Design of an All-dielectric Band-stop Frequency Selective Surface

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***Abstract* - Design of an all-dielectric band-stop frequency selective surface (FSS) is proposed for X-band application. The unit particle of the FSS consists of a thick upper hexagonal prism part and a thin lower hexagonal prism part for monolithic construction. The proposed FSS has planar array of hexagonal ceramic prisms having a honey comb-shaped structure. The proposed FSS has three resonant dips. Those are combined to establish a broad stop-band of 24.4 % (center frequency of 10 GHz) -10-dB fractional bandwidth (FBW). To demonstrate resonant characteristic modes, the cylindrical cavity mode analysis based on the cylindrical wave functions is used.**

***Index Terms* — All-dielectric, frequency selective surface (FSS), band stop spatial filter, hexagonal prism.**

1. Introduction

Frequency selective surfaces (FSSs) are electromagnetic spatial filters designed to pass or block particular frequency band of interest. Because of their frequency selective characteristic, research on FSS has been widely conducted for various applications such as microwave absorbers, artificial magnetic conductors, and concealment technology [1]. Generally, FSS is realized by utilizing periodical conducting sheet on a substrate [2]. However metallic materials have inherent disadvantages, such as oxidization, corrosion, and high-power problems (arcing, breakdown, and heating). To overcome its limitations, all-dielectric FSSs without using metallic patches are emerged. However dielectric materials are more difficult to interact with electromagnetic field than metallic structure in microwave frequency region. Thus researches on an all-dielectric FSS have been focused on terahertz and infrared frequency applications [3].

For X-band band-stop application, all-dielectric metamaterial FSS based on the effective medium theory and dielectric resonator theory was proposed. The unit rectangular particle size was reduced to 2 mm × 2 mm × 3 mm and a 1.5 GHz -10-dB bandwidth by using the dielectric material with high-permittivity of $\varepsilon_r = 115$ [4]. However a dielectric material with very high-permittivity causes the cost problem.

In this paper, design of an all-dielectric band-stop FSS for X-band application is proposed. The unit particle of proposed dielectric FSS has a shape of hexagonal prism and its array has a honey comb structure. The optimized FSS has three resonant frequencies and they merge into a wide stop-band of 24.4 % -10-dB FBW, at the center frequency of 10 GHz. Each resonant mode is approximately analyzed by using cylindrical resonant mode patterns.

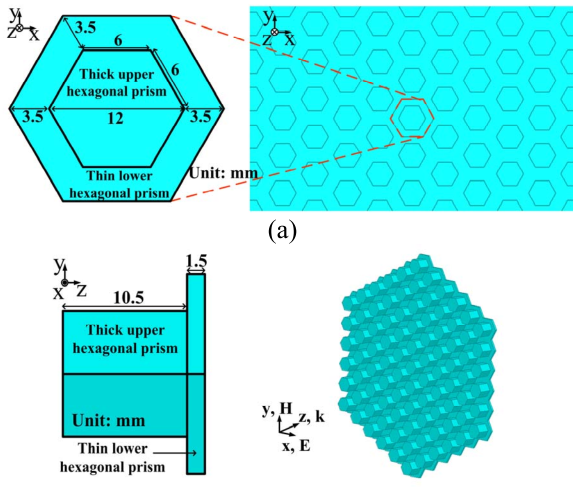

Fig. 1. Geometry of the proposed all-dielectric FSS: (a) top view of the unit particle and array structure, (b) side view of the unit particle, (c) perspective view indicating the direction of incident electromagnetic wave

2. Cylindrical Cavity Mode Analysis

Under the condition of the dielectric resonator to function as a cylindrical resonant cavity, which has radius r and height h, the dielectric-air interface can be approximated by a hypothetical perfect magnetic conductor (PMC). Using the PMC boundary conditions of vanishing tangential components of the magnetic field, the resonant frequencies for the TM and TE modes become

$$(f_r)_{npq}^{TM} = \frac{1}{2\pi r\sqrt{\varepsilon_0 \varepsilon_r \mu_0 \mu_r}} \sqrt{(x'_{np})^2 + \left(\frac{q\pi r}{h}\right)^2} \quad (1)$$

$$(f_r)_{npq}^{TE} = \frac{1}{2\pi r\sqrt{\varepsilon_0 \varepsilon_r \mu_0 \mu_r}} \sqrt{(x_{np})^2 + \left(\frac{q\pi r}{h}\right)^2}$$

where x'_{np} represents the zeros of the derivative of the Bessel function of order n and x_{np} is the zeros of the Bessel function of order n. When the cylindrical PMC cavity model has radius r = 6 mm, height h = 10.5 mm, and $\varepsilon_r = 10$ ($\mu_r = 1$), the calculated resonant frequencies for various modes are tabulated as shown in Table 1. In this work, neighboring resonant modes except for TE_{01q} and TM_{01q} modes are adopted to generate a dielectric FSS with broadband characteristic when TEM wave is excited.

TABLE I

Calculated Resonant Frequencies for the Cylindrical PMC Cavity with Radius of 6 mm and Height of 10.5 mm

	TM_{110}	TM_{111}	TE_{110} TM_{010}	TE_{111} TM_{011}	TE_{112}	TE_{211}
$(f_r)_{npq}$ [GHz]	4.63	6.47	9.64	10.64	13.2	13.68

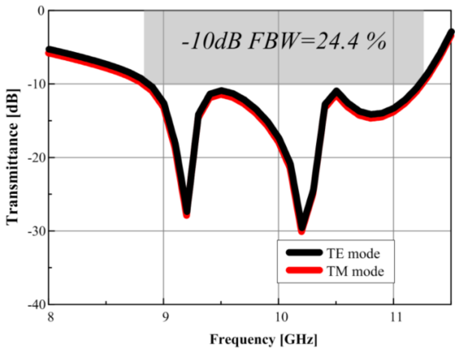

Fig. 2. Simulated transmittance characteristics for the band-stop FSS at different incident modes (TE and TM modes)

3. All-dielectric FSS Design and Simulated Results

Fig. 1 shows the geometry of the proposed all-dielectric FSS. The unit particle of the proposed FSS is designed as a hexagonal shape instead of a cylindrical shape in order to avoid unwanted coupling at gap between unit parts and to realize an array convenient. However they have reasonably identical resonant characteristics with those of a cylindrical shape. The unit particle of the FSS consists of a thick upper hexagonal prism part with a height of 10.5 mm and a thin lower hexagonal prism part with a height of 1.5 mm for monolithic construction which provides robustness to vibration, heating, and other problems from composite materials. The relative permittivity and tangent loss of both structures are $\varepsilon_r = 10$ and $\tan\delta = 0.001$, respectively. The FSS comprises planar array of hexagonal ceramic prisms having a honey comb-shaped structure as shown in Fig. 1(a). The separation distance between array elements is 7 mm. To derive transmittance values, the incident electromagnetic wave is excited along the z-axis as shown in Fig. 1(c).

Fig. 2 shows the simulated transmittance characteristics for the band-stop FSS at two orthogonal modes of normal incident wave. The resulting transmittance characteristics are identical and it shows that the proposed FSS structure has polarization insensitivity. The proposed all-dielectric FSS provides over 10-dB of field rejection over a fractional bandwidth of 24.4 % (8.8 GHz – 11.25 GHz). Three resonant frequencies are well merged so that the broad stop-band characteristic is established.

Although the proposed FSS has a hexagonal-shaped structure, as it has already been mentioned above, the cylindrical cavity mode analysis based on the cylindrical wave functions is equivalently adopted to demonstrate the behavior of characteristic modes and to obtain optimum dielectric resonant frequencies. Fig. 3(a), (b), and (c) illustrate the electric field distributions at each resonant dip (at 9.2 GHz, 10.2 GHz, and 10.8 GHz). We can observe that the upper hexagonal prism operates as TM_{11q} resonant mode at 9.2 GHz, TM_{11q} resonant mode at 10.2 GHz, and TE_{11q} resonant mode at 10.8 GHz, respectively. However the

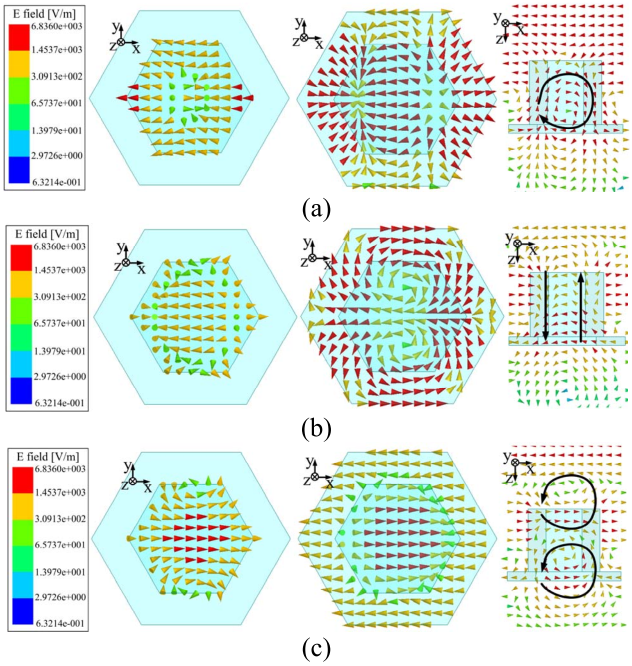

Fig. 3. The electric field distributions on the unit particle at each resonant frequency (left: upper prism, middle: lower prism): (a) at 9.2 GHz, (b) at 10.2 GHz, and (c) at 10.8 GHz

electric field is dominant at a lower hexagonal prism with TE_{11q} resonant mode at 10.2 GHz. The value q of each mode are q = 1, 0, and 2 at 9.2 GHz, 10.2 GHz, and 10.8 GHz, respectively This phenomenon is approximately the same as that of cylindrical cavity mode with the PMC boundary conditions. It proves that the analysis method used in this paper is suitable for designing hexagonal prism-shaped dielectric FSS.

4. Conclusion

In this paper, design of an all-dielectric band-stop FSS is proposed. The proposed FSS operates in X-band with a broad stop-band of 24.4 % -10-dB FBW (8.8 GHz – 11.25 GHz) by merge of three resonant frequencies. In order to demonstrate operating characteristic modes and to obtain the optimum dielectric resonant frequencies, the cylindrical cavity mode analysis is adopted. From simulated results, it verifies that the analytical approach used in this paper is appropriate for designing a honey comb-shaped all-dielectric FSS.

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