

A *K*-Band 3D Printed Horn Antenna Coated with a Copper Shielding Paint

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A *K*-band horn antenna was simulated, modeled, and 3D printed using fused deposition modeling (FDM) out of Acrylonitrile Butadiene Styrene (ABS). The antenna was coated in copper shielding paint and the gain was calculated to be an average of +16.75 dBi across the band. The peak internal reflection of the antenna across the band was found to be -15.77 dB. The results were promising, and the cost of manufacturing the antenna was significantly lower than buying a comparable antenna that is commercially available. The ability to manufacture high-gain aperture antennas at low cost, and with a quick turnaround will increase the availability and accessibility of quality horn antennas for various uses.

I. INTRODUCTION

Horn antennas have a wide variety of applications in the field of radio frequency (RF), such as radio astronomy, telecommunications, and biomedical sensing, where the high directivity and gain of a horn antenna allows for a better ratio of power transmitted to power received by a target. They are also valued for their ability to be designed for a wide range of frequencies with low return loss [1][2]. Studies have been conducted around the viability of designing horn antennas with additive manufacturing in mind, such as a study that proposed 3D printing a *Ku*-band horn antenna out of ABS and coating it using a metal aerosol spray [3]. Another study proposed a horn antenna designed for the *K*-band with the intention of being manufactured using metal 3D printing, which had a simulated reflection coefficient of less than -10dB for the entire band [4]. The results of these two experiments alone warrant the design of a horn antenna in the *K*-band that can be made using additive manufacturing, especially if it can be manufactured for less than the price of a commercially available horn antenna, which is around \$1,550 [5]. To this end, this paper proposes using a 3D printer using ABS that is metalized using metallic paint for ease of manufacturing and assembly. The focus of this study was to make the whole process as accessible as possible. The main design restraint is the creation without the use of uncommon equipment.

II. DESIGN, FABRICATION, AND COATING

The antenna was modelled in Autodesk Fusion 360 to have a total length of 100mm, with the inner dimensions of the aperture end being 45mm wide and 35mm tall. These dimensions were chosen based on the desired operational band and formulas from [1]. The transmission line was designed as a WR-42 waveguide and the mounting bracket was designed to be 5mm thick to support the weight of the antenna. The walls have a thickness of 2mm to make the printing process easier.

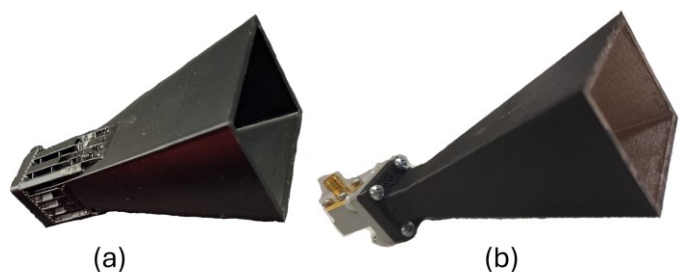


Figure 1. The 3D printed antenna (a), and the same antenna supports removed and the copper shielding paint applied.

The antenna model was exported as a .step file and imported into Ansys HFSS. Two far field simulations were conducted to ensure the validity of the antenna design. The first simulation had the antenna modeled as solid copper and yielded a gain of +20.34 dB at 24 GHz. Once the original design was confirmed to have acceptable gain, a second simulation was created simulating the antenna model as high-density polyethylene (HDPE) plastic in place of ABS because Ansys did not have the electrical properties for ABS. To simulate the copper shielding paint, a sheet of copper 50 μ m thick was added to all inside faces of the antenna. The simulation results showed the coated antenna with a gain of +20.25 dB at 24 GHz. The E-plane in Fig. 2 (a) and H-plane in Fig. 2 (b) radiation patterns between the two simulations were also similar.

The antenna was printed using fused deposition modeling (FDM) out of Acrylonitrile Butadiene Styrene (ABS) plastic, seen in Fig. 1 (a), because the material is very accessible and affordable at around \$20 per kilogram [6]. Ultimaker Cura estimated the antenna to use 36.6g of material, and the service

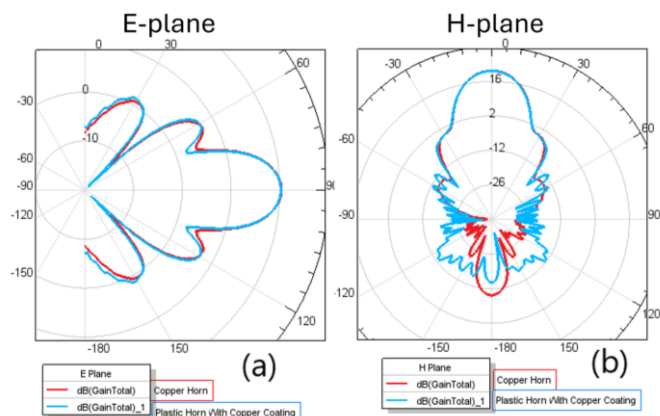


Figure 2. The comparison of the E-Plane (a) and the H-Plane (b) between the simulated copper horn and the simulated plastic horn with the copper coating.

that was used to fabricate the antenna charged \$0.10 per gram. This resulted in a total model cost of \$3.66 for the creation of a single horn antenna. The model was oriented to print with the aperture face down to remove the need of internal support during printing. The only supports for the model are external and are used to prop the mounting bracket and print on the outside of the horn antenna, which doesn't need to be smooth.

After fabrication, the supports were removed, and a single coat of 843WB Super Shield was applied to all inside faces of the antenna, seen in Fig. 1 (b). This paint is a water-based conductive paint composed of silver-coated copper flakes and was chosen for its ease of application, strong bond with ABS, and extremely low surface resistance [7]. A fine tip brush was used to apply the shielding, and careful consideration was taken to ensure an even and thin coat. The print was left oriented with the aperture end down for 24 hours to ensure the coating had dried before testing. The cost of a 55mL bottle of coating is \$47.97, and roughly 5mL was used to coat the antenna, resulting in a coating cost of \$4.36 and a total fabrication cost of \$8.02 [8].

III. TESTING

A realized gain test was conducted by placing the 3D printed horn antenna one meter away from a commercially available horn antenna, the HD-220SGAH20+K, seen in Fig 3, with a known gain [9]. The loss system due to a combination of the cable to the 3D printed horn antenna and the right-angle adapter to the commercially available antenna was calculated to be around -9 dB. To cancel out the loss of the system and make the calculation of the 3D printed horn antenna's gain, the power from the signal generator used to drive the fabricated horn was increased to +9 dBm to cancel this out.

The free space path loss (FSPL) equation, which is normally used to find the loss of signal strength in dB through an open space, was manipulated to make use of the known variables to find the gain of the transmitting antenna, which resulted in (1)

$$G_t = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) - (1) \\ G_r - FSPL.$$

The FSPL was measured from 18 GHz to 26 GHz and the results were used to calculate the G_t , which is the gain of the 3D printed antenna. Once the gain for the band was calculated, MATLAB was used to plot the data in Fig. 4 (a) and find that the antenna had a mean gain of +16.75 dB.

The reflection coefficient of the antenna was also measured over the 18 GHz to 26 GHz range shown in Fig. 4 (b). The

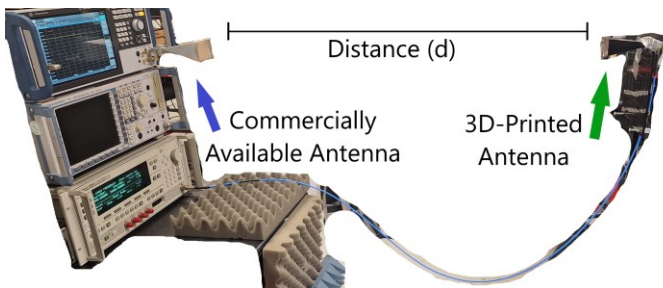


Figure 3. The set up to measure the gain of the 3D printed horn antenna (right) using a commercially available antenna (left).

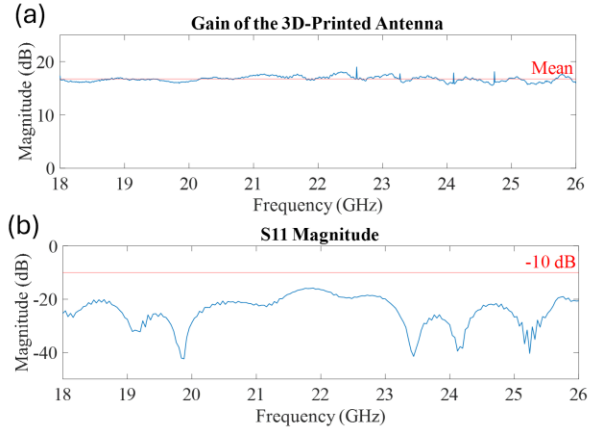


Figure 4. The plot of the gain of the 3D printed antenna across the 18 GHz to 26 GHz range (a) and the S11 for the across the 18 GHz to 26 GHz range (b).

resulting S11 was -15.77 dB at its peak and had an average of -24.44 dB across the K-band.

IV. CONCLUSION

This paper reviews research into an alternative method to manufacturing horn antennas. A K-band horn antenna is designed and manufactured to achieve low cost and high accessibility. A cost analysis of the fabrication reveals a total material cost of \$8.02. The antenna was manufactured using ABS and coated with a shielding paint to mimic an entirely metal antenna structure. The results from testing revealed an average gain of +16.75 dBi across the K-band, as well as a peak reflection coefficient of -15.77 dB. While there is room for improvement in results, the manufacturing is much cheaper than the typical commercially available K-band horn antenna and future testing will revolve around improving the manufacturing and coating process to have improved gain results while still maintaining affordability.

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