International Journal of Scientific Research Engineering & Technology (IJSRET)
Volume 1 Issue 5 pp 084-090 August 2012 www.ijsret.org ISSN 2278 - 0882

EBG STRUCTURES AND ITS RECENT ADVANCES IN MICROWAVE ANTENNA

Alka Verma
Department of Electrical Electronics and Instrumentation Engg.
Moradabad Institute of Technology, Moradabad
Email: alkasinghmail@rediffmail.com

ABSTRACT

Electromagnetic Band Gap (EBG) structures are non-periodic structures that show unique electromagnetic features, such as frequency band gap for surface waves and in-phase reflection coefficient for incident plane waves, which makes them desirable for low-profile antenna designs. A very innovative topic for antenna scientists and engineers are the applications of EBG structures in antenna designs. In this paper we have initially reviewed the fundamentals of these structures and then demonstrating recent advances in this field by using several representative microwave antenna examples.It has been concluded that proper utilizations of EBG structures could enhance the performance of low profile antennas.

Keywords: *EBG, bandwidth, substrate, return loss, micro-strip*

I. INTRODUCTION

Microstrip patch antennas offer an attractive solution to compact and ease-low-cost design of modern wireless communication systems due to their many advantages as lightweight and low volume, low profile, planar configuration which can be easily made conformal to host surface, low fabrication cost, and the capability of obtaining dual and triple frequency operations. When mounted on rigid surfaces microstrip patch antennas are mechanically robust and can be easily integrated with microwave integrated circuits However, microstrip patch antennas suffer from a number of disadvantages as compared to conventional non printed antennas. Some of their major drawbacks are the narrow bandwidth, low gain, and surface wave excitation that reduce radiation efficiency.

Many new technologies have emerged in the modern antenna design arena and one exciting breakthrough is the discovery development of electromagnetic band gap (EBG) structures The electromagnetic-bandgap (EBG) structures are periodical cells composed of metallic or dielectric elements. The major characteristic of EBG structures is to exhibit bandgap feature in the suppression of surface-wave propagation. This feature helps to improve antenna's performance such as increasing the antenna gain and reducing back radiation [1].

This paper is organized as follows. In Section II, the theory of EBG structure is introduced with its corresponding bandgap features. In Section III the recent advances done by various researchers has been discussed.

II. EBG STRUCTURE CONFIGURATION

EBG structures are periodic arrangement of dielectric materials and metallic conductors. They can be categorized into three groups according to their geometric configuration: (1) three-dimensional volumetric structures, (2) two-dimensional planar surfaces, and (3) one-dimensional transmission lines. Figure 1.shows the one-dimensional EBG transmission line designs [2], [3].

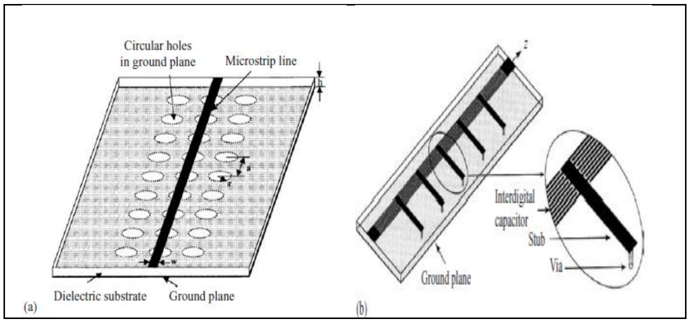


Fig 1:One-dimensional EBG transmission lines: (a) a microstrip line with periodic holes on the ground plane (from [2], C _ IEEE, 1998) and (b) a composite right- and left-handed transmission line (from [13], C _ Wiley-IEEE, 2005).

The concept of electromagnetic band gap (EBG) structures originates from the solid state physics and optic domain, where photonic crystals with forbidden band gap for light emissions were proposed in 1987 [4–5] and then widely investigated in the 1990s [6–8]. Thus, the terminology, *photonic band gap (PBG)* structures, was popularly used in the early days. Since then we have witnessed new forms of electromagnetic structures are invented for radio frequency and microwaves [9]. The band gap feature was first realized and experimentally demonstrated by periodic dielectric structures in the early 1990s [10–11]. Subsequently, arrays of dielectric rod [12–13] and woodpile structure [14] were reported. Figure 3 shows two representative 3-D EBG structures: a woodpile structure consisting of square dielectric bars [4] and a multi-layer metallic tripod array [5]. A 2-D EBG surfaces are plotted in Fig. 4 shows a mushroom-like surface [6] and a uni-planar design without vertical vias [7].

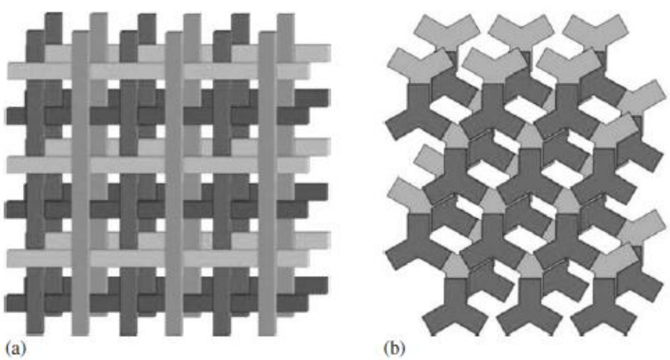


Fig2. Three-dimensional EBG structures: (a) a woodpile dielectric structure and (b) a multi-layer metallic tripod array.

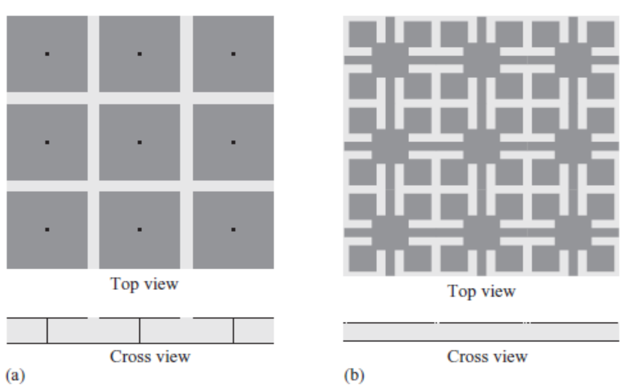


Fig3. Two-dimensional EBG surfaces: (a) a mushroom-like surface and (b) a uni-planar surface.

A. Design consideration:

The EBG structure shown in figure 4 consists of four parts: a metal ground plane, a dielectric substrate, periodic metal patches on top of the substrate, and vertical vias connecting he patches to the ground plane. The geometry is similar to the shape of a mushroom. The parameters of the EBG structure are labeled in Fig. 5 a as patch width *W*, gap width *g*, substrate thickness *h*, dielectric constant εr, and vias radius *r*. When the periodicity($W + g$) is small compared to the operating wavelength, the operation mechanism of this EBG structure can be explained using an effective medium model with equivalent lumped LC elements, as shown in Fig.5 b. The capacitor results from the gap between the patches and the inductor results from the current along adjacent patches.

The impedance of a parallel resonant LC circuit is given by:

$$Z = j\omega L/1 - \omega^2 LC \quad (1)$$

.

The resonance frequency of the circuit is calculated as following:

$$\omega_0 = 1/\sqrt{LC} \quad (2)$$

$$C = W\varepsilon 0(1 + \varepsilon r)/\pi \cosh^{-1} [(W + g)/g] \quad (3)$$

$$L = \mu o\, h \quad (4)$$

The bandwidth of the electromagnetic band gap is given by;

.

$$BW = 1/\eta\sqrt{L/C} \quad (5)$$

.

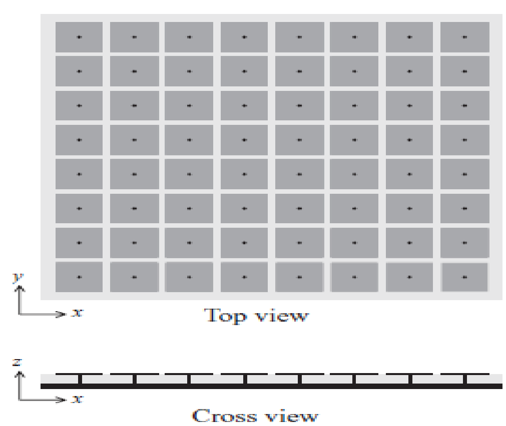


Fig 4. Geometry of a mushroom-like electromagnetic band gap (EBG) structure.

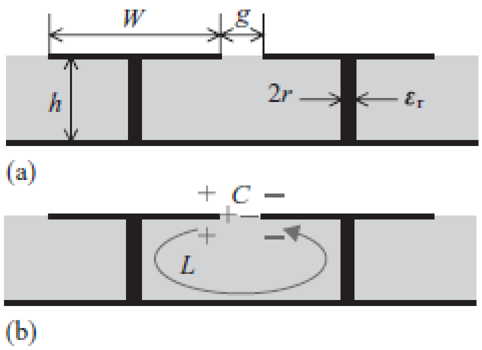


Fig5. LC model for the mushroom-like EBG structure: (a) EBG parameters and (b) LC model.

.

III. RECENT ADVANCES

The unique electromagnetic properties of EBG structures have led to a wide range of applications in antenna engineering. This section summarizes several typical EBG applications in antenna designs in the hope of stimulating discussions and new venues of research in this area.

Surface waves are by-products in many antenna designs. Directing electromagnetic wave propagation along the ground plane instead of radiation into free space, the surface waves reduce the antenna efficiency and gain. The diffraction of surface waves increases the back lobe radiations, which may deteriorate the signal to noise ratio in wireless communication systems such as GPS receivers. In addition, surface waves raise the mutual coupling levels in array designs, resulting in the blind scanning angles in phased array systems

The band gap feature of EBG structures has found useful applications in suppressing the surface waves in various antenna designs.

A. Spiral Electromagnetic Band Gap (EBG) structure

The schematic of the proposed spiral EBG structure is shown in Figure 6.

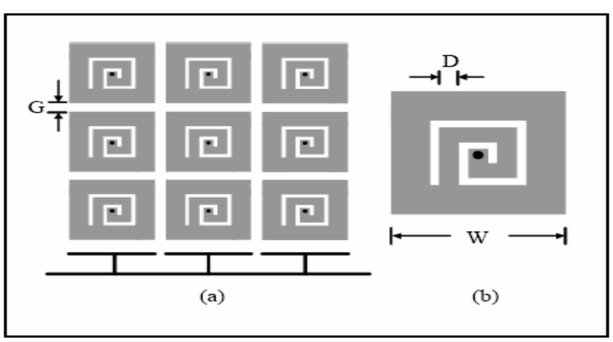


Fig 6. (a) Spiral EBG structure. (b) Details of one unit of the structure [15]

Gray parts in the figure 6 represent the metallic periodic structure which is etched on a dielectric substrate. Each element of this EBG lattice consists of a square metal patch with a spiral branch inserted inside, as shown in Figure 6 (b). The patch is connected to the solid lower ground plane by a metal plated via [15].

A 3 by 3 spiral EBG structure as above have been fabricated by the researchers before. The array is built on 1mm thick substrate with the relative permittivity of 2.2. The length of the square patch (W) is 6 mm. The width of the spiral branch (D) is 0.6 mm. The distance between the adjacent patches (G) is 0.4mm. The period of the lattice is W + G = 6.4 mmThe measured and simulated results are shown in Figure 9 A distinctive stop-band has been observed with the central frequency of 2.28 GHz. The frequency range with S 21below -10 dB extends from 2.07 GHz to 2.34 GHz.

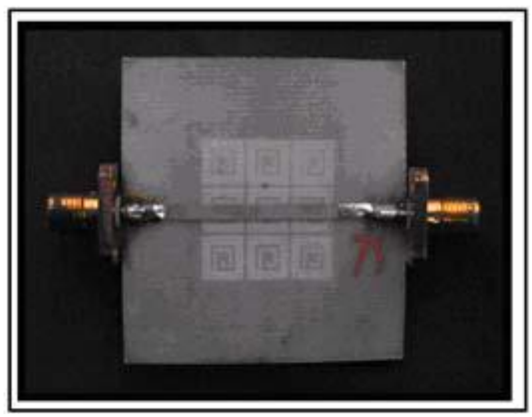


Fig7. Photograph of the 3 by 3 Spiral EBG with suspended microstrip [15]

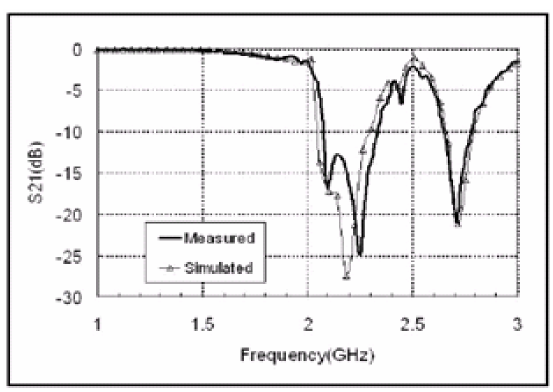


Fig8. Measured and simulated S21 of the 3 by 3 Spiral EBG structures [15]

International Journal of Scientific Research Engineering & Technology (IJSRET)
Volume 1 Issue 5 pp 084-090 August 2012 www.ijsret.org ISSN 2278 - 0882

B. Stack EBG structure

In order to suppress the surface wave, EBG lattice is typically placed around the patch antenna in coplanar position. However, such placement enlarges the area needed and runs counter to the principle of compact design in wireless communication circuits. Researchers have verified that EBG structure can still exhibit band-gap feature beneath suspended microstrip [16].A stacked EBG utilization accommodating with patch antenna will be discussed in this section, as shown in Figure 9. One layer of EBG lattice is inserted beneath the patch antenna. The surface wave will be coupled to the EBG lattice and forced to radiate. Such structure has the winning feature of compactness [16].

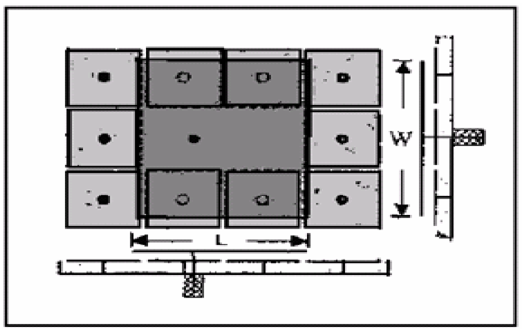


Fig9. Stacked EBG structure [16]

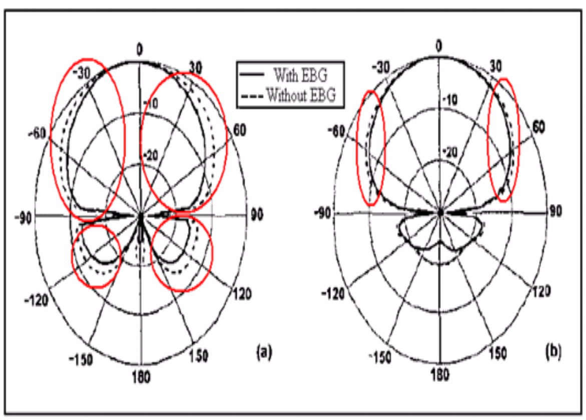


Fig10. Radiation patterns of the patch antenna with and without EBG (a)E-plane (b) H-plane [16]

From the radiation pattern shown in figure10, the patch antenna with EBG structure has lower side lobe and back lobe compared to the patch antenna without EBG structure especially in E-Plane direction. The antenna with EBG structure seemed has narrower beam width. So, the EBG structure helps the microstrip patch antenna to be more directional. The red circle on the figure shows the difference of radiation pattern characteristic for both structures. The conclusion can be made referring to the research is the EBG structure can improve the radiation pattern of the microstrip antenna design [16].

C. Fork like EBG structure

In EBG design also miniaturization is very important since the EBG structure will be use periodically together with antenna design and this results in lower fabrication cost. To overcome the problem of miniaturization , a researcher in [16] proposed the fork-like EBG structure as shown in figure 11.

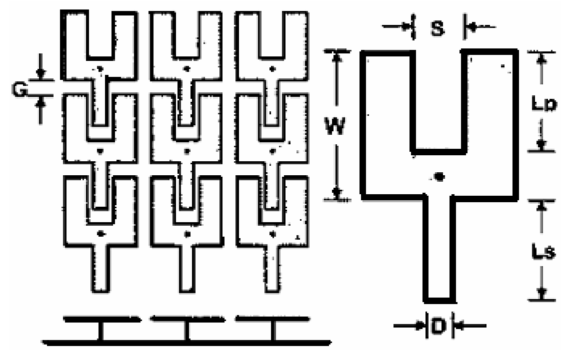


Fig11. Configuration of fork-like EBG structure [16].

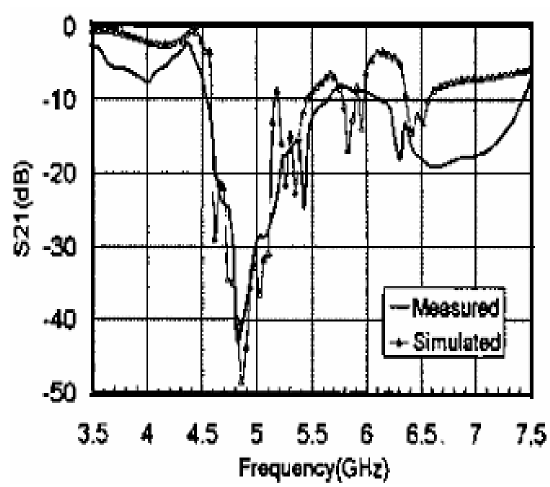


Fig12. The S21 result for fork-like EBG structure [16].

As compared to mushroom EBG the overall size of the proposed EBG size is 40% smaller operating at same frequency. The band gap frequency is shown in figure 12. The fork like EBG structure has good size reduction for EBG design and had good S21 value but it still operates at single frequency band.

D. Hexagonal shape EBG structure

Figure13 shows the hexagonal shape EBG structure that has been designed and fabricated by Dan Sievenpiper in [17]. The structure is used as ground plane for horizontal wire antenna. In figure 14, the comparison for the antenna performances has been made between wire antenna on metal ground plane and hexagonal shape EBG structure.

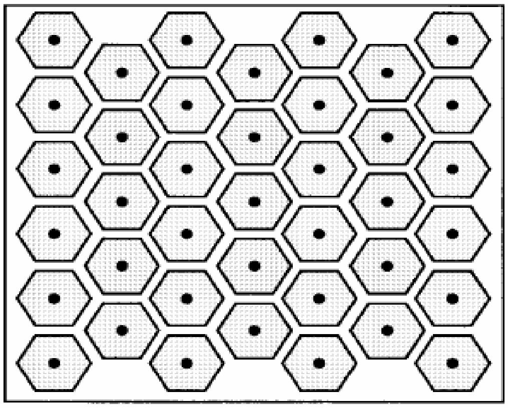
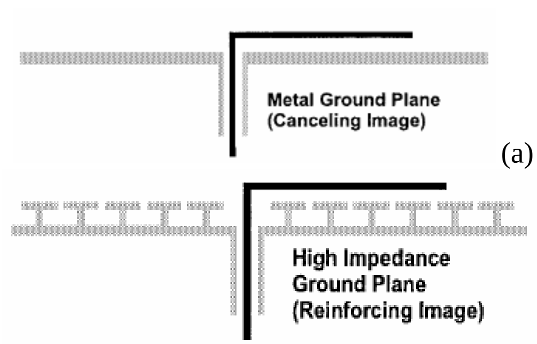


Fig15. Hexagonal shape EBG structure [17]



(a)

(b)

Fig16. Horizontal wire antenna. [17](a) On metal ground plane (b) on hexagonal shape EBG structure

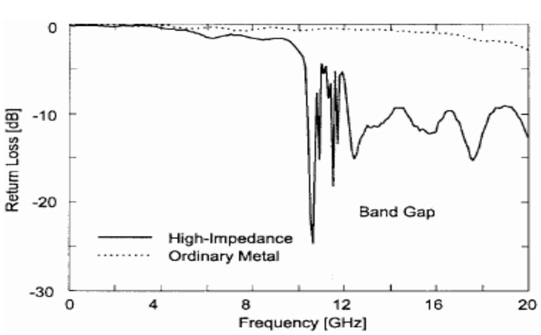


Fig17. Return loss for horizontal wire antenna on hexagonal shape EBG structure [17]

Figure 17: shows the result of the return loss for horizontal wire antenna on hexagonal shape EBG structure and horizontal wire antenna on metal ground plane. The signal transmitted to the horizontal wire antenna on the flat metal ground plane is almost reflect back to the system and cannot be radiated effectively From figure 17 , the return loss value for horizontal wire antenna on hexagonal shape EBG structure has better return loss in both E-plane and H plane where the value is almost below -10 dB in wide frequency ranges. The radiation pattern is also improved with higher front radiation and the back radiation is smaller. The radiation pattern for horizontal wire antenna on EBG structure is smooth with improvement of the characteristic as mentioned before.

E. Elongated mushroom electromagneticband-gap (EM-EBG) structure

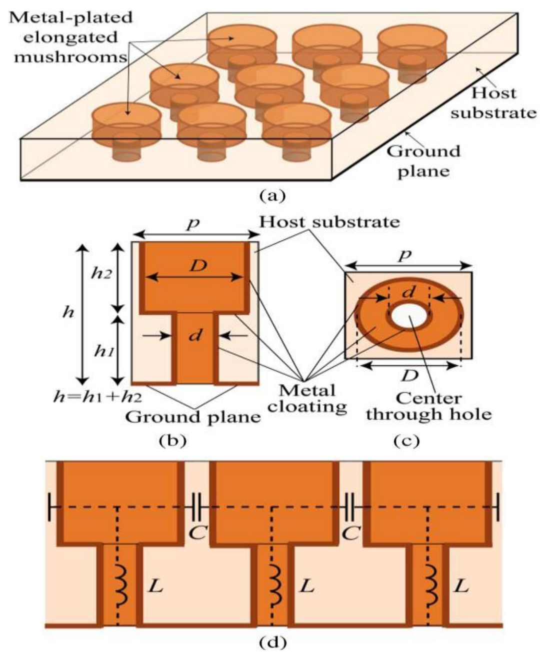


Fig18. Proposed-elongated-mushroom (EM)-EBG structure. (a) Perspective view. (b) Cross sectional view of the unit cell. (c) Top view of the unit cell. (d) Simplified circuit model.18]

Fig. 18 shows the proposed EM-EBG structure with its design parameters. It consists of a periodic array of metal via holes within a host dielectric grounded substrate. These shave a smaller diameter at their lower part, which is connected to a ground plane, and a larger diameter at their higher part, which extends up to the top of the substrate. The terminology EM-EBG is motivated by the shape of these double-dia meter vias, which look like "elongated

International Journal of Scientific Research Engineering & Technology (IJSRET)
Volume 1 Issue 5 pp 084-090 August 2012 www.ijsret.org ISSN 2278 - 0882

mushrooms” (EM) in reference to CM-EBG mushroom elements

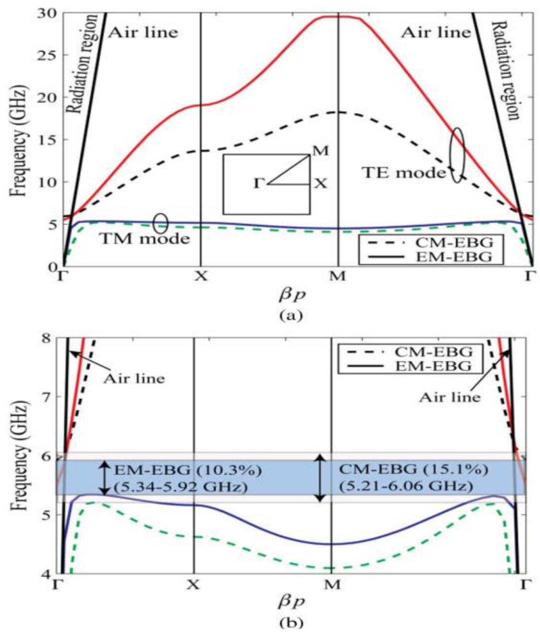


Fig19. Dispersion diagram of the proposed EM-EBG structure compared with that of the CM-EBG structure.

In figure 19 it is seen that see that, by strongly increasing, in addition to slightly decreasing, the EM-EBG decreases the bandwidth compared to the CM-EBG. Nevertheless, the resulting bandwidth, which is of 10.3% here, is still largely sufficient for the vast majority of applications. Specifically, in the case of microstrip patch antenna arrays, the bandwidth of the system is limited by the bandwidth of the patch antennas, which typically does not exceed 5%

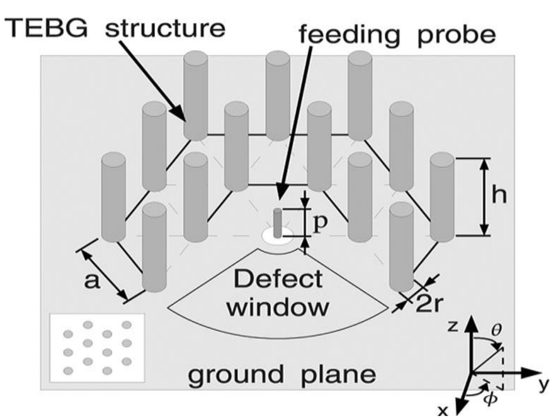


Fig.20.TEBG antenna geometry and (inset) triangular lattice of circular dielectric rods.[19]

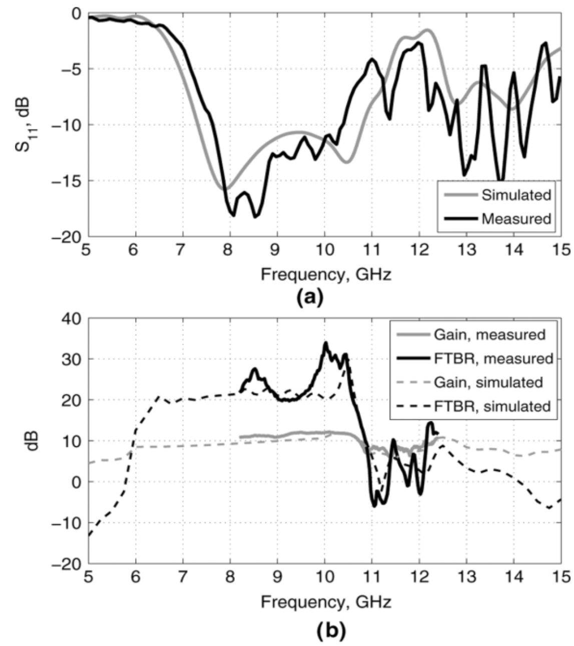


Fig21. TEBG antenna wit a=13 mm, r=1.5 mm, , and h=20 mm, simulated and measured: (a) _S11; (b) gain and FTBR.[19]

In Figs 21 simulations and measurement results designed to operate in the X-band are compared and hence showing good agreement with each other It is seen that 31% fractional bandwidth is achieved from7.63 to 10.4 GHz with an average gain and front-to-back-ratio of 11.5 dBi and 27 dB, respectively which is good in comparison to conventional patch without EBG. The antenna is very directive in the H-plane, reaching a peak gain and front-to back-ratio of 12 dBi and 34 dB, respectively, in the 10-GHz

IV. CONCLUSION

After going through the various works done by various researchers as discussed above, concluded that the proper utilizations of EBG structures could enhance the performance of low profile antennas.

REFERENCES

[1] D. Sievenpiper, L. Zhang, R. F. J. Broas, N. G. Alexopolous,and E. Yablonovitch, “High-impedance electromagnetic surfaces with a forbidden frequency band,” EEE Trans. Microwave Theory & Tech., vol. 47, pp. 2059-2014, Nov.1999

[2]V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, “Novel 2-D photonic bandgap structure formicrostrip lines,” IEEE Microw. and Guided Wave Lett., vol. 8, no. 2, 69–71,

1998.

[3] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, "Novel 2-D photonic bandgap structure formicrostrip lines," IEEE Microw. and Guided Wave Lett., vol. 8, no. 2, 69–71, 1998

[4]. E. Yablonovitch, "Inhibited spontaneous emission in solid-state physics and electronics," Phys. Rev. Lett., vol. 58, 2059–63, 1987

[5]. S. John, "Strong localization of photons in certain disordered dielectric super lattices," Phys.Rev. Lett., vol. 58, 2486–9, 1987

[6]. J. D. Joannopoulos, R. D. Meade, and J. N. Winn, Photonic Crystals, Princeton University Press, 1995

[7]C. M. Bowden, J. P. Dowling, and H. O. Everitt, "Development and applications of materials exhibiting photonic band gaps," J. Opt. Soc. Amer B., Opt. Phys., vol. 10, 280, February 1993

[8]. G. Kurizki and J. W. Haus, "Special issue on photonic band structures," J. Mod. Opt., vol. 41, 171–2, February 1994

[9] IEEE Trans. Microwave Theory Tech., Special Issue on Electromagnetic Crystal Structures,Designs, Synthesis, and Applications, vol. 47, no. 11, November 1999

[10] K. M. Ho, C. T. Chan, and C. M. Soukoulis, "Existence of a photonic gap in periodic dielectric structures," Phys. Rev. Lett., vol. 65, 3152–5, 1990

[11] E.Yablonovitch,T. J. Gmitter, and K. M. Leung, "Photonic band structures: the face-centeredcubic case employing non-spherical atoms," Phys. Rev. Lett., vol. 67, 2295–8, 1991

[12] P. K. Kelly, J. G. Maloney, B. L. Shirley, and R. L. Moore, "Photonic bandgap structuresb of finite thickness: theory and experiment," Proc. 1994 IEEE APS Int. Symp., vol. 2, pp. 718–21, Seattle, WA, June 1994

[13] M. M. Beaky, J. B. Burk, H. O. Everitt, M. A. Haider, and S. Venakides, "Two-dimensional photonic crystal Fabry-Perot resonators with lossy dielectrics," IEEE Trans. Microwave Theory Tech., vol. 47, no. 11, 2085–91, 1999

[14]. K. M. Ho, C. T. Chan, C. M. Soukoulis, R. Biswas, and M. Sigalis, "Photonic band gaps in three dimensions: new layer-by-layer periodic structures," Solid State Commun., vol. 89, 413–16, 1994

[15] Li Yang, Mingyan Fan, and Zhenghe Feng, "A Spiral Electromagnetic Bandgap(EBG) structure and is Application in Microstrip Antenna Arrays," IEEE Asia-Pacific Conf. Proc., Microwave Conf., Proc., Vol. 3, pp. 4, Dec. 2005

[16] Fan Yang, Chul-Sik Kee, and Yahya Rahmat-Samii, "Step-Like Structure and EBG Structure to Improve the Performance of Patch Antennas on High Dielectric Substrate", 2001 IEEE AP-S Digest, vol. 2, pp. 482-485, July 2001

[17] Dan Sievenpiper, Lijun Zhang, Romulo F. Jimenez Broas, Nicholas G. Alex´opolous, and Eli Yablonovitch, "High Impedence Electromagnetic Surface with forbiddenfrequency band," IEEE Trans on Microwave Theory and Techniques, Vol 47, No.11, November 1999.

[18] Martin Coulombe, Sadegh Farzaneh Koodiani, Member, IEEE, and Christophe Caloz, SeniorMember,'Compact Elongated Mushroom (EM)-EBGStructure for Enhancement of Patch Antenna ArrayPerformances', IEEETranssactions on antennas and propagation ,VOL. 58, NO. 4, APRIL 2010

[19] Claudio Biancotto, Student Member, IEEE, and Paul RecordTriangular Lattice Dielectric EBG Antenna', IEEE Antennas and wireless propagation letters, , VOL. 9, 2010