3D Printed Helical Antenna with Lens

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Abstract—The gain of an antenna can be enhanced through the integration of a lens, however this technique has traditionally been restricted to planar antennas due to fabrication limitations of standard manufacturing processes. Here, with a unique combination of 3D and 2D inkjet printing of dielectric and metallic inks respectively, we demonstrate a Fresnel lens that has been monolithically integrated to a non-planar antenna (helix) for the first time. Antenna measurements show that the integration of a Fresnel lens enhances the gain of a 2-turn helix by around 4.6 dB giving a peak gain of about 12.9 dBi at 8.8 GHz.

Keywords—Helical antenna; lens; inkjet printed; 3D printing

I. INTRODUCTION

Helical antenna is one of the most widely used antennas due to its many attractive features such as high gain, wide bandwidth, circular polarization and the ability to radiate both omnidirectional and directive patterns [1]. The gain of the helical antenna can be increased by increasing the number of turns. However, the gain is not linearly proportional to the number of turns and after many turns, the addition of more turns has little effect [2]. Another method of increasing the gain of the helical antenna can be through integration of a dielectric lens.

Dielectric lenses are typically used to increase the directivity of the antennas because of their ability to focus electromagnetic waves in certain directions. Traditionally, lenses are used with planar or aperture antennas [3] due to the ease of integration and the limitations of manufacturing techniques. Integration of a hemispherical lens to a helical antenna has been proposed in [4], but only the simulation results have been shown. Inkjet printing technology provides an attractive method for low cost and rapid manufacturing of complex 3D objects that are very difficult, expensive and time consuming to fabricate using conventional techniques such as carving, molding and computer numerical control (CNC) machining [5]. Printing technology uses an additive process, which reduces material wastage, and by using a digitally controlled process, deposits a precise amount of material at a desired location. However, RF structures usually require integrated metal and dielectric, and current inkjet printing technology is still immature in depositing dielectric and metal at the same time. There are not many reports that show

Fig. 1. Helical antenna integrated to a Fresnel lens, dimensions in cm.

integration of inkjet-printed metal and dielectric to realize RF structure.

Here a unique combination of inkjet printing of dielectric and metal has been utilized for the realization of a novel 3D antenna configuration. A helical antenna has been monolithically integrated to a dielectric Fresnel lens through inkjet printing technology. As a result of the lens integration, a two-turn helical antenna provides a peak gain of 12.9 dBi in the X-band. This work shows the advantage of inkjet printing technology through which a dielectric lens, that has been typically limited to planar antenna designs, can easily be integrated to a helical structure.

II. ANTENNA DESIGN

A 2 turn helical antenna has been designed with the radius and spacing between the turns meeting the criteria for end-fire circular polarized (CP) operation given in [1]. The diameter of the helix is 1 cm and spacing between the turns is 0.7 cm. The helix is then integrated into a dielectric Fresnel lens as shown in Fig .1. The Fresnel lens structure consists of grooved zones such that the phase velocity of wave travelling within the zones is higher than in solid material. The depth of the grooves determines the phase difference between adjacent zones that should be equal to the desired phase compensation in order to transform the incoming spherical wave into a plane wave. The radius of each zone is given by [6].

$$R_n = \sqrt{\frac{2nF\lambda_0}{P} + \left(\frac{n\lambda_0}{P}\right)^2} \quad (1)$$

Fig. 2. Simulated and measured S11

Where n is the zone index, λ_0 is the free space wavelength, F is the focal length and P is the number of different phases to implement phase compensation. The depth of the zones is given by

$$d = \frac{\lambda_0}{4(\sqrt{\epsilon_r} - 1)} \quad (2)$$

The radiation efficiency of the lens increases with P . Here, P is equal to 4, which means the phase needs to be corrected for every 90 degrees. For this quarter wave zone lens, successive groove depths of d , $2d$ and $3d$ are used. A Fresnel lens has been designed with a focal length to diameter ratio (F/D) of 0.04, as shown in Fig. 1. The diameter of the lens has been chosen to be around twice of the wavelength in order to have reasonable dimensions of the lens when operating in the X-band. Simulated electric field pattern on the lens show that the fields are concentrated towards the center of the lens, and that the lens is able to focus the incoming waves from the helical antenna.

III. FABRICATION AND RESULTS

The antenna has been manufactured by a combination of 3D inkjet printing of dielectric and 2D inkjet printing of metal. The helical structure along with the lens has been monolithically manufactured using the 3D inkjet printer Stratasys Objet260 Connex1. After 3D printing of helix and lens, the helix is metallized using inkjet printing of silver nanoparticle ink using Dimatix 2831 printer. Since helix is a 3D structure and metal inkjet printing is a 2D process, the metallization process involves three cycles of inkjet printing. After each cycle, the helix is rotated about 120° .

The S_{11} of the antennas are measured using Agilent's E8361C PNA series network analyzer. The results are shown in Fig. 2. There is a downward shift in the operating frequency of the antennas as compared to the simulations. Also, slight mismatch occurs at around 11 GHz. A possible reason for this effect can be the launch pitch angle of the helix. Since the ground plane is not part of the monolithically printed 3D structure of the antenna and is later attached manually, slight

Fig. 3. Radiation patterns at 9 GHz. (a) Co-polarization. (b) Cross-polarization

tilt of the helical structure with respect to ground plane can change the pitch angle and affect the input impedance of the antenna. The gain patterns of the antenna are measured in Satimo SarLab near field measurements system. The measured radiation patterns at 9 GHz are shown in Fig. 3 demonstrating an increase in directivity after lens integration. The measured peak gain of the helical antenna with Fresnel lens is 12.9 dBi at 8.8 GHz, giving an increase in gain of around 4.6 dB compared to helical without the lens. The 3 dB axial ratio (AR) bandwidth is around 5.5%. The measured efficiency of our design is 65 % which is considerably higher compared to inkjet-printed antennas [7,8].

IV. CONCLUSION

In this work, a 2 turn helical antenna monolithically integrated with a lens through 3D printing is presented. The integration of lens results in the enhancement of gain by 4.6 dB giving a peak gain of 12.9 dBi. This work shows the utility of additive printing technologies for realizing complex 3D RF components that are very difficult and expensive to realize using conventional manufacturing techniques.

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