A Circularly-Polarized X-band Patch Array Antenna with Corporate Feeding for CubeSats

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2021 CubeSat Developers Workshop

Outlines

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- Proposed 2X2 Patch Array Antenna Geometry
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SWARM-EX

- A National Science Foundation (NSF) funded CubeSat (nanosatellite) project under its Ideas Lab initiative.
- **SWARM-EX:** Space Weather Atmospheric Reconfigurable Multiscale Experiment (SWARM-EX) is a swarm of three CubeSats that will probe the equatorial ionization & thermosphere anomalies (300 km - 600 km) in an integrated way.
- Inter satellite distances will vary from 0.25 Km to 1000 Km.
- This explorer mission has science, engineering, and educational goals.
- Collaborative project with 6 universities lead by University of Colorado Boulder. Other 5 universities: Georgia Institute of Technology, Stanford University, University of South Alabama, Western Michigan University, Olin College of Engineering.

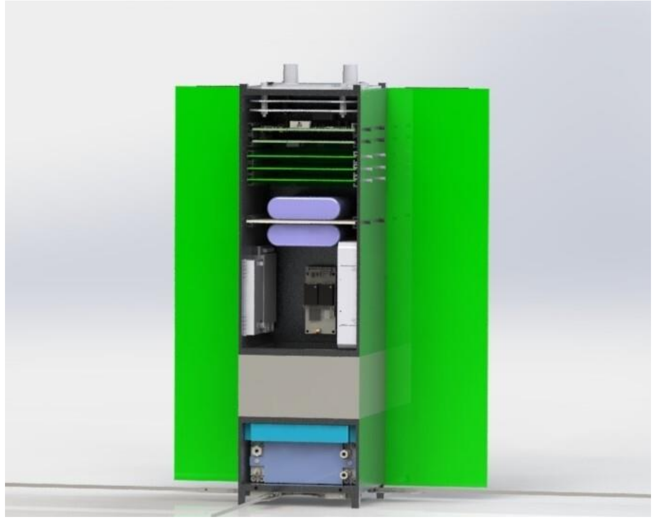


Fig. 1: SWARM-EX CubeSat. **Credit:** Structure Team, SWARM-EX

Communication Subsystem of SWARM-EX

- UHF Uplink and Downlink Communication for transmit/receive telemetry data
- UHF Crosslink Communication for inter-satellite communications
- X-Band Downlink Communication for science data download
- X-Band patch array antenna will work with Bluefin X-Band radio for X-band communication (8.45 GHz – 8.5 GHz).
- SWARM-EX has GPS system to determine satellite positions and Globalstar communication system for telemetry downlink.

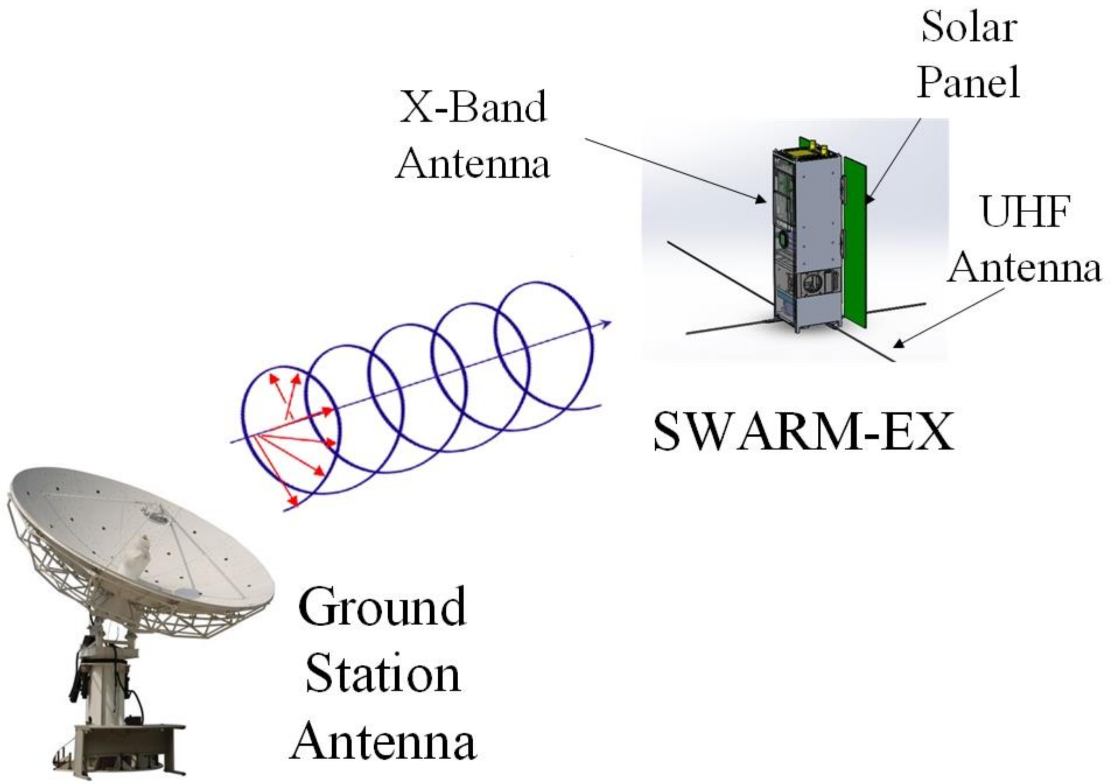


Fig. 2: A Representation of Right-hand Circular Polarization Communication between SWARM-EX X-Band Antenna, and a ground station antenna.

Ground Station Antenna Figure Picture Credit: Shaanxi Academy of Aerospace Technology Application Co., Ltd.

Link Budget: SWARM-EX X-Band Downlink Communication

Parameter	Value	Unit	Reference
Frequency	8.475	GHz	
Altitude	500	Km	
Slant Range	1695	Km	For 10 degree elevation angle
Transmitting Antenna Gain	13	dBi	From Ansys HFSS design simulation
Transmitter Output Power	1.5	W	
Ground Station Antenna Gain	47	dBi	KSat Lite 3.7m Dish
Receiver Figure of Merit	26.5	dB/K	KSat Lite Ground Station
Data Rate	10	Mbps	
Required Bit Energy to Noise Ratio	11.5	dB	
Link Margin	7.6	dB	

Table 01: A summary of SWARM-EX X-Band Downlink Communication Link Budget.

Single Element RHCP Antenna

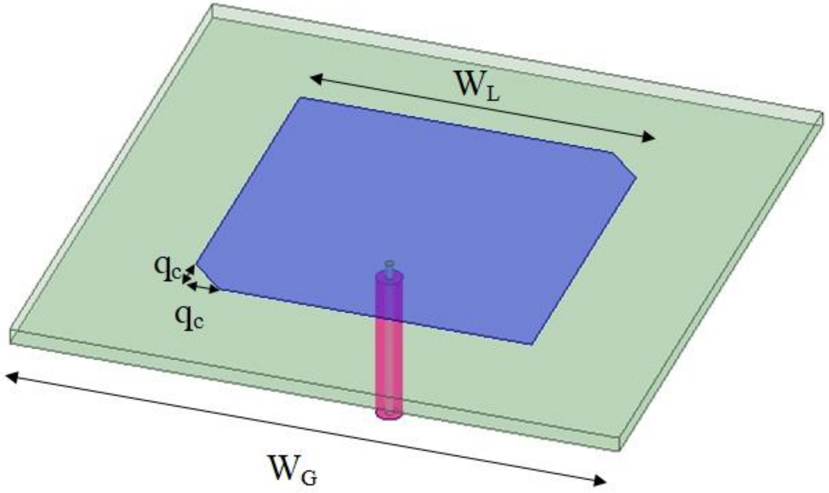


Fig. 3: Single Element of X-Band Array Antenna.

Parameter	Value
Patch Width, W_L	11.4 mm
Square Ground Plane and Substrate width, W_G	20 mm
Corner Perturbation, q_c	1.15 mm

Table 02: Design Parameters of the Single Element of the X-Band Array Antenna

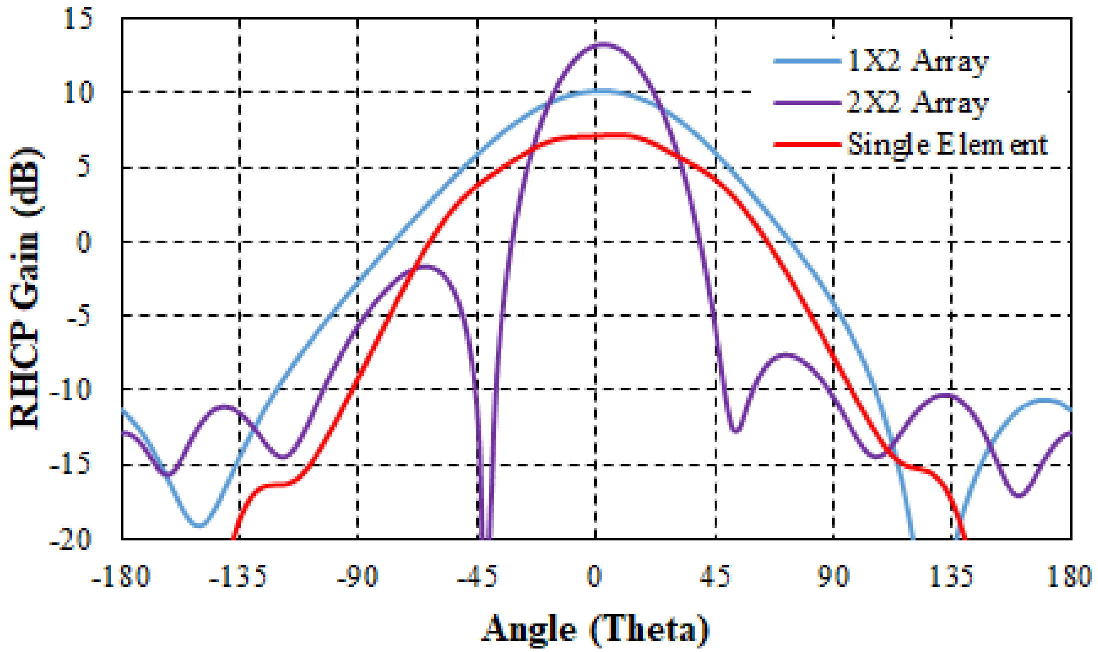


Fig. 4: RHCP Gain comparison between the single element and 1X2, 2X2 arrays.

Substrate Used: Rogers RT/Duroid 5880, 0.79 mm thick
Dissipation factor of .0009 at 10GHz

Proposed 2X2 Patch Array Antenna Geometry

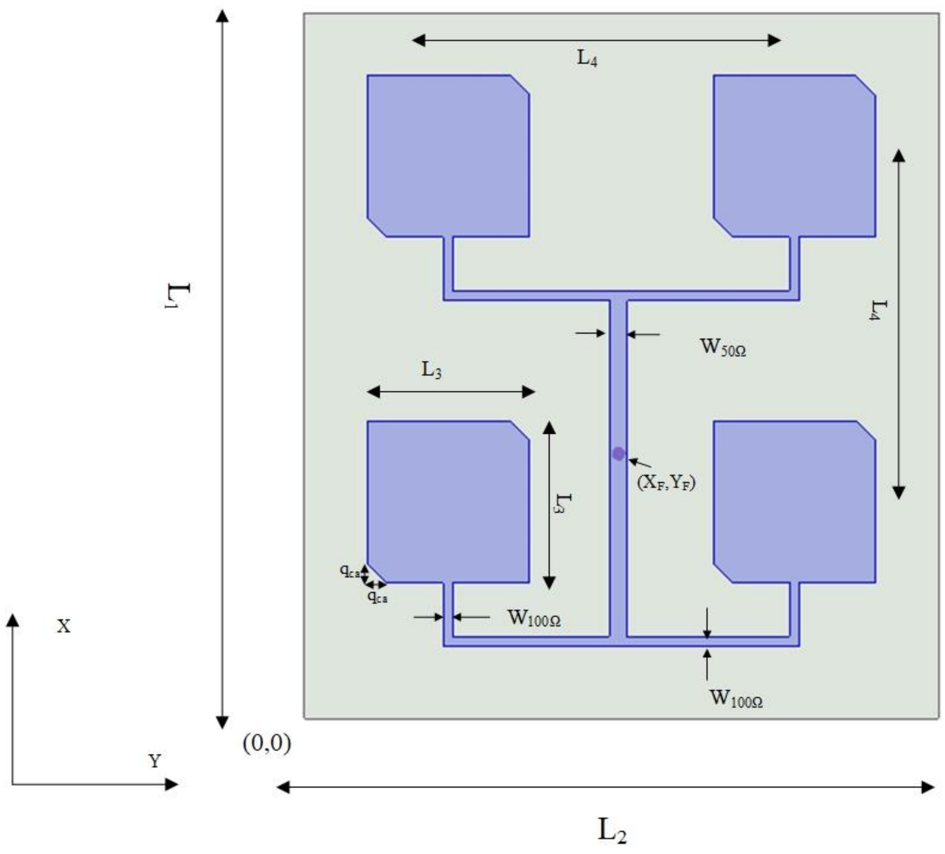


Fig. 5: Geometry of the designed X-Band Array Antenna for SWARM-EX CubeSat

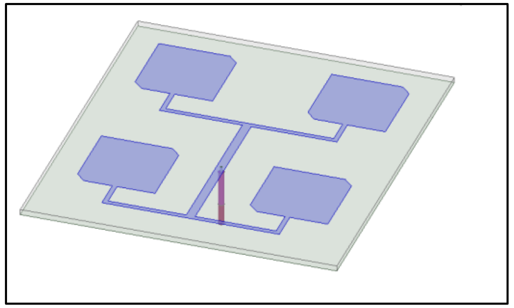


Fig. 6: 3D View of the designed X-Band Array Antenna

Parameter	Value
Ground Plane and Substrate Length, L_1	49 mm
Ground Plane and Substrate Length, L_2	44 mm
Square Patch Width, L_3	11.2 mm
Center to Center Patch Spacing, L_4	24 mm
Corner Perturbation, q_{ca}	1.3 mm
Probe Position (X_F, Y_F) (mm)	(18.375, 21.81)
50 Ω line width, $W_{50\Omega}$	1.23 mm
100 Ω line width, $W_{100\Omega}$	0.66 mm

Table 03: Design Parameters of the X-Band Array Antenna

S11, Axial Ratio, and Gain

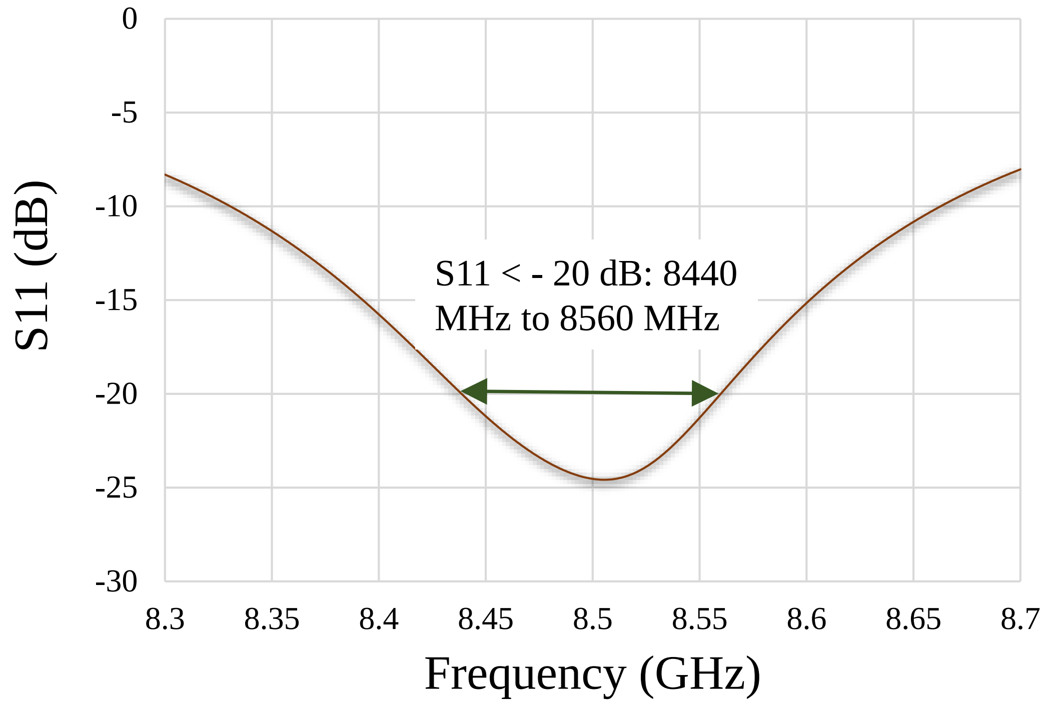


Fig. 7: Simulated S11 Versus Frequency, S11 < - 10 dB: 8332 MHz to 8664 MHz (332 MHz, 3.9%).

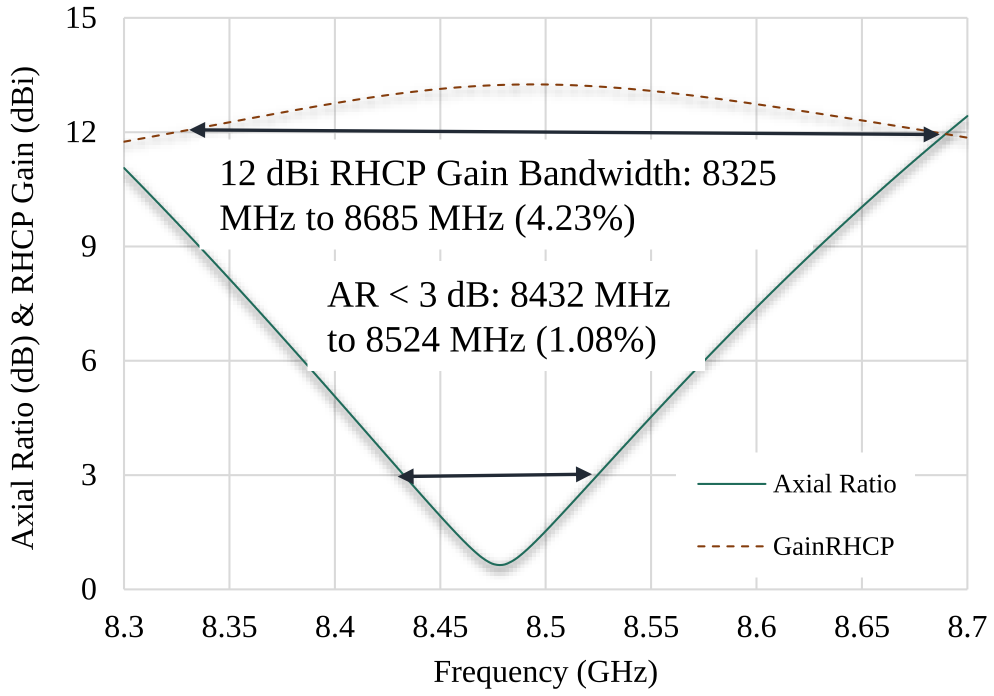
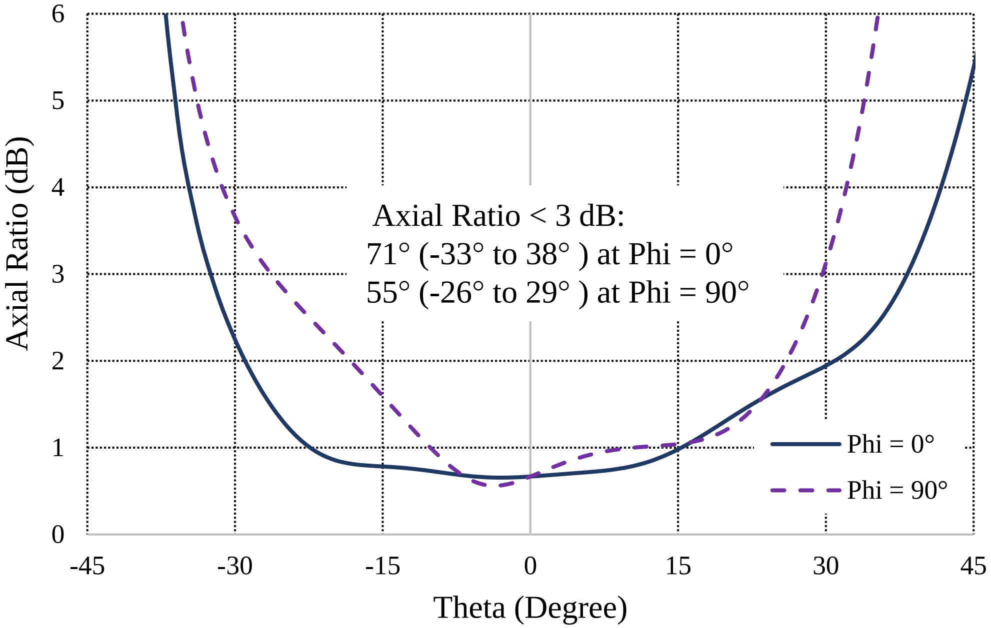
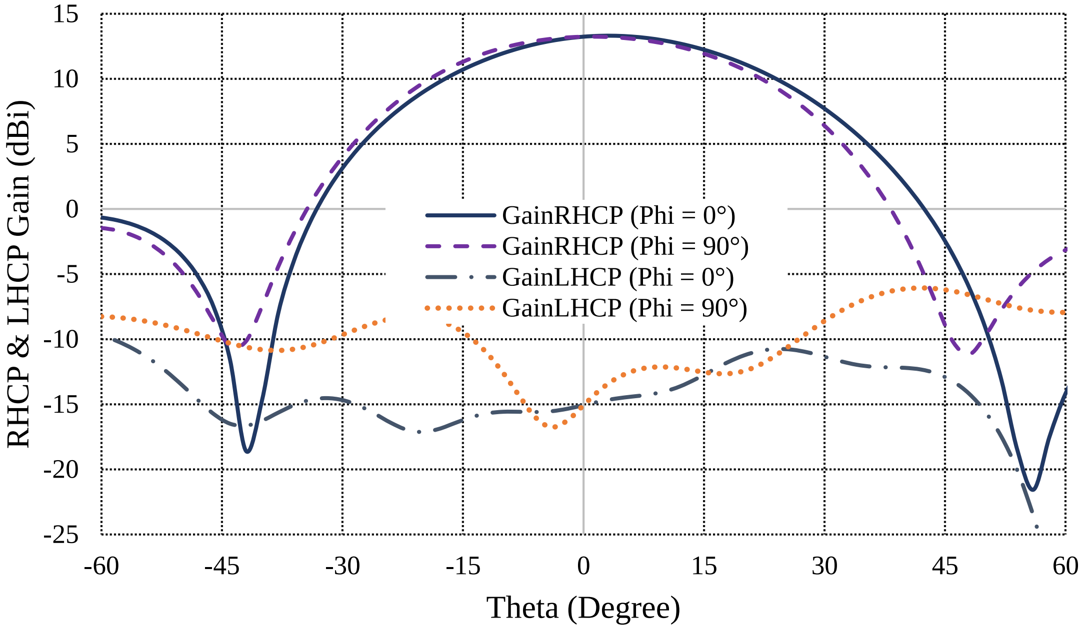


Fig. 8: Simulated Axial Ratio & RHCP Gain Versus Frequency Plot of the Proposed CP Array Antenna.

Beamwidths at 8.475 GHz (Center Frequency)



(a)

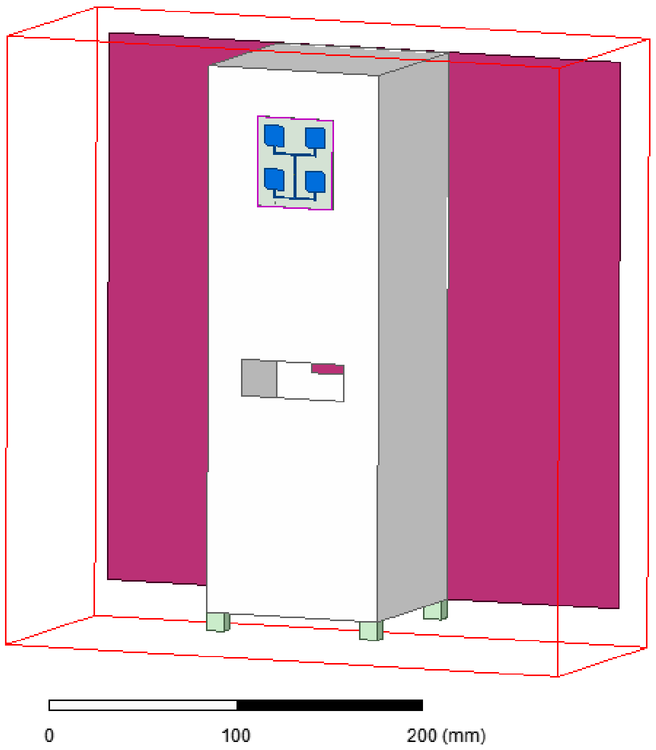


(b)

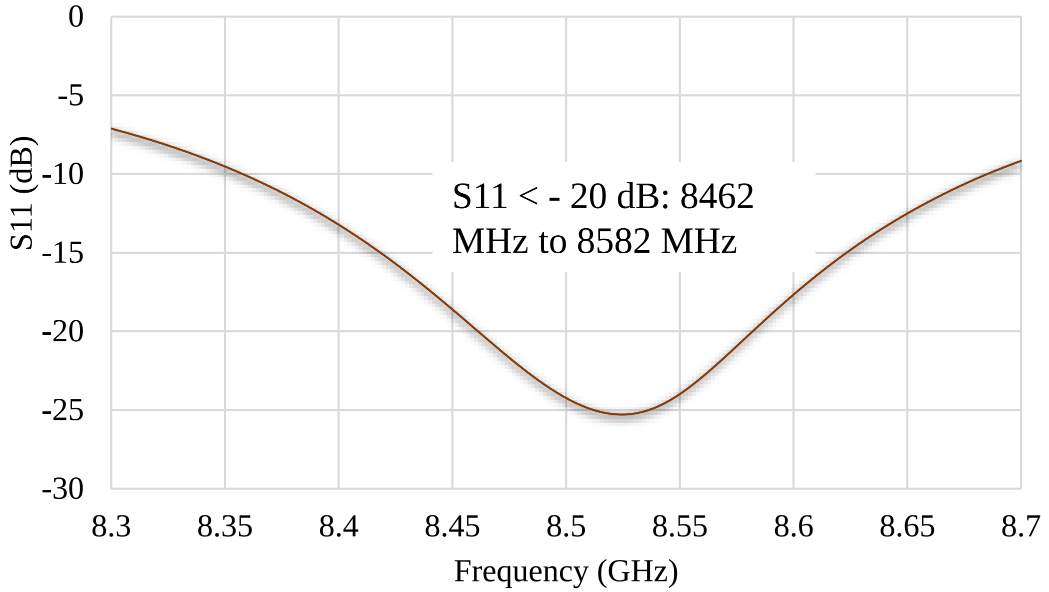
Fig. 9: (a) Axial Ratio Versus Elevation Angle Plots in Phi = 0° and 90° at 8.475 GHz, and (b) Gain Versus Elevation Angle Plots in Phi = 0° and 90° Planes at 8.475 GHz.

3 dB RHCP Gain Beamwidths: 38° (-16° to 22°) at Phi = 0° and 39° (-18° to 21°) at Phi = 90°.

Antenna Performance on SWARM-EX CubeSat



(a)



(b)

Fig. 10: (a) HFSS Simulation model of the Antenna with SWARM-EX, (b) Simulated S11 plot of the array on SWARM-EX CubeSat.

Antenna Performance on SWARM-EX CubeSat (Cont.)

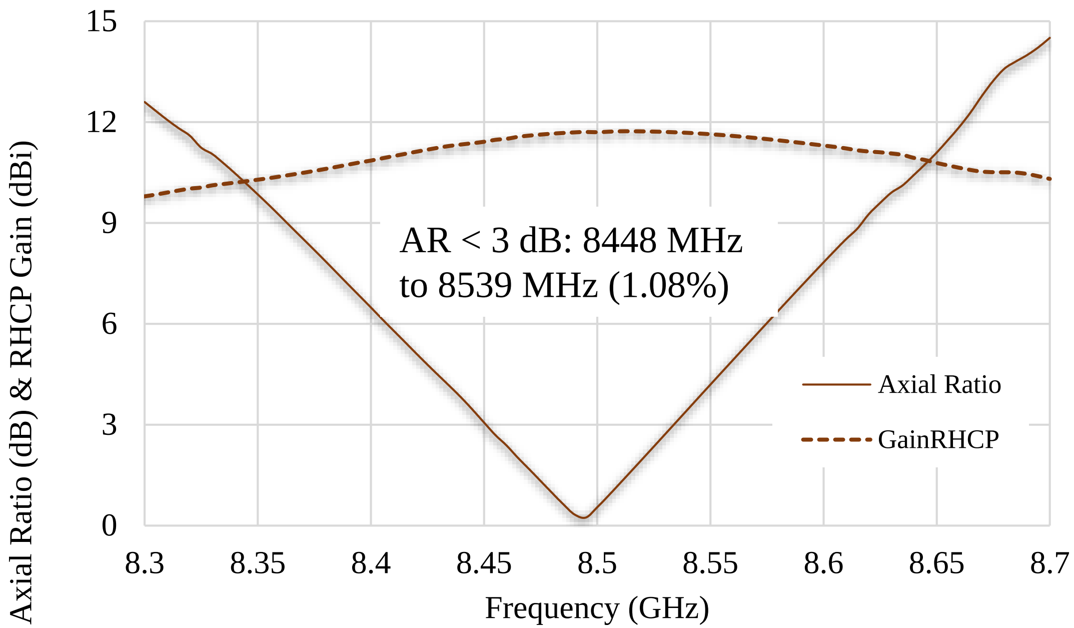


Fig. 11: Simulated Axial Ratio & RHCP Gain Versus Frequency Plot of the Array Antenna with SWARM-EX CubeSat.

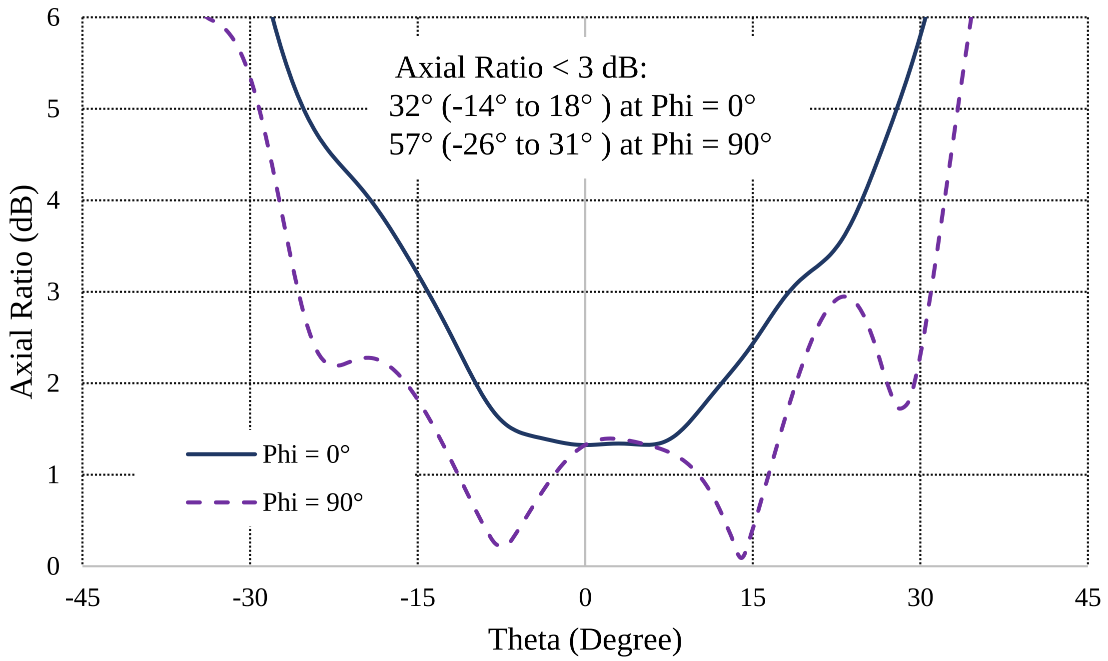


Fig. 12: Axial Ratio Versus Elevation Angle Plots in Phi = 0° and 90° at 8.475 GHz

Antenna Performance on SWARM-EX CubeSat (Cont.)

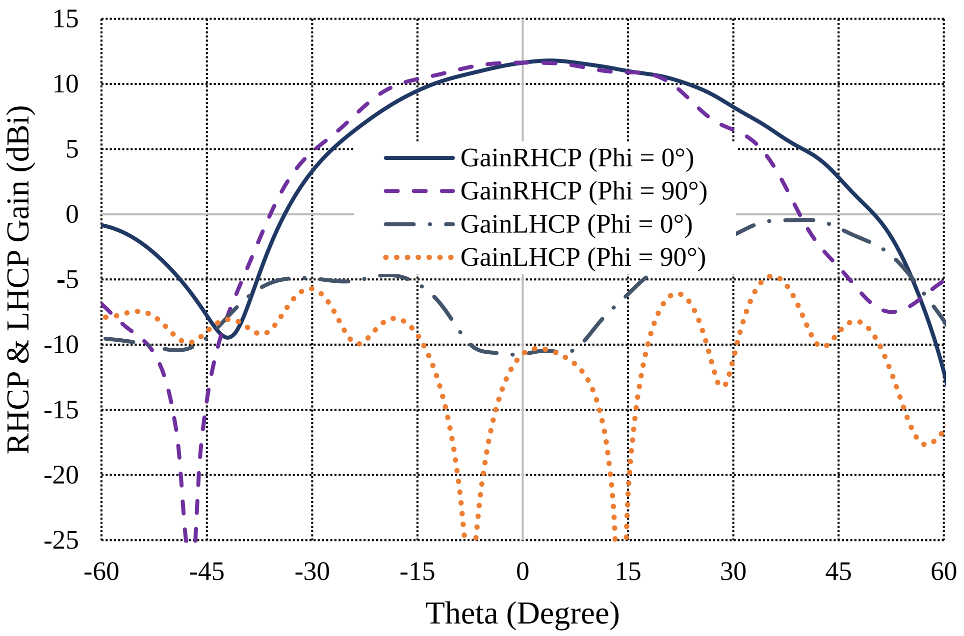


Fig. 13: Gain Versus Elevation Angle Plots in Phi = 0° and 90° Planes at 8.475 GHz.

3 dB RHCP Gain Beamwidths: 47° (-18° to 29°) at Phi = 0° and 46° (-22° to 24°) at Phi = 90°.

Table 04: Antenna Performance comparison between the stand-alone antenna vs antenna on CubeSat

Parameter	Stand-alone Antenna	Antenna on CubeSat
S11 < - 10 dB	8332 MHz to 8664 MHz (332 MHz, 3.9%)	8358 MHz to 8685 MHz (327 MHz & 3.83%)
Axial Ratio < 3 dB	8432 MHz to 8524 MHz (92 MHz & 1.08%)	8448 MHz to 8539 MHz (91 MHz & 1.08%)
Peak RHCP Gain (dBi)	13.2 dBi	11.8 dBi
Axial Ratio <3 dB Beamwidths at 8.475 GHZ	71° at Phi = 0°, and 55° at Phi = 90°	32° at Phi = 0°, and 57° at Phi = 90°
3 dB RHCP Gain Beamwidths at 8.475 GHz	38° at Phi = 0°, and 39° at Phi = 90°.	47° at Phi = 0°, and 46° at Phi = 90°.

Conclusion

- Achieved an excellent impedance matching of S11 < - 20 dB from 8440 MHz to 8560 MHz covering the targeted frequencies.
- Achieved required axial ratio (< 3 dB) performance.
- Obtained a Peak RHCP gain of 13.2 dBi, meeting the 11 dBi RHCP gain requirement from the SWARM-EX link budget.
- Symmetric Gain beamwidths to broadside.
- Meet the requirements while simulating with the SWARM-EX CubeSat.
- Fabrication and measurements are in progress.

Thank You