A Compact Frequency Selective Surface (FSS) Type Superstrate for Wideband Directivity Enhancement of Microstrip Patch Antennas

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Abstract: In this paper, a novel design of a compact Frequency Selective Surface (FSS) superstrate for wideband directivity enhancement of a microstrip patch antenna is presented. A compact FSS superstrate whose size is almost the same as that of a typical single patch antenna including the ground plane is designed and a 16 dB maximum directivity, along with greater than 16.7% bandwidth is achieved.

1. Introduction

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 [1]. The use of dielectric type EBG superstrate for enhancing antenna performance on directivity has also been investigated by a number of authors [2-3]. However, the dielectric EBG antenna composites are often difficult to fabricate in practice, because the dielectric rods with a specified dielectric constant and dimensions for the EBG structure are not always available commercially.

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 via the use of etching processes. 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.

In this paper, we propose an FSS superstrate consisting of single-layered strip dipole arrays for wideband directivity enhancement. A design scheme using the unit cell of the FSS composite is introduced to estimate the directivity enhancement frequencies of the FSS composite efficiently. 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) [4]. We first design an 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 compact FSS Type Superstrate

Directivity enhancement using FSS composites often require that their sizes be large. For instance, a typical FSS superstrate comprising of 11×11 dipole strip is about 22 to 30 times larger in size than the patch antenna it covers. Furthermore, the 3 dB directivity bandwidth of the above superstrate is only 2.5~3.3% when the quality factor of FSS composite is about 30~40, which is relatively narrow in some applications.

In this work, we present a compact design of the FSS composite, comprising of only 3×12 dipole strip array that achieves a 20% wide directivity-bandwidth together with a 16 dB of maximum

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directivity. Of course, as we well know, the size of the FSS superstrate determines the effective aperture of the antenna and, hence, its directivity.

The structure of the 3×12 strip dipole FSS superstrate, with 3 strip dipoles along the x-axis and 12 strip dipoles along y, is shown in Fig. 1. The size of the FSS superstrate including the ground plane is 5.94 cm × 5.94 cm, while it is 3.96 cm×3.96 cm for the FSS superstrate alone. This size is almost the same as that of the single patch antenna itself including the substrate and the ground plane because a 3~4λ length of the substrate and ground plane is usually needed in order to support the fringing field of patch antenna and avoid the back lobes in the radiation patterns. This means that its performance is comparable with that of a single patch or a 2×2 array antenna.

An important design parameter for the compact FSS superstrate is the quality factor of the unit cell, which should be relatively low to achieve a wideband directivity bandwidth. For example, the quality factor of the unit cell needs to be 5 in order to obtain 20% directivity bandwidth. In this case, the strip dipole length d_l and the ratio *b/a*, which control the value of the quality factor, are chosen to be 0.7 cm and 0.25, respectively, when L_1 is 1.3 cm. From the study of the trade-off between the size of the FSS array and its maximum directivity, we find that the maximum directivity is less than 16 dBi for a compact-sized FSS arrays, such as a 3×12 or a 5×20 size structure.

An alternative way to realize a compact FSS array with relatively high directivity is to just crop a large-size FSS array, which has a high directivity and a large quality factor, and retain only the center region only in order to lower the quality factor. As known in the field distributions, the center region of the FSS array traps most of the electric fields between the ground plane and the FSS superstrate. Hence, it can provide a relatively high directivity even though we may lose the weak fields at the edge of the FSS superstrate when we truncate it. However, in this approach, we cannot obtain the radiation patterns with low side lobe levels because the field distributions of the center of the compact FSS superstrate are similar to those of aperture antenna with a uniform power distribution.

Figure 2 shows the comparison results of the two methods for compact-sized FSS superstrate with wide directivity bandwidth. The designed unit cell using the first method has dimensions of d_l = 0.824 cm and L_1 = 1.53 cm, and a quality factor of 5. The corresponding dimensions for the one based on the second method are d_l = 0.99 cm and L_1 = 1.43 cm, realized by cropping the 7×28 FSS array with relatively large quality factor (about 14 for the 7×28 FSS array) with the ratio of b/a = 0.25 and d_w/b = 0.33. These parameters are scaled from the d_l = 0.7 cm and L_1 = 1.3 cm case with the resonant frequency near 14 GHz, and the d_l = 0.9 cm and L_1 = 1.3 cm case, with a 13 GHz resonant frequency, by tuning the center frequency of directivity enhancement to 12 GHz with the resonator length, L_1.

The result for the directivity for the 3×12 FSS array, with d_l = 0.824 cm and L_1 = 1.53 cm, shows a 17.6 % (2.15 GHz) wide directivity bandwidth with a maximum directivity of 13.52 dBi at 12.2 GHz, while that from the 3×12 FSS array with d_l = 0.99 cm and L_1 = 1.43 cm has a 16.3% (1.96 GHz) directivity bandwidth, with the maximum directivity of 16.08 dBi at 12 GHz. These results show that we can achieve a 6.5~9.5 dB directivity enhancement, as compared to that of the single patch (6.9 dBi max at 12GHz), as shown in Fig. 2. Figure 3 compares the E- and H-plane radiation pattern results of the two compact FSS arrays at 12 and 12.2 GHz, respectively, with those of the patch antenna alone.

3. Conclusions

In this paper, we have presented a compact FSS antenna composite with a patch antenna and a compact superstrate with single FSS layers to achieve wideband directivity enhancement. We have designed a 3×12 compact FSS superstrate and have achieved a 16dBi maximum directivity and a 16.7% directivity bandwidth,

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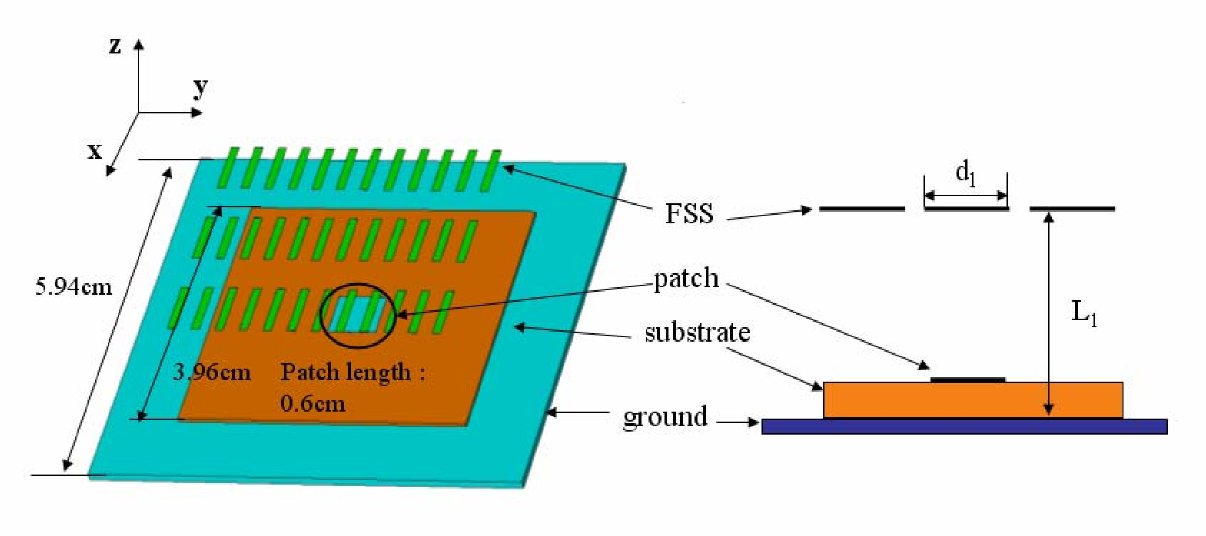


Fig. 1. Geometry of a patch antenna with a compact 3×12 strip dipole FSS superstrate.

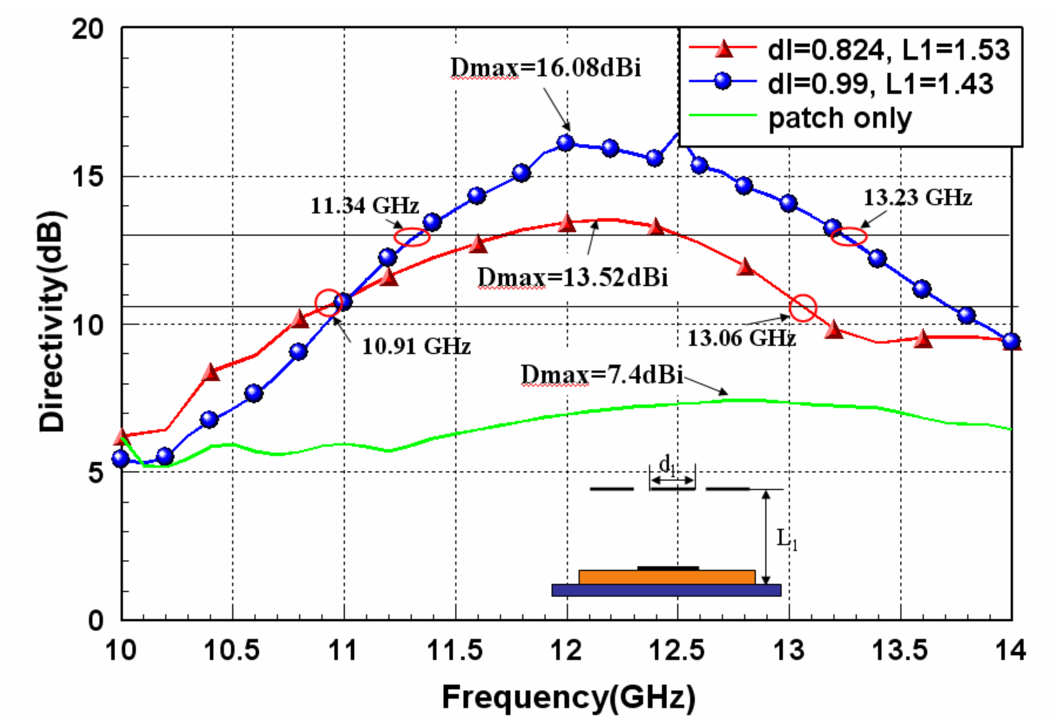
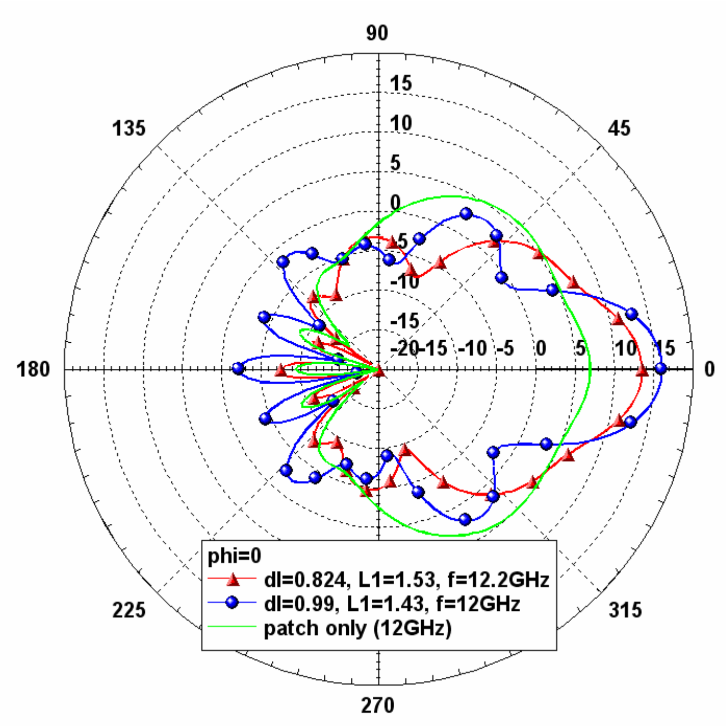
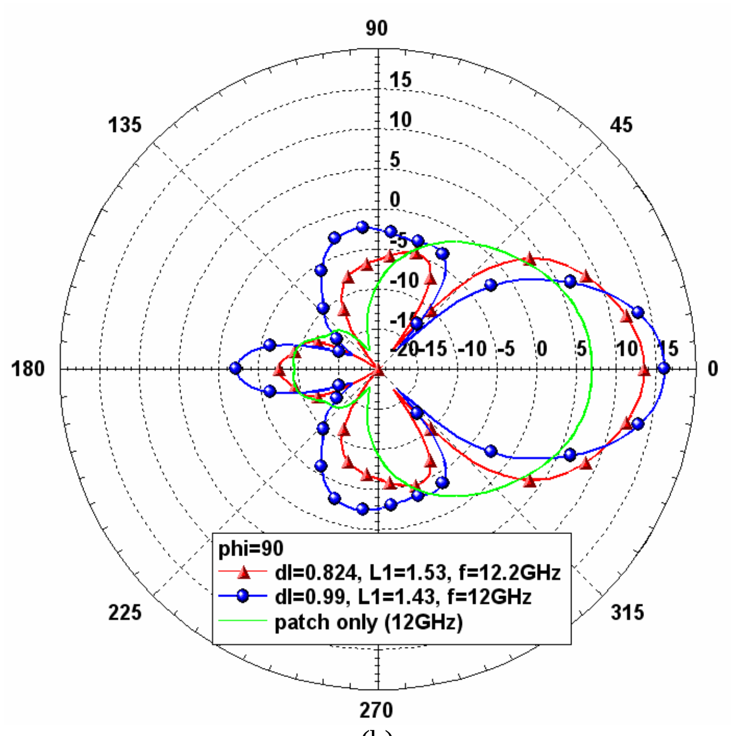


Fig. 2. Directivity of the patch antenna with the 3×12 FSS superstrate designed by using two different methods.



(a)



(b)

Fig. 3. Comparison of the radiation patterns of the patch antenna with and without the compact 3×12 FSS superstrate: (a) ϕ=0° cut; and (b) ϕ=90° cut.