3-D Printed Discrete Dielectric Lens Antenna with Matching Layer

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***Abstract*—A discrete dielectric lens antenna is studied in this paper as a possible low-loss and low-cost solution for high-gain millimeter-wave (MMW) antennas. Dielectric slabs with variable heights are used as the lens elements for phase compensation. Matching layers at the interfaces between dielectric and air are added to reduce the reflection and to enhance directivity of the lens antenna. A low-cost three-dimensional (3-D) printing technology is utilized to fabricate the antenna, and both numerical and experimental results are presented for a prototype operating at 60 GHz. This study shows that the proposed design approach is a promising method of realizing high-gain MMW antennas.**

***Index Terms* — 3-D printer, millimeter wave, lens antenna.**

I. Introduction

Recently, more and more researches have been done in the unlicensed frequency band of 60 GHz, which allows instant massive data transmission, e.g., uncompressed high-quality multimedia streaming and point-to-point connections to serve Wireless Local Area Networks. Due to high path loss during propagation in the frequency band, high-gain directivity antennas are expected, especially for point-to-point communications.

Different kinds of high-gain antennas have been studied for millimeter-wave (MMW) applications, e.g., patch antenna arrays [1]-[2] and slot antenna arrays [3]-[4]. However, the former suffer from serious loss of feeding network in the MMW region. The later can obtain high-gain characteristic, but they are generally narrow band, or require high-cost, high-precision fabrication process. Comparatively, reflectarrays and lens antennas (LAs) are suitable candidates for MMW operations, because of their space-fed structures, ease to obtain high-gain characteristic with small feeding loss [5]-[6].

Design and operation of LAs and reflectarrays are very similar in principle. Comparing with the reflectarrays, LAs could eliminate the blockage of the feeding antenna, and therefore, the LAs installation and measurement are more flexible. However, the reflection at the interfaces between air and dielectric may reduce the antenna efficiency [5]-[7].

In this work, a discrete dielectric MMW LA is studied, square-lattice dielectric slabs with different heights are ultilized as LA elements to produce different phase shifts [5]-[6]. Two matching layers (MLs) are added at the interfaces between air and dielectric to reduce the reflection. Acturally, the ML is a dielectric slab with squre holes. The simulated results show that the LA features a high-gain characteristic in MMW region and the MLs can enhance the LA directivity. Additionally, a three-dimensional (3-D) printer is ultilized to simplify the fabrication process and reduce the cost.

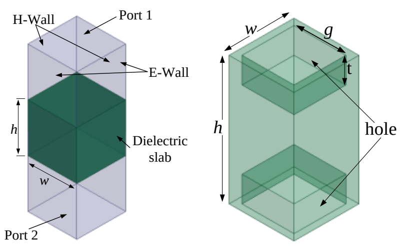


Fig.1. (a) Simulation setup of the phase shift element without ML. (b) The phase shift element with MLs. w = 2.5mm, g = 1.9 mm, t = 0.95 mm.

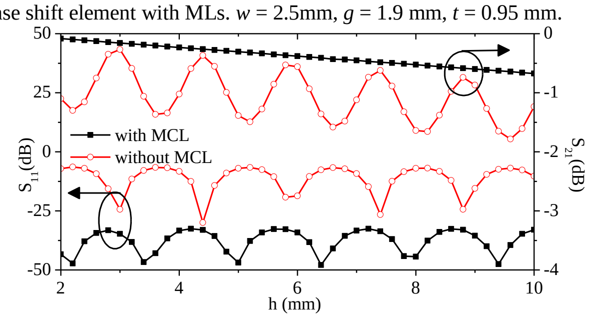


Fig.2. Transmission and reflection coefficients of the LA elements with and without ML at 60 GHz.

II. Design of the Matching Layer

Fig. 1 shows the simulation setup of the LA elements. Fig. 1(a) is the LA element without ML, which is a square dielectric slab with a height h and a width w. Fig. 1 (b) shows the LA element with MLs, i.e., square holes drilled in dielectric slab with a height t and a width g. The measured electrical properties of the dielectric material at 60 GHz are ε_r = 2.95 and tan δ = 0.01.

Fig. 2 shows the reflection and transmission coefficients of the LA elements versus element height at 60 GHz. Without MLs, the element transmission coefficient is poor due to the dielectric and reflection losses. The dielectric loss cannot be eliminated because of the lossy nature of dielectric, but the reflection coefficient can be improved by adding a quarter-wavelength MLs at the interfaces between air and dielectric

[7]-[8]. The thickness t and effective permittivity ε_e of the ML required for zero reflectivity [7]-[8] should satisfy:

$$\varepsilon_e = \sqrt{\varepsilon_r \bullet \varepsilon_0} \quad (1)$$

$$\lambda_e = \lambda / \sqrt{\varepsilon_e} \quad (2)$$

$$t = \lambda_e / 4 \quad (3)$$

where λ is the wavelength in air, and λ_e is the effective wavelength in the ML. According to Eqs. (1)-(3), the ML effective permittivity ε_e should be 1.72, and correspondingly t = 0.95 mm. As reported in [9], the periodic structures can act as an effective medium with different permittivity by changing the structure parameters. In the following simulations, the thickness of the ML is set as t = 0.95 mm, and the hole width g is optimized to obtain the needed ε_e. The final optimized parameter is g = 1.9 mm and the simulated reflection and transmission coefficients are shown in Fig. 2. The element with MLs obtains much smaller reflection loss and obviously improved transmission coefficients than the one without MLs.

III. Lens Antenna with Mtaching Layer

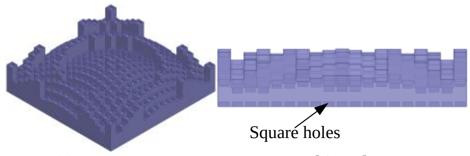
To demonstrate the effects of the MLs, two dielectric LA prototypes are designed at the operating frequency of 60 GHz. Both prototypes have square apertures with 19 × 19 dielectric elements to provide the necessary phase shift. They are fed by point sources in the simulations with a focus-to-diameter (F/D) of 0.41.

Fig. 3 shows the proposed LA with MLs. The directivities of LA with and without MLs are presented in Fig. 4. It can be observed that the directivity of LA with MLs is higher by 0.7 dB on average than the without one in the operating frequency band, which proves the validity of the MLs.

The LA with MLs is fabricated by a low-cost 3-D printer. Fig. 6 (a) shows the 3-D printed model, and Fig. 6 (b) shows the simulated and measured radiation patterns of the proposed LA fed by an open waveguide at 60 GHz. The measured and simulated radiation patterns in H and E planes are presented in Fig. 7. The side-lobe levels are below -18 dB and -14 dB in H and E planes, respectively. It can be observed that the measurements agree well with simulations.

IV. Conclusion

In this paper, we have presented our recent work on a 3-D printed dielectric MMW LA. Variable height dielectric slabs are proposed as the LA elements for phase compensation. MLs are added at the interfaces between air and the LA to enhance the directivity. The validity of the ML is confirmed by comparing the directivities of LAs with and without MLs. A 3-D printer is utilized to easily fabricate the proposed LA with low cost. The measured results show the proposed LA has a good performance at the operating frequencies. Those results prove the proposed LA is a promising candidate to obtain high-gain characteristic in MMW region.



(a) 3D view (b) Side view

Fig. 4. Geometry of LA with MLs. (a) 3D view (b) Side view.

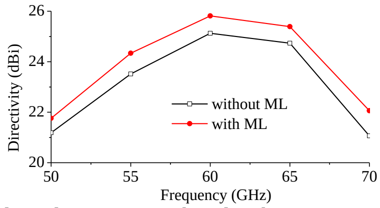
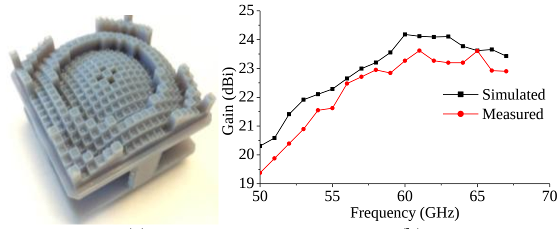
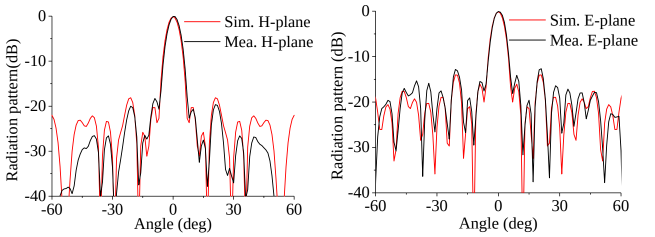


Fig. 5. Simulated LA directivities with and without MLs.



(a) (b)

Fig. 6. (a) View of 3-D printed LA model. (b) Measured and simulated gains at 60 GHz.



(a) (b)

Fig. 7. Simulated and measured radiation patterns at 60GHz. (a) H-plane (b) E-plane.

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