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A Bias Voltage Supply Method to Reduce Reflection Loss in Liquid Crystal Reflectarray

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***Abstract*—A bias voltage supply method to reduce the reflection loss (RL) in liquid crystal reflectarray (LCRA) is proposed. Compared to the traditional supply method which controls all resonant structures by a single bias line, the proposed method controls each resonant structure independently, realizing independent control of reflection amplitude and phase. Both simulated and experimental results demonstrate that the proposed LCRA achieves a maximum RL reduction of 17 dB while maintaining a reflection phase range of 570 degrees.**

***Index Terms*—Liquid crystal (LC), millimeter wave, reflectarray (RA), reflection loss.**

I. Introduction

Reflectarray (RA) is an effective means to increase the electromagnetic (EM) signal level in the target area without excessive power consumption, and its two dimensional arrangement makes it easy to integrate into structures such as building facades and interior walls [1]. To meet the complex coverage requirements, the RA which can change beam direction has gained widespread attention. Numerous studies on RA have been conducted so far [2]–[5], including such as the use of diodes, mechanical methods and nematic liquid crystal (LC). The rod-shaped molecular structure of nematic LC can be deflected continuously by an external electric or magnetic field, resulting in a corresponding continuous change in its permittivity. This feature of LC allows RA to continuously shift the beam direction, which is the primary advantage of liquid crystal reflectarray (LCRA).In addition, the ease of applying an external electric field to the LC through bias lines further contributes to the design simplicity and cost-effectiveness of the LCRA.

However, LCRA has a disadvantage of high reflection loss (RL). High RL not only results in the dissipation of the incident electromagnetic (EM) wave but also introduces significant variations in reflection magnitude at different reflection phases, which decreases the aperture efficiency of the LCRA [6]. To address this issue, a novel bias voltage supply method is proposed. Simulated and measured results show that the proposed method widens the range of selectable reflection coefficients, making it possible to select larger reflection magnitudes at different reflection phases. Additionally, the proposed method does not sacrifice the reflection phase range. The proposed LCRA structure has reduced RL, low cost, and easy processing characteristics.

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II. Structure and Results

The LCRA unit structures of the proposed and traditional bias supply methods are illustrated in Fig. 1, comprising a superstrate layer, an LC layer, and a metal ground. Traditional bias voltage supply method uses single bias line to control two dipoles, as shown in Fig. 1(a). While the proposed method control the two dipoles independently by two bias lines, as shown in Fig. 1(b). This arrangement enables independent control of the resonance states of the two dipoles via two different bias voltages (V_1 and V_2).The relative permittivity ($\varepsilon_{r\perp}$) of the LC without bias voltage is 2.5, and the loss tangent ($\tan\delta_\perp$) is 0.02. Conversely, when the full bias voltage is applied, the relative permittivity ($\varepsilon_{r//}$) and loss tangent ($\tan\delta_{//}$) are 3 and 0.007, respectively. Additionally, to ensure smooth surfaces for the polymide film coating process, glass ($\varepsilon_r = 3.7, \tan\delta = 0.007$) is chosen as the material for the superstrate.

Fig. 2 illustrates the simulated performances of traditional and proposed bias voltage supply methods at 41 GHz. The reflection magnitude and phase under different LC relative permittivity of the traditional method are shown in Fig 2(a) and (b). As can be seen, the traditional method exhibits a phase variation of 570°, but with high RL (up to 19 dB) where the phase changes rapidly. Fig. 2(c) and (d) display the reflection magnitude and phase of the proposed method. As the two dipoles are controlled independently, there have

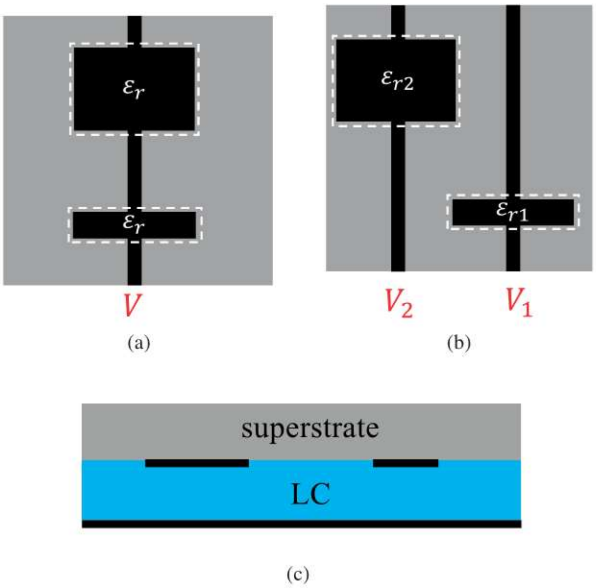


Fig. 1. Top view of the (a) proposed bias voltage supply method and (b) traditional method. (c) Side view of the LCRA unit cell.

two LC relative permittivity variations (ε_{r1} and ε_{r2}) in the proposed method. It is evident that the reflection phase and magnitude exhibit a one-to-multiple correspondence for the LC permittivity. The reflection phase range is almost the same as the traditional method, and the independent control allows one phase mapped to multiple value sets of $(\varepsilon_{r1}, \varepsilon_{r2})$. Consequently, the optimal reflection magnitude can be chosen from these value sets to obtain low RL.

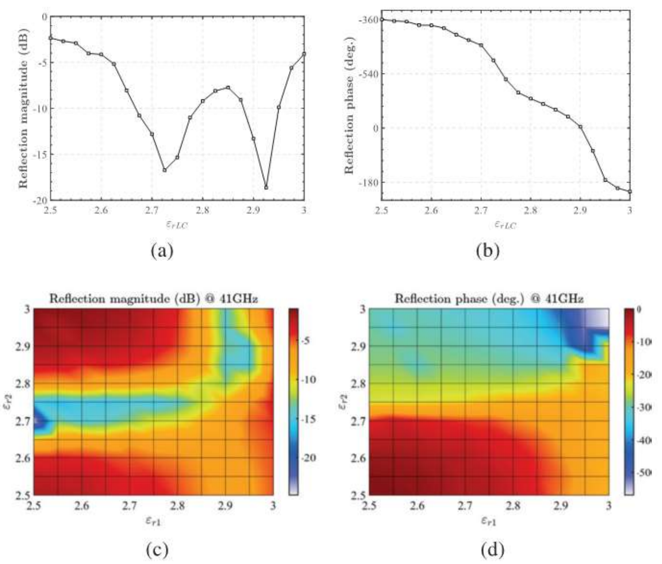
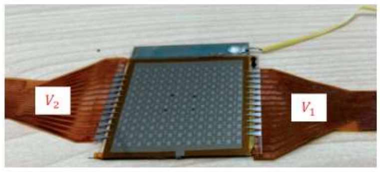


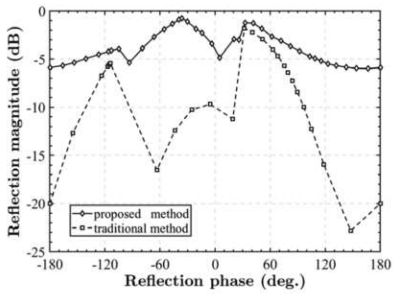
Fig. 2. (a) Reflection magnitude and (b) reflection phase of the traditional method. (c) Reflection magnitude and (d) reflection phase of the proposed method.

For demonstration, a 12 × 13 LCRA prototype controlled by the proposed bias voltage supply method is fabricated. the prototype and measurement environment is shown in Fig. 3. Measured reflection magnitudes corresponding to phase under traditional and proposed bias voltage supply methods at 41 GHz are depicted in Fig. 4(a). Ia can be seed that across the full 360° phase, the reflection magnitude under the proposed method surpasses that under traditional method, with a maximum RL reduction of 17 dB.



(a)

Fig. 3. (a)Prototype LCRA of the proposed method, and (b) measure environment.



(a)

Fig. 4. Measured reflection magnitude and phase correspondence at 41 GHz under the traditional and the proposed bias voltage supply method.

III. Conclusion

A method to reduce the RL of LCRA is proposed. By controlling the permittivity of LC under resonant structures individually, independent control of the reflection magnitude and phase of LCRA is realized. Simulate and experiment results indicated that the structure effectively reduces the RL of the LCRA, without sacrificing the reflection phase range.

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