

Novel Three-Dimensional Frequency Selective Surface with Incident Angle and Polarization Independence

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Abstract—In this paper, a novel three-dimensional frequency selective surface (3D FSS) which is independent of incident angles and polarizations is presented. The periodic unit cell of the proposed 3D FSS is composed of a square metallic waveguide with modified dumbbell slots in all waveguide walls. Frequency transmission characteristics of this 3D FSS for both TE and TM polarizations under different incident angles are simulated. From the results, it is founded that the proposed 3D FSS can provide excellent frequency stability for different incident angles and polarizations. What's more, using 3D printing technology, the novel 3D FSS will be easy for fabrication.

Keywords—Three-Dimensional (3D); frequency selective surface (FSS); waveguide; dumbbell slot; incident angle; polarization

I. INTRODUCTION

Frequency selective surfaces (FSSs) are widely used in microwaves, millimeter wave and radar communication [1], which are periodic resonant structures that behave like spatial filters. Traditional FSSs consist of two-dimensional planar resonant unit cells, such as patch elements or slot arrays backed by dielectric layers. Generally, the size of the resonant unit cells is comparable with half of the wavelength at the operating frequency. However, large electrical dimensions will lead to the incident angles of the FSSs sensitive. Therefore, many works [2-4] have been focused on miniaturizing the unit cells of the FSSs, which can improve the frequency stability for incident angles. The element miniaturization may be achieved using fractal geometry [2], spiral shapes [3], or adding capacitive and inductive bulk components [4]. Recently, three-dimensional (3D) FSSs [5-8] have also been studied, compared with the conventional 2D FSSs, they can provide an extra design degree of freedom. 3D FSSs can also be used to improve the stability of incident

angles. However, most 3D FSSs [5, 6] are difficult to implement and fabricate.

In this paper, we propose a novel miniaturized 3D FSS. The new structure consists of a periodic array of metallic waveguides with modified dumbbell slots in the waveguide walls. The working principle of the proposed 3D FSS is analyzed. Then the frequency transmission characteristics for both TE and TM polarizations under different incident angles are simulated. Since the geometry of the proposed 3D FSS is symmetrical, and its dimension is much less than half of the wavelength at the operating frequency, it can provide good frequency stability for different angles and polarizations. In addition, using 3D printing technology, this novel 3D FSS will be easy for fabrication.

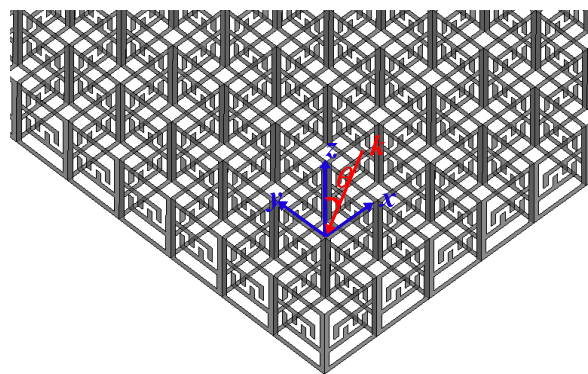


Fig. 1. 3D view of the proposed FSS.

II. PRINCIPLE AND DESIGN OF 3D FSS

As shown in Fig. 1, the proposed 3D FSS is formed by a number of unit cells with square metallic waveguides, which are placed periodically along the x -axis and y -axis directions. For one unit cell, a modified dumbbell slot is etched in each waveguide wall. Fig. 2 illustrates that the modified dumbbell slot is composed by a meander slot and two rectangular patterns in the

waveguide wall. In this paper, the length l and width w of the square metallic waveguide is chosen at 13 mm and 11 mm, respectively. The dimensions of rectangular slots are $l_1=3$ mm, $w_1=9$ mm. The parameters of the meander slot are as follows: $l_2=3$ mm, $s=w_2=1$ mm, $w_3=1$ mm.

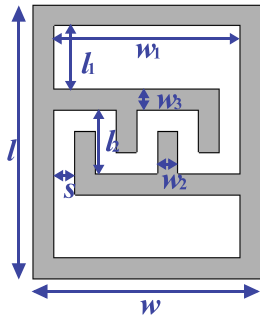


Fig. 2. Geometry of the modified dumbbell slot in the waveguide wall of the FSS unit cell.

To verify the working principle of our proposed 3D FSS, firstly, the square metallic waveguide FSS without slots in waveguide walls is analyzed. The simulated transmission coefficients at normal incidence (0°), 20° , 40° and 60° for both TE and TM polarizations are shown in Fig. 3. From the simulated results, it is found that the waveguide FSS has highpass response, the cutoff frequency is about 13.6 GHz. Above the cutoff frequency, TE or TM modes can propagate, while under the cutoff frequency, only evanescent waveguide modes exist, these modes can't propagate. However, since the cutoff frequency f_c of the square waveguide FSS is determined by the width w of the waveguide unit cell, i.e. $f_c=c/2w$, where c is the velocity of light, which means that the width of the waveguide FSS unit cell is half of the wavelength at the operating frequency, when the incident angle becomes larger, the transmission characteristics of the highpass band change obviously. To improve the frequency stability for incident angles, under the condition of unchanging the dimensions of the waveguide unit cell, the operating frequency should be decreased. Then a new method is considered to miniaturize the electrical dimension of the waveguide FSS.

In [9], the traditional dumbbell slots etched in the ground of a microstrip structure have been reported to construct a planar filter. Here they are considered to etch in the waveguide walls, since each slot can act as a LC resonant circuit, if the dimensions of the slots are chosen at proper values, the resonant frequency can be located in the forbidden frequency range of the square metallic waveguide FSS, and this 3D FSS can have a passband. Further more, the traditional dumbbell slot is modified, the middle narrow slot is replaced by a meander one, so that the parameters of the LC resonant circuit become

larger, the operating frequency can be reduced. The transmission coefficients of both 3D FSSs with modified and traditional dumbbell slots in waveguide walls at normal incidence are depicted in Fig. 4, it can be seen that the resonant frequency of the 3D FSS with traditional dumbbell slots is 6.3 GHz, while the resonant frequency of the 3D FSS with modified dumbbell slots is down to 3.85 GHz. Both the operating frequencies of the two 3D FSSs are much lower than the cutoff frequency of the metallic waveguide FSS. So this method using modified dumbbell slots etched in the waveguide walls can efficiently miniaturize the electrical size of the metallic waveguide FSS.

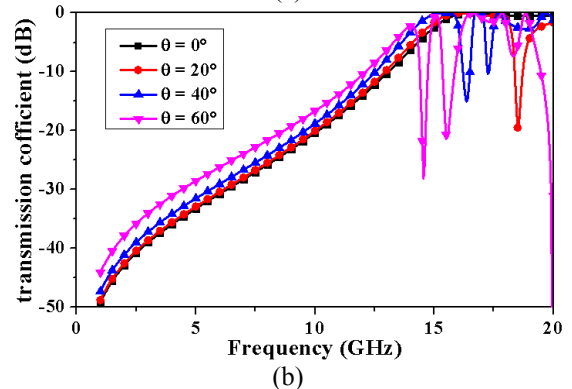
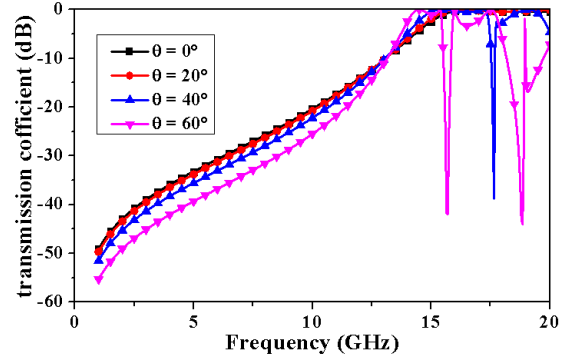


Fig. 3. Simulated transmission coefficients of the waveguide FSS for different incident angles (0° , 20° , 40° and 60°), (a) TE mode, (b) TM mode.

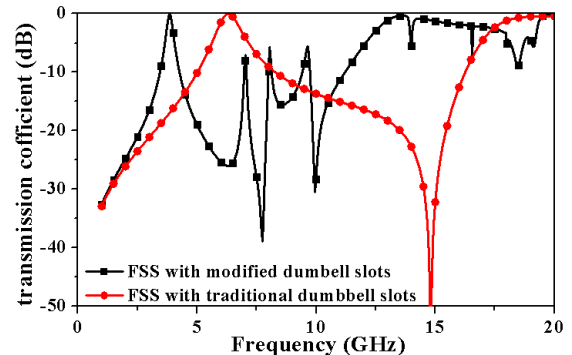


Fig. 4. Simulated transmission coefficients of the two waveguide FSS with modified and traditional dumbbell slots in waveguide walls at normal incidence.

III. SIMULATION RESULTS

The dimensions of the proposed 3D FSS are given in section II. In this section, this novel 3D FSS is simulated. The simulated transmission coefficients of the proposed 3D FSS for both TE and TM polarizations under different incident angles are illustrated in Fig. 5(a) and (b), respectively. It is observed that the frequency performance of the proposed structure does not change significantly at normal incidence (0°), 20° , 40° and 60° for both TE and TM polarizations, the operating frequency shifts about 2.6% at TE60 and 1.9% at TM60. In addition, the proposed 3D FSS gives an identical response for both TE and TM modes of polarization because the structure is symmetrical. From the results, the proposed structure shows excellent incident angular stability and provides an identical response for both TE and TM modes of polarization. The width and length of the unit cell are only $0.14\lambda_g$, and $0.167\lambda_g$ respectively, where λ_g is the wavelength at the operating frequency.

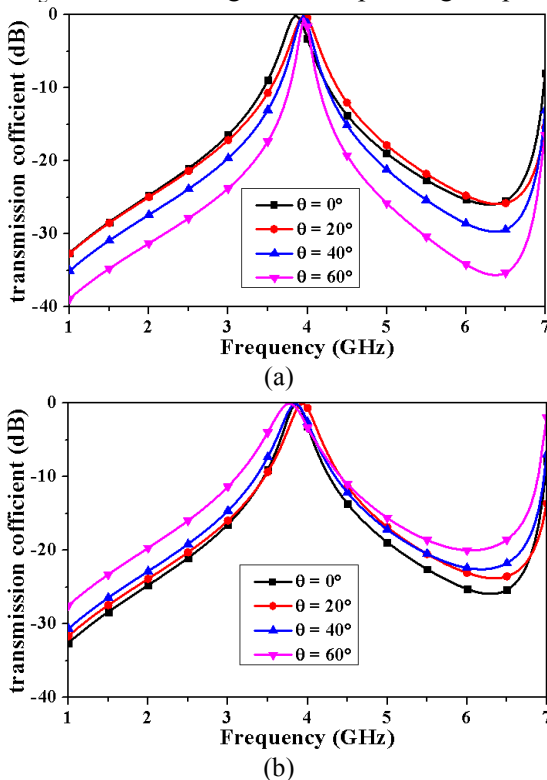


Fig. 5. Simulated transmission characteristics of the proposed 3D FSS for different incident angles (0° , 20° , 40° and 60°), (a) TE mode, (b) TM mode.

IV. CONCLUSION

In this paper, a novel 3D FSS has been presented, which is composed of an array of square metallic waveguides with modified dumbbell slots in the waveguide walls. The working principle of the proposed 3D FSS has been analyzed. From the simulated transmission coefficients, it can be found that this novel FSS provides an identical response for both TE and TM polarizations and different incident angles. What's more, using 3D printing technology, the proposed 3D FSS will be easily fabricated.

V. ACKNOWLEDGMENT

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