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Tunable frequency selective surface with a shorted ring slot*

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In order to realize the tunable performance of a frequency selective surface (FSS), a new unit cell is designed in this paper by properly adding two metal shorts to the ring slot. Based on the spectral-domain method, the frequency responses of the FSS structure with two shorts per slot ring are analysed for both the horizontal and the vertical polarizations at the normal incidence. It is demonstrated that the presence of the metal shorts does not affect the resonant frequency of the horizontally polarized wave but doubles the resonant frequency of the vertically polarized wave. Therefore based on the analysis of the novel transmission properties, a new approach to adjusting the resonant frequency by rotating the FSS screen 90° is presented in this paper.

Keywords: tunable frequency selective surface, horizontal and vertical polarizations

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1. Introduction

In recent years, many studies have focused on the tunable frequency selective surface (FSS), which has been found to have widespread applications in the areas of filters for microwave and optical signals.[1−3] The FSS usually has a two-dimensional (2D) planar periodic structure consisting of one or more slot patterns on a metallic screen. The frequency response of the FSS structure can be characterized by the geometry in one period called the unit cell. In the traditional FSS design, the frequency selective properties result from the mutual interactions between the periodic FSS elements.[4−6] Therefore, to obtain a desired frequency selective behavior, a proper unit cell must be selected first.[7−10]

Using a ring slot as an FSS unit cell has been widely investigated.[11,12] Resonance occurs when the circumference of the ring slot is approximately equal to the wavelength. A novel transmission response appears when metal shorts are added to the ring slot at suitable locations. This simple modification enables the FSS structure to be tunable by rotating the FSS screen 90°.

Based on the spectral-domain approach,[13] the frequency response of a tunable FSS model and the other properties are analysed, including the influences of the slot width and the metal short length. The simulation results show that the metal shorts added to the ring slot enable the rapid adjustment of the resonant frequency. The proposed novel approach is simple in structure and easy to control and realize.

2. Design and simulated performance

The ring slot FSS design is shown in Fig. 1. The elements are arranged on a square lattice. By adding two metal shorts to the ring slot, we obtain the proposed FSS model shown in Fig. 2.

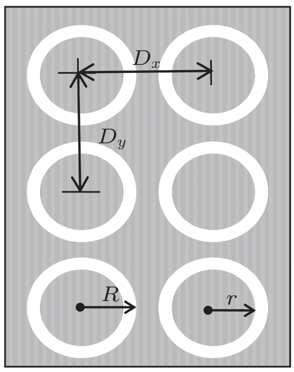

Fig. 1. Ring slot FSS.

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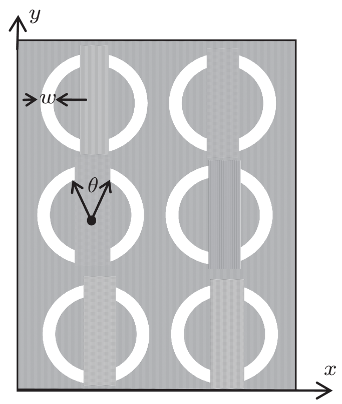

Fig. 2. FSS with two shorts per lot.

The parameters of the element array are illustrated in Figs. 1 and 2. They are element spacings $D_x = D_y = 9$ mm, ring inner radius $r = 3.4$ mm, ring outer radius $R = 3.8$ mm, slot width $w = 0.4$ mm, angular size of the metal short length $\theta = 20°$, dielectric thickness $t = 0.0254$ mm, and dielectric constant $\varepsilon = 3$.

By using the spectral-domain approach, we investigate the effects of the ring slot FSS and the FSS based shorted ring slot resonators. The magnetic-field integral equation of the spatial domain expression for the slot element array is obtained as

$$-\begin{bmatrix} H_x^{\rm inc}(x,y) \\ H_y^{\rm inc}(x,y) \end{bmatrix} = -\begin{bmatrix} H_x^{\rm inc}(x,y) \\ H_y^{\rm inc}(x,y) \end{bmatrix} = \frac{4\pi}{{\rm j}\omega\mu_0 ab}\sum_{m=-\infty}^{\infty}\sum_{n=-\infty}^{\infty}\begin{bmatrix} k_0^2-\alpha_{mn}^2 & -\alpha_{mn}\beta_{mn} \\ -\alpha_{mn}\beta_{mn} & k_0^2-\beta_{mn}^2 \end{bmatrix} \times \tilde{\boldsymbol{G}}(\alpha_{mn},\beta_{mn})\begin{bmatrix} M_x(\alpha_{mn},\beta_{mn}) \\ M_y(\alpha_{mn},\beta_{mn}) \end{bmatrix} \times {\rm e}^{{\rm j}\alpha_{mn}x}\,{\rm e}^{{\rm j}\beta_{mn}y}, \tag{1}$$

where

$$\alpha_{mn} = \frac{2m\pi}{a} + k_x^{\rm inc}, \quad \beta_{mn} = \frac{2n\pi}{b\sin\Omega} - \frac{2m\pi}{a}\cot\Omega + k_y^{\rm inc}, \tag{2}$$

k_0 is the wave number $k_0 = \omega\sqrt{\mu_0\varepsilon_0}$, and M is the equivalent magnetic surface current at the aperture. The superscript inc represents the incident field. Two kinds of unit cells are discretized to employ the rooftop subdomain basis function. Here Ω is the oblique angle, $\Omega = 90°$. For $k_0^2 > \alpha^2 + \beta^2$,

$$\tilde{\boldsymbol{G}} = \frac{-{\rm j}}{2\sqrt{k_0^2-\alpha^2-\beta^2}}\boldsymbol{I},$$

otherwise

$$\tilde{\boldsymbol{G}} = \frac{1}{2\sqrt{\alpha^2+\beta^2-k_0^2}}\boldsymbol{I},$$

where $\boldsymbol{I}$ is an identity tensor.

Equation (1) can be solved by using the method of moments. Then we can determine the transmission coefficients after the unknown magnetic surface current distribution in the aperture of the inductive FSS has been obtained.

The plots of the frequency versus the transmission coefficient are obtained for the normal incident angle and different polarizations to illustrate the different resonant behaviors between the two kinds of elements.

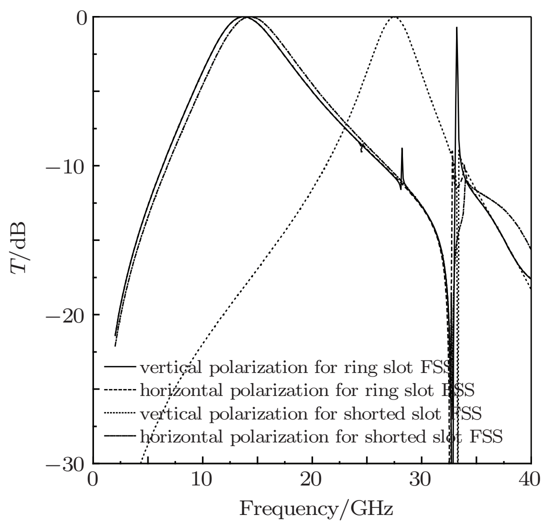

Fig. 3. Computed transmission coefficients of two FSS structures.

The results of the computed transmission coefficients for the two FSS structures are presented in Fig. 3. For the ring slot FSS, the resonant frequency can be determined by the average radius, and two different polarizations have the same transmission characteristic because of the symmetry of the ring slot element. The resonant frequency is 13.8 GHz, and the −3 dB bandwidth is 7.5 GHz. The presence of the two metal shorts has hardly any influence on the transmission characteristic of the horizontal polarization. The resonant frequency is 14.2 GHz, and the −3 dB bandwidth is 7.5 GHz However, the resonant frequency of the vertical polarization is doubled. The resonant frequency is 27.5 GHz, and the −3 dB bandwidth is 4.3 GHz. That is to say, we can obtain two different resonant frequencies, i.e., 14.2 GHz and 27.5 GHz, for the different polarizations of the incident waves to the metal shorts. So we can easily rotate the FSS screen by 90° to adjust the resonant frequency. The rotation angle requires particular attention. We cannot obtain the maximum transmission energy at the resonant frequency when the rotation angle is not 90°. The energy is distributed according to the rotation angle, which is shown in Fig. 4.

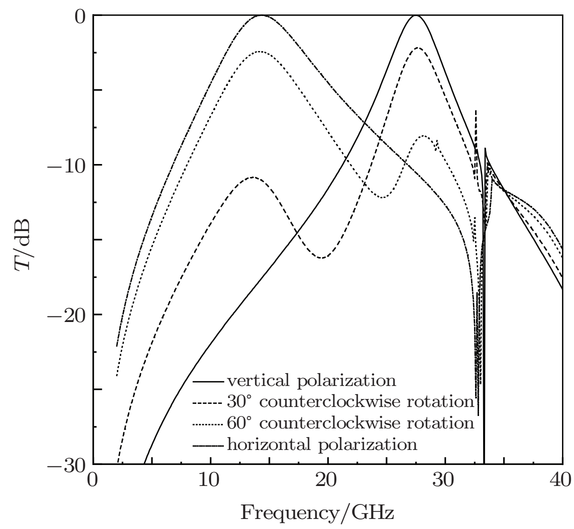

Fig. 4. Transmission coefficients calculated for different rotation angles of the FSS screen.

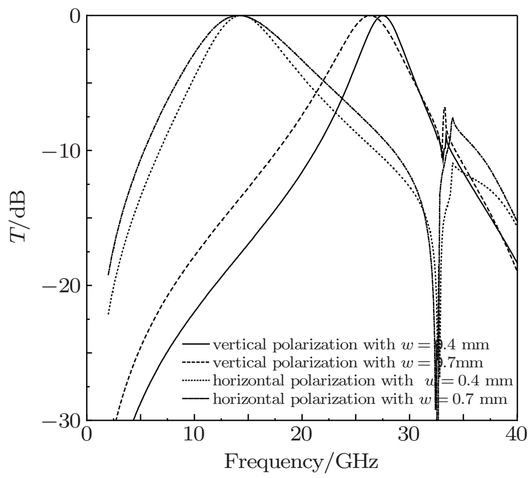

Fig. 5. Transmission coefficients calculated with different slot widths.

The plane-wave transmission coefficients calculated for different values of slot width and metal short length θ are shown in Figs. 5 and 6. The comparison of the FSS transmission coefficients for 0.4 mm and 0.7 mm slot widths leads to the conclusion that the slot width affects mainly the bandwidth, but also the resonant frequency slightly. With the increase of the slot width, the pass-band width increases for both polarizations, and the resonant frequency remains stable for the vertical polarization, while it decreases from 27.5 GHz to 26.4 GHz for the horizontal polarization. Furthermore transmission coefficients calculated for different short lengths given in Fig. 6 show that the resonant frequency can be adjusted by changing the metal short length θ. The resonant frequency changes from 27.5 GHz to 30.3 GHz for the vertical polarization and from 14.2 GHz to 15.8 GHz for the horizontal polarization when the short length changes from 20° to 40°. The pass-band width changes little under the same conditions.

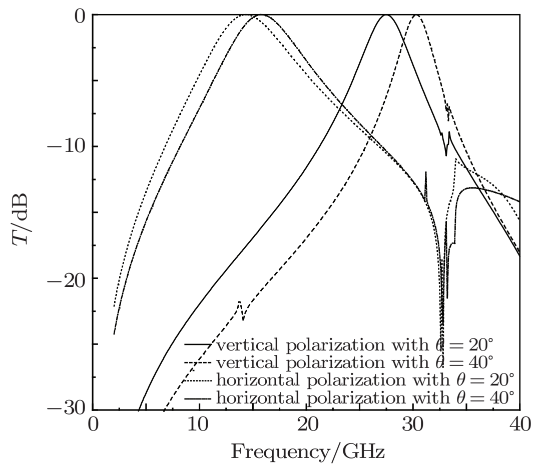

Fig. 6. Transmission coefficients calculated with different short lengths.

3. Conclusion

A novel approach to designing a tunable FSS is presented by using the proposed single-layer shorted ring-slot FSS structure. The simple modification of the FSS unit cell by adding two metal shorts to the ring slot enables the resonant frequency of the vertical polarization to be doubled, and it has hardly any influence on the transmission characteristic for the horizontal polarization. From the analysis of the results, we conclude that the resonant frequency can be adjusted from 14.2 GHz to 27.5 GHz by rotating the FSS screen 90°. Finally, the effects of changing the slots width and the short length on the transmission bandwidth and the resonant frequency are discussed.

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