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Additive Manufacturing of a Dual-Ridged Horn Antenna

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Abstract—A 3D printed dual-ridged horn antenna (DRHA) is presented. The antenna design is optimized for additive manufacturing and is 3D printed using acrylonitrile butadiene styrene (ABS) and then painted with nickel based aerosol spray. The coaxial transition is also included in the 3D printed prototype. The antenna was manufactured with the intention of improving learning and education of electromagnetism and antennas for undergraduate students using a low-cost personal desktop 3D printer. The painted DRHA has a 10 dB return-loss bandwidth of 6621 MHz (1905 MHz–8526 MHz) with a peak gain of 11 dBi. This prototype is the first known ABS-based horn antenna with the coaxial transition embedded into it.

1. INTRODUCTION

Broadband horn antennas like dual-ridged horn antenna (DRHA) are very useful as gain horns for antenna measurement chambers and EMC laboratories. Their bandwidth prevents the requirement of suspending antenna tests to change gain horns. They are also useful for wide band transmit and receive applications. The dual-ridged horn antenna was first mentioned in 1964 [1] even though the concept of ridged waveguides was mentioned as early as 1947 [2]. A detailed manufacturing drawing and measurements can be found in [3].

3D printed horn antennas have been recently investigated with a lot of enthusiasm. Additive manufacturing technique have already proved itself to be a game changer and have decreased prototyping effort, time and cost by quite a fraction. Unfortunately additive manufacturing of metal is not yet available for the consumer market and is still mostly industrial and costly. Ku Band 3D metal printed pyramidal horns were investigated recently [4], and it was found that surface roughness had negligible impact in that particular band. Inhouse 3D printing with ABS material is easier and less time consuming, and pseudo-metallic antennas can be made by painting ABS parts with metallic paints. Another recent literature investigated Ku Band corrugated conical horn, printed and spray painted with metallic paint, and it was found to perform satisfactorily [5].

Conventional manufacturing of ridged horns are difficult, and they are quite heavy for lower operating frequencies, and an alternative low-cost manufacturing technique based on honeycomb material as the inner frame is proposed in [6]. 3D prints also allow similar weight reduction technique by the choice of infill [7]. The structural integrity of the prototype also depends on the percentage infill [8, 9]. Most 3D printed horns used a commercial coaxial adapter [4, 5], but a DRHA cannot be fed with a commercial coaxial adapter. In this letter, an optimized design of a DRHA is presented and prototyped to evaluate the feasibility of manufacturing ABS based DRHA with embedded coaxial transition, and having satisfactory operational characteristics.

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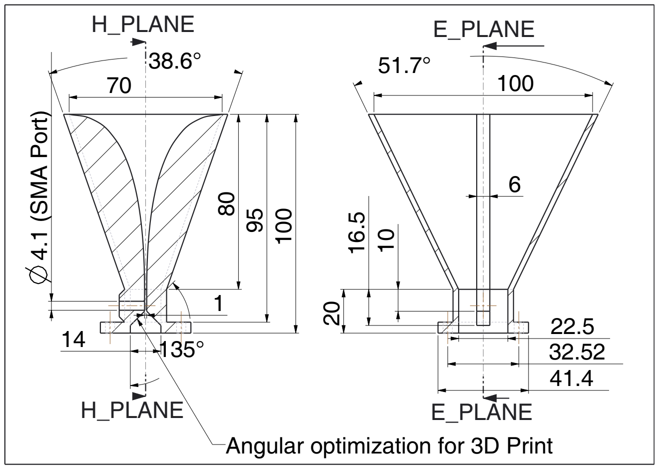

Figure 1. Manufacturing drawing of the DRHA showing the sectional views at E-plane and H-plane.

2. DESIGN AND IMPLEMENTATION

The DRHA has an overall height of 100 mm, and the aperture size is 100 mm $\times$ 70 mm. The manufacturing drawing showing the sectional views at E-plane and H-plane is given in Fig. 1. The profile curve points are given in Table 1. It is usual to have a rectangular short ridge at the end of the main ridge near the back cavity of the DRHA [3, 6]. But 3D printers usually cannot print any overhang (without the help of support structures) which has a gradient angle more than 45° [10]. Printing with support structures inside the cavity may not be successfully removed post print and may result in poor finish of the design. The proposed design completely eliminated the requirement of support structures by creating an incline of 45° at the end of the main ridge near the back cavity. This transition removed the necessity of having a short ridge and also alleviated the requirement of support structure. A separate backshort is manufactured to bolt on to the back of printed ridge. In this case a 5 mm aluminium plate was used as it was easier to make it through conventional manufacturing process. The gap between the ridges at the begining of the wave guide is 1 mm. The curve is exponentially tapered till half way and then curve fitted to meet the free space aperture smoothly. The thickness of the external walls is 2.58 mm, which is thick enough for structural stability. The thickness of the ridge is 6 mm. The value was so chosen to accomodate the 4.1 mm SMA teflon insulator covering the probe at the beginning of the waveguide. If the ridge is thinner than 6 mm, the drilling process of the SMA hole may destroy the side-wall of the corresponding ridge.

Table 1. Profile co-ordinates of the ridge from the base of the curve to the aperture. (Base of the curve is 20 mm away from the backshort.)

X (mm)	0.5	0.6	1.1	2.0	3.5	5.7	7.2	9.1	10.7
Y (mm)	0	10	20	30	40	50	55	60	63
X (mm)	12.5	14.9	17.0	19.6	23.9	26.9	30.3	35	
Y (mm)	67	70	72.5	75	77.5	78.8	79.4	80	

A basic desktop 3D printer from 3D Printing Systems, 'Up Plus 2', was used to print the ridged horn. Z resolution of 0.2 mm (layer thickness) and 'Solid Honeycomb' infill was configured pre-print. Better quality 3D printers can have layer thickness of 0.02 mm which will create a very smooth surface finish. The printing time was about six hours and a half. To save production cost, a nickel based conductive spray paint was chosen instead of a silver based spray. The intention was to investigate if the performance of nickel based paints were satisfactory. The aerosol spray having a part-number

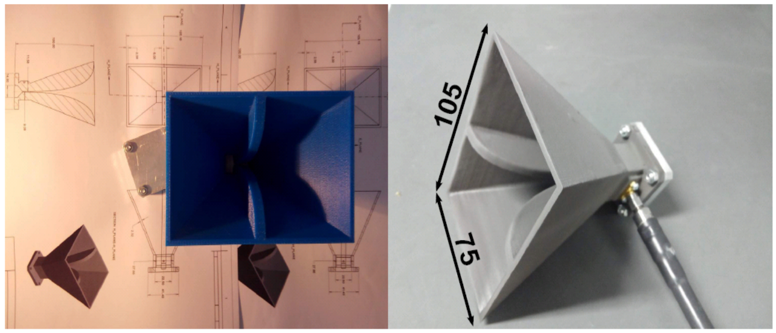

Figure 2. The 3D printed DRHA before and after nickel based spray painting.

568-483 was procured from RS Components Australia at a cost of AUD 55.48 per 400 ml canister. Four coats of spray were done to make sure the ABS surface has satisfactory and even conductivity. SMA female panel 2 hole straight probe was procured from Lih Yeu Sheng Industries, Taiwan. The SMA probe has a part number of SMA611-26.5_6G and is priced at USD 1.05 each. The SMA probes are rated only upto 6 GHz though. Unlike other 3D printed horn antennas found in the literature, this design integrated the coaxial to waveguide transition in the antenna. The probe is placed at the beginning of the ridge just after the incline and is 12.5 mm away from the backshort. The placement of the coaxial probe is critical to the operation of the DRHA and is different from waveguide fed horns. The design of DRHA is such that the coaxial probe has to be shorted to the opposite ridge and the the SMA ground should be connected to the body. After assembly, a DC Ohm-Meter would measure minimum resistance across the two terminals of the SMA connector.

Figure 2 shows the 3D printed structure before and after painting with the conductive spray. Fig. 3 shows the incline beyond which the SMA connector is fixed. An aluminium backshort is bolted at the base using four M4 bolts.

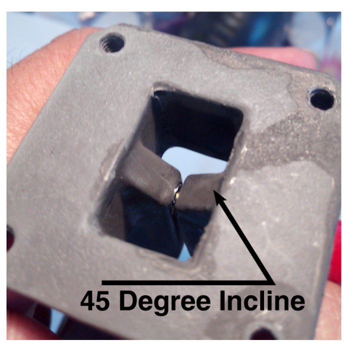

Figure 3. Close up photograph of the ridge incline optimized for 3D printing.

3. SIMULATION AND MEASUREMENT

The model was designed using PTC Creo CAD (formerly known as Pro/Engineer) and exported as an STL file. The STL file was imported into CST Microwave Studio 2015 for full wave electromagnetic simulation. Optimizations and changes were made again in Creo and the iteration was continued for a few cycles. The initial simulations were done with Aluminium as the manufacturing material and then with ABS ($\epsilon \approx 2.5$) with multiple thickness of ohmic sheet coatings (70 µm, 100 µm and 300 µm). After painting the measured ohmic sheet thickness was approximately 250 µm. The resistivity of the ohmic sheet obtained from the data-sheet of the aerosol spray is $0.9\Omega/\square$. The base material of the aerosol is acrylic resin but the exact relative permittivity is unknown. It is also unknown how the different paint coatings stack up with respect to the acrylic resin and nickel particles.

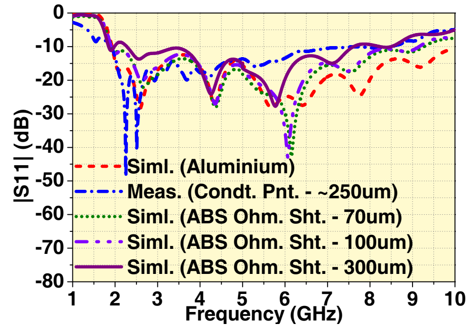

Figure 4. Predicted and measured return loss of the proposed DRHA.

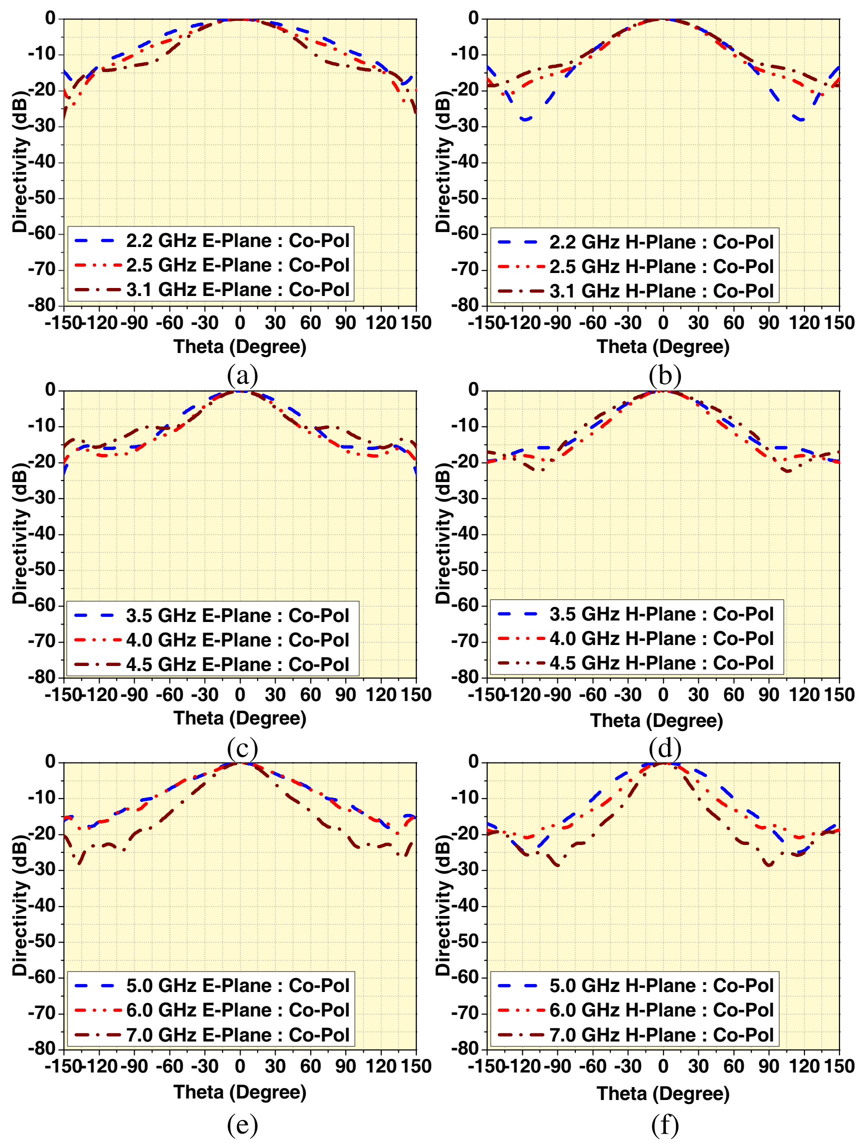

Figure 5. Normalized farfield pattern of the DRHA predicted by CST Microwave Studio 2015 (a) E-plane at 2.2 GHz, 2.5 GHz and 3.1 GHz, (b) H-plane at 2.2 GHz, 2.5 GHz and 3.1 GHz, (c) E-plane at 3.5 GHz, 4.0 GHz and 4.5 GHz, (d) H-plane at 3.5 GHz, 4.0 GHz and 4.5 GHz, (e) E-plane at 5.0 GHz, 6.0 GHz and 7.0 GHz, and (f) H-plane at 5.0 GHz, 6.0 GHz and 7.0 GHz.

Figure 4 shows the simulated return loss obtained using an aluminium body and with multiple thickness of ohmic sheets over ABS. It also shows the measured return loss which agrees satisfactorily in the lower frequencies to the aluminium body simulation but is in more agreement to the 300 μm ABS ohmic sheet simulation in the higher frequencies. The complex reflection coefficient magnitude ($|S11|$) can deteriorate drastically if SMA connection is not correctly done (to make a DC short with the opposite ridge). This is one critical area of the DRHA which separates it from other 3D printed horn antennas fed with commercial coaxial transitions. The measured 10 dB return-loss bandwidth is 6621 MHz (1905 MHz–8526 MHz).

Figures 5 and 6 shows the simulated and measured farfield patterns in the E-plane and H-plane at multiple frequencies. The simulation and measurement results are in good agreement to each other. The average cross polarization isolation (measured) is over 25 dB. The measurements were taken in AusAMF spherical nearfield chamber in farfield mode and thus the rotation (Theta) was limited to

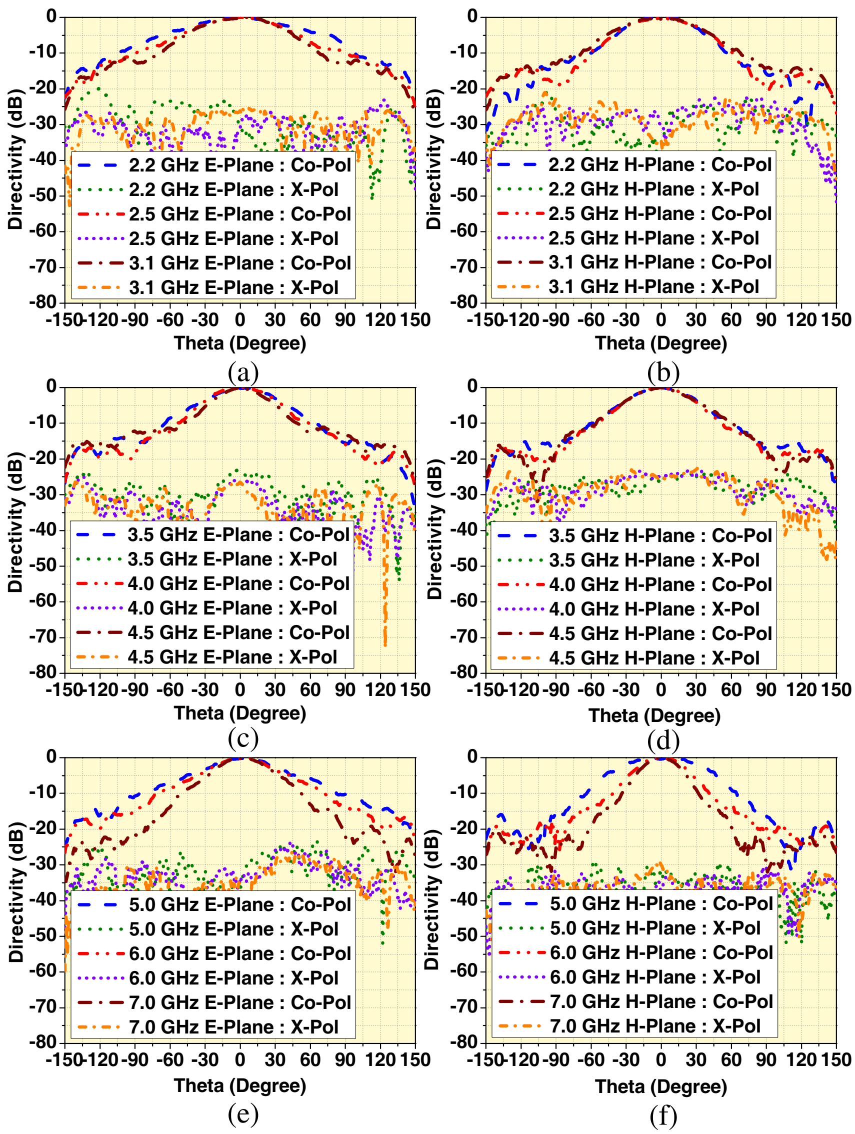

Figure 6. Normalized farfield pattern of the DRHA measured at AusAMF spherical nearfield facility (a) E-plane at 2.2 GHz, 2.5 GHz and 3.1 GHz, (b) H-plane at 2.2 GHz, 2.5 GHz and 3.1 GHz, (c) E-plane at 3.5 GHz, 4.0 GHz and 4.5 GHz, (d) H-plane at 3.5 GHz, 4.0 GHz and 4.5 GHz, (e) E-plane at 5.0 GHz, 6.0 GHz and 7.0 GHz, and (f) H-plane at 5.0 GHz, 6.0 GHz and 7.0 GHz.

300° only. From measurements, the gains of the DRHA are 5.5 dBi, 6.5 dBi, 7 dBi, 8 dBi, 9 dBi, 8 dBi, 7.5 dBi, 9 dBi and 11 dBi at 2.2 GHz, 2.5 GHz, 3.1 GHz, 3.5 GHz, 4.0 GHz, 4.5 GHz, 5.0 GHz, 6.0 GHz and 7.0 GHz, respectively. Total efficiency is around 80% over the entire range.

The measured weight along with the small aluminium backshort is only 130 gms, which is quite light than an equivalent metallic DRHA.

4. CONCLUSION

A 3D print optimized lightweight dual-ridged horn antenna with coaxial transition is proposed. The 3D print can be successfully obtained without any support structure and works satisfactorily with nickel based acrylic aerosol paints. Future studies are ongoing about the effect of better Z resolution (smaller layer thickness), silver based acrylic spray paints and better coaxial connectors. The proposed antenna was a successful demonstration of rapid deployment for dual ridged horns required for various applications including promotion of practical demonstrations at a undergraduate level programme.

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