Prototyping a Broadband Waveguide Circulator Centered at 2.45 GHz Using 3D Printing

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Abstract: *The ferrite waveguide circulator available on the market nowadays has a rigid housing made up of metal and connected with several mechanical joints. The parts are assembled by molding, brazing, metallization, silver, or conventional soldering. These traditional techniques usually increase the production cost of one unit. The testing of these devices and the corresponding fine-tuning for the desired frequency and bandwidth lead to further increase of the cost and time. Hence, we propose to use the 3D printing technology to prototype the ferrite waveguide circulator. The metal circulators commonly used in industries are generally more expensive. Therefore, the experimental prototype of a WR340 ferrite waveguide circulator can be built using a cost-effective 3D printing technology for validating the design and comparing with the simulation results. The said circulator has a simple structure; hence by using the Lego method, the unit can be quickly produced and assembled. This paper presents how to 3D print a circulator housing, which is then metal coated. the ferrite discs are then fixed at the chamfer center enclosed by the magnets on both sides to complete the magnetic circuit. The circulator developed by this additive manufacturing is expected to have a bandwidth of 150 MHZ or higher with a transmission of 93% operated at 2.45GHz frequency*.

Keywords: 3D printing, S-band, broadband, ferrite waveguide circulator.

Introduction

The circulator is widely used in industrial microwave heating or radar communications. The waveguide circulator has rapidly developed into civilian communication, industrial, agricultural, and medical fields in recent years because it plays an irreplaceable role in absorbing and guiding reflected energy in the waveguide. The quality of the waveguide circulator depends upon the absorption of reflected energy, and this relatively increases the cost.

The traditional methods of fabrication include molding, soldering, and metallization of the rigid circulator housing along with the ferrite and magnetic components. Even a simple change to the assembled product cannot be done easily, and this increases the initial production cost of these devices. The introduction of 3D printing technology as one of additive manufacturing methods might completely change the manufacturing industries. The recent revolution in 3D printing technology has brought about higher accuracy, and it has a greater degree of freedom, which makes it easier to be applied in various fields. The 3D printing technology first started off by printing in plastics, which was later improved to print almost all types of materials such as metals, organic materials, etc.

Laser sintered metal 3D printing technology is one of the most common metal layer superimposition processing technology. Because laser sintered products have good precision, molding time period, high strength, etc., it is widely used to print various metals. But the cons of this method is that the cost of the equipment is too high, and the surface of the powder sintering is rough, which will reduce the performance of the part at high frequencies. Compared with metal printing, 3D plastic printing, followed by subsequent metallization is widely used for various parts of production. 3D plastic printing has the advantages of smooth printing surface and lighter product quality. The finished 3D printed pieces are then surface coated using physical or chemical methods.

This work details the process of 3D printing the circulator using a Lego technique, which makes the complex sealed structure simpler and easier to metalize. Lego method is basically splitting one piece into multiple parts and then assembled using pins and holes. The 3D printing was done by using PLA material because they have higher accuracy in printing, therefore reducing the manufacturing errors.

3D printing and fabrication

1. Design, simulation, and 3D CAD sketching

The ferrite waveguide circulator was first designed using the finite element method and fine-tuned to be operated at 2.45 GHz frequency. The simulation was self-consistent that combines the non-uniform field from a magnetostatic solver to an electromagnetic solver to get the S-parameters. The design uses N-35 magnets, iron pieces, aluminum discs, and G-610 ferrite discs, enclosed at the center of a circular chamfer. The design achieved has a broad bandwidth of 180 MHz and a transmission of about 94% with an applied bias field of 7 kA/m. After confirming the detailed geometrical aspects of each part, CAD software was used to draw the layout and sketch for all parts. In the design, only the circulator shell and the metal stage are 3D printed and metalized. The upper and lower shell edges of the circulator are made by adding pillars and holes like structures similar to Lego. The printed results can be combined with proper alignment. Due to the accuracy error of 3D printing, we give the hole a larger diameter of 0.3mm to mitigate the errors.

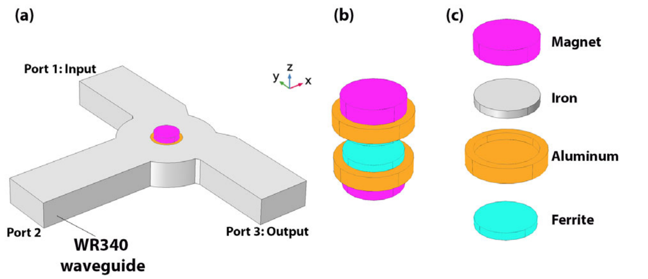

Figure 1. (a) FEM model of the WR340 circulator, (b) the magnetic circuit, and (c) disassembled parts of the magnetic circuit.

2. 3D printing

In terms of printing options, not all parts need to be physically printed. At least the outer shell of the circulator can be printed by choosing the filling method. We have selected a hexagonal filling method inside. The advantage of doing so is not only that it saves material but also reduces printing time by 50%.

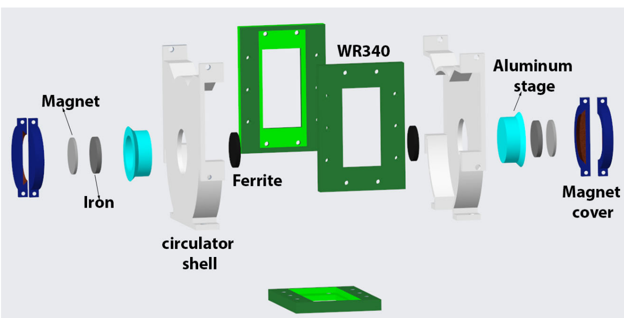

Figure 2. 3D CAD drawings of WR340 circulator components.

3. Assembly

After all the parts are printed out, electroplating or a layer of aluminum foil is used to metalize them. The ferrite and the metal stage are glued together by silver glue. Figure 2 shows all the components of the WR340 waveguide circulator and Figure 3 shows the total assembly. Figure 4 shows some 3D printed components such as (a) stage shell and (b) circulator shell.

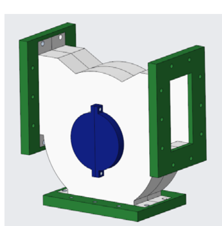

Figure 3. 3D CAD drawing of the waveguide circulator assembly.

Measurement and comparison

After completing all printing, metallization, and precise assembly, the performance of the WR340 waveguide circulator is measured by a vector network analyzer (VNA). The measured results serve a feedback to the FEM modeling for finalizing the optimal dimensions of all parts. When the prototype is validated, massive production using molding can be pursued.

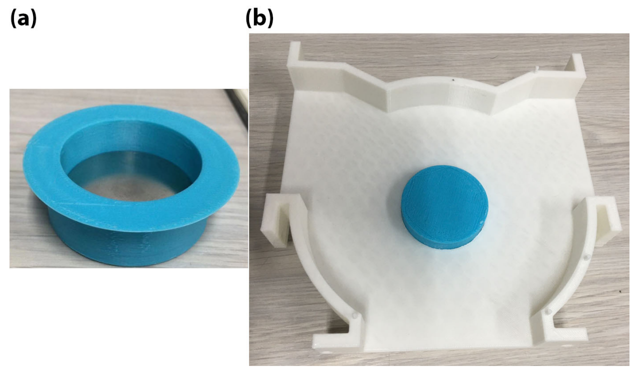

Figure 4. 3D printed (a) stage shell and (b) circulator shell.

Conclusion

The 3D printing technology as one of additive manufacturing methods can significantly reduce the prototyping cost and time. The prototype of the WR340 waveguide circulator has been designed and developed using 3D printing. The assembly is finally successful after time-consuming of working in 3D printing rooms. The validation is ongoing by comparing the measured results using a VNA with the simulation results using FEM. The finalized dimensions can be used for massive production with conventional manufacturing such as molding and brazing.

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