Review of Radiation Pattern Control Characteristics for The Microstrip Antenna Based On Electromagnetic Band Gap (EBG)

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***Abstract*—Radiation Pattern of the antennas is necessary for many applications in the telecommunication field, such as wireless communications and radar. They lessen the interference by channelling the radiation of antenna to the interested direction to achieve the enhancement of spectrum efficiency and multipath propagation reduction that results in the saving of radiation power and the increase in gain. Various techniques have been used to implement beam steering for several years. Electromagnetic band gap (EBG) with unique features helps to prevent/assist the electromagnetic waves propagates in a specific band of frequency for all polarisation states and all incident angles. In this paper, the advantages of the EBG surface wave band gap feature were identified, if it is inserted with microstrip antennas design, which helps to rise the gain of antenna, reduce the back lobe and lessen the mutual coupling in array components. Additionally, more advantages due to the surface waves suppression and the stopping band and passing band of the EBG have been achieved in the beam steering by integrating the single patch microstrip antenna with EBG. Additionally, the new antenna structure based on the combination of the concept of a reconfigurable planar array antenna with the EBG elements requires further research to produce a new radiation pattern control technique.**

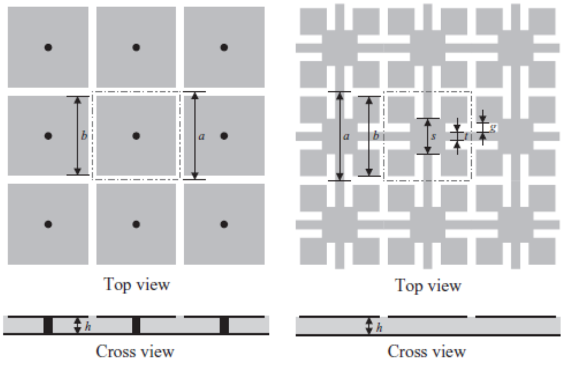
***Index Terms*—EBG; Radiation Pattern Control; Microstrip Antenna; Mushroom-like EBG.**

I. INTRODUCTION

Antennas play an essentially significant part in wireless communications; hence, it is nearly impossible to get wireless communication system without antennas. Accordingly, there has been a wide range of researched effectual approaches for designing antennas to achieve these requirements. Antennas with important features, such as a good directivity with suitable radiation pattern steering at real time are identified to be qualified for getting these requirements as they raise the gain and spectral efficiency. The antennas for Beam steerable have been in practice since the 1930's [1]. Radiation pattern control is a method that used to change the direction of the main lobe radiation pattern of antenna, with the purpose of accomplishing spectrum efficiency improvement and reduction of multipath propagation [2]. Wireless communication networks, compact sized low profiled antennas with planar structure, are easily integrated and low fabrication cost antennas have become highly essential. The rapidly increasing applications for high-data-rate in wireless communication transmitter and receiver, such as smartphone handsets, internet modem, and computer devices need high signal-to-noise ratio (S/N). Therefore, antennas for such services are required to possess enhanced gain and steerable radiation patterns. In this context, the beam-steerable antennas have become much popular in the modern orientation of antenna propagation. Reconfigurable (beam steerable) antennas allow stronger signals for the transmission and reception for both the desired directions. The technique of beam steering reduces interference, saves power, enhances directivity and increases gain of the antenna. There are four reconfiguration properties that can be achieved by a reconfigurable antenna. An antenna can exhibit a reconfigurable frequency of operation, a reconfigurable radiation pattern, a reconfigurable polarization behavior, or a combination of any of these properties [3]. Reconfigurable Antenna can offer more additional tasks than the usual antenna. When altering their radiation behavior, for example, their operational frequencies can be altered by using the EBG structure in [4], where the antenna with frequency re-configurability has been designed by using EBG unit cells. The combinations of EBG to the antenna successfully realize an antenna that is capable to be reconfigured to various multiple frequencies with different EBG configuration. The multiband reconfigurable frequencies are 1.8 GHz, 2.3 GHz, 2.67 GHz, 3.78 GHz, and 5.25 GHz. Additionally, we can use the EBG for radiation pattern control: When connecting the vias between the patch and ground plane, it works as reflection to radiation (stop band); when disconnecting the vias, the EBG works as directed to the radiation (pass band); and finally, a reconfigurable radiation pattern is achieved [5]. Radiation patterns controllable by antennas are necessary for numerous applications in telecommunication field. They reduce interference that result from channeling the antenna's radiation to the desired direction. To realize the directivity aim, the main notion of taking together two or more of the element antennas to arrangement, an array is engaged. The arrangement of these elements gets other parameters that can be optimized to realize a wanted directivity. This is accomplished by either the optimization of numerous parameters limited by the array antenna or the nature and schedule of the excitation of each member of the array. The procedure of radiation pattern control is responsible for focusing in the main lobe of the radiation pattern of an array to a specific direction. The rearrangement of its beam pattern to the new direction of interest helps to decrease the dissipation power in other directions while maintaining high gain. Also, there will be a need to form multiple beams for point with multipoint applications. A lot of techniques have been used to the appliance of beam steering over the years, most of which attain steering at the expenditure of the performance of antenna. Most researchers only study the beam steering of the EBG properties on a single microstrip patch antenna, and to the best of our knowledge there are no comprehensive results stated or reported for array antenna with EBG.

II. ELECTROMAGNETIC BAND GAP (EBG)

Antenna designs have encountered colossal advances in the previous few years and they are still experiencing great improvements. Numerous new advancements have risen in the current modern antenna-designing field and an energizing leap forward is the discovery/improvement of electromagnetic band gap structures. The utilizations of the structures of EBG in antenna designs have turned into an exciting theme for researchers and specialists in the field of antennas. The structures of electromagnetic band gap are characterized as the “artificial periodic (or sometimes non-periodic) objects that prevent/assist the propagation of electromagnetic waves in a specified band of frequency for all incident angles and all polarization states”. In the meantime, "metamaterials," with interesting features not promptly accessible in nature likewise showed up and have turned out to be famous in the electromagnetics group. The idea of EBG structures begins from the solid state of physics and optic space, where photonic crystals with taboo band gap for light outflows were suggested in 1987 [6][7], and subsequently examined in the 1990s [8]. Accordingly, the terms, photonic band gap (PBG) structures were prominently utilized as an important part of the early days. From that point onwards, an abundance of logical imagination has been seen as new types of electromagnetic structures created for microwaves and radio frequency [9]. The band gap was first acknowledged and tentatively showed by periodic dielectric structures in the beginning of 1990s[10]. In the electromagnetic and antenna group, two research headings have been autonomously created, which are firmly identified with the exploration of EBG. The first is frequency selective surfaces [11], and the other one is the soft/hard surfaces [12]. Utilizing the periodic designs, these structures can stop the wave propagation or enhance the propagation of wave at certain frequency limits. In the late 1990s, two vital planar EBG structures were created, where metallic sections were adequately consolidated into the unit cells. One is the mushroom-like EBG surface, as described in [13] and the other description is in [14], the uni-planar EBG surface. Figure 1 relates to the geometries of the uni-planar EBG and the mushroom-like EBG. A significant characteristic in the design of the uni-planar EBG is the vertical vias that has been removed. Thus, the fabrication process became easier. The main benefits of the mushroom-like EBG surface are the achievement of a wide-ranging bandwidth and a lower frequency. At a certain frequency, the size of the mushroom-like EBG is lesser than the uni-planar EBG. Whereas the uni-planar EBG surface is less sensitive for the polarization and incident angle.



(a) (b)

Figure 1: Geometries of (a) mushroom like EBG and (b) uni-planar EBG. Dashed line indicates the periodic boundary condition[15].

From that point onwards, numerous EBG structures have been suggested [16][17][18]. The applications of Electromagnetic band gap (EBG) in antenna designs have become a new way of research in the antenna communal. It was first suggested to answer for some challenges in antenna with wireless communication fields, for instance the ways for suppressing and eliminating the bad effect of the surface waves in ground plane of antenna. However, several questions need to be addressed: How to propose effective low-profile wire antennas that close a ground plane? What are the methods that can increase an antenna gain? In what way can we realize a uniform field distribution for rectangular waveguide?

A. *EBG Structure With Characterization Of The Band Gap*

The structure of the mushroom-like EBG was primary suggested in [13]. It comprises of four main sections: ground plane, substrate, patches, and linking vias. The structure of EBG shows an unmistakable stop band for surface wave spread. As shown in Figure 2, the operation component of the EBG construction can be clarified by a LC filter model. The estimations of the inductance L and capacitance C are controlled by the EBG geometry and the resonance conduct is utilized to clarify the highlight of band gap. The parameters of the EBG structure are named in Fig. 3 as patch width (W), gap width (g), substrate thickness (h), dielectric constant (ϵ_r), and the radius of vias (r). As shown in Fig. 3, the (2r) represents the diameter of each vias in the EBG structure, where the (r) is the radius of vias (half of diameter).

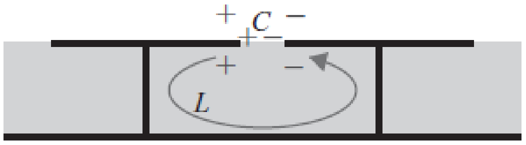


Figure 2: Lumped LC typical for EBG analysis [13].

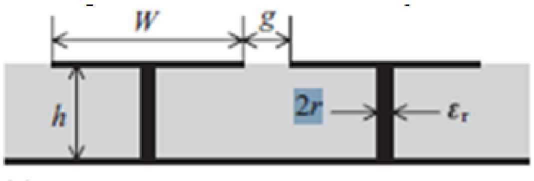


Figure 3: Parameters for the structure of mushroom-like EBG [13]

The inductor *L* comes from the flow of current via the vias and the capacitor *C*, which is the result of the gap impact between the neighbor patches. For an EBG structure with the width of patch and gap and substrate thickness (*h*) and dielectric constant (ϵ_r), the values estimation of the inductor *L* and the capacitor *C* are dictated by the accompanying formula [19]:

$$L = \mu_o h \tag{1}$$

$$c = \frac{W\varepsilon_o(1+\varepsilon_r)}{\pi}\cosh^{-1}\left(\frac{2W+g}{g}\right) \tag{2}$$

where μ_o is the free space permeability and ϵ_o is the free space permittivity. Likewise, we can calculate the frequency band gap using the following formula,

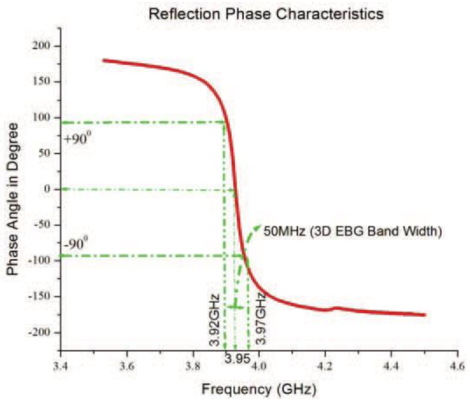
$$W = \frac{1}{\sqrt{LC}} \tag{3}$$

$$BW = \frac{\Delta W}{W} = \frac{1}{\eta}\sqrt{\frac{L}{C}}$$

(4)

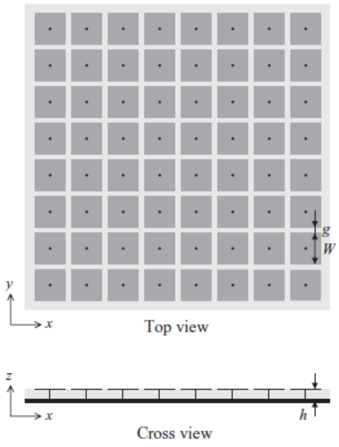
where η is the impedance of the free space, which is 120л. These details are extremely straightforward; be that as it may, their outcomes are not exceptionally exact. For instance, this model does not consider the specific range of the radius for vias. We can find in [20] a precise yet complicated sample type utilizing the hypothesis of transmission lines and periodic circuits. Some different techniques, for example reflection phase description, have additionally been used to distinguish the band gap properties [21]. The reflection phase characteristics vary from +180° to -180° as the frequency progresses. At lower and higher frequency regions, this structure exhibits similar reflection phase characteristics as the PEC surface. At the frequency of resonance, multi-layer EBG has zero degree of reflection phase (connecting vertical piv vias) and exhibits the property of artificial magnetic conductor (AMC) between +90° to -90° region (when disconnected pin vias). For example, A 3D EBG (3Delectromagnetic band gap structure) exhibits the property of AMC over a band of 50MHz (from 3.92GHz to 3.97GHz) with a center frequency of 3.95GHz, as shown in Figure 4(a) [22].

To comprehend the operation system of EBG structures, several models of circuit were offered. Let us begin with a basic two-dimensional planar for the structure of the electromagnetic band gap, as shown in Figure 4(b). This construction was initially offered in [13]. The EBG structure comprises of four sections: a metal ground plane, dielectric substrate, periodic metal patches above the substrate, and vertical vias interfacing between the ground plane and patches. This is alike to the form of a mushroom.



(a)

Figure 4(a): Reflection phase characteristics of EBG[22]



(b)

Figure 4(b): A mushroom like EBG structure [13].

B. *Characteristics of main parameters of a mushroom like EBG structure*

Electromagnetic characteristics of an EBG structures are dictated by its physical measurements. For the same shape of a mushroom like EBG structure shown in Figure 4, there are four primary parameters influencing its execution, specifically, patch width W= 0.12 $\lambda_{12\mathrm{GHz}}$, width of gap g= 0.02 $\lambda_{12\mathrm{GHz}}$, thickness of substrate h= 0.04 $\lambda_{12\mathrm{GHz}}$, and substrate permittivity ϵ_r=2.20. Note that the radius of vias r = 0.005 $\lambda_{12\mathrm{GHz}}$ has an insignificant impact since it is thinly contrasted with the working wavelength [23].

1. *Effect of Patch Width*

The width of patch assumes an imperative part in deciding the resonant frequency. When examining the impact of the patch width of EBG, the other different parameters, for example the width of gap, substrate permittivity, and thickness of substrate, are reserved as the similar value as above. The width of patch is altered from 0.04 $\lambda_{12\mathrm{GHz}}$ to 0.20 $\lambda_{12\mathrm{GHz}}$, a wider patch width prompts a bigger capacitance C. In this manner, the frequency diminishes, and the bandwidth gets narrower according to equations 2, 3and 4 for the *LC* filter model.

2. *Effect of Gap Width*

The gap width panels the coupling between EBG patch components. Henceforth, a variety of the gap width likewise influences of the EBG surface frequency band. Through this analysis, the width of patch, permittivity of substrate, and thickness of substrate are reserved with the same original value. The width of gap is expanded from 0.01 λ_{12GHz} to 0.12 λ_{12GHz}. At the point when the width of gap is changed to greater than 0.12 λ_{12GHz}, the gap width turns into the same value as the patch width. At the point when the gap width is expanded, the value of resonant frequency will increase. As indicated by the lumped *LC* model, expanding the gap width will cause a reduction in the capacitance *C* value. Therefore, both the bandwidth and the resonant frequency show increments according to equations 2, 3 and 4 for the *LC* filter model.

3. *Effect of Substrate Thickness*

In the preceding studies, we saw that the bandwidth alters similarly as the resonant frequency. At the point when the frequency diminishes, the bandwidth will become narrower. From a designer perspective, would we be able to diminish the resonant frequency while expanding the bandwidth? This can be realized by altering the thickness *h* of the substrate. The widths of patch and gap, and substrate permittivity are reserved with similar original value and the thickness of substrate is altered from 0.01 λ_{12GHz} to 0.09 λ_{12GHz}. Note that the substrate thickness is constantly kept small and parallel to the wavelength for the reason that a thin EBG surface is favored in the functional requests, on the off chance that the substrate thickness is expanded, the frequency diminishes. This can be likewise clarified according to equations 1, 3 and 4 from the model of *LC*. At the point when the substrate thickness is expanded, the proportional inductance L will also increase. Hence, the frequency decreases, but there will be an increment in the bandwidth.

4. *Effect of Substrate Permittivity*

Relative permittivity of a substrate, likewise known as the dielectric constant, is a new active parameter used to regulate the frequency conduct. The EBG structure examined here, has similar parameters esteems aside from that the permittivity is altered. At the point when air is utilized as the substrate, the EBG surface has the biggest bandwidth and most elevated resonant frequency. At the point when the permittivity is expanded, the resonant frequency reduces, resulting in the bandwidth to be in accordance to equations 2, 3 and 4 for the *LC* filter model. Hence, we can simply utilize a high dielectric consistent substrate to decrease the size of the EBG cell. For example, several antennas with and without the EBG structure are fabricated on Rogers RT/Duroid 6010 with high substrates Permittivity (10.2). The measured results demonstrate the utility of the EBG structure, and this approach is potentially useful for a variety of array applications [24]. The expense we pay is the narrow bandwidth. This influence is alike to design of a microstrip patch antenna.

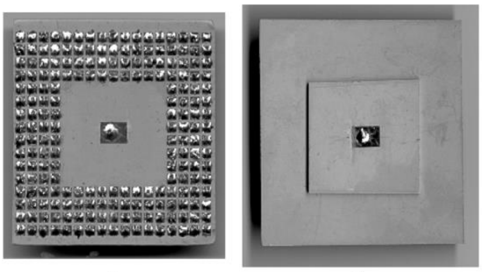
5. *Effect of radius of vias*

The authors in [23] did not mention any changes in the radius of vias, but the another article [25] has considered different vias radius. Overall, when increasing the radius of vias in EBG structure, the band gap will change to the greater range of frequencies. That means, the outcomes of the band gap shifting in the direction of the greater band of frequency.

III. EBG APPLICATIONS IN ANTENNA DESIGNING

A. *Improved the Performance of Microstrip Antennas*

Usually the microstrip antennas are utilized in the field of wireless communication because of their benefits, such as counting a low-profile conformation, little cost of production; confirming the ability with radio frequency (RF) integrated circuit and light weight. In optimal design ways for microstrip antenna, undesirable surface waves are energized in the substrate. The bad effects of surface waves thus corrupt the execution of antenna by reducing the gain of antenna, expanding the mutual coupling and back lobe. The exceptional electromagnetic characteristics of EBG structures have prompted an extensive variety of utilization in antenna designing. Surface waves are the results of numerous designs of antenna. When the electromagnetic wave spread was directed at the ground plane rather than radiation into free space, the surface waves decrease the gain and the effectiveness of antenna. The radiations of back lobe rise due to the diffraction of surface waves, which may break down the signal to noise ratio proportion in the systems of wireless communication, for example, GPS receivers. Moreover, surface waves increase mutual coupling ranges in the design of array antenna, bringing about the blind scanning angles in the systems of phased array. The band gap that highlights the EBG structures has discovered helpful requests for stifling the surface waves in different designs of antennas. So, we can design the EBG for any band of frequency according to our requirements and applications. In this article, we explain different bands of frequency, for example in [23] 6 GHz for satellite application, 5.8 GHz in [26], which are potentially useful for various array applications. [27] mentioned a useful operational frequency band for low-profile wire antenna design and 2.4 GHz in [28] for the industrial, scientific and medical (ISM) radio bands and so on. The EBG structure is utilized for surrounding a microstrip patch antenna to decrease the surface wave impact and increment in the gain of antenna and lessen the back lobe [29] [30] [31]. The characteristics of EBG band gap are exposed at two main behaviors: the surface wave spread suppression and the other is in phase reflection coefficient. An important property of surface wave suppression supports to develop the performance of antenna, like the growing gain of antenna [32], decreasing back radiation [33] and reduction in antenna size [34]. The main idea in [26] is to design the suitable patch size. Thus, the antenna resonant frequency drops inside the band gap of EBG and then the surface waves will be prohibited. The ranging of the patch sizes was started from 2 mm (0.025 $\lambda_{5.8GHz}$) to 4 mm (0.0125 $\lambda_{5.8GHz}$). The band gaps of 4 mm and 2 mm patches have either low or high antenna frequency. That means, the antenna frequency drops outside that range area, and there is no improvement in the mutual couplings, while the band gaps of 3 mm (0.016 $\lambda_{5.8GHz}$) and 2.5 mm (0.02 $\lambda_{5.8GHz}$) patches are suitable for the mutual couplings reductions, where there is a significant decrease by using the electromagnetic band gap with suitable patch size and also the position. At the same time, the in-phase reflection merit helps to provide the design of low profile antenna [35]. The use of the mushroom like EBG structure was investigated in a single microstrip antenna component [36], as shown in Figure 5(a). It demonstrates a patch antenna that has been bounded by an EBG structure. An essential thought is to legitimately design the EBG structure with the goal that the band gap of the EBG structure should cover the resonant frequency of the patch antenna; henceforth, the surface waves instead of propagating along the substrate will be prevented. It ought to be underscored that the compact EBG structure has been established due to a thick and a high dielectric constant of the substrate. A microstrip patch antenna has been designed and tested for comparison determinations, as schemed in Figure 5(b). The impression is to utilize a thick substrate directly underneath patch that will assist to keep its wide bandwidth and compacted size. On the other hand, a thin substrate will be used around the patch for decreasing the surface waves generation. The substrate, therefore has a stepped shape.



(a) (b)

Figure 5: Photographs for microstrip patch antenna with improved performance of radiation: (a) antenna bounded by mushroom like EBG structure: (b) antenna with step like substrate[36].

All of four types of patches in [36], such as the patch on thin sub, patch on thick sub, step like substrate and EBG organization, have been tuned to 5.8 GHz resonate frequency. To validate the above design concepts, four antennas were fabricated on a RT/Duroid 6010 (εr = 10.2) substrate with a finite ground plane that was 52 mm×52 mm (1λ×1λ at 5.8 GHz) in size. To establish references, two normal patch antennas were built on 1.27- and 2.54-mm-thick substrates, respectively. The step-like structure stacked two 1.27-mm-thick substrates under the patch and the distance from the patch edge to the step was 10 mm. The EBG structure was built on the 2.54-mm-thick substrate and its patch size was 2.5mm×2.5 mm with a 0.5-mm gap width. Four rows of EBG patches were used to suppress the surface waves. It is remarked that the narrowest impedance bandwidth appeared, when the patch was designed on the thin substrate, just 1%, whereas the other three have the same bandwidths, approximately 3% to 4% as shown in Figure 5(c). The lowermost front radiation achieved from the antenna with a thick substrate, while it has the largest back radiation. The step like structure radiation performance is the same as the antenna structure with thin substrate. The better performance of radiation was realized on the structure of EBG. It has the highest front radiation with, 3.24 dB greater than the thick situation and it has the lowermost back radiation, 15 dB lesser than the other suitcases. Figure 5(d) presents the E-plane radiation patterns of these antennas. In brief, the advantages of using the EBG structure with a microstrip antenna are to increase the gain and decrease the back lobe, whilst preserving the same impedance bandwidth.

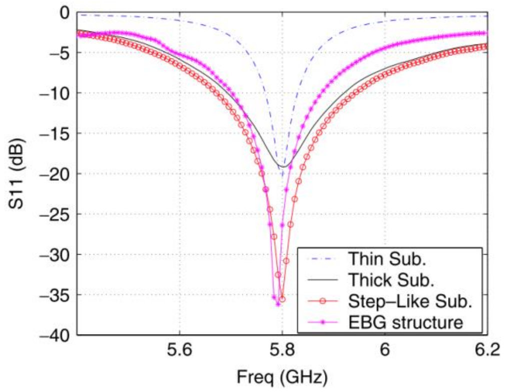


Figure 5(c): Results of four microstrip antenna designs: in return loss[27]

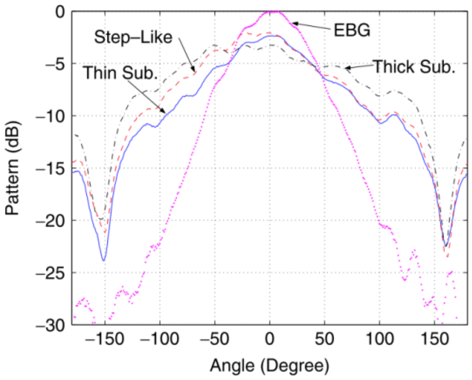


Figure 5(d): E-plane radiation patterns of four microstrip antenna designs[27]

After the positive application of a single microstrip patch antenna with the EBG, there are a lot of array antennas as well as integrated EBG structures for reducing the level of the mutual coupling [37] [38]. Figure 6(a) and 6(b) demonstration the patch antenna before and after using EBG structures and 8 dB decrease in mutual coupling was noted at the same resonant frequency after using the EBG structure between the radiator elements. In this case, the E-plane coupled with microstrip antennas on a thick and high permittivity substrate exhibits very strong mutual coupling due to the pronounced surface waves, since the EBG structure has already demonstrated its ability to suppress surface waves. Four columns of EBG patches are inserted between the antennas to reduce the mutual coupling, as shown in Figure 6(a). The resonant frequency 5.8 GHz falls inside the EBG band gap so that the surface waves are suppressed, resulting a great reduction of the mutual coupling by only 25.03dB at the resonant frequency as shown in Figure 6(b) [24].

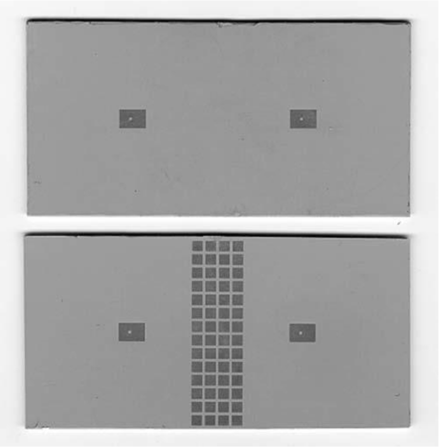


Figure 6(a): EBG with microstrip array design for reducing mutual coupling by suppressing surface wave [24]

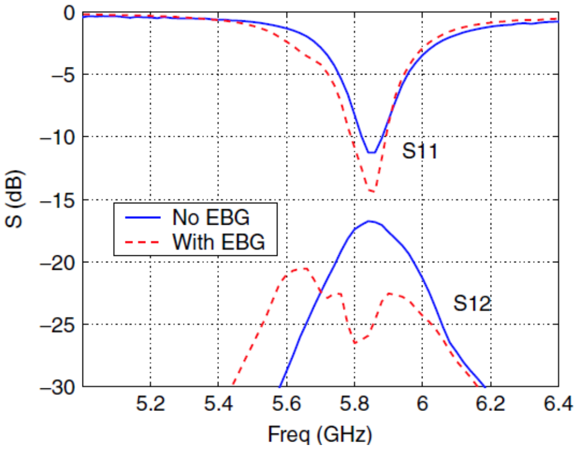


Figure 6(b): Scatterings measurement coefficients for array antenna and 8dB reduction in mutual coupling [23].

The EBG design method is one of the better candidates for decreasing the mutual coupling in definite frequencies between radiator elements. The authors in [39] designed a mushroom like EBG as shown in Figure 7. For array miniaturization with reduction in mutual coupling, the mushroom-like EBG band-gap feature was used to suppress the surface-waves. The researchers achieved the last results that demonstrates a -23dB decrease in mutual coupling with reduction in size of antenna related to the construction of antenna array offered in the preceding literature [24], at the same band of frequency (5.8GHz).

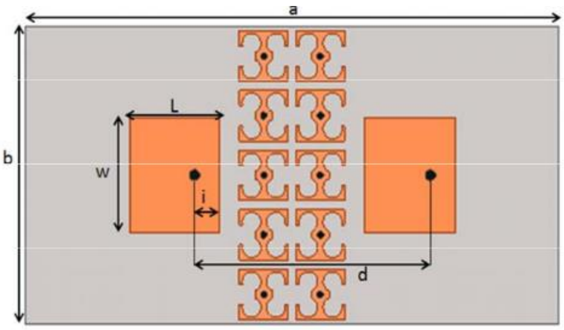


Figure 7: Patch array antenna integrated with EBG[39]

The idea for utilizing EBG structure between patch antennas has resulted in the reduction of mutual coupling in different antenna designs, In[40][41], the array patch antenna designs with a structure of dumbbell EBG have been achieved and discussed. Figure 8 demonstrates a 2 × 2 microstrip patch antenna array constructed on a 2 mm substrate thickness and a 4.6 dielectric constant [41]. A dumbbell EBG structure is intended for suppressing the surface waves at 5.6 GHz resonant frequency. The results confirm at that the mutual coupling between the radiator elements is decreased by about 4 dB, when using EBG. As a result of this, the gain improvement was a 1.5 dB and the reduction in side lobe level was 1.7 dB.

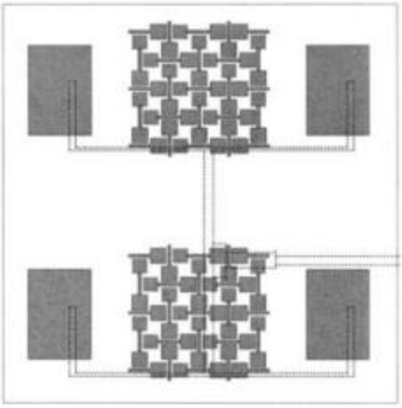


Figure 8: Photograph of a 2 × 2 rectangular patch antenna array with dumbbell EBG cells between array elements[41].

There are additional beneficial applications of EBG for designing the low profile of wire antenna to achieve suitable radiation efficiency [42]. Many wire antennas were created on the EBG ground plane [43][35][44][45]. The characteristic structures contain dipole and monopole antennas and spiral antenna. Also, the EBG structure was applied for the purpose of designing high gain antenna about or above 20 dBi. Usually, the antennas with high gain are recognized by using either large antenna arrays or parabolic antennas. On the other hand, the parabolic antennas with the curved surface make it hard to-be conformable with platforms of mobile. Further, the huge antenna array is continuously influenced by the lost at the feeding of network. So, the planar EBG offers a good solution for solving the above mention problem.

B. *Radiation Pattern Control with EBG (Electromagnetic Band Gap).*

In the latest years, there has been an increasing attention for using the structures of EBG in antennas design and electromagnetic fields. Meta-material and the electromagnetic surface design had been used to develop the surface wave antenna which had effectually decreased the antenna size with overall enhancements in an antenna performance [46]. Reconfigurable antennas had received a growing attention in the new systems for wireless communication due to their ability to provide more implementation tasks than the conventional antenna designs [47]. Different design characteristics can be satisfied in only one antenna unit by the way of reconfiguring its radiation features, for example the operational frequencies, polarizations and radiation patterns or their incorporation. The configurability can be achieved by various approaches, such as with mechanical tuning and semiconductor components, for example diodes or varactors, or (MEMS) micro-electro mechanical system actuators. Paralleled to the conventional designs, reconfigurable antennas had good advantages, like low interference and compact antenna size.

Many designs and forms of EBG structures were applied at the metal surfaces for the dielectric substrates with a view to stop and pass the propagation of surface wave. Surface wave antenna was designed to get the benefits from propagation of the surface wave. The concept of the Surface wave antenna (SWA) was coined in the 1950's [48][49][50][51] with the theory, principles and investigational results. The surface wave antennas usually have radiation Pattern and they are shaped by the surface waves diffraction effect at the ground plane boundary. SWA implementation for low profile monopole like antenna was investigated in [52]. The same authors also achieved in [53] the excitation of the low profile for surface wave antenna through a circular shape patch, which has the radiation pattern similar to the radiation of a vertical monopole antenna using the periodic square patches under the circular patch. It has successful effects to convert the electromagnetic fields to the radiation of surface waves over the plane of ground. Authors in [54] also achieved the benefit of a low profile configuration by examining the SWA application for low profile monopole-like dual-band by tunable EBG surface impedance. The authors in [55] employed the steering power pattern for the leaky wave type antennas and the antenna tuning mechanically for steering range from 5 to 50 using just 1/500 for motion wavelength. The authors in [27] designed the ground plane of EBG to achieve reconfigurable wire antenna and a feeding probe linked for two strips via two switches at the center to get a one-dimensional beam switch. Due to the ability for tilting the beam of the bent monopole, it provides a good chance to design and adjust the radiation pattern as presented in Figure 10. When the switch is ON, the electrical probe is connected at the left side of the metal strip. Thus, the monopole is directed alongside of the -x orientation, the beam of antenna indicate $\theta = 26^\circ$, the gain equals to 6.5 dB while at this time the right switch is OFF. At the point when the right switch is ON, the electrical probe is connected at the right side of strip. So, the monopole is directed alongside of the +x orientation and the antenna beam has been swapped to $\theta = -26^\circ$ with the same value of the previous gain, when the switch is at its OFF.

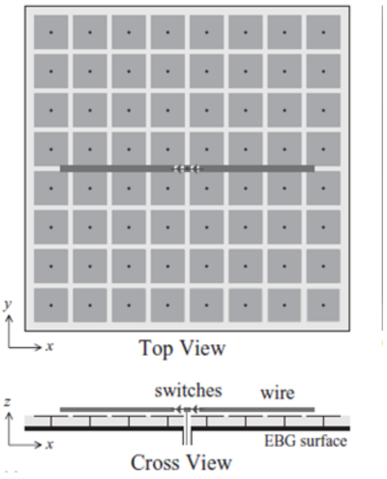


Figure 10: A monopole designing above ground plane of EBG [27]

The measured result of antenna return loss is presented in Fig.10 and it is paralleled with the simulation result of FDTD. Antenna has a better return loss of −20 dB at 4.40 GHz resonated frequency. The antenna radiation pattern has been restrained at the same band of resonant frequency of 4.40 GHz, as shown in Figure.11.

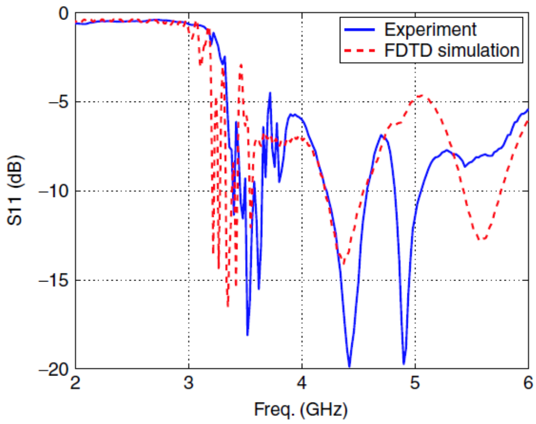


Figure 11: Restrained results of return loss[27]

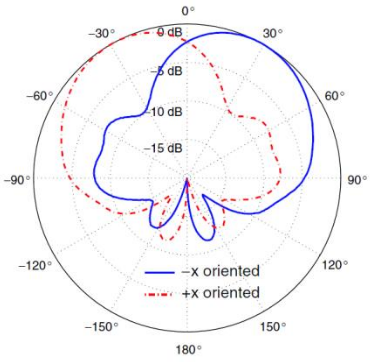


Figure 12: Measured results of E plane radiation pattern at 4.4 GHz. Switching beams among • -26◦ and +26◦ are perceived[27]

The same authors in [27] achieved the two-dimensional switching beam by using the same procedure, but adding two more strips and switches to achieve the two dimension of radiation pattern by using four strips and switches to connect at the center of feeding probe. By regulating the switches, the monopole has been oriented alongside of the ±x and ±y direction ways, producing four various antenna radiation patterns. As a result, radiation pattern of antenna can be switched in both of the planes, xz and yz. When switch one is ON state and all of the other switches are OFF state, the direction of antenna is along the –x orientation and the beam of antenna is switched to $\theta = -35^\circ$ in the plane of xz. Strip 3 and strip 4 act as reflectors in the y-direction, while it works as the coupling isolation between strip 1 and 2. When only the fourth switch is ON, the beam of antenna points to the elevation angle =35◦ and the azimuth angle =90◦. Therefore, by changing the status of these four switches, two-dimensional beam switching has been realized as shown in Figure 13.

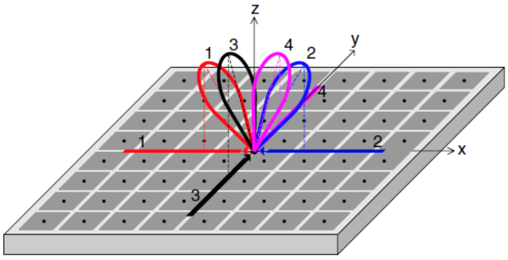


Figure 13: A switchable antenna structure for two dimensional beam diversity[27]

Author in [56] achieved the beam scanning antenna by utilizing a band gap surface for switching sectors of the EBG components, which have the properties of band stop and band pass propagations. These band features can be changed by switching the vias in to two statuses, IN and OUT of sectors. Circular EBG, as shown in Figure 14 which describes the circular cells that have been integrated with the patch antenna and organized in six sectors. The patch antenna has been incorporated above the electromagnetic band gab surface and the elements of the circular EBG with the vias were organized in each sector pattern. The radiation pattern control has been realized by switching vias (IN), means the status is ON and when vias (OUT), means the status is OFF for one or more sectors and getting similar adaptability, antenna with stability in reflection coefficient when the switched vias, as shown in Figure 15 and 8dB expanding of gain.

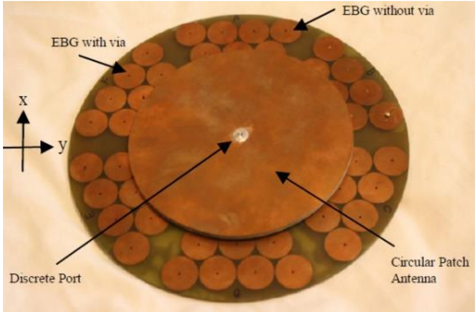


Figure 14: Circular patch antenna above EBG surface sectors [56]

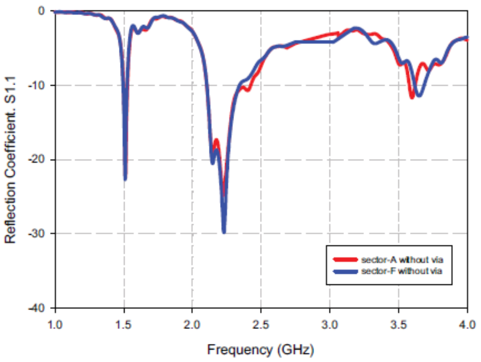
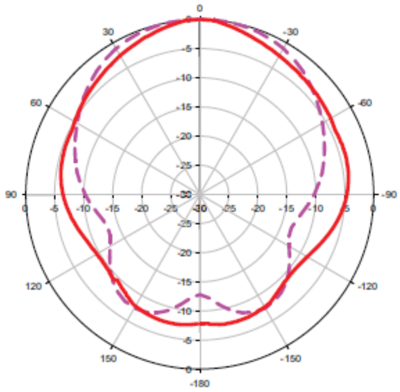
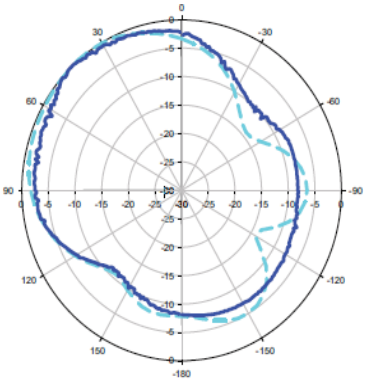


Figure 15: Reflection coefficient for patch antenna (Sectors A and F) without Vias [56]

The measured results for the beam of antenna of sectors A and F when the out switching for the vias are shown in Figure 16, the significant acceptance for the simulation results are increasing in direction and power.



(a) Sector-A

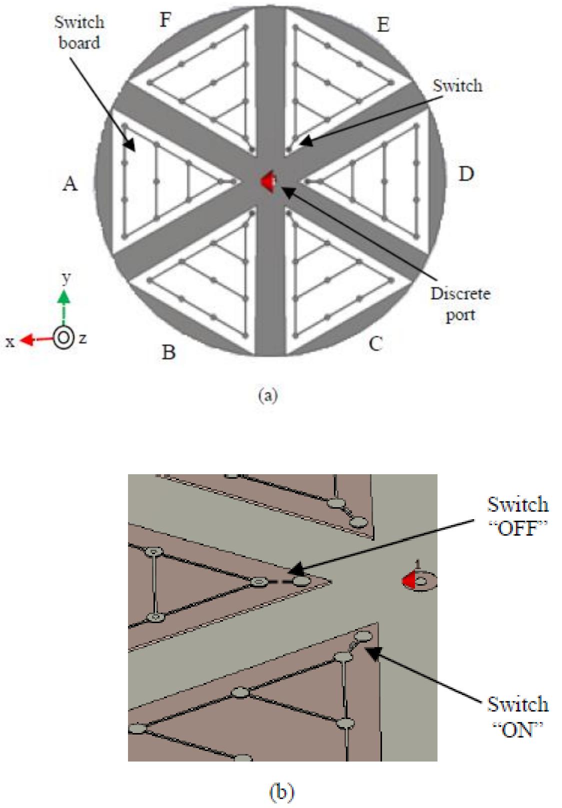


(b) Sector-F

▬ Experimentation ---- Simulation

Figure 16: Radiation pattern at 2.2 GHz when the vias switched out (a) Sector A and (b) Sector F[56]

In [57], the same authors achieved the beam steering technique around the antenna by placing the vias at the center of every EBG circular patch element for altering the switch of each sectors and band gap surface features with the same improvement of gain (8db). The vias in each sector has been joined by a switch board to facilitate the individual sector through switching technique as shown in Figure 17. The vias in each sector have been combined using a switch board as shown on Figure 17(a), etched on FR4 0.8mm thick. A switch represented by a perfect conductor (PEC) is employed to connect the via pins to the ground plane for switching them in and out. Each sector is virtually denoted as A to F. The switch characterized by a perfect conductor (PEC) to link the vias pins to the ground plane to switch them in and out. Switching boards, which combine the vias in each sector, have been used to simplify the individual sector via switching technique.

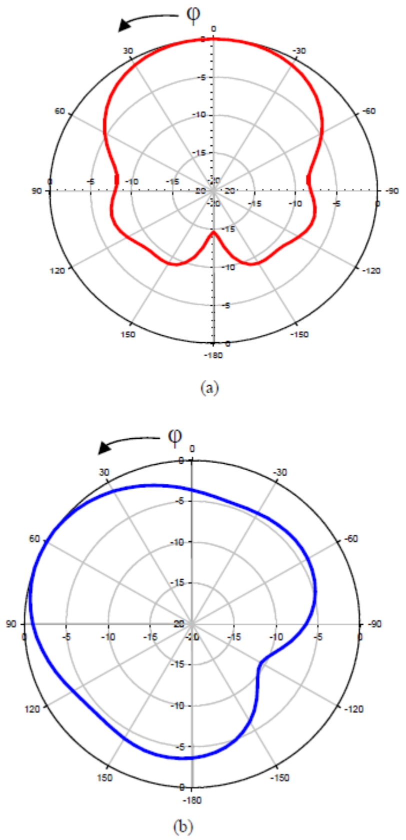


(a)

(b)

Figure 17: EBG with switch board (a) switch board under the EBG (b) Switch ON and OFF[57]

The antenna radiation was steered to the direction of the sector with the state of switched OFF. When the switches at sector A are set to OFF, the radiation pattern is steered to 0º and sector F is steered to 60º as shown in Figure 18.



(a)

(b)

Figure 18: Radiation pattern at 2.2 GHz when the switch board is OFF (a) Sector A and (b) Sector F [57]

A mushroom-like EBG structure exhibits a superior execution to improve the antenna performance. Enhancement in the directivity, gain and the surface radiation diminishes significantly when an EBG structure is utilized as a part of the antenna system [58]. The authors in [5] also used the mushroom type EBG to achieve a low profile antenna by integrating the patch antenna with a square EBG as shown in Figure 20. The optimization of the EBG dimensions has been implemented using the microstrip transmission line technique, which measures the surface mutual coupling within two edges as shown in Figure 21. The explanation for the band stop and band pass propagations can be derived when the status of the pin vias is ON and OFF. Fig. 22 shows the simulated transmission characteristics of the proposed EBG structure [5].

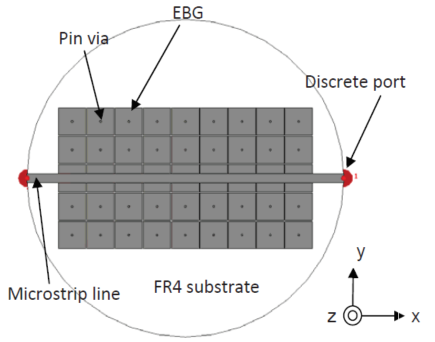


Figure 21: Microstrip transmission line to measure EBG surface mutual coupling [5]

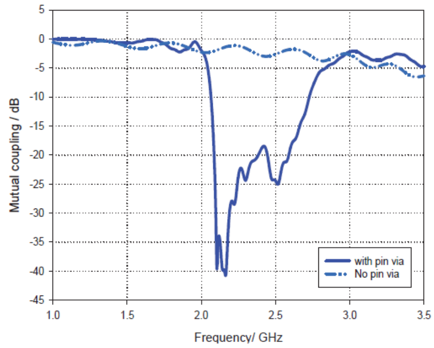


Figure 22: Transmission characteristics of the proposed EBG structure [5].

The EBG surface mutual coupling, as shown on Figure 22, represents the band gap characteristics for the EBG with optimized parameters that cover the antenna operating frequency of 2.2GHz. The mutual coupling for the EBG structure illustrates the enhancement in EBG surface mutual coupling when the pin vias are removed. Additionally, the results when the pin vias are inserted illustrate that the EBG structure rejects the surface wave propagation. So, the EBG in the sector has shown its capability to control the direction of the radiation pattern when the pin vias have been switched IN and OUT at each sector. EBG structures typically consist of metal patches that are separated by a gap on a dielectric substrate with vias connecting the metal patches to the ground plane. The capacitance of the EBG structure is represented by the gap between the patches, while the inductance is represented by the via. The power pattern has been directed towards the EBG sector without the pin vias due to the higher mutual coupling across this surface, whereas, the EBG structure with the inserted pin vias has introduced a lower mutual coupling, which has reflected the surface wave radiation accordingly [5], for getting scanned radiation pattern with expanding gain by around 8dB. By orchestrating the patch antenna in 6 sectors, each sector for the 3-columns of the square EBG with 2 rows and 1-column are located under the patch antenna. To prevent and assist the properties for the band propagation of the mushroom-like EBG with changing switch vias IN and OUT of sectors, the radiation pattern of antenna has been controlled in different directions as the surface impedance in every sectors has been modified. The radiation pattern was reflected from the EBG sectors with high surface impedance and directed towards the lower surface impedance of EBG.

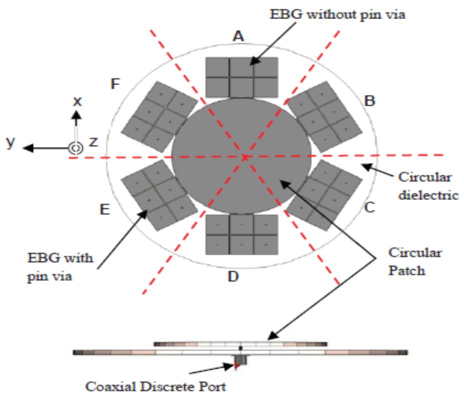
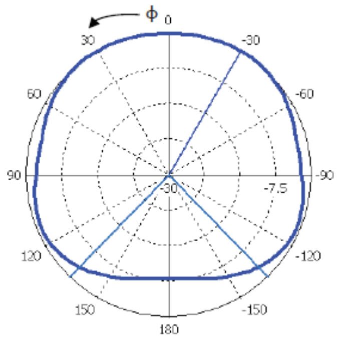
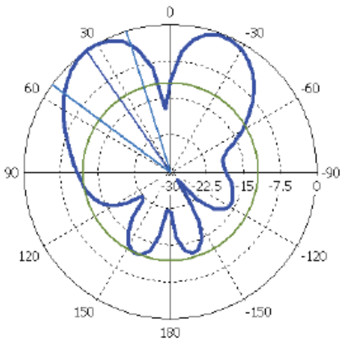


Figure 20: Patch antenna at the center of Sectorized Square EBG[5]

Figure 23(a) shows that at θ =60° the phi-plane power pattern, which is directed to the direction of sector A by 7.5dB maximum rises in gain. The elevation pattern, shown in Figure 23(b) also shows that the antenna power radiation has been radiated towards of the sector A at θ = 30°.



(a) Phi(theta=60)



(b)Theta(phi=0)

Figure 23: Antenna power pattern at 2.2 GHz for Sector A without pin vias [5]

IV. CONCLUSION

Radiation pattern control is a strategy applied to alter the main lobe direction of an antenna radiation pattern, with a specific goal to achieve the improvement of spectrum efficiency and diminishment of multipath propagation. Reconfigurable (beam steerable) antennas permit stronger signals for both ways in transmission and reception in the wanted directions. Beam steering system is a technique that decreases interference, raises the amount of gain, improves directivity and saves power of the antenna. To accomplish the purpose of directivity, the concept of uniting at least two component antennas to shape an array is utilized. The EBG structures, utilized in antenna designs have turned into an energizing point for antenna researchers and scientists. The main targets of the EBG in a specific band of frequency are to prevent and assist the electromagnetic waves propagation at various incident angles and all polarization states. The mushroom type-like EBG comprises of four main sections: the first is a ground plane; the second is a dielectric substrate; the third is metallic patches; and last section is the linking vias. EBG structure shows a featured stop or prevents band issue for the spreading of surface wave. EBG structure utilized with microstrip antenna is to decrease the surface wave impact and increment in the gain of antenna and decrease both mutual coupling and the back-lobe radiation. After the fruitful application of the EBG structure with microstrip in a single patch antenna for a beam scanning, a lot of array antennas have been integrated with the EBG structures to decrease the mutual coupling level. Depending on the best of our information, there are no comprehensive outcomes stated for planar array antenna beam steering with EBG.

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