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A Frequency Selective Surface with Polarization Rotation Based on Substrate Integrated Waveguide

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Abstract—A frequency selective surface (FSS) with polarization rotation which provides a quasi-elliptic bandpass response is presented in this paper. Based on substrate integrated waveguide cavity (SIWC), 90 degrees polarization rotation is obtained when electromagnetic wave passes through the frequency selective surface at specially appointed polarization in a range of 16.28–16.70 GHz. Moreover, TM_{120}/TM_{210} dual-mode configuration appears in the cavity within the passband. The design has been proved with high stability to electromagnetic wave of different incident angles. And the measured results in anechoic chamber provide good agreement with those from commercial software simulations.

1. INTRODUCTION

With the development of wireless communication, electromagnetic interference (EMI) becomes a prominent problem to communication system design, especially in military areas [1–3]. Due to good transmission or high reflection characteristics to electromagnetic (EM) wave, frequency selective surfaces (FSSs) are widely applied in electromagnetic compatibility (EMC), playing the role of space filters with stable responses to frequencies and polarizations [4–8]. In recent years, EM wave propagation controlling has become a hot research topic in these areas. Massive EM metamaterials are designed, which focus on controlling the propagation direction or changing the polarization [9–11]. There are many merits of FSS to deal with EMI for good selectivity in frequency and propagation controlling at the same time. Polarization rotating FSSs are proposed and studied in [12–14], but they perform poorly in frequency selectivity. It is difficult to design and fabricate EM metamaterials due to complex structures and non-periodic unites. On the other hand, FSSs are widely used in radomes, antenna reflectors, EM absorbers, electromagnetic band-gap (EBG) materials, and electromagnetic shields in the microwave and millimeter wave fields [15–18].

In this paper, FSS with polarization rotation is proposed, based on substrate integrated waveguide (SIW). The polarization rotating frequency selective surface (PRFSS) achieves a quasi-elliptic passband response at Ku-band, with two transmission poles (16.43 GHz, 16.57 GHz) within the passband and two transmission zeros (15.93 GHz, 16.97 GHz) on the sides of passband accordingly. It has wide application and significance in controlling electromagnetic wave propagation.

2. FSS DESIGN

Basic geometries of the proposed PRFSS are presented in Fig. 1. The PRFSS consists of two metallic layers with two orthogonal h-shaped slots on the sheets and lots of metallization through-holes connecting the two metallic layers. Two metallic layers, metallization through-holes and medium substrate constitute a rectangular substrate integrated waveguide cavity. The center of an FSS cell

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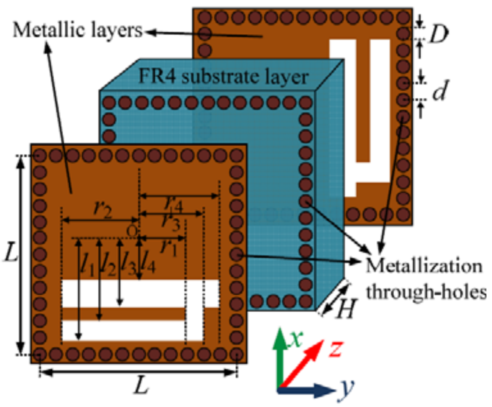


Figure 1. Geometries of the proposed PRFSS.

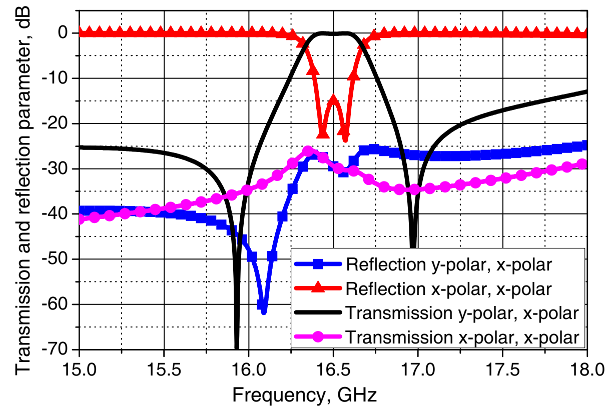
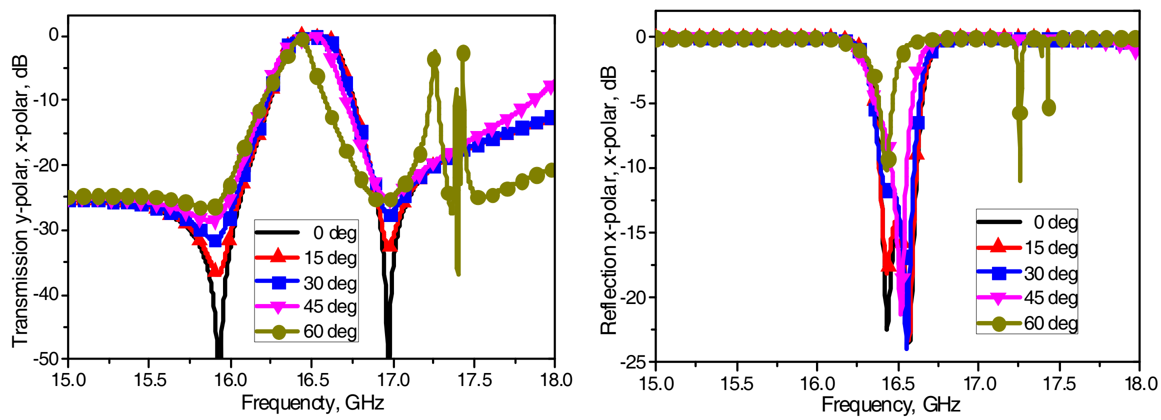


Figure 2. Transmission and reflection characteristics of the PRFSS at x-polar wave.



(a) (b)

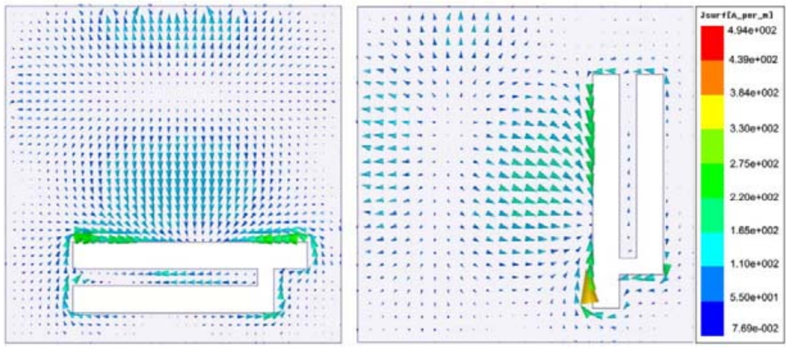
Figure 3. (a) Simulated transmission and (b) simulated reflection characteristics of proposed PRFSS for different incident angles (0°, 15°, 30°, 45°, 60°).

is located at point "O". The unit cell's length in (x, y) direction is $L = 10$ mm, and the thickness of medium substrate is $H = 1.5$ mm. Diameter of metallization through-holes is $D = 0.3$ mm, and granularity of adjoin holes is $d = 0.5$ mm. The position and size of the h-shaped slots depend on parameters $l_1 = 3.0$ mm, $l_2 = 2.5$ mm, $l_3 = 3.0$ mm, $l_4 = 4.0$ mm and $r_1 = 2.0$ mm, $r_2 = 2.8$ mm, $r_3 = 3.3$ mm and $r_4 = 4.1$ mm. PRFSS is arranged on an FR4 substrate, with relative permittivity $\varepsilon_\gamma = 4.4$ and loss tangent $\delta = 0.001$. All simulated results are obtained from commercial software ANSYS HFSS.

Figure 2 shows the transmission and reflection characteristics of the proposed PRFSS at normal incidence (0°) when the incident EM wave propagates along $+z$ axis at x-polarization. It is found that PRFSS has bandpass selectivity characteristics at Ku-band (16.28–16.70 GHz, -3 dB bandwidth), and the EM wave polarization changes from x- to y-polarization.

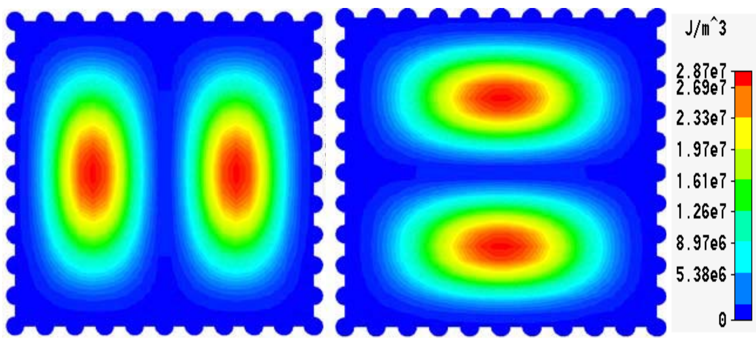
Figure 3 shows the transmission and reflection characteristics of the proposed PRFSS for different incident angles (0°, 15°, 30°, 45°, 60°). When EM wave's incidence angle changes in the range from 0°to 45°, the PRFSS performs very well in the selectivity and restriction to EM wave. Fig. 4 shows the current distribution on metallic sheets at 16.5 GHz. Based on the h-shaped slot, the x-polarized EM wave excites the resonance in the SIW cavity, where TM_{120} and TM_{210} modes coexist, and only y-polarized EM wave is radiated out at the other side.

To further expound the mechanism of the PRFSS, the electric field distributions in SIW cavity of TM_{120} and TM_{210} modes have been presented in Fig. 5. Only TM_{mn0} (m, $n = 1, 2, 3, \ldots$) exist in the



(a) (b)

Figure 4. Current distribution on metallic sheets at 16.5 GHz on (a) front sheet and (b) back sheet.



(a) (b)

Figure 5. Electric field distributions in SIW cavity of (a) TM_{120} and (b) TM_{210} mode at 16.49 GHz.

rectangular SIW cavity, and the resonant frequencies are described as

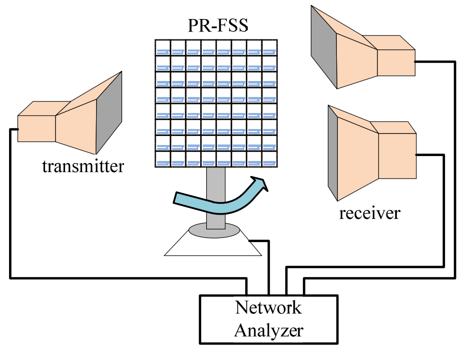
$$f_{r,mn} = \frac{c}{2\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m}{W_{\mathit{eff}}}\right)^2 + \left(\frac{n}{L_{\mathit{eff}}}\right)^2} \quad (1)$$

In formula (1), ε_r, μ_r and c are relative dielectric constant, relative magnetic permeability and velocity of electromagnetic wave in free space, respectively. W_{eff} and L_{eff} are equivalent width and length, and the magnitudes are described as $W_{\mathit{eff}} = W - D^2/0.95d$ and $L_{\mathit{eff}} = L - D^2/0.95d$, where W, L, D, d are defined as in Fig. 1.

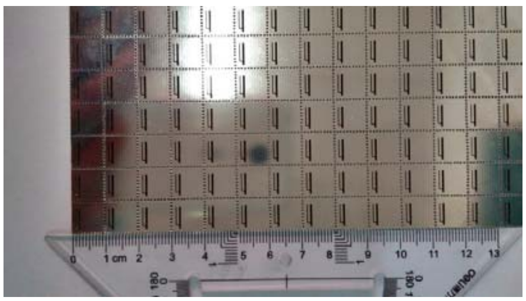
3. EXPERIMENTAL RESULTS

Free-space measurement method is used to check the performance of fabricated PRFSS in Fig. 6(a). The PRFSS is placed in the middle of two horn antennas that stand for transmitter and receiver. To receive a different polarization wave, the receiver antenna should rotate by 90 degrees. In Fig. 6(b), 20×20 units of PRFSS are fabricated to ensure FSSs work under the boundary condition that edge effect can be ignored and measured in anechoic chamber in Fig. 6(c).

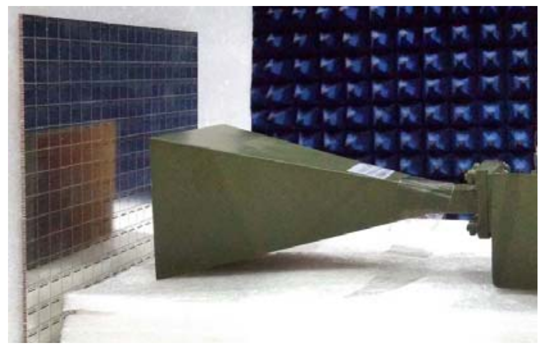
In order to compare the results, measured results of the fabricated PRFSS and the simulated results from the software are both shown in Fig. 7. There are some deviations between the measurements and simulations in the working band, which is possibly due to test system accuracy and test systematic error. The transmission of x-polarization to x-polarization are less than -25 dB both in the simulated and measured results. But still, the measured results are in good agreement with the simulation in general. The rate of polarization rotation rate is up to 90% form 16.35 GHz to 16.62 GHz, approximately 370 MHz.



(a)



(b)



(c)

Figure 6. Free-space measurement method for PRFSS, (a) free-space measurement method; (b) fabricated PRFSS; (c) PRFSS measurement of fabricated prototype.

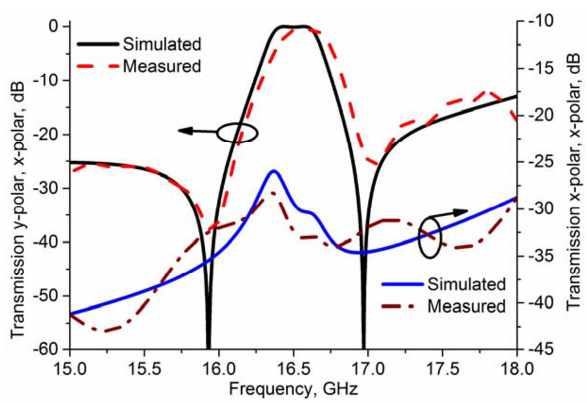


Figure 7. Measured and simulated transmission characteristics of proposed PRFSS.

4. CONCLUSION

A novel FSS with polarization rotation, quasi-elliptic bandpass response has been presented. Based on SIW, two transmission poles and two transmission zeros emerge at Ku-band. At resonant frequencies, TM_{120}/TM_{210} dual-mode configuration appears in an SIW cavity, which causes two transmission poles. Because of its signal-layer structure and thin thickness, the FSS fabrication is simple and cheap. The PRFSS has been fabricated and measured, and the measured results have quite a good agreement with the simulated ones.

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