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A Frequency Reconfigurable Patch Antenna Based on Liquid Crystal

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***Abstract*—A frequency reconfigurable patch antenna based on a liquid crystal (LC) is proposed in this study, and the patch is positioned above the LC. DC bias voltage is applied to both sides of the LC. The permittivity of the LC changes with the DC bias voltage so that the resonant frequency is reconfigurable. The direct current (DC) bias voltage and the radio frequency (RF) signal can be isolated since the patch is fed by an aperture-coupled microstrip feed line. Thus, the DC bias voltage can not influence the RF signal. The presented antenna is simulated, fabricated and measured. The simulated resonant frequency spans the 7.28 to 7.38 GHz range, whereas the measured resonance frequency spans the 7.28 to 7.36 GHz range. The measured reflection coefficients are compared with simulated reflection coefficients for the proposed antenna. The comparison shows that the frequency reconfigurable patch antenna based on a liquid crystal (LC) is feasible.**

I. Introduction

Frequency reconfigurable antennas are becoming more and more significant nowadays due to their advantages for wireless communication systems such as multi-frequency and larger-bandwidth applications. Therefore they are widely applied in various areas such as multiband antennas [1], satellite communication systems [2] and cognitive radio applications [3].

To realize the frequency reconfiguration, several methods have been reported in the literature. By switching three PIN diodes, the antenna's resonance frequency is altered [4]. The metasurface is rotated to change the permittivity to change the band of the antenna [5]. In [6], the resonant frequency is controlled by pumping dielectric fluid to alter the cavity's shape beneath the antenna. A varactor diode is placed across the slot to give the antenna's reconfigurable band [7]. In [8], RF switch is embedded in the feeding and shorting strip to provide different resonant modes. A leaky wave antenna in [9] used LC which is a homogeneous material to change the permittivity, controlling the resonant frequency of the antenna. An antenna with polarization agility is suggested based on the LC's tunability of permittivity [10].

In this study, a frequency reconfigurable patch antenna based on LC is suggested. The antenna is composed of two substrates and one layer of LC. The patch is placed above the LC whose permittivity will change with the tunable DC bias voltage. DC voltage is applied on both sides of LC. The positive pole connects to the patch and the negative pole connects to the ground plane. When changing the bias voltage, the nematic LC molecules will be deflected thus the resonant frequency will change. What's more, the RF signal enters the antenna through the microstrip feed line. Patch and ground are used to feed the DC bias voltage. So, it is possible to separate the RF signal from the DC bias voltage. The resonant frequency shifts from 7.28 GHz to 7.38 GHz, according to simulation data. Measured results reveal a shift in the resonance frequency from 7.28 GHz to 7.36 GHz.

II. Antenna Design

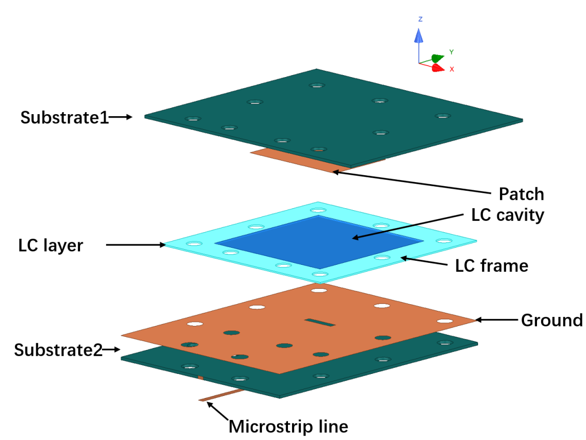

Fig. 1. Configuration of the antenna

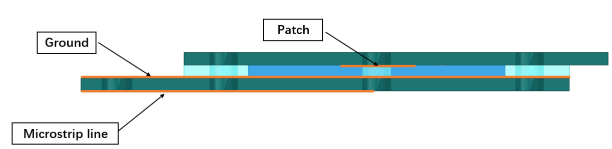

Fig. 2. Side view of the assembled antenna

The details of the antenna are provided in this section. Fig. 1 depicts the proposed antenna's structure which includes two substrates and a LC layer. The first substrate material is FR4 (ε_r = 4.4, $tan\delta = 0.02$) and the second substrate material is RO4003C (ε_r = 3.55, $tan\delta = 0.0027$). On the underside of

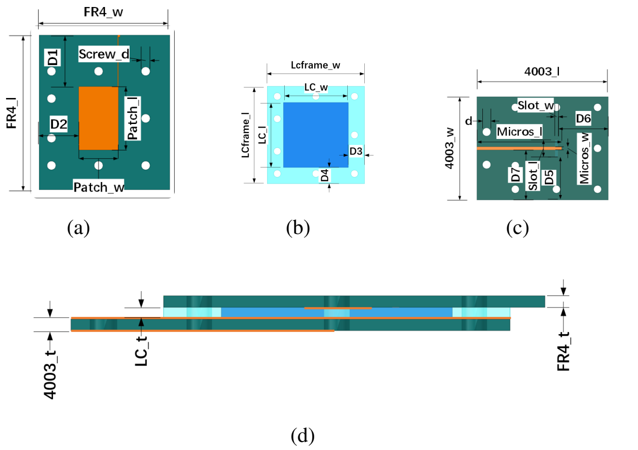

Fig. 3. Four views of the proposed antenna. (a) The first substrate. (b) The layer of LC. (c) The second substrate. (d) Side view of the antenna.

TABLE I
GEOMETRIC PARAMETERS OF THE ANTENNA

Geometric parameters (Unit: mm)					
FR4_w	33	FR4_l	39	Screw_d	1.1
Patch_l	16	Patch_w	10	LCframe_w	30
LCframe_l	30	LC_w	20	LC_l	20
4003_l	38	4003_w	30	Micros_l	24.5
Micros_w	0.9	Slot_l	5	Slot_w	1
d	1.18	FR4_t	0.4	4003_t	0.406
LC_t	0.2	D1	13	D2	10
D3	5	D4	5	D5	12.5
D6	14.5	D7	14.55		

the first substrate, the patch is printed. The patch is attached to the DC bias line. In the layer of LC, the LC is surrounded by the frame. The BaYi Space firm manufactures the LC material type BHR40300. The ground plane is given a slot on the top sides of the second substrate. Additionally, the RO4003C's bottom side has a print of the microstrip feed line.

The details of two substrates and a LC layer are shown in Fig. 2. TABLE I displays the antenna's geometrical parameters.

The patch is placed above the LC layer and the ground is placed under the LC layer. In order to use the DC voltage to alter the state of the LC, the positive DC bias voltage is provided to the patch and the negative DC bias voltage is fed to the ground. Under the DC bias voltage changing from zero to the value of saturation, the LC molecules will be deflected and the permittivity will tune. The antenna's length and the substrate's permittivity have an impact on the patch's resonance frequency. The substrate for this paper is the LC. The patch's resonance frequency is given by

$$f_r = \frac{c}{2(b+2\Delta l)\sqrt{\varepsilon_e}} \tag{1}$$

where the speed of light is c. The patch's length is b which is equal to Patch_l in Table 1, and Δl is the distance that the patch extends at each end along the length of b. Δl is equal to

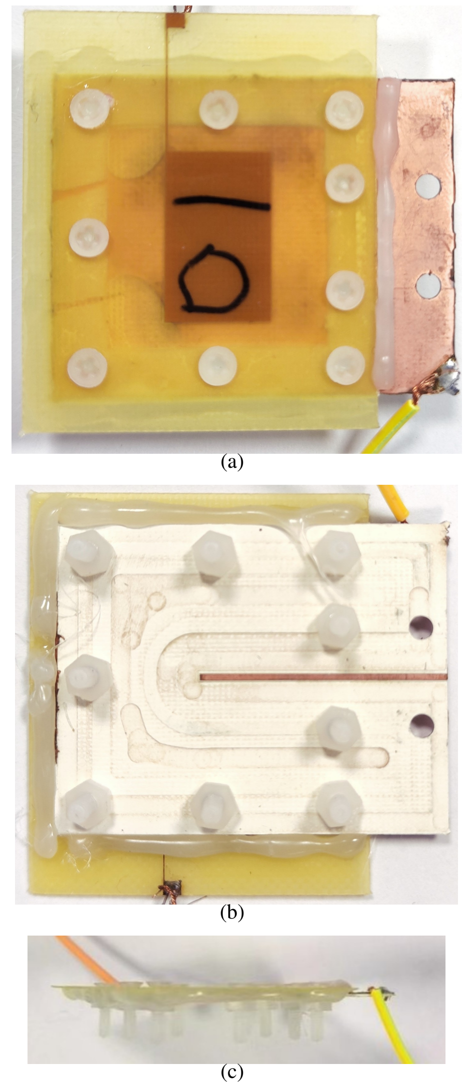

Fig. 4. Photograph of a realized frequency reconfigurable patch antenna: (a) top view, (b) bottom view and (c) side view.

D1 in Table 1. ε_e is the effective permittivity of the antenna, which is related to the LC. As the DC bias voltage changes, the permittivity of LC changes, and the patch's resonance frequency likewise shifts.

The ground slot allows the RF signal to enter from the microstrip line and couple to the patch. The DC bias voltage positive pole connects to the DC voltage feed line. And the negative connects to the ground. The RF signal and the DC bias voltage don't touch each other directly. Thus, the DC bias voltage will not affect the RF signal.

III. Simulation and Measurement Results

The realized frequency reconfigurable patch antenna is depicted in Fig. 4. The simulated reflection coefficients with different LC permittivity states (ε_r = 2.75, ε_r = 2.81, ε_r = 2.85) are shown in Fig. 5. When ε_r = 2.75, the simulated band ranges from 7.22 GHz to 7.32 GHz, with 7.27 GHz serving as the resonant frequency. The resonant frequency in

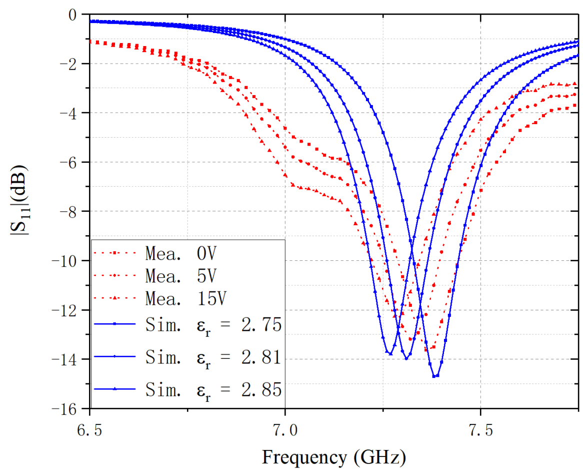

Fig. 5. Simulated and measured reflection coefficients.

the simulated band, which spans the 7.26 GHz to 7.36 GHz range, is 7.31 GHz when $\varepsilon_r = 2.81$. The simulated band ranges from 7.33 GHz to 7.44 GHz for $\varepsilon_r = 2.85$, and the resonant frequency is 7.38 GHz. Fig. 5 also shows the measured reflection coefficients with different DC bias voltage states ($V = 0$ V, $V = 5$ V, $V = 15$ V). The measured band is from 7.22 GHz to 7.35 GHz, with 7.29 GHz serving as the resonant frequency when $V = 0$ V. The measured frequency range is between 7.25 and 7.40 GHz, and for $V = 5$ V, the resonant frequency is 7.32 GHz. When $V = 15$ V, the resonance frequency is 7.36 GHz, while the measured band ranges from 7.29 to 7.44 GHz. The measured reflection coefficients are basically consistent with the simulated reflection coefficients. The deviation is mainly caused by antenna processing error.

IV. Conclusion

In this study, a liquid crystal-based patch antenna with frequency reconfigurability is designed. The liquid crystal's permittivity changes in proportion to variations in the DC bias voltage, affecting the resonant frequency. The patch is fed by an aperture coupling microstrip line in order to separate the DC bias voltage from the RF signal. The resonance frequency will shift from 7.29 GHz to 7.36 GHz when the DC voltage is increased from 0 V to 15 V.

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