3D Printed Antenna for a Balloon Test Flight

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NASA Goddard Space Flight Center: Code 562

Engineering Colloquium March 4, 2025 @ 3 PM

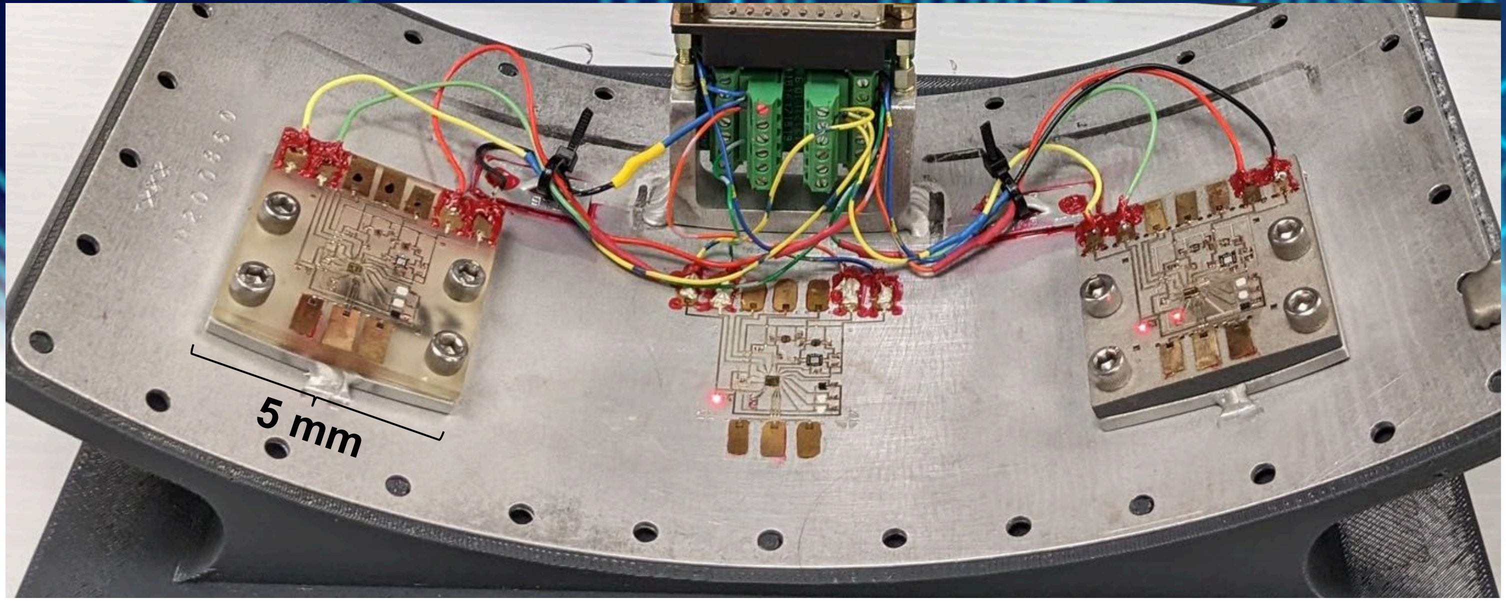
NASA GSFC 3D Printing Electronics Group

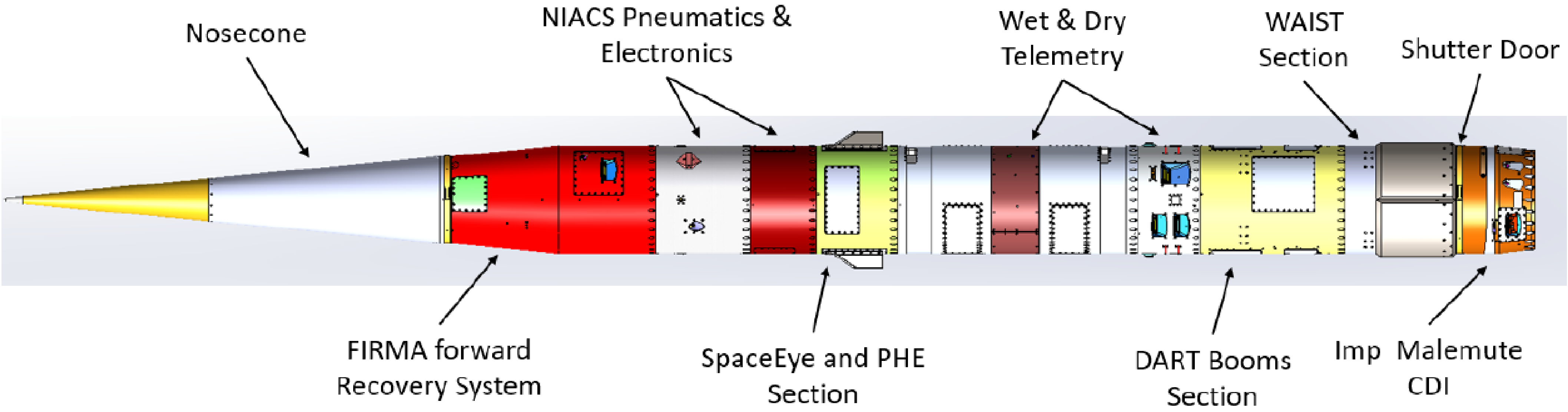
Overarching goal: Demonstrate capability for 3D Printing electronics to both **maximize customization** for unique needs of spaceflight missions while **minimizing cost and schedule.**

We plan to accomplish this via two prongs:

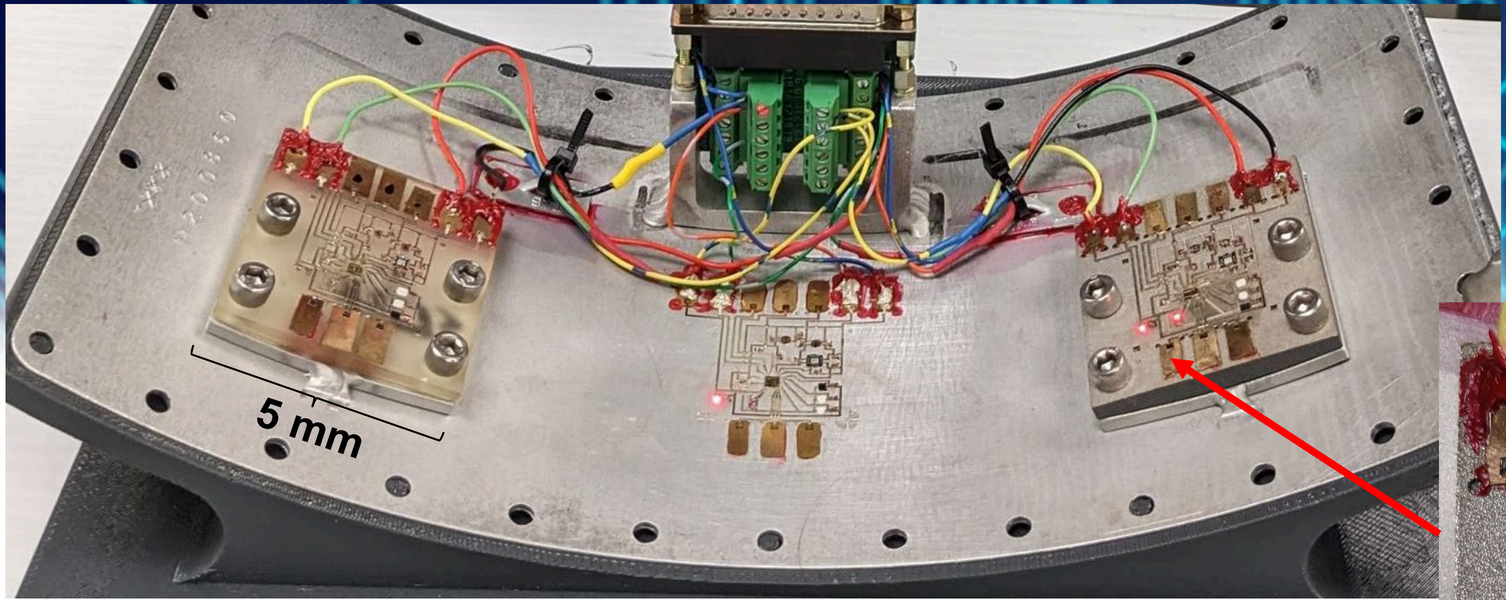
1. **Research:** applications for spaceflight projects with unique needs
2. **Rapid prototyping:** helping low-risk missions prototyping boards and other electronics early, enabling earlier testing and addressing design flaws

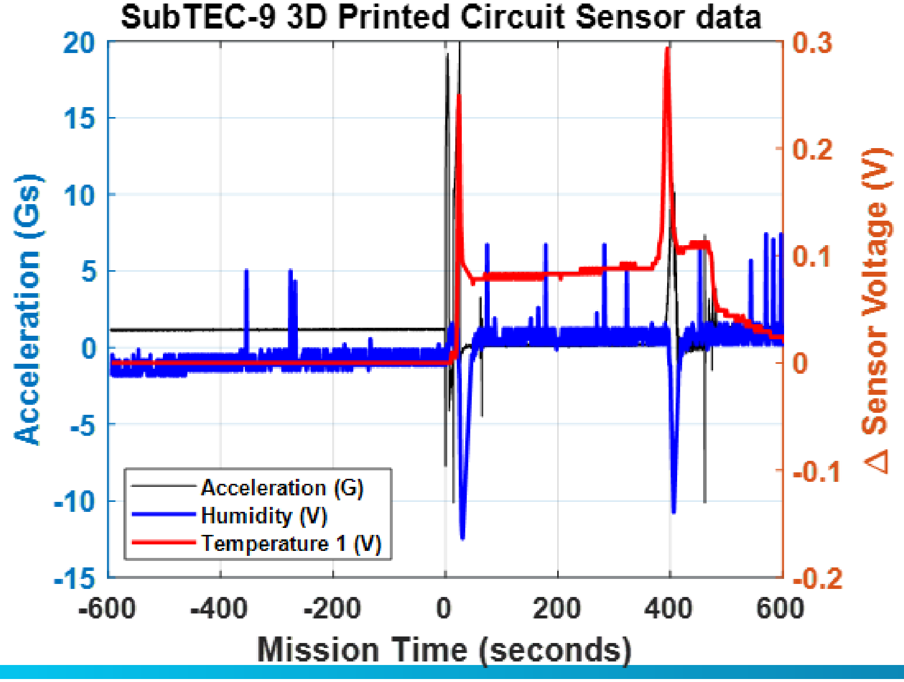
Past work

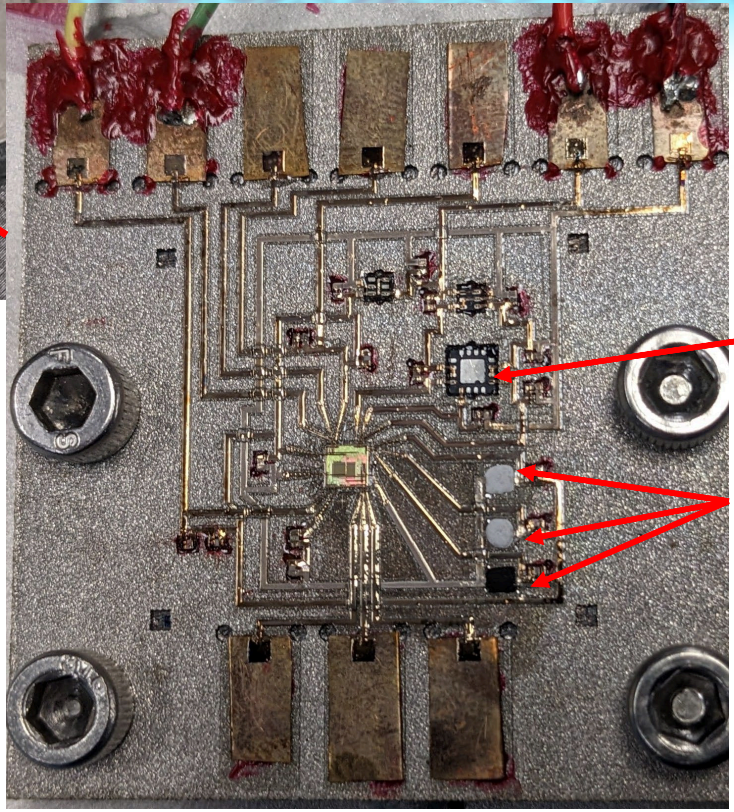




April 2023 SubTec-9 Sounding Rocket Demonstration





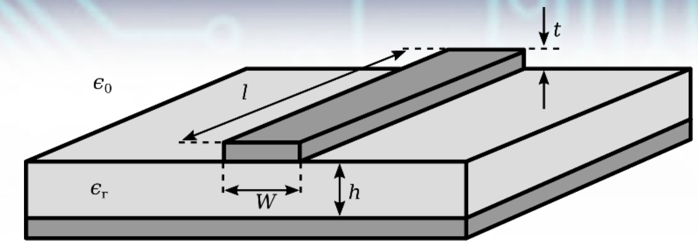


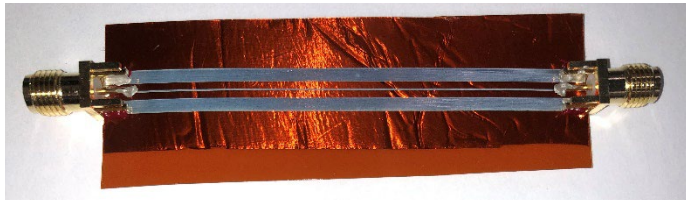
Accelerometer

Printed Temperature and Humidity Sensors

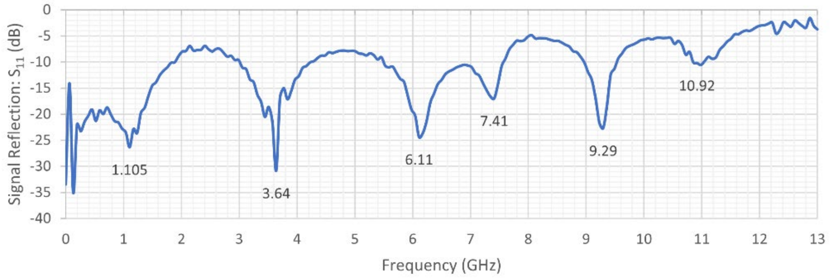
April 2023 SubTec-9 Sounding Rocket Demonstration

GPS transmission lines

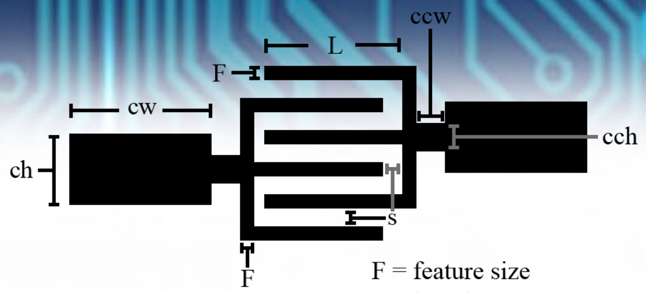




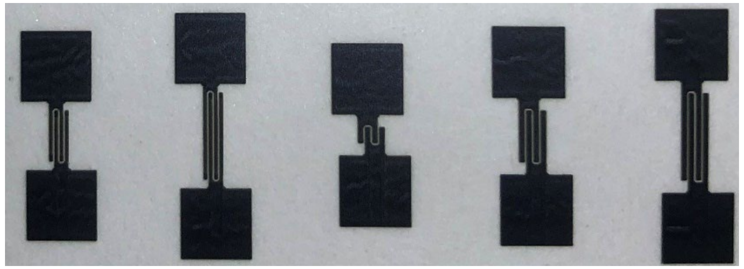
Scattering Parameter S_{11}(Signal Reflection) of an Aerosol-Jet Printed GPS Transmission Line

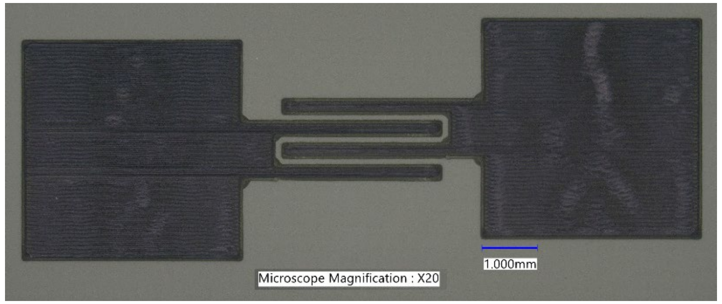


Interdigitated supercapacitors

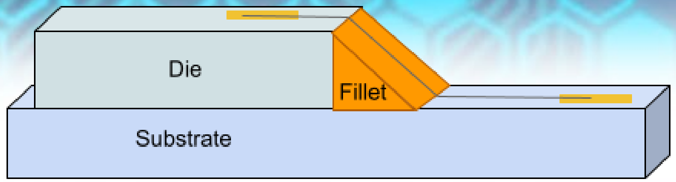


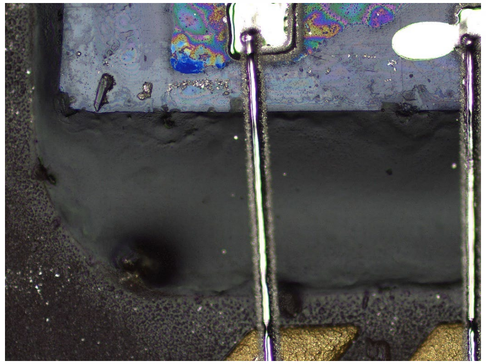
F = feature size
L = length
s = spacing
ccw = current collector width
cch = current collector height
cw = contact width
ch = contact height

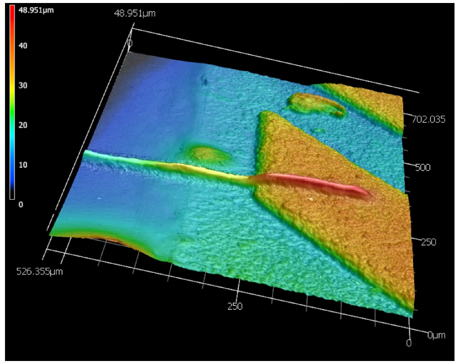


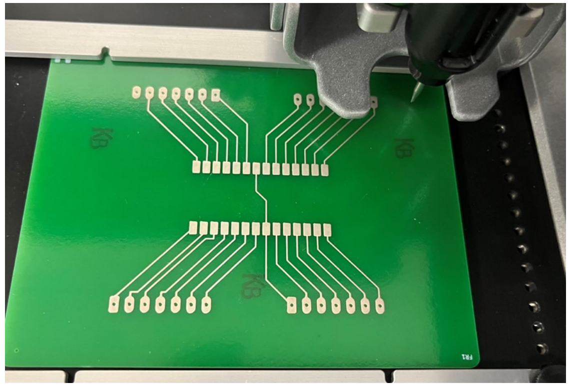


Printed interconnects: a wire bonding alternative





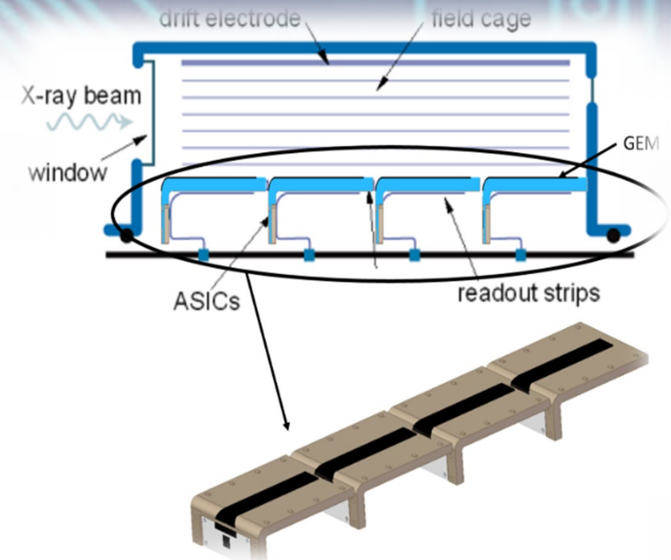


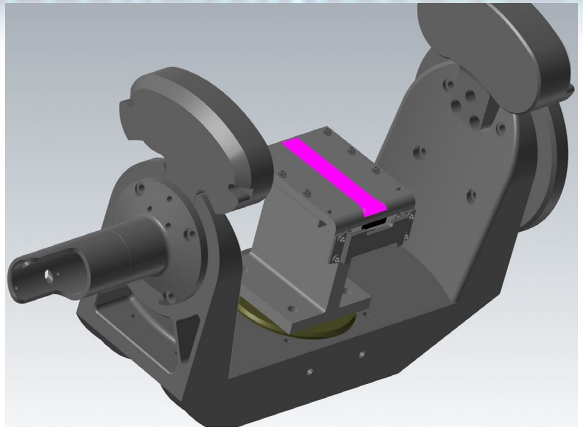


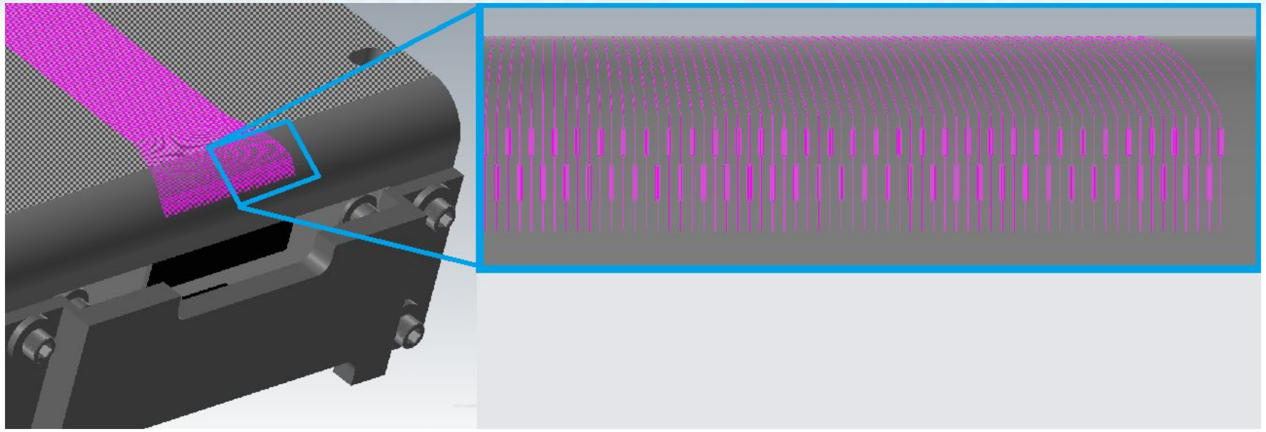
3D Printing Electronics Group

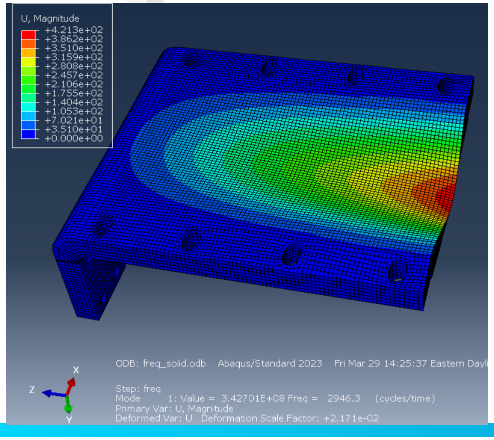
Current work

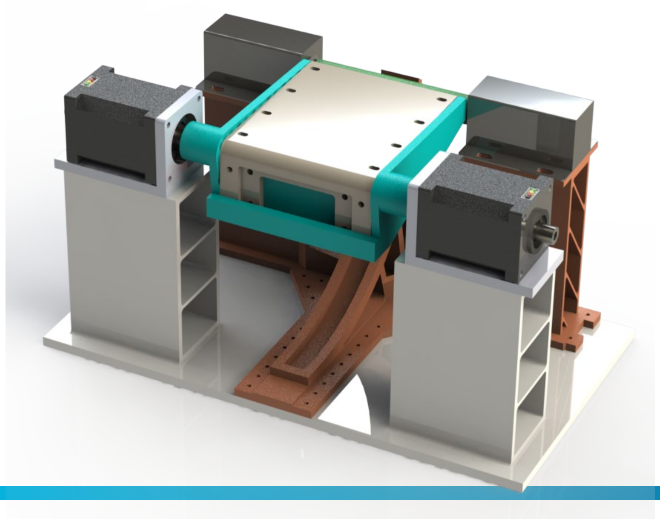
APRA: "Development of 3D Hard X-ray Photoelectric Polarimeter Assembly Using Additive Manufacturing Technology"

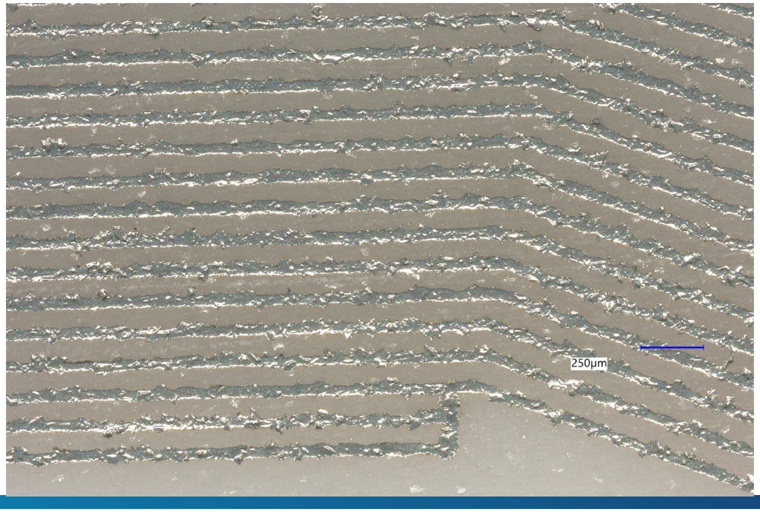






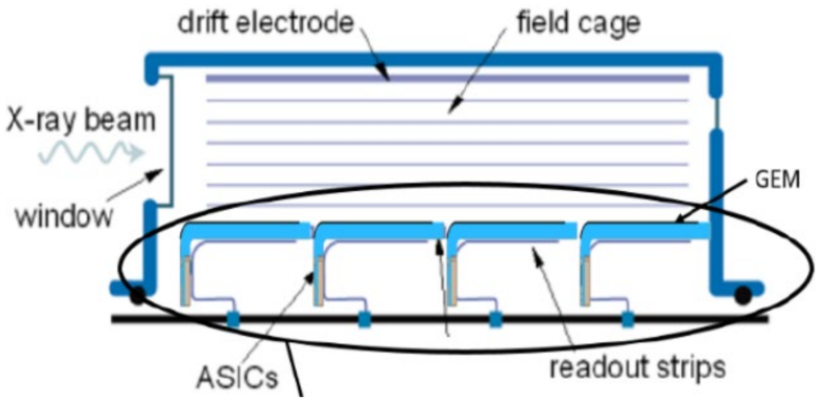


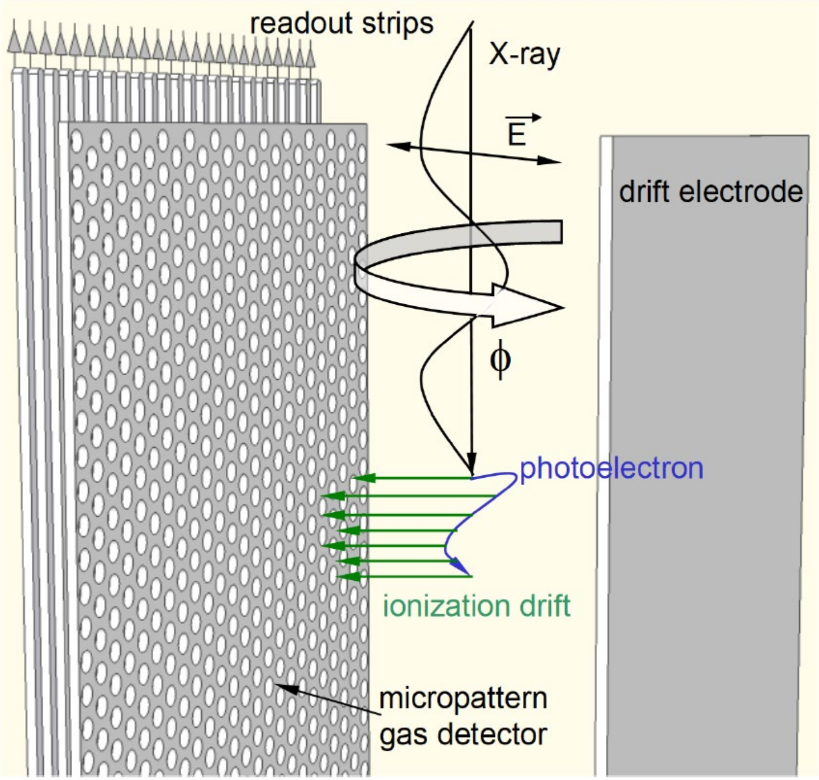


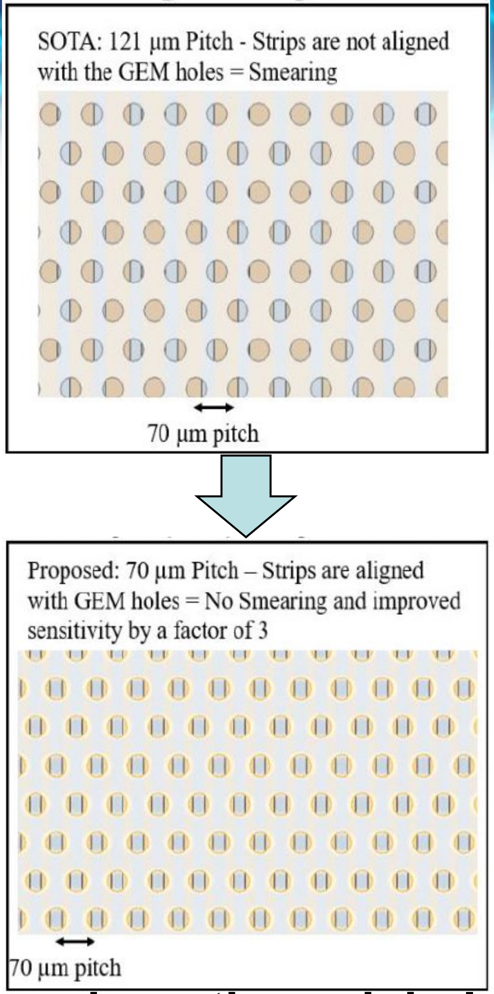


Mode 1: 2946.3Hz

APRA: "Development of 3D Hard X-ray Photoelectric Polarimeter Assembly Using Additive Manufacturing Technology"



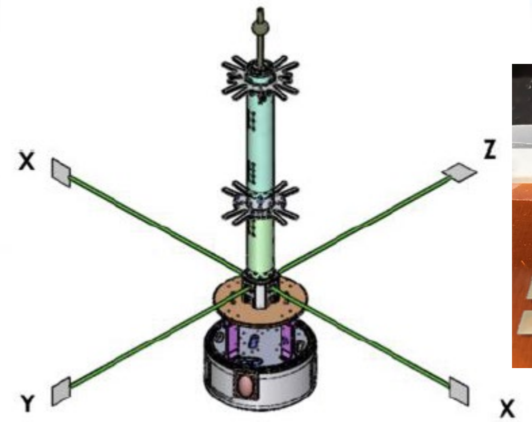


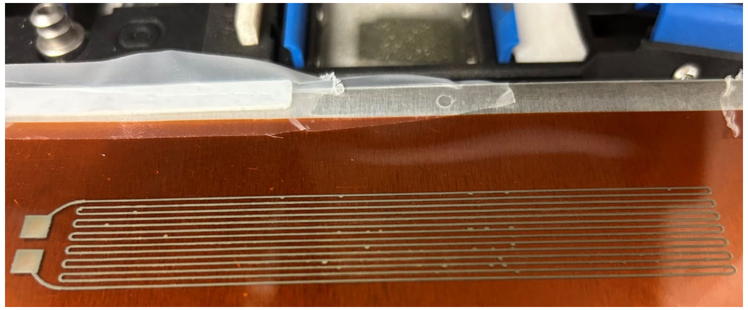


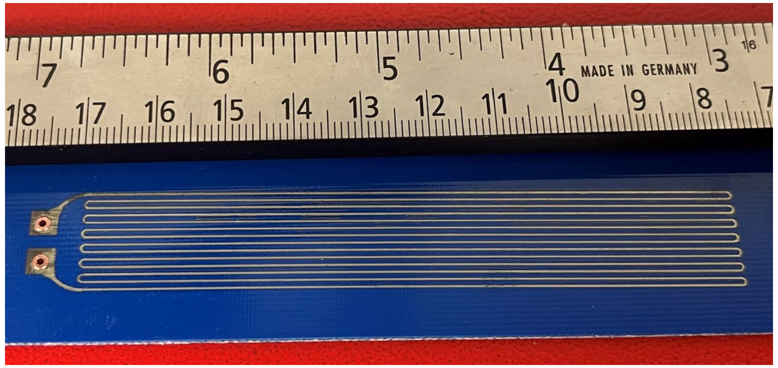
Looking down through holes on Gas Electron Multiplier (GEM) to detector strips underneath

Heliophysics: "Printed strain gauge for Sounding rocket boom measurements"

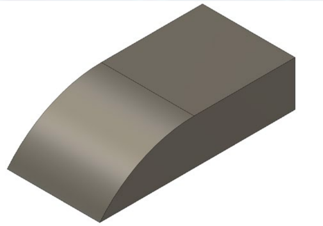
- Printing strain gauges on ends of ½" diameter fiberglass tube – measure displacement due to wind velocity
- Initial prints with Ag ink yielded resistance of 400 – 500 Ohms → *Need resistive inks*
- Design strain gauge with:
  - Adhesion (ASTM testing)
  - 1 kOhm resistance
  - 10^{-6} sensitivity





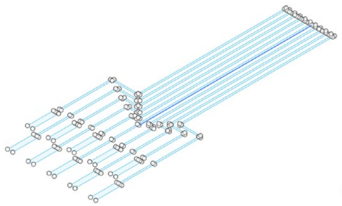


Crowdsourcing Contenders: "Automated Design and Placement of Printed Hybrid Electronics on Non-Traditional Surfaces"

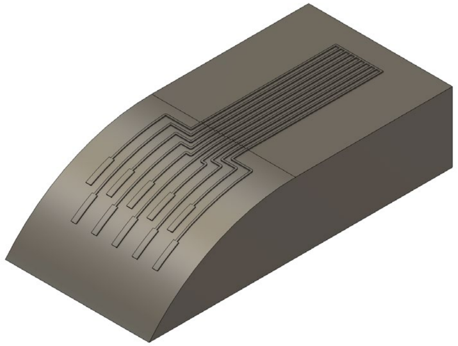


3D Part

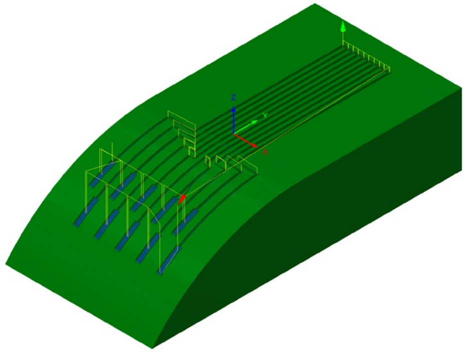
2D Circuit



Projection



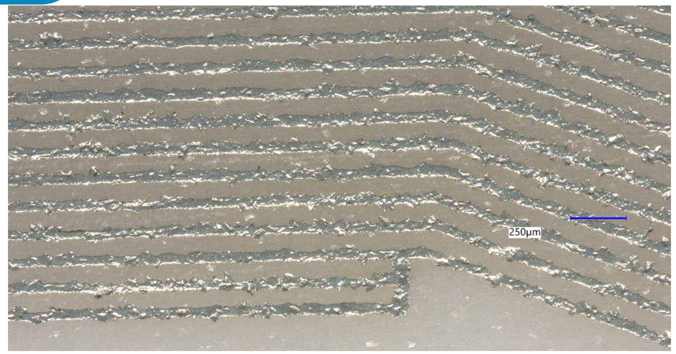
CAM toolpath



Machine code toolpath

G-code transpiler

Print



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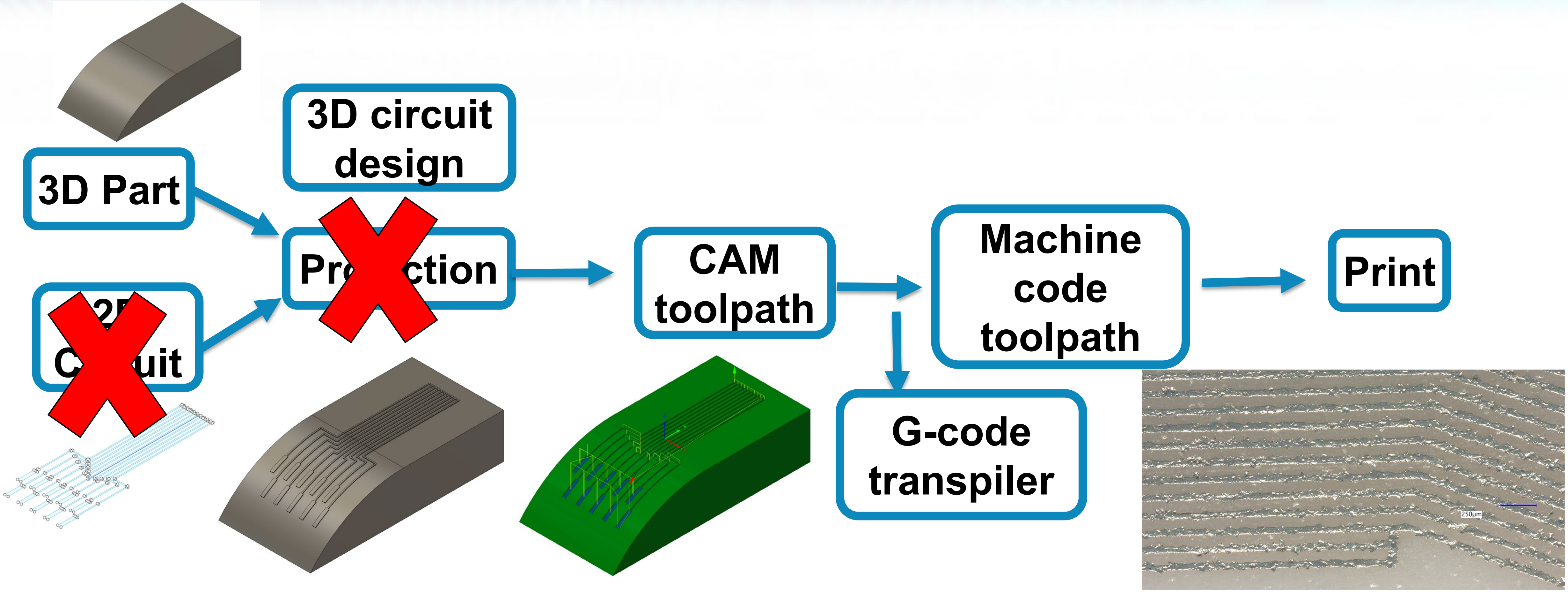

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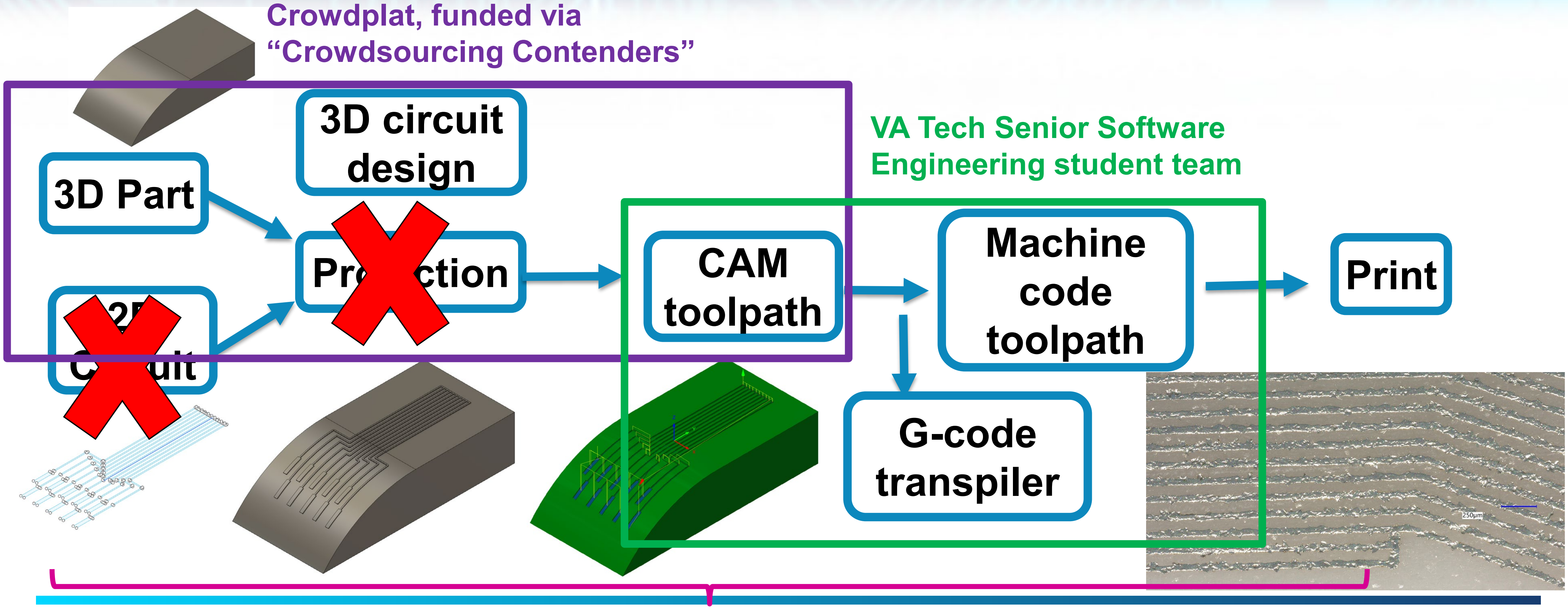
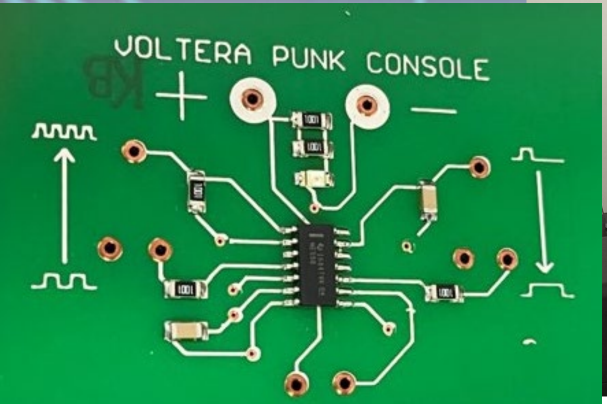
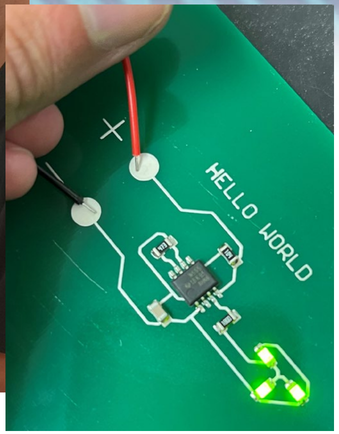
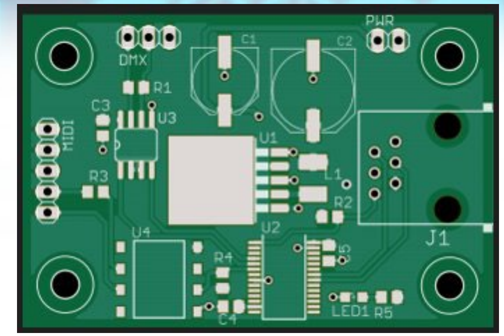


Process sketched ACSPL transpiler begun by Jesse Trutna, OSTEM summer intern

3D Printing Electronics Laboratory

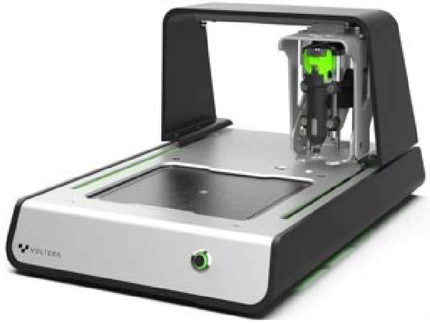






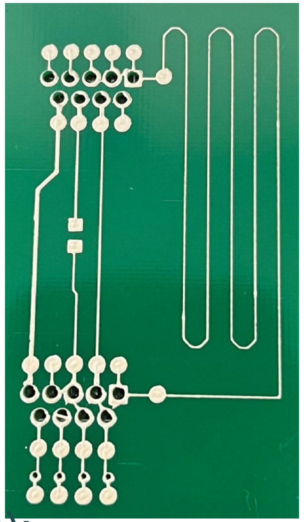
<u>Voltera V-One</u>

- Min. line width: *200 μm*
- Hole drilling:
  - *0.4 mm* diameter rivets
  - *1.0 mm* diameter rivets
- Ag-based conductive ink for traces and pads
- Reflow soldering built in
  - Sn42Bi57.6Ag0.4
- Also hand solderable



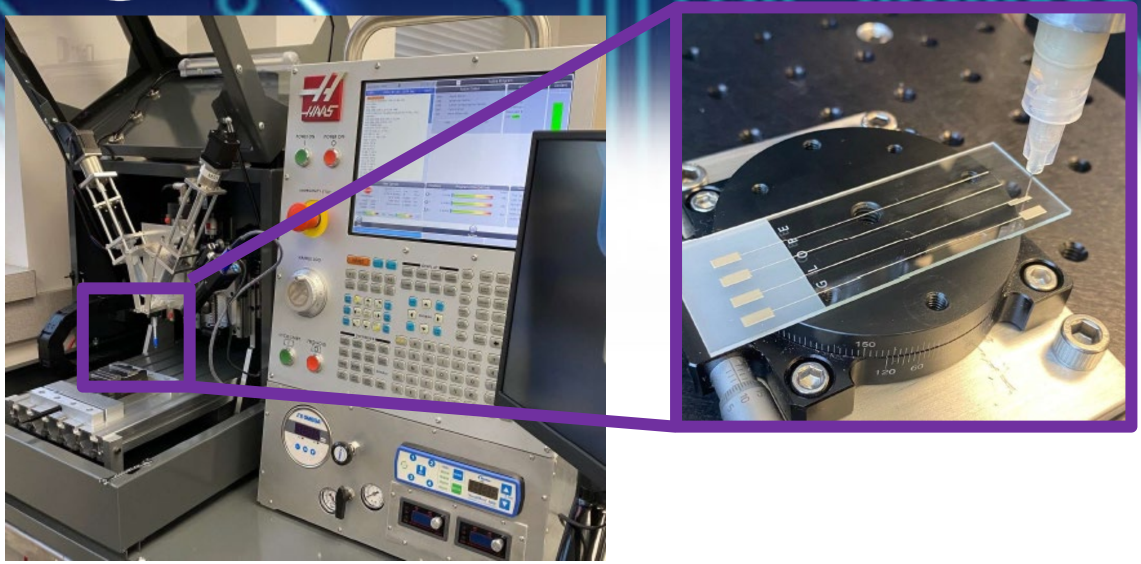
<u>Botfactory SV2 Professional</u>

- Min. line width: *200 μm*
- *Conducting* and *Insulating* ink
- Up to *6 layers* in a single print
- *Pick and Place*
- Reflow soldering built in
- Expected Resistance performance
- For a single printed layer (40 mΩ/sq):



	Line Width (μm)			
	250	500	1000	2000
Expected Resistance (mΩ/mm)	160	80	40	20

3D Printing Electronics Laboratory: coming soon



<u>3D Flexible Tabletop</u>

- Min. line width: *100 µm*
- Additive and subtractive capabilities (milling, laser cutting)
- Direct Ink Write
- 3-axis printing
- Prints conductive, insulating, ceramic, custom inks
- Multiple print head controls

<u>Voltera NOVA</u>

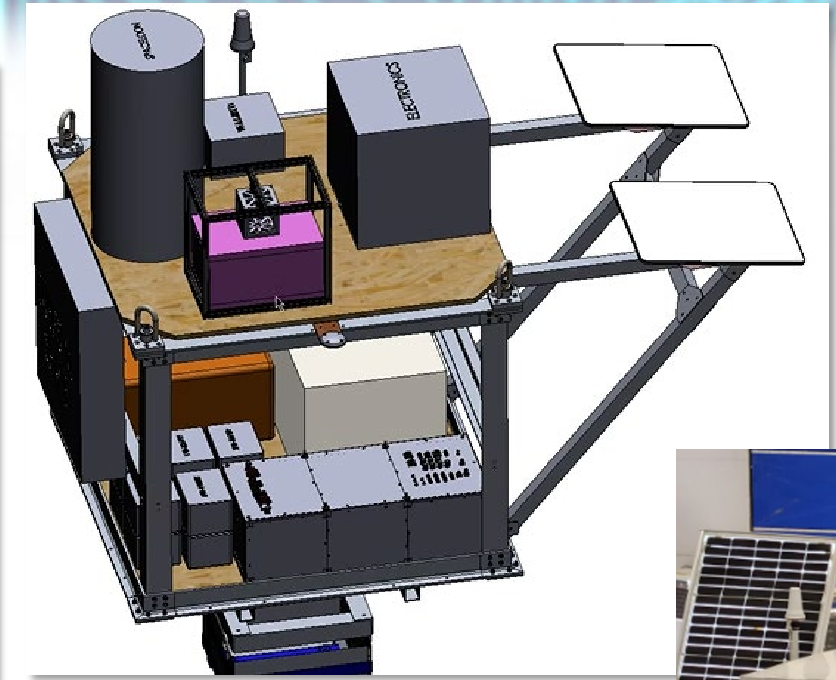
- Min. line width: *100 µm*
- *Conducting* and *Insulating* ink
- Up to *6 layers* in a single print
- Direct Ink Write
- Up to 30^{o} curved surface prints
- Prints customized inks
- Multiple print heads
- Modular print heads for future adaptability

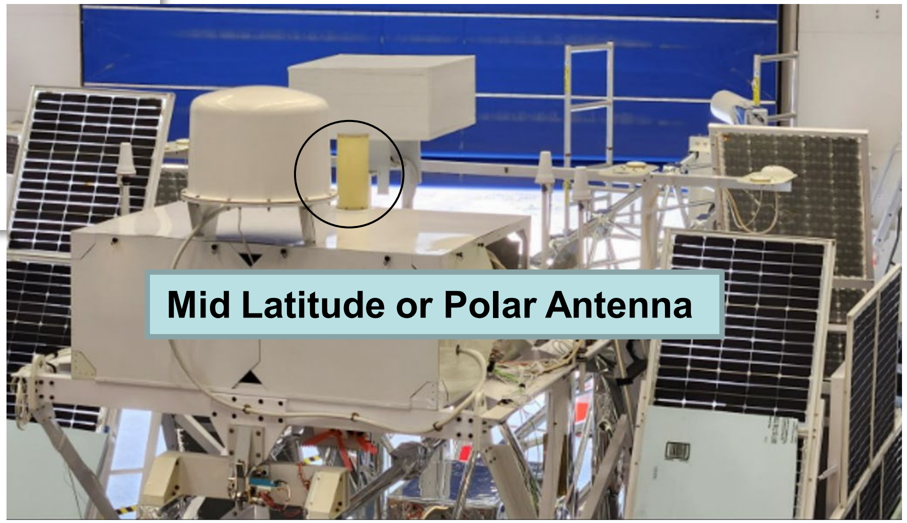
FY24 IRAD: 3D Printed antenna for a balloon flight

Scientific Balloon Program

- Balloon program is run from Wallops Flight Facility in Virginia
- 10 – 15 launches per year
- Launch sites include:
  - Fort Sumner, NM
  - Sweden
  - New Zealand
  - Antarctica
- For more information about the missions: https://www.nasa.gov/scientificballoons/

Balloon Payload Configuration - Salter Test Flight

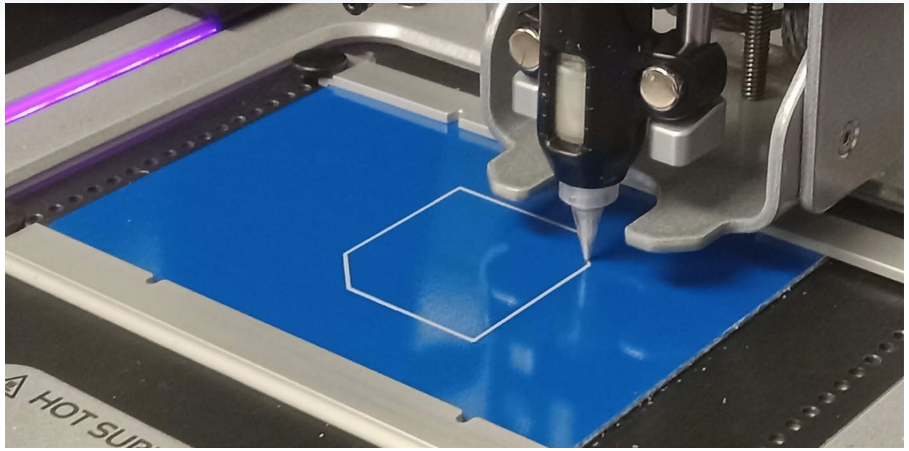


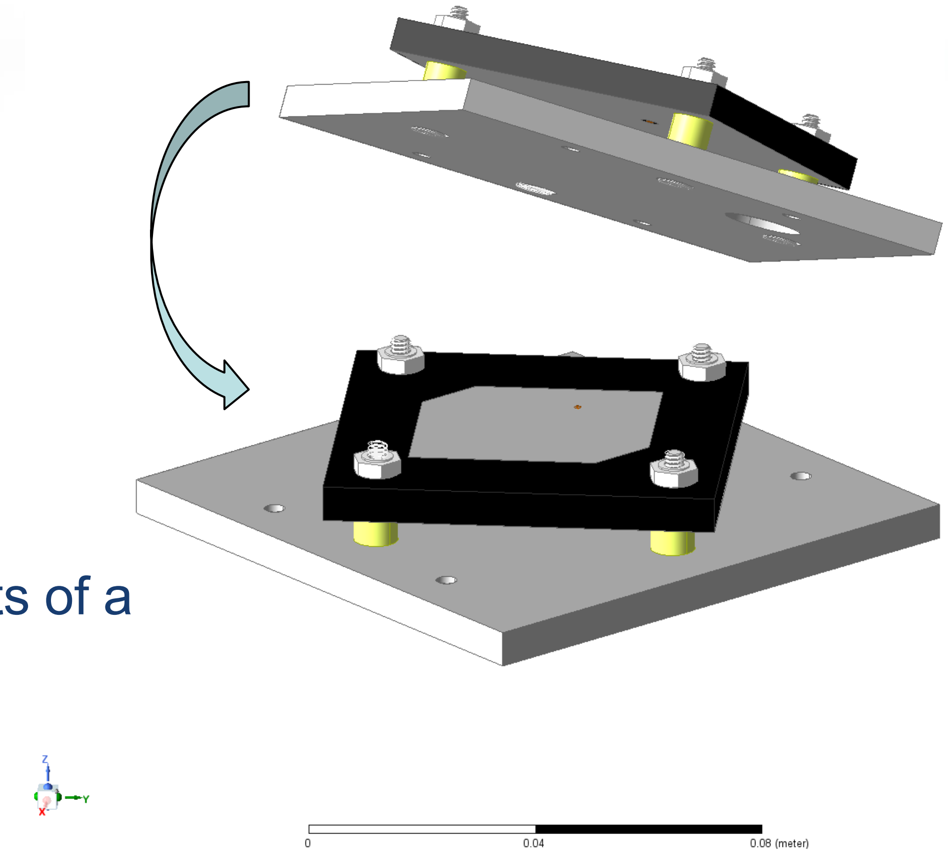


Balloon Deployment

Gondola for the Salter Test Flight

FY24 Antenna on Balloon Flight Goals





- Fly a printed TDRSS antenna, not transceiving
- Ground to satellite testing before flight
- Assessment of how printed materials hold up to elements of a balloon flight:
    - Pre- and post-flight antenna performance testing
    - Pre- and post-flight visual inspection

*Antenna design by Peter Moschetti/567
Printing by Tristan Epp Schmidt/562 Alexander Moricette/FAMU/FSU and Joshua Davey/FAMU/FSU

Project timeline

Time frame	Task	Location	Status
May 15	Funding approved	GSFC	-
May/June	Antenna design	Greenbelt, MD	Complete
June	Print prototypes	Greenbelt, MD	Complete
June	Adhesion testing	Greenbelt, MD	Complete
June	Drill holes in print	Greenbelt, MD	Complete
June 24	MIC/ORDM/ODR Design Review with BPO	WFF/GSFC	Complete
Early-Mid July	Iterate design and print if needed, otherwise, print extra for T-Vac and thermal tests	Greenbelt, MD	Complete
Early July	RF assembly	Greenbelt, MD	Complete
July 10	Pre-Integration Review with BPO	WFF/GSFC	Complete
Early-Mid July	Anechoic chamber testing	Greenbelt, MD	Complete
July 18, 19	Ground Testing	Palestine, TX	Complete
Late July	Instructions for mounting antenna plate and returning assembly	Greenbelt, MD	Complete
August	Integration and flight	Fort Sumner, NM	Flew Aug 22, 2024
September	Post-flight anechoic testing, inspection, data analysis	Greenbelt, MD	Late Sept – Early Oct

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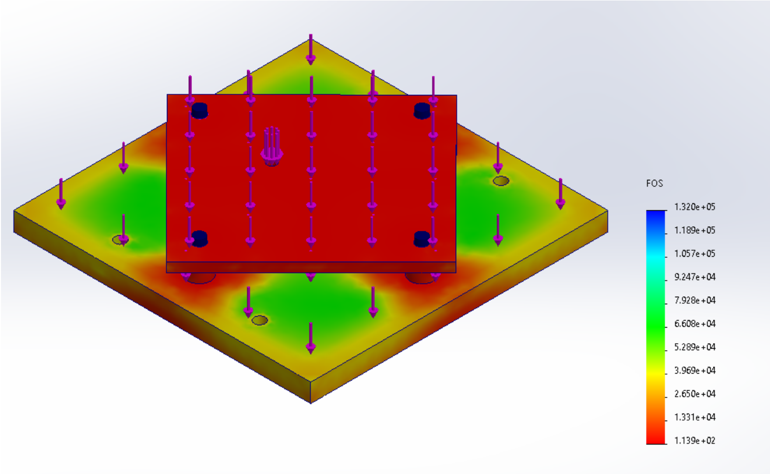
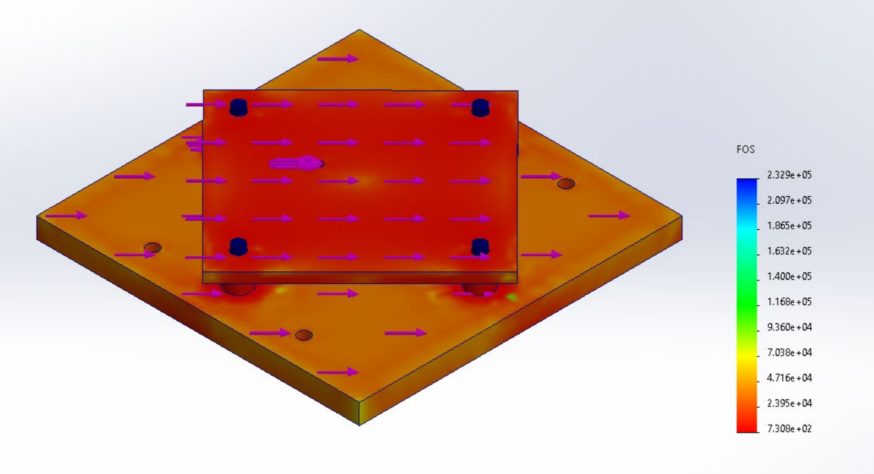
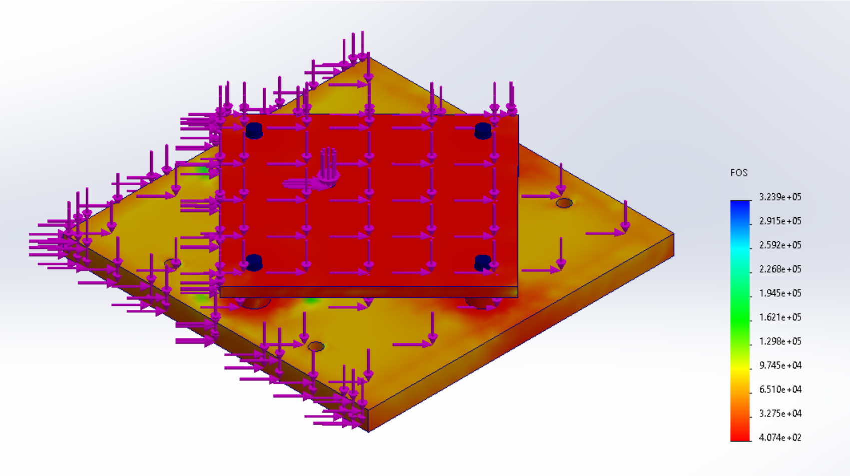
Structural Finite Element Analysis







Case 1: force applied vertically downwards

- F = 8x(Weight of assembly)
- FOS ~**110**

Case 2: force applied laterally

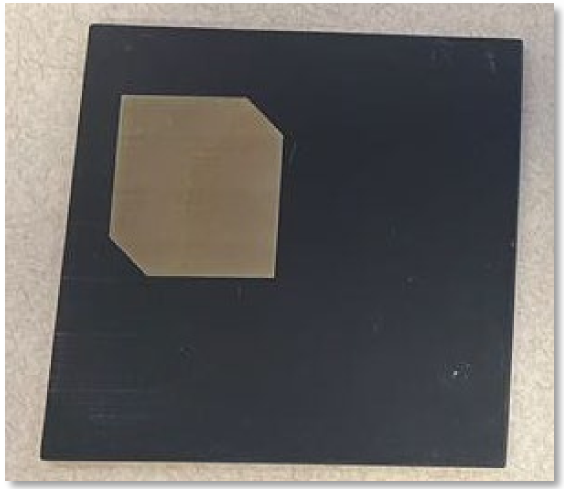
- F = 4x(Weight of assembly)
- FOS ~**730**

- Case 3: force applied at a 45^o angle
- F = 4x(Weight of assembly)
- FOS ~**410**

*Structural analysis performed by Joshua Davey/FAMU/FSU as per 820-PG-8700.0.1 Gondola Structural Design Requirements

Adhesion Testing

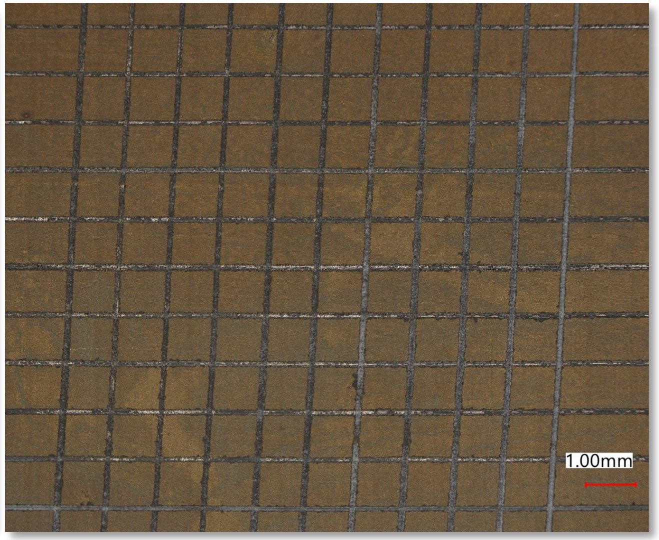
ASTM D3359 Method B Tape Adhesion Test



Pre-Test

Post-Test

Before Tape removal



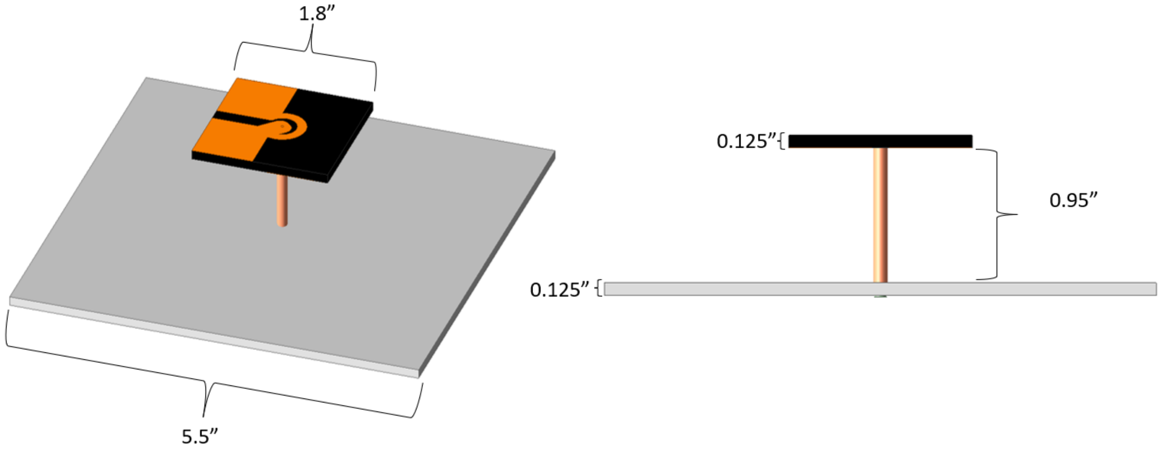
After Tape removal

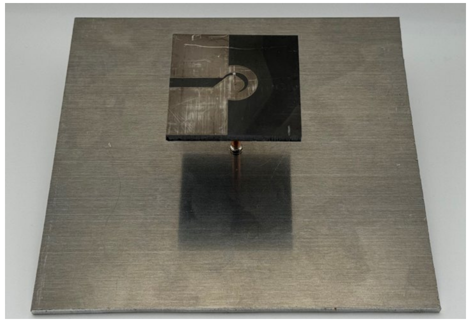
Method Description: A cross hatch of 6 parallel 1mm spaced cuts are made on the coated sample in the vertical and horizontal directions. A specified tape is applied firmly to the cut area and removed rapidly (not jerked) after 90 seconds wait time. The area is inspected and graded on a 0 to 5 scale where 5 is no material removed and 0 is greater than 65% material removed.

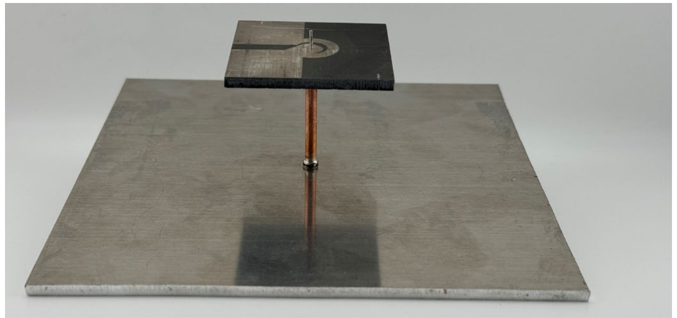
Results: 4B, less than 5% of material removed. This represents very good adhesion of conductive ink to the Radix substrate.

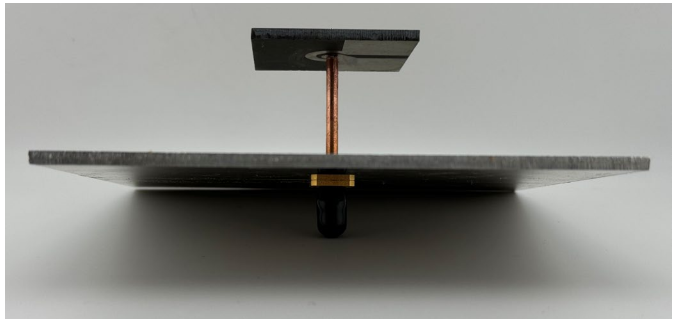
*Adhesion testing performed by Md Alamgir Hossain/FAMU and Tristan Epp-Schmidt/562

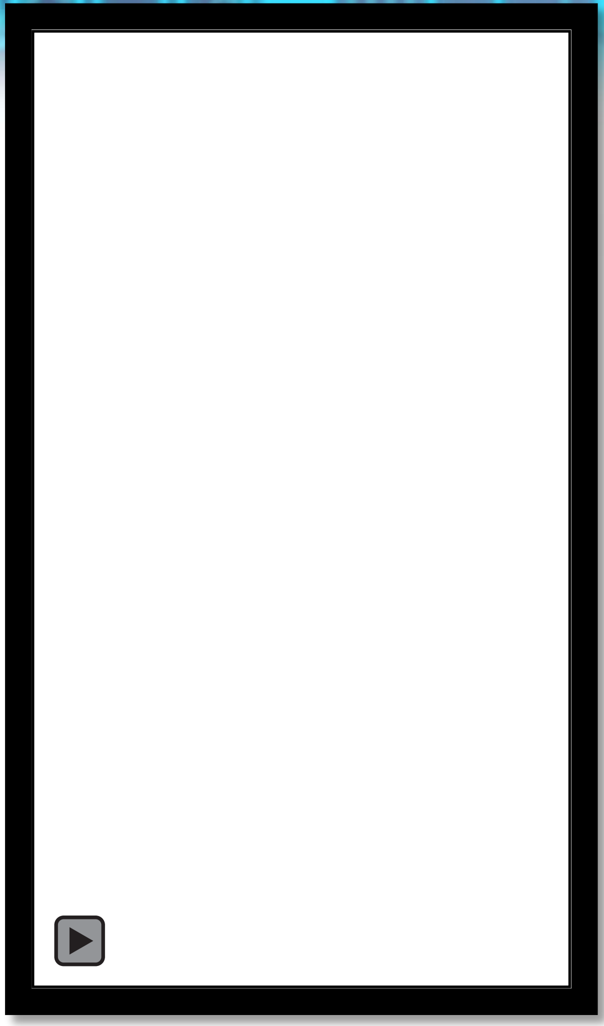
Printed magneto electric dipole design











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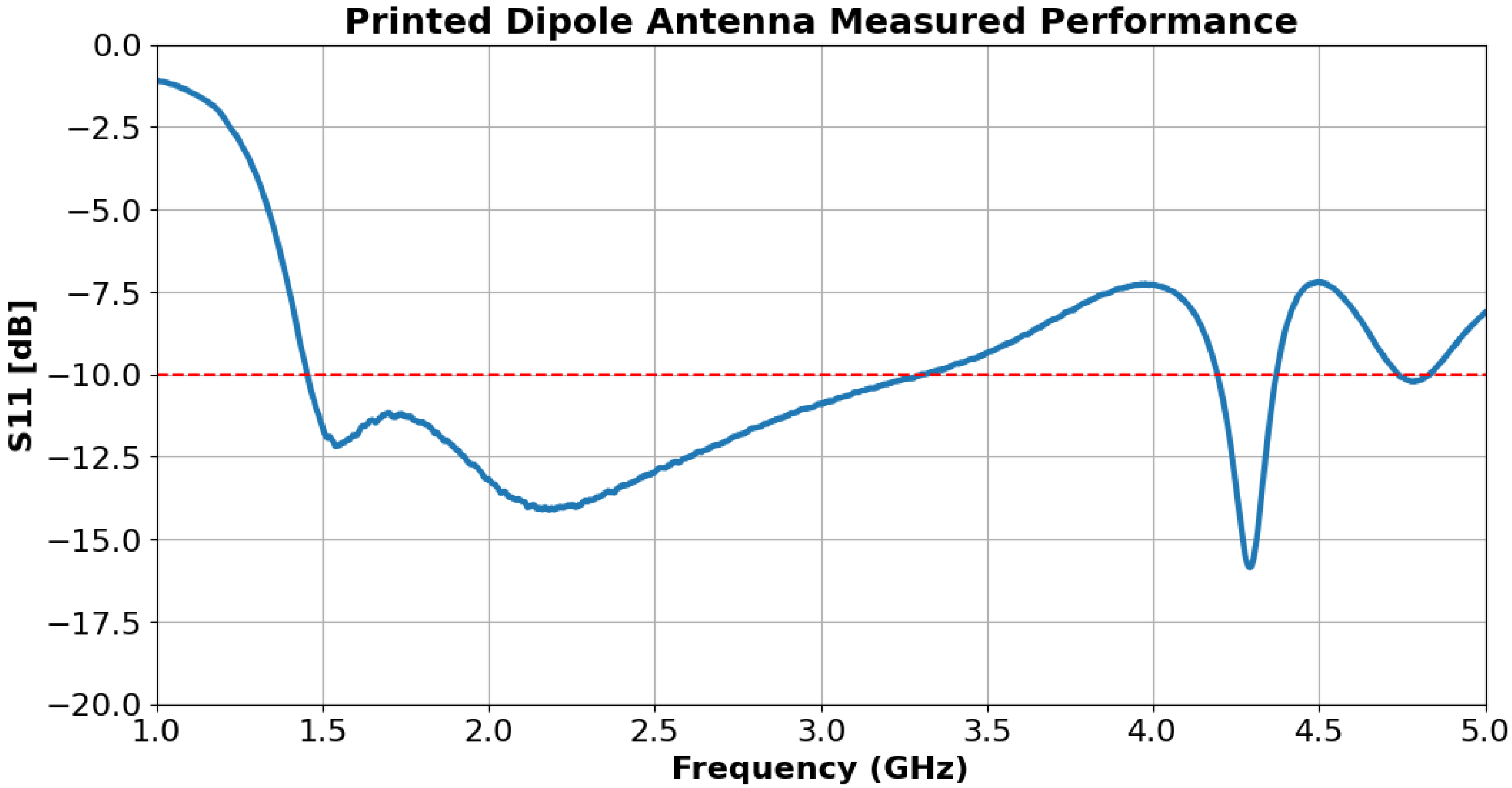
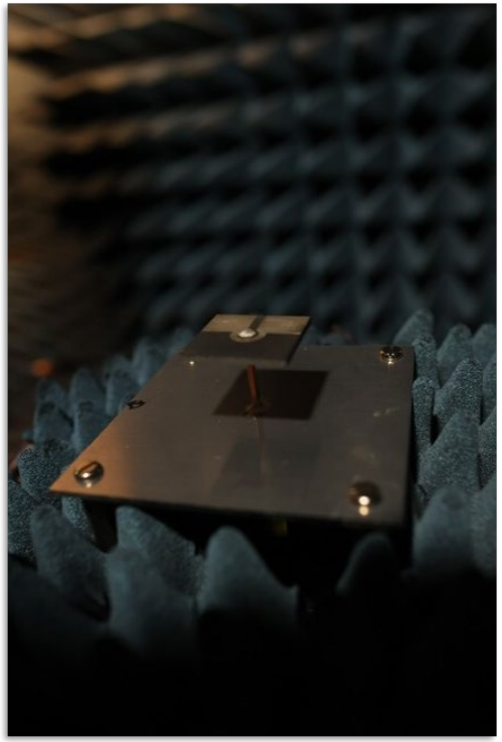
Printing by Tristan Epp Schmidt/562 Alexander Moricette/FAMU/FSU and Peter Moschetti/567

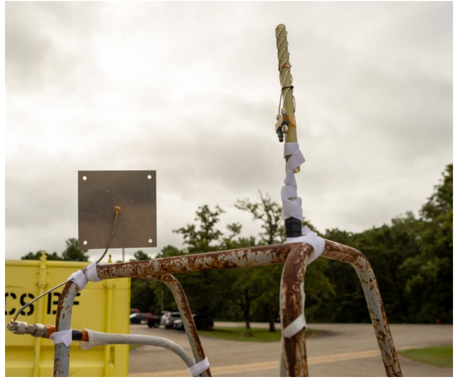
Anechoic chamber testing: Antenna signal vs. frequency

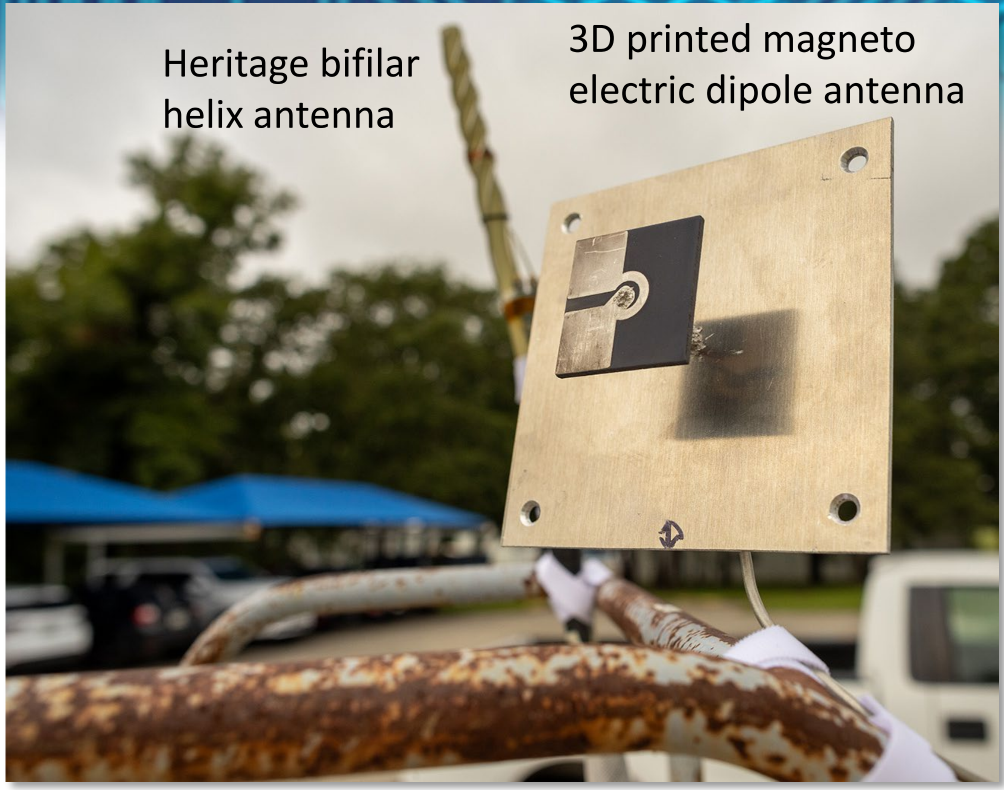




*Antenna testing performed by Justin Long/567

TDRSS Uplink and Downlink Testing





Testing with satellite F6

Bifilar helix antenna strongest signal:
- Signal Strength at F6: 13.15 - 13.33 dB

3DP ME Dipole strongest signal:
- **~45˚ from vertical and 100˚ azimuth**
- Signal Strength at F6: 15.54 - 16.01 dB

*Antenna testing performed by Peter Moschetti/567 and the Columbia Scientific Balloon Facility NASA personnel

Aug 22, 2024: Balloon flight launched!

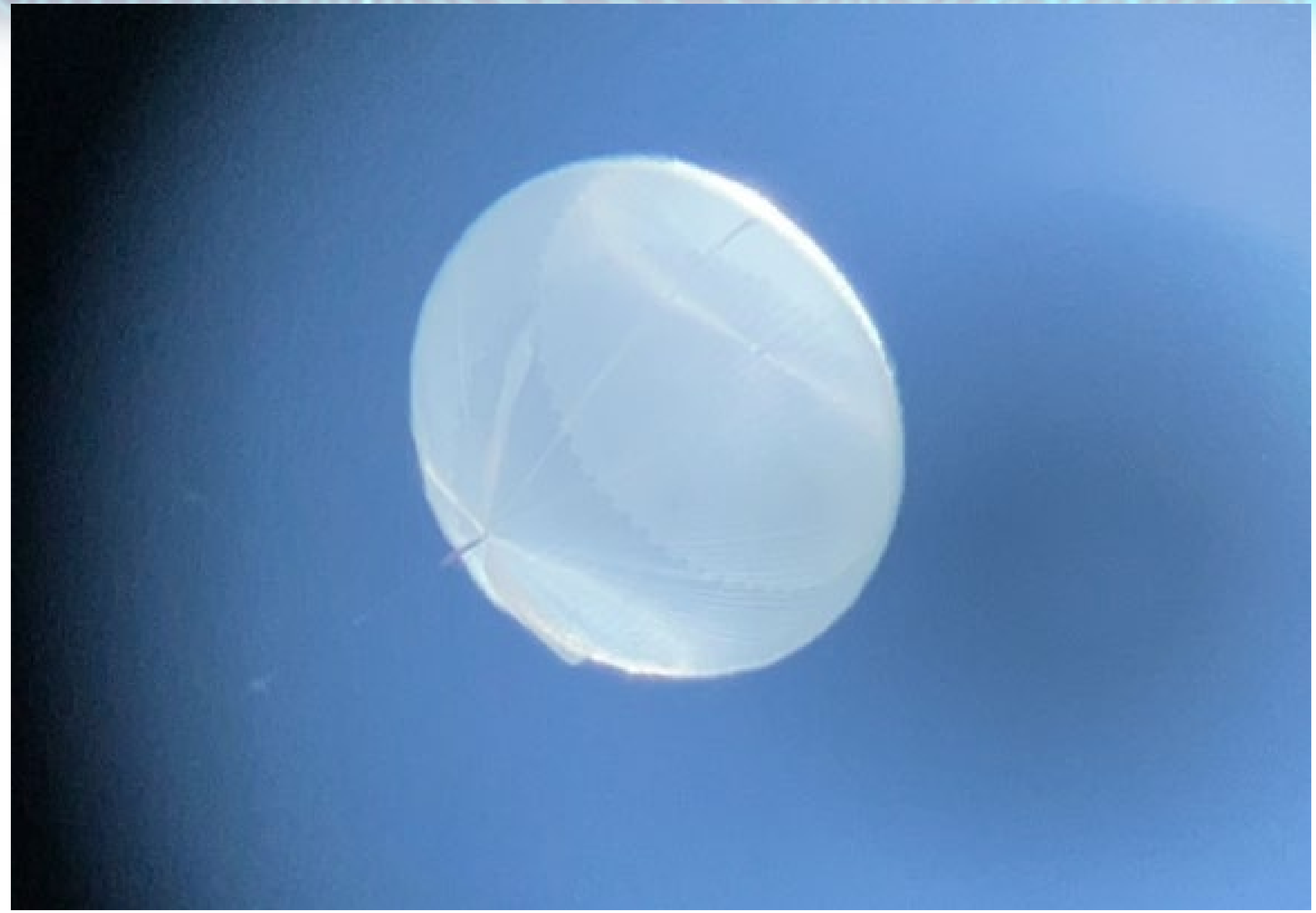
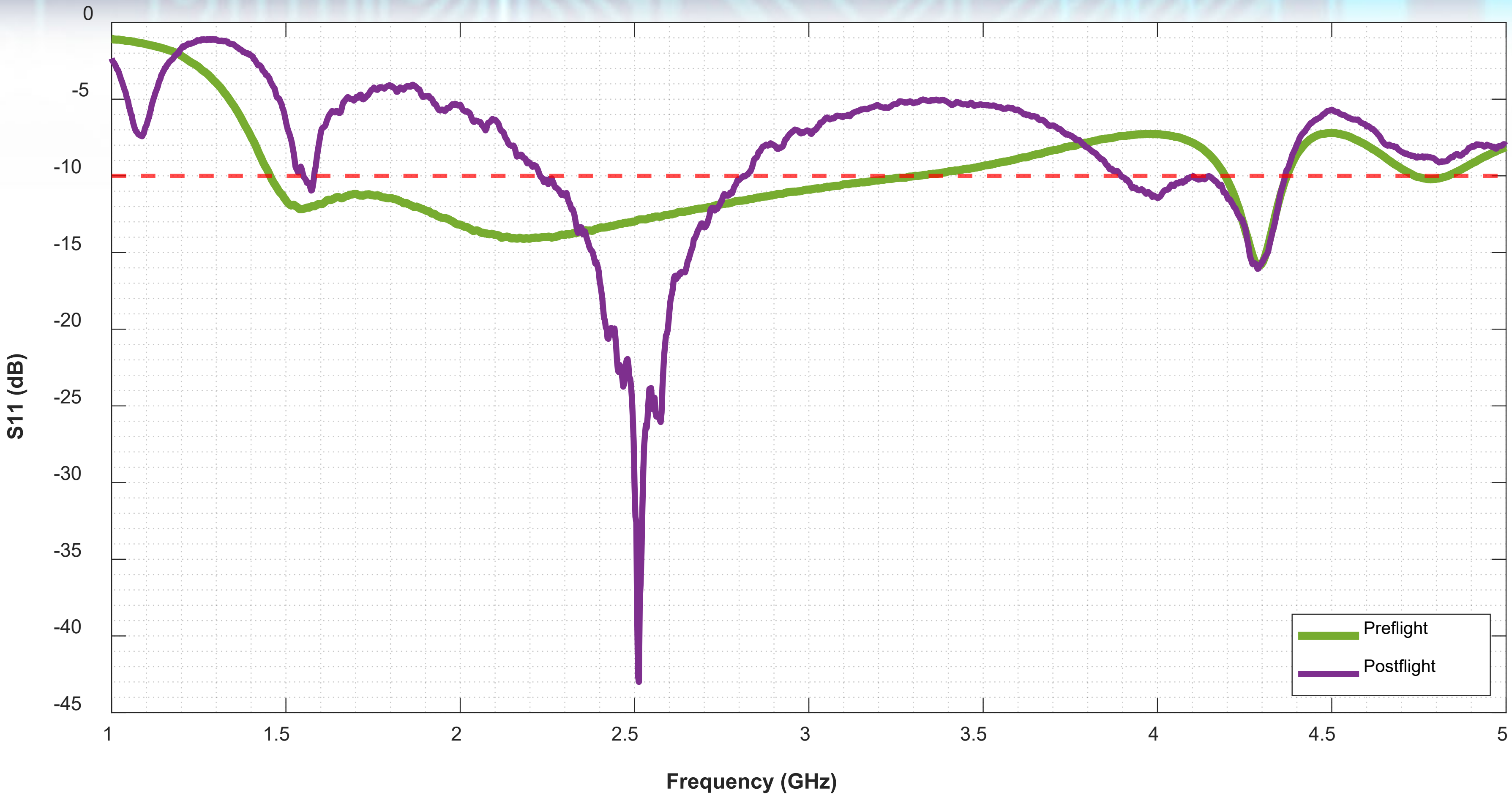


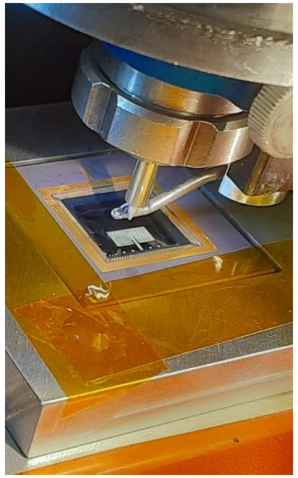
*Photo credit to Scott Hesh/569

Comparing pre and post flight antenna performance

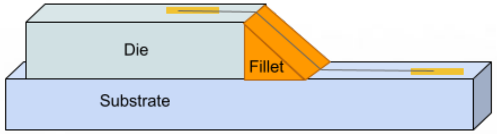


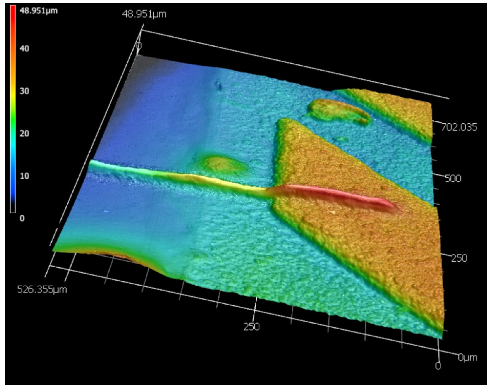
*Antenna testing performed by Justin Long/567 and Brian Banks/569

Future work for 3D Printing Electronics at NASA GSFC

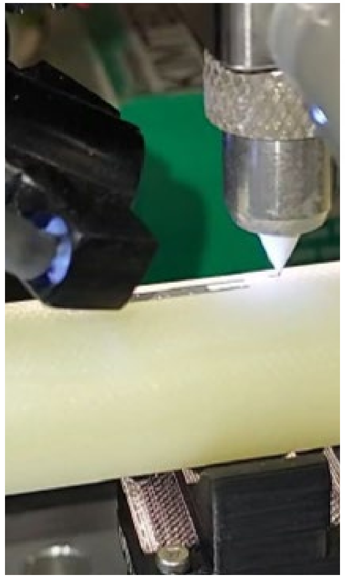


Printing antennas to minimize losses

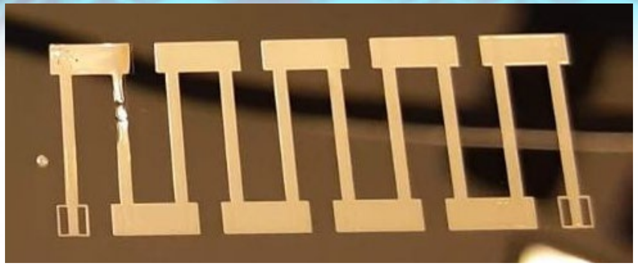


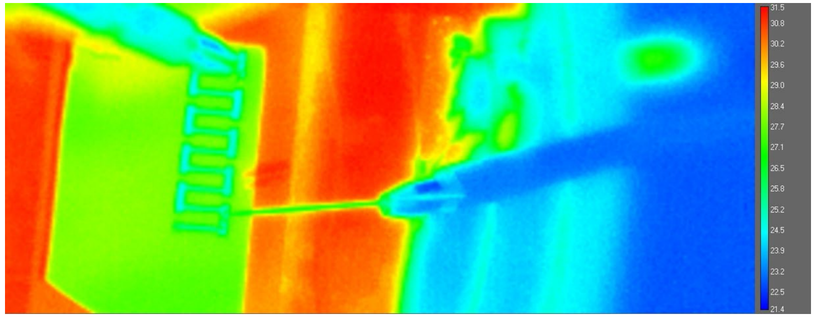


Printing interconnects and large interconnect arrays



Curved surface print applications:
Antennas, strain gauges, sensors



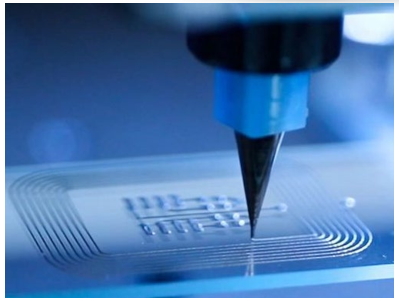


Localized heating for outgassing sensors; temp control at cryo interfaces

*RF patch antenna designed by Wei-chung Huang/567 for Multifunctional Sensor Platform (MFSP) Project led by Mahmooda Sultana/699

3D Printing of Electronics Lab:
available for project prototyping and research needs!

<u>Botfactory SV2 Professional</u>
- Min. line width: *200 μm*
- *Conducting* and *Insulating* ink
- Up to *6 layers* in a single print
- *Pick and Place*
- Reflow soldering built in
- ***Great for iterating early board designs; test early and often, eliminating design flaws early and inexpensively!***



<u>Voltera NOVA</u>
- Min. line width: *100 μm*
- *Conducting* and *Insulating* ink
- Up to *6 layers* in a single print
- Direct Ink Write, 3-axis printing
- Prints customized inks
- Multiple, modular print heads

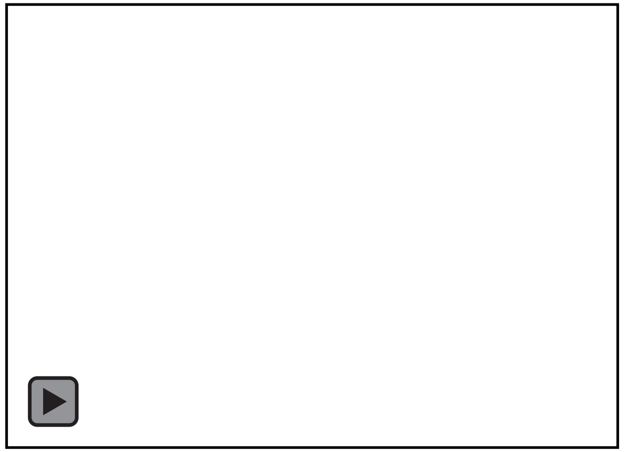
<u>3D Flexible Tabletop</u>
- Min. line width: *100 μm*
- Additive and subtractive capabilities (milling, ***laser cutting***)
    - ***Can also print ceramics, including ceramic structures for PV and battery applications***
- Direct Ink Write, 3-axis printing
- Prints conductive, insulating, ceramic, ***custom inks***
- Multiple print head controls

Location: Bldg 22, Room 080 **POC: margaret.h.samuels@nasa.gov**

Special thanks to all teammates and collaborators:

- *NASA GSFC 3D Printed Electronics Team:*
  - Tristan Epp-Schmidt/562, Matthew Minogue/562, Beth Paquette/562, Mohammed Abdin/555
- *NASA GSFC Code 567, RF branch:*
  - Peter Moschetti/567, Justin Long/567
- *NASA WFF Balloon Program Office and Columbia Scientific Balloon Facility:*
  - Brian Banks/569, Scott Hesh/569, Amy Davis/569
  - Chip Choquette/820, Erin Reed/820
  - Curtis T. Wooten/820, Joseph A. Jones/820
- *Summer 2024 Florida A&M University interns:*
  - Alexander Moricette, Joshua Davey, and Md Alamgir Hossain
- *NASA GSFC 560 Support:*
  - Chris Green/501, Domonique Johnson/1593
  - Shavesha Rutledge/562, Chris Tiu/562

Our partners



Aerosol Jet Printing Detector Strip Pattern on Liquid Crystal Polymer [M. Samuels/562, LPS]

Acronym Table

Acronym	Definition
ASTM	American Society for Testing and Materials
CAD	Computer aided design
CAM	Computer aided manufacturing
IRAD	Internal Research and Development
TDRSS	Tracking and Data Relay Satellite System
RF	Radio frequency
BPO	Balloon Program Office
MIC	Mission Initiation Consultation
ORDM	Operations Requirements Design Meeting
ODR	Operations Design Review
LHCP	Left hand circular polarized

Backup

Material Profiles

- G10/FR4: Spacers
  - Elastic Modulus: 1.8616e+10 N/m^2
  - Poisson's Ratio: 0.12
  - Mass Density: 1800 kg/m^3
  - Yield Strength: 2.62e+8 N/m^2
- Aluminum: Ground Plane
  - Elastic Modulus: 6.8e+10 N/m^2
  - Poisson's Ratio: 0.36
  - Mass Density: 2699 kg/m^3
  - Yield Strength: 4e+7 N/m^2

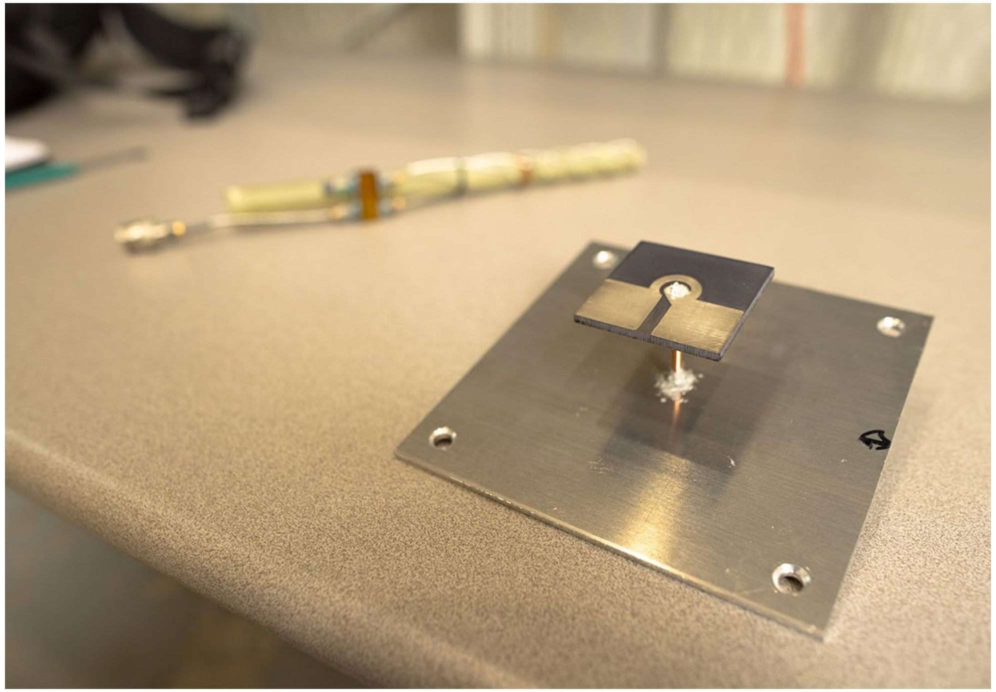
Material Profiles cont.

- PTFE: Screws and Bolts
  - Elastic Modulus: 5.64e+8 N/m^2
  - Poisson's Ratio: 0.46
  - Mass Density: 2070 kg/m^3
  - Yield Strength: 2.05e+7 N/m^2
- Radix: Antenna
  - Elastic Modulus: 1.652e+9 N/m^2
  - Poisson's Ratio: 0.394
  - Mass Density: 1360 kg/m^3
  - Yield Strength: 3.8e+7 N/m^2

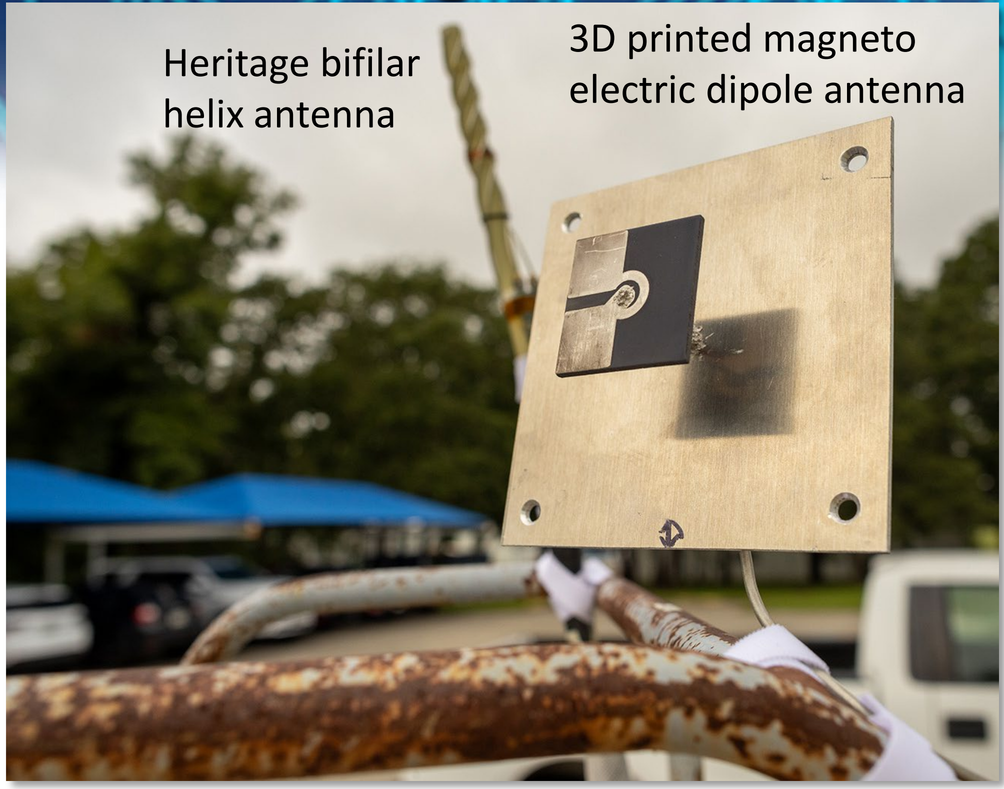
Comparing TDRSS antennas

3D Printed Magneto Electric Dipole Antenna
- Directional- Boresight
- S-Band
- LHCP
- Cost $$

Bifilar helix Antenna
- Omni Directional
- S-Band
- LHCP
- Cost $$$$$$



TDRSS Uplink and Downlink Testing



<u>**Testing with satellite F6**</u>
- From our location Azimuth 100˚ , Elevation 35˚
- Data rate: 6k
- Power Out from Transceiver: 5W

[Expecting Signal Strength from 9 to 13]

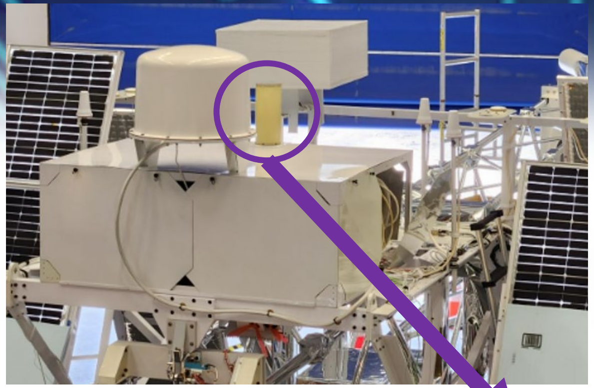
Mid-latitude (nominal) [Expecting Signal Strength from 9 to 13]
- Signal Strength at F6: 13.15 - 13.33 dB

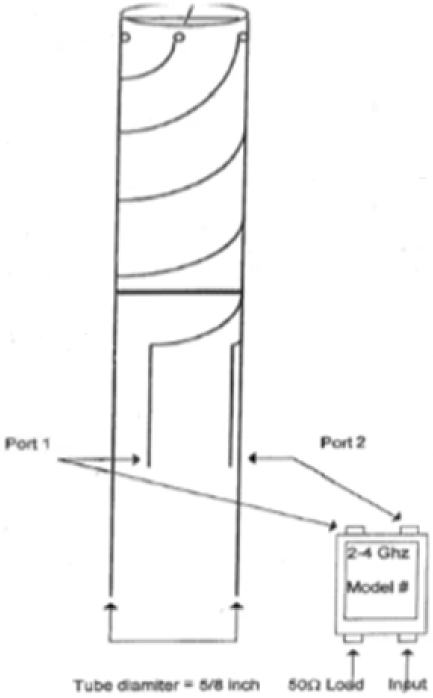
<u>**ME Dipole Transmit:**</u>
- **Vertical position:**
- Signal Strength at F6: 9.12 - 10.94 dB
- **~45˚ from vertical and 100˚ azimuth**
- Signal Strength at F6: 15.54 - 16.01 dB
- **~90˚ from vertical and 100˚ azimuth**
- Signal Strength at F6: 14.51 dB
- **~90˚ from vertical and 160˚ azimuth**
- Signal Strength at F6: 11.18 dB

<u>**Test Antenna Receive:**</u> [Expecting an AGC of <2.0]
- **Vertical position**
- AGC at Modem: 0.9-1.1
- **~45˚ from vertical and 100˚ azimuth**
- AGC at transceiver: 0.7 - 1.1
- **~90˚ from vertical and 160˚ azimuth**
- AGC at transceiver: 1.5 - 1.8

*Antenna testing performed by Peter Moschetti/567 and the Columbia Scientific Balloon Facility NASA personnel

FY25 Antenna on Balloon Flight Goals





- Print TDRSS Mid-latitude helical antenna, ports, hybrid coupler, etc. onto fiberglass rod
- Fly antenna and transceive, collect data
  - Bonus if we can compare to other antenna data
- Ground testing before flight
- Demonstrate capability to custom design antennas and RF circuits

Remaining work

- Post-flight anechoic chamber testing (late September)
- Environmental testing to space specs (late September)
- Further evaluate anechoic testing data and ground testing data (October)
- Post-flight inspection of printed antenna after exposure to atmospheric conditions (October)