Mutual Coupling Reduction in Patch Antenna Arrays Using a UC-EBG Superstrate

Hossein Sarbandi Farahani, Mehdi Veysi, Manouchehr Kamyab, and Alireza Tadjalli

Abstract—**Reducing mutual coupling between elements of an antenna array is one of the main topics in array designs. The use of electromagnetic band-gap (EBG) structures built by microstrip technology is an attractive way to mitigate the mutual coupling problem. This letter describes a novel configuration of uniplanar compact electromagnetic band-gap (UC-EBG) structures to reduce mutual coupling between the radiating elements. The idea is to use the UC-EBG structures placed on top of the antenna layer. The main objective is to reduce both the element separation and the mutual coupling between the patch antennas, which in turn increases antenna directivity. The proposed configuration eliminates drawbacks of similar structures presented in previous works.**

Index Terms—**Antenna miniaturization, mutual coupling reduction, patch antenna array, uniplar compact electromagnetic band-gap (UC-EBG) superstrate.**

I. INTRODUCTION

OWING to the fast development in electromagnetic band-gap (EBG) structures, various configurations of EBG structures have been successfully applied in the patch antenna arrays to improve array characteristics, such as total size and radiation efficiency. Nowadays, an important challenge in communication industry is to reduce the total size of devices. Likewise in antenna engineering, array size reduction has attracted increasing interest in recent years. Placing elements of an antenna array close to each other is obviously one way to reduce the total size of an array. However, mutual coupling, which depends on interelement separation and relative orientation, causes undesirable effects on antenna characteristics [1], [2].

To overcome the problem of mutual coupling, various types of EBG loaded patch antenna arrays have been proposed in the literature [3]–[6]. Reviewing the literature, some conventional structures have also been proposed to reduce the mutual coupling between the radiating elements of microstrip antenna arrays such as cavity backed and substrate removal microstrip antennas [5], [7], [8]. These configurations have been compared to the mushroom-like EBG loaded microstrip array in [5]. This comparison reveals that the mutual coupling can be significantly reduced, using mushroom-like EBG structure. Another approach to reduce mutual coupling in microstrip antenna arrays is to use metamaterial insulators. Such metamaterial insulators operate in a certain frequency band-gap, also referred to as insulating region [7], in which effective permittivity and permeability have opposite signs. However, it should be pointed out that the insulating region occurs in a narrow bandwidth, which is the main limitation associated with this structure. It is worth noting that the optimum element separation to avoid grating lobes in the visible region of the phase array antenna has to be $0.5\lambda_0$ (where λ_0 is the free-space wavelength) [3], [9], [10]. When the uniplanar compact EBG (UC-EBG) structures and patch antennas share the same layer, the array size is significantly increased due to the complicated interaction of antennas and EBG structures, which in turn disturb antenna return loss [3]. Consequently, the element separation should be selected larger than $0.5\lambda_0$.

The purpose of this work is to decrease both the element separation and the mutual coupling in array structures. The proposed structure is equivalent to a new patch antenna array, where the UC-EBG structures are printed on a superstrate layer. It was demonstrated in [4] that the periodic structures printed on the bottom layer of a multilayer substrate help to reduce both the element separation and the mutual coupling in patch antenna arrays. However, these periodic structures have a very narrow EBG bandwidth. As a consequence, small structural fluctuations, occurring during the fabrication process, may strongly affect the final results. One of the main topics in developing EBG structures is to reduce EBG cell size [8]. The large cell size of the EBG structures used in [4] makes it difficult for them to be used in many practical applications. Therefore, it is not convenient to use this periodic structure in large array antennas. In addition, when the periodic structure proposed in [4] is used, a separate radome is inevitably required. In contrast, the top layer of our proposed structure acts as a protective layer (radome). Furthermore, when the EBG structure proposed in [4] approaches the patch antennas, the antenna resonant frequency shifts toward the higher frequencies due to the reduction on the fringing fields [11]. Moreover, the matching in one of the patches becomes almost negligible [4].

In contrast, in our proposed configuration, since the EBG structure is placed on the upper layer, the fringing fields of the patch antennas are not reduced, and thus the resonant frequency does not change. On the other hand, since the structure proposed in [4] decreases effective dielectric constant, antenna dimensions would be increased [11]. Based on the concepts discussed, a new configuration of UC-EBG structures has been proposed for both mutual coupling reduction and miniaturization purposes. The UC-EBG superstrate is capable of re-

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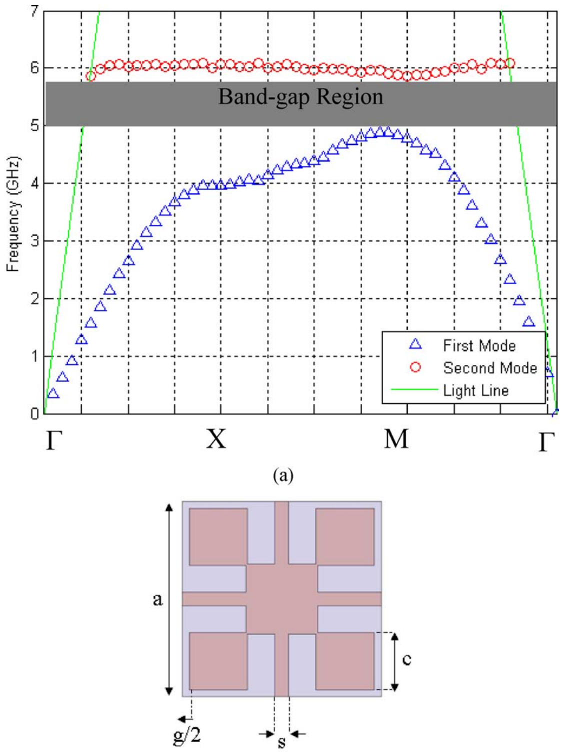


(a)

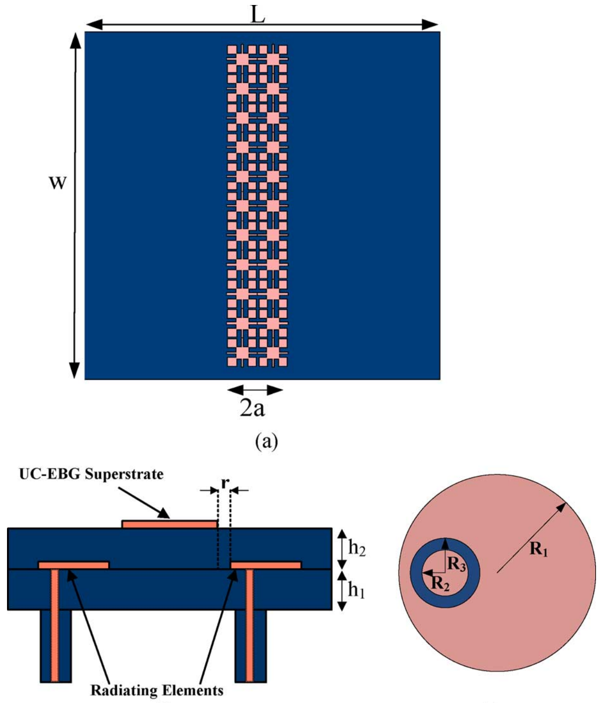
(b)

Fig. 1. (a) Dispersion diagram and (b) unit cell of UC-EBG structure: $a = 6.6$ mm, $c = 1.7$ mm, $s = g = 0.46$ mm.

ducing the surface waves within a certain frequency band. Consequently, when the UC-EBG superstrate is used, the mutual coupling becomes almost negligible and the radiation pattern improves. In other words, as compared to the array without EBG, our proposed array has a relatively larger directivity. The high-frequency structure simulator (Ansoft HFSS 11) has been adopted to validate the primary claims. This package is a full-wave simulator based on finite element method (FEM).

II. DESIGN PROCESS

One of the main characteristics of the EBG structures is the capability to suppress surface waves at frequencies located in the band-gap region. Fig. 1 shows a unit cell of the UC-EBG structure used in the proposed configuration. This structure exhibits interesting behaviors in the microwave frequencies [12]–[14]. Compared to the mushroom-like EBG structure, the UC-EBG structure is easy to fabricate. The frequency band-gap of the UC-EBG structure can be tuned by changing the geometrical dimensions of each unit cell. In the case at hand, the antenna resonant frequency is selected at 5.75 GHz. The parameters of the UC-EBG structure are designed in a way that the desired frequency band-gap can accommodate the resonant frequency of the antenna. To observe the desired band-gap, the dispersion diagram was used since it is an effective tool for studying band-gap properties of the EBG structures. The design parameters of the UC-EBG structure are labeled in Fig. 1. The dielectric constant was set to 10.2 (Roger RT/ Duroid 6010), which could provide an equivalently miniaturized design. To make a fair comparison, the substrate and the UC-EBG dimensions were kept similar to those in [3]. The radiating element of the antenna array is a circular metallic patch that is fed by the top loaded pin, as shown in Fig. 2(c). The top loaded pin is used to compensate for the inductive effect of the pin. The design parameters of the patch antenna array are also labeled in Fig. 2.



(a)

(b)

(c)

Fig. 2. Schematic view of proposed array. (a) Top view: $a = 6.6$ mm, $W = L = 78.26$ mm. (b) Side view: $h1 = h2 = 1.27$ mm, $\varepsilon_r = 10.2, r = 6.7$ mm. (c) Radiating element: $R1 = 3.7$ mm, $R2 = 1.016$ mm, $R3 = 1.26$ mm.

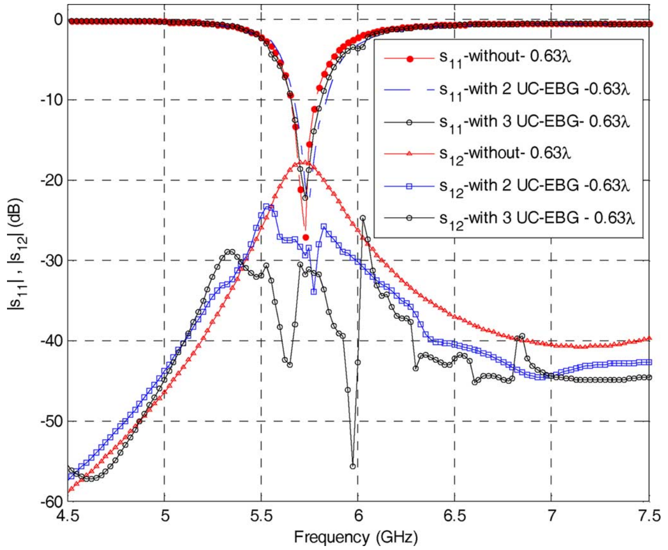


Fig. 3. Simulated mutual coupling without and with two or three rows of UC-EBG superstrate together with antenna return loss in each case (element separation is assumed to be $0.63\lambda_0$).

At first, the separation between the patches is selected to be $0.63\lambda_0$. The simulated mutual coupling (S_{12}) and return loss in both cases (i.e., with and without UC-EBG superstrate) are compared in Fig. 3. As revealed in the figure, the proposed configuration improves the mutual coupling between the patch elements. As a consequence, for the case of two rows of the

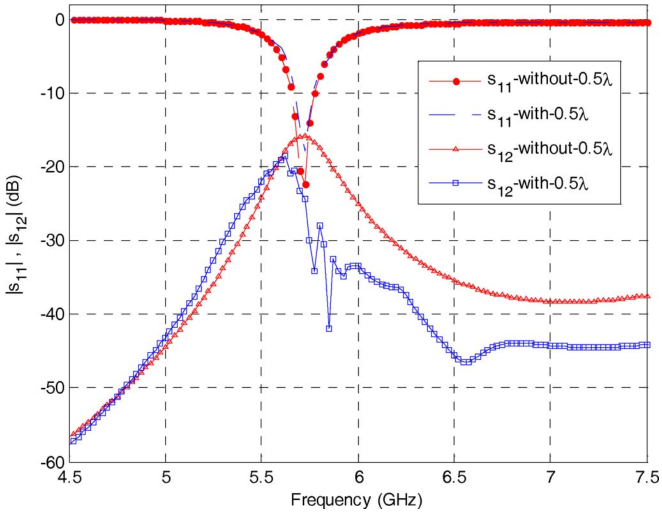


Fig. 4. Simulated mutual coupling without and with two rows of the UC-EBG superstrate together with antenna return loss in each case (element separation is assumed to be $0.5\lambda_0$).

UC-EBG superstrate, an 11-dB reduction in mutual coupling and a 1.3-dB increase in directivity are achieved as compared to the array without EBG. The effect of the three rows of the UC-EBG superstrate on the mutual coupling has also been investigated. In this case, the mutual coupling is reduced about 14 dB compared to the array without EBG, as shown in Fig. 3. Second, the separation distance between the patch antennas is decreased and approached $0.5\lambda_0$. Fig. 4 presents the simulation results of the patch antenna array with $0.5\lambda_0$ element spacing. As revealed in the figure, about 10 dB reduction in mutual coupling is achieved by using just two rows of the UC-EBG superstrate.

III. CONCLUSION

In this letter, a novel configuration of the UC-EBG structures for array miniaturization with reduced mutual coupling has been introduced. An array of two patch antennas including a superstrate layer of the designed UC-EBG structures has been simulated to validate the primary claims. A careful comparison between the proposed configuration and previous ones demonstrates the unique capability of the proposed structure to reduce both the mutual coupling and the array size. The final results show a 10-dB reduction in mutual coupling and a $0.13\lambda_0$ reduction in size compared to the initial array structure.

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