E2.03 - Team Waveguide

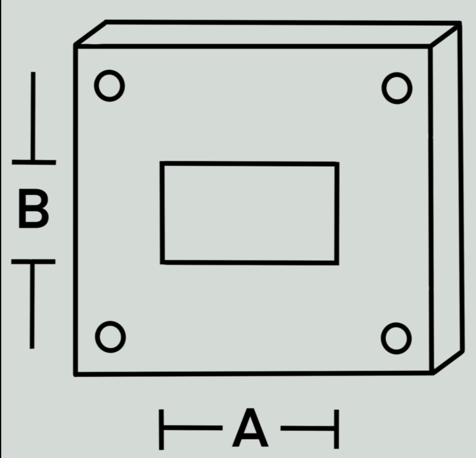
TEXAS STATE INGRAM SCHOOL OF ENGINEERING

Anurag Kumar (PM) | Matthew Bistricer | Josue Garcia | Cole Knapek
Vahid Jalaliani | Brodrick Mills | Sarah Picas | Dylan Woody
Dr. Richard Compeau




Anurag — Coax Adapter | Vahid — Coax Adapter | Sarah — Straight Section | Dylan — Bulkhead Adapter

The WR-90 Standard



Key Features

- Transmits frequencies in the 8.2-12.4 GHz range (X Band).
- WR-90 flange has the following dimensions:
  - A = 22.82mm
  - B = 10.1 mm
- Allows for integration of waveguides from different manufacturers.

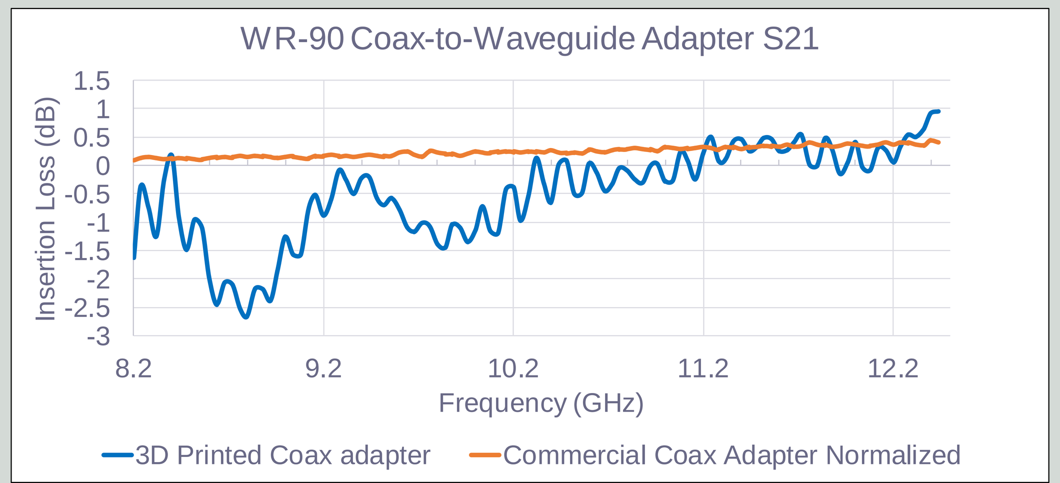
Component Characterization Process

Vector Network Analyzer

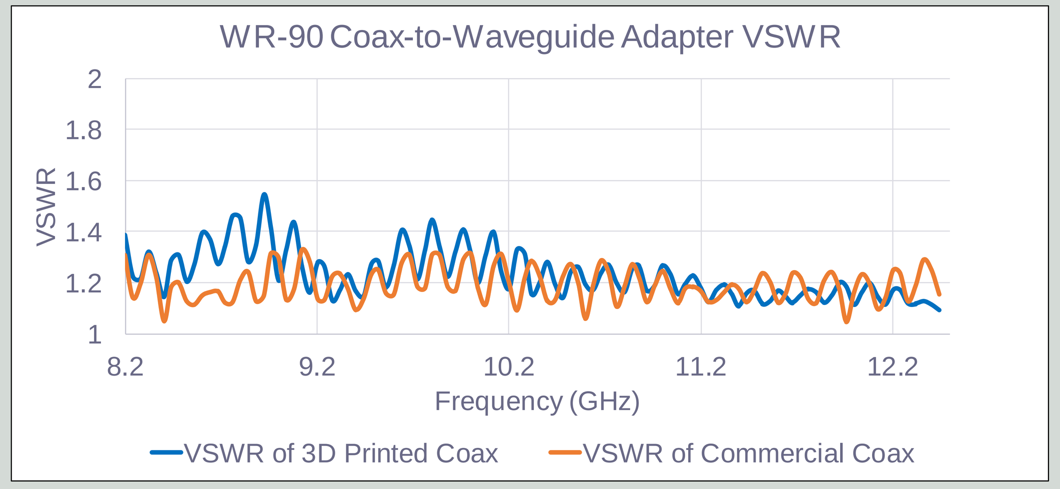
- Measures Scattering or S-parameters of microwave components, for our project this involves a two-port network.

- Utilized an 18 GHz Keysight Fieldfox VNA.
- Performed normalization by connecting two commercial coax adapters.
- Measured the insertion loss, S21 parameter.
- Measured the return loss, S11, and used those values to calculate the VSWR using the following formula: $VSWR = \frac{1+|S_{11}|}{1-|S_{11}|}$

Coax Adapter Data

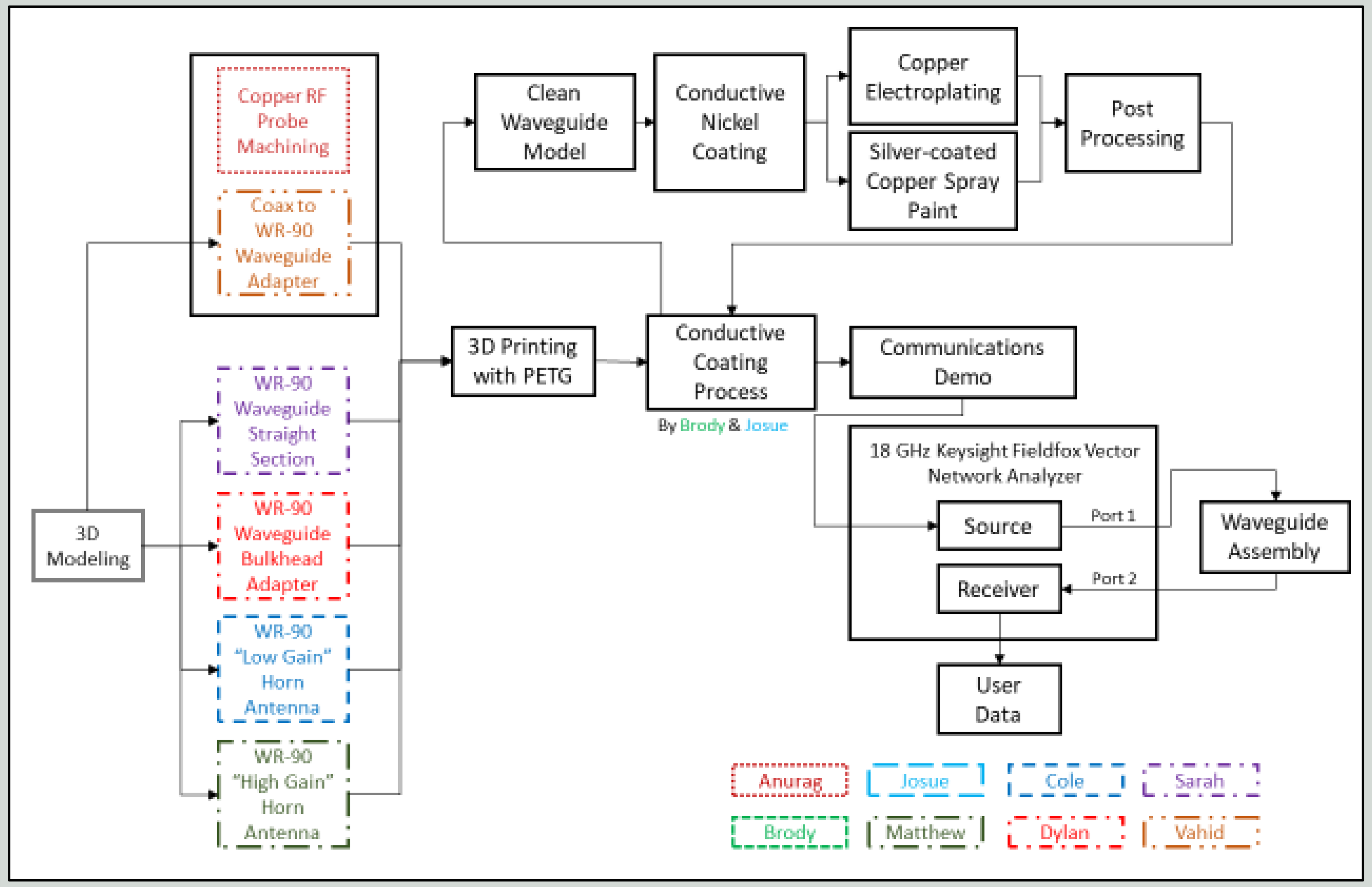


- While this doesn't meet the requirements of being less than 1 dB of insertion loss over the passband, the performance of this component still performs quite well, especially at higher frequencies.



- The VSWR values for the 3D printed coax adapter are very close to the commercial coax adapter. It met the requirement of being <1.5 over the passband.

Process Flow Diagram



Project Scope

- Replicating and verifying commercial WR-90 waveguide components and their characteristics with conductive coated 3D printed components.

What are Waveguides?

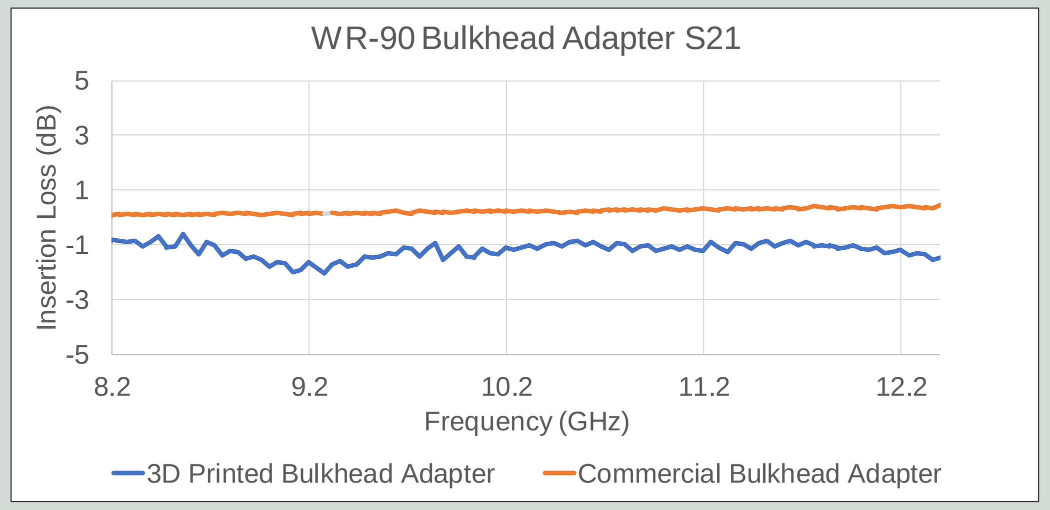
- Structures that transmit waves with low losses using their shape and physical characteristics.
- Focus EM waves in one direction, instead of letting them propagate normally.

Requirements

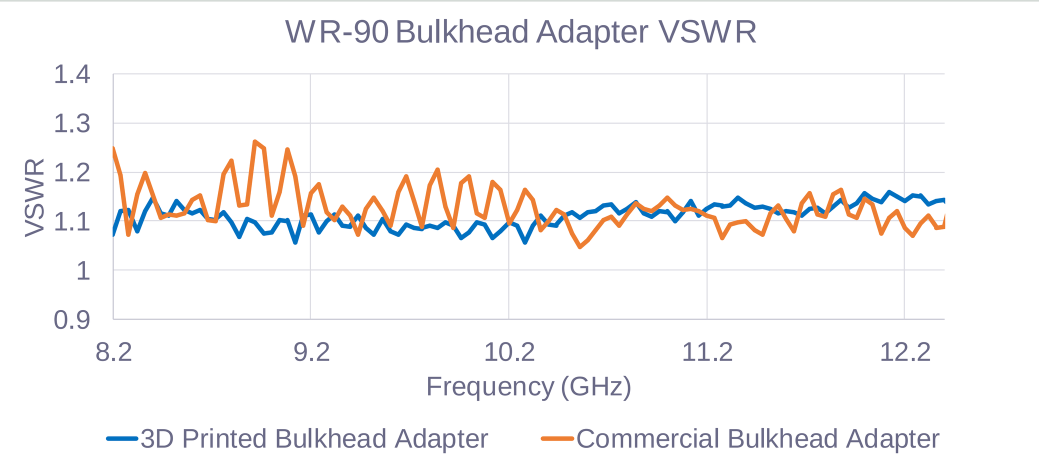
- Insertion Losses are losses in transmitted signal through the waveguide.
- VSWR measures how efficiently power is transmitted through the waveguide.
- Budget was to remain within 20% of the commercial component.

Data Type	Waveguide Bulkhead Adapter	Waveguide Straight Section	Coax-to-Waveguide Adapter
Insertion Loss Req.	0.5 dB/m	0.5 dB/m	1 dB
Insertion Loss Measured [Commercial] Max/Average (dB)	1.33 / 0.43	1.33 / 0.43	n/a
Insertion Loss Measured [3D Printed] Max/Average (dB)	2.02 / 1.20	0.76 / 0.18	2.66 / 0.49
VSWR Req.	<1.5	<1.5	<1.5
VSWR Measured [Commercial] Max/Average	1.26 / 1.13	1.26 / 1.15	1.33 / 1.19
VSWR Measured [3D Printed] Max/Average	1.16 / 1.11	1.16 / 1.11	1.54 / 1.23
20% of Commercial Cost	$73.00	$40.00	$72.00
Estimated Project Component Cost	$17.50	$15.00	$18.50

Bulkhead Adapter Data

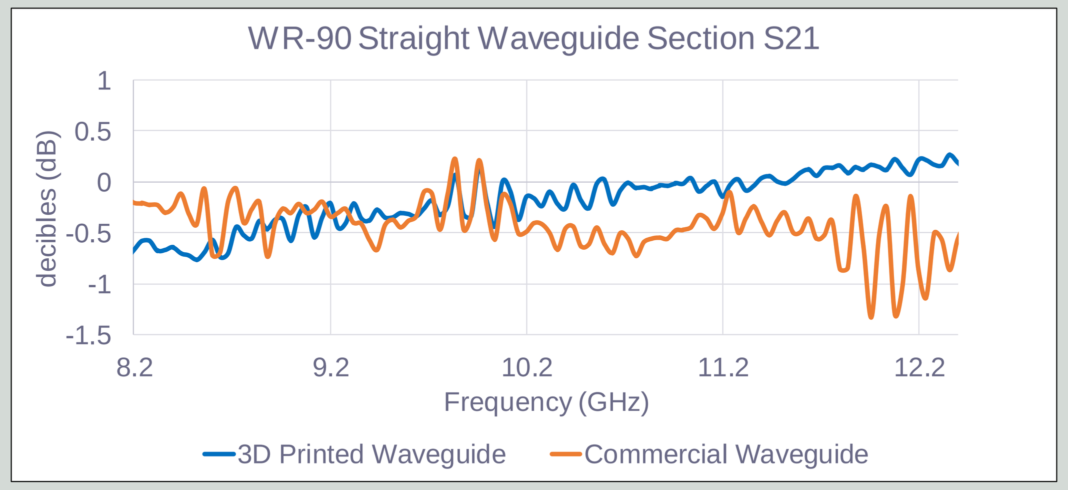


- The S21 readings from the VNA show data close to within requirement, measurements that are nearly comparable to the commercially available components.

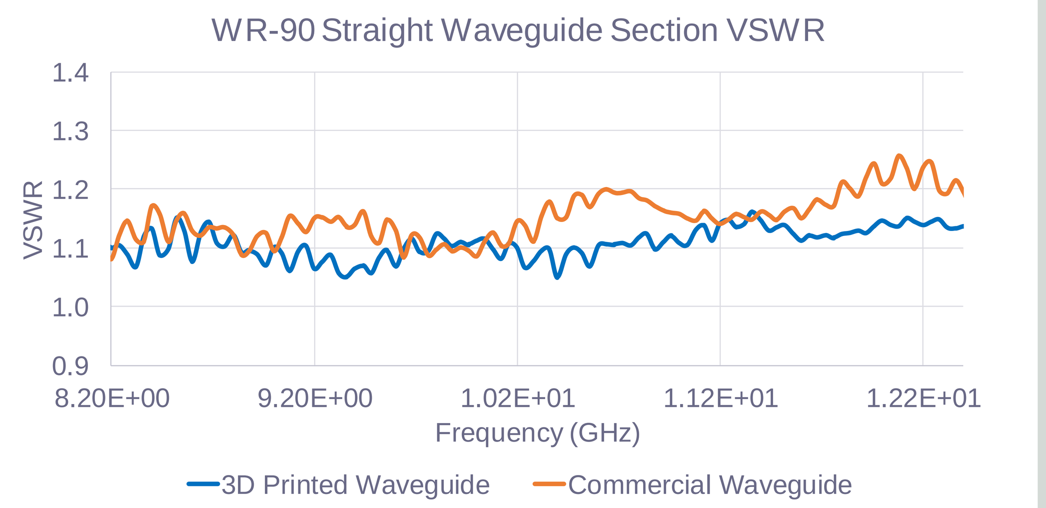


- The S11 data was utilized to find the VSWR which was comparable to the commercially available components.

Straight Section Data



- VNA data for the S21 parameter was collected and favorably comparable between the commercial straight section and the 3D printed and electroplated component.



- VNA data for the S11 parameter was collected and utilized to calculate the VSWR (equation on the left). The data was comparable to the 3D printed component as it performed within 1.5 of the commercial component.

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Matthew
High-Gain Horn

Josue
Conductive Coating

Cole
Low-Gain Horn

Brodrick
Conductive Coating

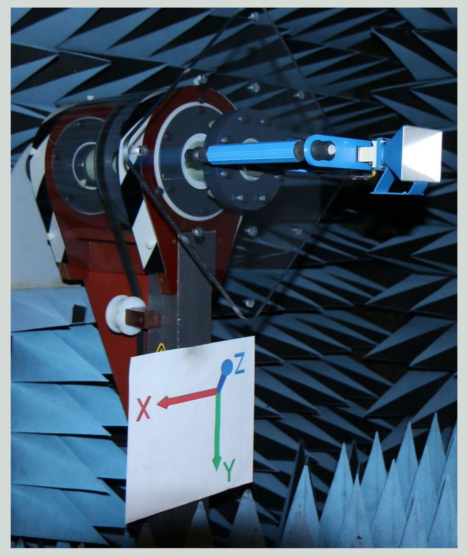
Low-gain Horn Requirements

- The requirements of the low-gain horn
- Major lobes and peak points are the same between HFSS Simulation, Commercial, and 3D Printed Horns
- Peak gain is sufficiently similar between the Commercial, and 3D Printed Horns

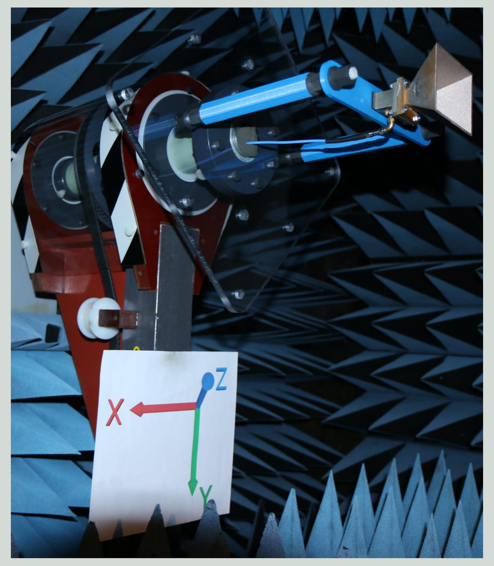
Testing the low-gain horn

The 3D printed and commercial low-gain horns were sent to a professional antenna test lab to characterize their performance. The collected performance characteristics were

- Antenna gain pattern
- Peak/Z-axis gain
- Antenna Radiation Efficiency



Commercial Horn in Test Chamber



3D Printed Horn in Test Chamber

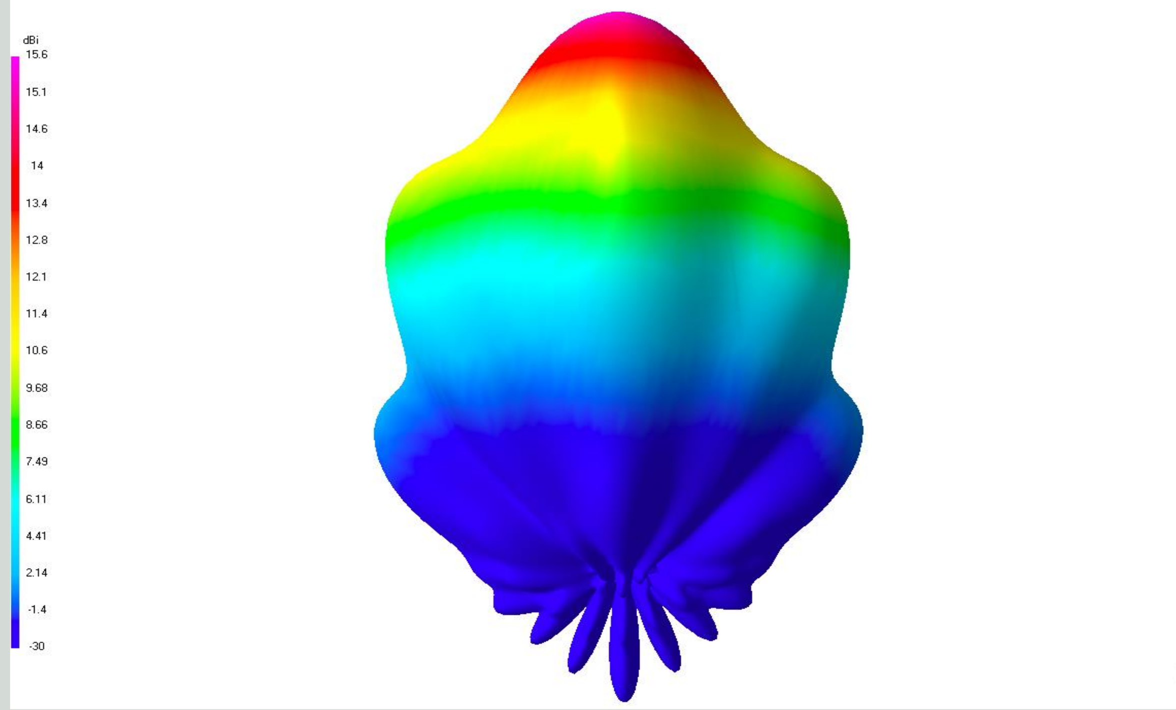
Link to the antenna test lab: antennatestlab.com

High-gain horn

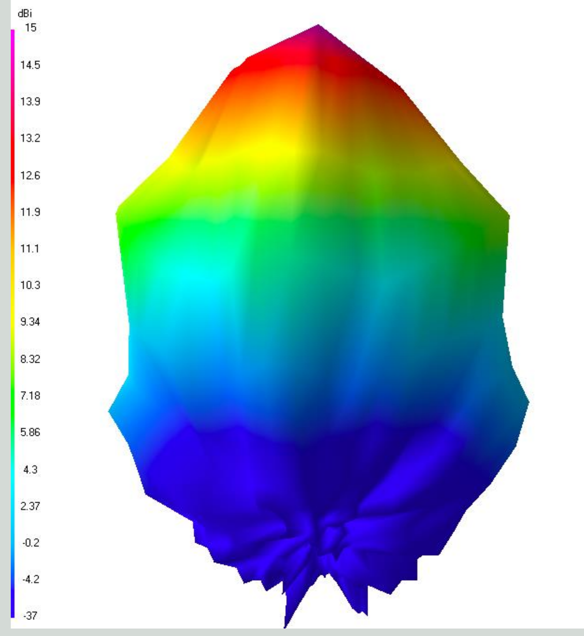
The high-gain horn was intended to be testing using the "Image method under a mismatched condition" described in [1]. However, we did not have the capability to do that testing, and thus don't have the data for it.

[1] R. Lee and M. Baddour, "Absolute gain measurement by the image method under mismatched condition," 1987 Antennas and Propagation Society International Symposium, 1987, pp. 398-401, doi: 10.1109/APS.1987.1150112.

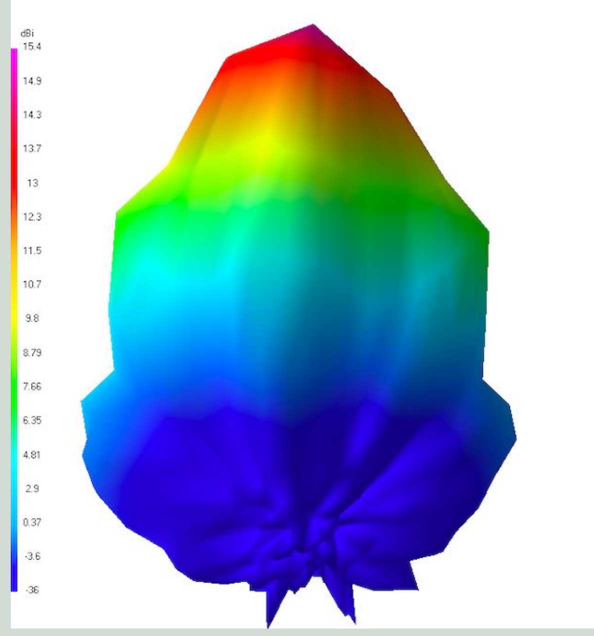
Low-Gain Horn Results



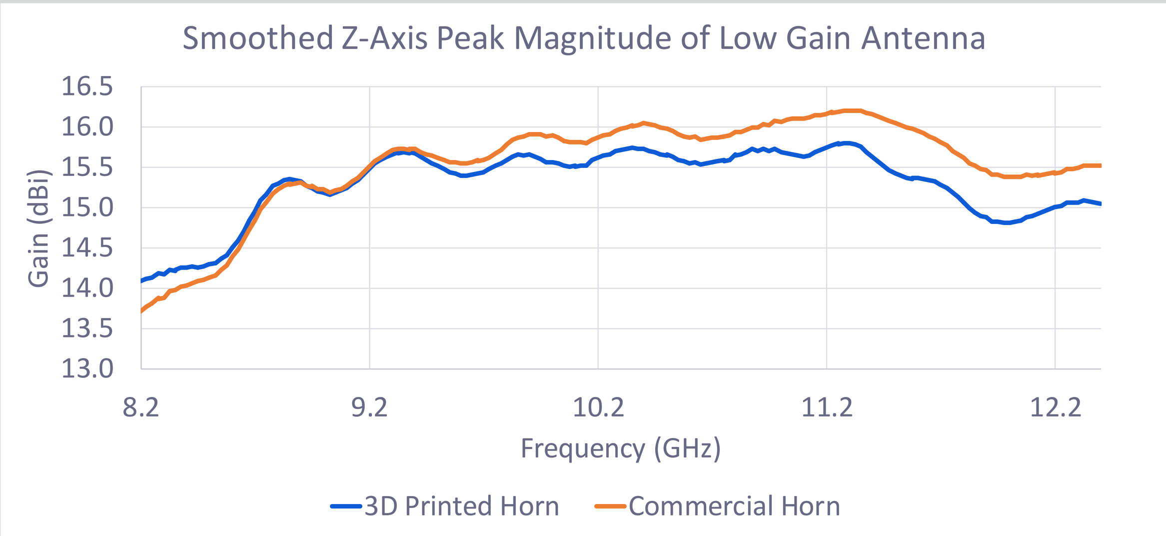
HFSS Simulation of Low Gain Horn Radiation Pattern



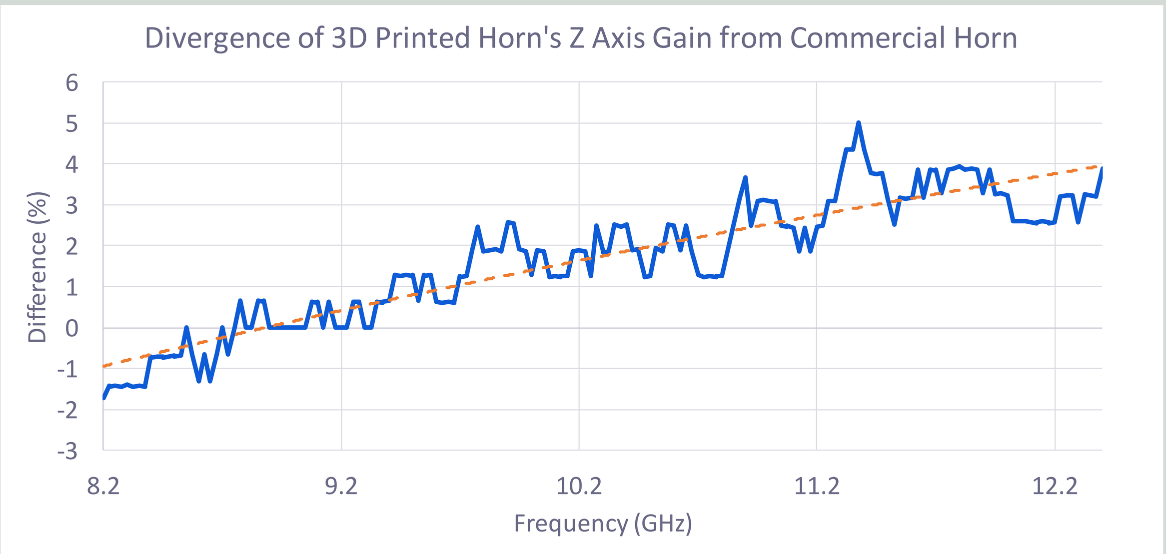
3D Printed Horn Radiation Pattern - 11 GHz



Commercial Horn Radiation Pattern - 11 GHz

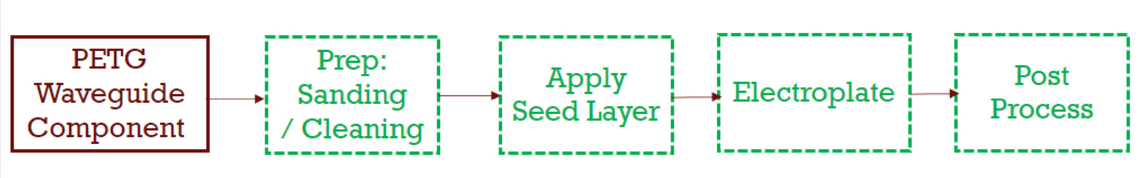


The Z-axis Peak Gains for Both Horns Show Similar Values Across the Horns' Operating Range



The Maximum Difference Between 3D and Commercial Z-axis Magnitude was Below a Half Percent Throughout the Operating Region

Conductive Coating Methods



Due to difficulties getting 100% coverage with electroplating, alternatives were researched.

- A combination of electroplating and/or silver coated copper spray was used to apply the conductive layer.
- At least 4 layers of copper spray was applied to all components.

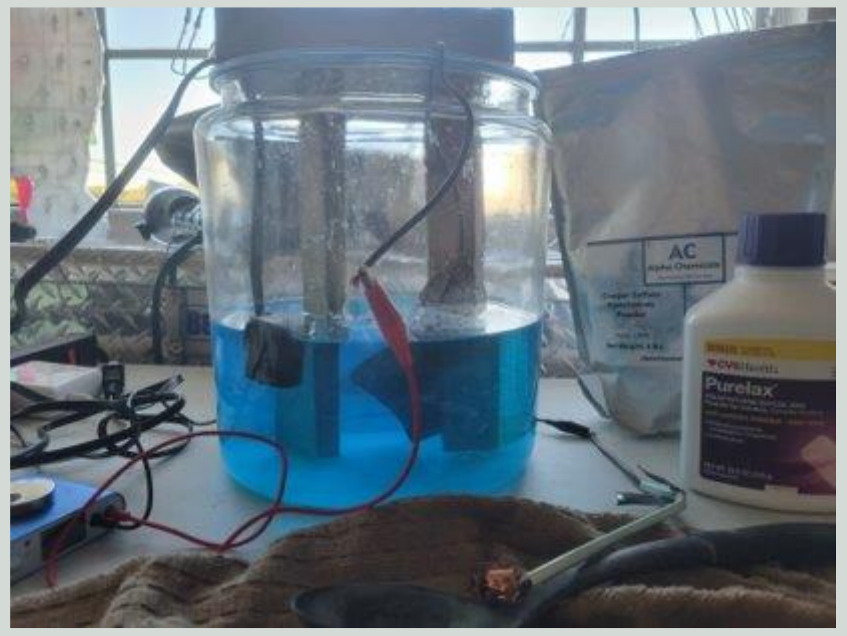
The final process developed for electroplating yielded a thickness of about 45µm and resistivity nearly identical to pure copper in a plating time of 30 minutes.

- ½ Gallon of water
- 100g Copper Sulfate
- 3V DC 0.35A *Amperage varies by substrate
- PH 4.2
- ½ Teaspoon of Miralax.

Conductive Coating Process

Shaped Copper Anode

Electroplated Low-gain Horn



Electroplating Bath

Silver Coated Copper Spray

Conductive Coating Thickness Requirements

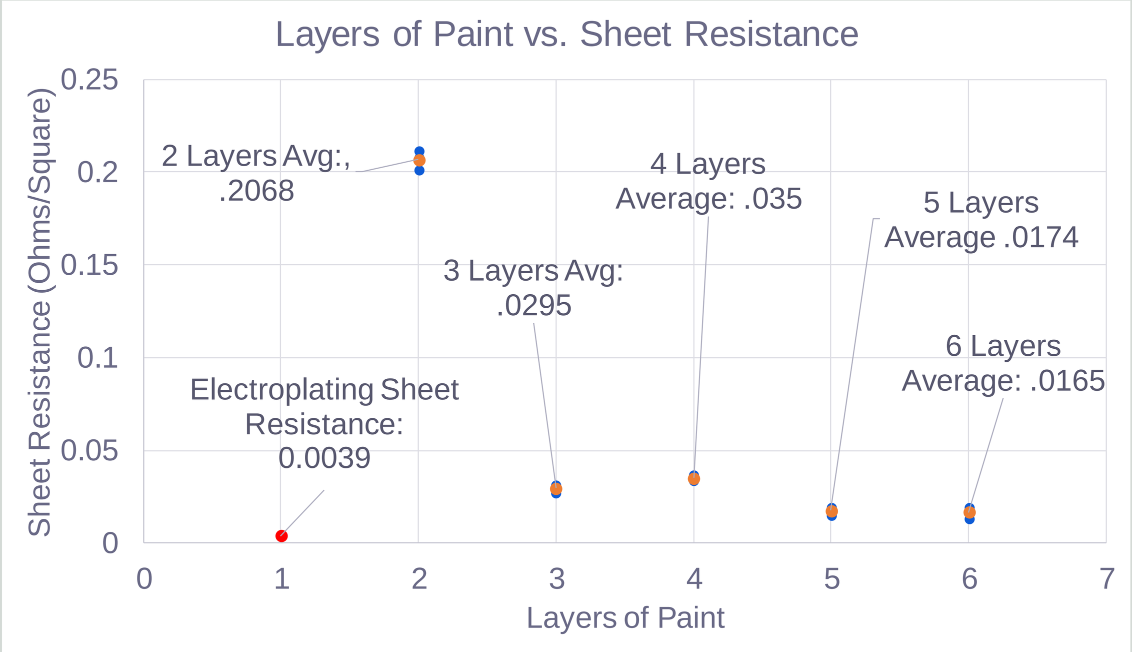
$$Skin\ Depth\ (\delta_s) = \sqrt{\frac{\rho}{\pi f_o \mu_r \mu_o}} \qquad f_o = AC\ frequency, \quad \rho = resistivity$$

$$Bulk\ resistivity = thickness * sheet\ resistance$$

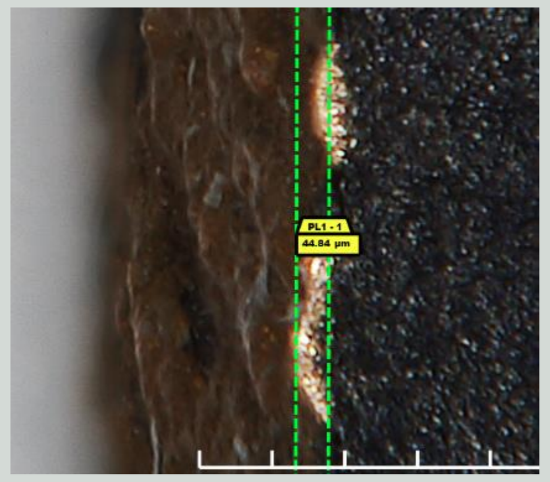
Material	Bulk Resistivity (µΩ cm)	Skin Depth @ 8.2 GHz	δs = 5 (µm)	δs = 10 (µm)
Copper (ideal)	1.678	0.720	3.60	7.20
Silver-coated Copper Paint (ideal)	220	8.20	41.0	82.0
Copper (measured)	0.174	.735	3.675	7.35
Silver-coated Copper Paint (measured)	314	9.85	49.25	98.5

- Minimum of 5 skin depths needed for performance req.
- Targeting at least 10 skin depths of thickness
- Measured values were taken as average of multiple samples' data

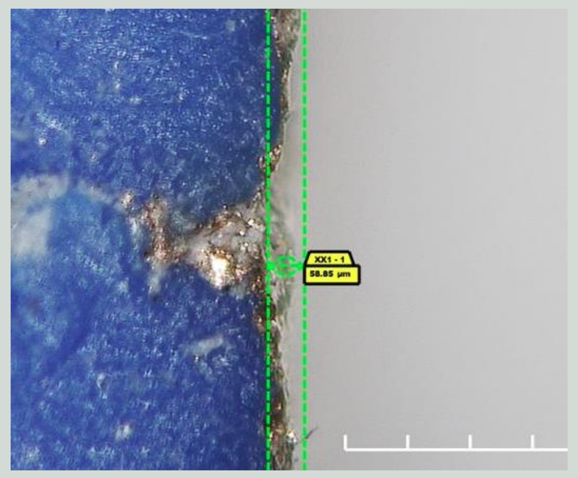
Sheet Resistance Data



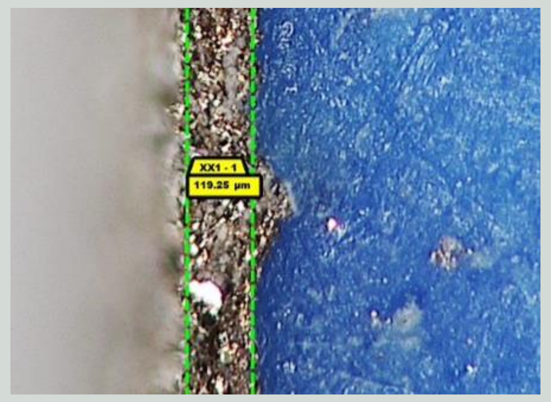
Conductive Coating Thickness



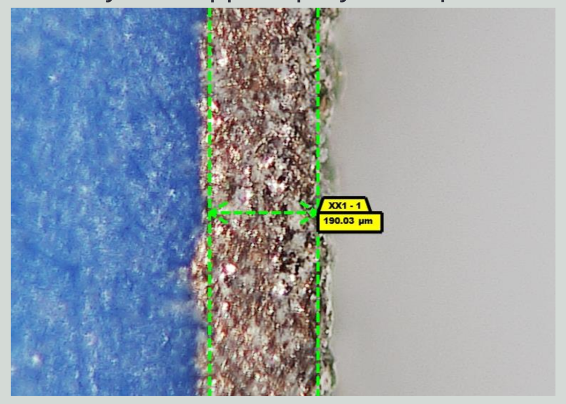
Electroplate 7-2 – ~45µm



2 – Layers Copper Spray – ~60µm



3 – Layers Copper Spray – ~120µm



6 – Layers Copper Spray – ~190µm