The Design of Band-pass Frequency Selective Surface with the Grid Dielectric Metamaterial

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Abstract— Metallic parts are indispensable to traditional frequency selective surfaces. However, for millimeter waves, because of surface wave skin effect, the loss of metal-containing FSS is so large that the performance is badly affected. Besides, metal materials are quite unfavorable for high-temperature resistance and corrosion resistant requirements. The article adopt period dielectric structure to achieve band-pass frequency selective properties. The design principles proposed in this paper are of great practical values in designing all-dielectric metamaterials frequency selective surfaces.

1. INTRODUCTION

Frequency selective surface (FSS), as a kind of spatial filter, is planar or curved surfaces composed of periodically arranged scatter arrays. FSS can exhibit one or more pass-bands or stop-bands. Conventional FSSs are usually two-dimensional structures composed of periodically arranged metallic patches or slits. Metamaterial are artificial composite structures or composite materials that exhibit u-natural physical properties [1–5]. The concept of metamaterial not only gives us a new material form, but only provides us a new material design concept. This brings revolutionary changes to the world view and methodology of human beings [6].

All-dielectric metamaterial are now receiving more and more attentions from the academic world. This kind of metamaterial includes no metallic part and thus has the advantages of low loss, simple structure, better homogeneity and isotropy at high frequencies (millimeter waves, sub-millimeter waves, infrared waves and etc.).

Based on these merits, this thesis introduces all-dielectric metamaterials into the design of FSSs and mainly investigates the principles and methods of designing all-dielectric FSSs using high-permittivity dielectric materials [7, 8].

2. THE ANALYSIS OF THE THEORY BASED ON MIE SCATTERING [9–11]

Mie scattering is the most widely used application and the basic algorithms of the particle scattering than any other theories. There is nothing comparable to this precision in the processing in the wavelength particle scattering problem. Specifically refers to isotropic, particles in a highly dilute medium system, such as air scattering and the particle diameter, the refractive index difference between incident particles to the medium on the theory of the relation between the wavelength of incident light.

Traditional mie scattering thought is as follows.

Plane wave scattering problem of small ball can be calculated strictly by matching the boundary conditions. For isolation of single spherical scatterer, the electromagnetic wave into the background material of the dielectric constant as ε_b, permeability as μ_b, the radius of spherical scatterer as r_0, dielectric constant as $\varepsilon_r = n^2$ (n for the refractive index of the scatterer). The m class of scattering coefficient a_m and coefficient b_m respectively:

$$a_m = \frac{n\Psi_m(nx)\Psi_m'(x) - \Psi_m(x)\Psi_m'(nx)}{n\Psi_m(nx)\xi_m'(x) - \xi_m(x)\Psi_m'(nx)} \quad b_m = \frac{\Psi_m(nx)\Psi_m'(x) - n\Psi_m(x)\Psi_m'(nx)}{\Psi_m(nx)\xi_m'(x) - n\xi_m(x)\Psi_m'(nx)}$$

where, $x = k_0 r_0$, $k_0 = {}^{\omega}/_{c}$ is the wave vector in Vacuum, Ψ_m, ξ_m is Reccati-Bessel Functions.

According to the Clausius-Mossotti Equation, if $\lambda > r_0$,

$$\varepsilon_{\mathit{eff}} = \frac{2(k_0 r_0)^3 + 6ifa_1}{2(k_0 r_0)^3 - 3ifa_1} \qquad \mu_{\mathit{eff}} = \frac{2(k_0 r_0)^3 + 6ifb_1}{2(k_0 r_0)^3 - 3ifb_1}$$

where, $f = {}^{4\pi N r_0^3}/_{3}$, N for the number of the unit volume of the spherical scatterer.

According to mie scattering theory,

$$a_1 = j\frac{2}{3}\left(k_0^2\mu_b\varepsilon_b\right)^{3/2}\frac{\varepsilon_b - \varepsilon_r F(\theta)}{2\varepsilon_b + \varepsilon_r F(\theta)}r^3 \quad (1)$$

$$b_1 = j\frac{2}{3}\left(k_0^2\mu_b\varepsilon_b\right)^{3/2}\frac{\mu_b - \mu_r F(\theta)}{2\mu_b + \mu_r F(\theta)}r^3 \quad (2)$$

where,

$$F(\theta) = \frac{2(\sin\theta - \theta\cos\theta)}{(\theta^2-1)\sin\theta + \theta\cos\theta}, \quad \theta = k_0 a\sqrt{\varepsilon_r'\mu_r'}$$

3. THE DESIGN AND SIMULATION OF BAND-PASS FSS WITH THE GRID DIELECTRIC METAMATERIAL

For the symmetry of the grid unit, we should adjust the only parameter length during the optimization. And the sample with grid unit is much easy to implement. Based on these reasons, a kind of grid as the basic unit of the whole medium type FSS is designed.

As can be seen from the Figure 1(b), unit structure is periodic extension in the XY plane. The dielectric grid and the air are the two different kind of material structure. The effect of band-pass may be produced by this structure. As shown in Figure 2 is obtained by frequency domain calculation, S parameters of the curve.

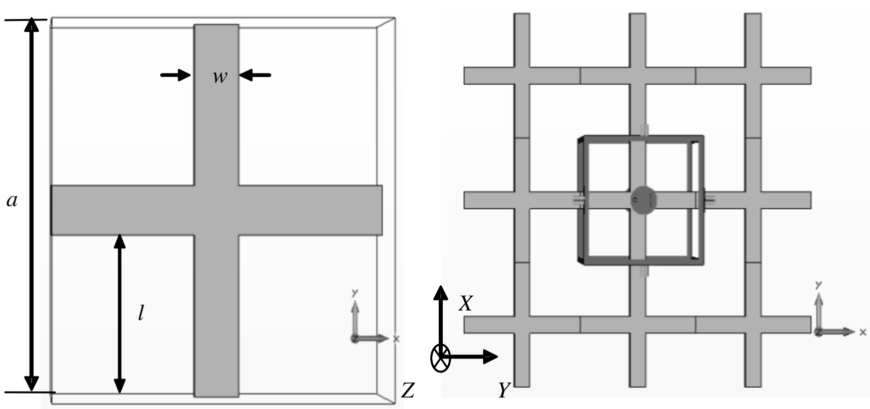

Figure 1: The structure diagram of the grid dielectric metamaterial single band FSS.

Figure 2 for the TE polarized wave is incident when the FSS S_{11} and S_{21} frequency response curve. As can be seen from the graph, the pass band is a single band, the pole is 11.17 GHz, 3 dB work pass band is 1.08 ∼ 11.34 GHz, the bandwidth is 260 MHz, the reflectivity of resonant pole is greater than −40 dB.

However, we found that the pass band result is not very ideal by analysis of transmission characteristics of the corresponding curve, the smooth curve does not appear in the pass band, the

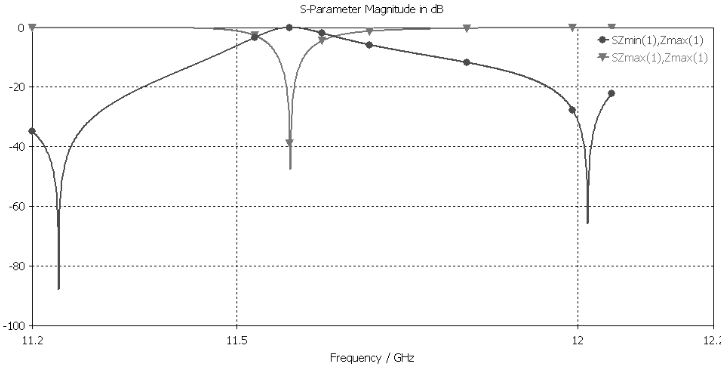

Figure 2: The S parameters of the grid dielectric metamaterial single band FSS.

decrease is not significantly with inside and outside.

Figure 3 for the set in a free space of the double layer grid dielectric metamaterial FSS. Keep the dielectric constant, dielectric loss and the size of unit the same.

From Figure 3 we can find the pass band characteristics can be significantly improved. The optimized FSS has good pass band performance. Contrast can be seen in Figure 2 that transmission pass band center frequency has not changed, the two poles of pass band are 11.13 GHz and 11.24 GHz, 3 dB pass band is 10.07 ∼ 11.32 GHz, the passband bandwidth of 1.23 GHz, reflectivity of two resonant pole are larger than −40 dB.

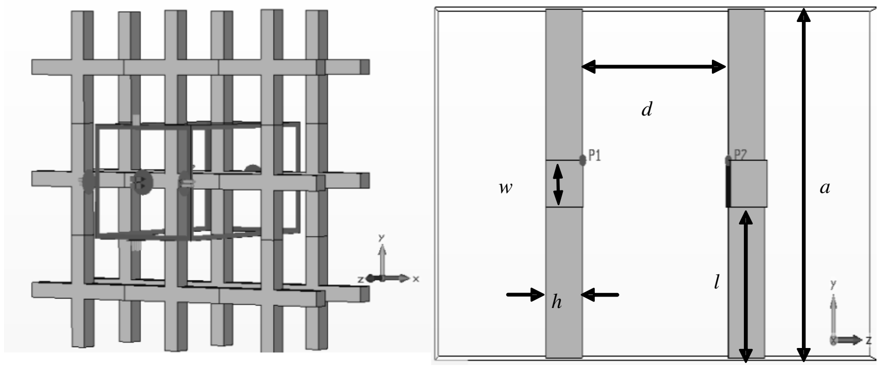

Figure 3: The structure diagram of the double layer grid dielectric metamaterial FSS.

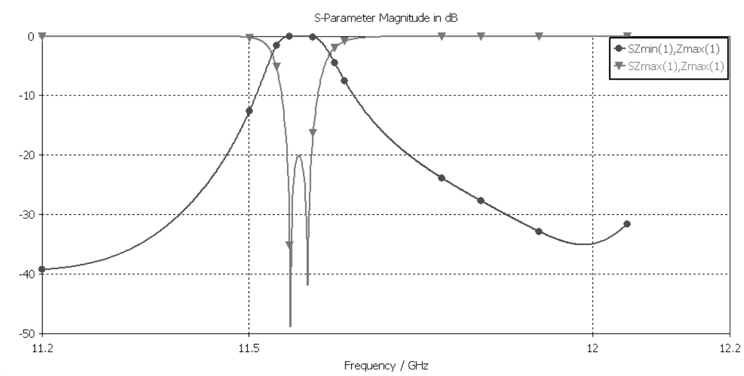

Figure 4: The S parameters of the double layer grid dielectric metamaterial single band FSS.

4. CONCLUSION

This paper uses the method of the combination of the FSS and the metamaterial design, and analyze the mechanism of pass band characteristic by Mie scattering principle. Through the coupling between different layers of pass band bandwidth, designs the grid type all dielectric metamaterials FSS, formed pass band in x-band, 3 dB transmission pass band is 10.07 ∼ 11.32 GHz, pass band bandwidth is 1.23 GHz, in-band insertion loss maximum 0.78 dB. The principle proposed by this paper is important to guide significantly to design the all dielectric metamaterials FSS.

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