ANALYSIS OF WIDEBAND MILLIMETRE WAVE PBG ANTENNA

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Abstract - Present paper has been set to analyze the effects of PBG structure over a new generation communication systems, which is in great demand in today's era. Efficiency and gain improvement are the major concern to enhance the bandwidth to support multimedia activities properly. Author has analyzed the rectangular antenna structure for wideband applications with and without PBG material using commercial software CST microwave studio and through coding. Most specific properties like return loss, VSWR and bandwidth are obtained as high as compared to simple rectangular antenna. Radiation pattern also supports the analysis in proving effect of single mode over multimode operation.

Keywords - PBG structure; Band gap; Rectangular Microstrip Antenna; Antenna Efficiency; CST Microwave Studio.

I. INTRODUCTION

Increasing demand of bandwidth requirement has enhanced an interest in field of antennas to fit into new generation of mobile communication. From larger size antennas to very thin and slick antennas have been developed as per need and users requirement. Simple Microstrip patch antennas played an important role in communication through wireless connections [1]-[2]. Variations in parameters of patch antennas have been given effective values of measurable quantities. Besides this, antenna miniaturization characteristics are also being used to develop and plant to improve the radiation properties.

Microwave PBGs have their own specifics properties that are different from optics. First, the higher wavelength means bigger absolute tolerances than in optics. Secondly, capacitance and inductance are specific properties, not directly seen in optics, because which can vary shape characteristics impedance and make influence on the formation of band gaps. 3-D PBG is complicated for simulation, realization and investigation, due to dependency over the angle of incident and on polarization (may be cross polarization). Quasi3-D and 2-D structures are more successful and is being improvised to enhance and isolate the antennas characteristics and photonic crystal based waveguide. PBG implantation in antenna design improves the directivity and total gain. It incorporates mainly: suppression of higher harmonics, suppression of the current surface waves, which is the biggest challenge for antenna designers. As surface waves radiate from the roughness of the substrate edges and can cause a problems to the radiation pattern.

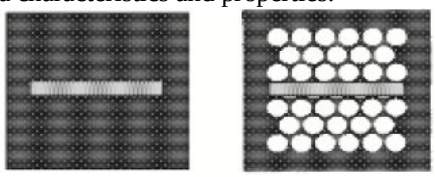
The microstrip suffers from an inherent problem of narrow bandwidth and low gain, which restricts the antenna designers to think about advance technology. Bandwidth improvement can be done in many ways [3]. In present paper, such problems have been removed using PBG structures. In such antennas, microstrip feeding has been used for excitation.

First proposed PBG based antenna [4] was based on printing an element on 2-D PBG material. If the operating frequencies of the substrate modes fall within the stop-band, decay take place exponentially, this suppresses the surface wave to reduce side lobes. Dielectric slab with planar square gratings (Square air implants) [2] was examined with a printed dipole antenna over it [5].

Use of PBG material removes many problems like oscillator type active antenna using MESFET or Gunn diode, which has spurious radiation near its operating frequency and low gain of MSA. Frequency selective surface is a low cost printed electromagnetic material, used to control the surface currents and this is usually implanted by two dimensional arrays of metallic patterns.

New branch of antennas deal with printed antenna suitable for wireless communication equipment and cell phones. But these applications demand some important features like compactness, wideband or multiband operation, high gain, diversity reception, uniform radiation pattern, reduced radiation hazards etc. Radiation hazard is an important issue from the point of view of user's health.

The PBG structure is basically a periodic metallic pattern printed on dielectric substrate for microwave and millimetre wave applications and this provides a stop band of electromagnetic waves propagating through it. A microstrip line printed on substrate (Fig. 1(a)) and on a PBG material (Fig.1(b)) both are showing different transmission characteristics as revealed from Fig.2. Unlike conventional microstrip line, the microstrip on PBG substrate shows a stop band over 5.5 to 10.5 GHz for their transmission characteristics which restricts the propagation/generation of surface waves in a mictostrip, the PBG attributes new features in a microstrip structures. Those are applied to improve antenna characteristics and properties.



(a) (b)

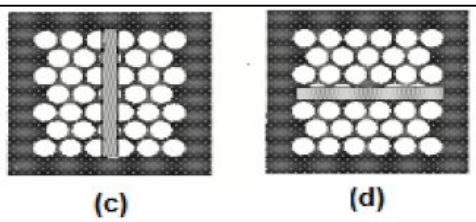


Fig.1 Microstrip line on a usable substrate (a), microstrip line on a PBG substrate (b). microstrip line on a PBG substrate with a defect (c) and (d) [4].

II. MATHEMATICAL EXPLAINATION

To design the structure of planar microstrip antenna, the very first important parameter is design frequency, which probably has taken in millimetre frequency range and that represents the resonant frequency of that particular antenna. In case of microstrip antenna, three layers are designed Fig.2, to use it for wide band application. Ground, substrate and patch, form microwave microstrip antenna, in which patch and ground planes act as conductors, whereas middle layer substrate provide supports to these two layers [6].

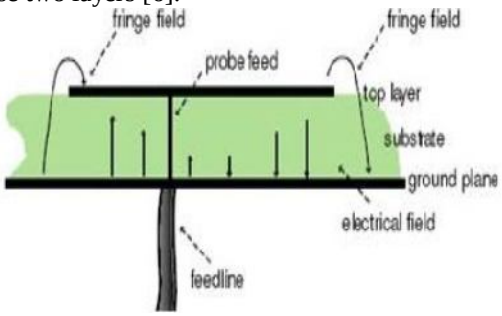


Fig. 2 Fringing Field Pattern in Microstrip Antenna [6].

As stop band characteristics of PBG preferable for electromagnetic wave propagation, is fully analyzed by drawing the dispersion diagram for rectangular PBG microstrip antenna, gives the frequency spectrum at 45 GHz to initiate the required mode and neglects the higher harmonics. Figure 3, reveals the stop band characteristics for designed structure and justify the importance of PBG material. Blue line represents the stop band characteristics where required mode propagates with their normalized resonant frequencies.

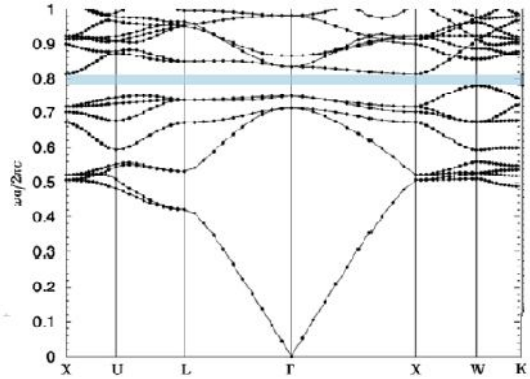


Fig.3 Dispersion diagram for PBG structure for required radius of rod 2 mm with periodicity of 6 mm.

Figure 4, presents the refractive index for substrate Rogers RT5870, after taking PBG structure with gap size $\Delta\omega/\omega_0$, which represents resonant frequencies. Gap size is the periodicity of rods, the main effective part of PBG.

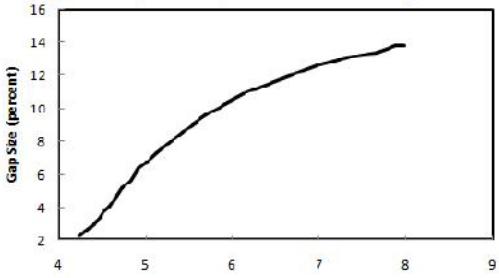


Fig.4 Dielectric constant behaviour with normalized periodicity.

For simple rectangular microstrip antenna (MSA), the resonance frequency depends on the patch size, cavity dimension, and the filling dielectric constant, given as,

$$f_{mn} = \frac{k_{mn} c}{2\pi\sqrt{\varepsilon_r}}, \quad (1)$$

where m, n = 0, 1, 2,.... k_{mn} = wave number at m, n mode, c is the velocity of light, ε_r is the dielectric constant of substrate, and

$$k_{mn} = \sqrt{\frac{(m\pi)^2}{W} + \frac{(n\pi)^2}{L}}, \quad (2)$$

For TM_{01} mode, the length of non radiating rectangular patch's edge at a certain resonance frequency and dielectric constant according to equation (1) becomes,

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_r}} \quad (3)$$

$$W = \frac{c}{f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}, \quad (4)$$

where f_r = resonance frequency at which the rectangular microstrip antennas are to be calculated. The radiating edge W, patch width, is usually chosen such that it lies within the range $L \langle W \langle 2L$, for efficient and intense radiation. The ratio W/L = 1.5 gives good performance according to the side lobe and back lobe appearances in radiation pattern. In usual practice, the fringing effect causes the effective distance between the radiating edges of the patch to be slightly greater than L. Therefore, the actual value of the resonant frequency is slightly less than f_r. Taking into account the effect of fringing field, the effective dielectric constant for TM_{01} mode is derived using [4], [7]. Using these equations, total length can be calculated as,

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{eff}}} - 2\Delta l, \quad (5)$$

where, ε_{eff}=effective dielectric constant and Δl=line extension which is given as,

$$\varepsilon_{eff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r + 1)}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (6)$$

$$\frac{\Delta l}{h} = 0.412\frac{(\varepsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)} \quad (7)$$

A combination of parallel plate radiation conductance and capacitance susceptance loads both radiating edges of the patch, which can be measured as,

$$G_1 = \frac{W}{120\lambda_0}\left[1-\frac{(k_0 h)^2}{24}\right], \frac{h}{\lambda_0} < \frac{1}{10}. \quad (8)$$

where λ_0 is the free-space wavelength and wave number $k_0 = (2\pi f_r)/c$. The input conductance of the patch fed on the edge will be twice the conductance of one of the edge slots, which can be obtained as.

$$R_{in} = \frac{1}{2G_1}. \quad (9)$$

Here, the patch is fed by microstrip feedings, so the impedance will vary from zero in the center to the edge resistance approximately as,

$$R_{in} = \frac{1}{2G_1}\cos^2\frac{\pi}{L}x_0, 0 \le x_0 \le L/2, \quad (10)$$

Now, arranging PBG structure in rectangular patch antenna follows certain rules, because of periodic structure, in which period of PBG structure T is half of the guide wavelength of a general microwave strip λ_g, can be written as,

$$T = \lambda_g / 2, \quad (11)$$

$$\text{where, } \lambda_g = \frac{c}{f\sqrt{\varepsilon_e}}, \quad (12)$$

$$\varepsilon_e = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}\left[1+12\frac{h}{W}\right]^{-1/2}, \quad (13)$$

Here, the rectangular patch antenna is designed in a conventional fashion by itself and then surrounded properly by the PBG lattice structure in substrate. The period of PBG with square lattice is $T = 6$ mm. Several cases of return loss with different cell size a relative to the period T are simulated, and an optimum size of the hole $a/T = 2/3$ is measured. The mutual coupling among rectangular conformal microstrip antenna elements and interconnection feeding scheme should be figured out in the design steps. The distance between two elements of proposed array is 12.5 mm, integrated with groove loaded microstrip feeding with the depth l_{slot}. For the matching of input impedance with the antenna can be calculated [4],

$$l_{slot} = \arccos\left(\sqrt{Z_c / R_a}\right)\frac{L}{\pi}, \quad (14)$$

where, Z_c is the characteristic impedance of the microstrip, $R_a = (120\pi\lambda_0 hQ)/(\varepsilon_r LW)$.

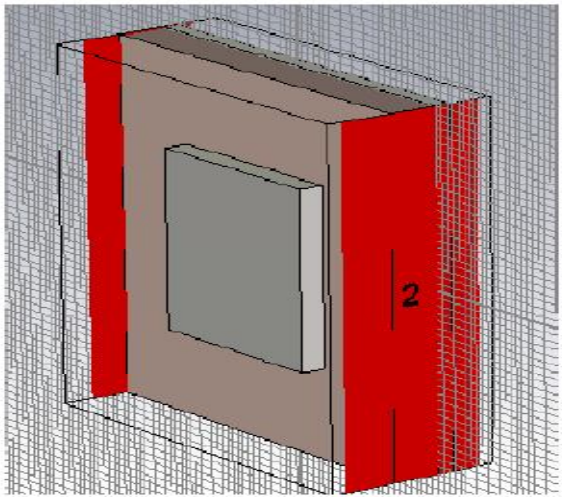
III. IMPLEMENTATION OF ANALYSIS

Comparative analysis has been performed between simple MSA and PBG based structure for frequency approximately 45 GHz and results related to this work are properly analyzed using commercial software CST microwave studio. Parameters have been decided using equations in section III, and have been kept same for both designs (Simple MSA, PBG MSA). PBG based antenna has been taken to check the compatibility with 5G advance cellular system technology. For PBG, rods have been taken, putting at equal periodicity. Parameters are considered according to the resonant frequency given in Table 1.
Design structure of proposed antenna for simple rectangular shape and PBG, have been shown in Figs. 4a and b respectively. From figure 4a, it is clear about the shape of simple radiating patch, rectangular structure to radiate properly and reduces the losses such as surface radiation loss etc.

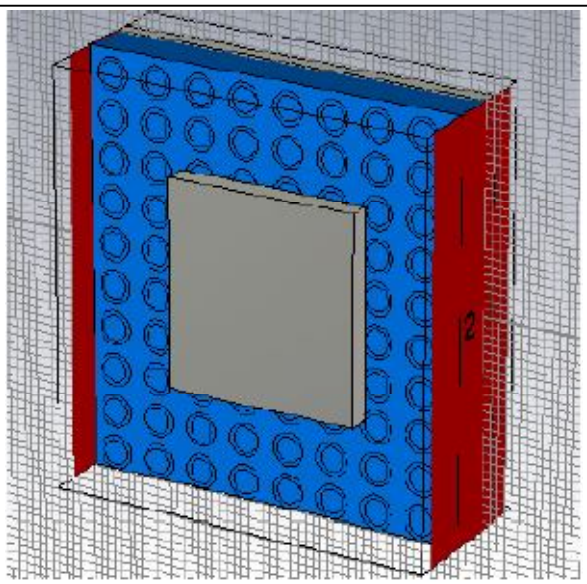
Design Configuration Antenna	Material used	Parameters
Substrate	Roger RT 5870	Height = 3 mm,
Patch	Copper (PEC)	Height = 0.4 mm
Ground Thickness	PEC	L = 25 mm, W = 25 mm, Height = 0.8 mm
PBG rods	Vacuum	100 Periodicity = 6 mm
Microstrip Transmission Line	PEC	Calculated using equations and based on matching impedance

Table 1. Design specification of PBG Antenna

Figure 4(b) reveals the PBG based structure, where all the parameters are same, only the difference in having rods below the patch, which actually being used to propagate single mode TM01 mode including propagation of EM waves through stop band of the structure. The PBG especially used to remove losses through substrate and create a channel for propagation through a particular stop bands. Substrate material is Roger RT5870 shows a better compatibility and removes complexity as compared to other dielectric materials.
The return loss for both types of structures is most important parameter to reveal its applicability and mobility in wireless field communication. As shown in figs. 5(a) and (b), return loss is more improved in case of PBG antenna, as compared to simple microstrip antenna. From fig 5(a), return loss is minimum at 45.11 GHz, has value -13.50 dB, whereas in fig 5(b), return loss is minimum at 44.12 GHz and 45.11, but not comparable with fig 5(a). Value at these frequencies are -22 dB and -15 dB. Although, fig 5(b) is giving wideband property, but because of losses, noise signal (reflection noise) is responsible for such return loss.



(a)

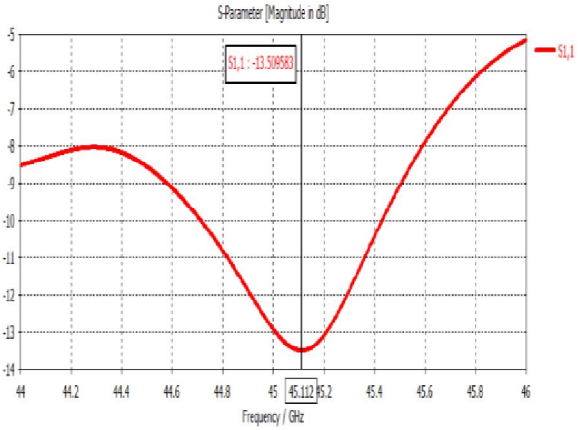


(b)

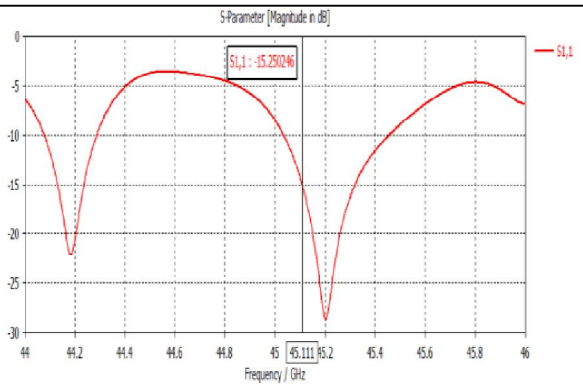
Fig. 4 Simple Microstrip rectangular antenna (a), PBG based rectangular antenna (b).

One of most important parameter is VSWR, which proposed antenna compatibility with transmission from input to output and gives information about reflection from output in form of standing wave ratio, actual cause of loss. Ideal value of VSWR is one, which can be achieved only on zero reflection, which is not possible in case practical antennas. Figs 6(a) and (b) show the value of VSWR at the resonant frequencies. It is very clear from plots, the VSWR is better in case of PBG antenna. In the plot, passes have been taken during simulation to get more accurate results under CST microwave studio.

Total efficiency and radiation intensity of planer antennas give directivity, gain, field pattern (Electric and Magnetic) and spectral power density. From, figures. 7a, b, c and d, efficiency of both antennas directly measured using simulated plots. From the data, given below in the plots 7(a) and (b) much more informative in terms of gain, where PBG antenna is giving higher gain as compared to simple antenna.

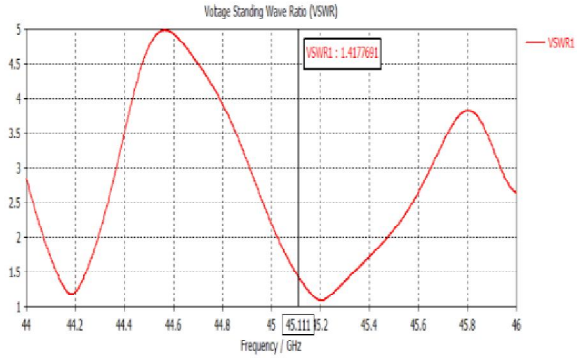


(a)

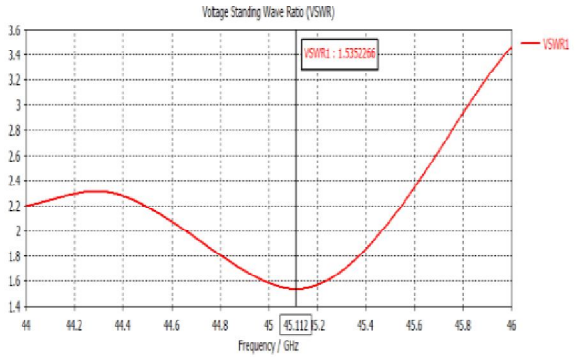


(b)

Fig. 5 Return loss for PBG antenna (a), Return loss for simple rectangular microstrip antenna (b).



(a)



(b)

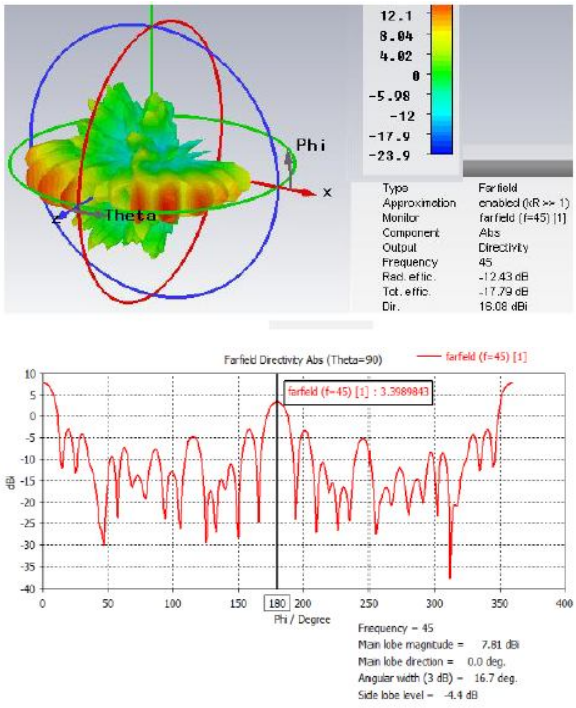
Fig. 6 VSWR of simple rectangular microstrip antenna (a), VSWR of PBG antenna (b).

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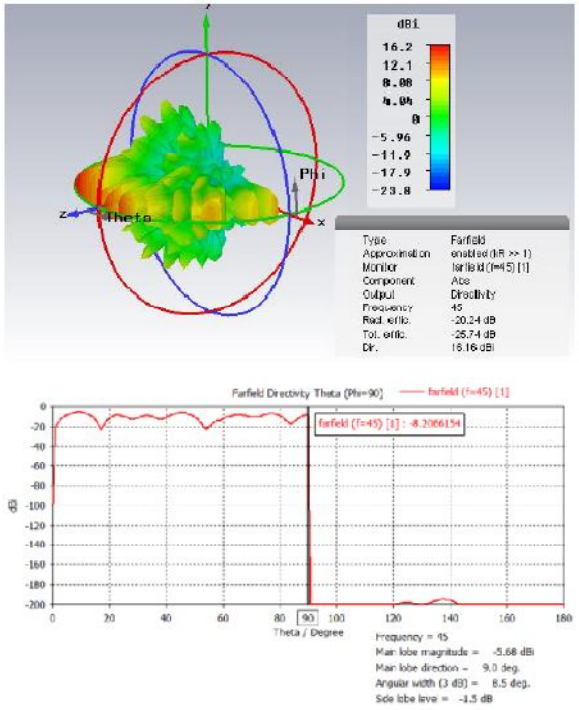
Comparative analysis between simple rectangular antenna and PBG antenna, designed at same high frequency is given below Table II for 5G advance technology.

Design Configuration Antenna	Simple RectanGular MSA	PBG
Return Loss	- 15 dB	-13.11 dB
Bandwidth	0.2 GHz	1 GHz
Directivity	16.5 dBi	16.08 dBi
VSWR	1.4 dB	1.5 dB

Table II. Comparison chart between simple rectangular antenna and PBG antenna



(a)



(b)

Fig. 7 Total and radiation intensity of PBG antenna (a), Total and radiation efficiency of simple microstrip rectangular antenna (b).

CONCLUSION

Above analysis and obtained results are turned up the interest towards fifth generation and set the utility standard between simple rectangular MSA and rectangular MSA with introduction of PBG. Both can be used to drive up to enhanced bandwidth, but comparative analysis shows the much improvement in PBG based MSA, which is quite acceptable. Both antennas are analyzed in terms of return loss, VSWR, gain and bandwidth, which has clearly revealed that for advance technologies, PBG antenna will be better as compared to simple MSA. Efficiency is better in case of PBG antenna as 70 %. Obtained results are simulated and coded, but has not been checked experimentally.

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