3D Printed Metalized Plastic Waveguides for Microwave Components

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Abstract

This paper investigates the design and fabrication of 3D printed waveguide and their application for the design of microwave passive components. This includes a simple waveguide structure, a band pass filter, and a leaky wave. A Lego-like approach is used to assemble together different 3D printed sub-sections after metal coating. These allow the structure to be fabricated in multiple layers. Simulation and measured results match closely. Details of modeling, fabrication and measurement are presented for these three passive components.

Key words

Waveguide, 3D Printing, Plastic, Lego-like assembly, Electroplating

I. Introduction

Light weight and low-cost microwave components are required for space borne and satellite communications, automotive and hand-held systems [1-2]. Waveguides are broadly used for a variety of low-loss components such as filters, resonators, attenuators, and antennas. Hollow metallic waveguides are preferred over other waveguides due to their low-loss, high power handling capability, and improved isolation between neighboring structures [3]. In spite of these advantages, metallic waveguides are expensive to manufacture, and also due to the use of solid metal these waveguides are heavy. Waveguides structures are mostly fabricated using techniques such as metal plate soldering, electroforming, dip-brazing and electronic discharge machining [4-5].

Additive manufacturing or 3D (3-dimensional) printing holds significant potential to lower the cost and weight while adding the ability to easily fabricate complex geometries [6-8]. Recently, many microwave and millimeter-wave components with complex structure designs have been successfully 3D printed. Metal 3D printing by laser sintering is the most common technique to additively manufacture metal parts layer by layer. Most of the direct metal 3D printing techniques have surface roughness which can degrade the performance of components at high frequency [9]. However, 3D plastic printing and subsequent metallization has been utilized instead of metal 3D printing to achieve smooth surface and lighter weight. Recently, many common RF components such as patch antennas, Vivaldi antennas [10-11] have been successfully demonstrated using 3D plastic printing. 3D printed plastic followed by electroless- or electro-plating has been utilized for the manufacturing of waveguide structures [12-13].

This paper presents the fabrication of metal coated 3D printed plastic waveguides and its utility in the design of X-band passive components such as filters and antennas. In order to achieve good metal coating, each of the passive components is printed into two separate pieces (plastic), metallized and then assembled using a Lego-like technique which allows easy fabrication and metallization of complex. Furthermore, it allows for the fabrication of multi-level waveguide components. These structures are printed using a professional-grade commercially available 3D printer (Objet Connex350) utilizing a photo-polymer resin called “VerowhitePlus” which has a dielectric constant (ε_r) of ~2.8 and a loss tangent ($\tan\delta$) of ~0.04 measured over a frequency range of 0.1-1 0.8THz [14]. Both clear and white colored resins were utilized here. All of the structures were metallized using sputtering deposition of copper (Cu) seed layer followed by electroplating. All the designs and simulations presented were performed using a commercial FEM (Finite Element Method) solver, ANSYS HFSS (High Frequency Structural Simulator). The 3D printing of waveguides using polymers enables applications requiring lightweight systems and design of complex low-loss components is feasible.

II. Fabrication

The 3D printed structures were first cleaned using iso-propyl alcohol and further cured under UV light. The waveguide based structures are printed in two separate layers as shown in Figure 1. Lego-like support pillars and holes are printed to allow the two layers to snap together with each other with good alignment. Metallization of 3D printed structures is carried out using two steps, i.e., sputtering of seed layer followed by electroplating of copper (Cu). At first, the bottom seed layer of Titanium/ Copper (Ti/Cu) is sputtered having thickness of 50/500 nm. Ti is used here as an adhesive layer. This step provides the conductive layer necessary for electroplating. This is followed by the electroplating process to achieve a total metal thickness of 5-6 µm. In the final step, the structures are assembled together. Figure 2 and 3 shows an example of 3D printed waveguide structure before and after assembly. A thin layer of highly conductive silver paste was used to permanently join the pieces together.

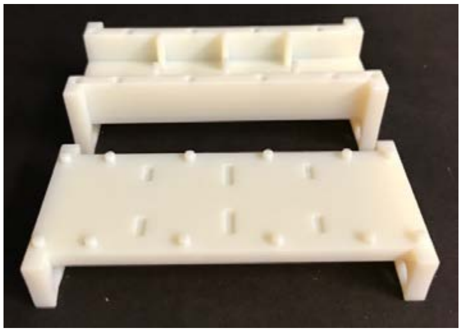

Figure 1. 3D printed waveguide structure pre-metallization.

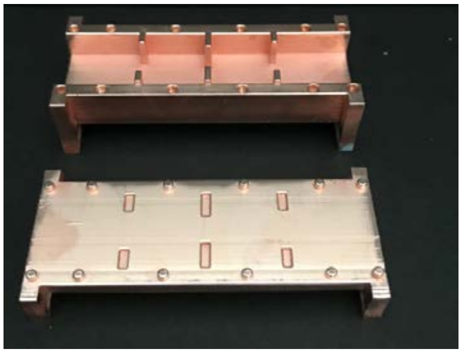

Figure 2. Metalize 3D printed waveguide structure (sputtering plus electroplating)

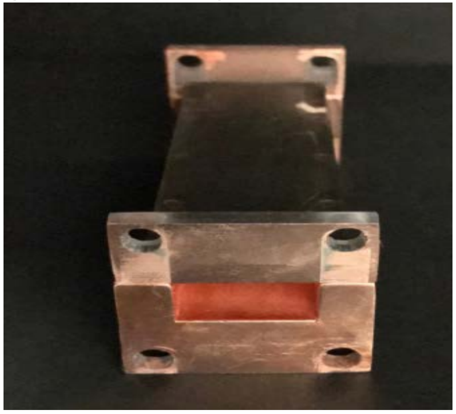

Figure 3. Lego-like assembly of metalize 3D printed waveguide structure.

III. Simulation and Measurement

A. X-band Rectangular Waveguide

Rectangular waveguide is one of the commonly used waveguide structure in RF components. The cut-off frequency depends on the dimension of the dimensions of inner hollow structure. In this paper, the chosen frequency band is the X-band region (8 – 12) GHz. For X-band region, the dimension used are: height (b) = 28.66mm, width (a) = 10.16mm as shown in Figure 4. The 3D printed and metalized rectangular waveguide before and after assembly is shown Figure 5(a) and (b), respectively. Figure 6 shows the simulated and measured S-parameters over a frequency range of 5-13 GHz. The measured surface roughness of the structure is approximately ~3µm. Overall the simulated and measured results matches fairly closely even without accounting the surface roughness. The discrepancy near the cut-off frequency can be attributed to surface roughness, fabrication tolerances of the printer (~ ± 25µm) and potential air gap due to warping between the two pieces when snapped together.

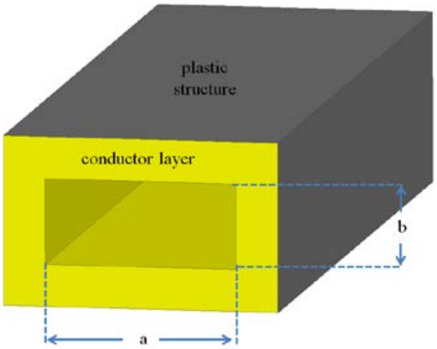

Figure 4. The dimension of the waveguide.

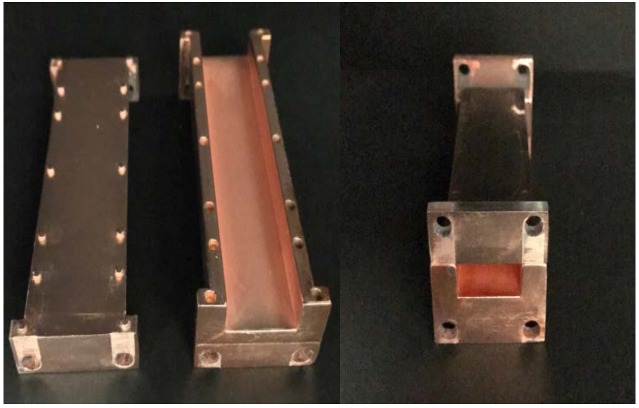

Figure 5. (a) Two separate metalize waveguide. (b) The assemble metalize waveguide structure.

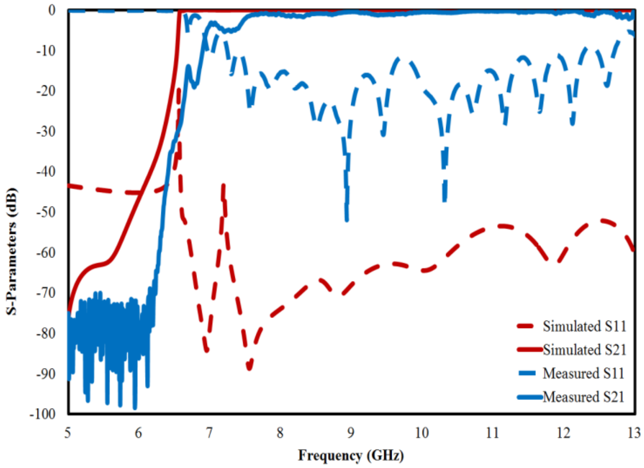

Figure 6. Simulated and measured S-parameters of the waveguide.

B. *Iris filter based Rectangular Waveguide*

Waveguide filters are essential part for a microwave system such as communication where a selective frequency band is allowed to pass (bandpass) or blocked (bandstop). One of the popular waveguide filters is the iris filter. It consists of multiple metal partitions in the waveguide to form capacitive and inductive regions (high and low impedance regions). Figure 7 shows the schematic of an iris filters along with dimension used in design. The 3D printed iris filters before and after metallization is shown in Figure 8 (a) and (b), respectively. Simulated and measured results of the iris filter which shows the bandpass properties of the filter are shown in Figure 9, and the results matches fairly closely. The slight discrepancy of the results can be accounted due to the dimension tolerant of the 3D printer capability as well as the surface roughness that cause the extra loss in the measurement. A slight shift in the resonance frequency can be attributed to the tolerances of slots.

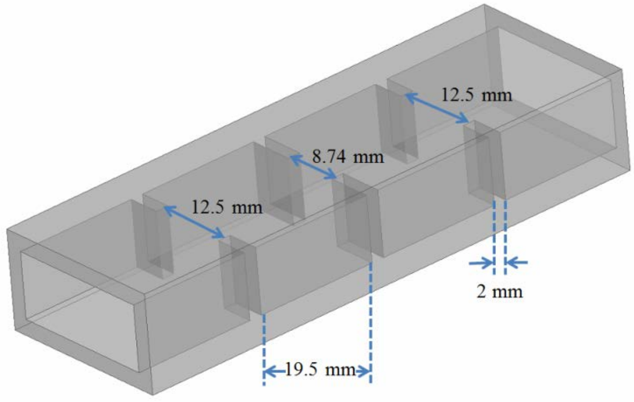

Figure 7. Schematic of an Iris filters along with dimension used in design.

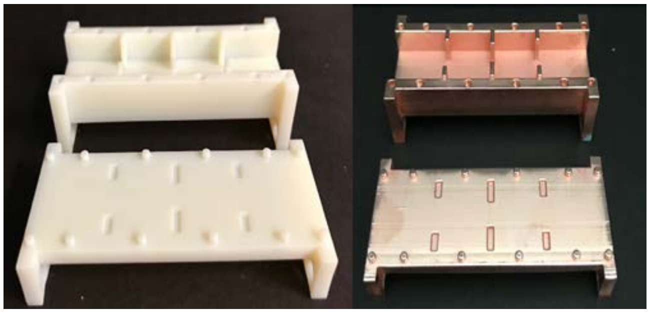

Figure 8. The fabricated iris filter (a) before and (b) after metal coating.

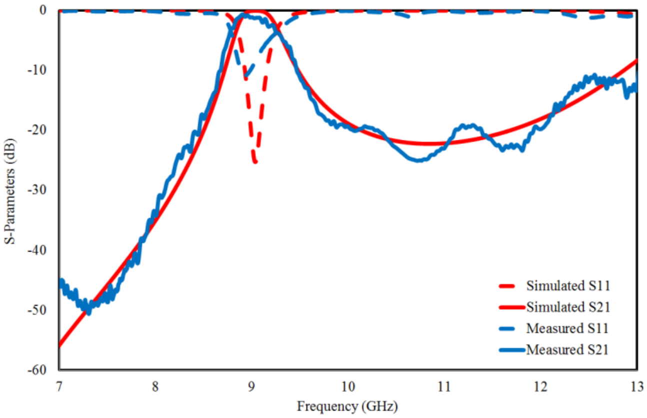

Figure 9. The waveguide iris filters simulated and measured results.

C. *Leaky Waveguide Antenna*

Leaky wave antenna is among the well-known antennas that exhibit various applications in the microwave and millimeter wave regions. One of the leaky wave antennas is the rectangular waveguide with a slit along the structure. The waves leak from the waveguide along the slot gap causing a radiation leakage. The X-band leaky waveguide structure dimension design as well as the fabricated structure is shown in Figure 10. Figure 11 shows the measured and simulated return loss of the antenna. The slight discrepancy in the results is due the reasons discussed earlier. Figure 12 shows the simulated and measured radiation pattern at 8.8 GHz. The frequency was chosen due the highest gain measured at this frequency. The measured gain is approximately 10 dBi. The results show that the simulated and measured results are almost identical.

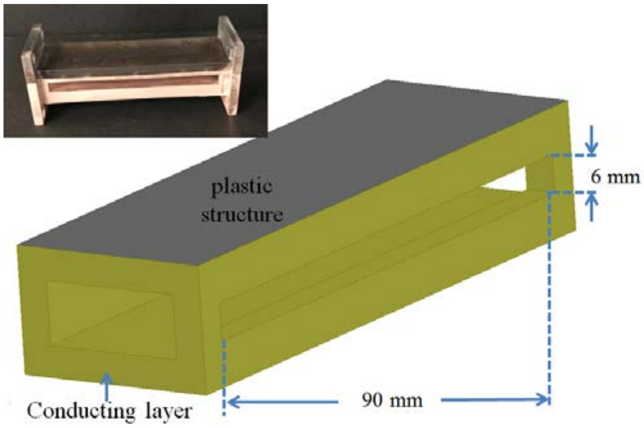

Figure 10. The dimension structure of the X-band leaky waveguide antenna and the fabricated structure.

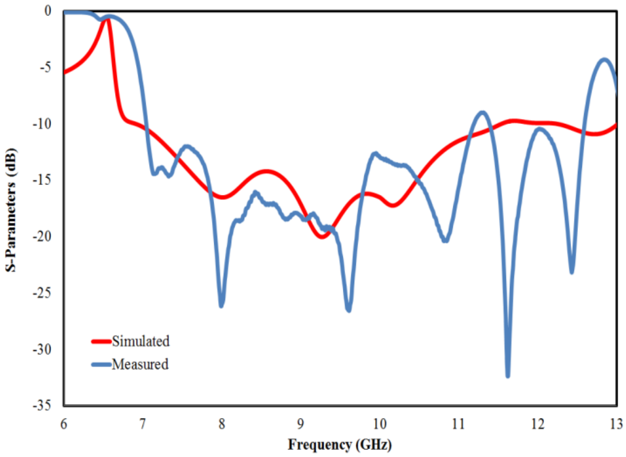

Figure 11. S-parameters of the simulated and measured results the leaky waveguide antenna.

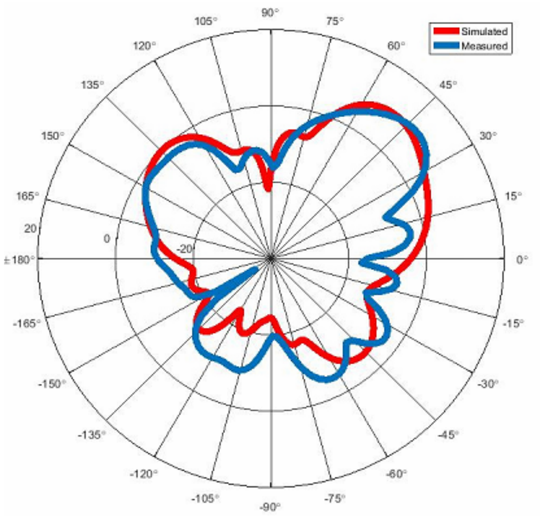

Figure 12. The radiation pattern at 8.8 GHz in the H-plane direction for the simulated and measured results.

IV. Conclusion

This paper exemplified the capability of 3D printing to design different application related to waveguide structures. The rectangular waveguide shows that the functionality of the components in the X-band frequency region. The iris filter demonstrates that 3D printing allows the fabrication of low-loss filters having similar performance to their conventional metallic structures. In addition, a waveguide based leaky waveguide antenna is demonstrated using here, to the best our knowledge, for the first time. The measured results a gain of 10.11 dBi which matches closely with simulation results. Overall, this paper demonstrates that high frequency, low-loss, light-weight waveguide based passive structures can readily be fabricated using 3D plastic printing. These structures can be directly fabricated on any platform to make them integral part of any RF system.

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