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3D-Printed Millimeter Wave Lens Antenna

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Abstract—In this work, we present a flat lens design using the Dial-a-Dielectric (DaD) and 3D-printing technique to realize the materials that are not available off-the-shelf. We design the proposed flat lens and compare its performance with that of the ray-optics (RO)-based lens. We find from the results that both designs show comparable performance.

I. INTRODUCTION

The design of flat lens antennas have been discussed in several recent publications [1] – [7]. Such a lens antenna can be designed to have a high gain and wide bandwidth and still maintain its low-profile characteristics.

The lens can be designed as a collection of concentric rings, whose permittivity values can be determined by using the ray optics approach so that the path lengths of the rays passing through the lens are all equal. But, the material parameters that this type of design calls for may not be readily available commercially off-the-shelf. To address this issue, we propose to design these needed materials using a combination of DaD (Dial-a-Dielectric) or 3D-printing methods [8]–[9].

II. DESIGN

We design the RO lens in the form of concentric rings, with variable permittivity values, as shown in Fig. 1. The desired permittivity values are calculated by enforcing equation 1, which imposes the condition that the rays from the different rings of the lens collimate at focal point with equal path lengths [10].

$$\epsilon_n = \left[\frac{h\sqrt{\epsilon_1 + F - \sqrt{x^2 + F^2}}}{h} \right]^2 \quad (1)$$

The design specifications of the lens (see Fig. 1) are: frequency range $f = 30\text{--}35$ GHz; focal length $F = 150\text{mm}$; thickness $h = 13.08\text{mm}$. The diameter D (120 mm) and, hence, the number of rings are chosen to satisfy the gain requirements. The number of rings is chosen to be 6 and each ring has a width of 10 mm. The desired permittivity values that are needed to satisfy the path length condition for these rings are shown in Table I and have been obtained by using equation 1.

A quick search of available materials reveals that not all of these materials are commercially available, off-the-shelf; consequently, we use the Dial-a-Dielectric (DaD) approach, in conjunction with the 3D-printing technique to realize these materials. For this design, we use the 3D-material with $\epsilon =$

Fig. 1: Lens design principle

2.72. So, if the permittivity needed for a particular ring exceeds 2.72, we combine the DaD approach with the 3D printing to realize it. Looking at Table I, we can see that the rings 1–3 require a combination of the DaD technique with 3D printing, while the 3D printing alone is adequate for the rings 4–6. In the DaD approach we modify the permittivities of the COTS materials, by covering these materials with metallic patches while in the 3D-printing technique, we insert air voids in the 3D-printing material to realize the required permittivity. We have found that neither DaD nor the 3D-printing approaches [8]–[9] lead to material realizations that are lossy, dispersive and narrowband, as they would be if we had used resonant metamaterials instead.

For comparison, we design two lenses: one (uniform dielectric lens, RO lens) with parameters shown in Table I and the other (proposed lens) whose parameters are presented in Fig. 2 and Table II. The local periodicity of the patches is chosen to be $2\text{mm} \times 2\text{mm}$ for this design. For both lenses, full wave simulations are run in HFSS.

TABLE I: Material Parameters of Uniform Dielectrics Lens.

ϵ_1	ϵ_2	ϵ_3	ϵ_4	ϵ_5	ϵ_6
3.46	3.25	2.90	2.41	1.84	1.24

TABLE II: Patch Sizes for Proposed Lens

Ring No.	Patch size
1	$1.46\text{mm} \times 1.46\text{mm}$
2	$1.35\text{mm} \times 1.35\text{mm}$
3	$0.9\text{mm} \times 0.9\text{mm}$
4	N/A
5	N/A
6	N/A

Fig. 2: Proposed Lens

III. RESULTS

Fig. 3 shows the electric field distribution along the axis of the RO lens when a plane wave is incident upon the lens from the left. Fig. 4 shows that the electric field converges at the focal point (O). Similarly in Fig. 4 we compare the electric field magnitudes along the axis for both lenses. We note from this figure that the field magnitudes at the focal point are comparable for both lenses. It is important to point out that the materials for the RO lens aren't available and we had to artificially synthesize them in the proposed lens.

Fig. 5 shows the gain, defined as $20\log_{10}(|E_f|/|E_i|)$, where E_f is electric field at the focal point (O) and E_i is the electric field of the incident plane wave (here, $E_i=1$ V/m for simulation). The gain values are within 0.6 dB of each other.

IV. CONCLUSIONS

Two different flat lens designs have been presented in this work. The first of these, namely the RO Lens, is based on the use of uniform dielectrics that are not commercially available,

Fig. 3: Electric field distribution at 30GHz

Fig. 4: Electric field distribution along axial direction at 30GHz

Fig. 5: Simulated gain of lenses

and is included here for comparison. The second lens is designed using the DaD, and its performance is comparable to that of the RO lens, which requires permittivities not available off-the-shelf.

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