Liquid Metal 3D Printed Microfluidic Channel Reconfigurable Patch Antenna with Switchable Slots

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***Abstract*—In this work, we propose a wide-band frequency reconfigurable patch antenna with switchable slots (PASS) based on liquid metal manipulation in 3D printed microfluidic channel. The antenna operation relies on continuous movement of the liquid metal volume over the channel that covers the antenna slots. The patch antenna was designed with three pairs of composite slots, with the microfluidic channel bonded on top of the metal layer. Simulation results shows that by tuning and switching the liquid metal loaded slot in the designed microfluidic channel, a frequency tuning bandwidth of around 70% is achieved, without significant changing in the radiation pattern and radiation efficiency. Prototype has been fabricated and preliminary testing shows good agreement between simulations and measurements.**

I. Introduction

The rapid development of wireless communication and emerging applications have led to great demand for compact wireless systems that can operate for different standards. Antennas with wide-band frequency reconfigurability are the essential enabling components for this endeavor. Comparing to existing reconfiguration methods based on varactors, MEMS and PIN diodes, microfluidic and liquid metal based reconfiguration has been shown as a promising technique in terms of lower loss, more power handling, and more flexibility [1]. Advanced 3D printing technologies are widely used in microfluidic chips [2], but have not been utilized in liquid metal antennas.

In this paper, we propose a wide-band and continuous frequency reconfigurable patch antenna with switchable slots (PASS) based on manipulating liquid metal in a 3D-printed microfluidic channel. The frequency reconfiguration is achieved by continuous movement of the liquid metal droplet over the channel that covers the slots. Simulation results showed that by tuning and switching the liquid metal loaded slot in the designed microfluidic channel, a frequency tuning bandwidth of around 70% is achieved. A feasible process to integrate 3D printed microfluidic channel to patch antenna was developed. Compared to traditionally used PDMS channels, 3D printing provides a cheaper, faster and more flexible solution for liquid metal antenna design. The prototype has been fabricated, and preliminary measurement results show good agreement with the full-wave simulations.

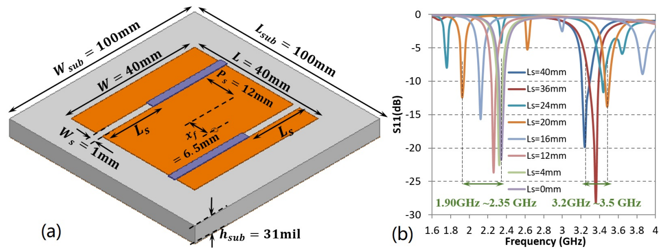

Fig. 1. (a) A basic PASS structure with two composite tuning slots and (b) the simulation results of S11 for continuous frequency tuning by varying the slot lengths L_s of a PASS antenna with one pair of slots.

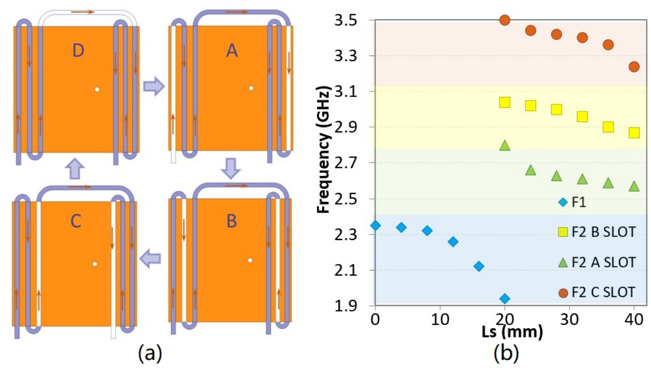

Fig. 2. A multi-slot PASS with 3 pairs of composite slots for wide-band and continuous frequency reconfiguration. The higher-frequency tuning band is changed by switching the location of the slots.

II. Multi-Slot PASS Antenna for Wide-band Continuous Frequency Tuning

Slot-loaded patch antennas have been widely used in wireless communication, due to their low-profile, low-cost feature and capability of realizing various functionalities. A basic PASS structure with composite tuning slots has been used as a starting point. The antenna was built on a RT5880 substrate, with the dimensions listed in Fig.1 (a) Two composite slots with width W_s located at position P_s are cut through on copper, and the slot lengths L_s are controlled by the amount of liquid metal which is pumped into the two microfluidic channels and bridging the gap formed by the slots. It has been shown that dual-band operation with good impedance matching could be achieved using PASS antenna with composite slots, with the frequency-ratio of the two frequency bands controlled by the lengths of the slots [3]. Thus, by tuning the length of liquid metal filling, the length of the slots could be changed continuously, and frequency reconfiguration in two continuous frequency bands is achieved.

As shown in Fig. 1 (b), patch antenna with dimension 40×40 mm with 1 mm slot was simulated in HFSS. Two liquid metal droplets cover the slots with length varying from 0 to 40 mm. The frequency band of 1.9 GHz to 2.35 GHz is covered by slot length from 0 to 20 mm, while the frequency band of 3.2 GHz to 3.5 GHz is covered by slot length from 20 to 40 mm. The simulated antenna radiation pattern, peak directivity and radiation efficiency has not changed significantly with the slot length tuned by liquid metal.

The higher-frequency tuning band can be relocated by adjusting the location of the two composite slots P_s. As shown in Fig. 2 (a), state A to C corresponds to patch with the composite slots in 3 different locations. By integrating three pairs of composite slots on one patch, a 70% continuous frequency tuning range is achieved. Tuning and switching the slots can be done by injecting liquid metal into the designed microfluidic channel attached on top of the patch antenna. As shown in Fig. 2, the meander microfluidic channel was designed to sweep over the 3 pairs of composite slots on the patch antenna. During the continuous pumping of liquid metal droplet, there is always a pair of slots with unfilled liquid metaland location of the slot is changed by pumping.

III. Prototyping and Liquid Metal Handling

The prototype frequency reconfigurable PASS antenna was fabricated by attaching a 3D-printed microfluidic module to the antenna patch made on a RT5880 substrate. The microfluidic module was printed using acrylic material VeroClear from Stratasys Inc. Two parts were bonded together using 3M's double sided adhesive tape, which was patterned with a silhouette cutter to remove the adhesive material inside the channel. Polytetrafluoroethylene (PTFE) tubes were inserted to the inlet and outlet and sealed by Ultra Violet (UV) cured epoxy. A 1 mL syringe was attached to the tube to manipulate liquids. The channel was then further passivated by flushing PTFE dispersion surfactant to reduce the residue as reported in [1].

Eutectic gallium-indium (EGaIn) carried by mineral oil has been used for prototyping and measurements. They were loaded into the PASS as illustrated in Fig. 3. A reservoir containing both liquid metal and mineral oil was made by mixing them in a 1 mL vial, where they stratified by themselves. The channel was first filled with mineral oil and then with a EGaIn plug by withdrawing from respective layers. Another segment of mineral oil was then withdrawn into the tube to encapsulate the EGaIn into two segments of carrier liquid.

A single-pair-slot prototype has been fabricated for preliminary testing. The liquid metal can be injected into and removed from the microfluidic channel. Two states (empty and full) were first characterized by measurement. As shown in Fig. 4, the measured S11 results for the empty and full states agrees very well with the simulation results from HFSS, proving the feasibility of this approach in developing frequency reconfigurable PASS antenna.

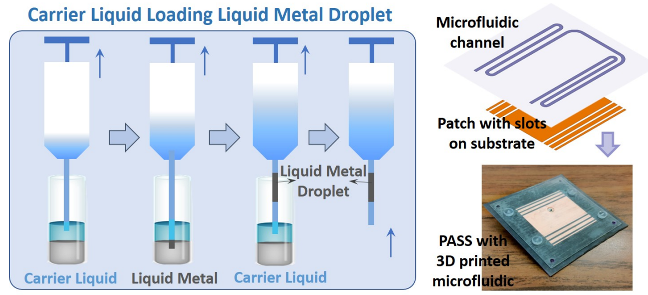

Fig. 3. The prototype frequency reconfigurable PASS antenna is fabricated by attaching a 3D-printed microfluidic channel to the patch with slots printed on RT5880 substrate. Carrier liquid of mineral oil has been used to load the liquid metal droplet into the designed channel that covers the slots.

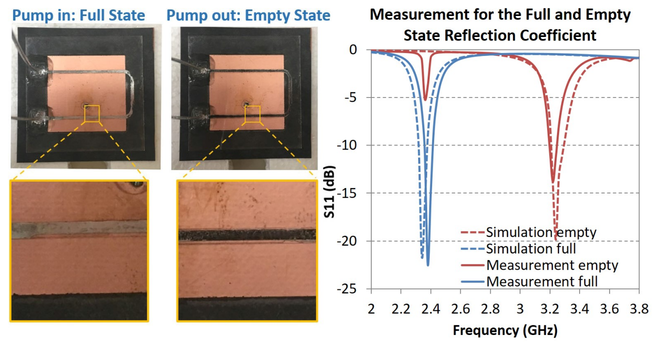

Fig. 4. A single-pair-slot prototype has been fabricated. Two states (empty and full) were first characterized by S11 measurement.

IV. Conclusions and Future Works

A wide-band and continuous frequency reconfigurable PASS antenna based on microfluidic and liquid metal has been demonstrated in the paper. EGaIn carried by mineral oil has been used for prototyping and measurements. Simulation results present a frequency tuning bandwidth of around 70%. Preliminary measurement results show good agreement with the simulations. Future work includes prototyping and measurement for the muti-slot PASS and advanced liquid metal manipulation technique for automation and improved accuracy.

Acknowledgement

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