Two-way waveguide power divider using 3D printing and electroless plating

Lee, Y.; Sim, S.; Kang, R.; Llamas-Garro, I.; Wang, Y.; Jang, Y.; Kim, J.

DOI:
10.23919/EuMC.2018.8541546

Two-way waveguide power divider using 3D printing and electroless plating

Yeonsu Lee[1], Sung-min Sim[1], Hye-Lim Kang[1], Ignacio Llamas-Garro[2], Yi Wang[3], Yun-Ho Jang[4], Jung-Mu Kim[1]

[1]Chonbuk National University, Republic of Korea

[2]Centre Tecnològic de Telecomunicacions de Catalunya, Spain

[3]School of Engineering, The University of Birmingham, UK

[4]Microfluidics for all, Inc., USA

[1]jungmukim@jbnu.ac.kr , [2]ignacio.llamas@cttc.es, [3]Y.Wang.1@bham.ac.uk, [4]yunhojang@gmail.com

Abstract — **In this paper, we report an X-band 3D printed two-way rectangular waveguide power divider made up of electroless plated non-conductive material. In contrast to conventional metal machining fabrication processes, such as computerized numerically controlled (CNC) milling and laser beam machining (LBM), it is verified that 3D printing methods can be used to fabricate rectangular waveguide power dividers with low cost and low weight in short time.**

***Keywords* — rectangular waveguide, 3D printing, power divider, resonator, electroplating**

I. INTRODUCTION

Conventionally, metallic rectangular waveguides are manufactured from bulk metal targets using machining technologies such as a computerized numerically controlled (CNC) milling and laser beam machining (LBM) methods [1]. These methods have been exploited in manufacturing industries to fabricate complex metallic structures with relatively good tolerance and great surface finish. However, it has a limitation in structure size, since these methods are cost effective only considering small etching volumes. For this reason, studies to improve the efficiency of the machining process have been conducted by many researchers in the field of manufacturing [2]. Despite these efforts, new methods are still needed to substitute the conventional manufacturing methods.

The past few years have witnessed a booming development of three-dimensional (3D) printing technologies. The 3D printing methods can be classified as fused deposition modelling (FDM), stereolithography (SLA), selective laser sintering (SLS) and poly-jet methods, according to the operation principles [3, 4]. Among them, the SLA method based on inexpensive UV-curable resins is being increasingly exploited as a fabrication technique for various applications. Many researchers have reported that the SLA based 3D printing methods can substitute conventional manufacturing processes with low cost, reduced material waste and short prototyping time [5, 6]. In electromagnetic engineering, the fabrication of RF devices using 3D printing has been investigated [7, 8]. We also verified that the 3D printing technology can be potentially used to fabricate a rectangular waveguide filter [9]. However, it has been observed that 3D printed structures are prone to partial deformation of the structure and fracture of the metallized copper surface, occurred during the electroless plating process. Therefore, it is most important that the 3D printed structure should be metallized with an optimized metallization process including a suitable base material.

3D printed rectangular waveguide power dividers have not been reported yet. For the fabrication of rectangular waveguide power dividers, an exquisite fabrication process is required due to the relatively complex features of the structures.

In this study, we report an X-band two-way rectangular waveguide power divider made up of metallized non-conductive material using 3D printing technology. This report is organized as follows. Section II explains the design and simulation results of the two-way rectangular waveguide power divider. In section III, the fabrication process of the power divider is presented. In section IV, measurement setup and RF characteristics results of the power divider are given. Discrepancies between the simulated and measured results are also discussed in detail.

II. DESIGN & SIMULATION

A. Two-way rectangular waveguide power divider

Figure 1 shows a schematic view of the proposed two-way rectangular waveguide power divider with inductive irises, having a central frequency of 10 GHz with a fractional bandwidth of 500 MHz and a return loss of 20 dB. This structure is designed with an integrated third-order Chebyshev response using only resonators. The coupling topology of the design is shown in Table 1, along with the required external quality factor (Q_{ext}).

The two-way waveguide power divider consists of one feed port and two output ports and four resonators. When an RF power is applied through the input port, the input signal is divided to the half power signals at the two output ports. The power divider is designed using only resonators, without connecting transmission lines [10]. This power divider structure has the advantage of device size and volume reduction because of the elimination of connecting transmission lines used in power dividers.

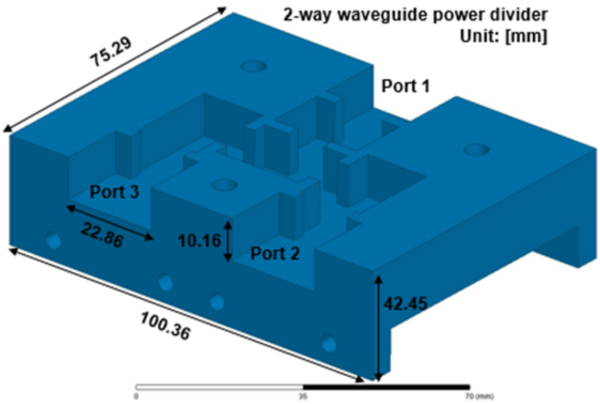
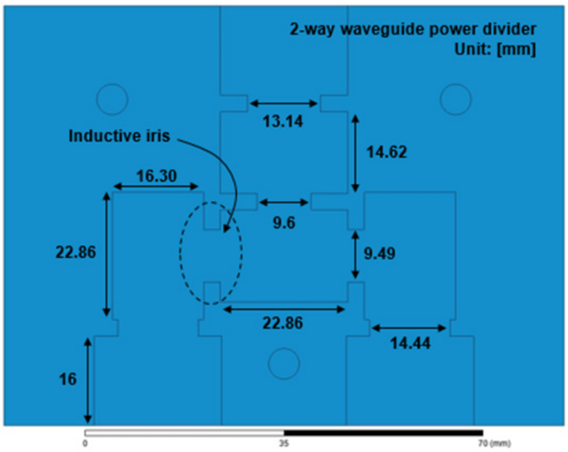
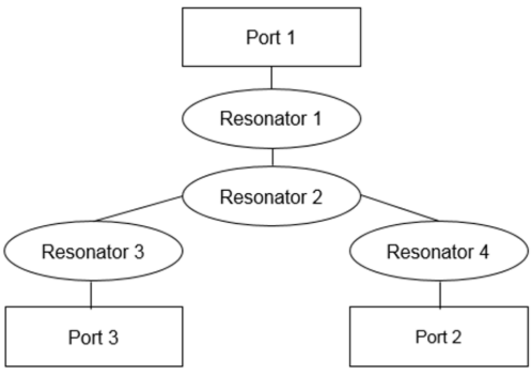


Fig. 1. A schematic view of the proposed two-way waveguide power divider (without cover plate)



(a)



(b)

Fig. 2. (a) A top view of the proposed two-way waveguide power divider (without cover plate); (b) two-way power divider topology

Table 1. Device projected coupling matrix (according to resonator couplings in Fig. 2) and external quality factor of the power divider

	1	2	3	4
1	0	0.0516	0	0
2	0.0516	0	0.0365	0.0365
3	0	0.0365	0	0
4	0	0.0365	0	0
$Q_{ext} = 17.0536$				

The input and output ports have cross-sectional dimensions of 22.86×10.16 mm^2, thus this power divider is based on the WR-90 waveguide structure to take into account the RF measurement setup. Fig. 2 shows a top view of the proposed two-way waveguide power divider with key dimensions. 3 mm-thick inductive iris structures are designed to determine the proper inter-resonator couplings. At the iris structures, the waveguide width is narrowed to 9.49 mm, 9.6 mm, 13.14 mm and 14.44 mm, respectively as shown in Fig. 2(a).

B. Simulation

RF characteristics of the proposed power divider are simulated using high frequency FEM simulation software (Ansoft HFSS), based on design parameters of the power divider coupling matrix. In this simulation, the whole surface of the power divider is considered ideal lossless metal (simulations including nickel will be added in the final version of this paper, if accepted). Fig. 3 shows the optimized simulation results. The maximum return loss (S_{11}) was about 20 dB. The half power bandwidth is from 9.75 GHz to 10.25 GHz. Insertion losses (S_{21}) at the same frequency range are calculated to be about 3 dB.

In these simulation results, it is clear that half power of the input signal applied to port 1 can be acquired at ports 2 and 3 using the symmetrical, proposed two-way rectangular waveguide power divider. Since the proposed power divider is designed to be a two-way half power divider, it is ideal that the RF characteristic at port 3 has same results with those results at port 2, as observed in simulations.

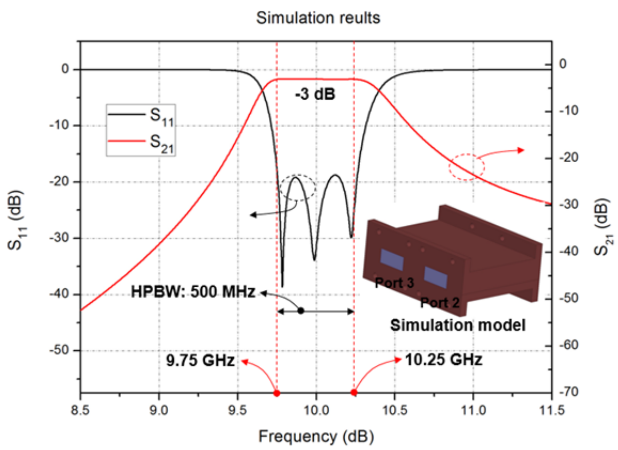


Fig. 3. FEM simulation results of the proposed two-way power divider

III. Fabrication

A. 3D printing process

The waveguide power divider was fabricated using a commercial 3D printer (Form 2, Formlabs, Inc.). Taking into account the deformation problem of the printed structures occurred on a previous study [9]. For this design, we used the heat resistant resin (RS-F2-HTAM-01, Formlabs, Inc.). In this study, the fabricated two-way power divider is accomplished in two parts, built separately. Thus, the printed two parts can be referred as the power divider structure and a simple plain cover plate, respectively.

The 3D printed power divider structure has a whole size of 100.36×75.29×42.45 mm^3 and very light-weight compared with a conventionally fabricated all-metallic rectangular waveguide device. In order to realize the two-way power divider, it is necessary to coat the whole surface of the printed power divider structure with a conductive metal layer.

B. Metallization

In order to metallize the surface of the printed structure, an electroless plating method, based on a commercialized nickel plating process, is employed in this study. Firstly, a palladium colloidal solution was applied on the surface of the printed structure as a catalyst. Then, the printed structure was dipped into a chemical bath. In this chemical bath, the surface of the power divider was covered up with a 5 µm thick nickel layer by the palladium molecules.

Fig. 4 shows the fabricated two-way waveguide power divider. In order to measure the RF characteristics of the power divider, we combined the two printed parts using conventional screws and nuts.

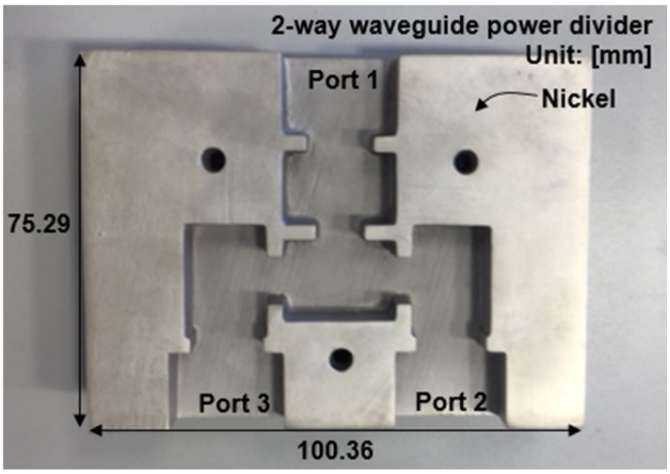


Fig. 4. Fabricated two-way waveguide power divider (without cover plate)

IV. Measurement & results

A. RF characteristic measurement

RF characteristics of the fabricated two-way waveguide power divider were measured using a two-port network analyser (PNA E8362C from Keysight Technologies) with two WR10 waveguide adapters. A SOLT calibration is used to obtain the measurements, using short, open, load and thru standards. The measured frequency range is from 8.2 GHz to 12.4 GHz. To investigate the performance of the two-way power divider, one port of the PNA is connected to port 1 of the fabricated power divider. Then, the measured RF characteristics are obtained when the other port of the PNA is alternately connected to port 2 and port 3. An impedance matching termination was attached to the unmeasured port. No tuning screws were used to tune the response of the device.

B. Measurement results

Fig. 5 shows the measured RF characteristics. S_{11}, S_{21} and S_{31} relate to return loss at port 1 and insertion loss when the PNA is connected to port 2 and port 3 of the fabricated power divider, respectively, considering port 1 as the input port. The minimum return loss (S_{11}) is determined to be about 13 dB in the bandwidth from 10 GHz to 10.5 GHz. Insertion losses (S_{21}, S_{31}) for the same frequency range are measured to be between 4.2 dB and 5 dB.

Generally, these results demonstrate a good agreement with simulation results and mean that the applied RF signal can be divided into two RF signals, with similar power level by using the fabricated power divider. However, the power divider has a central frequency shift from 10 GHz to 10.25 GHz. Furthermore, the power divider has from 1.2 to 2 dB higher loss in comparison with FEM simulation results considering an ideal copper structure (revised simulations with nickel will be included in the final version of this paper if accepted). A non-perfect contact between the power divider structure and the cover plate during the RF characteristics measurement and the surface non-uniformity, caused by the metallization process are considered as the primary causes of these discrepancies.

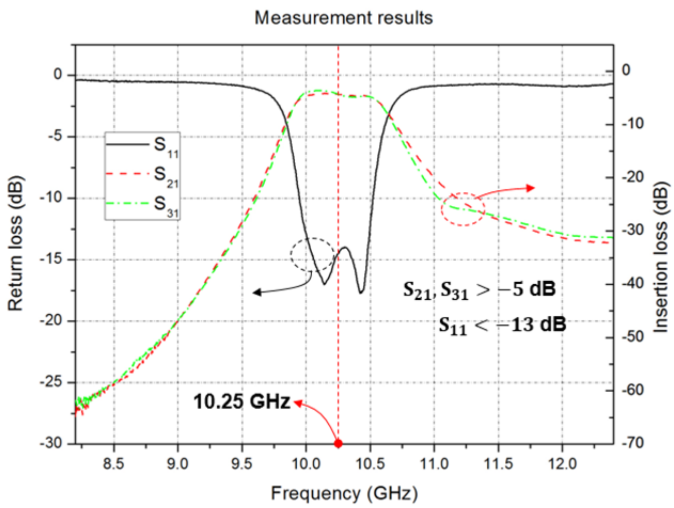


Fig. 5. Power divider measured RF characteristics

V. Conclusion

In this study, a two-way rectangular waveguide power divider is fabricated using 3D printing and electroless plating methods. The surface of the 3D printed power divider is metallized with a 5 µm thick nickel layer. RF characteristics of the fabricated power divider are measured and the results were compared with FEM simulation results. The measured results had discrepancies in comparison with the simulation results. It is clear that, with an optimized circuit structure and fabrication process, 3D printing can be potentially used to fabricate RF circuit systems effectively. We expect that the 3D printing method can be exploited as an effective solution to solve the limitations of conventional manufacturing methods of metallic RF devices, which have large size and weight, enabling the production of complex feature structures.

Acknowledgment

This work was supported by the NRF–Korea (NRF–2017R1A2B4005687), North Atlantic Treaty Organization, (NATO, SfP 984809) and Generalitat de Catalunya (LLAV00045). Thanks to Dr. Cheng Guo, Yang Yu (University of Birmingham, UK) and Pilar Soriano Garcia (CTTC, Spain) for carrying out the measurements.

References

[1] I. Stil, A. L. Fontana, B. Lefranc, A. Navarrini, P. Serres, & K. F. Schuster, "Loss of WR10 Waveguide across 7-116GHz", in *Proc. 22nd Int. Symp. Space Terahertz Technol*, pp. 1-3, Apr. 2012.

[2] S. T. Newman, A. Nassehi, R. Imani-Asrai, & V. Dhokia, "Energy efficient process planning for CNC machining", *CIRP Journal of Manufacturing Science and Technology*, vol. 5(2), pp. 127-136, 2012.

[3] S. Singh, S. Ramakrishna, & R. Singh, "Material issues in additive manufacturing: A review", *Journal of Manufacturing Processes*, vol. 25, pp. 185-200, 2017.

[4] F. Cai, W. T. Khan, & J. Papapolymerou, "A Low Loss X-band Filter Using 3-D Polyjet Technology", in *proc. Microwave Symposium (IMS), 2015 IEEE MTT-S International*, pp. 1-4, May, 2015.

[5] F. P. Melchels, J. Feijen, & D. W. Grijpma, "A review on stereolithography and its applications in biomedical engineering", *Biomaterials*, vol. 31(24), pp. 6121-6130, 2010.

[6] V. A. Lifton, G. Lifton, & S. Simon, "Options for additive rapid prototyping methods (3D printing) in MEMS technology", *Rapid Prototyping Journal*, vol. 20(5), pp. 403-412, 2014.

[7] M. D'Auria, W. J. Otter, J. Hazell, B. T. Gillatt, C. Long-Collins, N. M. Ridler, & S. Lucyszyn, "3-D Printed Metal-Pipe Rectangular Waveguides", *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 5(9), pp. 1339-1349, 2015.

[8] P. I. Deffenbaugh, T. M. Weller, & K. H. Church, "Fabrication and Microwave Characterization of 3-D Printed Transmission Lines", *IEEE Microwave and wireless components letters*, vol. 25(12), pp. 823-825, 2015.

[9] Y. S. Lee, S. M. Sim, H. L. Kang, F. Mira, I. Llamas-Garro, Y. Wang, Y. H. Jang, J. M. Kim, "Fabrication of air-filled waveguide filter with pillar array using 3D printing and MEMS copper-plating method", *in Proc. 43rd International conference on Micro and Nanoengineering*, Sep, 2017.

[10] X. Shang, Y. Wang, W. Xia, & M. J. Lancaster, "Novel Multiplexer Topologies Based on All-Resonator Structures", *IEEE Transactions on Microwave Theory and Techniques*, vol. 61(11), pp. 3838-3845, 2013.