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A Pattern and Polarization Reconfigurable Liquid Metal Helical Antenna

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Abstract*—A pattern and polarization reconfigurable helix antenna with mechanically actuated liquid metal in a helical channel is presented for L1 frequency band (1.575 GHz). The Antenna is composed of a flexible polymer tube shaped into a helix which is filled in and out with a peristaltic micropump. The micropump is controlled using a Raspberry Pi computer via an H-bridge DC circuit which can change direction and speed of the pump. The antenna provides linearly polarized semi-doughnut and axial beams; elliptically and circularly polarized axial beams with a maximum gain of 1.1 dBi, 5.9 dBi, 7.6 dBi and 8.5 dBi, respectively, corresponding to different lengths of liquid metal in the channel.

Keywords*—Liquid metal, helix antenna, pattern reconfigurable, polarization reconfigurable.

I. INTRODUCTION

Reconfigurable antennas are highly advantageous in the field of wireless communication with the ability to dynamically modify their frequency and radiation properties in a controlled and reversible manner. Conventionally reconfigurable antennas have employed phased array [1] and beam switching [2]- [3] techniques for pattern reconfiguration. There are various challenges with such techniques, e.g., limited number of polarization states, losses in phase shifters, slow switching speed and complex switching circuits.

However, to overcome these limitations and develop more versatile reconfigurable RF systems, liquid metals have recently been used for a variety of systems like tunable microwave components, filters, antennas and so on. Particularly, Galinstan (**G**a**I**n**S**n) has received much attention due to its liquid state (conductivity, $\sigma = 3.4 \times 10^6$ S/m) at room temperature with a melting point as low as -19°C and low toxicity compared to Mercury (Hg). Galinstan is being widely used for creating reconfigurable antennas such as tunable monopoles [4], dipoles, microstrip patch antennas [5], Yagi-Uda antennas [6]. These antennas employ different techniques to actuate liquid metal flow such as Electrochemically Controlled Capillarity (ECC), or micropumps. Galinstan oxidizes when in contact with air and forms a surface oxide layer and sticks to the surface in contact. But with presence of an electrolyte it forms a slip layer between the oxide and the contact surface and assists the flow.

In this paper, we demonstrate a pattern and polarization reconfigurable Liquid Metal Helical Antenna (LMHA) with peristaltic micro pumping of Galinstan in a helix-shaped channel. The speed and pumping direction of the peristaltic pump is controlled using an H-bridge circuit and a Raspberry Pi computer.

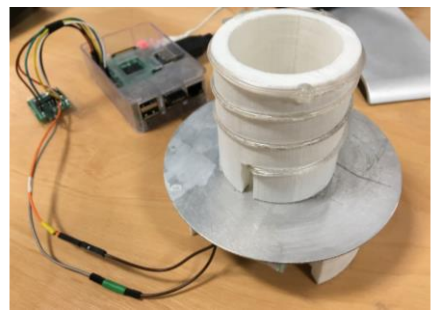

Fig.1. Fabricated prototype of Liquid Metal Helical Antenna

II. ANTENNA DESIGN

Fig. 1 shows the fabricated prototype of the LMHA. A 3D printed ABS plastic (the relative permittivity is $\varepsilon_r \simeq 3$ and the loss tangent is 0.005) structure is used as a frame for the helix. The frame has a circumference C ($=\pi$D) of approximately one wavelength ($\lambda_{1.575\ \mathrm{GHz}}$ =190mm), where D is the diameter of the helix. A transparent flexible polymer tube having an outer diameter of 1.2 mm is wound around the frame, as shown in Fig. 2. A DC controlled peristaltic pump is used to pump Galinstan into the hollow tube channel, as shown in Fig. 3. The tube has a diameter of 0.8 mm. A plastic tee connecter is used to combine the liquid metal inlet and the SMA feed to the helix tube. The SMA feed is attached to the bottom of the ground plane.

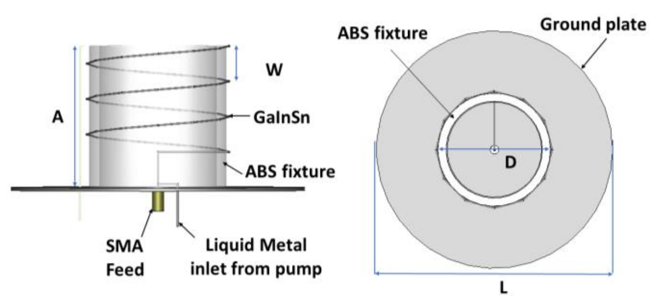

Fig.2. Side and top view of LMHA. A = 65mm, W = 15mm, D = 60mm, L = 140mm.

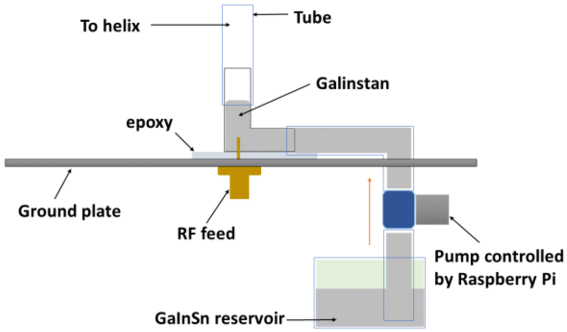

Fig. 3. Schematic diagram of the peristaltic pump and GaInSn reservoir of LMHA.

Control voltages to the pump are supplied using an H-bridge circuit (L293D) with a Raspberry Pi computer. The Raspberry Pi takes the command from a python-based GUI to vary the length of the liquid metal inside the helix tube. The motor starts pumping Galinstan into the helix tube and can stop at different positions to provide desired polarization. The pump can also reverse the flow of liquid metal to shorten the length of the helix.

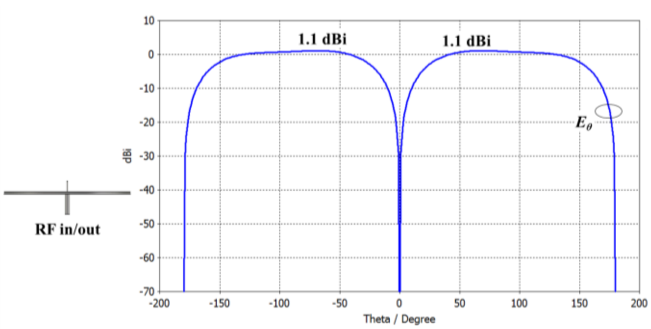

Fig. 4. Linearly polarized semi-doughnut beam radiated from the vertical section.

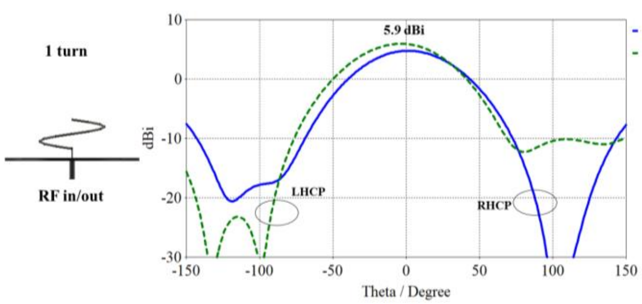

Fig. 5. Linearly polarized axial beam at 1 turn.

III. Results

The antenna was simulated with different points to where liquid metal is pumped for different patterns and polarisations. Fig. 4 shows the 2D radiation pattern formed by the LMHA when the liquid metal fills only the vertical section of the helix, producing a linearly polarized semi-doughnut beam with a gain of 1.1 dBi. Further, the LMHA provides a linearly polarized axial beam of 5.9 dBi (Fig. 5), an elliptically polarized axial beam of 7.6 dBi (Fig. 6) and a circularly polarized axial beam of 8.5 dBi (Fig. 7) when the liquid metal fills one, two and three circumferences of the helix, respectively. Note that the gain for the LHMA is smaller (more than 0.5 dB) than that for the copper-based helix antenna.

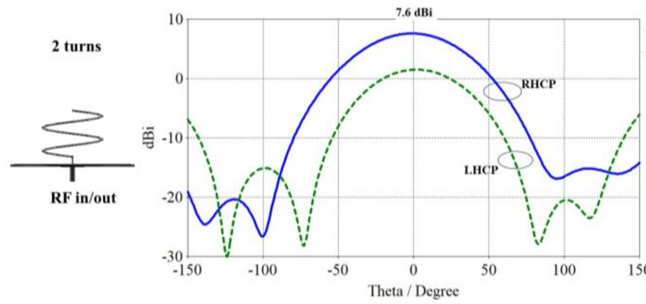

Fig. 6. Elliptically polarized axial beam at 2 turns

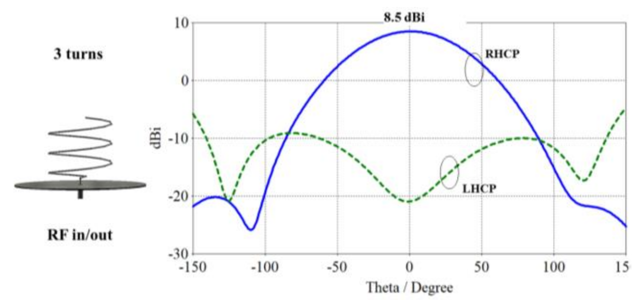

Fig. 7. Circularly polarized axial beam at 3 turns.

IV. Conclusion

A helical liquid metal antenna is presented for reconfigurable pattern and polarization applications. The antenna achieves reconfiguration by altering the turns of helix by pumping liquid metal into the channel using a peristaltic micro pump.

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