3D Printed Reconfigurable Helical Antenna Based on Microfluidics and Liquid Metal Alloy

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***Abstract*—This paper demonstrates a new approach to build 3D reconfigurable antennas at an extremely low cost and the first 3D printed reconfigurable helical antenna based on microfluidics and liquid metal alloy (LMA). With the fused deposition modeling (FDM) 3D printing technique, 3D microfluidic channel can be fabricated in a short production cycle cost-effectively. EGaIn, a non-toxic LMA, is filled into a 3D printed helix channel and form the helical antenna. As the gain of the antenna is determined by the number of turns of the helix which is controlled by the volume of LMA, the gain of the antenna can be tuned when needed. A more than 4 dB gain increase around 5 GHz is measured with the prototype when the number of turns of helix increases from 2 to 8 (0.2 mL LMA volume change), which demonstrates the reconfigurability of the proposed helical antenna.**

I. Introduction

In the recent decades, additive manufacturing techniques such as 3D printing has attracted an increasing amount of attention, as it can create complex 3D objects directly from computer-aided design (CAD) files without any need for assembly saving production time and cost [1]. Under this concept, different printing technologies have been developed, including fused deposition modeling (FDM), stereolithography (SLA), and Selective Laser Sintering (SLS), all with their own advantages and disadvantages in different applications. FDM, the most accessible and economic printing method is chosen for its ability to fabricate water-tight microfluidic channels without any support structure [2].

Generally, 3D antennas, such as helical antennas, are hard to fabricate with traditional planar electronics fabrication process. With the current state of 3D printing technology, metallization is still a shortcoming in fabricating 3D antenna. In this background, liquid metal alloy (LMA) applied in a 3D printed channel could be a novel solution because it is capable to not only metallizes the 3D printed dielectric objects but also build reconfiguration antennas.

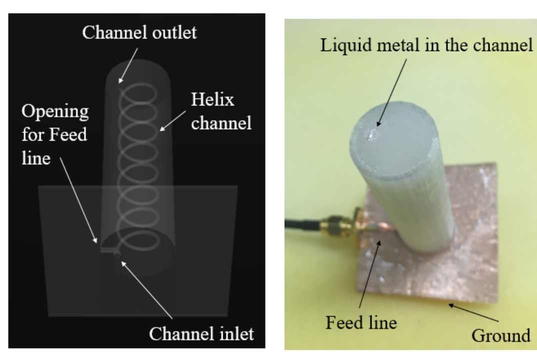
Unlike mercury, Eutectic GalliumIndium (EGaIn) (Ga 75.5% and In 24.5%) used in this paper is a safe and non-toxic LMA. EGaIn has a resistance as low as $29.4 \times 10^{-6}\Omega$-cm [3] and was used in various tunable antennas and microwave applications [4], [5]. This paper combines an extremely low-cost 3D printing technique with LMA to develop a new approach for reconfigurable 3D antennas and prototypes a reconfigurable helical antenna to evaluate the method.

II. Theory of Operation

Axial-mode helical antenna is a 3D directional antenna with circularly polarization. The directivity (or maximum gain) of the antenna is closely related to the number of turns of the helix. The mathematical approximation is in (1) [6], where N is the number of turns, C is the circumference, S is the spacing between turns and λ is the wavelength. The directivity of antenna grows with the number of turns as the current in the increased turns would direct the radiation power to the end of helix (end-fire).

$$D_{dB} = 11.8 + 10log(N) + 10log(C^2S/\lambda^3) \qquad (1)$$

In this paper, a cylinder on a square base with a helix channel inside is 3D printed, as shown in Fig. 1. By filling the LMA into the channel from the inlet in the bottom, a helical antenna can be built. Thus, the number of turns is determined by the volume of LMA filled, so the gain of the antenna can be controlled in use. With NinjaFlex ($\epsilon_r = 2.95$ and $tan\delta = 0.06$) [2] used, the helix radius is deigned as 5.5 mm with a pitch of 8.7 mm to work at 5 GHz. As the diameter of the channel is only 1 mm, the LMA needed for each turn is only 34.6 μL, which is smaller than a drop of water.



(a) (b)

Fig. 1. Geometry (a) and photograph of a fabricated prototype (b) of the proposed helical antenna.

As the impedance of the axial-mode helical antenna is much higher than 50 Ohms, a quarter-wavelength impedance transformer is designed and used with its parameters in Table I. In order to eliminate the distance between feedline and the channel inlet, the feed line is design on the top of the 3D printed base and the ground is attached on the bottom of the base as a microstripline.

TABLE I
PARAMETERS FOR THE FEED LINE

Name	Width (mm)	Length (mm)
Transformer inside the cylinder	1.4	4.5
Transformer outside the cylinder	2.2	4.7
50 Ohms line	3.1	10.3

III. Fabrication

To demonstrate the proposed antenna, prototypes with 8-turns helix are printed with FDM technique. A $399 Printrbot Play was used, allowing high resolution prints with 100-μm layer height and 0.4 mm minimum feature sizes out of the box. Supports for prints can be printed using multi-material printers with a dissolvable material or single material printers can generate support structures, but both support structure can be difficult to remove from small cavities and channels. Due to this, a design without support material was printed with low overhang angles and short bridges. To make the print water-tight, over-extrusion is exploited to make a non-porous print in addition to printing at higher temperatures to increase layer-to-layer adhesion. The transparent NinjaFlex filament was printed with an extrusion multiplier of 1.15 (15% additional material per calculated volume of material needed) at 235 °C (typical print temperatures 210-220 °C). With these parameters, a low cost microfluid structures can be printed rapidly, with these techniques likely applicable to a variety of FDM thermoplastic materials. After printing, the feedline is inserted into the remained openning and a ground plane is attached to the bottom with copper tape.

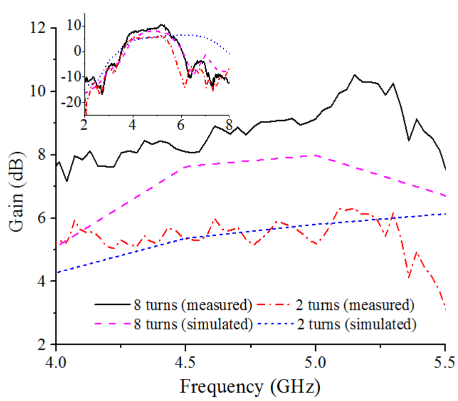
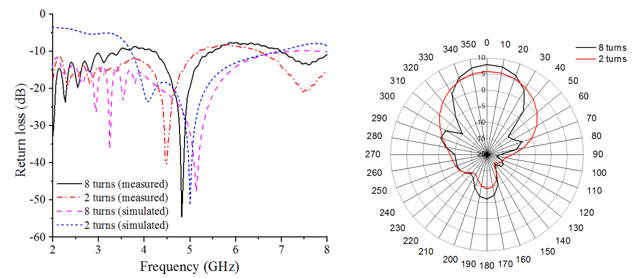


Fig. 2. Measured and simulated gain value of the helical antenna with different turns of helix filled with LMA.

IV. Simulations and Measurements

The helical antenna is simulated and optimized with Ansoft HFSS and measured with a vector network analyser (VNA) and two horn antennas. In the Fig. 2, the gain at working frequency range is shown with gain at full range inserted.



(a) (b)

Fig. 3. Measured and simulated return loss value (a) and simulated radiation pattern (Unit: dB) (b) of the helical antenna with different numbers of turns of helix filled with LMA.

There is an approximate 4 dB gain difference between 8 turns and 2 turns helical antenna. Therefore the proposed antenna features a good tunability, as the directivity value increased by 1.5 times by changing the volume by 0.2 mL. Fig. 3(a) shows that the antenna is well matched and resonant around 5 GHz regardless of the amount of turns. The ripples at lower frequency are due to the hole in the ground (channel inlet) and varying impedance of the antenna and the feedline at different frequencies. The simulated radiation pattern in Fig 3(b) also demonstrates the directivity reconfiguration of the proposed antenna.

V. Conclusion

This paper demonstrates a new methodology to build 3D reconfigurable antenna at a very low cost by using 3D printing technique and liquid metal alloy. A reconfigurable helical antenna is designed, fabricated and measured. A 4 dB gain increase is achieved by increasing the volume of liquid metal feed by 0.2 mL without affecting the normal functionality of the antenna at the resonant frequency (5 GHz).

Acknowledgement

The author would like to thank the National Science Foundation for supporting this research.

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