

3D-Printed Graded Index Lens for RF Applications

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Abstract - This paper presents a novel 3D-printed low-cost, light weight, broadband and high gain planar graded index (GRIN) lens. The GRIN lens was designed to transform spherical wavefronts into planar wavefronts which can be used for antenna gain enhancement. Fused deposition modelling 3D-printing was used to fabricate the lens in a single process with bespoke radially varying relative permittivity. Measured results showed that the lens had a realised gain of 16 to 24 dBi over the Ku-band frequency range from 12 to 18 GHz when fed by a conical horn.

Index Terms — planar lens, graded index, 3D-printing, additive manufacturing.

1. Introduction

A lens is a well know antenna component designed to transform a plane wave into spherical wave for focusing optical rays to a single point. It also converts the spherical wavefronts emanating from a feed, located at the focal point, into planar wavefronts; and, therefore, it can be used for antenna application to realise a high directivity antenna. Furthermore, lenses generally provide broadband advantages over the conventional antenna arrays. A flat lens has a low-profile, is light-weight and can be easily used in proximity to the antenna. In recent years, research into a variety of flat lens antennas has been carried out based on field transformation, transformation optics, ray optics and transmit array approaches [1]–[4].

The lenses are generally designed with radially varying refractive indices to manipulate the EM waves. However this is challenging to realise and fabricate. For practical fabrication, the lenses are often comprised of several tight-fitted zones with different EM properties. However, it is difficult to source the materials in commercially off-the-shelf form that have the required EM properties. Another method to produce tailored EM properties is by perforating a homogeneous slab with variable hole diameters or separations [5]. Precise machining and tight tolerances are required particularly for high frequency applications. Sometimes the maximum number of holes is limited to prevent the material from physically cracking.

This paper presents the design of a novel wideband planar GRIN lens and its fabrication using rapid prototyping 3D-printing. 3D-printing is an additive manufacturing technique which creates 3D-objects in successive layers. It provides a practical fabrication approach to produce highly customisable structures with the advantages of low-cost and fast automated repeatable design and manufacturing. The 3D-printing process allows

creating embedded sub-millimetre internal structures such as air voids in the 3D-object in a single process without machining. 3D-printed dielectric substrates with different relative permittivities ϵ_r was reported in [6]. Compared with perforating a solid material, the design can be easily modified and rapidly prototyped in-house using low-cost 3D-printing materials. The lens was then 3D-printed and its far-field performance was measured using an azimuth-plane scanning system.

2. 3D-printed planar lens

In this work, a Makerbot[®] Replicator[™] 2X 3D-printer was used to fabricate the flat GRIN lens. Thermoplastic polylactic acid (PLA) was used as the print material. The heated printer nozzle extruded the PLA material and created the lens layer by layer from the bottom up. This process enabled the fabrication of embedded air voids in a single process without machining. By varying the volume fraction of the air voids, the effective relative permittivity of the 3D-printed structured were tailored to desired values. The required PLA volume percentage v for tailoring the effective permittivity ϵ_{reff} of the 3D-printed dielectrics can be determined by using equation (1):

$$v = \frac{\epsilon_{reff} - 1}{\epsilon_{r0} - 1} \quad (1)$$

where ϵ_{r0} is the relative permittivity of the PLA material ($\epsilon_{rPLA} = 2.72$).

For practical fabrication, the fabricated lens was comprised of six 10 mm wide discrete dielectric concentric cylindrical rings. The maximum and the minimum permittivities of the rings were 2.72 and 1.30 respectively. The final 3D-printed lens is shown in Fig. 1. Fig. 2 shows the step function of the variation effective permittivity versus radial distance across the lens. The 3D-printed lens had good stiffness to resist deformation or deflection.

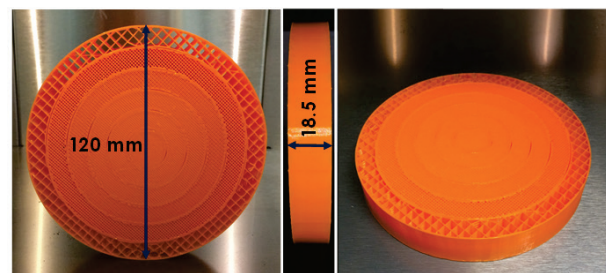


Fig. 1. 3D-printed planar lens

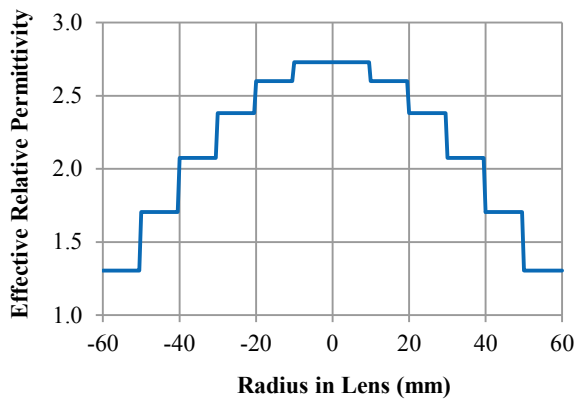


Fig. 2. The effective permittivities for 6 rings in the 3D-printed lens as a function of radius position

A 180° azimuth-plane scan measurement was set up for testing of the performance of the 3D-printed lens. A Ku-band pyramid waveguide horn antenna, which was placed at a distance of 1.5 m along the lens axis, served as the receiving antenna. The measured gain patterns in the E-plane and H-plane of the lens, at the frequency of 12, 15 and 18 GHz, are shown in Fig. 3. The radiation patterns had a higher directive main beam at higher frequencies. The secondary side-lobes were due to the feed source. At 15 GHz the half-power beamwidth in the H-plane was approximately 11° and 9.5° at 18 GHz. The peak of the main beam was approximately 13.8 dB higher than the first side lobe level at the centre frequency 15 GHz.

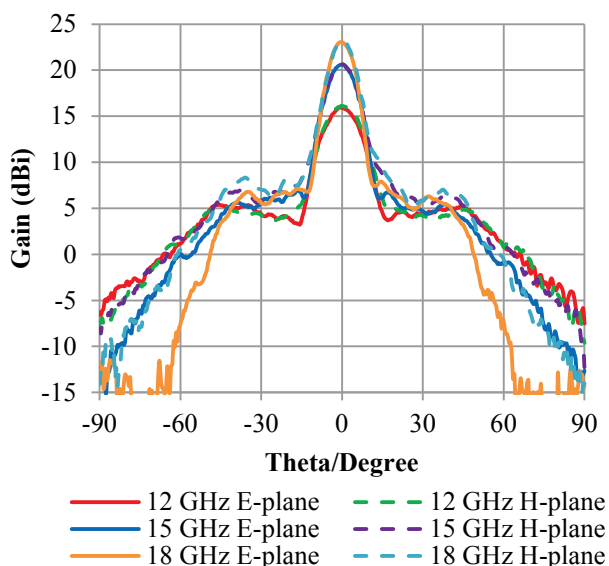


Fig. 3. Measured far field pattern of 3D-printed lens fed by a conical horn located at the focal point

3. Conclusion

This paper has presented a low-cost, light-weight and wideband 3D-printed flat lens which can be rapidly prototyped and be used for antenna applications. The entire lens weights approximately 130g and the material cost is less than \$10. The 12 cm diameter GRIN lens is comprised of six concentric rings with different permittivity values. Air voids are created inside the lens during 3D-printing fabrication to reduce the permittivity of the 3D-printed material to the bespoke values. The entire lens is 3D-printed in a single process without the need for machining or assembling. The lens had a broadband realised gain of 16 to 24 dBi from 12 to 18 GHz when illuminated by a conical horn. The directivity enhancement realised by this lens shows its potential for numerous antenna applications.

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