Optimizing Antenna Integration and Deployment for Alpha's ChipSat-Light Sail System

Apurva Hanwadikar, Langston Johnson

Space Systems Design Studio

INTRODUCTION

This project focused on integrating dipole antennas for ChipSats mounted on Alpha CubeSat's deployable light sail (Fig. 1). The primary goal was to ensure reliable antenna deployment and signal performance. Early antenna prototypes mounted directly onto the folded sail experienced resonance shifts and worsened transmission after deployment. Through iterative testing with different materials and configurations, we developed a hybrid solution that now serves as the final flight configuration for Alpha CubeSat.

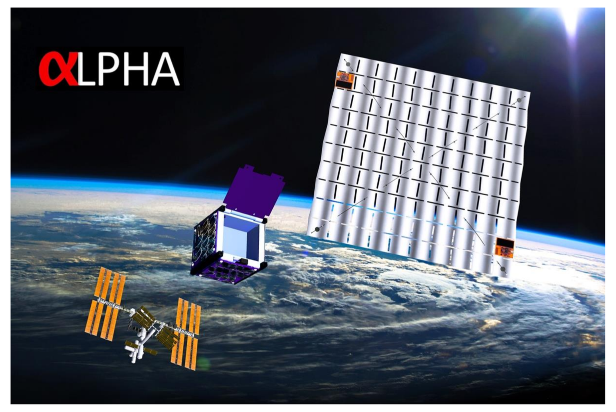

Fig. 1 Alpha Mission Launch poster. The CubeSat deploys a light sail with ChipSats attached at each corner.

METHODS

Each ChipSat used copper dipole antennas on flexible Kapton-based PCB. We designed and tested two antenna types: LoRa radio antennas (437.4 MHz) and GPS antennas (1575.42 MHz) for location data. Performance was measured using a NanoVNA, which provided signal loss data (in dB) across a frequency sweep. A strong dip in the loss curve near the target frequency indicated effective tuning (Fig. 5–6).

To tune the antennas, we began with traces slightly longer than needed and incrementally trimmed the copper to shift the resonance toward the target.

System-level mechanical testing with the full sail and ChipSats mounted allowed us to evaluate interference between antennas and ensure reliable performance in this configuration. We simulated placing the entire sail-ChipSat assembly in the CubeSat for multiple days, comparing loss graphs before and after to determine shifts due to long stowage (Fig. 5–6).

ACKNOWLEDGEMENTS

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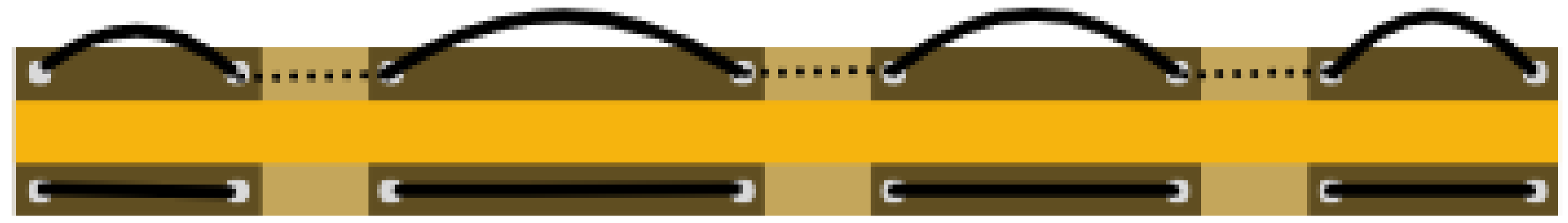


Fig. 2 Diagram depicting the nitinol weaving on the hinged design. The strip running through the middle represents the copper traces and the dark and light brown represent stiffer PCB and Kapton PCB material, respectively.

DESIGN PROCESS

After testing several configurations, we finalized a hybrid antenna system combining unstiffened laminated antennas and stiffened antennas with nitinol-reinforced hinges.

The **unstiffened antennas** are made from flexible Kapton-based PCB material and are placed diagonally across the sail. This configuration minimized interference, as copper traces adhered to the natural folds of the sail and unfurled upon deployment (Figure 3)

The **stiffened antennas** use rigid PCB sections and Kapton hinges, with nitinol wire woven along the edges. The nitinol straightens when released, deploying the antenna. These antennas face outward to reduce interference and optimize spatial distribution (Figure 4).

A hybrid design was necessary to fit within the sail compartment's volume constraints, offering a balance between reliable deployment and minimal interference.

DESIGN CHALLENGES

Antenna performance was limited by three key factors:

- **Electromagnetic Coupling**: Proximity of LoRa and GPS antennas led to frequency shifting and radiation pattern distortion.
- **Mutual Obstruction**: Antennas facing inward interfered with each other's radiation patterns.
- **Deformation from Stowage**: Rigid PCB materials retained folds, causing incomplete deployment and off-resonance behavior.

Initial tests showed resonance deviations up to 18 MHz due to folding-induced stress. Laminated and hybrid designs were developed to address these mechanical and electrical issues simultaneously.

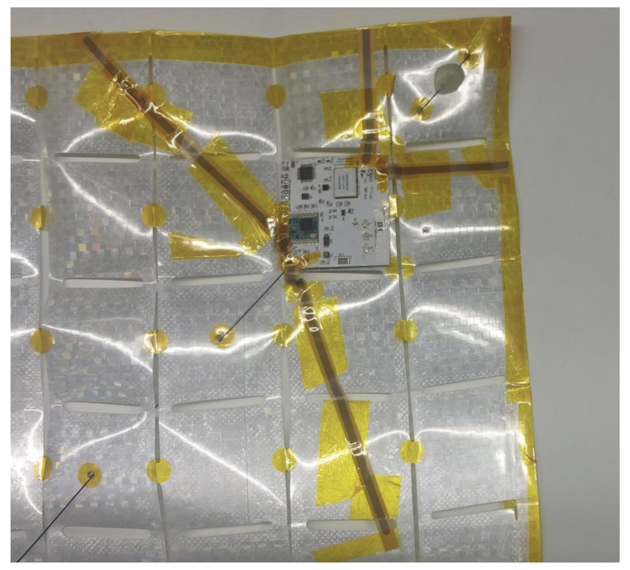


Fig. 3 Unstiffened antenna laminated onto the light sail in the flight configuration.

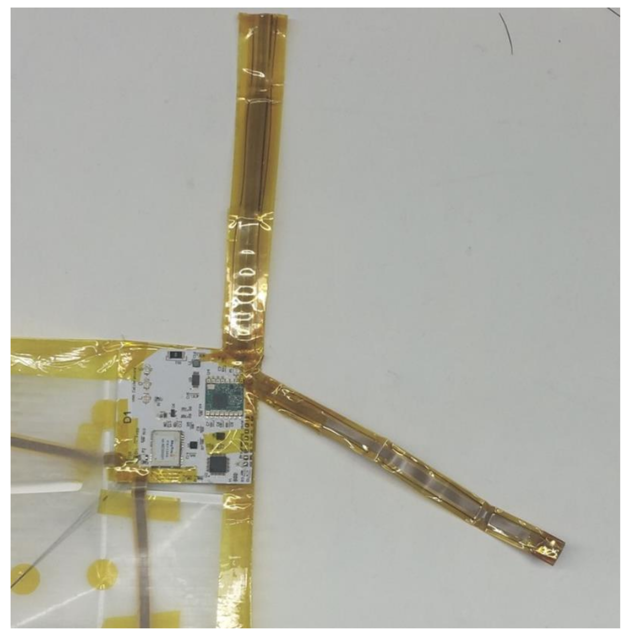
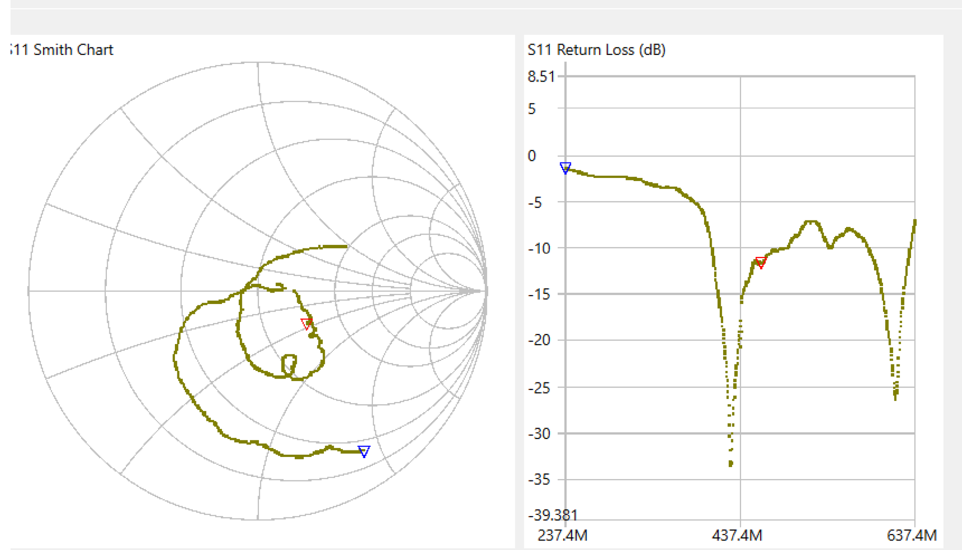


Fig. 4 Stiffened antenna on the light sail in the flight configuration.



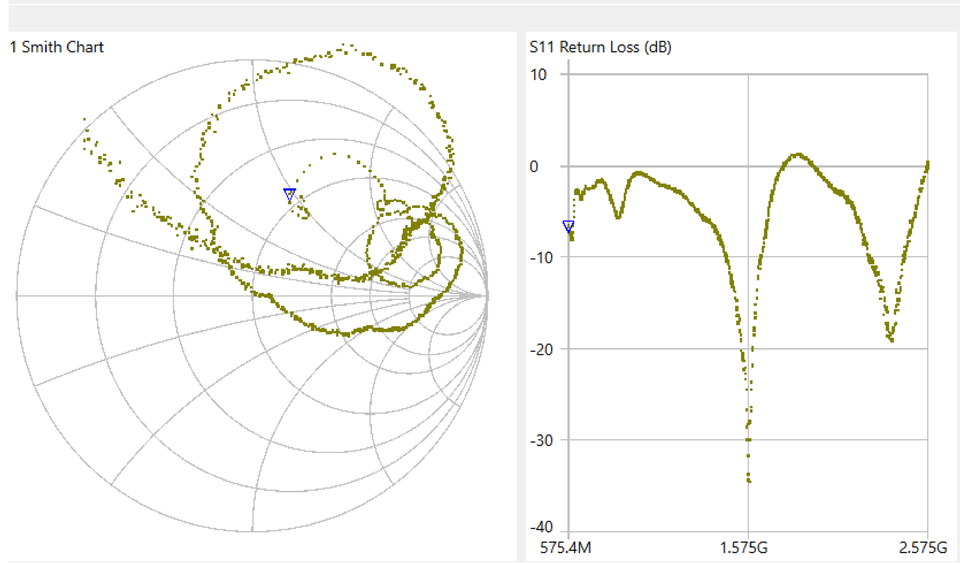
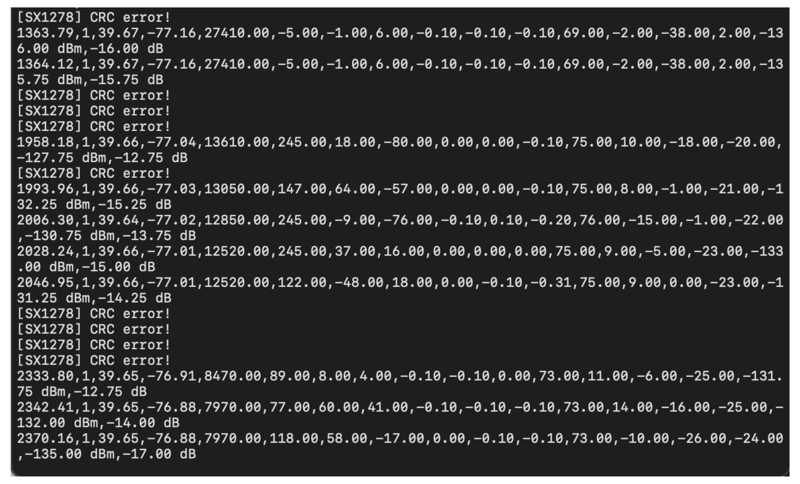


Fig. 5–6 NanoVNA portal displaying loss as a function of frequency for a slightly shifted LoRa antenna (up) and a perfectly tuned GPS antenna (right). The graph line in the middle is the target frequency (437.4MHz and 1.575GHz for LoRa and GPS respectively. At the target frequency the impedance should be 50 ohms, right at the center of the Smith Chart.

Attenuator turned on at 10:50am				
Time between readings generally indicates how long it took to get the first packet				
Time	Attenuation	Packet	CRC Error	Notes
11:04	9	no	n	
11:06	8	no	n	
11:07	7	yes	n	
11:08	8	yes	y	
11:10	9	yes	y	
11:11	10	yes	y	
11:12	11	yes	y	
11:12	12	yes	y	
11:14	13	no	y	
11:20	12	yes	y	
11:24	0	yes	n	
11:25	2	yes	n	
11:25	4	yes	n	
11:26	6	no	n	
11:28	5	no	n	
too low, stopped getting packets at all				



```
[SX1278] CRC error!
1363.79,1,39.67,-77.16,27410.00,-5.00,-1.00,6.00,-0.10,-0.10,-0.10,69.00,-2.00,-38.00,2.00,-13
6.00 dBm,-16.00 dB
1364.12,1,39.67,-77.16,27410.00,-5.00,-1.00,6.00,-0.10,-0.10,-0.10,69.00,-2.00,-38.00,2.00,-13
5.75 dBm,-15.75 dB
[SX1278] CRC error!
[SX1278] CRC error!
[SX1278] CRC error!
1958.18,1,39.66,-77.04,13610.00,245.00,18.00,-80.00,0.00,0.00,-0.10,75.00,10.00,-18.00,-20.00,
-127.75 dBm,-12.75 dB
[SX1278] CRC error!
1993.96,1,39.66,-77.03,13050.00,147.00,64.00,-57.00,0.00,0.00,-0.10,75.00,8.00,-1.00,-21.00,-1
32.25 dBm,-15.25 dB
2006.30,1,39.64,-77.02,12850.00,245.00,-9.00,-76.00,-0.10,0.10,-0.20,76.00,-15.00,-1.00,-22.00
,-130.75 dBm,-13.75 dB
2028.24,1,39.66,-77.01,12520.00,245.00,37.00,16.00,0.00,0.00,0.00,75.00,9.00,-5.00,-23.00,-133
.00 dBm,-15.00 dB
2046.95,1,39.66,-77.01,12520.00,122.00,-48.00,18.00,0.00,-0.10,-0.31,75.00,9.00,0.00,-23.00,-1
31.25 dBm,-14.25 dB
[SX1278] CRC error!
[SX1278] CRC error!
[SX1278] CRC error!
[SX1278] CRC error!
2333.80,1,39.65,-76.91,8470.00,89.00,8.00,4.00,-0.10,-0.10,0.00,73.00,11.00,-6.00,-25.00,-131.
75 dBm,-12.75 dB
2342.41,1,39.65,-76.88,7970.00,77.00,60.00,41.00,-0.10,-0.10,-0.10,73.00,14.00,-16.00,-25.00,-
132.00 dBm,-14.00 dB
2370.16,1,39.65,-76.88,7970.00,118.00,58.00,-17.00,0.00,-0.10,-0.10,73.00,-10.00,-26.00,-24.00
,-135.00 dBm,-17.00 dB
```


Fig. 7–8 Balloon Test Data: The top spreadsheet shows attenuation levels and whether packets were received from the ChipSat. We aimed for attenuation ≥2, which was achieved. Early and late data points reflect setup errors and descent-related signal loss. Figure 9 shows the antenna log during descent, where CRC errors indicate expected data corruption due to decreasing altitude and signal quality.

RESULTS

A high-altitude balloon test validated antenna functionality under flight-like conditions. The payload, integrated by the University of Maryland, was launched with the sail stowed flat. Ground stations at the Hartung-Boothroyd Observatory employed Yagi and ground plane antennas for receiving packets, aligned using the predicted flight trajectory.

The test demonstrated that:

- LoRa antennas achieved reliable data downlink at altitude (Fig. 7).
- GPS signals were successfully transmitted and correlated with real-time balloon telemetry.
- Deployment reliability improved.

No significant frequency shifts were observed post-storage in repeated testing, indicating consistent performance after 24–48 hour stow cycles.

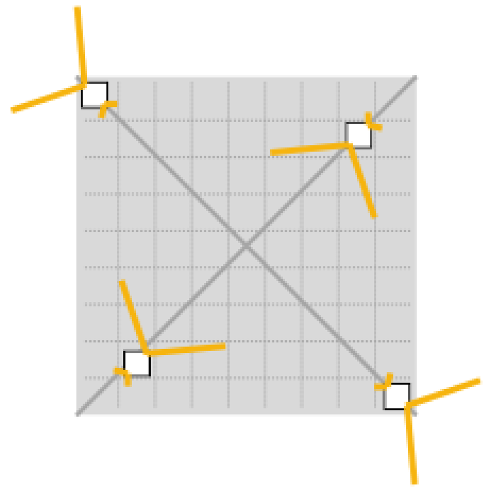


Fig. 9 Configuration of the four Alpha ChipSats on the sail. One of the stiffened antenna experienced shearing leading to its failure.

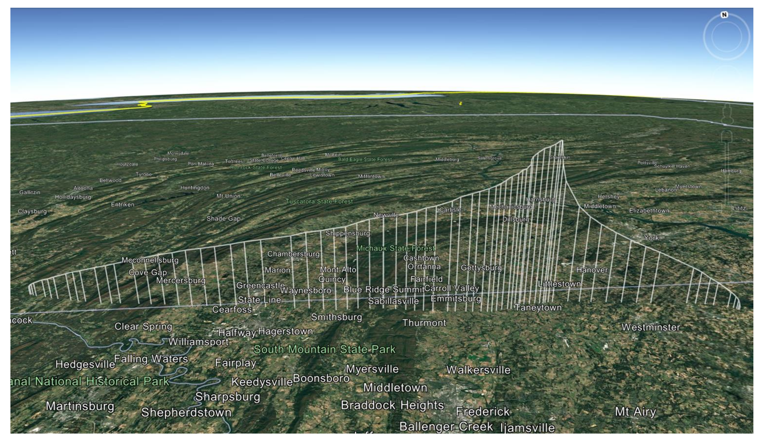


Fig. 10 Trajectory of the high altitude balloon with the vertical white lines indicating its altitude. The yellow dot indicates Ithaca.

CONCLUSIONS

The balloon test confirmed that our hybrid antenna system performs reliably under flight conditions. LoRa transmission from 75% of ChipSats and successful GPS data recovery demonstrate effective deployment and signal integrity.

Post-stow frequency drift remained below 2 MHz across all trials, validating the system's mechanical resilience. By combining flexible laminated traces with nitinol-reinforced hinges, we achieved reliable deployment within strict volume constraints (sail compartment) while minimizing electromagnetic interference.