Mm-Wave Frequency Reconfigurable Antenna with Multilayer Integrated Microfluidic Actuation

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***Abstract*— A microfluidically reconfigurable frequency tunable mm-wave patch antenna is presented. Different than the previously reported work on microfluidically reconfigurable RF devices, the actuation of the multiple metallized plates reconfiguring the antenna is carried out by using a piezoelectric disk within a multilayered fluid reservoir stack. The antenna operates with 7% and 9% $|S_{11}|$ <-10 dB impedance matching bandwidth in its 28 GHz and 38 GHz states respectively. Additionally, it exhibits a simulated realized gain of 5.66 dBi and 4.9 dBi at 28 GHz and 38 GHz, respectively.**

Keywords*— *Microfluidics, frequency reconfigurable antennas

I. Introduction

Microfluidically reconfigurable RF devices are attractive for their compact size, low insertion loss, high radiation efficiency, and high-power handling capability. Several research groups applied microfluidics for reconfigurable antennas and RF devices. For mm-wave applications, liquid-metal based device realizations like the ones in [1] and [2] can potentially suffer from high conductive losses in addition to challenges associated with their packaging and long-time operation. Replacing liquid metal volumes with metallized plates that are repositionable within microfluidic channels can significantly enhance the efficiency of the devices with improved reliability. A recent work has successfully demonstrated an mm-wave microfluidically reconfigurable single-pole single-throw (SPST) switch with low insertion loss (0.42 dB) and wide bandwidth (>18 GHz) performance [3]. The switch is realized by constructing a microfluidic channel over a printed circuit board (PCB) that carries the stationary metallization patterns (i.e., microstrip line exhibiting gap discontinuity). A selectively metallized plate within the microfluidic channel is repositioned over the PCB layer. The vertical spacing between the selectively metallized plate and stationary metallization pattern is less than 10 µm. Consequently, overlapping the metallized plate with the metallization patterns of the PCB leads to strong capacitive coupling that can be utilized to achieve the desired SPST functionality. The switch employs a piezoelectric disk as its integrated actuator. Therefore, the switch achieves a high reconfiguration speed (1.12 ms) from a compact size.

The goal of this paper is to advance this recently introduced integrated actuation of microfluidic device concept to mm-wave frequency tunable antennas. In addition, another goal is to introduce a novel actuator that can reposition multiple metallized plates simultaneously within the microfluidic channel to achieve the desired functionality. Specifically, a microfluidically reconfigurable patch antenna that can switch its operation between 28 GHz and 38 GHz bands is presented.

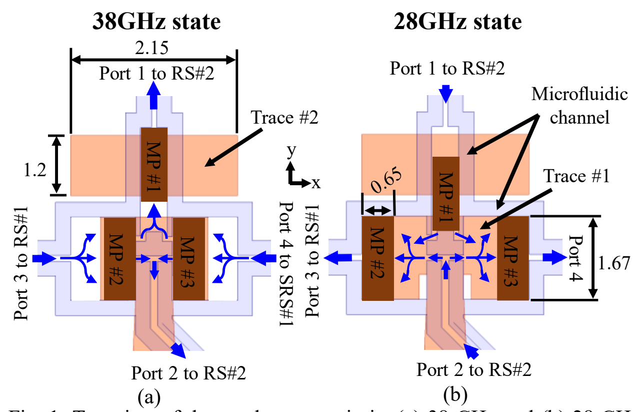


Fig. 1. Top view of the patch antenna in its (a) 38 GHz and (b) 28 GHz radiation states. Unites are in mm.

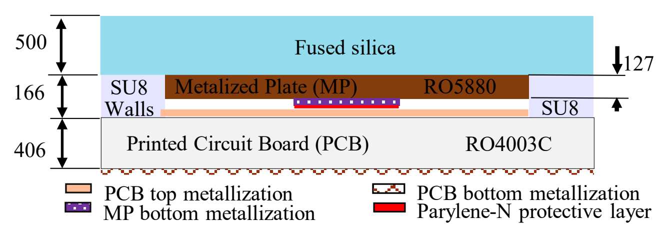
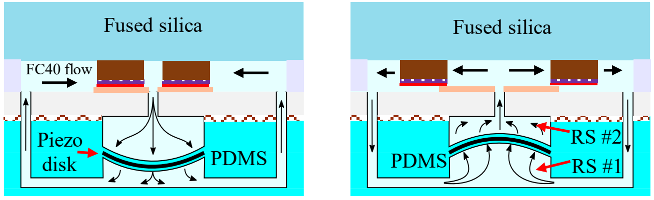


Fig. 2. Substrate stack-up. Dimensions are in µm. All conductors are 17 µm thick.

II. Operation Principle and Design

Fig. 1 shows the layout of the patch antenna in its two radiation states. Fig. 2 shows the substrate stack up. The layout consists of two rectangular traces marked as trace #1 (1.67 × 2.15 mm^2) and trace #2 (1.2 × 3.35 mm^2). These traces are stationary and realized on the 406 µm thick Rogers RO4003C PCB ($\varepsilon r = 3.55$, $\tan\delta = 0.0027$). Traces are separated from each with 0.43 mm in the y-direction. Trace #1 is modified with 0.15 × 0.5 mm slots to realize an inset feed mechanism from a 0.9 mm wide 50 Ω microstrip line. A microfluidic channel is overlapped with these traces as shown in Fig. 1. Three metallized plates, marked as MP#1, #2, &3, are included in the microfluidic channel. The remaining volume of the channel is fully filled with low loss dielectric liquid FC-40 (εr



(a) (b)

Fig. 3. Stacked PDMS actuator showing FC40 flow for (b) OFF state and (c) ON state.

= 1.9, tanδ = 0.0005) As shown in Fig. 2, the microfluidic channel is constructed from hard materials as in [3] with a thickness of 170 µm. MPs are realized from 0.127 mm thick RO5880 (εr = 3.55, tanδ = 0.0027). The MPs have 17 um metal thickness and coated with 2 um Parylene-N (εr = 2.40 and tanδ = 0.0006). The fabrication tolerances, as explained in [3], causes the MP and PCB and metallizations to be ~10 µm apart. Nevertheless, this spacing allows creating an effective RF short between the MP and PCB traces with very small overlap areas (>0.35 mm^2). The design takes advantage of this principle to realize a frequency reconfigurable patch antenna. As shown in Fig. 1(a), when the antenna operates at 38 GHz, MP#1 is fully overlapped with trace #2 and the remaining MPs are fully overlapped with trace #1. Consequently, trace #1 radiates like a traditional rectangular inset fed patch antenna. To lower its radiation frequency to 28 GHz, MP#1 needs to be repositioned to capacitively load and connect trace #1 and #2 through RF shorting principle. However, due to the extreme spacing between the 28 GHz and 38 GHz frequencies, the antenna loses its impedance matching (i.e. from 50 Ω to 70 Ω). Consequently, MP#2 and MP#3 need to be repositioned to extend the antenna width for improving impedance mathcing. Fig. 1(b) demonstrates the position of the MPs at the 28 GHz operation state.

It is essential to operate the antenna with a single actuator for achieving compact size and low-cost. For this, a piezoelectric actuator with stacked reservoirs is proposed as shown in Fig. 3. The reservoirs are placed at the backside of the PCB and constructed from flexible PDMS polymer. As shown in Fig. 3(a), actuating the piezoelectric disk with proper DC voltage compresses the bottom reservoir marked as RS#1 and pushes the dielectric liquid from the horizontal channels marked as RS#1 in Fig. 1(a). Simultaneously, the top reservoir marked as RS#2 is expanded and this causes the dielectric liquid to be pulled from vertical channels marked as RS#2 in Fig. 1(a). The channel shapes need to be properly selected to actuate MP#1 before letting liquid flow out from the opposite channel end. Reversing the polarity of the actuation voltage flips the state of the reservoirs as shown in Fig. 3(b). In turn, the MPs are repositioned as shown in Fig. 1(b).

The design of the antenna is carried out with Ansys Electronics desktop R2 2019 with the selected substrate stack up. The total lateral dimensions of the substrates and ground plane were selected as 25 × 30 mm^2 to be able to fit the reservoirs. The size of the MPs is adjusted based on a parametric study for the overlap area and layout simplification. In simulations, the antenna operates with 7% and 9% $|S_{11}|$ <-10 dB impedance matching bandwidth in its 28 GHz and 38 GHz states, respectively.

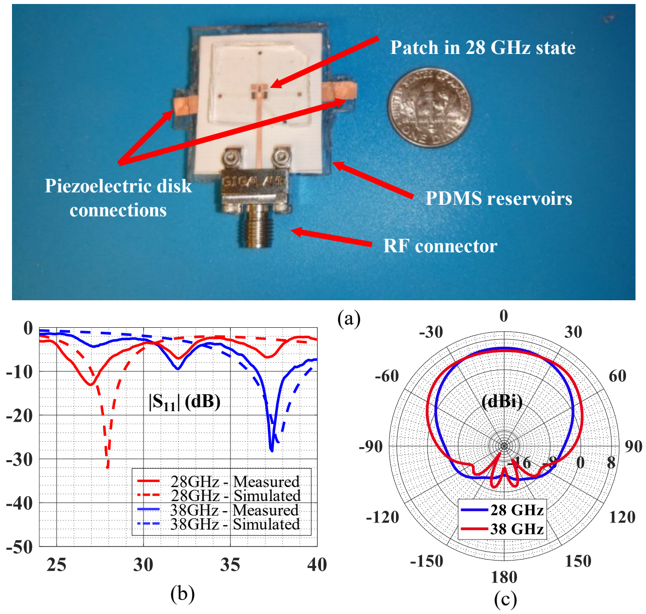


Fig. 4. (a) Prototype; (b) $|S_{11}|$; (c) Realized gain pattern

III. Measured Performance

The antenna prototype is shown in Fig. 4(a). Fig. 4(b) depicts the $|S_{11}|$ performance. As expected, the antenna is well matched for both of its states with measured bandwidths of 7% and 9% at 28 and 38 GHz, respectively. Fig. 3(c) shows the realized gain patterns of the antenna in H-plane at 28 and 38 GHz operation. It exhibits a realized gain of 5.6 dBi and 4.9 dBi at 28 GHz and 38 GHz, respectively. This corresponds to > 90% radiation efficiency. The H-plane half-power beamwidth of the antenna is 136° at 38 GHz and 96° at 28 GHz. A minimum actuation voltage of 70 V is needed to switch between the operation states. The actuation speed is estimated as ~100 ms based on initial experiments.

IV. Concluding Remarks

An mm-wave microfluidically reconfigurable frequency tunable antenna has been demonstrated. To the best of our knowledge, this is the first frequency tunable microfluidically reconfigurable antenna demonstrated in mm-wave band. The antenna has been integrated with a novel actuation technique to achieve microfluidic reconfiguration with high actuation speed and compact size. Further design and measurement details will be provided at the time of the conference.

References

[1] A. Dey, R. Guldiken, and G. Mumcu, "Microfluidically Reconfigured Wideband Frequency-Tunable Liquid-Metal Monopole Antenna," *IEEE Transactions on Antennas and Propagation,* vol. 64, no. 6, pp. 2572-2576, 2016, doi: 10.1109/TAP.2016.2551358.

[2] K. Y. Alqurashi and J. R. Kelly, "Continuously tunable frequency reconfigurable liquid metal microstrip patch antenna," in *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, 9-14 July 2017 2017, pp. 909-910, doi: 10.1109/APUSNCURSINRSM.2017.8072497.

[3] E. González and G. Mumcu, "Integrated Actuation of Microfluidically Reconfigurable mm-Wave SPST Switches," *IEEE Microwave and Wireless Components Letters,* vol. 29, no. 8, pp. 541-544, 2019, doi: 10.1109/LMWC.2019.2925889.