Low-Cost Dielectric Flat Lens for Near-Field Focusing

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***Abstract*—This paper presents a NF-focused antenna based on a low-cost dielectric planar lens. The working principle is based on the variation of dielectric material density in order to obtain a variation in the effective ε_r. A prototype in the 28GHz band is designed and manufactured with a 3D printer using Polylactic Acid (PLA) material. The breadboard is simulated with a full wave tool and measured in an XYZ planar range, resulting in a very good agreement between simulations and measurements.**

***Keywords*—3D-printed lens, dielectric flat lens, near-field focusing.**

I. Introduction

In the last years the near field antennas become more interesting because of the number of applications. In some of them near field focusing in the Fresnel region is required. When it comes to focus the near field an aperture antenna should be used and different solutions can be proposed. For example, reflector and lens based antennas are suitable candidates but both are bulky and in the case of reflector antennas offset optics are usually used in order to avoid feed blocking. In the case the use of high dielectric-constant material allows to reduce the volume of the antenna. In this line, there are some previous works where a dual dielectric hyperbolic lens is proposed with this goal [1, 2]. However, the manufacturing process is not much simple because of the curved surfaces to be implemented and expensive if low roughness is required. As an alternative reflectarray and transmitarray antennas are planar solutions which simplifies manufacturing and integration processes but they include printed conductor elements.

As an intermediate solution in this work a flat dielectric lens is proposed and studied for near-field focusing in the 28 GHz frequency band. The phase distribution to be introduced by the lens is implemented by varying the dielectric material density in order to control the effective dielectric constant along the surface of the lens.

The flat dielectric lens proposed in this work provides an easier manufacturing process with a similar performance. A prototype is designed, manufactured and measured, which demonstrates the performances of the antenna.

II. Near-Field Focusing Antenna

The proposed antenna is based on the structure shown in Fig. 1 and it is made up of two elements: a horn antenna working as primary feed and a planar lens that focuses the incident electric field to produce a near-field focusing spot. As shown in the figure, two focal distances are defined for the antenna F1 and F2 that are the distances from the lens to the placement of the feed and the focussing spot respectively. Based on a Gaussian beam equation, focal lengths F1 and F2 of 100 and 150 mm respectively with a beam waist of 30 mm require a lens diameter of at least 120 mm at 28 GHz. As primary feed the NARDA V637 standard horn antenna is used. This horn antenna generates an illumination taper of 10 dB at the edges of the lens ensuring low diffraction.

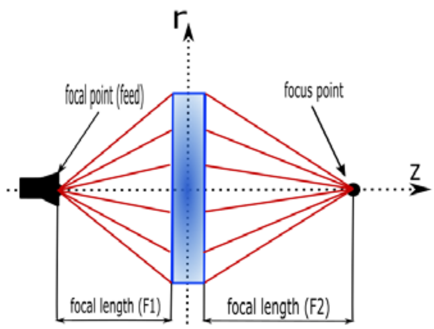

Figure 1. Description of the system employed to design the lens.

The working principle of the antenna consists of the constant phase delay from the feed to the focusing point for all the possible paths. So, as the path length from the feed changes along the radius of the lens, the phase delay introduced by the lens along its surface should be adjusted. In order to do that, the lens is divided into a number of cells in a regular lattice of $0.5\lambda_0 \times 0.5\lambda_0$ as usually in transmitarrays so each one can be considered as a phase shifter. In this case, the equation to be fulfilled by all the cells of the lens is:

$$\phi_{in}(r) + \phi_{lens}(r) + \phi_{out}(r) = C_{tant} \quad (1)$$

where $\phi_{in}(r) = -k_0\sqrt{F_1^2 + r^2}$ is the phase of the incident field on the inner surface of the lens cell (because of the phase delay from the feed to the cell), $\phi_{lens}(r)$ the phase introduced by the lens, $\phi_{out}(r) = -k_0\sqrt{F_2^2 + r^2}$ the phase introduced by path from the outer surface of the cell to the focusing point, r is the distance from the centre of the cell to the centre of the lens and C_{tant} is constant. Thus, $\phi_{lens}(r)$ can be computed as, assuming $C_{tant} = 0$:

$$\phi_{lens}(r) = k_0 \left(\sqrt{{F_1}^2 + r^2} + \sqrt{{F_2}^2 + r^2}\right) \qquad (2)$$

According to (2) and the antenna optics defined above the phase distribution to be introduced by the planar lens are computed.

III. Fabrication and Results

In order to implement the phase required along the lens surface, a variation in the dielectric material density is defined so the equivalent dielectric constant can be modified and therefore the phase introduced by the lens cell [3].

In order to achieve a low-cost lens, it was used a 3D printing option. This method consists of making a three dimensional object using an additive process. The material is deposited layer by layer until the desired shape is achieved. In this work, the Polylactic Acid, PLA, ($\varepsilon_r = 2.98, \tan\delta = 0.015$) [4] was used to print the lens. The flat dielectric lens was designed in a square shape of 120×120 mm^2. This shape allows an easier integration with the assembling structure which is also manufactures using 3D printing process.

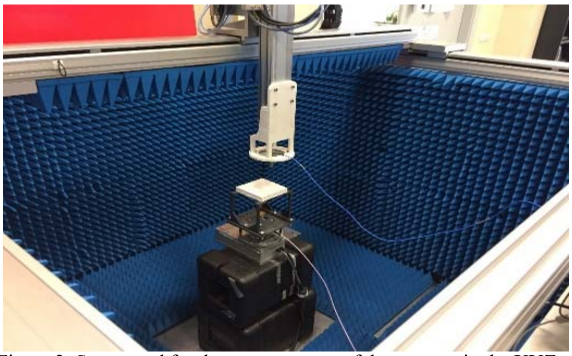

Figure 2. Setup used for the measurement of the antenna in the XYZ planar acquisition range of Universidad de Oviedo.

The lens was measured in the XYZ planar acquisition range in anechoic environment at Universidad de Oviedo, see Fig. 2, using an open-ended waveguide as probe. In order to check the accuracy of the manufacturing process, the co-polarization component of the electric field was measured along the z-axis (axial axis of the antenna), and these results are compared with simulations carried out with CST-Microwave Studio [5].

As it is showed in Fig. 3 an excellent agreement was found between the measurement and the simulation results. Although the theoretical focus point is placed at a distance of 150 mm from the surface of the lens, the experimental results suffered a displacement of 40 mm, being placed the focus point achieved at 110 mm far from the lens. This behaviour is well known and has been discussed in previous works [6].

Finally, the weight of the lens is 168 grams which is 80% of the equivalent dual hyperbolic lens (214 grams), while the volume is 288 and 961 cm^3 for the planar and hyperbolic lenses respectively.

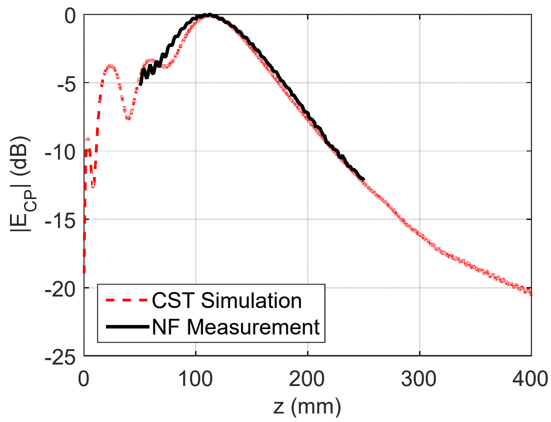

Figure 3. Normalized electric field intensity (copolar) of the flat dielectric lens along the axial axis of the lens.

IV. Conclusion

A low-cost flat dielectric lens for focusing in the near field region at 28 GHz has been presented in this contribution. The lens was manufactured using a 3D printing technique based on an additive process of PLA material to reduce the cost. The antenna has been measured in a XYZ planar range and compared with the simulations carried out with CST obtaining very good agreement. Compared with conventional hyperbolic lenses, the one proposed in this work is 20% more lightweight and requires 70% less volumen.

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