A Novel Tri-band Frequency Selective Surface

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Abstract. This paper presents a novel tri-band frequency miniaturized frequency selection surface (FSS). The proposed FSS consists of single-node folding and single-node folding bending. The single-layer FSS exhibits three stop bands centered at 2.45, 3.61 and 5.79 GHz, with bandwidths of 0.42, 0.48 and 0.70 GHz, respectively. The proposed FSS has better miniaturization characteristics, and its cell size is 0.126λ x 0.126λ. The three stop band frequencies of the FSS can be independently controlled by simply changing the length of the corresponding branch. In addition, the proposed FSS is symmetrical about the center and exhibits good resonance stability in both TE and TM polarization. The prototype of the proposed FSS was fabricated and tested, compared with the simulation results, the FSS showed stable performance. This method provides ideas for designing multiband FSS in the future.

1. Introduction

Frequency selection surface (FSS) is also called a spatial filter due to its selective permeability to electromagnetic waves and usually consists of a two-dimensional periodic structure. It can transmit, reflect or absorb the incident electromagnetic waves at a specific frequency, so it is widely used in the design of high-performance radome, antenna reflector, space electromagnetic interference shielding and absorber, electromagnetic stealth in.

Over the past decade, a large number of experts and scholars have conducted in-depth research on the frequency selection surface and proposed a variety of methods to design dual-frequency FSS with miniaturization [2]-[11]. Two-dimensional compact U-groove resonators are used in each FSS unit to achieve dual frequency bands in [2]. A cross bends geometry structure element is proposed, and the curved and branched structure are used to achieve a dual-frequency response band-stop filter-type FSS in [3]-[7]. Dual-band FSS structures are designed to realize coupling and cascading performance in [8]-[11].

In this letter, a tri-band band-stop FSS is proposed, whose the center frequency are 2.45, 3.61 and 5.79 GHz, respectively. The FSS has independent controllability, and the corresponding resonance frequency can be controlled separately by adjusting the length of the corresponding branch. The proposed FSS has better miniaturization characteristics, its cell size is 0.126λ x 0.126λ, where λ represents the free space wavelength of the lower resonance frequency. In addition, the designed FSS shows good stability to TE and TM under different incident angles. In order to verify the FSS array, it was manufactured and tested. The physical test results are consistent with the simulation results, proving the stability performance of the proposed FSS.
2. THE FSS DESIGN AND ITS PERFORMANCE

The unit structure is shown in Figure 1, which shows the periodic metal pattern printed on the single-sided dielectric substrate. It is formed by the conventional cross-shaped structure by folding to form LL1 and LL2, and then by folding and bending more times to form LL3, thus forming a three-frequency band-stop type FSS. Using FR4 dielectric board, the dielectric constant is 4.4 and the loss tangent is 0.02. The variable size of the unit structure is shown in Table 1.

![Figure 1. Unit size of the proposed FSS](image)

| Parameter | L (mm) | H (mm) | W (mm) | L1 (mm) | L2 (mm) | L3 (mm) |
|-----------|--------|--------|--------|---------|---------|---------|
| Value     | 15.4   | 1.2    | 0.4    | 7.4     | 3.6     | 7.0     |
| Parameter | L4     | L5     | L6     | L7      | L8      | L9      |
| Value     | 3.6    | 6.1    | 3.1    | 4.0     | 2.0     | 2.6     |

When Ansys HFSS simulates the cell structure with periodic boundary conditions and the TE (TM) wave is incident along the Z-axis direction. The designed FSS exhibits three stopband characteristics at 2.47, 3.55 and 5.72 GHz, with transmission coefficients of -31.65, -28.09 and -27.44 dB in Figure 2.

![Figure 2. Transmission coefficient of the proposed FSS under normal incidence](image)
The designed FSS has the characteristic of central symmetry. Figure 2 shows that it has good polarization stability, and its band-stop response is the same under TE and TM polarization (Under normal incidence along the Z axis, the maximum offset of the third frequency point is 0.04 GHz). In addition, Figure 3(a) and (b) are the stability performance of the FSS when the incident angle changes under TE and TM polarization. When the angle rises to 60°, the maximum shift of the resonance point under TM polarization is only 1.37%, but the maximum shift of the resonance point under TE polarization is 2.22%. Although its deviation is slightly larger under TE polarization, the stability is still very good.

![Figure 3. Simulated transmission coefficient of the proposed FSS under different incidence (a) TE modes and (b) TM modes.](image)

In order to verify the frequency-independent controllability of the designed FSS, we simulated the lengths of L2 in LL1 and L4 in LL2. As can be seen in Figure 4, the second frequency point is mainly controlled by the change of L4 in the branch LL2, and has a regularity with the change of the length of the L4 branch. Although the third frequency point also changes, the change law is messy. As shown in Figure 5, the third frequency point is mainly affected by L2 in the LL1 branch. As L2 in the LL1 branch increases, the third resonance frequency decreases, and the first and second resonance frequencies remain almost unchanged, thus achieving Independent control of the third resonance frequency. By adjusting the length of the above branches to obtain the control of the corresponding resonance frequency, it is very practical to design a multi-frequency FSS.

![Figure 4. The transmission coefficient of the proposed FSS under the change of L4 value](image)
3. MEASUREMENT RESULTS

In order to better verify the simulation results, the physical object of the proposed FSS etched on FR4 with a thickness of 1.2 mm, and the metal thickness is 0.035 mm. At the same time to prevent metal oxidation, tin plating process is added to the metal surface, as shown in Figure 6. The size of the FSS is 200×200 mm², which is composed of 13×13 units. In a microwave darkroom, this measurement is performed by two horn antennas connected to a network analyzer. Under the normal incidence, the measured and simulated transmission coefficients of TE and TM polarizations are shown in Figure 7. From the measurement results, the resonance at the first frequency point coincides, and the second resonance point and the third resonance point are offset, respectively shifted to the left by 0.05 GHz and 0.06 GHz, but the bandwidth width has not changed. The similarity of the results verifies the excellent performance of the FSS.
4. CONCLUSION

A novel three stop-band FSS resonating at 2.45, 3.61 and 5.79 GHz is proposed in this paper. The proposed FSS has better miniaturization characteristics, and its cell size is 0.126λ×0.126λ. The three stop band frequencies of the designed FSS can be independently controlled by simply changing the length of the corresponding branch. In order to better verify the performance of the designed FSS, the processed objects were made and tested. The physical test results and simulation results show a good uniformity. In addition, the method of obtaining better resonance frequency by bending and folding branches provides a way for later researchers.

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References

[1] MUNK.BEN, A. (2005) Frequency Selective Surfaces: Theory and Design.
[2] Cimen, S. (2013) Novel Closely Spaced Planar Dual-band Frequency-selective Surface[J]. Iet Microwaves Antennas&Propagation, 7(11):894 – 899.
[3] Ghosh, S. Srivastava, K. V. (2017) An Angularly Stable Dual-Band FSS With Closely Spaced Resonances Using Miniaturized Unit Cell[J]. IEEE Microwave and Wireless Components Letters, 27(3):218-220.
[4] Sivasamy, R.Kanagasabai, M. A Novel Dual-Band Angular Independent FSS With Closely Spaced Frequency Response[J]. IEEE Microwave & Wireless Components Letters, 25(5):298-300.
[5] Chiu,C.N.Wang, W.Y.(2013) A Dual-Frequency Miniaturized-Element FSS With Closely Located Resonances[J]. IEEE Antennas and Wireless Propagation Letters, 12(2):163-165
[6] Sheng, X.J.Fan, J.J.Liu, N.(2017) A Miniaturized Dual-Band FSS With Controllable Frequency Resonances[J]. IEEE Microwave & Wireless Components Letters, 27(10):915-917.
[7] Yan, M.Qu, S.Wang, J.(2014) A Miniaturized Dual-Band FSS With Stable Resonance Frequencies of 2.4 GHz/5 GHz for WLAN Applications[J]. IEEE Antennas & Wireless Propagation Letters, 13:895-898.
[8] Hu, X.D.Zhou, X.L.Wu L.S.(2009) A Miniaturized Dual-Band Frequency Selective Surface (FSS) With Closed Loop and Its Complementary Pattern[J]. IEEE Antennas and Wireless Propagation Letters, 8:1374-1377.
[9] Wang, D.Chang, Y.Che, W.(2013) A novel low-profile tri-band frequency selective surface[C]//
IEEE International Wireless Symposium. IEEE.
[10] Yan, M. Qu, S. Wang, J. (2015) A Miniaturized Dual-Band FSS with Second-Order Response and Large Band Separation [J]. IEEE Antennas & Wireless Propagation Letters, 14:1-1.
[11] Salehi, M. Behdad, N. (2008) A Second-Order Dual X-/Ka-Band Frequency Selective Surface [J]. IEEE Microwave & Wireless Components Letters, 18(12): p.785-787.