Design, Fabrication and Measurement of a Millimeter Wave Fresnel Lens using Additive Manufacturing

Kyoung Ho Jeong and Nima Ghalichechian
ElectroScience Laboratory
Department of Electrical and Computer Engineering, The Ohio State University
Columbus, OH, 43212, USA
jeong.265@osu.edu, ghalichechian.1@osu.edu

***Abstract*—The design, fabrication and measurement of a 3D-printed Fresnel lens is presented. A dielectric characterization of polylactic acid material prior to simulation and fabrication of the lens is introduced. A full-wave simulation is used to design and optimize the gain of the lens. The focal length of the lens is chosen to be 40 mm. Fused deposition modeling is adopted to manufacture the lens. The final fabricated model is composed of 4 full-wave zones with 3 subzones and 1 supporting layer. The structure has 16 annular rings with maximum radius of 69.3 mm. Also, it has the thickness of 11.8 mm. The gain pattern measurements are performed in an anechoic chamber. The results show that the lens achieves a gain enhancement of 9 dB at 30 GHz.**

Keywords—Millimeter wave; 3D printing; additive manufacturing; Fresnel lens; dielectric material;

I. Introduction

Recently, millimeter wave (mmW) lenses with RF devices have been frequently implemented due to their abilities to improve directivity and gain of the devices. Especially in Ka-band (26.5 GHz to 40 GHz), which is commonly used for satellite communication and radar systems, antennas should have high gain and directivity to transmit and receive signals in longer distances. The lens can help with achieving the improved gain or directivity of a given antenna. In this study, 30 GHz is chosen as center frequency of the lens.

Because the dielectric characteristics of the material are not well-understood in these bands, before simulating and fabricating the RF lens, characterization of the real dielectric constant and loss tangent of the material in the mmW bands should be investigated. In this study, polylactic acid (PLA), which is one of the most commonly-used material in 3D printing, is adopted as a lens material. THz-time domain spectroscopy (THz-TDS) [1] is employed to define the exact value of the dielectric constant and loss tangent of PLA in the mmW band.

In the following section, fabrication and measurement of the lens is described. A full-wave simulation is used, and fused deposition modeling (FDM) is chosen because of its time-efficiency and suitability for nonplanar structures at a low cost. Lastly, the performance of lens is investigated in an anechoic chamber.

II. Design and THz-TDS measurement of PLA

A. Design

Various strategies have been developed to achieve the desired phase correction. One of the methods is to make annular rings of dielectric material with discrete stepwise patterns. First, the outer radii of the zones, R_F, are expressed by [2-3],

$$R_F=\sqrt{(\frac{n\lambda}{4})^2+(\frac{2nD\lambda}{4})} \quad (1)$$

where n is the number of full-wave zones multiplied by the number of subzones. D is the focal length of the lens and λ is the wavelength. The step size of the lens is determined by,

$$T_F=\frac{\lambda}{4(\sqrt{\varepsilon_r}-1)} \quad (2)$$

Four full-wave zones with 3 subzones in each full-wave zone are designed. The focal length (D) is chosen as 40 mm. The dielectric constant (ε_r) is defined in the following section and the size of the lens including the thickness is presented in the fabrication section.

B. THz-TDS Measurement of PLA

To define the real dielectric constant (ε_r) and the loss tangent ($tan\delta$) of PLA, a commercial THz-TDS system (TPS Spectra 3000 from TeraView Ltd) is implemented over the frequency range of 0.3 THz to 1 THz. A 0.8mm-thick sample of PLA is measured and its data are used to calculate ε_r and $tan\delta$. Results are shown in Fig. 1.

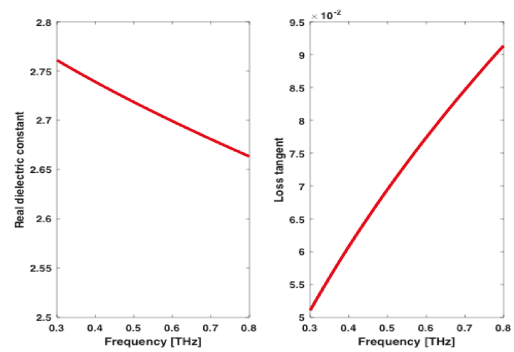


Fig. 1. Real dielectric constant (left) and loss tangent (right) of 0.8 mm-thick sample of PLA.

Havrilliak-Negami relaxation model [4], which is commonly used to model the permittivity of a polymer, is employed to calculate dielectric characteristics at 30 GHz. ε_r and $tan\delta$ are found to be 2.86 and 0.01, respectively. Those values are used in the design and simulation of the lens.

III. Fabrication

The lens is manufactured using a desktop 3D FDM printer, Ultimaker 2+. FDM is relatively a low cost and fast fabrication method compared to other 3D printing methods such as stereolithography (SLA) or selective laser sintering (SLS). Bonding strength among layers of PLA is strong and can reduce the possibility of distortion on the supporting layer of the lens, the thinnest part of the device. The thickness of the supporting layer is related to the wavelength which is 0.1λ. Therefore, if the material has a warping characteristic, the supporting layer cannot be realized in mmW and THz frequency. The final fabricated model of Fresnel lens with PLA is shown in Fig. 2. The lens has the maximum radius of 69.3 mm and the thickness of 11.8 mm. It takes 23 hours to be totally printed with FDM printer.

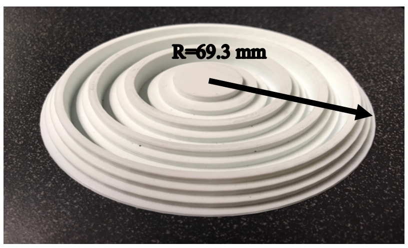
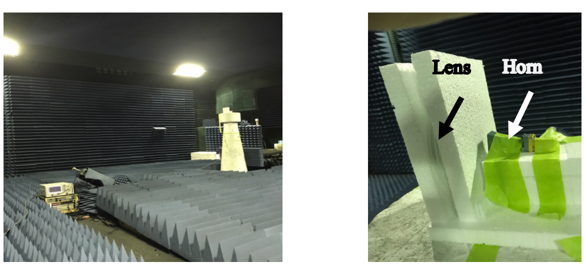


Fig. 2. Fabricated Fresnel lens with PLA

IV. Measurement setup and Results

A. Measurement Setup

Performance of the lens with the antenna is measured in an anechoic chamber. Narda V637 is used as a receiving horn antenna positioned at the focal point of the lens. Fig. 3 indicates the measurement setup in the anechoic chamber. To avoid interference which can occur in the direction of the electromagnetic wave, styrofoam, is used to position the horn and lens together.



(a) (b)

Fig. 3. Measurement setup; (a) Whole view and (b) Setup on AUT

B. Results

Fig. 4 shows the measured and simulated radiation pattern of the horn antenna without the lens. The measured frequency range is from 27 GHz to 33 GHz and the rotating angle is investigated from -90° to 90°. The simulated gain of a horn antenna is 16.1 dB as compared to the measured gain of 15.5 dB. Lastly, the half power beam width (HPBW) is 30° as compared to the measured HPBW of 28°.

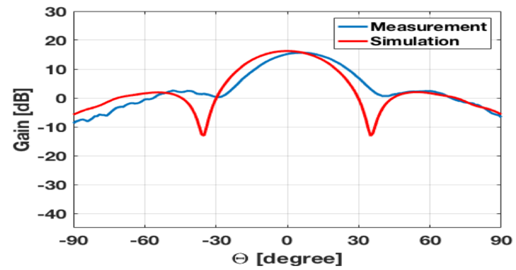


Fig. 4. Radiation pattern of the horn antenna without lens

Fig. 5 shows the simulation and measurement result of the horn antenna with the lens. It indicates that the simulated gain of the horn with the lens is 22.8 dB as compared to the measured gain of 24.6 dB. Measured gain enhancement is 9 dB as compared to the simulated gain enhancement of 7 dB. There is discrepancy of 2 dB due to the differences between the geometry of actual horn and designed horn in full-wave simulation. Also, a misalignment of horn and lens in the measurement setup might be one of the reasons of discrepancy. However, expected gain enhancement can be achieved using the fabricated lens. Also, the main lobe has HPBW of 6°, which has comparative value with the simulated result of 8°.

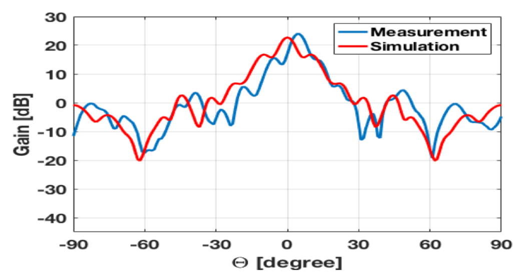


Fig. 5. Radiation pattern of the horn antenna with lens

V. Summary and Conclusions

A 3D-printed Fresnel lens operating at 30 GHz (Ka-band) has been presented in this paper. As expected, Fresnel lens with 4 full-wave zones, 3 subzones, and 1 supporting layer is successfully fabricated by a 3D FDM printer, and its performance of enhancing the gain of 9 dB is achieved from the measurement results.

References

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