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RESEARCH ARTICLE

Design, fabrication, and testing of a helical antenna using 3D printing technology

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Abstract
We report the design, fabrication, and measurements of a circularly polarized 3D-printed helical antenna operating at 5 GHz. Several commercially-available dielectric printers and materials (eg, PLA, ABS, PC) were evaluated for the fabrication process. Metallization was performed with nickel electroless plating followed by copper electroplating. Fabrication and metallization process completed within 24 hours. Maximum gain of the antenna is measured as 13.9 dBic at broadside (RHCP). Measured efficiency of the antenna is 89.1% which shows the effectiveness of our metallization process. The results demonstrate the feasibility of rapid fabrication of lightweight and high efficient antennas using 3D printer technology.

KEYWORDS
3D printing, additive manufacturing, antenna, electroless plating

1 | INTRODUCTION

Advancements in 3D printer technology and availability of desktop printers offer a unique opportunity in exploring new fabrication techniques for various complex RF components and antenna structures. Currently, printed circuit board (PCB) fabrication process is widely used for planar antenna structures such as patches.[1] On the other hand, fabrication of the 3D and complex structures are highly costly and not suitable for mass production. 3D printing or additive fabrication techniques addresses these shortcomings and offer low cost and rapid prototyping/manufacturing of complex structures.

Conventional fabrication of helical antennas involves bending of copper tubing, which it is extremely difficult to maintain a precise pitch and diameter. Another method is using 3D milling machine, which entails a complex, expensive and lengthy process. In contrast, rapid and precise 3D printing of the helical antenna is possible. Researches have shown the feasibility of 3D printing on wire structure antennas such as electrically small spherical antenna or helical antenna.[2-4] However, dielectric supporting structures are usually needed to suspend the wire,[4,5] which degrades the antenna performance.

Another challenge in 3D printed RF components is the metallization of 3D structures. Copper paint has been used for metallization but the low conductivity of the paint will introduce significant dissipative loss.[5] To improve the conductivity, nanoparticles can be introduced in inkjet printing of 3D structures.[5] However, the silver ink used is expensive while the conductivity is not enhanced significantly. Conductive ABS material is also used in the fabrication of flexible antennas but they suffer from low efficiency due to their low conductivity.[5] In Reference 6, 3D printed waveguides and filters are metallized with plating process on plastic, therefore, highly conductive surfaces are achieved. It has been shown that copper electroplating provides ideal conductivity with sufficient thickness.[7]

In this paper, we present an example of 3D-printed high-gain helical antenna. Helical antennas are attractive, especially in satellite platforms due to their circular polarization, high gain, and simple structure. The proposed antenna is fabricated using PolyJet 3D printing technique without any supporting structures. Metallization is performed using nickel electroless plating followed by copper electroplating, which provides equivalent conductivity with metal and lower cost compared with aforementioned metallization techniques.

2 | ANTENNA DESIGN

Geometry of the helical antenna is depicted in Figure 1. Antenna is designed in axial mode for C-band (4-6 GHz) at

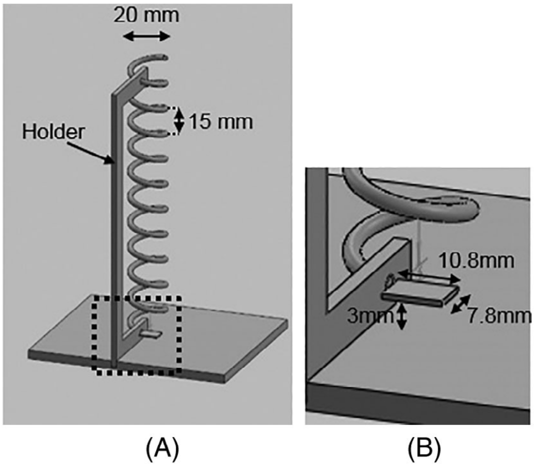

FIGURE 1 A, Geometry of the proposed helical antenna. The height of helix is 162 mm. B, The detailed view of the suspended quarter-wave microstrip line

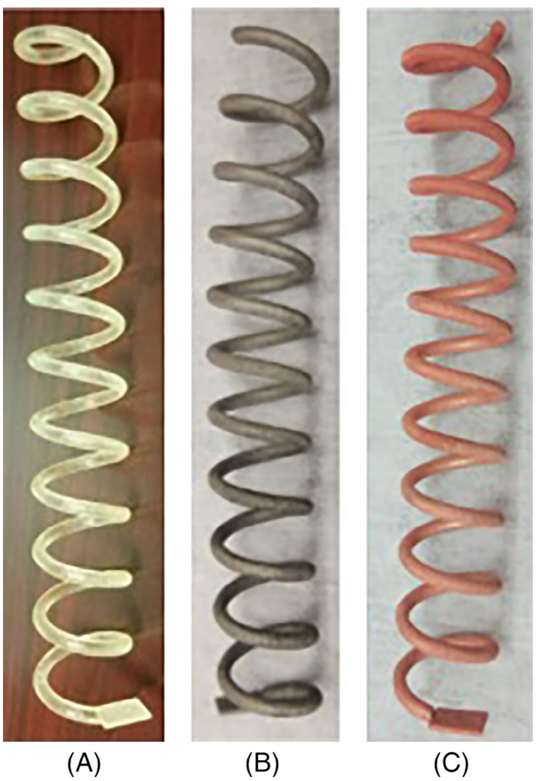

FIGURE 2 A, Fabricated helical antenna before plating. B, Fabricated helical antenna after nickel electroless plating. C, Fabricated helical antenna after copper plating [Color figure can be viewed at wileyonlinelibrary.com]

the center frequency of 5 GHz. Helix has a diameter of 20 mm with circumference of approximately one wavelength and a wire diameter of 3 mm. Antenna has 10.6 turns with a total height of 162 mm. Practical fabrication limitations were taken into account in our design. Antenna input impedance is matched to 50 Ω using a 3D-printed suspended quarter-wave microstrip transmission line. Microstrip is suspended on the ground plane at the height of 3 mm with the

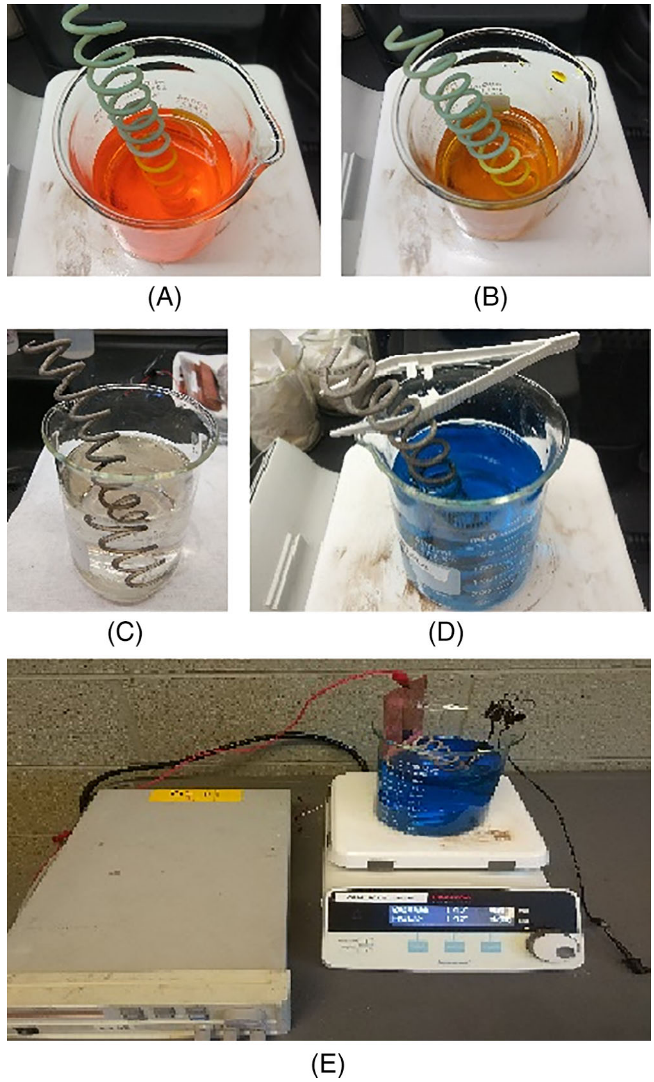

FIGURE 3 A, The metallization process: etching. B, The metallization process: activation. C, The metallization process: fixing. D, The metallization process: Ni deposition. E, The metallization process: Cu electroplating [Color figure can be viewed at wileyonlinelibrary.com]

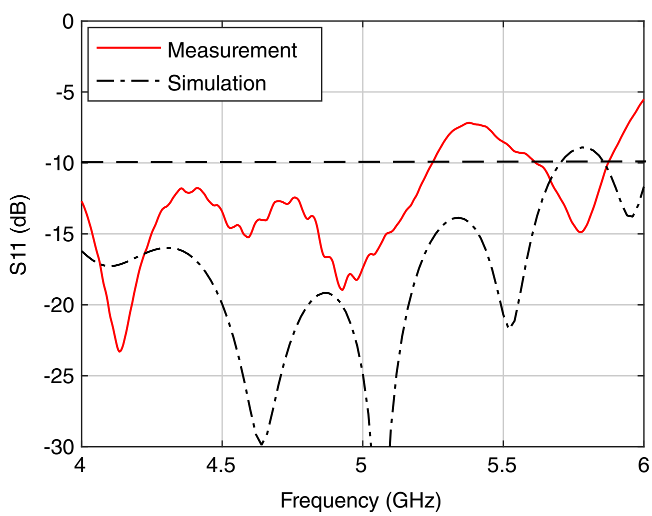

FIGURE 4 Measured and simulated reflection coefficient of the helical antenna at the frequency range of 4 to 6 GHz [Color figure can be viewed at wileyonlinelibrary.com]

characteristic impedance of 76 Ω. The design is verified by performing full-wave simulation in ANSYS-HFSS.

3 | FABRICATION AND METALLIZATION

Helical antenna is 3D printed in three sections; ground plane, holder, and helix with microstrip matching feed (Figure 2). Ground plane and holder are 3D printed using a FDM printer with PLA and ABS-PC material, respectively. The Helical antenna is printed using a PolyJet printer (Objet Prime 30) with photo-polymer RGD720 to achieve high precision and low surface roughness (Figure 2A).

The metallization of the helix antenna is performed by electroless nickel (Ni) plating followed with copper (Cu) electroplating.[8] The Ni electroless plating consists of four steps: etching, activating, fixing, and Ni deposition. The etching solution (mixture of chromium trioxide and sulfuric acid (Transene Company Inc.) creates micro-pores on plastic, which acts as the bonding layer between substrate and subsequent metal layer. The second activating solution (mixture of hydrochloric acid and palladium chloride) removes the residual chromium ions (Cr^{6+}) from the plastic substrate. Then, the palladium chloride is deposited in the micro-pores created by the etching process. The palladium acts as a seed layer for the nickel deposition. Next, the part is immersed in the fixing solution without water rinsing. The fixing solution is composed of sodium hypophosphite monohydrate, which helps to reduce the Ni^{2+} ions into Ni metal on the plastic substrate. Finally, the part is immersed in the electroless Ni plating solution, which is composed of a mixture of citric acid monohydrate, ammonium hydroxide, hydrochloric acid, nickel sulfate, and sodium hypophosphite. The plating is performed at 41°C for 15 minutes. Then, the part is uniformly covered with Ni as shown in Figure 2B. After Ni plating, Cu electroplating is performed to achieve desired metal thickness and conductivity (Figure 2C). A pre-electrolyzed copper-based electrolyte (Technic, Inc.) is used for electroplating process, which is performed at 30°C for 30 minutes with 0.4 A current. Figure 3A shows the metallization process for each step. The entire fabrication process including 3D printing and metallization is completed within 14 hours.

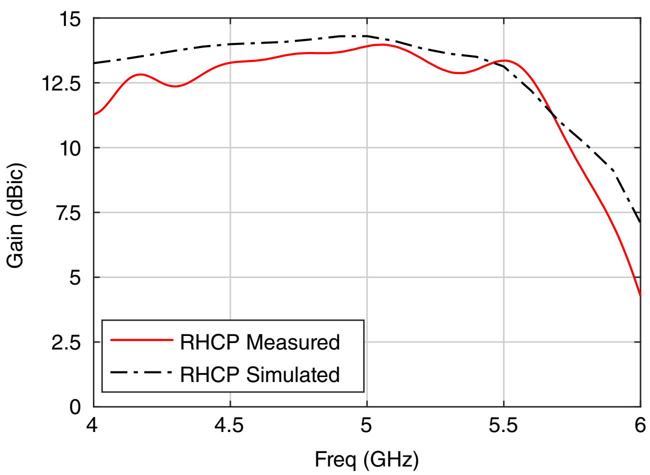

FIGURE 5 Measured and simulated broadside RHCP gain of the helical antenna at the frequency range of 4 to 6 GHz [Color figure can be viewed at wileyonlinelibrary.com]

4 | MEASUREMENT RESULTS

Reflection coefficient of the fabricated helical antenna is measured using Agilent N5230A network analyzer over the frequency range of 4 to 6 GHz and compared with the

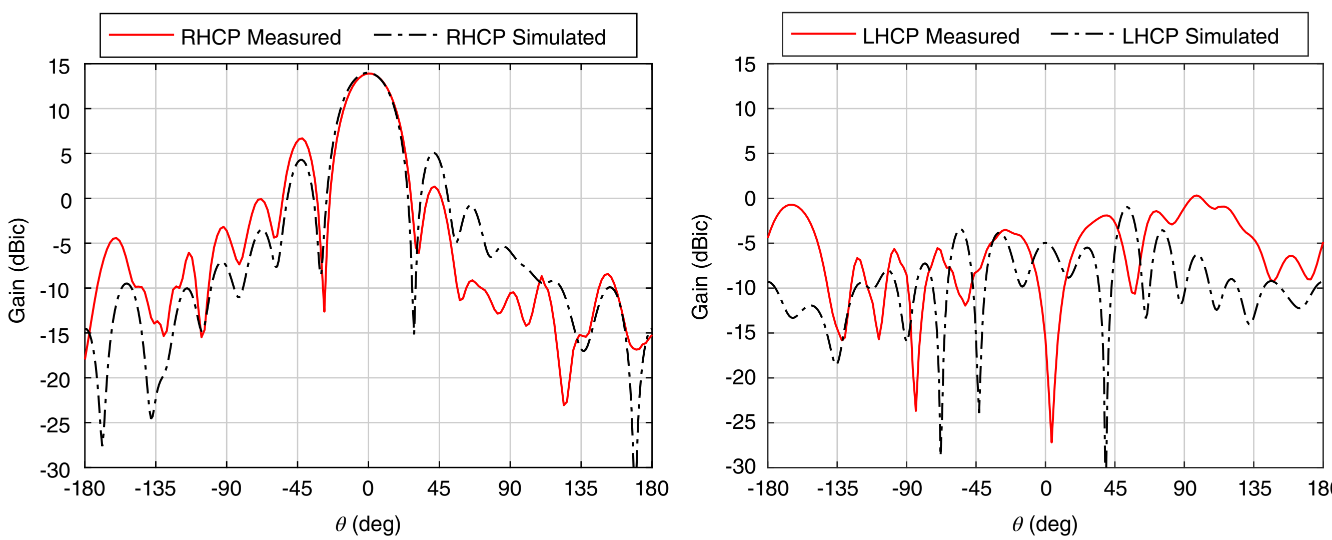

FIGURE 6 Measured and simulated RHCP gain pattern of the helical antenna at the frequency of 5 GHz. Measured and simulated LHCP gain pattern of the helical antenna at the frequency of 5 GHz [Color figure can be viewed at wileyonlinelibrary.com]

simulation data (Figure 4). Antenna is matched with a return loss of better than 10 dB over the frequency range of 4 to 5.2 GHz. Discrepancies between measured and simulated data is due to uneven height of the quarter-wave transformer and the variation of the pitch of the helix throughout the length of the antenna. Deformation of the helical antenna during the metallization process is caused by the increased solution temperature. As a result of temperature increase, photo-polymer RGD720 shrinks in size and consequently, the total length of the antenna decreases. The pitch of the helix is decreased by 2 mm and measured to be 13 mm. As a result, the gain of the antenna is decreased. This can be avoided in the future by using temperature durable 3D printing material.

Pattern measurements of the antenna are performed at an anechoic chamber with Cobham H-1479 broadband feed antenna. Since the fabricated helical antenna is right-handed, polarization of the radiated field is right handed circularly polarized (RHCP). Circularly polarized (CP) gain is calculated by measuring the pattern with both vertical and horizontal polarization and their relative phase difference. RHCP gain at broadside is shown in Figure 5 and the antenna has a RHCP gain >12.5 dBi for the frequency range of 4.1 to 5.6 GHz. Pattern measurements of the antenna at 5 GHz are illustrated in Figure 6. It is seen that measured gain values agree well with the simulation data for the most of the elevation angles. Antenna has a maximum measured gain of 13.9 dBi at broadside with HPBW of 29° and the side lobe level of −7.2 dB. Efficiency of the antenna is calculated as 89.1% using the ratio of the peak gain to the calculated directivity. Broadside cross-pol (LHCP) isolation of the antenna is better than 20 dB.

5 | CONCLUSION

In this work, we demonstrated rapid manufacturing of a helical antenna using 3D printer technology. Measurement results illustrate a close agreement with full-wave simulation. Antenna has a high efficiency of 89.1% which shows the effectiveness of our metallization process.

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