3D Printed Reflectarray Antenna at 60 GHz

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Abstract **–A 3D printed reflectarray antenna is designed for operation at 60 GHz. The design methodology is based on the all-metal reflectarray approach in which the required reflection phase distribution is achieved by controlling the depths of the rectangular grooves on the reflecting surface. The metallic grooved surface is conveniently fabricated using 3D printing technology followed by metallization via electroplating. The presented fabrication approach allows for fast prototyping of 3D antennas for proof of concept.**

Index Terms **— All-metal reflectarray, 3D printing, RF magnetic sputtering, electroplating, rectangular groove.**

1. Introduction

The advent of affordable 3D printing technology has spurred innovation in antenna and waveguide filter designs. 3D printed dielectric lens antennas operating at millimeter-wave and terahertz frequencies with fixed and frequency scanned beams have been successfully demonstrated [1]. However, there are occasions that metallization of the whole or parts of the 3D structures is required, e.g., all-metal reflectarray antennas [2]-[7].

Metallization of 3D printed rectangular waveguides has been demonstrated in [8]. For a W-band bandpass filter operating at a center frequency of 107.2 GHz, the measured insertion loss of the filter, including the feed sections and flanges, was only 0.95 dB. First of the two-step metallization process was electroless plating of a 2-μm-thick nickel seed layer followed by the second electroplating of 27-μm-thick copper layer.

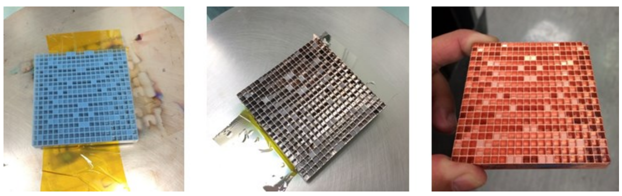
In this paper, the electroless plating is replaced by RF magnetic sputtering to coat a thin seed copper film on the 3D printed surface. For millimeter-wave applications, the second step of electroplating of a thicker layer of copper is also needed. For applications at even higher frequency, due to the reduction of skin depth, the first step of sputtering alone may be sufficient. To illustrate our metallization process of 3D printed structures, we have designed, fabricated and tested an all-metal reflectarray antenna operating at 60 GHz. Good agreement between simulated and measured results is obtained. However, its performance has not been optimized as this is not the main objective of the paper.

2. All-Metal Reflectarray Antenna

The design of all-metal reflectarrays follows the conventional approach that reflection phase curves are generated for phase compensation of the various path lengths from the feed first to the reflecting surface and then to the reflecting phase front. Full 2π phase coverage can be easily achieved by varying the depth of the rectangular groove. This can be interpreted as a shorted metallic rectangular waveguide with different length having different surface impedance at its aperture [9].

The designed reflectarray has an F/D of 1.0 where F is the focal length and D is the linear dimension of the reflectarray. An open-ended waveguide is employed as the feed for convenience. The reflecting surface in the xy-plane was fabricated by 3D printing using a Stratasys OBJET30 Scholar system with VeroBlue RGD240 printing material. The printer has a resolution of 42 μm × 42 μm × 28 μm in x-, y-, and z-axes, respectively. The 3D printed grooved surface is shown in Fig. 1(a). The next step is to coat the surface with copper.

Before metal deposition, a surface treatment of oxygen (O_2) plasma on the 3D printed polymer structure is performed using reactive ion etching (RIE) (Plasma Therm 790 series) for cleaning and improving the adhesion between polymer surface and the metal film. Next, a high-quality copper film with a thickness of ~300 nm was deposited onto the polymer surface using an RF magnetron sputtering system (Norodiko NM2000). To avoid deformation of the printed structure due to heating, deposition was performed for 2 minutes and then followed by a cooling period of 10 minutes. The deposition rate is controlled at ~30 nm/min and the final thickness was measured with Ambios XP200 step profiler. The semi-finished surface is shown in Fig. 1(b). For an all-metal reflectarray antenna operating at 60 GHz, a copper film with a thickness of ~15μm was coated onto the surface using electroplating (MiniContac RS) and the finished grooved surface is shown in Fig. 1(c).



(a) (b) (c)

Fig. 1. Reflecting surface with rectangular grooves. (a) Before sputtering, (b) after sputtering and (c) after electroplating.

With the metallized grooved surface and the supporting strut for the open-ended waveguide feed also fabricated by 3D printing, the designed all-metal reflectarray antenna was assembled and is shown in Fig. 2. The radiation patterns of the antenna were then measured using an NSI near-field measurement system.

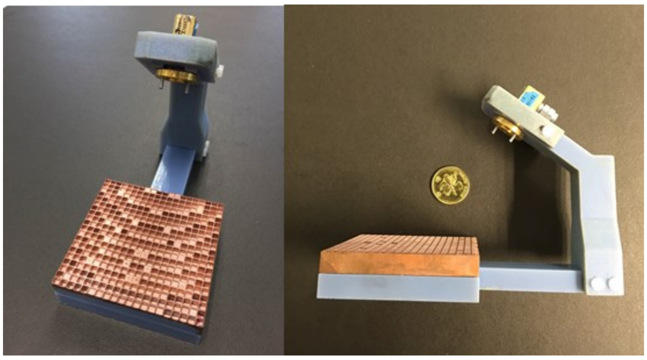
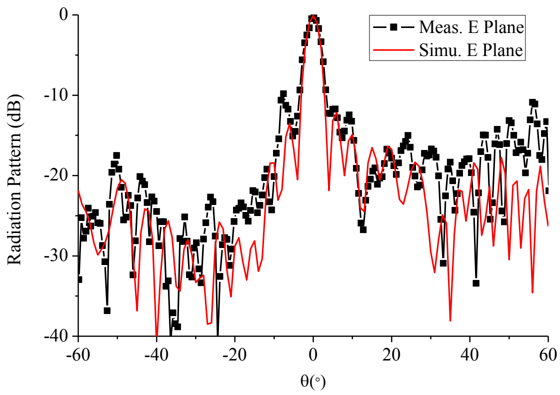


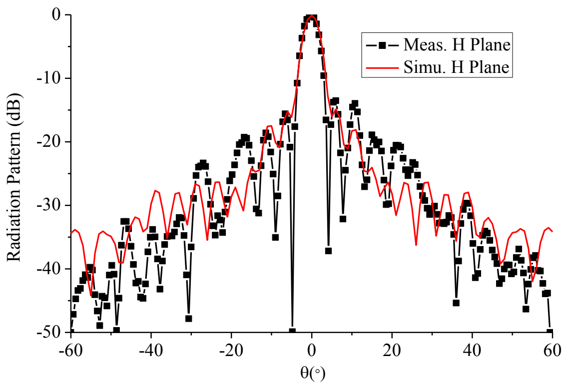
Fig. 2. Assembled all-metal reflectarray antenna.

3. Results

The measured radiation patterns in both E- and H-plane at 60 GHz are compared with simulated results using commercial electromagnetic simulator ANSYS HFSS. As seen in Fig. 3, good agreement is achieved.



(a)



(b)

Fig. 3. Comparison of simulated and measured radiation patterns. (a) E-plane and (b) H-plane.

4. Conclusion

In this paper, we have successfully demonstrated a metallization process for 3D printing structures. The simulated and measured peak gains are 25 dBi and 23.8 dBi, respectively. The slight discrepancy in gain may be due to misalignment of the open-ended waveguide feed. The 3D printed strut is not as rigid as a metallic one that the weight of measurement cable may introduce bending of the strut, causing the misalignment. Nevertheless, this 1.2 dB gain difference indicates that the metallic loss of copper at 60 GHz does not significantly affect the antenna performance. At higher frequencies, the metallization of the 3D printed surface can be made by the RF magnetic sputtering alone and different metals can be used. The presented approach provides fast prototyping of new and innovative antenna designs.

Acknowledgment

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References

[1] H. Yi, S.-W. Qu, K. B. Ng, C. H. Chan and X. Bai, “3D printed terahertz and millimeter-wave lenses with fixed and scanning beam,” *IEEE Trans. Antennas Propag.*, vol. 64, no. 2, pp. 442-449, Feb. 2016.

[2] Y. H. Cho, W. J. Byun, and M. S. Song, “Metallic-rectangular-grooves based 2D reflectarray antenna excited by an open-ended parallel-plate waveguide,” *IEEE Trans. Antennas Propag.*, vol. 58, no. 5, pp. 1788-1792, May 2010.

[3] W. J. Byun and Y. H. Cho, “60 GHz 2D metal-only reflectarray with high gain and high aperture efficiency,” *in Proc. IEEE Antennas Propag. Soc. Int. Symp.*, 2011, pp. 688-690.

[4] Y. H. Cho, W. J. Byun, and M. S. Song, “High gain metal-only reflectarray antenna composed of multiple rectangular grooves,” *IEEE Trans. Antennas Propag.*, vol. 59, no. 12, pp. 4559-4568, Dec. 2011.

[5] W. An, S. Xu, and F. Yang, “A metal-only reflectarray antenna using slot-type elements,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 1553-1556, 2014.

[6] H.-T. Chou, C.-Y. Lin, and M.-H. Wu, “A high efficient reflectarray antenna consisted of periodic all-metal elements for the Ku-band DTV applications,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 14, pp. 1542-1545, 2015.

[7] M. Yi, Y. Hong, W. Lee, and J. So, “Digitized millimeter-wave beam forming metal reflectarray antenna,” *in Proc. Int. Workshop Antenna Tech,* 2015, pp. 229-230.

[8] M. D’Auria, W. J. Otter, J. Hazell, B. T. W. Gillatt, C. Long-Collins, N. M. Rider, and S. Lucyszyn, “3-D printed metal-pipe rectangular waveguides,” *IEEE Trans. Compon., Packag. Manuf. Technol.*, pp. 1339-1349, Sept. 2015.

[9] D. G. Berry, R. G. Malech, and W. A. Kennedy, “The reflectarray antenna,” *IEEE Trans. Antennas Propag.,* pp. 645-651, Nov. 1963.