Development of Optically Transparent Patch Antennas for Solar Panel Integration on CubeSats

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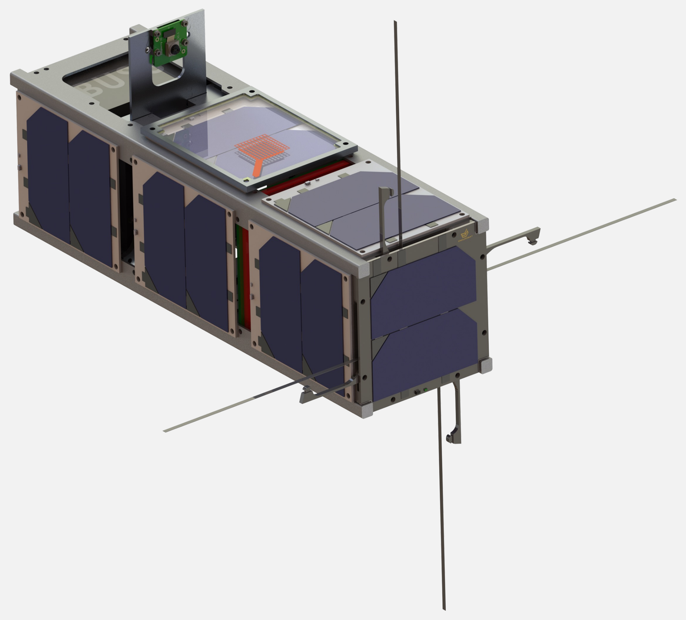
Introduction

Satellite design faces the challenge of optimizing external surface area to accommodate various components, such as solar panels, antennas, sensors, and technology demonstrations. For small satellites, solar cells occupy most of the external faces, offering little surface area for other functions.

To solve this problem, researchers and developers have attempted to create an S-band patch antenna that can integrate with a solar cell, providing higher gain and maximizing solar panel power generation. The most common option is to create a meshed patch antenna on a transparent substrate, increasing optical transparency. Often, this involves using conductive ink printed onto a transparent material such as glass or thick plastic.[1] This transparent patch antenna (TPA) allows satellites to use a patch antenna without losing a solar panel. The TPA is designed to function at 2.425 GHz.



3D rendering of GASRATS

GASRATS Overview

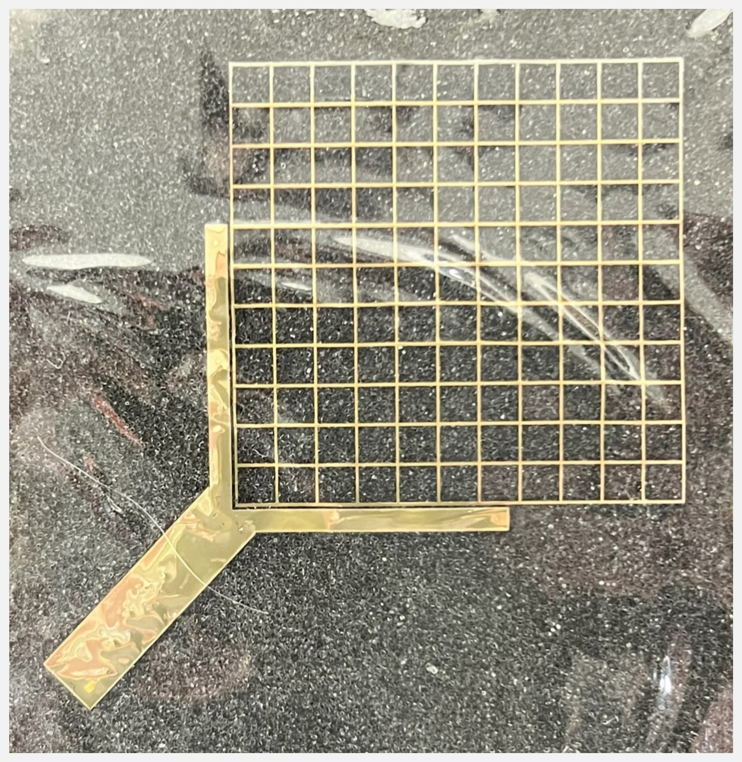
The Get Away Special Radio and Antenna Transparency Satellite (GASRATS) is an education and technology demonstration CubeSat mission developed by the Get Away Special (GAS) Student Satellite Team at Utah State University (USU) in collaboration with USU professor Dr. Reyhan Baktur. The 3U CubeSat will demonstrate an optically transparent, solar panel-integrated patch antenna in low-Earth orbit and verify the antenna's long-term durability in the space environment.

- Summer 2022 — GASRATS Begins Development
- Fall 2022 — TPA Begins Development
- Spring 2024 — GASRATS Selected for NASA CSLI
- Summer 2026 — Expected Launch Date

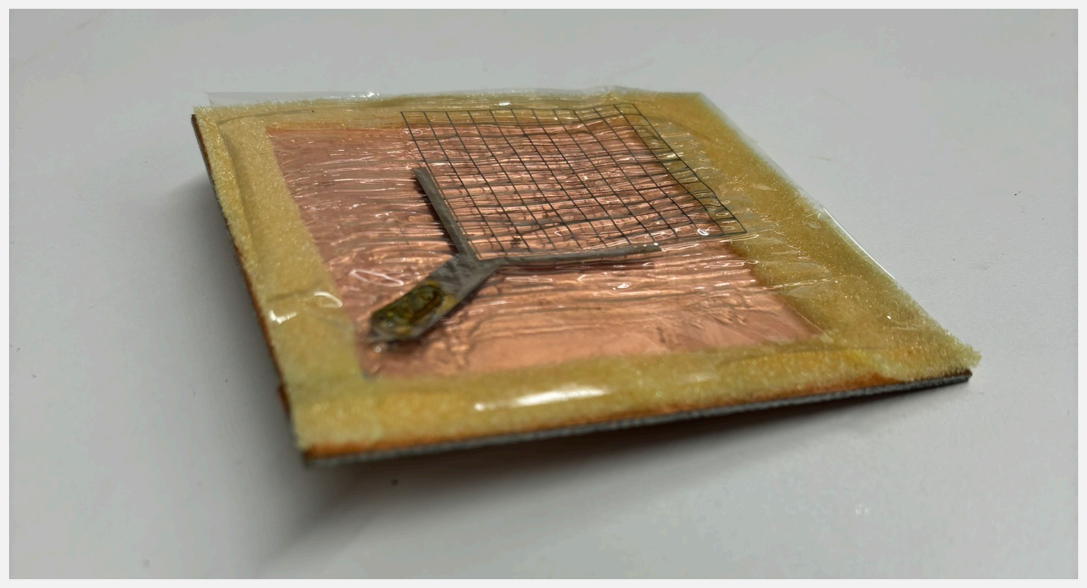
Design

For the design of an optically transparent patch antenna (TPA), start with a standard patch antenna shape and size appropriate for the desired frequency. Research has shown that for a general patch antenna design, the patch can be meshed into a grid configuration to increase transparency.[2] In this case, the mesh has 92% transparency. This change may have small effects on the RF properties of the antennas, but the antenna can be tuned accordingly.

To be an effective antenna for satellite applications, the TPA must be circularly polarized (CP). There are several ways to achieve CP for patch antennas, including altering the dimensions, adding thin slots, trimming corners, and using multiple feed locations. The chosen method for achieving CP for the TPA is to increase one of the side lengths of the patch by 4%, resulting in a phase difference that realizes CP. Once the patch antenna is meshed and circularly polarized, the antenna's impedance must be matched to that of the feed line.



Meshed TPA prototype printed on a transparent substrate



Constructed TPA prototype with dielectric, ground plane, and feed line

Fabrication

For the fabrication of a TPA the substrate, a thin, transparent polyimide sheet, must be treated to decrease the contact angle of the ink. A low contact angle is created by increasing the surface energy of the substrate to be greater than the surface tension of the ink. Results show that an ultraviolet (UV) ozone treatment of approximately 45 min yields the most precise and successful prints. After treatment, the antenna is printed from silver nanoparticle ink using an inkjet printer. Next, the antenna and substrate are cured in an oven at 195 °C for 35 min.

Lastly, the substrate is attached to foam using acetone. This acetone treatment melts the substrate into the foam, creating a strong chemical bond. Using copper tape, the feedline is soldered to the SMA connector on the ground plane. All soldering for the TPA is done using solder paste. Research has shown that solder flux can melt the substrate and degrade the ink used for printing the antenna.

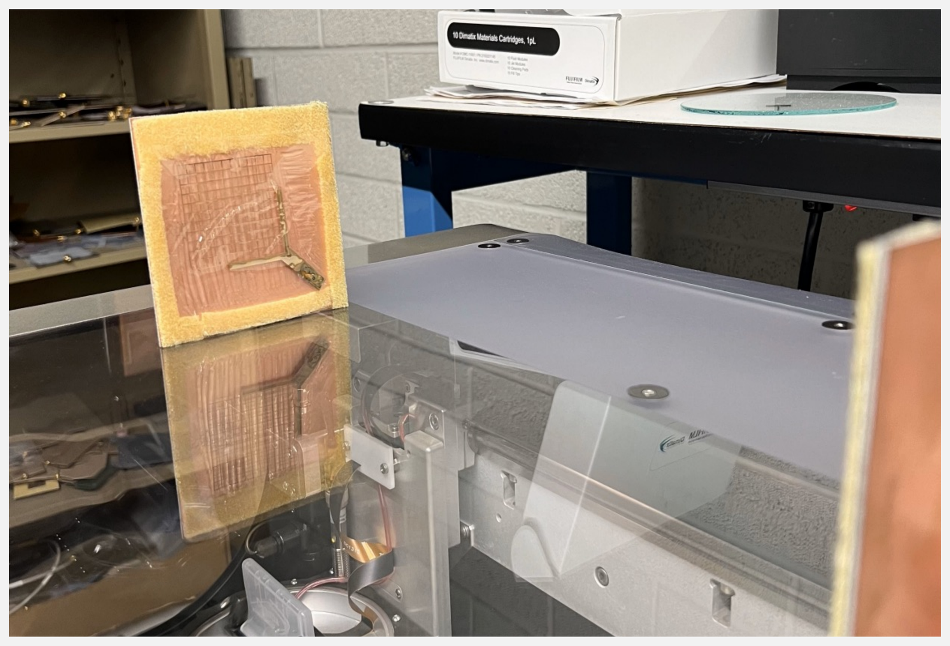
Surface energy using differing treatment methods

Treatment	Time (min)	Surface Energy (dyne/cm)	Successful Print?
UV Ozone	10	34	No
UV Ozone	30	38	N/A
UV Ozone	45	50	Yes
UV Ozone	50	52	N/A
Corona	0.5	56	No
Corona	1	58	No
Corona	1.5	58	No
Corona	2	58	No
Chemical	N/A	38	Yes
None	N/A	<32	No

Testing

In Ansys HFSS, the GASRATS TPA is simulated to have a peak gain of 8.8 dBi, an axial ratio of 4.94 dB, and a reflection coefficient (S_{11}) of -22.70 dB. Using Friis Transmission Equation, the antenna has a peak gain of 0.25, the S_{11} value is -8.95 dB, and the antenna was verified to have circular polarization.

$$S_{21} = \frac{P_r}{P_t} = G_t G_r (1 - |\Gamma_t|^2)(1 - |\Gamma_r|^2)\left(\frac{\lambda}{4\pi R}\right)^2 |\hat{\rho}_t \cdot \hat{\rho}_r|^2$$



Two TPA prototypes in a gain testing orientation

Future Development

The TPA for GASRATS will undergo a series of tests over the coming year to evaluate the gain pattern, bandwidth, polarization, and other relevant antenna properties.

Further work will integrate the TPA with a solar panel, refining the mounting method, and exploring feedline placement. Once the TPA is properly mounted to a solar panel, the transparency will be measured and the antenna's effects on the solar panel's power generation will be quantified.

Lastly, the integrated TPA will undergo a series of environmental tests, including radiation, thermal vacuum, and vibration, to verify the antenna's readiness for a space mission.

The TPA has several impactful applications. Integrating an array of transparent patch antennas onto an array of solar cells can enhance communication capabilities without interfering with power generation. This application is particularly relevant for deep space missions. Additionally, the flexible polyimide substrate can be folded and deployed.

References

[1] Baktur, R., *Antenna Design for CubeSats*, Artech House, Massachusetts, 2022

[2] Clasen, G. and Langley, R., "Meshed Patch Antennas," IEEE Transactions on Antennas and Propagation, vol. 52, No. 2, June 2024.

GAS GET AWAY SPECIAL STUDENT SATELLITE TEAM

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