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3D Printing Prototypes for a Reflector-Based Broadband Axion Search

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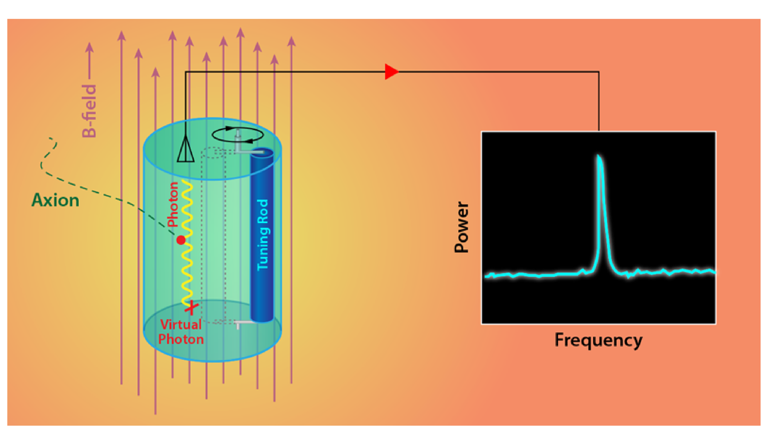
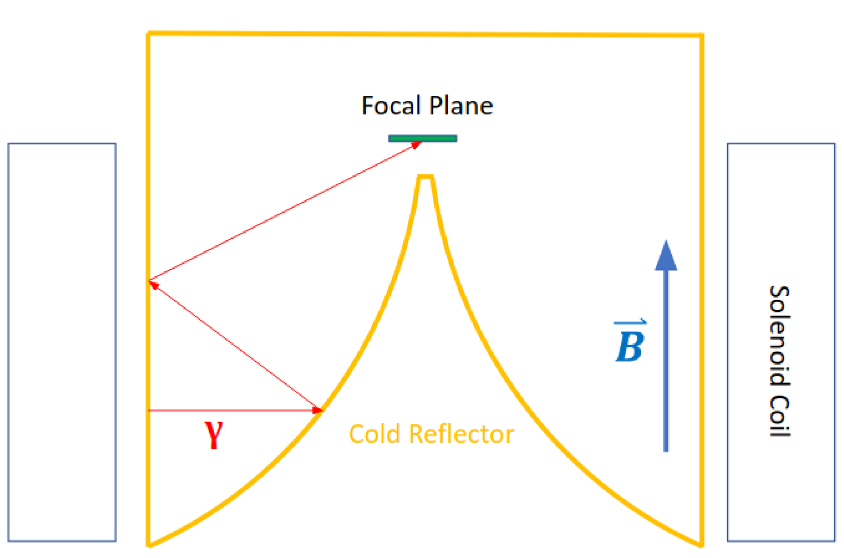
Background

Cosmological observations indicate that there is more matter in the universe than physicists can currently account for [1]. The axion is a proposed particle which not only accounts for some of this unknown matter, but also solves another problem in Quantum Chromodynamics (the theory of the strong force) called the strong CP problem [2]. Importantly, axions convert to photons under a strong magnetic field and many axion detection experiments seek to convert axions into photons and detect the resulting photons [2]. Haloscopes are a popular axion detector which use a resonant cavity to enhance the microwave photon signal from an axion [2].



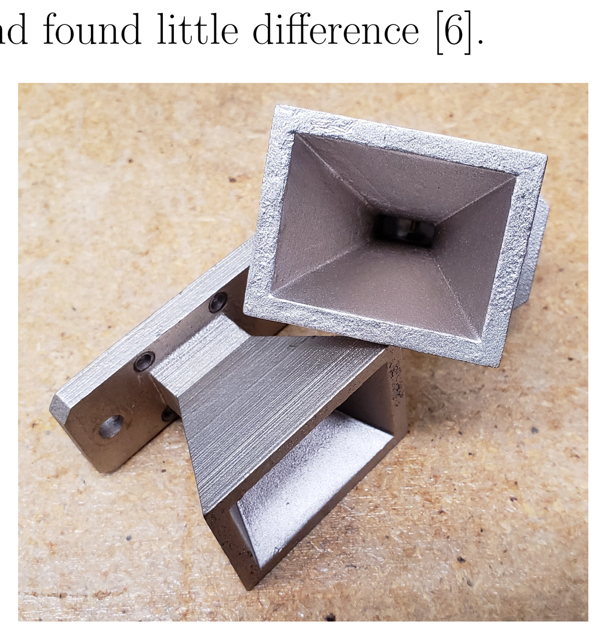
A diagram of a haloscope [3]

Unfortunately, haloscopes are narrow band because the resonant cavity can only effectively enhance a narrow range of microwave frequencies at a time [4]. By contrast, the reflector-based detector would be broadband [5]. Photons of all frequencies are focused to the reflector's focal point where they can be coupled to a coaxial cable using some form of horn antenna. The design of this horn antenna is the focus of this work.



A 2D illustration of the reflector design [5]

This work uses 3D printed models coated in a conductive, metallic spray paint in order to prototype the reflector and some horn antennas. The Antennas Lab tested the quality of 3D printed horns coated in conductive spray paint and commercial horns and found little difference [6].



3D printed pyramidal horn coated in conductive spray paint.

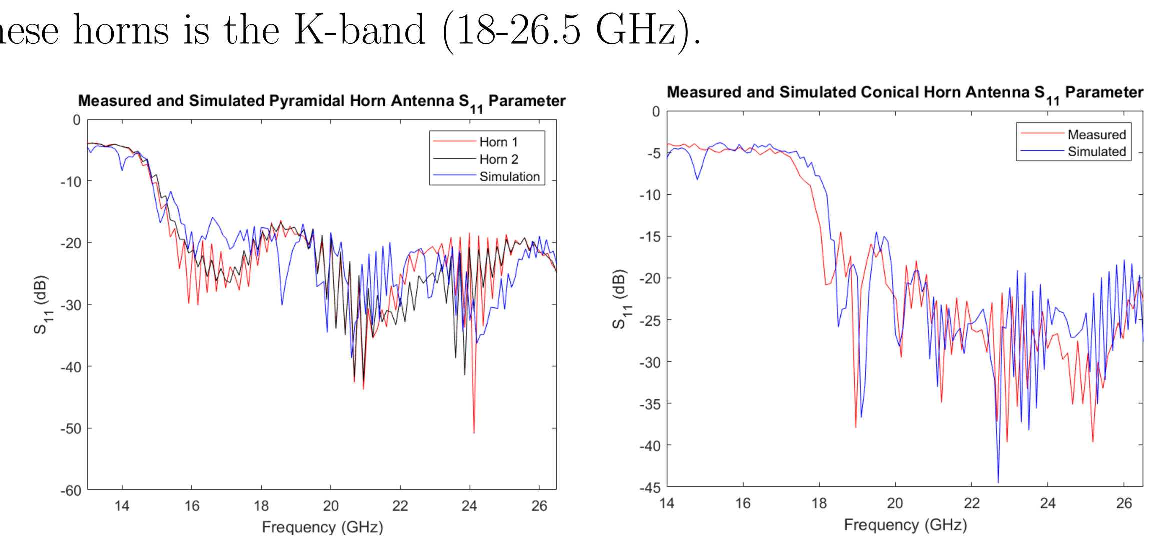
3D printed Parabolic reflector coated in conductive spray paint.

Abstract

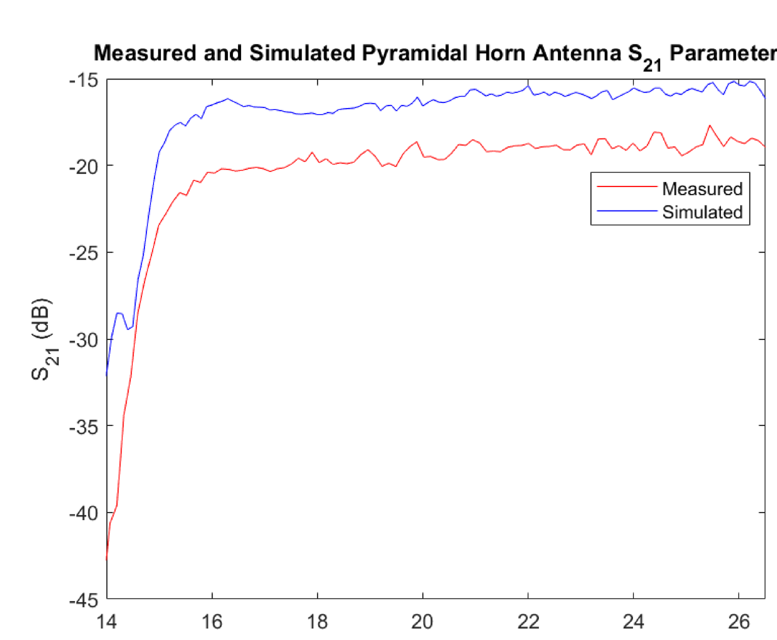
This work sought to begin research and development on a horn antenna which can be used to transfer the energy of microwave photons produced by axions in a strong magnetic field to a coaxial cable for measurement. 3D prototypes of pyramidal horn antennas and a parabolic reflector were printed and then coated with conductive spray paint. The S_{11} parameter was measured and simulated for both 3D printed horn antenna and the conical horn antenna both with and without the reflector present to determine how much of the radiated power was reflected back. Ultimately, for both the conical and pyramidal antennas, less than one percent of the energy emitted by the antennas was reflected back. When the pyramidal antenna was tilted by about 45 degrees, however, around 30-40 percent of the microwaves emitted by the antennas was reflected back.

Results

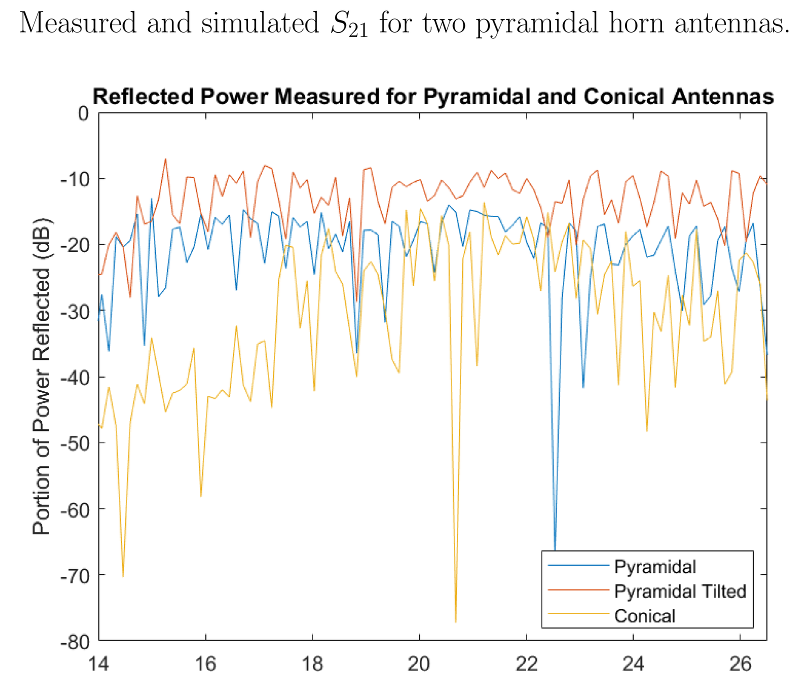
The S parameter plots of the HFSS simulations of the pyramidal horn antenna and the conical antenna as compared to the measured S parameters are shown below. Note that the operating frequencies for these horns is the K-band (18-26.5 GHz).



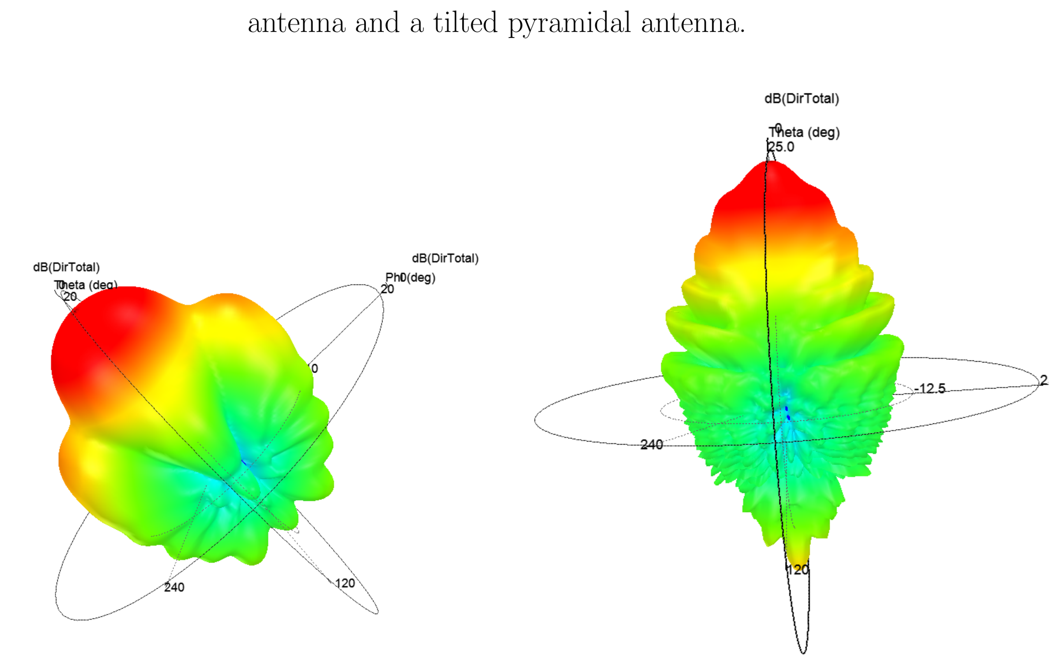
Plots of measured and simulated S_{11} for both the pyramidal horn antennas (left) and the conical horn antenna (right).



Measured and simulated S_{21} for two pyramidal horn antennas.



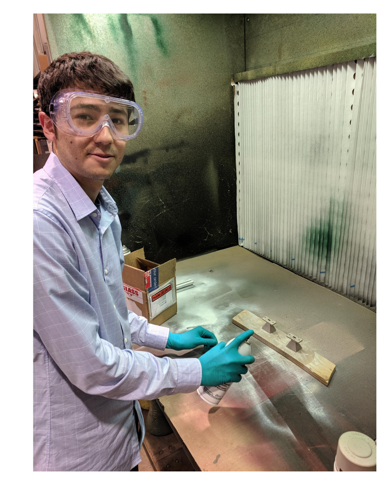
Measured portion of the emitted power which is reflected back for a pyramidal and conical horn antenna and a tilted pyramidal antenna.



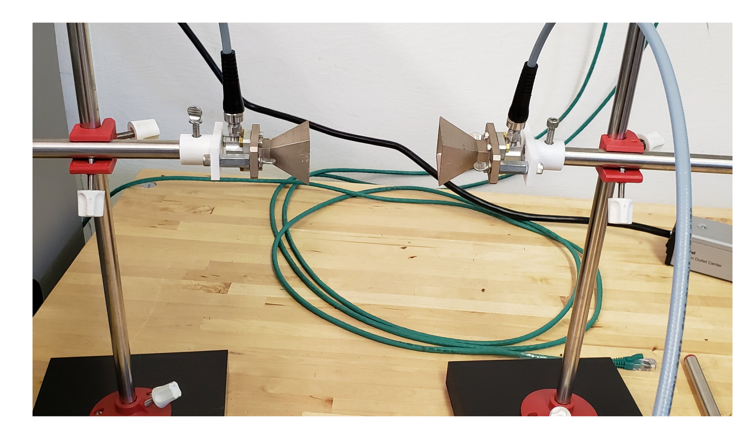
3D pyramidal horn (left) and conical horn (right) radiation patterns.

Methods

Pyramidal horn antennas were 3D printed, filed smooth, and coated with a conductive coating [6]:

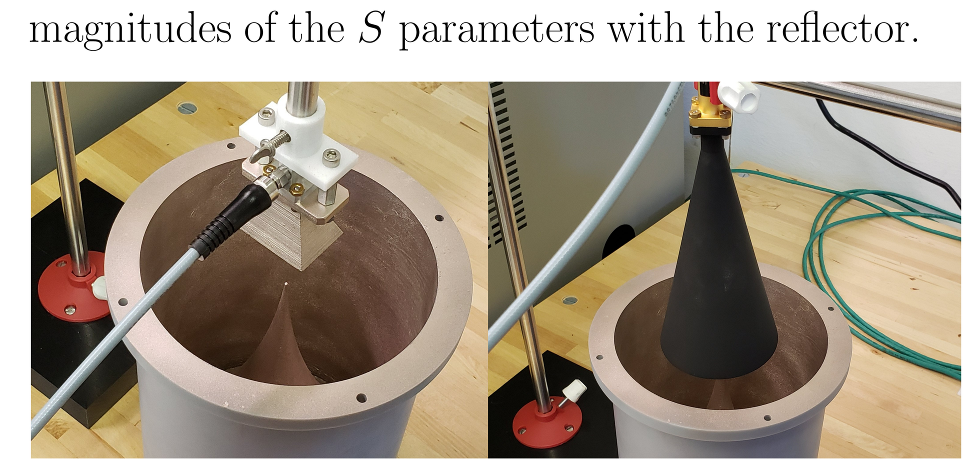


The S_{21} and S_{11} parameters were measured and simulated for these 3D printed pyramidal horns. The S_{21} parameter was measured with two pyramidal horns separated by 6.5 inches from aperture to aperture.

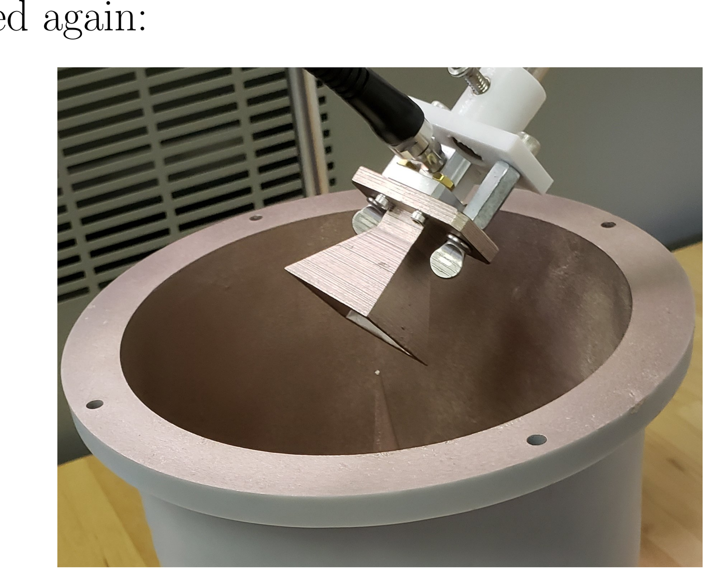


A model of the parabolic reflector was 3D printed, sanded smooth, and coated with conductive coating.

The the S_{11} parameters were measured for a commercial conical antenna and our 3D printed antenna both with and without the parabolic reflector present. These S parameters were also simulated in HFSS. The magnitudes of the S parameters without the reflector were subtracted from the magnitudes of the S parameters with the reflector.



Finally, the pyramidal horn was tilted by roughly 45 degrees off axis and the S_{11} parameter was measured again:



Pyramidal horn antenna tilted off axis and mounted above the reflector.

References

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[5] A. Sonnenschein, "R&d towards broadband axion to photon converter", May 2019.

[6] *3d printing your own antennas*, available at `https://antennatestlab.com/3dprinting`.

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