Minaturised Bandstop Frequency Selective Surface Based on Multilayer 2.5-Dimensional Structure

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Abstract—A hexagonal minaturized frequency selective surface (FSS) based on multilayer 2.5-dimensional (2.5D) closed loop is proposed in this paper. The finite element analysis software Ansoft HFSS 19 is used to simulate the performance of FSS under different polarization modes and incident angles of electromagnetic wave. The simulation results show that the FSS resonates at 2.36 GHz and the corresponding unit size is 0.041λ₀×0.041λ₀. It also shows an outstanding stability under different polarization modes and incident angles.

Keywords— Frequency Selective Surface; Multilayer; Stability; Miniaturization;

I. INTRODUCTION

Frequency selective surface (FSS), exhibiting spatial filtering performance to the incidence waves, is widely used in microwave and millimetre-wave areas as electromagnetic shields, spatial filters, absorbers, radomes, antenna reflectors to name a few [1]. In theory, the array of FSSs should be infinitely large in dimension. However, considering the practical application, it is important to miniaturize the element of FSSs to arrange enough number of resonant elements in limited space to achieve anticipative filtering response. In addition, compared with the normal frequency selective surface structure, the miniaturized frequency selective surface improves the stability of resonance and move the working frequency band from high frequency to low frequency, which is very beneficial for FSS applications. In recent years, many scholars propose different structures and methods to miniaturize FSS. For instance, a miniaturized FSS with the element size of 0.083λ₀ is proposed in [2], which is made up of a two-dimensional metallic closed loop periodic array and similar structures on the other surface of the dielectric plate. In [3], bending closed loop with its complementary pattern is used to miniaturize the unit cell size of the FSS, whose element size reaches 0.086λ₀. However, these FSSs usually not only have poor response stability, but also miniaturization is not obvious enough. In order to further solve above problems, several novel FSS structures are reported to further miniaturize the FSSs, such as an FSS with the unit cell size of 0.048λ₀ based on 2.5D closed loop [4], and a compact bending dual-band FSS with the unit cell size of 0.072λ₀ based on 2.5D structure for GSM shielding [5]. In addition, an effective via-based methodology for unit cell minimization which is achieved by bending metallic patch and vertical via [6] and a novel FSS based on inductance structure of bending patch and parallel plate capacitor of upper and lower surface patches of dielectric substrate to miniaturize the FSS unit cell size [7] are proposed, and the unit cell sizes of them are 0.046λ₀ and 0.036λ₀ respectively. More recently, an miniaturized-element FSS based on compact bending metallic patch and ultrathin dielectric substrate has been also presented in [8], whose unit cell size is only 0.017λ₀. Although these structures have been further miniaturized in unit cell sizes, there is no significant improvement on resonant stability.

A multilayer hexagonal 2.5D minaturized-element FSS with stable response is presented in this paper. The multilayer 2.5D FSS structure exhibits bandstop characteristics at 2.36 GHz with the unit cell size of 0.041λ₀×0.041λ₀. Compared with previous FSSs, the proposed FSS exhibits a good characteristic of miniaturization, and it also shows an outstanding stability under different polarization modes and incident angles (up to 80°) of electromagnetic waves.

II. ANALYSIS AND DESIGN OF THE FSS

A novel 2.5D minaturized FSS with stable performance is designed in this paper. As shown in Figure 1, the structure consists of three layers of dielectric substrates and four layers of metallic patches. The three-layer dielectric substrates are closely connected, and the adjacent two-layer patches are connected through metallic vias. In the FSS element, there are three pairs of the metallic opening rings on the upper dielectric substrate and the lower surface of the lower dielectric substrate respectively. Six pairs of rectangular metallic patches are printed on upper and lower surfaces of intermediate dielectric substrate. There are six metallic vias in each dielectric substrate. The metal opening ring and the rectangular metal sheet form a closed ring structure through the vias.

The resonance of FSS is closely related to its equivalent electrical length. When its equivalent electrical length is half of the resonant wavelength (λ₀/2), it will produce resonance. Therefore, the equivalent electrical length of the closed ring can be increased by bending metallic patch on the surface of the dielectric substrate and the vias of the dielectric substrate to reduce resonance frequency. From the view of resonant circuit, in this FSS cell structure, the bending metallic patch structure on the horizontal plane can increase the inductance and capacitance of the cell, while the metallic vias on the vertical plane connecting the upper and lower metallic patches can increase the inductance of the cell [8]. This FSS is a closed loop structure based on multilayer 2.5D and its electrical size.

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increases, so the FSS unit cell obtains a good characteristic of miniaturization. This is especially beneficial for maintaining the stability at different polarization modes and incident angles of electromagnetic waves.

The parameters of the structure in Figure 1 as follows (unit: mm): $P = 4$, $L_1 = 0.5$, $L_2 = 2.2$, $W = 0.2$, $S = 0.1$, $d = 0.3$, $M = 0.6$, $H_1 = 0.5$ mm, $H_2 = 0.3$ mm. All three dielectric substrates are FR4 with dielectric constant of 4.4.

![Figure 1. Geometry and dimension of the frequency selective surface (a) 3D model (b) Upper layer patch structure (c) Intermediate layer patch structure](image)

**III. SIMULATION RESULTS AND ANALYSIS**

As shown in Figure 2, the proposed miniaturized FSS resonance at 2.36 GHz, and its unit cell size is $0.041 \lambda_0 \times 0.041 \lambda_0$. Furthermore, the FSS shows good stability under different polarization modes and incident angles. There is only a little deviation in the resonance frequency when the incidence angle is as large as 80°, and the deviation is only about one percent. The comparison of the proposed FSS and previous miniaturized FSSs is shown in Table 1. As we can see, the proposed FSS has improved both in miniaturization and stability. Although the unit cell size of FSS in [8] is smaller compared to the proposed structure, the range of incident angle is only $0^\circ$–$60^\circ$, which cannot satisfy the situation when a larger incident angle is needed.

![Figure 2. Simulated transmission coefficients of proposed FSS under different polarisations and incident angles (a) TE polarization (b) TM polarization](image)

**TABLE I COMPARISON OF MINIATURIZED FSSS**

<table>
<thead>
<tr>
<th>FSS unit cell</th>
<th>Resonant frequency (GHz)</th>
<th>FSS unit cell size</th>
<th>Angular stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref. [2]</td>
<td>6.23</td>
<td>0.083\lambda_0</td>
<td>$0^\circ$–$45^\circ$</td>
</tr>
<tr>
<td>Ref. [3]</td>
<td>2.4</td>
<td>0.086\lambda_0</td>
<td>$0^\circ$–$30^\circ$</td>
</tr>
<tr>
<td>Ref. [4]</td>
<td>2.85</td>
<td>0.048\lambda_0</td>
<td>$0^\circ$–$60^\circ$</td>
</tr>
<tr>
<td>Ref. [5]</td>
<td>0.9</td>
<td>0.072\lambda_0</td>
<td>$0^\circ$–$60^\circ$</td>
</tr>
<tr>
<td>Ref. [6]</td>
<td>4.22</td>
<td>0.046\lambda_0</td>
<td>$0^\circ$–$75^\circ$</td>
</tr>
<tr>
<td>Ref. [7]</td>
<td>2.42</td>
<td>0.036\lambda_0</td>
<td>$0^\circ$–$60^\circ$</td>
</tr>
<tr>
<td>This FSS</td>
<td>2.36</td>
<td>0.041\lambda_0</td>
<td>$0^\circ$–$80^\circ$</td>
</tr>
</tbody>
</table>

**IV. CONCLUSION**

In this paper, a hexagonal miniaturized frequency selective surface (FSS) based on multilayer 2.5-dimensional (2.5D) closed loop is designed, which shows an outstanding miniaturization performance with the unit cell size of $0.041\lambda_0 \times 0.041\lambda_0$. In addition, the simulation results also show that the proposed FSS structure has a promising stability under different polarization modes and incident angles of electromagnetic waves. Compared with other FSSs, this FSS has more advantages under the conditions of finite space and large angle incident wave.

**REFERENCES**

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