3D-Printed Frequency Scanning Slotted Waveguide Array with Wide Band Power Divider

Kunchen Zhao, Grant Senger, and Nima Ghalichechian

ElectroScience Laboratory
Department of Electrical and Computer Engineering, The Ohio State University
Columbus, OH 43212, the USA

Abstract—In this paper we present the design, simulation, and fabrication results of a full 3D-printed frequency scanning slotted waveguide array (SWA) with an accommodating 3D printed power divider and a matched termination. An 18×4 non-resonant SWA operating at 12 - 18 GHz is designed with symmetric beam scanning range. A 1:4 waveguide power divider is proposed to feed the SWA. Inductive walls are added to the power divider to improve the impedance matching. A conical load is designed based on the lossy 3D printing material to terminate the SWA. Fabrication is done by fused deposition modeling (FDM) 3D printing technique. Simulation performed with CST shows a symmetric beam scan range from -15.2° to +15.4°. The broadside gain is 15 dBi at 14 GHz. The lowest and the highest gains are 9.3 dBi at 12 GHz and 23 dBi at 16 GHz, respectively. Although there were documented works on non-scanning 3D printed SWAs, to the best of our knowledge, this is the first work on 3D printed two-dimensional scanning SWAs.

Keywords—3D Printed; Slotted Waveguide Array; Frequency Scanning; Ku Band

I. INTRODUCTION

3D printing techniques is an attractive fabrication tool for waveguide structures due to rapid prototyping and low cost. A 3D printed resonant slotted waveguide array working at 12.5 GHz have been studied with a measured gain of 24.6 dBi [1]. However, non-resonant slotted waveguide arrays are still underdeveloped. There are two major difficulties in designing the non-resonant slotted waveguide array: a) wide-band feed structures for waveguide array are underdeveloped, b) commercial terminations cannot be employed to the waveguide array due to the physical size of the flange. Historically, an end-feed structure with a π junction is employed in the slotted waveguide array [2], but the bandwidth is small due to the non-identical length of signal paths. The waveguide power divider can be used to feed the SWA because it features wide band performance with a low return loss [3]. However, preliminary research of power dividers shows that strong resonances start to appear as the output ports are placed closely together. In addition, researches have shown the feasibility of 3D printed waveguide terminations [4]. In this paper, we propose an 18×4 non-resonant SWA with an accommodating power divider and a matched termination; all parts were fabricated using 3D printing technique with short delivery time.
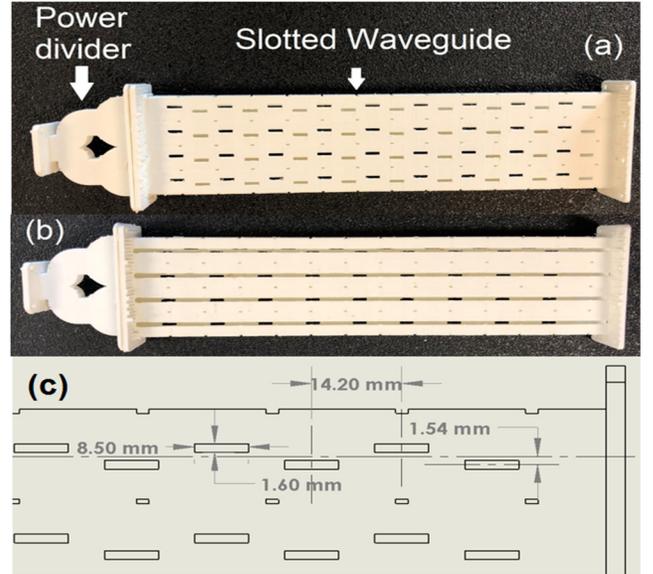

Fig. 1. (a) Top view of the fabricated SWA and power divider, (b) bottom view, and (c) critical dimensions of SWA.

II. ANTENNA DESIGH

The proposed antenna includes three parts: the waveguide power divider, the slotted waveguide, and the 50 Ω termination. The design of these will be presented in subsequent sections.

A. Single Slotted Waveguide

The antenna operates at Ku band (12 - 18 GHz) and is designed based on the WR-62 standard waveguide with the cross section dimensions of 15.79×7.89 mm. The SWA is chosen to have 18 radiating slots (Fig. 1). The length of each slot is 8.5 mm, which is tuned to optimize the gain flatness. The width of each slot is 1.6 mm. The slot spacing determines the phase shift between adjacent slots. As the frequency scans, the phase shift will vary, thus producing different beam angles. The longitudinal distance between adjacent slots is 14.2 mm, which is tuned to provide a symmetric beam scan angle over the frequency band. The slot offset from the center of the waveguide broad wall is 1.54 mm, optimized to minimize the reflection. Non-radiating slots are added onto the waveguide to enable the metallization of the inner waveguide (Fig. 1). The locations of the non-radiating slots are chosen to avoid disrupting the current distribution on the waveguide as the TE10 mode is excited. The 2-D SWA is built by placing four single waveguides in parallel to reduce the beam width in the *H*-Plane.

B. Waveguide Power Divider

The antenna is fed by a 1:4 waveguide power divider. A traditional power divider cannot be directly connected to 2-D SWA because resonances will emerge as the two output ports are joined together. A tapered shape power divider will eliminate the resonance but at the cost of lifted return loss. As two dividers are cascaded to form a 1:4 divider, the reflection from each stage will add up in phase and thus deteriorate the return loss. This problem is approached by adding inductive walls to each power divider. As shown in Fig. 2, the return loss is less than -10 dB across the frequency band after adding the inductive walls. The length of the inductive wall is optimized to minimize the reflection loss.
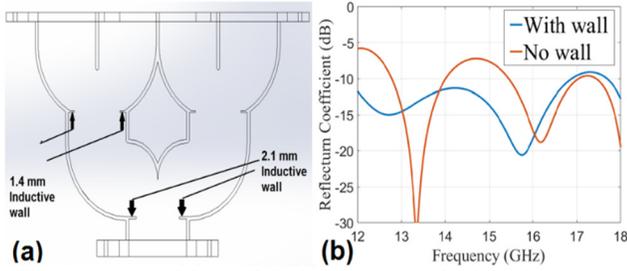

Fig. 2. (a) Position of inductive post inside the power divider, (b) reflection reduced after adding the walls.

C. Waveguide Terminationss

Commercial waveguide terminations cannot be directly connected to the two dimensional SWAs due to the physical size of the flange. Alternatively, a tapered conical load is designed to terminate the waveguide. As shown in Fig. 3, the termination has a conical shape with a bottom radius of 3.94 mm. The total length of the termination is 50 mm. The return loss of a simple waveguide with this termination is less than -40 dB. The material used in this simulation utilized the measured data from [4] with $\epsilon = 9.3$ and $\tan\delta = 0.03$.
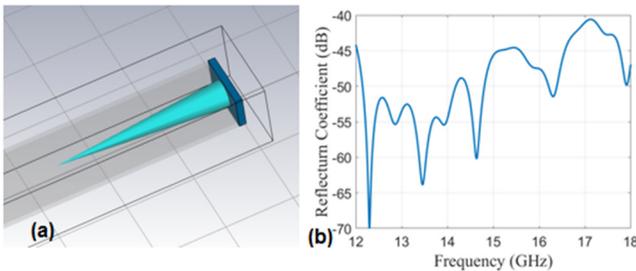

Fig. 3. (a) Conical load geometry, (b) simulated reflection coefficient.

III. FABRICATION

A fused deposition modeling (FDM) desktop 3D printer (Ultimaker 2 Extended) is used for the fabrication of all three parts of the antenna including the SWA, the power divider, and the terminations. Acrylonitrile butadiene styrene (ABS) is used as the 3D printing material due to its mechanical robustness. The entire printing process takes around 80 hours but can be further reduced. Electroless plating is used to form a thin conductive copper layer inside the waveguide.

IV. RESULTS AND ANALYSIS

All three parts of the antenna are simulated using CST Microwave Studio. As is shown in Fig. 4, the return loss of the antenna system is less than -10 dB from 12 to 17 GHz and reaches -7 dB from 17 to 18 GHz. The beam scan angle varies from -15.4° to +15.2°. The lowest realized gain is 9.3 dBi at 12 and 18 GHz. The broadside realized gain is 15 dBi at 14 GHz (Fig. 5). The side lobe level (SLL) is approximately -13 dB from 12 to 17.5 GHz, which is expected from the uniform slot distribution. As the frequency increases, the distance between adjacent slots will exceed half wavelength, thus producing grating lobes. Due to the grating lobe effect, the side lobe level increases to -9.5 dB at 18 GHz.
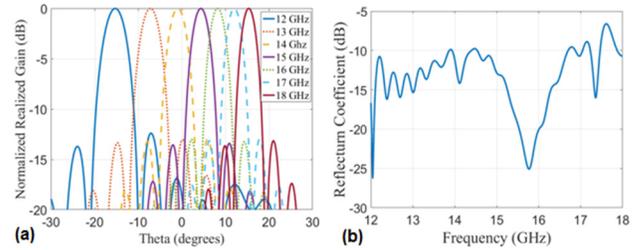

Fig. 4. (a) Normalized realized gain at different frequencies showing beam scan angles from -15.2° to +15.4°, (b) reflection coefficient from the input port.
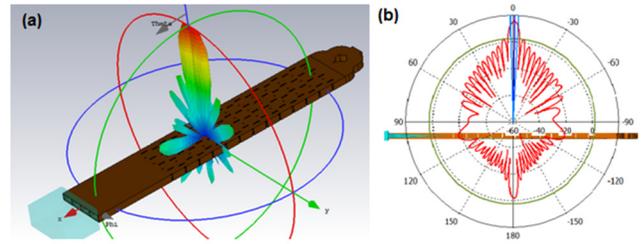

Fig. 5. (a) 3D gain pattern at 14 GHz showing broad side radiation, (b) H-Plane pattern at 14 GHz.

V. FUTURE WORK

The fabrication process will be completed by implementing electroless plating on the 3D-printed SWA and waveguide power divider. Measured beam patterns will be presented at the meeting.

REFERENCES

[1] G. P. L. Sage, "3D printed waveguide slot array antennas," *IEEE Access,* vol. 4, pp. 1258-1265, 2016.
[2] M. A. J. Hirokawa, N. Goto, "Waveguide pi-junction with an inductive post," *IEEE Antennas and Propagation Society International Symposium 1992 Digest,* pp. 2130-2133, 1992.
[3] L. L. Jianxing Li, Ling Lu, Hongyu Shi, Huimin Huo, Anxue Zhang, "Four-way waveguide power divider design for W-band applications," *Int J RF Microw Comput Aided Eng,* vol. 28, no. 5, 2018.
[4] V. L. Younès Arbaoui, Azar Maalouf, Patrick Quéffélec, Damien Passerieux, Arnaud Delias, and Pierre Blondy, "Full 3-D printed microwave termination: a aimple and low-cost solution," *IEEE Transactions on Microwave Theory and Techniques,* vol. 64, no. 1, pp. 271-278, January 2016.