THIN FREQUENCY SELECTIVE SURFACE (FSS) SUPERSTRATE WITH DIFFERENT PERIODICITIES FOR DUAL-BAND DIRECTIVITY ENHANCEMENT

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Abstract: In this paper, we present a novel design of a high directivity resonator antenna that utilizes a two-layered Frequency Selective Surface (FSS) superstrate with different periodicities—as an alternative to a conventional FSS superstrate—for dual band directivity enhancement to reduce its height. Two strip dipole arrays with different periodicities are placed above and below a dielectric layer. The proposed thin FSS superstrate yields 13.1 and 19.54 dBi directivity enhancements at 8.75 GHz and 12.7 GHz, respectively, as compared to that of a patch antenna (6dBi), while its height is only one half of that of a conventional patch antenna.

1. Introduction

Frequency Selective Surfaces (FSSs) have been studied by many researchers for a variety of applications in microwave and optics. They are often used as dichroic surfaces of reflector antennas in frequency re-use systems, and as spatial angular filters in numerous applications [1]. However, in most of these antenna applications, the FSS is not placed close to a ground plane, as it is in the design to be considered in this paper. In recent years, metamaterials based on Electromagnetic Band Gap (EBG) structures using FSSs, with and without vias connected to a ground plane, have been widely investigated for the bandwidth enhancement of a class of antennas [2-3].

The use of dielectric type EBG structures for enhancing antenna performance on directivity has also been investigated by a number of authors [4-5]. However, the dielectric EBG antenna composites are often difficult to fabricate in practice, because an elaborate and complex low-dielectric constant fixture is required to support an EBG structure above a patch antenna, and the dielectric rods with a specified dielectric constant and dimensions for the EBG structure are not always available commercially. As a result, the FSSs are good candidates as alternatives to dielectric EBGs for directivity enhancement, because they have transmission and reflection characteristics that are similar, but are much easier to fabricate using etching techniques. In addition, the use of an FSS superstrate makes the antenna composite compact, especially, in terms of its thickness, as compared to that of its dielectric EBG counterpart. Recently, Lee *et al*. have described a technique for designing FSS superstrates for dual-band directivity enhancement that entailed the use of two FSS screens with about a half wavelength gap between them [6]. Although it has the advantages of ease fabrication and smaller thickness than that of a dielectric EBG superstrate, its height is almost one wavelength at the operating frequency, and it is desirable to reduce it.

In this paper, we propose a thin FSS superstrate consisting of two-layered FSS screens with two different periodicities for dual-band directivity enhancement. We first design a thin FSS superstrate based on the unit cell simulation, and compare the resonant frequencies of the unit cell of the FSS superstrate with those at which the FSS antenna composite achieves a high directivity.

2. Design of a thin FSS superstrate

In this work, we investigate the design of a thin FSS superstrate consisting of two-layered metallic strip dipole arrays with two different periodicities (see Fig. 2) as a replacement for a conventional two-layered FSS screens with the same periodicity, with the objective of reducing its height. Towards this end, we examine the resonator behavior of the FSS superstrate backed by the ground plane of a patch antenna, as a means for controlling the resonant frequency of the antenna.

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Figure 1 shows the proposed thin FSS resonator antenna composite and its unit cell structure. It consists of a patch antenna and a stacked superstrate with two FSS layers. The lower FSS layer is a 16×8 array of x-directed strip dipoles located at a distance of L_1 above the ground plane of the patch antenna, and is a rectangular lattice, with a = 1.2 cm, b = 0.6 cm, where ‘a’ and ‘b’ are the periodicities of the unit cell in the x- and y-directions, respectively. The strip dipoles of the lower screen have a length and width of d_{l_l} = 1.0 cm, and d_{w_l} = 0.2 cm, respectively. An 8×4 strip dipole array with twice the periodicity (2a, 2b) of the first one is located above the lower FSS layer with a gap spacing between two arrays as shown in lower part of Fig 1. The strip length and width of the upper FSS layer are d_{l_u}=2 cm and d_{w_u}=0.2 cm, respectively.

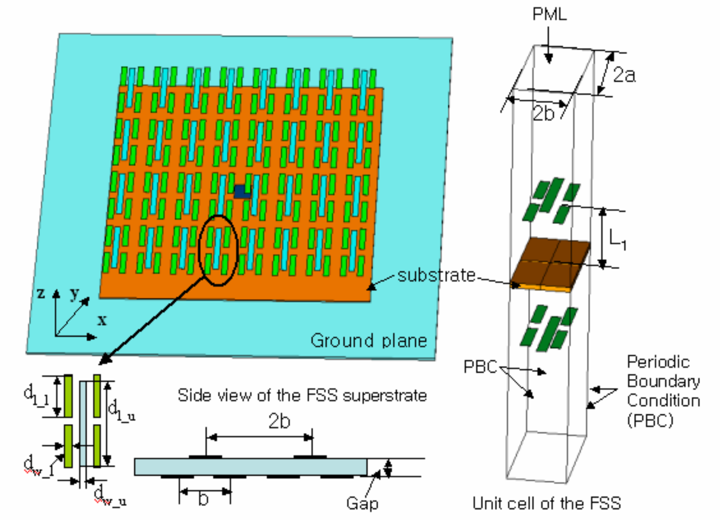
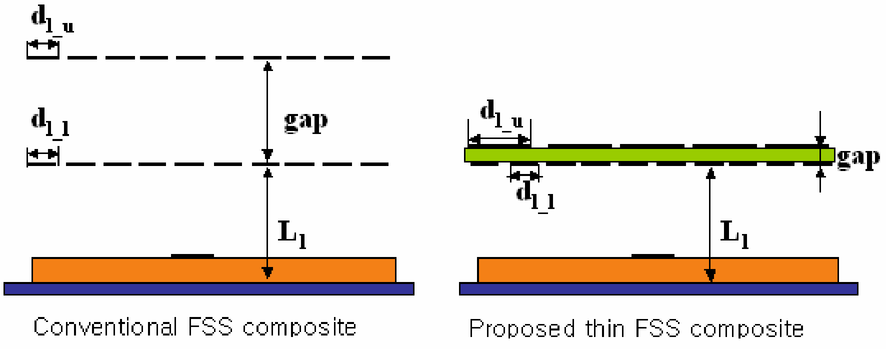


Fig. 1. Geometry of a thin FSS composite and its unit cell.

In a previous work [6], a two-layered FSS superstrate, comprising of screens with identical periodicity and different strip dipole dimensions has been designed for dual-band directivity enhancement, using a spacing (gap) between the two screens, to achieve dual-band operation, as shown in Fig. 2(a). For this configuration, the gap spacing is found to be on the order of the resonant length, L_1, the distance between the ground plane and the lower FSS layer, which is about a half wavelength of the frequency of directivity enhancement. Two resonant modes are generated corresponding to the gap length between the two screens and the resonant length L_1. As a result, the total height of the two-layered FSS composite needs to be approximately one wavelength.



(a) (b)

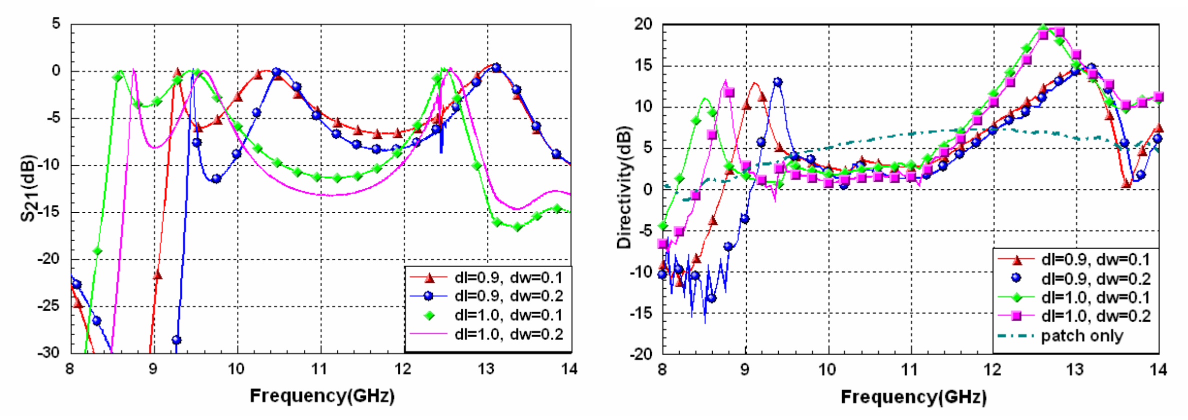
Fig. 2. Conventional vs. proposed thin FSS composites.

In a proposed design, we use a two-layered FSS superstrate with two different periodicities to reduce the gap between the two FSS layers, as shown in Fig. 2(b). For instance, we can reduce the gap dimension to less than one-tenth of the wavelength (0.1λ) by using this approach. To accomplish this we use different periodicities for the two FSS screens with a smaller gap spacing than that when screens with identical periodicities are used. In the example shown in Fig. 1, the periodicity of the upper FSS layer is twice of that of the lower layer, and the gap between them is just 1 mm.

A design scheme using the unit cell of the FSS composite has been introduced to estimate the directivity enhancement frequencies of the FSS composite efficiently, in [6]. Since it is computationally expensive to simulate a finite FSS composite, it is numerically more efficient to begin with an infinite periodic structure, so that we can work with its unit cell to characterize its resonant peaks by using the Periodic Boundary Condition (PBC), as shown in the right side of Fig. 1. One way to characterize the FSS composite is to examine its transmission characteristics as functions of the frequency. To derive these characteristics, we illuminate the unit cell of FSS with a plane wave from the bottom, and compute the transmission coefficient by using the Conformal Finite Difference Time Domain (CFDTD) code, with the PBC applied to the four sides of the FSS, and the Perfectly Matched Layer (PML) type of absorbing boundaries for the top and bottom of the unit cell. Note that we remove the ground plane and the upper part by using the image theory to simulate the unit cell.

We have also known from the previous work [6] that the resonant frequencies of the FSS composite for directivity enhancement are dominantly controlled by choosing the resonant length, L_1 and the gap between the two FSS screens, and can be tuned by the strip dipole length and width of the two layers.

For the proposed thin FSS superstrate, the resonant length L_1 and the gap size are chosen to be 1.3 cm and 1 mm, respectively. As mentioned previously, the periodicity and strip length of the upper layer of FSS superstrate are chosen to be twice those of the lower layer, though, the strip widths of the upper and lower screens are still the same.



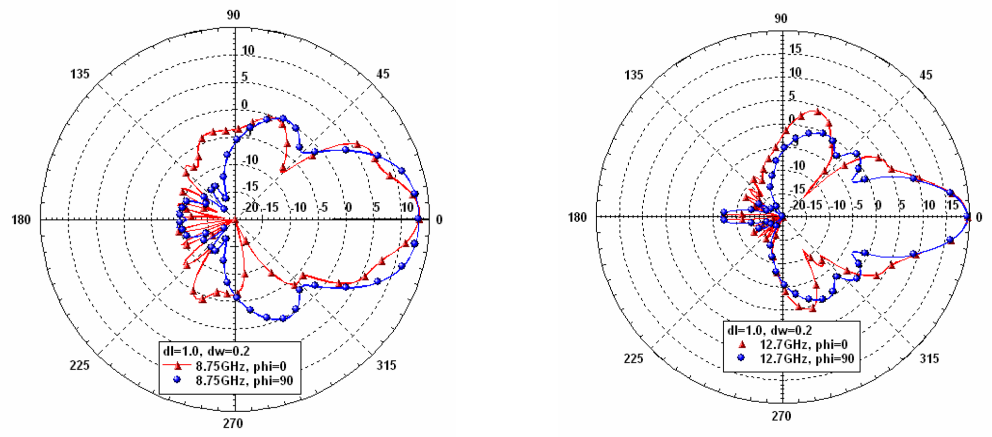
(a) (b)

Fig. 3. (a) Transmission coefficient of the unit cell of the proposed FSS composite and (b) directivity of the proposed FSS composite.

The results for the transmission coefficient of the unit cell of the proposed thin FSS composite are shown in Fig. 3(a). We note that there are three peaks in the frequency range from 8 to 14 GHz when the length and width of the strip are increased from 0.9 to 1.0 cm and from 0.1 to 0.2 cm, respectively. Only two of these peaks are available for dual-band directivity enhancement of the FSS composite, because the mode generated from the center peak cannot support the mode of the FSS composite [6]. We also observe that the two peak frequencies can be adjusted by changing the length of the strip dipole that moves the first peak toward higher frequencies with an increase in the strip width.

Next, we design a dual-band FSS composite for the specified operating bands of a patch antenna based on the knowledge of the characteristics of the unit cell, and then are use it as a superstrate for the patch antenna to assess the level of improvement on its directivity. Fig. 3(b) shows the results of the directivity of the proposed thin FSS composite as a function of the strip length, d_l, and width, d_w. For the simulation of the composite structure, we modeled a square patch antenna fed by a coaxial probe with a length of 6 mm using the CFDTD code. The patch antenna has a resonant frequency centered at 12 GHz, and the directivity of the antenna ranges between –1.5 to 7 dBi in the frequency range of 8 to 14 GHz, as shown in Fig. 3(b).

The resonant frequencies of the unit cell of the FSS composite, and those with high directivity for the FSS antenna composite, are compared to validate the proposed design scheme. It is shown that the two frequency bands with high directivities are achieved and the behavior of these bands is similar to that of the resonant peak frequencies of the unit cell, and the upper strip dipole array with double periodicity generates the first resonant band with a narrow bandwidth, while the second one, whose bandwidth is relatively wide, originates from the lower strip dipole array. We also observe that the two maximum directivities (13.1, 19.54dBi) are achieved at two frequencies for which band the length and width of the lower strip dipole are 1.0cm and 0.2cm, respectively, and that these levels are considerably higher than the 6 dBi figure of the patch-only case.



(a) (b)

Fig. 4. Directivity of the proposed thin FSS composite at (a) 8.75 GHz and (b) 12.7 GHz.

Figure 4 shows the radiation patterns of the proposed thin FSS antenna composite at dual band directivity enhancement when the length and width of the strip dipole of the lower layer are $d_l = 1.0$ and $d_w=0.2$ cm. Maximum directivity enhancement levels of 13.1 to 19.54 dB have been achieved for the case over the patch-only case (maximum 6 dBi) for the two main cuts, *viz.*, $\phi=0^\circ$ and $\phi=90^\circ$ at 8.75 and 12.7 GHz. The radiation patterns exhibit lower side lobe levels, range from -15 to -20 dB relative to the main lobe, along with an increase in the directivity relative to that of a single patch antenna, without requiring a complex feed network for dual-band operation.

3. Conclusions

We have investigated the design of a thin two-layered FSS composite with different periodicities for a patch antenna to realize dual-band directivity enhancement with reduced height. We have validated the proposed scheme by comparing the resonant frequencies of the unit cell of the FSS composite with those that yield enhanced directivities for the FSS composite antenna. We have demonstrated that the directivity of the proposed thin FSS composite antenna increases to 13.1 and 19.54 dBi, respectively, at 8.75 GHz and 12.7 GHz compared to that of the antenna only case, which has a maximum directivity of 6 dBi.

4. References

[1] R. Mittra, C. H. Chan, and T. Cwik, “Techniques for analyzing frequency selective surfaces-A review,” *Proc. of IEEE*, vol. 76, pp. 1593-1615, Dec. 1988.

[2] R. Coccioli, R. R. Yang, K. P. Ma and T. Itoh, “Aperture-coupled patch antenna on UC-PBG substrate,” *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 2123-2130, Nov. 1999.

[3] F. Yang and Y. Rahmat-Samii, “A low profile circularly polarized curl antenna over Electromagnetic Band-Gap (EBG) surface,” *MOTL.*, vol. 31, no. 4, pp. 478-481, Nov. 2001.

[4] C. Cheype, C. Serier, M. Thevenot, A. Reineix, and B. Jecko, “An Electromagnetic Bandgap Resonator Antenna,” *IEEE Trans.*, AP-50, no. 9, pp. 1285-1290, Sep. 2002.

[5] Y. J. Lee, J. Yeo, R. Mittra and W. S. Park, “Application of Electromagnetic Bandgap (EBG) Superstrates with Controllable Defects for a Class of Patch Antennas as Spatial Angular Filters,” *IEEE Trans.* AP-53, no. 1, pp. 224-235, Jan. 2005

[6] Y. J. Lee, J. Yeo, R. Mittra and W. S. Park, “ A Novel Design Technique for Control of the Resonant Frequency and Quality Factor of a Frequency Selective Surface (FSS) screen for Directivity Enhancement of Microstrip Antenna,” *MOTL.*, vol. 43, no. 6, pp. 462-467, Dec. 2004