

A Frequency-Reconfigurable Water-Loaded Planar Monopole Antenna

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Abstract—A novel frequency reconfigurable microstrip monopole antenna with a fluidic channel milled on its substrate is proposed. The fluid in the channel modifies the effective permittivity of the dielectric medium and perturbs the E-field distribution in vicinity to antenna arm. The achieved frequency shift is 20.3%, the impedance bandwidth is 28.6% and 32.1% and the peak realized gain is 3.31 dBi and 1.81 dBi when the channel is empty and filled with distilled (DI) water, respectively. Radiation pattern is omnidirectional in both the cases with low cross-polar components.

Index Terms—antennas, dielectric fluid, microstrip monopole, reconfigurable, tunable, microfluidics, microwaves

I. INTRODUCTION

Recent advances in wireless communications have seen the emergence of multiple radio systems integrated on a single hardware platform [1]. In cognitive radio, microwave front-end tunable components, including antennas, are critical to fully exploit the available free spectrum [2].

Previous work on antenna frequency tuning has often focused on altering the electrical length of the antenna using varactors and PIN diodes. In [3], varactor is used to design a dual band reconfigurable antenna while in [4], varactor diode is used along with open stub to realize ultra wide band reconfigurable notch reject antenna. PIN diodes have been included as switch to vary the physical length of the radiators [5]. A different method for planar antenna tuning consists of using dielectric fluids vary the effective permittivity of the medium. An important advantage of the fluidic technique compared to electronic methods is its high-power handling capability and low-distortion. In [6], water is used to minituarize the antenna along to achieve broad range tuning but narrow bandwidth around $\approx 5\%$. Further, [7] uses microfluidic channels on Polydimethylsiloxane (PDMS) to locally disturb the \mathbf{E} field on slot antenna but with narrow bandwidth.

In this paper, a planar monopole antenna is loaded with a fluidic channel and exhibits a wide impedance bandwidth [8] enabling downward shifted frequency bands to have improved bandwidth. Distilled (DI) water is used as the dielectric fluid to alter the effective permittivity and perturb the \mathbf{E} field to achieve frequency reconfigurability for the monopole antenna.

II. ANTENNA DESIGN

A. Reference Antenna

A microstrip monopole antenna without fluidic tuning is described in [9]. This monopole antenna is re-designed

on a 1.52 mm thick Rogers-4003 substrate ($\epsilon_r = 3.55$, $\tan \delta = 0.0027$) to operate around 6 GHz with 33% impedance bandwidth. The antenna uses a partial ground plane and the length of the monopole arm is set to $\lambda_g/4$, where λ_g is the guided wavelength in microstrip environment [10]. The ground plane size is optimized for best impedance bandwidth.

B. Reconfigurable Antenna

To incorporate fluidic tuning, the antenna is modified by partially milling out the substrate below the monopole arm from the back side and a second substrate of height 0.5 mm is added as back cover to create an air channel. The back cover height is chosen to maintain the low profile of the antenna and mitigate surface waves [11]. The relevant views of the antenna along with design parameters are shown in Fig 1. Removal of substrate material below the monopole arm lowers the effective permittivity of the medium hence resulting in a upward shift of antenna resonance around $\lambda_g/4$, where λ_g is the guided wavelength. Further, the milled air channel is filled with distilled water ($\epsilon_r = 81$, $\tan \delta = 0$ and $\sigma = 0.01$ Siemens per meter) to modify the effective permittivity to be higher

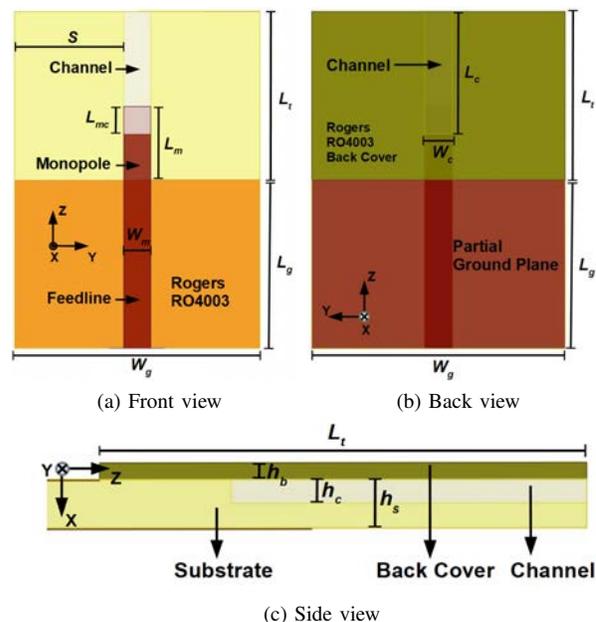


Fig. 1. Microstrip monopole antenna with air channel: $L_g = 20$ mm, $L_t = 20$ mm, $L_m = 8.7$ mm, $L_{mc} = 4$ mm, $W_g = 30$ mm, $W_m = 3.3$ mm, $h_b = 0.5$ mm, $h_c = 0.76$ mm, $h_s = 1.52$ mm, $S = 13.35$ mm

owing to high relative permittivity of distilled water and to perturb the E field distribution of the antenna. Thus, the $\lambda_g/4$ resonance of the antenna shifts to lower frequency.

III. RESULTS AND PARAMETRIC STUDY

The return loss for the antenna with and without the loading of distilled water is shown in fig. 2. As seen, the resonant

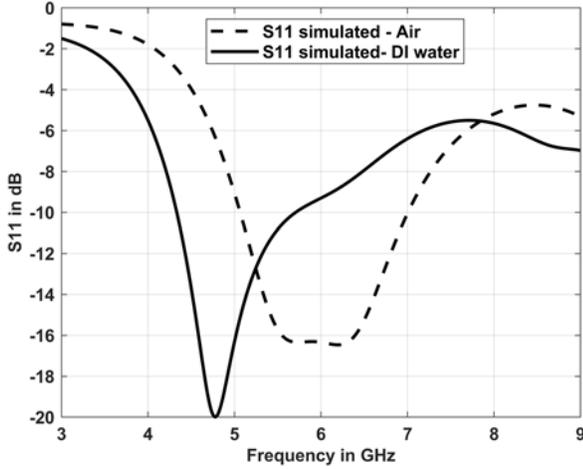


Fig. 2. Return loss for air and water loaded cases .

frequency has shifted downward from 6 GHz to 4.78 GHz around 20.3%. Also, the impedance bandwidth in air is ≈ 1.93 GHz (32.1%) while it is ≈ 1.37 GHz (28.6%) when the channel is filled with DI-water. The effect of variation in positioning and the geometric parameters of the channel are next presented.

A. Effect of variation in channel depth (h_c)

The return loss for different channel depths is shown in fig. 3. As expected, with increase in the channel depth, the frequency downshift increases. Particularly in current design, a deeper channel implies water channel's proximity to monopole arm, maximizing the E field perturbations below the arm.

B. Effect of variation in channel position (S)

The position of the channel is paramount with respect to desired frequency shift. As seen in fig.4, as the channel position is moved away from the center of monopole arm where the E field is maximum, it reduces the total field perturbation and consequently the downward frequency shift. Hence, the optimum position for the channel is directly below the center of the antenna arm.

C. Effect of variation in channel width (W_c)

The effect of the channel width has been studied with the optimized position (S) for the channel and nominal depth (h_c). The overall volume of the distilled water channel shrinks as W_c is reduced and vice-versa. A reduced volume compared to nominal value presents a lower effect on permittivity resulting in lower shifts while a greater volume results in higher

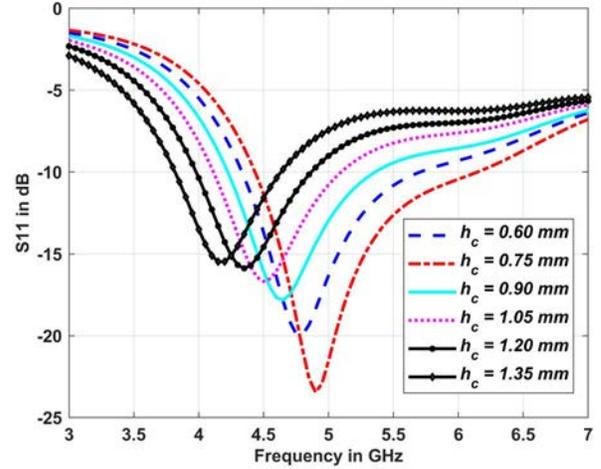


Fig. 3. Return loss with different water channel depths

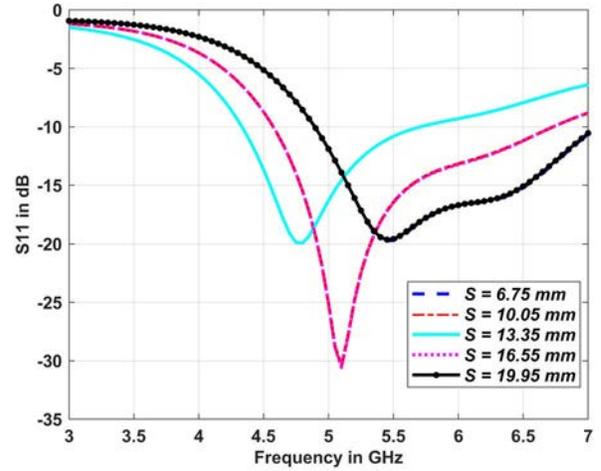


Fig. 4. Return loss with different water channel positions

permittivity and hence greater frequency shifts as shown in fig. 5.

D. Effect of variation in channel length (L_{mc})

The nominal values used for simulations cover $\approx 38\%$ of monopole length from the open end. As the channel length milled under the antenna arm is increased it results in slightly more downward frequency shifts. However, the effect saturates sharply as the length is increased as shown in fig. 6, this is because the E-field distribution is confined closer to monopole arm open end and the effect of channel length addition is limited effect on the E field perturbation.

IV. FAR FIELD ANALYSIS

3D gain of the antenna for both cases is shown in fig. 7. The maximum realized gain with the air channel is 1.81 dBi and with DI-water is 3.31 dBi. The 3D pattern for both the cases is identical with a slightly spread out null around the

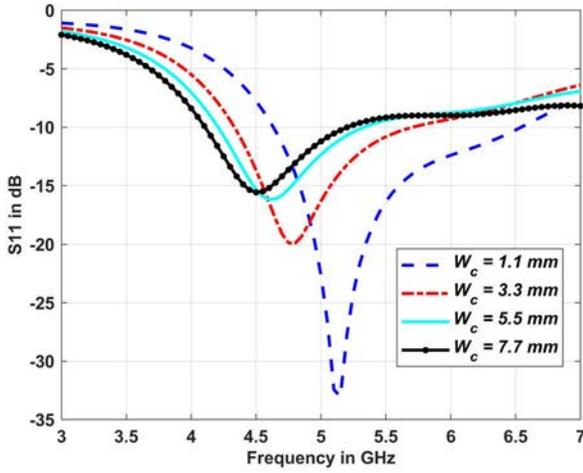


Fig. 5. Return loss with different water channel Widths

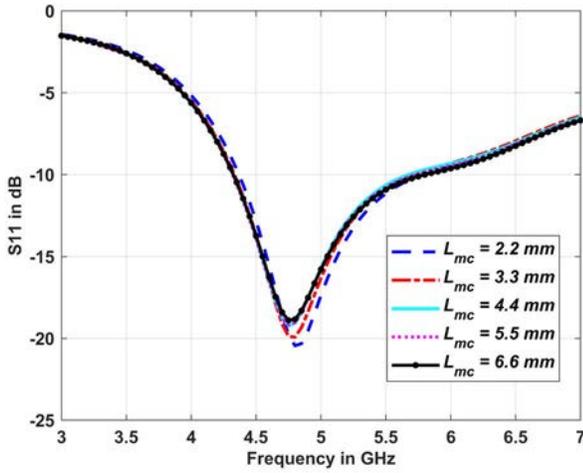


Fig. 6. Return loss with different water channel lengths below antenna arm

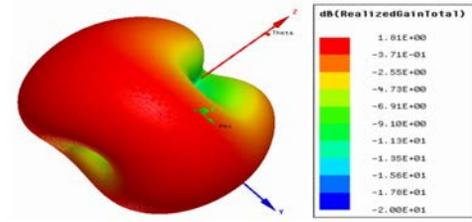
z direction for the water channel case as the fields are more confined. The 2D radiation pattern in the E-plane and H-plane is shown in fig. 8. The radiation pattern is omni-directional in both the cases and the cross polar component is at least 10 dB below the copolar component in the direction of maximum radiation for the monopole.

TABLE I
SUMMARY OF ANTENNA PERFORMANCE

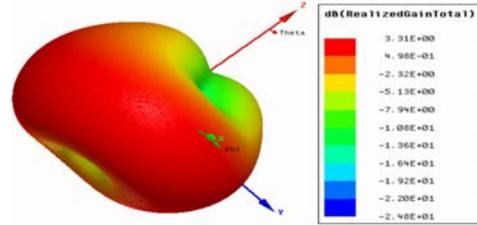
Channel Type	Center Frequency (GHz)	Impedance bandwidth (%)	Peak realized gain (dBi)
Air	6.00	32.1	1.81
DI Water	4.78	28.6	3.31

CONCLUSIONS

The proposed reconfigurable antenna is easy to fabricate with simple feed mechanism. The performance summary of the

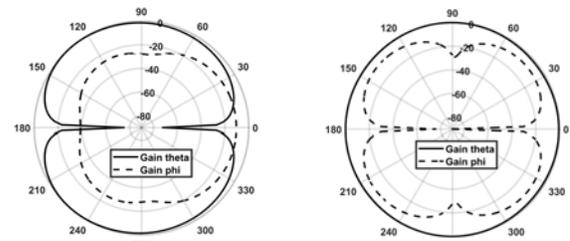


(a) Realized gain in Air at 6 GHz



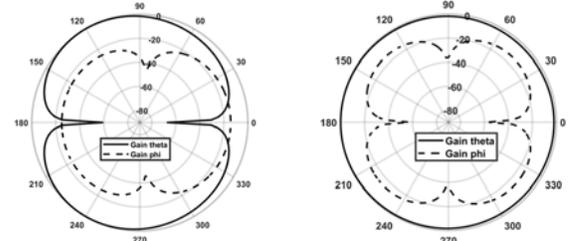
(b) Realized gain in DI-water at 4.78 GHz

Fig. 7. 3D Gain plot for Air and DI-Water loaded cases



(a) YZ-Air (6 GHz)

(b) XY-Air (6 GHz)



(c) YZ-Water (4.78 GHz)

(d) XY-Water (4.78 GHz)

Fig. 8. 2D radiation pattern for air and DI-water filled channel

simulated antenna is shown in Table.I. Proposed antenna with size (30 mm × 40 mm) is capable to provide frequency configurability of 20.3% with high impedance bandwidth around 28.6% and good realized gain of 3.31 dBi. The radiation pattern is omnidirectional with low cross-polar components. Thus, the antenna can serve 5G Wi-Fi band [12] and other linearly polarized applications.

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