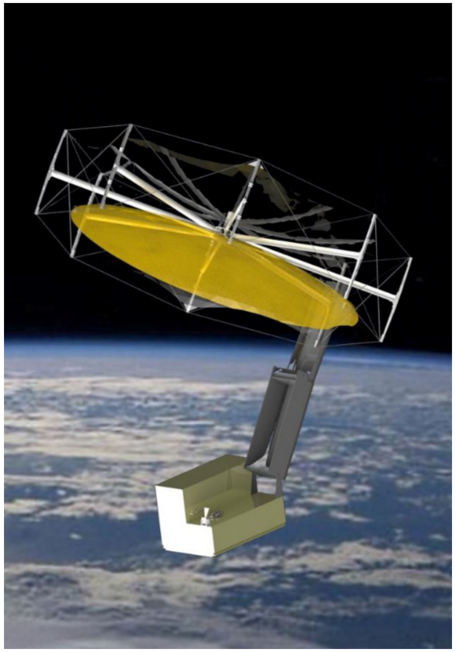


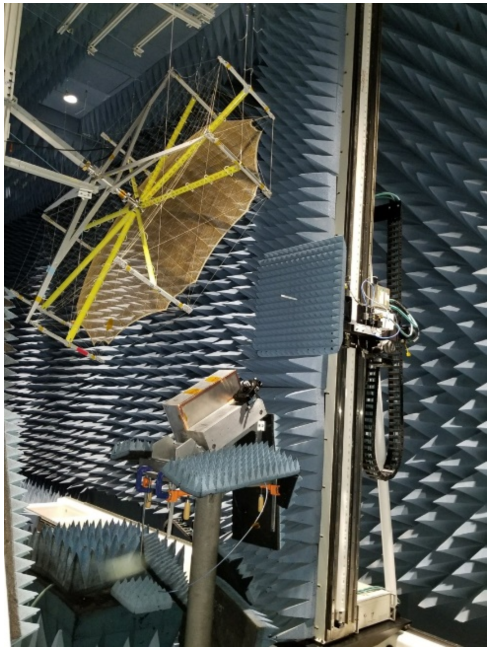
N. Chahat, R. Hodges, J. Sauder, M. Thomson, Y. Rahmat-Samii, IEEE-APS Trans. June 2016

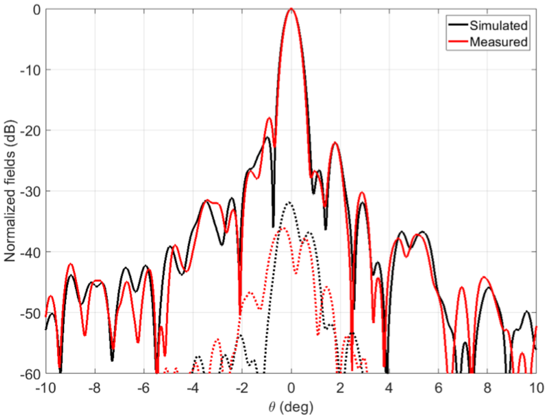
Reflector Antennas

Current State-of-the-Art

- RainCube ACT
  - 1.0m diameter
    - Can scale to >2m
  - Stows in 3U
  - Ka-Band (or lower)
  - 49.2 dB Gain
  - 60% efficiency
  - Fully offset reflector
  - Telecom & Radar







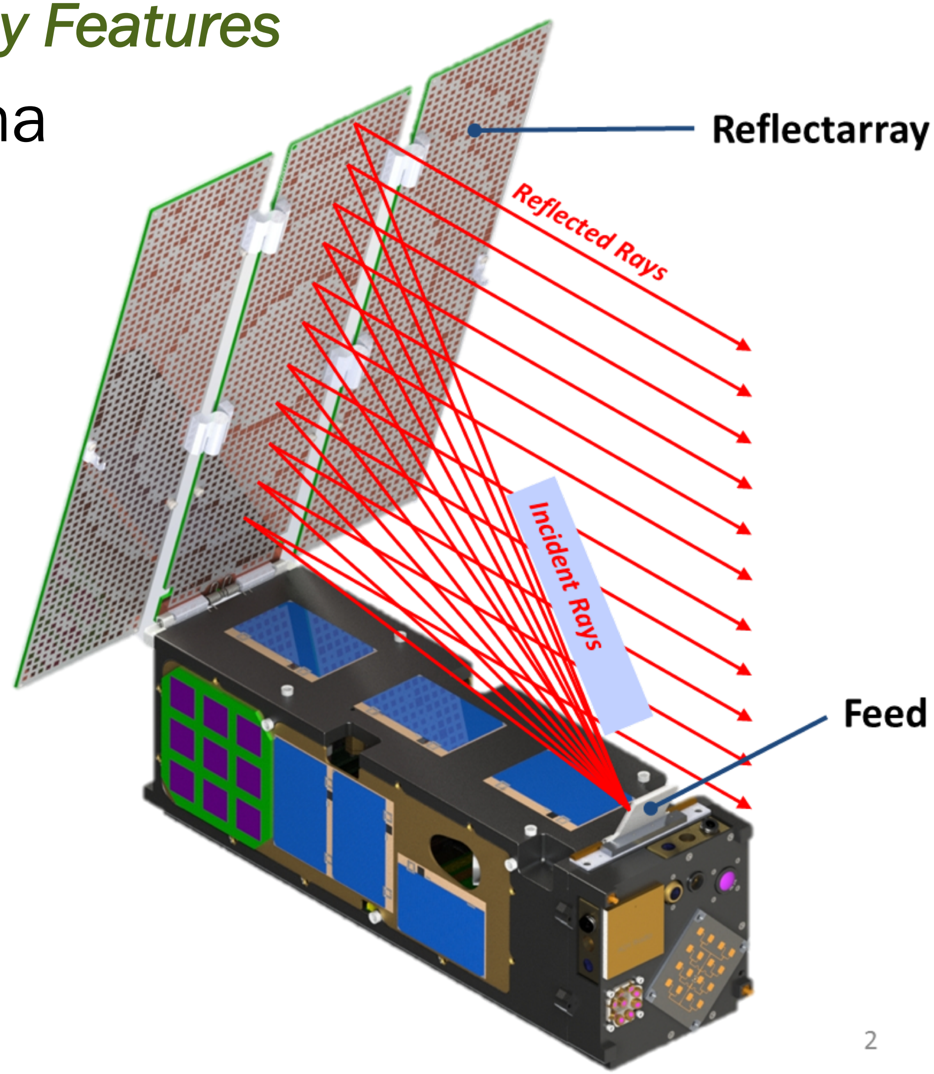
Y. Rahmat-Samii, E. Peral, R. Hodges, G. Freebury, “Ka-band Highly Constrained Deployable Antenna For Raincube: Engineering Development and Pattern Measurements”, IEEE-APS Symp. 2018.

Reflectarrays

Key Features

- Flat PCB Reflector Antenna
  - Low Cost
  - Low Mass
  - Small Stowage Volume

- Easily Tailored to Meet Unique Mission Needs
  - Custom beam shapes
  - Specify beam pointing direction
  - Rapid Development

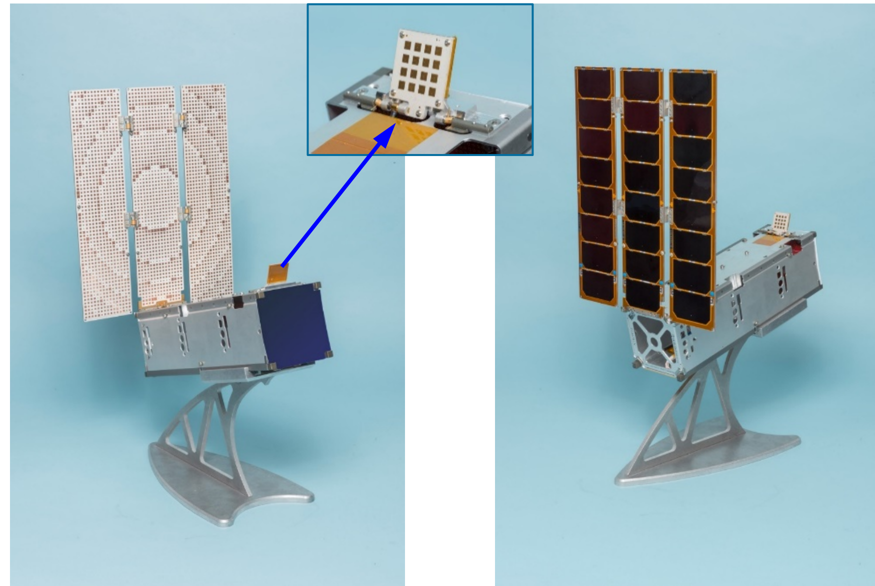


R. E. Hodges, et. al, "ISARA – Integrated Solar Array and Reflectarray Antenna CubeSat Deployable Ka-band Antenna," IEEE-APS Symp, July 2015.

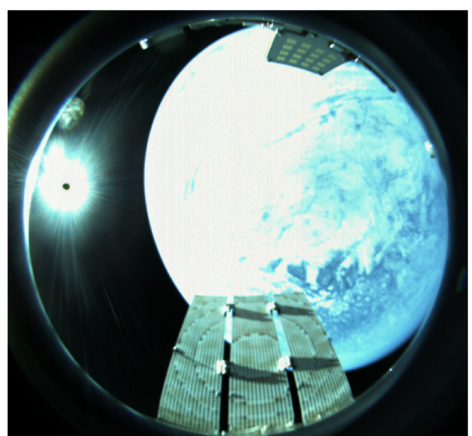
ISARA

Integrated Solar Array and Reflectarray Antenna

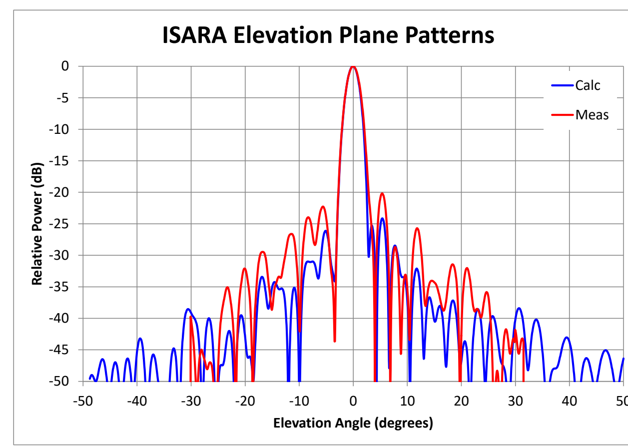
- Ka-Band (26 GHz)
- 33.5 dB Gain
- ISARA Technology Firsts
  - ✓ First reflectarray antenna flown in space
  - ✓ First high gain antenna integrated with solar panels
  - ✓ First calibrated antenna gain meas performed from space
  - ✓ First 100 Mbps CubeSat telecom capability



R. Hodges, et. al., IEEE-APS Symp. July 2015



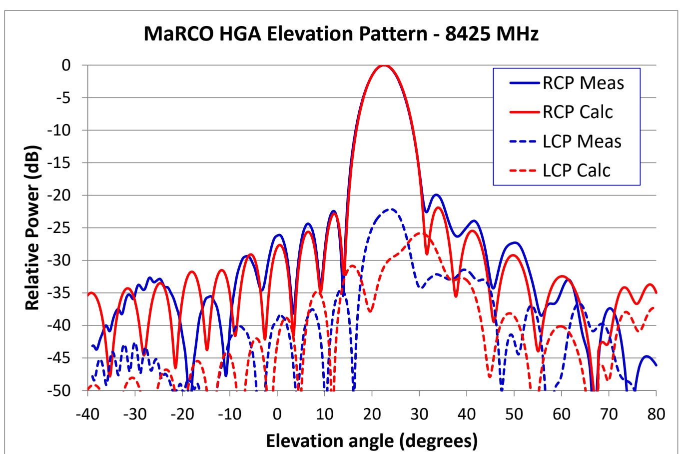
ISARA Reflectarray Deployed on Orbit

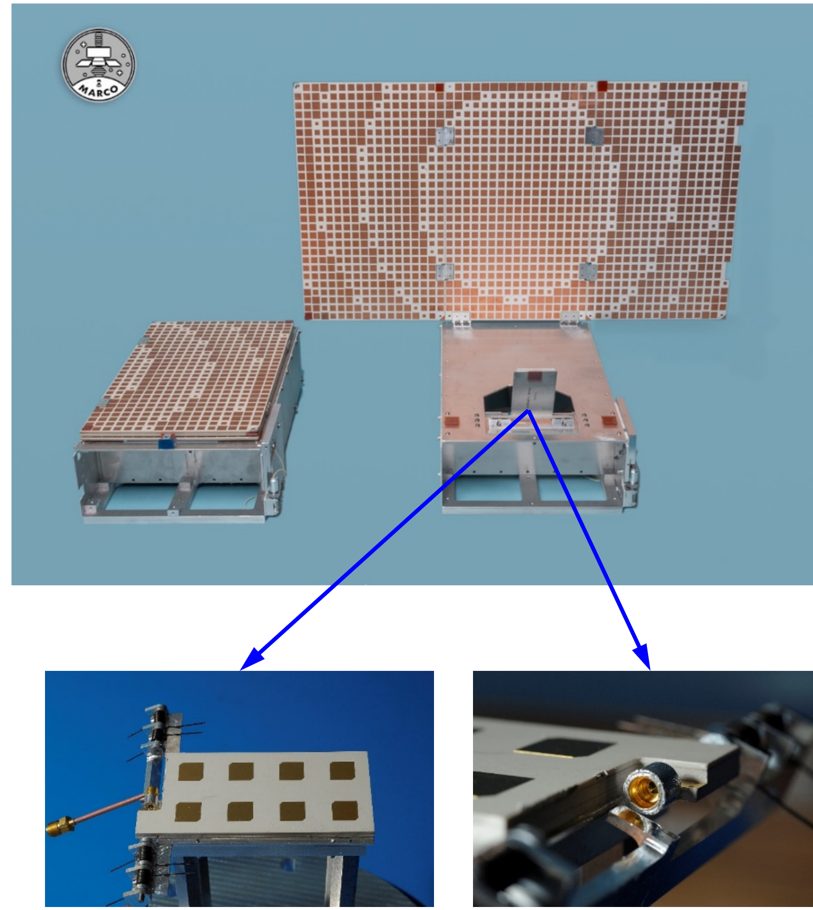


Reflectarray Antenna

Current State-of-the-Art

- MarCO
  - *Mars Launch: May 2018*
  - 59.7 cm x 33.5 cm
  - 70% stows between rails
    - Uses ~4% of payload volume
  - X-Band (8.425 GHz)
  - 29.2 dB Gain

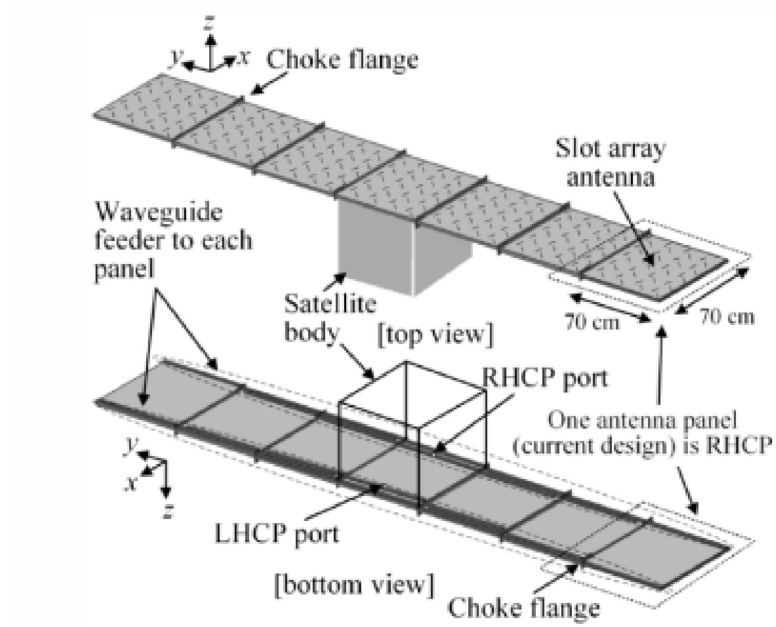


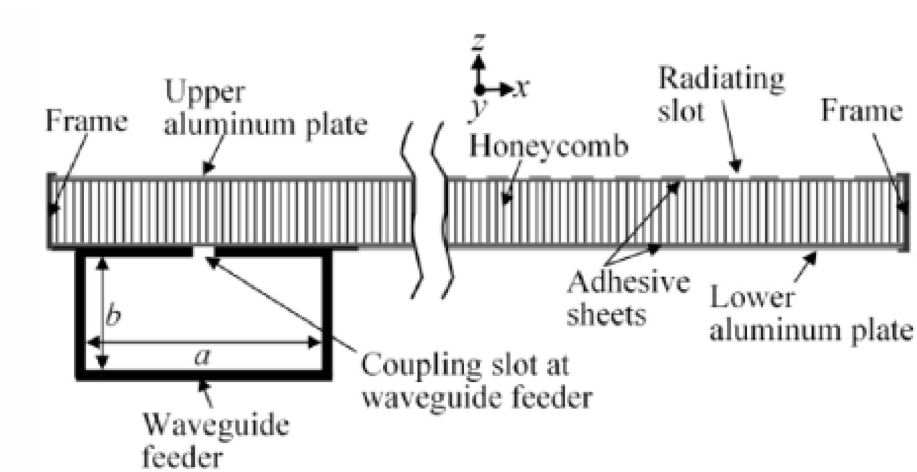


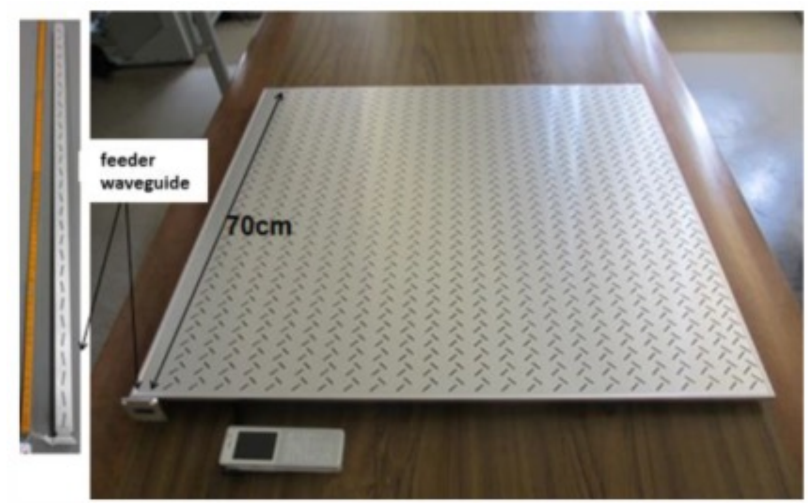
R. Hodges, et. al., IEEE-APS Mag.
April 2017

Parallel Plate Slot Array

- X-Band SAR Antenna
  - 100kg class satellite
  - Low mass
  - Good efficiency (~55%)
  - Can mount solar array on back side of panels





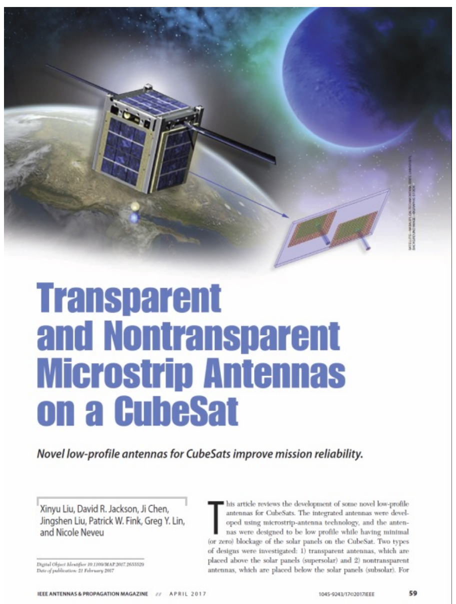


Akbar, et.al. "Parallel-Plate Slot Array Antenna for Deployable SAR Antenna Onboard Small Satellite," IEEE-APS Trans. May 2016

Integrated Solar Array Antennas

Next Generation

- Transparent Reflectarray
- Integrated Antennas
  - Slots between solar panels
  - Transparent Patch



Transparent and Nontransparent Microstrip Antennas on a CubeSat

Novel low-profile antennas for CubeSats improve mission reliability.

Xinyu Liu, David R. Jackson, Ji Chen, Jingshen Liu, Patrick W. Fink, Greg Y. Lin, and Nicole Neveu

Digital Object Identifier 10.1109/MAP.2017.2655529
Date of publication: 21 February 2017

This article reviews the development of some novel low-profile antennas for CubeSats. The integrated antennas were developed using microstrip-antenna technology, and the antennas were designed to be low profile while having minimal (or zero) blockage of the solar panels on the CubeSat. Two types of designs were investigated: 1) transparent antennas, which are placed above the solar panels (supersolar) and 2) nontransparent antennas, which are placed below the solar panels (subsolar). For

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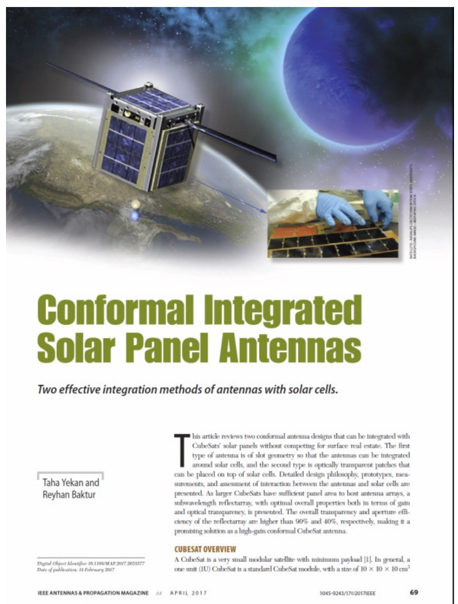

Conformal Integrated Solar Panel Antennas

Two effective integration methods of antennas with solar cells.

Taha Yekan and Reyhan Baktur

Digital Object Identifier 10.1109/MAP.2017.2655577
Date of publication: 14 February 2017

This article reviews two conformal antenna designs that can be integrated with CubeSats' solar panels without competing for surface real estate. The first type of antenna is of slot geometry so that the antennas can be integrated around solar cells, and the second type is optically transparent patches that can be placed on top of solar cells. Detailed design philosophy, prototypes, measurements, and assessment of interaction between the antennas and solar cells are presented. As larger CubeSats have sufficient panel area to host antenna arrays, a subwavelength reflectarray, with optimal overall properties both in terms of gain and optical transparency, is presented. The overall transparency and aperture efficiency of the reflectarray are higher than 90% and 40%, respectively, making it a promising solution as a high-gain conformal CubeSat antenna.

CUBESAT OVERVIEW

A CubeSat is a very small modular satellite with minimum payload [1]. In general, a one unit (1U) CubeSat is a standard CubeSat module, with a size of $10 \times 10 \times 10$ cm^3

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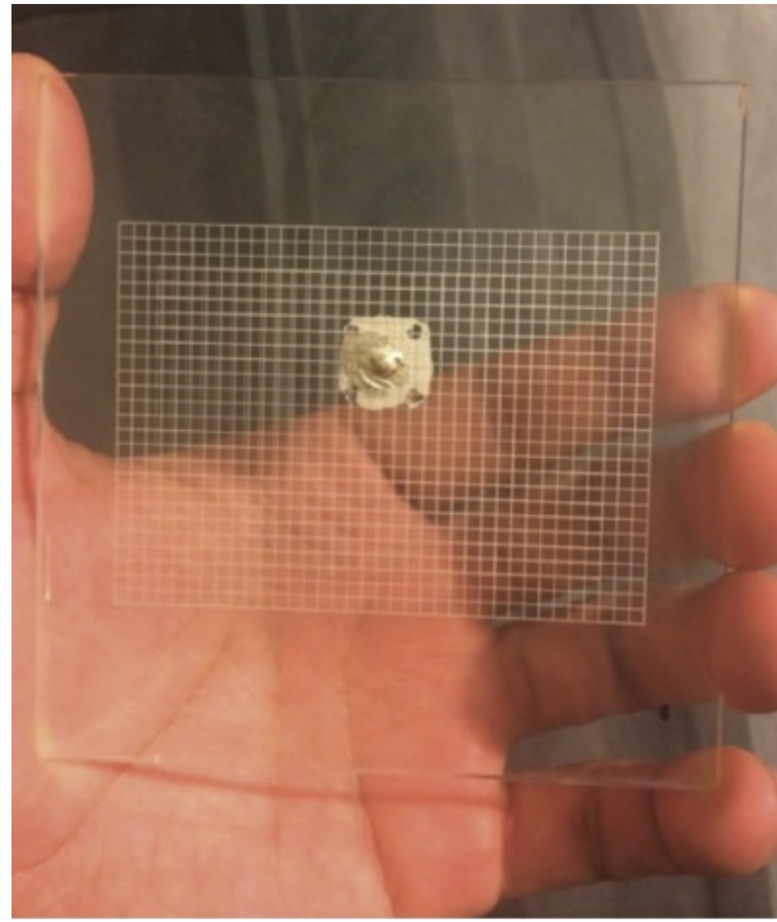
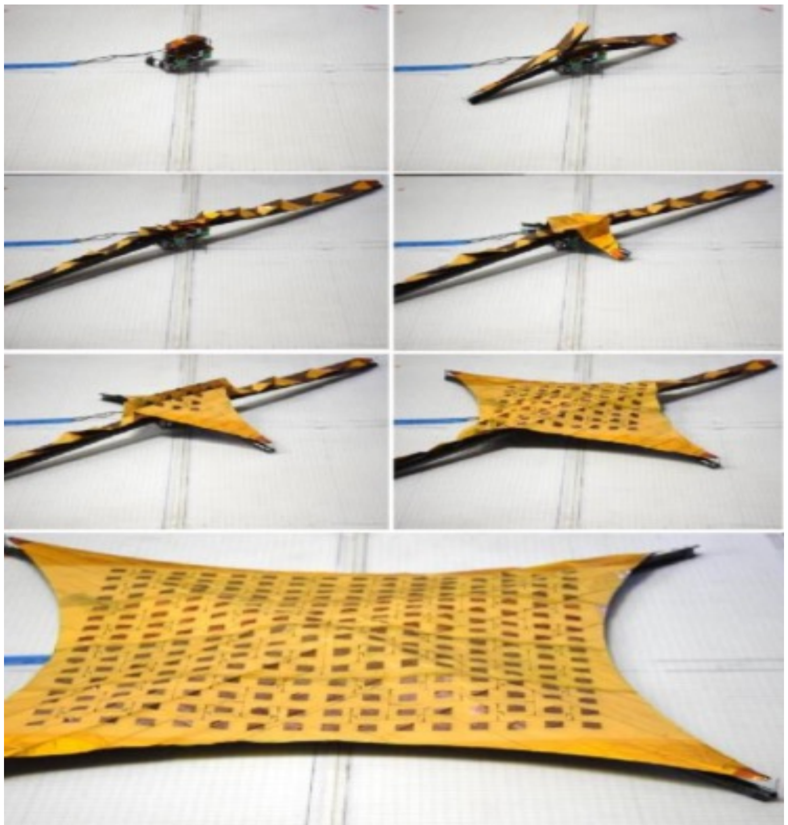
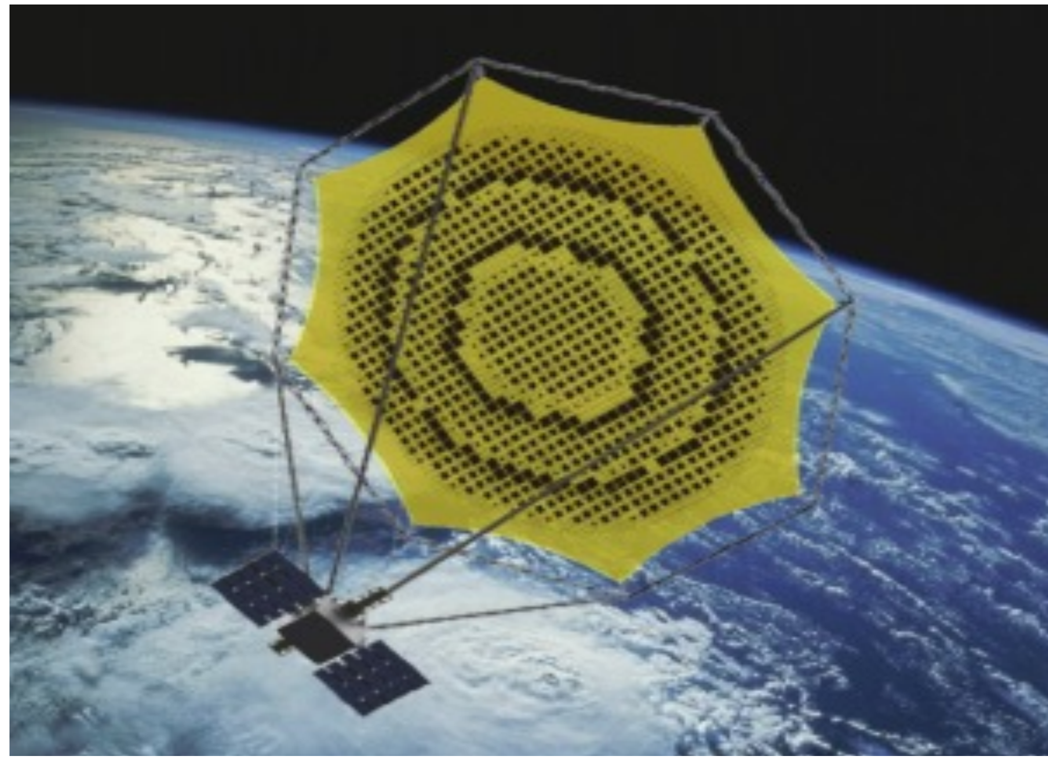


Membrane Antennas

Current Developments



Warren, et.al. "Large, deployable S-band antenna for a 6U CubeSat," Proc. 29th AIAA Conf. Small Satellites, 2015



Deployable High Gain Reflectarray (DaHGR)
http://mmadesignllc.com

Concluding Points

- CubeSat antenna challenge
  - Deployable – stowage volume
  - Mass
  - Cost
  - Environmental
  - Rapid Development

- Requirements are driving antenna research
  - Current antennas enabling new missions
  - Next generation antennas are developing rapidly