Design and Analysis of EBG Antenna for Wi-Fi, LTE, and WLAN Applications

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Abstract **─** A non-planar electromagnetic band gap (EBG) structured antenna is proposed in this paper for wireless communication applications. The proposed design consists of coplanar waveguide (CPW) fed square patch antenna embedded with triangular EBG backing on FR-4 substrate material for 2.4 GHz (Wi-Fi, LTE) and 5.2 GHz (WLAN) applications. Gain is improved from 2.8 dB to 13.9 dB by adding EBG structure in the proposed antenna and the parametric analysis is done for optimizing the antenna performance characteristics. The proposed antenna provides a maximum efficiency of 82.5% in the resonating frequencies. The prototyped antenna is having good correlation with the simulation results obtained from Finite Element Method (FEM) based Anyss-HFSS. High Frequency Structure Simulator is used to analyze the antenna parameters and the simulated and measured results are correlating well with each other with a slight change in frequencies.

Index Terms **─** Coplanar waveguide, EBG, high frequency structure simulator, long term evolution, wireless fidelity, wireless LAN.

I. INTRODUCTION

Over the past few years EBG structures are gaining much attention in the research activities for their ability to achieve compact size antennas than the conventional antennas by controlling the electromagnetic properties of the antenna [1]. EBG structures are artificial periodic structures which resists the electromagnetic waves in a particular frequency band. EBGs find applications in microwave filters, gratings, amplifiers and microstrip devices [2]. These structures exhibit the ability to vary the electromagnetic behavior and this unique property is incorporated in antennas to achieve enhanced gain, improved radiation pattern and thereby increasing the performance and efficiency of the antenna. The concept of EBG structures is based on the principle of total internal reflection realized by periodic structures. EBGs generate reflected and source waves in same direction which enables improvement in the radiation pattern and gain enhancement and can be used to increase the overall performance of an antenna [3]. The use of EBG structures provides improved capability of suppressing the surface waves and reducing the mutual coupling compared to other traditional approaches [4]. EBGs are basically of 3 types: one dimensional (1D) EBG, two dimensional (2D) and three dimensional (3D) electronic band gap structures. 1D EBG structures are periodic in one dimension only and as a result the band gaps are limited to that particular direction only. This limits the use of 1D EBG structures. 2D EBG structures are homogenous in one dimension and periodic in two directions which make them beneficious for achieving compactness and stability. 3D EBG structures are periodic in all dimensions and have a remarkable feature of blocking the electromagnetic waves in all directions due to its periodic nature but it is difficult to fabricate and analyze. Several researchers incorporated EBG structures in antenna to enhance the directivity and the bandwidth of the antenna [5-6]. Various EBG structures have been incorporated in wearable antennas for reducing SAR and efficient transmission [7-9]. The advantages of using EBGs in microwave applications have been reported in [10]. Various shapes of EBG structure like spiral, E shape, fork like, mushroom, woodpile for providing compactness have been investigated [11]. In this paper, we propose a 2D EBG structured antenna to enhance the gain and bandwidth by suppressing the surface waves. The 2D EBG structures are more valuable than 3D EBG due to their ease of fabrication and their capability of maintaining similar control like 3D structures on the wave propagation. The benefits of EBG structures have motivated us to design our proposed antenna which is a CPW fed square patch antenna embedded with triangular EBG backing with 0.4 depth of trench on FR-4 substrate material having dielectric conductivity of 4.4. This design provides an improvement in gain and efficiency by providing a maximum gain of 13.9 dB with an efficiency of 82.5%.

II. ANTENNA DESIGN

The antenna parameter performances are changed according to various shapes of EBG cells. In this work, we have considered sixteen different antenna

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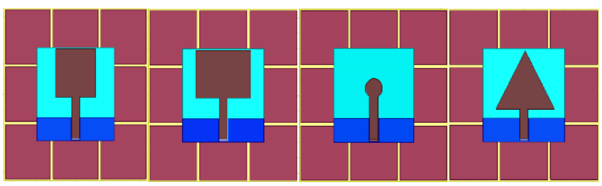
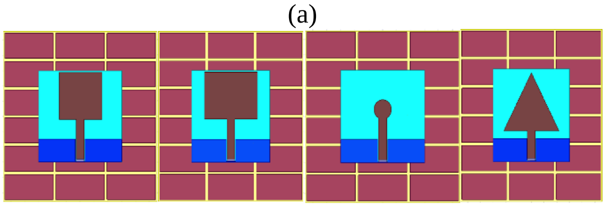
configurations by varying the EBG structures and the patch structures. Basic design structures consisting of rectangular, square, triangular and circular patches are presented. Similarly, the different EBG structures including square EBG, rectangular EBG, circular EBG and square EBG are considered. Figure 1 represents the groups of 4 different model designs considered. The antenna parameters of all the structures can be calculated from the standard expressions available in literature [12]. All the EBG structures are incorporated with trenches of depth of 0.4mm from the substrate. The four different patch structures with square EBG where each unit cell dimension is 37x37mm^2 is shown in Fig. 1 (a) and the corresponding reflection coefficient curves for all the four combinations is shown in Fig. 2. Figure 1 (b) shows the four different patch structures with rectangular EBG where each unit cell dimension is 37x15 mm^2 and the corresponding reflection coefficient curves can be observed in Fig. 3. Similarly Fig. 1 (c) and 1 (d) shows the four different patch structures with circular EBG where each unit cell dimension of radius 17.5 mm and four different patch structures with triangular EBG respectively. The corresponding reflection coefficient curves are shown in Figs. 4 and 5 respectively


(a)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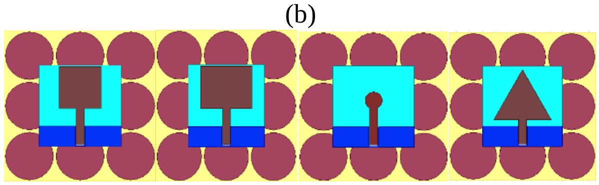
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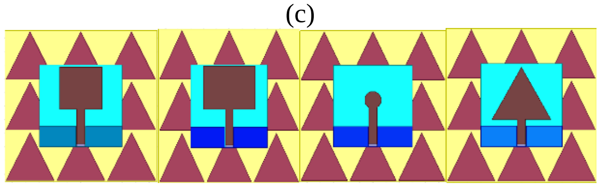

(d)

Fig. 1. Different EBG structures with variations in patch: (a) square EBG with different patch structures, (b) rectangular EBG with different patch structures, (c) circular EBG with different patch structures, and (d) triangular EBG with different patch structures.

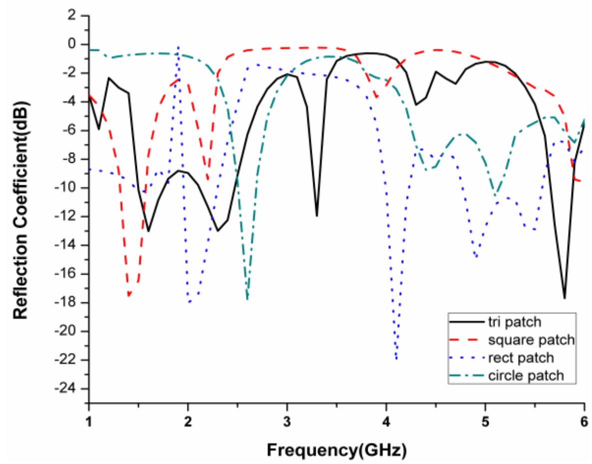


Fig. 2. Simulated reflection coefficient for square EBG with different patch structure.

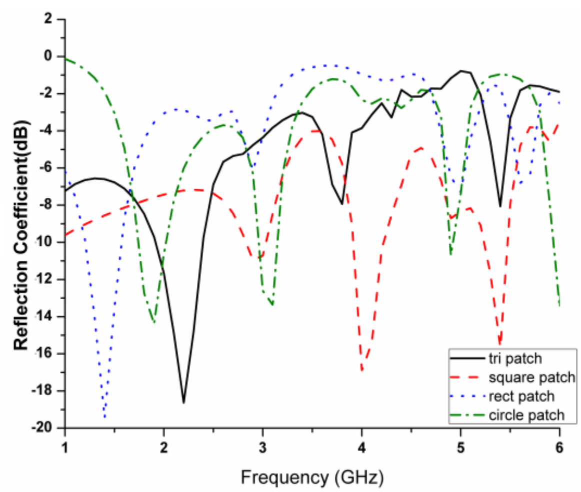


Fig. 3. Simulated reflection coefficient for rectangular EBG with different patch structure.

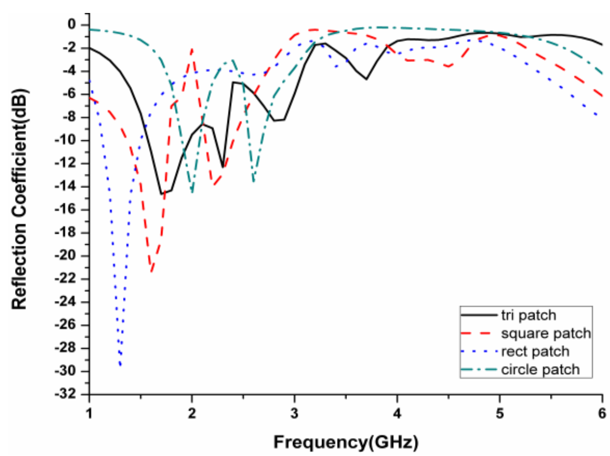


Fig. 4. Simulated reflection coefficient for circular EBG with different patch structure.

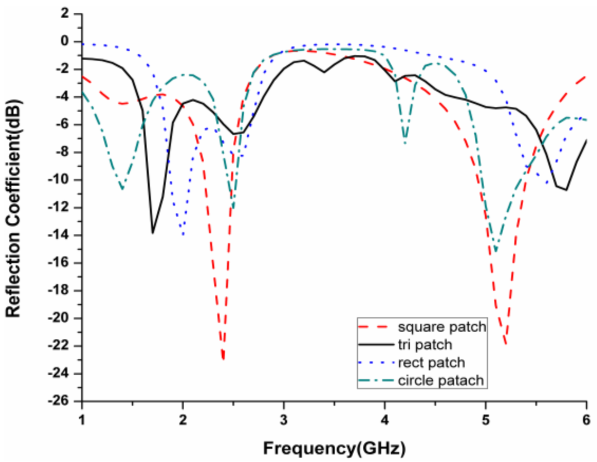


Fig. 5. Simulated reflection coefficient for triangular EBG with different patch structure.

From the analyses and observations implemented in this paper, it can be seen that the square patch antenna with triangular EBG structures gives the effective result in the desired frequency range which can be witnessed from the reflection coefficient curves of other models in Figs. 2, 3, 4 and 5 respectively. It is observed that out of the sixteen different designs, seven designs have satisfactory results in our desired range. The antenna parameters like gain, VSWR and reflection co-efficient of the seven models were compared with each other given in Table 1 and the analyses proved that the optimized result is given by our proposed design.

Table 1: Antenna parameters

Model	Reflection Coefficient (dB)	VSWR	Max Gain (dB)
Square EBG Circle Patch	-17	<2	4
Square EBG Triangular Patch	-13,-16	<2	8.1
Rectangular EBG Triangular Patch	-18	<1.5	4.5
Circular EBG Circle Patch	-13,-14	>2	4
Triangular EBG Square Patch	**-23,22**	**<1.5**	**13.9**
Triangular EBG Rectangular Patch	-12	<2	6.4
Triangular EBG Circle Patch	-14	<2.5	0.8

III. PROPOSED DESIGN AND RESULTS

The proposed CPW fed microstrip antenna with 3D EBG backing is shown in Fig. 6 (a). The antenna is mounted on FR-4 substrate which is one of the most commonly available materials with a relative permittivity of 4.4 and loss tangent of 0.005. The substrate thickness is 1.6 mm with trenches of 0.4 mm. Thickness of the substrate reduces the size of antenna and surface radiations. The bottom plane consists of periodically distributed triangular electronic band gap structures. The patch antenna is fed by a co-planar waveguide which is 6 mm in width and dimension of the feed length is 29.9 mm. A second substrate of height 1.6 mm is incorporated above the EBG surface with a gap of 1.4 mm. The other dimensions of the design are given in Table 2.

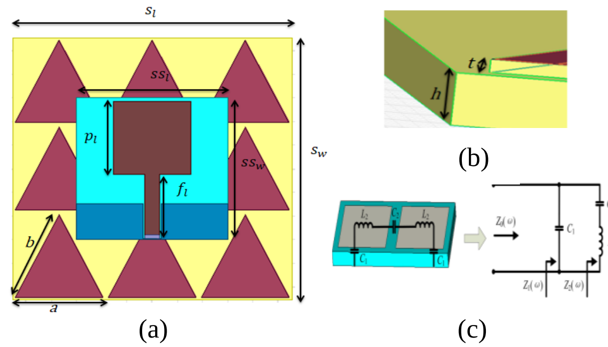


Fig. 6. Triangular EBG square patch antenna: (a) top view, (b) side view, and (c) equivalent circuit of EBG cell.

The side view of the model to show the dimension of the trenches and the equivalent circuit of a conventional EBG cell of the triangular structure is shown in Figs. 6 (b) and 6 (c) respectively.

Where C_1 is the capacitance between unit cells, C_2 arise as a result of gap between unit cells, and ground and L_2 represents the inductance of EBG. The input impedance can be given as:

$$Z_o(w) = Z_1(w)/Z_2(w),$$

$$Z_o(w) = \frac{j(1-w^2C_1L_2)}{W(C_1C_2L_2W^2-C_1-C_2)}.$$

As a result, the resonating frequency expression can be given as:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{C_1+C_2}{L_1C_1C_2}}.$$

It can be seen from the expression of resonating frequency that if we reduce the size of the unit cell then there is no effect in capacitance between the adjacent cells, however C_1 reduces and the overall inductance increases resulting in decrease in the resonating frequency. This can be further observed with the reflection co-efficient curves for square and triangular EBG structures as shown in Fig. 7.

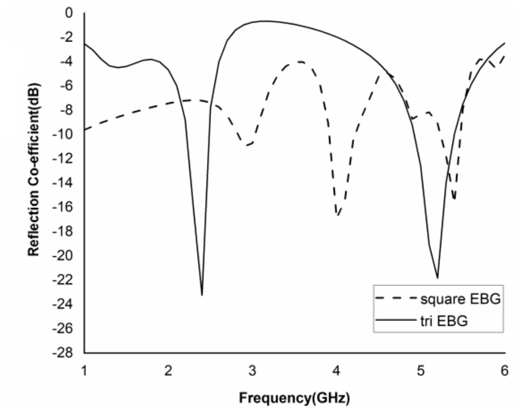


Fig. 7. Effect of cutting EBG.

Table 2: Antenna dimensions

Dimensions	s_l	s_w	ss_l	ss_w	p_l	f_l	a	b
mm	111	111	60	60	29.44	29.9	35	35

Reflection coefficient of the antenna is improved significantly with the use of the EBG structures and gain is also increased to a considerable extent which is evident from Figs. 8 and 9 for both the operating frequency.

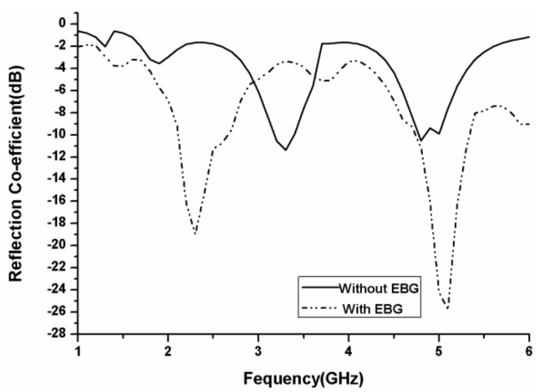


Fig. 8. Measured reflection coefficient with and without EBG for square patch.

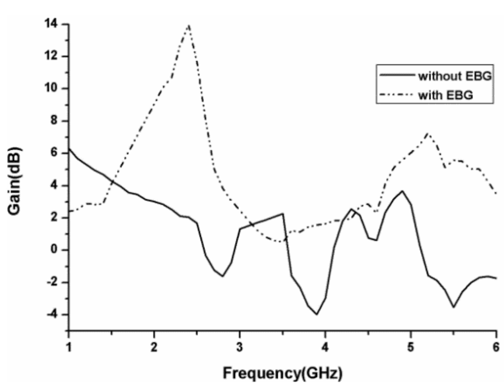
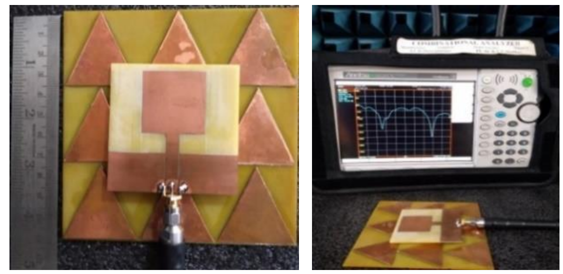


Fig. 9. Gain with EBG without EBG.

The fabricated antenna is shown in Fig. 10. Optimization of all parameters has been done for the best possible performance.



(a) (b)

Fig. 10. Fabricated antenna and measurement setup: (a) fabricated model and (b) measurement setup.

Ansoft High Frequency Structure Simulator (HFSS) version 13.0 is used for carrying out simulations of the proposed design and the measured results were carried out in Vector Network Analyzer manufactured by ANRITSU. The model number is MS2073C offering a frequency range from 5 kHz to 15 GHz and 350 µs/data point sweep speed.

A. Reflection coefficient

Figure 11 shows the measured and the simulated reflection coefficient for the proposed antenna. The proposed antenna is providing return loss greater than 18 dB and VSWR of less than 1.5 at the operating frequencies.

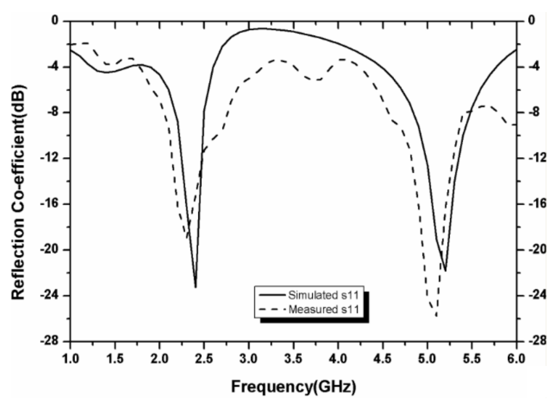


Fig. 11. Simulated and measured reflection coefficient.

It is visible from the figures that the measured and the simulated results are well matched with each other with slight change in frequencies.

B. Radiation pattern

Figures 12 and 13 shows the radiation patterns for both the H and E plane respectively for the two operating frequencies. The radiation pattern of the proposed antenna maintains good performance in both the resonating frequencies.

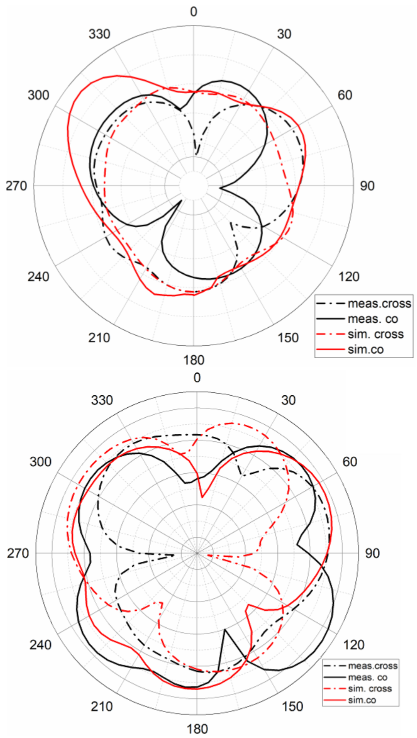


Fig. 12. Measured and simulated E and H plane radiation patterns for antenna at frequency 2.4 GHz.

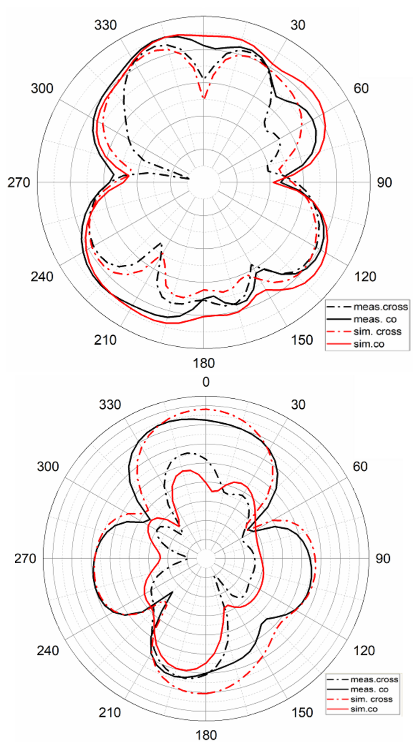


Fig. 13. Measured and simulated E and H plane radiation patterns for antenna at frequency 5.2 GHz.

It is observed that for every operating state of the antenna co-polarization is greater than X-polarization in the H plane. Thus, the antenna is having better transmission and reception efficiency. The gain versus efficiency plot is shown in Fig. 14.

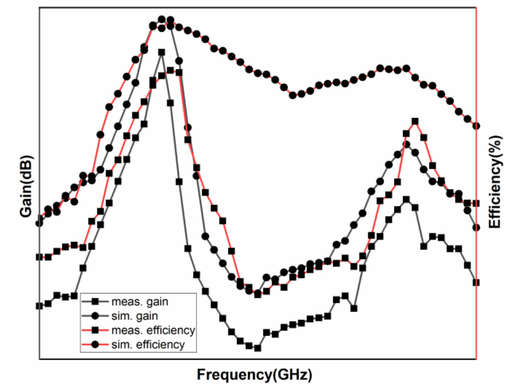


Fig. 14. Gain vs efficiency plot of proposed design.

The proposed design has a maximum gain of 13.9 dB and efficiency at 2.4 GHz resonating frequency in 82.5%. Another resonating frequency is obtained at 5.2 GHz with a gain of 7.2 dB and efficiency of 67%.

IV. PARAMETRIC ANALYSIS

To achieve the best possible performance, several physical parameters of the proposed design are varied to observe the changes in the reflection coefficient which are discussed in this section. The original dimensions used in the proposed model gives the optimized results which is visible from the observations.

A. Variation in width of feed

The antenna is CPW fed with a 50 ohm transmission line. The variations in the feed width were evaluated by changing the width to 5 mm and 7 mm and our proposed design gives the optimized result as shown in Fig. 15.

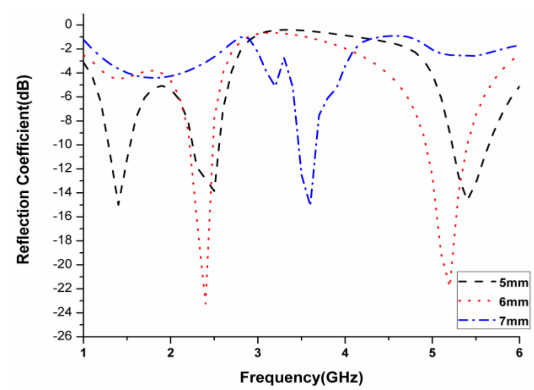


Fig. 15. Simulated reflection coefficient by changing feed width.

B. Variation in distance between EBG and antenna

Reflection coefficient is observed by changing the distance of the triangular EBG structures and the CPW antenna to 1 mm and 1.8 mm. The distance of 1.4 mm of our proposed design is gives the best results as evident from Fig. 16.

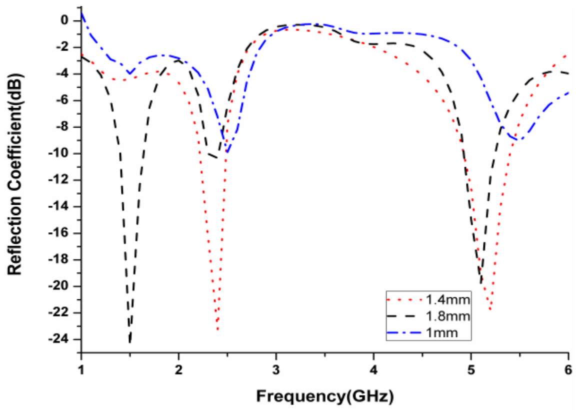


Fig. 16. Simulated reflection coefficient by changing the spacing between EBG and CPW antenna

Table 3 shows the comparison of size, bandwidth, gain and resonating frequencies of other antennas available in literature with the proposed design for wireless applications. It can be observed that the overall gain and bandwidth have been improved with our proposed design. Moreover, the size of our proposed design is also the optimized one with reflection coefficient > 20dB. Numerical results demonstrate that the proposed antenna is advantageous in terms of bandwidth, gain, low weight and cost of fabrication.

Table 3: Comparison with other antenna models

Ref. No.	Size (mm)	Resonance Frequency (GHz)	Gain (dB)	Bandwidth (GHz)
[13]	140x80	2.4	8.7	2.4-2.57
[14]	60x60	2.4	2.4	2.4-2.5
[15]	60x60	2.44	5.39	2.3-2.435
[16]	68x40	5.8	8.4	5.4-5.8
[17]	218x53x73	3.5	4.7	3.5
[18]	100x100	1.57 and 2.3	3.2	1.57-1.65, 2.2-2.4
This paper	60x60	2.4 and 5.2	13	2.2-2.5, 4.8-5.3

V. CONCLUSION

In this paper, triangular EBG structured CPW fed square patch antenna is proposed. Due to the transmission characteristics of EBG structures and the use of CPW feeding, the overall size of this patch antenna is smaller than the conventional patch antennas. The back lobes and mutual coupling are reduced to a greater extent and considerable gain has been obtained.

Proposed antenna will serve some of the S-band and C-band applications covering WiFi, WIMAX and LTE. The proposed antenna provides a gain improvement of around 10 dB with 82.5% efficiency and the resonating frequencies of 2.4 GHz and 5.2 GHz with good impedance matching makes the proposed antenna suitable for Wi-Fi, LTE and WLAN applications.

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