DESIGN ANAYSIS OF PATCH ANTENNA USING EBG STRUCTURE

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Abstract : ***Technology has become the most vital part of the daily life. With the development of antenna technology, the wireless devices became more capable of providing the services like Wi-BAN, point-to-point bridge, hotspot, public wireless, Wi-MAX, WLAN, Wi-Fi and wireless video systems. In this research work, we have been demonstrating the design composition of patch antenna backed by the electromagnetic band gap (EBG) structure to be operated at 4.8 GHz of resonant frequency. The dispersion diagram provides the aid to determine the bandgap characteristics of EBG structure. To cover the required band gap of 4.8 GHz, the dimensions of EBG structure are tuned and adjusted. The EBG was analyzed and implemented on coaxial feed microstrip patch antenna in order to determine the S_{11} parameter performances. Better results have been attained at a distance of -10 mm between the patch antenna and EBG in comparison to other varied distances.***

Index Terms - Dispersion curve, Electromagnetic Band Gap (EBG), Microstrip Patch Antenna (MPA), Phase reflection.

I. INTRODUCTION

In the era of the wireless communication, low profile, light weight, highly efficient, and low cost antennas are required. Various researchers have been working on most compatible planar microstrip patch antenna (MPA) to enhance the radiation performances and characteristics of an antenna at GHz as well as THz frequencies of Electromagnetic (EM) wave [Sharma et al, 2008, Sharma and Singh, 2009, Singh and Srivastava, 2018]. The *MPA* is used mostly because of its simple design, conformal geometry, ease in installation, variety of shapes, low fabrication cost, and its compatibility with microwave and Millimeter Wave Integrated Circuit (MIMC) [Balanis, 2005]. For better results such as huge bandwidth and bulged efficiency & radiation there is desirability that substrate should be of thick size on the basis of height, however the dielectric constant should be low [Kumar and Ray, 2003]. For radiation excitation of patch antenna distinct type feeding methods are used and categorized as two parts that is non-contacting and contacting [Bahl and Bhartia, 1980].

The surface wave excitation is one of the problems that associate with the patch antenna and which results into other disadvantages such as low gain, ripples in pattern of radiation and deterred efficiency. The back lobe radiation leads to increment of surface wave diffraction and consequently in wireless communication systems, there occurs a signal to noise ratio deterioration [Yang and Rahmat-Samii, 2009]. This happens because immense energy got trapped within the antenna irrespective of the transmitted signal [Kovcas and Urbanec, 2012].

The element that gains immense significance to surmount these predicaments is electromagnetic band gap structure due to its extravagant property of elimination of surface waves. This aids for performance amelioration of antenna by mush-rooming gain and de-escalating the back wave radiation [Yang and Rahmat-Samii, 2009. The *EBG* structures proved to be a boon for having various designs of antenna and operating at various frequencies for different applications along with least surface waves [Gonzal et al, 1999, Colburn and Rahmat Samii, 1999]. The *EBG* structures are also helpful for the reduction of mutual coupling when integrated with patch antenna arrays [Yang and Rahmat-Samii, 2003, Yang and Rahmat-Samii, 2001 and Kaabal et al, 2016]. For construction of *EBG* structures various parameters like periodicity, width and the size of columns of *EBG* are importantly considered and therefore ameliorated results are obtained in form of enhanced gain, efficiency, bandwidth, and directivity [Eriffi et al, 2014, khan et al, 2016], in addition with impoverishment of S_{11} parameter, back-lobe reduction [Hongnara et al, 2016, Tan et al, 2012] and miniaturization of antenna [Yang and Feng, 2004, Goussetis et al, 2006].

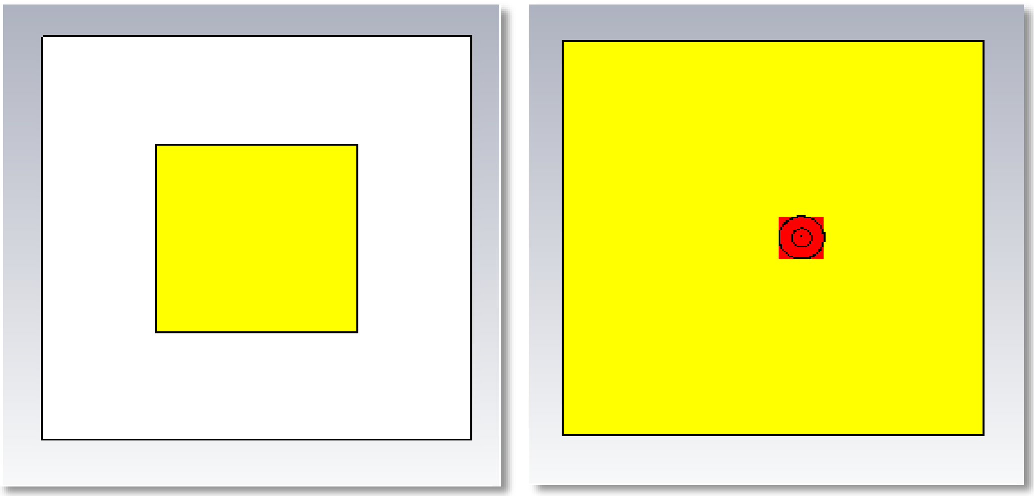
In this research work, we have been analysing a patch antenna with coaxial feeding technique, moreover the effects of placing the mushroom type electromagnetic band gap structure at distinct distances from antenna is simulated and analysed. The *EBG* unit cell is designed in such manner so that its band gap consequently covers antenna's resonant frequency of 4.8 GHz. By varying the distances we can obtain the best place to mount antenna away from *EBG* structure to enhance the parameters such as gain, efficiency, directivity and reduction of S_{11} parameter and back lobes.

This research work has been organised as follow: In *Section II*, we have designed a rectangular patch antenna with coaxial feed. Then a mushroom typed *EBG* structure is designed and its behaviour is optimized. Thereafter, we have implemented this *EBG* structure design on the rectangular patch. The simulation behaviour and results of the proposed EBG loaded rectangular patch antenna have been analysed in *Section III*. Finally, the conclusion has been made in the *Section IV*.

II. DESIGNING PROCESS AND STRUCTURAL ANALYSIS

2.1 Design of coaxial feed antenna

The illustration of basic coaxial feed patch antenna has been depicted in Fig. 1. Antenna incorporates a top radiating layer i.e. patch (copper annealed) backed by the FR-4 loss free substrate. Moreover, these both layers are grounded up by other



(a) (b)

Figure 1: Patch antenna with coaxial feeding at 4.8 GHz (a) front view and (b) back view.

Table 1: Dimensions of coax feed patch antenna

Parameters	Symbols	Values
Operating Frequency	f_o	4.8 GHz
Substrate Height	h	1.2 mm
Dielectric Constant	ε_r	4.3
Patch Thickness	t	0.035 mm
Substrate Length	L	30 mm
Substrate Width	W	30 mm
Length of Patch	l	14 mm
Width of Patch	w	14 mm

copper material layer. The type of the feed used in this antenna is coaxial cable. All dimensions of patch antenna fed up by the coaxial feed are mentioned clearly in the Table 1. However, in order to feed, the waveguide port is used and coaxial feed is of radius 1.2 mm.

2.2 Design of Mushroom Typed EBG Unit Cell Structure

These structures hold significant value with regards to the reduction of the surface wave losses. When some waves do not find a way out of the area between the substrate and the patch and results into the losses called as surface wave losses. The mushroom types *EBG* unit cell structure with via has been shown in Fig. 2. An 11.5 mm × 11.5 mm of mushroom-typed *EBG* unit cell structure has been designed. A via with radius of 1 mm has been inserted. The rest of the dimensions of the EBG unit cell structure are illustrated in Table 2**.** The EBG unit cell has been modified by etching off four rectangular slots of equal dimensions. This modifies the behaviour of the structure and corresponding resonant frequency.

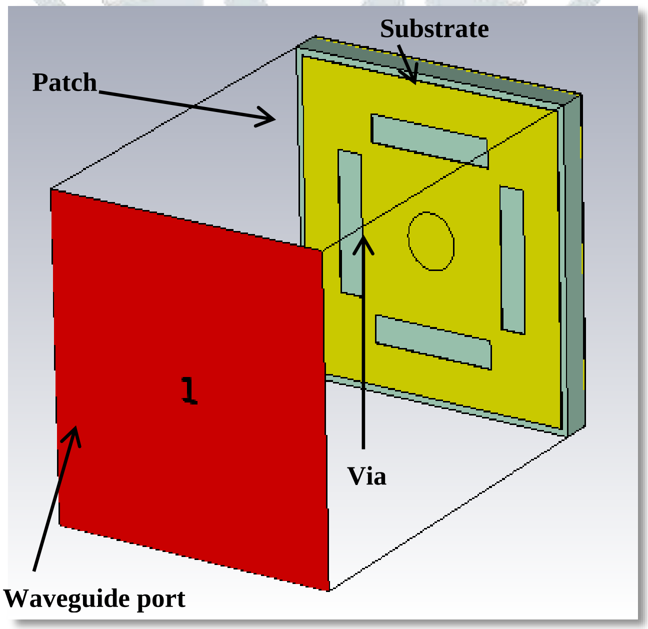


Figure 2: A 11.5 mm × 11.5 mm of mushroom-typed EBG unit cell structure with via.

Table 2: Dimensions of EBG unit cell with via

Parameters	Symbols	Value
Frequency	f_o	1-14 GHz

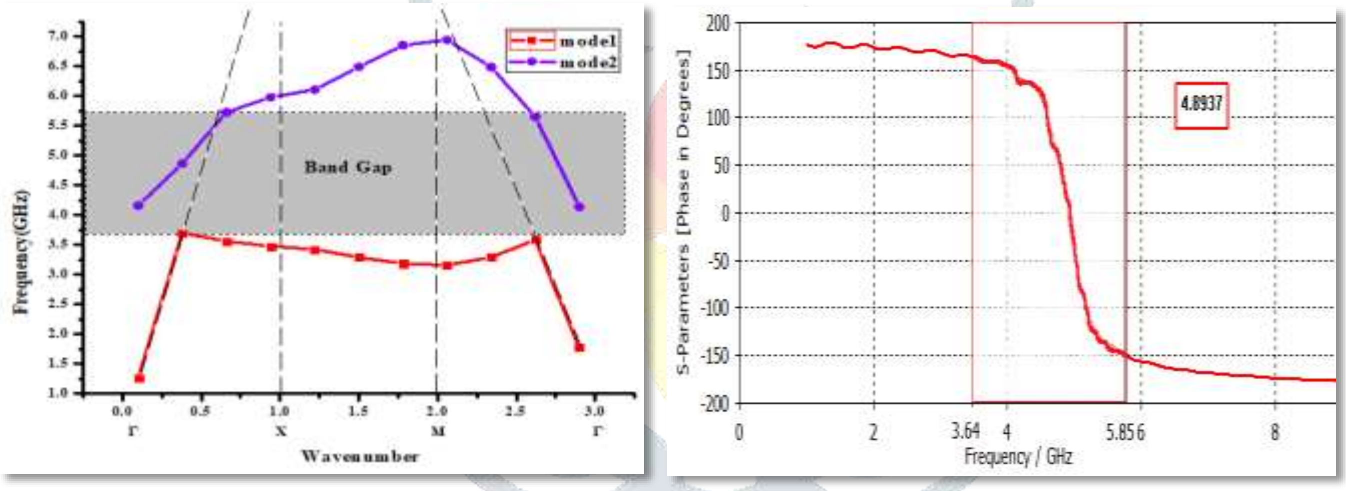
Dielectric Constant	ε_r	4.3
Substrate Height	h	1.2 mm
Patch Thickness	t	0.035 mm
Substrate Length	L	11.5 mm
Substrate Width	W	11.5 mm
Length of Patch	l	11 mm
Width of Patch	w	11 mm
Via Radius	r	1 mm

The waveguide port has been assigned towards positive z-axis While, unit cell boundary conditions have been assigned along x-axis and y-axis.

The *EBG* unit cell for which the surface losses needed to be suppressed for particular band of frequency can be comprehended by the help of dispersion diagram. To cover the frequency of 4.8 GHz the width of cell is varied and optimized to attain the required band gap. The band gap of the *EBG* structure was adjusted by tuning L/W and the gap between unit cells to cover the frequency of 4.8 GHz resonant frequency. The Figure 3(a) shows the dispersion curve of designed *EBG* unit cell. For the computation of phase shifting of a material the simulation is done considering parameters i.e. propagation constant with respect to mentioned frequency. The output graph is known as dispersion diagram and certain boundary conditions needed to be considered and implemented for the unit cell.

From the figure, it is clear that the bandgap for the *EBG* unit cell depicted in Fig. 2 lies between 3.69 GHz to 5.7 GHz. So, the referenced patch antenna which is designed to operating at 4.8GHz of the resonant frequency lies in between this range of the band gap. Electric field which reflected from the reflecting surface is described as phase of reflection. Moreover, the phase of electric field at reflecting surface is normal to the incident field [Liu et al, 2008].

The perfect electric conductor (PEC) has an 180^0 reflection phase for a normally incident plane wave, the phase reflection of materials which do not exists in nature known as perfect magnetic conductor is 0^0 [Li et al, 2005, Sievenpiper et al, 1999].There is the continuous variation from positive 180^0 to negative 180^0 phase reflection with respect to frequency for *EBG* surfaces. The particular property of the phase reflection raises *EBG* surfaces as distinctive materials. The reflection phase of 11.5 mm × 11.5 mm unit cell at 4.8 GHz has been shown in Fig. 3(b) depicting a zero phase reflection at a frequency of 4.8 GHz.



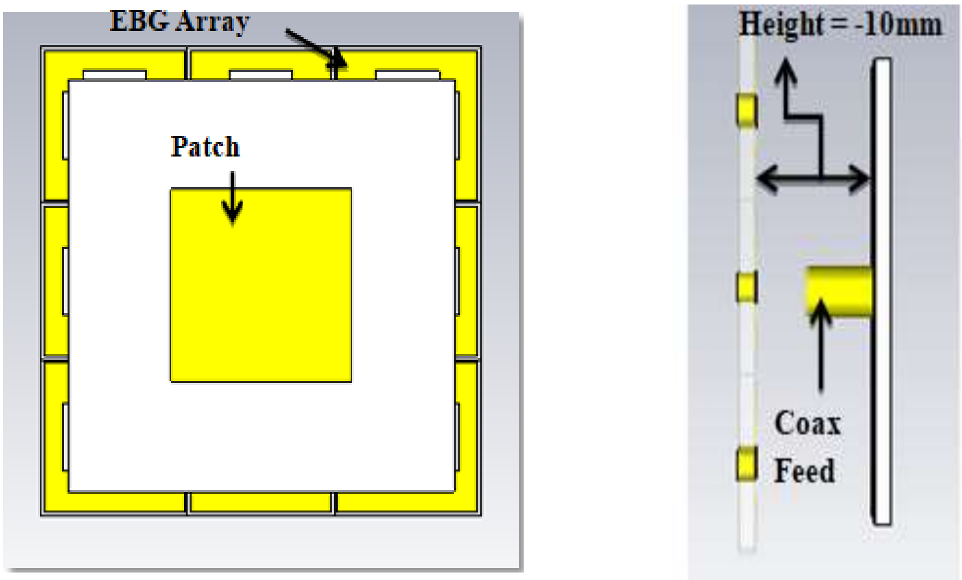
(a) (b)

Figure 3: A single EBG unit cell (a) Dispersion curve and (b) Phase reflection curve.

2.3 Implementation of EBG with Coaxial Feed Rectangular Patch Antenna

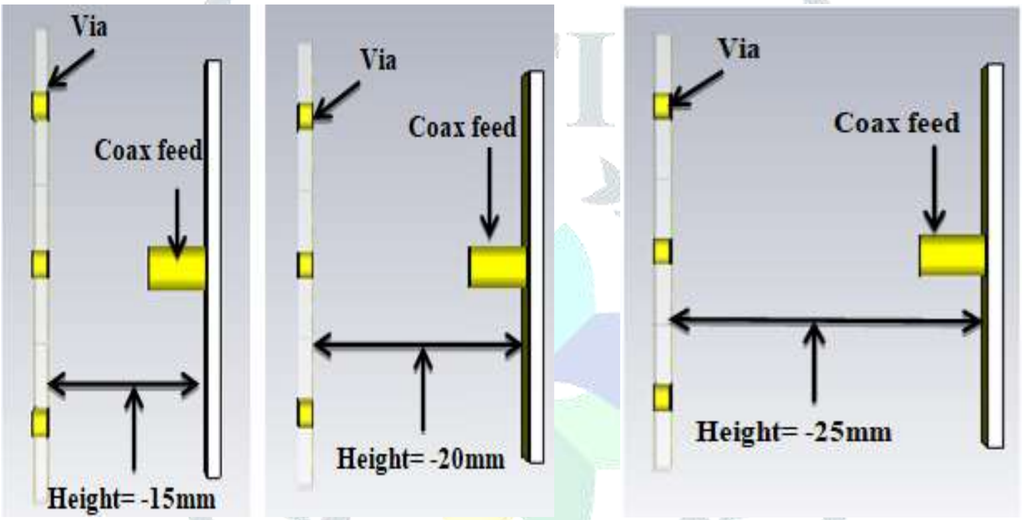
The Coaxial feed rectangular patch antenna is emplaced upon the 3 × 3 *EBG* unit cells at different distances and the results are simulated for amelioration of efficiency, gain, directivity along with deterioration of side lobes which in consequence reduce the surface wave losses. By the reduction of losses the performance of proposed patch antenna design further enhanced. The following fig. 4 shows the placement of 3 × 3 *EBG* structure, 10 mm below the basic coax feed antenna for analysis. The antenna is placed above 3 × 3 *EBG* unit cell structure at four distinct spacing of -10 mm, -15 mm, -20mm, and -25 mm, respectively. The presentation of all these antennas is as that of shown in Fig. 4 and Fig. 5, respectively.

In Figure 4(a), the front view of proposed coaxial feed patch antenna backed by the *EBG* array at the height of -10 mm has been given. Whereas, the side view of proposed antenna model has been shown in Fig. 4(b). For the purpose of comparison, the height of the *EBG* array backed rectangular patch antenna is varied. The Figure 5(a) shows the *EBG* array backed antenna at a height of -15mm. The Figure 5(b) shows the *EBG* array backed antenna at a height of -20 mm. Finally, the *EBG* array backed antenna at a height of -25mm has been depicted in Fig. 5(c).



(a) (b)

Figure 4: Coaxial feed patch antenna backed by the EBG array at the height of -10 mm (a) Front view and (b) Side view.



(a) (b) (c)

Figure 5: Coaxial feed patch antenna backed by EBG array with via at the heights of (a) -15 mm, (b) -20 mm, (c) and -25 mm, respectively

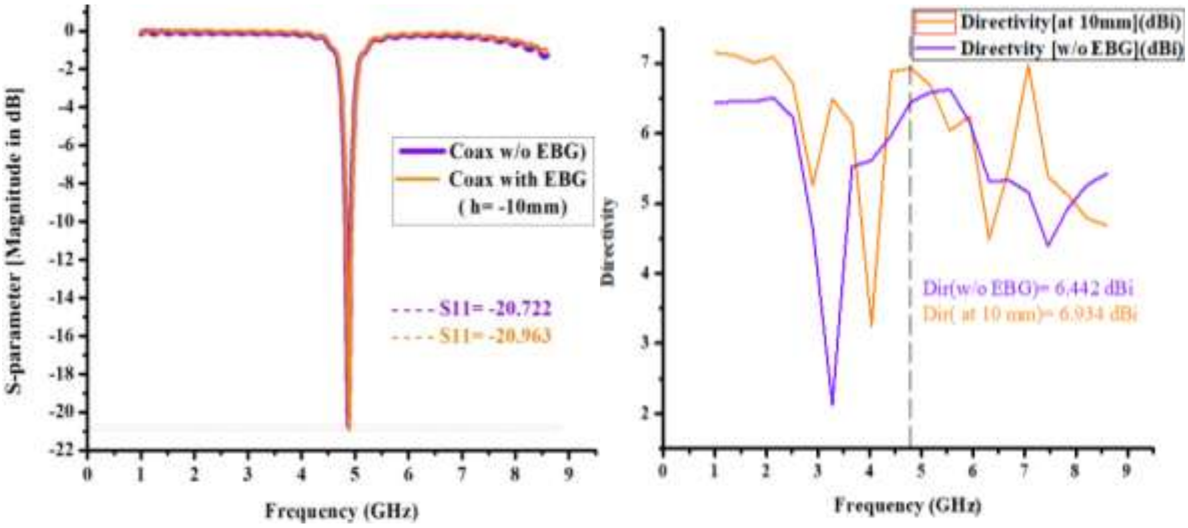
III. SIMULATION RESPONSE AND RESULT ANALYSIS

Analysis of patch antenna has been done with and without *EBG* structure and tabulated in Table 3. While analyzing all the results of referenced and proposed antennas, the better results are obtained at distance of -10 mm from *EBG* in relation to simple coaxial feed patch antenna. The S_{11} parameter of antenna with backed *EBG* improved slightly as compared with the referenced antenna operating at 4.8761 GHz. The value of S_{11} parameter is -20.722 dB, whereas it is reached to -20.963 dB with backed *EBG* at a distance of -10mm.

While for other structures the value of S_{11} parameter degraded. There is a slight shift in resonant frequency of the proposed

Table 3: Comparisons of proposed patch antenna with different heights

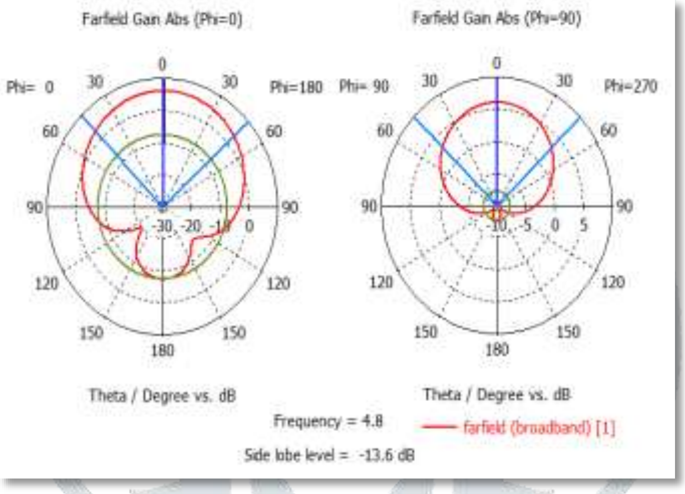
Parameters	Referenced Antenna	H= -10 mm	H= -15 mm	H= -20 mm	H= -25 mm
Resonant Frequency (GHz)	4.8761	4.8912	4.8912	4.8912	4.8912
Radiation efficiency (dB)	-0.3721(91.79%)	-0.2824(93.65%)	-0.2638(94.11%)	-0.2405(94.61%)	-0.2229(95%)
Total efficiency (dB)	-1.386	-1.618	-1.6	-1.571	-1.527
Gain (dB)	6.069	6.651	6.624	6.518	6.274
Directivity (dBi)	6.442	6.934	6.887	6.758	6.497
S_{11} (dB)	-20.722	-20.963	-21.0803	-21.201	-21.043
Side lobe (dB)	-13.6	-24.2	-23.8	-21.7	-19.1



(a) (b)

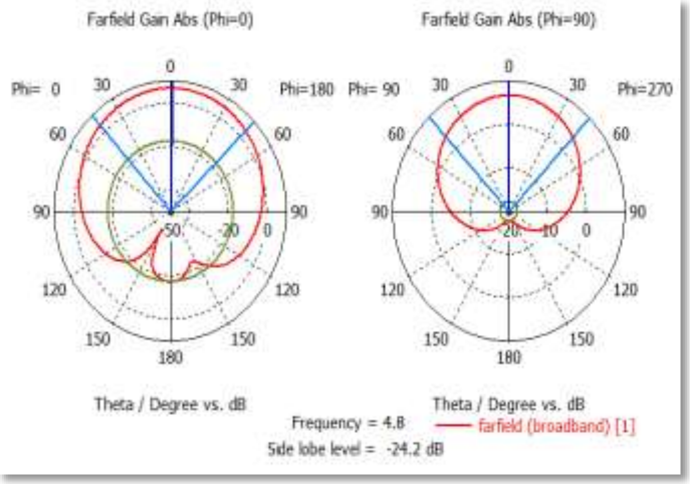
Figure 6: The radiation performances of referenced and proposed patch antenna (a) Reflection coefficient comparison (b) Directivity comparisons.

model with respect to the referenced model. At -10 mm height of proposed antenna attain a value of 4.8912 GHz frequency as compared to 4.8761 GHz of referenced antenna. We obtained efficiency of 93.65% for this proposed antenna. The side lobe level is -24.2 dB for proposed antenna while it is -13.6 dB for the referenced antenna. The value for directivity obtained is slightly increased and become equal to 6.934 dBi for the proposed antenna as compared to 6.442 dBi for referenced antenna. The gain of the proposed antenna is greatly enhanced for proposed antenna and become equal to 6.651 dB as compared to 6.069 dB for referenced antenna.



(a) (b)

Figure 7: Polar plots of the coaxial feed patch antenna for (a) E-plane and (b) H-plane.



(a) (b)

Figure 8: Polar plots of coaxial feed patch antenna backed by EBG array with the height of -10 mm for (a) E-plane and (b) H-plane.

Comparisons for the reflection coefficient and directivity have been made in Fig. 6. The Figure 6(a), shows the comparison between return loss of basic coaxial feed antenna and proposed antenna with 3 × 3 *EBG* structure placed at distance of -10 mm. Also, the directivity comparison of both the antenna without *EBG* and antenna with *EBG* at distance of -10 mm has been shown in Fig. 6(b). These clearly justify and validate the novelty of this research work. The polar plot defines the power level magnitude for different angles. At 4.8 GHz, the polar plot for the gain of the coaxial feed patch antenna with respect to the refrenced and proposed model are given and shown in Fig. 7 and Fig. 8, respectively.

IV. CONCLUSION

In this research paper, a patch antenna is designed along with *EBG* in which results are analysed in terms of gain, S11 parameter and directivity. Hence it is concluded that the results of a patch antenna can be enhanced by using *EBG* structures at the operating frequency of 4.8 GHz. Specifically, antenna gain and directivity are increased. Side lobe level and return loss is decreased by the introduction of *EBG* with patch antenna. So, from the obtained results it is justified that by the reduction of back lobes, surface losses are decreased and hence gain of the antenna is increased. This structure finds its applications in the areas of wireless communications for antenna design.

REFERENCES

[1] Bahl, I. J. and Bhartia, P. 1980. Microstrip antennas. Artech house.

[1] Balanis C. A. 2005. Antenna theory: analysis and design. MICROSTRIP ANTENNAS, third edition, John wiley & sons.

[2] Colburn, J. S. and Rahmat, Y. S. 1999. Patch antennas on externally perforated high dielectric constant substrates. IEEE Transactions on Antennas and Propagation, 47(12): 1785-1794.

[3] Errifi, H., Baghdad, A., Badri, A., and Sahel, A. 2014. Improving microstrip patch antenna directivity using EBG superstrate. American Journal of Engineering Research (AJER), 3(11): 125-130.

[4] Gonzalo, R., De, P. S., and Sorolla, M. 1999. Enhanced patch-antenna performance by suppressing surface waves using photonic-bandgap substrates. IEEE Transactions on Microwave Theory and Techniques, 47(11): 2131-2138.

[5] Goussetis, G., Feresidis, A. P., Apostolopoulos, G., and Vardaxoglou, J. C. 2006. Miniaturisation of defected ground plane using complementary metallodielectric electromagnetic band gap structures. Antenna Technology Small Antennas and Novel Metamaterials, 17-20.

[6] Hongnara, T., Schraml, K., Chaimool, S., Akkaraekthalin, P., and Heberling, D. 2016. Side-lobe reduction of horn antenna using circular patch mushroom-like EBG structure. Microwave Conference (GeMiC), 413-416.

[7] Kaabal, A., Ahyoud, S., and Asselman, A. 2016. A Low Mutual Coupling Design for Array Microstrip Antennas Integrated with Electromagnetic Band-Gap Structures. Procedia Technology, 22(no): 549-555.

[8] Khan, H. A., Ullah, S., Afridi, M. A. and Saleem, S. 2016. Patch antenna using EBG structure for ISM band wearable applications. Intelligent Systems Engineering (ICISE),157-160.

[9] Kovacs, P. and Urbanec, T. 2012. Electromagnetic band gap structures: Practical tips and advice for antenna engineers. Radio engineering, 21(1): 414-421.

[10] Kumar, G. and Ray, K.P. 2003. Broadband microstrip antennas. Artech House.

[11] Li, L., Dang, X., Wang, L., Li, B., Liu, H. and Liang, C. 2005. Reflection phase characteristics of plane wave oblique incidence on the mushroom-like electromagnetic band-gap structures. In Proc. Asian-Pacific Microwave Conf. APMC, 3.

[12] Liu, T., Cao, X. Y., Ma, J. and Wang, W. 2008. Effect of curvature on reflection phase characteristics of electromagnetic band-gap structures. Millimeter Waves, Global Symposium, 260-263.

[13] Sievenpiper, D., Zhang, L., Broas, R. F., Alexopolous, N. G., and Yablonovitch, E. 1999. High-impedance electromagnetic surfaces with a forbidden frequency band. IEEE Transactions on Microwave Theory and techniques, 47(11): 2059-2074.

[14] Sharma, A., Singh, G., and Chauhan, D. S. 2008. Design considerations to improve the performance of a rectangular microstrip patch antenna at THz frequency. Infrared, Millimeter and Terahertz Waves, 1-2.

[15] Sharma, A. and Singh, G. 2009. Rectangular microstirp patch antenna design at THz frequency for short distance wireless communication systems. Journal of Infrared, Millimeter, and Terahertz Waves, 30(1): 1-7.

[16] Tan, M. M., Ali, M. T., Subahir, S., Rahman, T.A., and Rahim, S. K. A. 2012. Backlobe reduction using mushroom-like EBG structure. Wireless Technology and Applications (ISWTA), 206-209.

[17] Yang, F. and Rahmat-Samii, Y. 2001. Mutual coupling reduction of microstrip antennas using electromagnetic band-gap structure. Antennas and Propagation Society International Symposium, 2: 478-481.

[18] Yang, F. and Rahmat-Samii, Y. 2003. Microstrip antennas integrated with electromagnetic band-gap (EBG) structures: A low mutual coupling design for array applications. IEEE transactions on antennas and propagation, 51(10): 2936-2946.

[19] Yang, F. and Rahmat-Samii, Y. 2009. Electromagnetic band gap structures in antenna engineering. Cambridge, UK: Cambridge university press, 1: 156-201.

[20] Yang, L. and Feng, Z. 2004. Advanced methods to improve compactness in EBG design and utilization. Antennas and Propagation Society International Symposium, 4: 3585-3588.

[21] http://www.emtalk.com/tut_2.html

[22] Singh, D., and Srivastava, V. M. 2018. Dual Resonances Shorted Stub Circular Rings Metamaterial Absorber. International Journal of Electronics and Communication, 83: 58-66.