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DESIGN AND ANALYSIS OF A 60 GHZ MILLIMETER WAVE ANTENNA

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Abstract

In this paper an inset feed 60 GHz millimeter wave microstrip patch antenna is proposed for future high speed wireless communication systems. The performance of a conventional 60 GHz patch antenna compared with metamaterial-based 60 GHz antennas. The later employs three types (mushroom, cross and hexagonal) of Electromagnetic Bandgap (EBG) surfaces as a ground planes. The millimeter wave antenna employing the cross-shaped EBG give improved gain as compared to the rest of the antenna models. The 60 GHz antenna based on the mushroom type EBG present better efficiency due to the surface suppression by the ground plane. The proposed antennas can be used in future high speed wireless applications. Due to the very small size these antennas are suitable for medical implants operating in the unlicensed millimeter wave band.

Keywords: Millimeter wave, metamaterial; bandgap, medical implants

1.0 INTRODUCTION

In this paper a millimeter wave antenna operating at 60 GHz is presented for future unlicensed band having bandwidth of 7 GHz (from 57 to 64 GHz)[1]. The high data rate (multi-gigabit per second), broadband wireless systems are becoming more ubiquitous and the number of users and corporations using wireless technology are rapidly increasing. Millimeter Wave (mmW) wireless technology decreasing the speed gap between the wireless and wired system.

The fiber optics is a high data rates and high bandwidth medium but due to high installation and operational cost the financial burden and logistic challenges limit its importance. Millimeter Wave (mmW) or sometimes called WiFiber (Wireless Fiber) possess the potential to deliver high data rates and bandwidth comparable to the fiber optics without the cost and deployment constraints.

Millimeter wave corresponds to the EHF (30-300GHz) band of the RF spectrum, the wavelength is in the range of 1-10 mm and hence the name mmW. This band is the future solution for high date point to point and point to multipoint and line of sight (LoS) terrestrial communication systems. The proximal wireless [2] provides short range Ethernet bridges (57-64GHz band) to establish wireless connection between small businesses and campuses. The over-crowding of existing wireless systems favors communication at millimeter-wave bands.

The range of the communication channel at millimeter waves is limited to less than 1 kilometer due to peak absorption of atmosphere oxygen and water vapor molecules [3]. Therefore 60 GHz band frequency can be independently reused in densely populated environments to deliver high data rates. The E-bands spectrum (70, 80, 90 GHz bands) is characterized as low probability of detect/low probability of intercept (LPD/LPI) [2] and the best secure, gigabit speed, point–to-point communication in battlefields and hostile territories. Millimeter band systems works at higher frequency (60, 70, 90GHz bands) resulting in compact antennas with much directive and focusing characteristics (pencil beams) [2] and possible to designed on chip. The 60 GHz band is unlicensed band which favors the mmW for future communication.

Microstrip antennas are effected by high conductor and dielectric losses (substrate) [4].surface waves and out of phase reflection from ground planes are the main disadvantages of micro strip patch antenna. The efficient technique for surface wave suppression and in phase reflection (reflect incident waves with near zero phase) is EBG (Electromagnetic band gap) [4] materials. The EBG produced a band gap frequency prohibiting the propagation for the surface waves. The EBG enhance antenna performance such as gain, directivity and multi-band operation [5].

In this paper a metamaterial based millimeter wave antenna operating in the 60 and70 GHz band is designed and analyzed on different types of periodic Electromagnetic Bandgap (EBG) structures. The square and cross metallic pattern periodic structures are preferred choices for improving the performance of the proposed antenna.

The rest of the paper is organized as follows: Section 2 present the geometry and design procedure of the patch antenna and EBG ground planes. Results are explained in Section 3. The Paper is concluded in Section 4.

2.0 GEOMETRY AND DESIGN PROCEDURE

2.1 Antenna

The proposed antenna is printed on a (8 mm x 8 mm x 0.5 mm) FR-4 epoxy substrate having a dielectric constant ε_r= 4.4, and a loss tangent of 0.02. The geometry of the patch antenna is outlined in Figure 1 and Table 1 shows the corresponding antenna dimensions. The electrical length (*L*) in terms of wavelength (λ_0) of the rectangular patch antenna lies in the range $\frac{\lambda_0}{3} < L < \frac{\lambda_0}{2}$.

The length (L_a) and width (W_a) of the patch are obtained using the well-known patch antenna theory in [6]:

$$W_a = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon r + 1}} \qquad (1)$$

$$L_a = \frac{C}{2f_r\sqrt{\varepsilon r}} \qquad (2)$$

The antenna is excited using a 50 Ω inset feed microstrip line of length L_f and width W_f. The feed dimensions are evaluated using [6].

$$W_f = \left(\frac{377 - 2Z_c\sqrt{E_r}}{Z_c\sqrt{E_r}}\right)h \qquad (3)$$

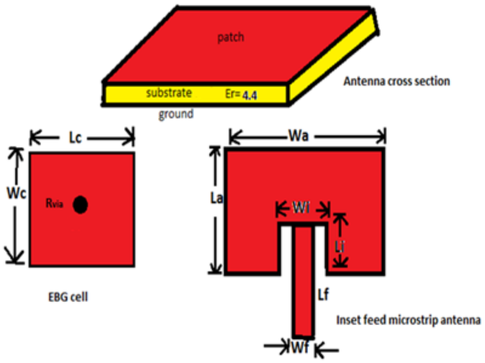

Figure 1 Antenna geometry

2.2 EBG

The geometry of EBG is shown in Figure 2. In EBG structures the patch and ground are connected through via with $R_{via} = 0.025mm$. The EBG surfaces behaves as a high impedance surface in the desired or specific frequency range and suppress unwanted surface waves from propagation, hence improving the antenna gain. Also EBG unit cells are design to ensure the in phase reflection from the ground plane which is add up with desire propagation and collectivity enhance the antenna propagation. The operating principle of the EBG surfaces can be explained by an LC equivalent circuit. In the equivalent circuit the capacitance and inductance can be approximated by the following formulas [7].

Table 1 Summary of antenna dimensions

Symbols	Dimension (mm)	Symbols	Dimension(mm)
L_a	0.9	L_i	0.4
w_a	1	W_i	0.26
L_f	1	W_f	0.18

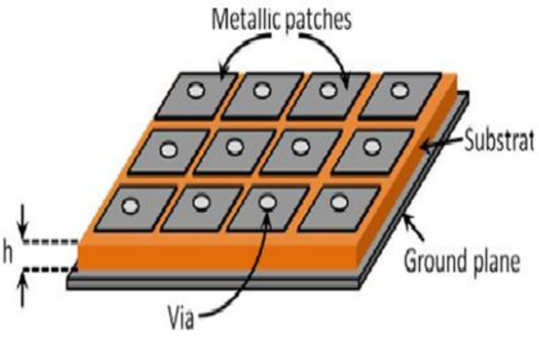

Figure 2 EBG Geometry

$$C = \frac{W_c\varepsilon_o(1+\varepsilon_r)}{\pi}\cosh^{-1}\frac{W_c + g}{g} \qquad (4)$$

$$L = \mu_o\mu_r h \qquad (5)$$

The resonant frequency of EBG cells is [7]

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad (6)$$

In the EBG structure, W_c, g, h, ε_r and μ_r are respectively, the width of the EBG cell, the gap width between adjacent cells, the substrate thickness, the permittivity and permeability of the material surrounding the EBG. These parameters are used to determine the surface wave impedance and resonant frequency of the EBG surface. The geometry of each type EBG unit cell is shown in the Figure 3 and the dimensions are summarized in the Table 2.

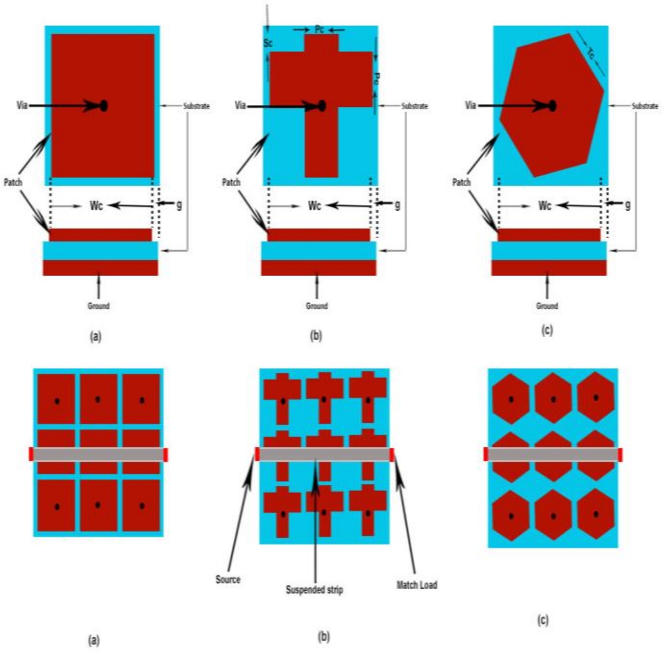

Figure 3 EBG unit cells and Surface Wave Bandgap setup (a) Mushroom (b) Cross (c) Hexagonal.

The length and width of EBG cell is [8, 9]

$$L_c = W_c = 0.12\lambda_0 \tag{7}$$

The periodicity of the EBG cells is

$$S_x = L_c + g \tag{8}$$

The gap between the cells is

$$g = 0.02\lambda_0 \tag{9}$$

The via of the EBG cell is

$$R_{via} = 0.005\lambda_0 \tag{10}$$

The cross sectional view of designed millimeter wave antenna with and without EBG structures is shown in the Figure 4.

Table 2 summary of dimensions of EBG unit cells

Types of EBG	Dimensions (mm)
Mushroom	W_c =0.6, g=0.09, via=0.05
Cross	W_c =1.02, g=0.08, via=0.025 P_c =0.34, S_c =0.17
Hexagonal	W_c =1, g=0.75, via=0.05 T_c =0.52

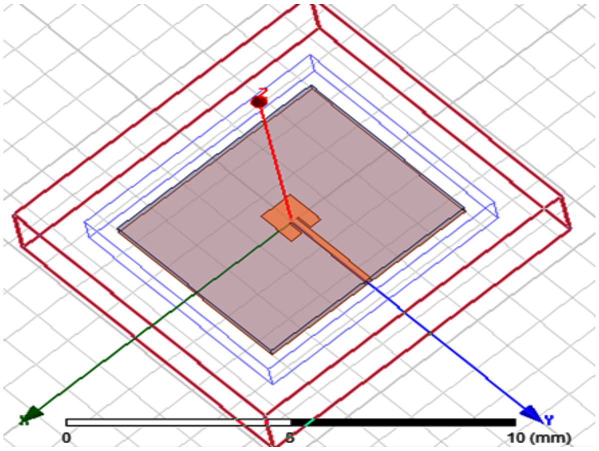

Figure 4(a) Basic Antenna

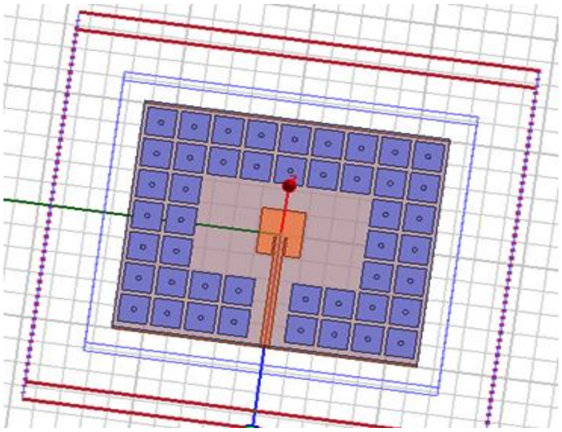

Figure 4(b) Mushroom EBG

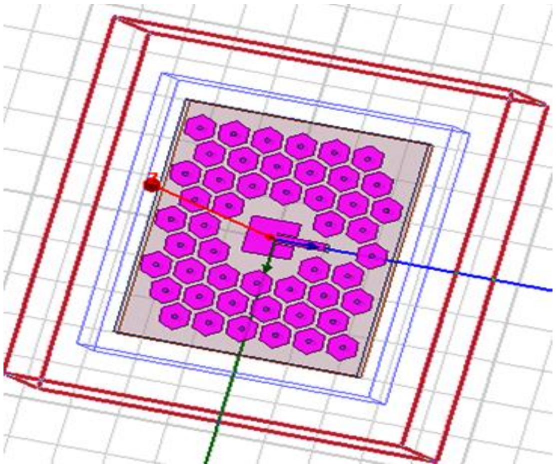

Figure 4(c) Hexagonal EBG

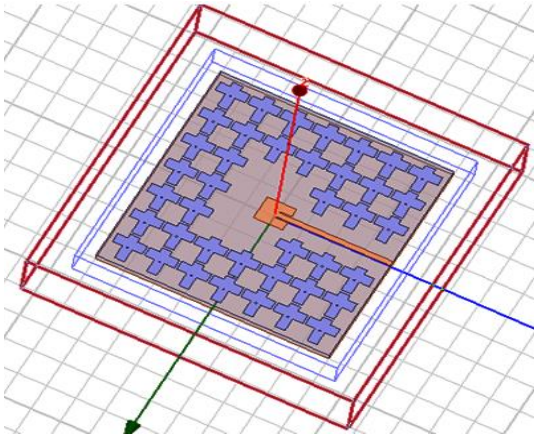

Figure 4 (d) Cross Structure EBG

For the high gain and bandwidth we simulate the cross, mushroom and hexagon EBG structure. For mushroom $L_c = W_c = 0.6$mm, $R_{via}=0.05$mm, for cross $R_{via}=0.025$mm $L_c = W_c = 1.02$mm, for hexagon $L_c=0.9$mm, $W_c=1$mm and $R_{via}=0.05$mm.

3.0 RESULTS

The basic antenna without and with EBG are analyzed using HFSS. The antenna parameters like return loss; radiation pattern and gain are compared and discussed.

3.1 Return Loss

The reflection coefficient (*return loss in dB*) shows the fraction of the input power being returned back at the input port of the antenna. This coefficient does not give any idea of the remaining power which is being radiated or dissipated. Hence it does not clarify whether the antenna is a bad or a better radiator of electromagnetic waves [10]. The antenna and EBG structures are analyzed in the 50-70 GHz range using HFSS. The antenna resonates at 60 GHz giving a return loss (S_{11}) and bandwidth (BW) of -33 dB and of 11 GHz respectively. The plotted curve shown in Figure 5 show that the antenna covers the whole unlicensed spectrum of 60 GHz.

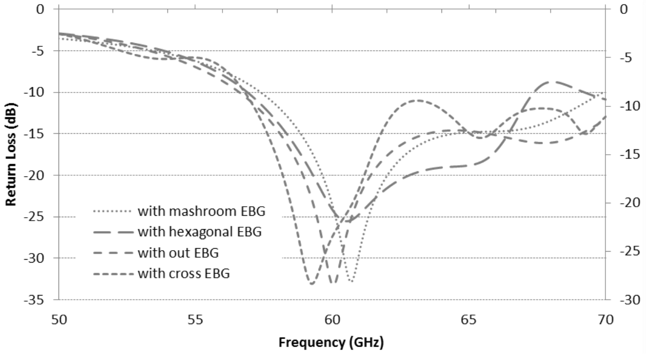

Figure 5 Return loss

3.2 Transmission and Reflection Co-Efficient

To analyze these coefficients for the proposed EBG surfaces the setup of Figure 3 is used. Transmission coefficient (S_{21}) is determined by using a 50 ohm microstrip line fixed above the proposed ground plane (Figure 3). The transmission line is excited at both ends using waveguide ports. One port works as a source and the other as a load. An Electromagnetic Bandgap ground plane reduces the propagation of surface waves within its band gap range. The scattering parameters of the proposed surfaces are illustrated in Figure 6 which shows that the bandgap of all EBG structures occurs near 60 GHz which is the desired frequency bandgap. The mushroom like EBG structure shows better transmission and reflection characteristic then the other EBG structure. Hence the mushroom EBG structure gives relatively better response in terms of in-phase reflection and surface wave reduction in the desired frequency due to its high impedance characteristics [11].

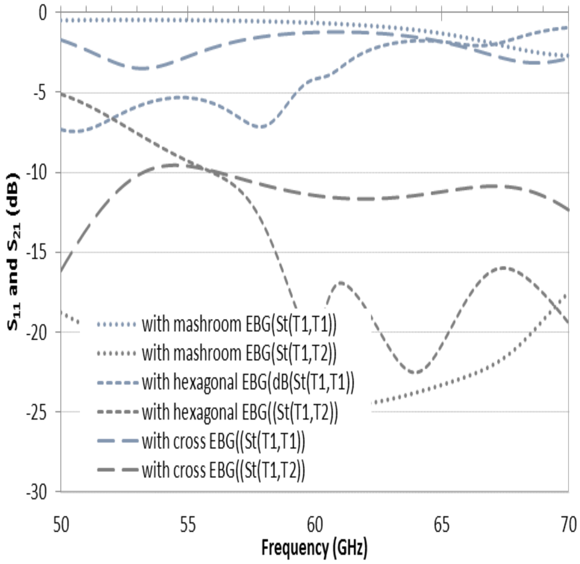

Figure 6 Scattering paramters of EBG Based 60 GHz Patch antennas

3.3 Radiation Pattern And Gain

The radiation pattern and E-plane gain of the proposed antenna backed by the proposed EBG structures are demonstrated in Figure 7. It is evident that the cross-shape EBG give very small back lobes, due to better surface wave suppression. It is worth mentioning that the gain of antenna backed by cross shaped EBG ground plane is enhanced by 2 dBi. Table 3 summarized the gain, directivity and efficiency of the antenna with and without EBG

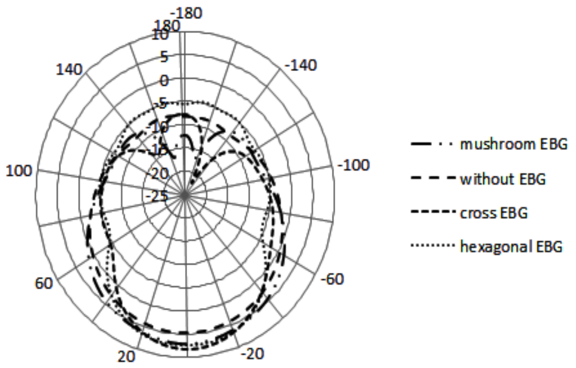

Figure 7(a) Radiation pattern at 0 deg

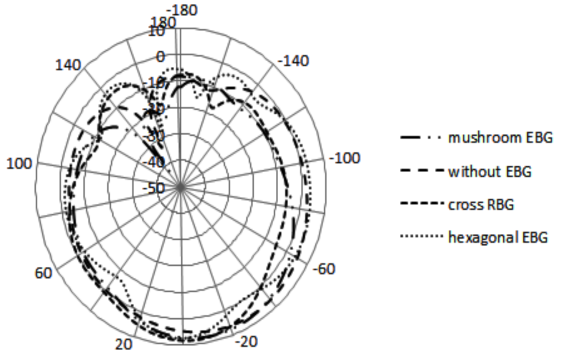

Figure 7(b) Radiation pattern at 90 deg

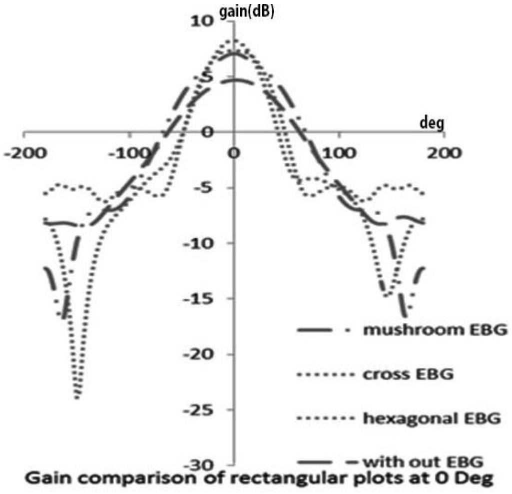

Figure 7(c). Gain at 0 degree

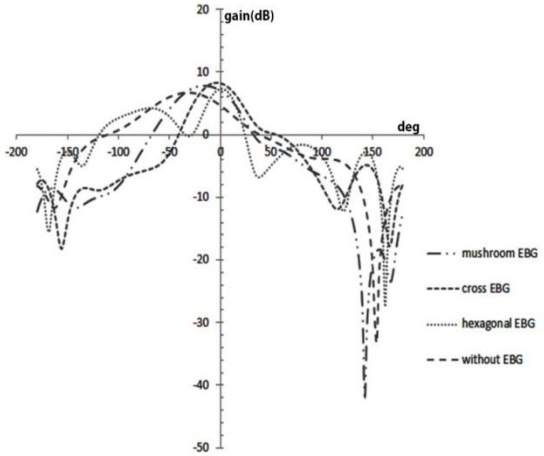

Figure 7(d) Gain at 90 degree

Table 3 Summarized results

Parameter	Antenna without EBG	Cross EBG	Mushroom EBG	Hexagonal EBG
Gain(dBi)	6.721	8.30	7.83	7.35
Directivity(dBi)	7.36	9.54	8.60	8.21
Efficiency(dB)	4.51	6.01	5.60	5.12

4.0 CONCLUSION

In this paper a conventional millimeter wave (60 GHz) patch antenna is designed using an FR4 substrate. The antenna operates well within the unlicensed 60 GHz band. In order to enhance the gain and efficiency of the conventional millimeter wave antenna, three different types of EBG surface (mushroom, cross and hexagonal) were used as a ground plane. These EBG surfaces were designed at 60 GHz using the basic theory of Sievenpiper's [11] surfaces. The surface wave characteristics of the EBGs were studied in detail using the microstrip line set up. It was found that the cross shaped EBG surface gives better surface wave suppression in the 60 GHz band.

The conventional antenna (without EBG) gave again of 6.7 dBi which has been enhanced to 7.35, 7.83 and 8.3 dBi by using a hexagonal, mushroom and cross EBG structures respectively. The proposed antenna can be used in short-range, future high-speed and portable communication systems.

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