Rectangular Microstrip Patch Antenna with Photonic Band Gap Crystal for 60 GHz Communications

R. N. Tiwari[1], **P. Kumar**[2], **and Nitasha Bisht**[2]

[1]School of Engineering and Technology, Bahra University, India
[2]Department of Electronics and Communication Engineering
Jaypee University of Information Technology, India

Abstract— In this paper, the design of rectangular microstrip antenna with 2-D photonic band gap crystal as substrate (dielectric substrate with regular cylindrical periodic air-gap) for 60 GHz applications, has presented. The photonic band gap structure is used to enhance the radiation efficiency and the bandwidth of the antenna. The periodic structures designed to open up frequency bands within which the propagation of electromagnetic waves is forbidden irrespective of the propagation direction. The design is optimized using the Finite Difference Time Domain (FDTD) based CST microwave studio simulator. The designed periodic air-gap rectangular microstrip patch antenna gives a bandwidth up to 20.53% for 60 GHz applications. Various parameters like directivity of the antenna, efficiency of the antenna etc. are also shown.

1. INTRODUCTION

The microstrip patch antennas are having many advantages such as low profile, versatile, conformal and low-cost devices. The advantages of microstrip antennas make them suitable for various applications like, vehicle based satellite link antennas [1–3] global positioning systems [4] radar for missiles and telemetry and wireless communication devices [4]. However these antennas have limitation of narrow bandwidth. Some of the common techniques proposed by researchers for widening the bandwidth are; increasing the height of antenna substrate [4] using aperture coupling method [4, 5] or using stacked patch structure [5], using gap-coupling [6–8]. The great interests have been given to the photonic crystal whose photonic band gap has attracted considerable possibility [9, 10]. By using the strong confinement of the light by the photonic band gap, it is expected that waveguide devices whose size is of the order of the wavelength of light can be realized [9]. In fact, many microscale photonic crystal optical waveguide devices have been proposed [11–13].

There is always the demand of increasing the bandwidth and data rate of the wireless communication systems. The present wireless systems, generally uses approximately frequency band of 1 to 6 GHz [14]. The second demand in the wireless communications systems is to reduce the interference [14]. To overcome these problems, the millimeter wave systems are becoming increasingly important in many military and commercial applications. The frequency range around 60 GHz presenting a license free frequency band is one of the possible solutions for the development of radio frequency systems [14, 15]. The 60 GHz band has the bandwidth of approximate 7 GHz (57 to 64 GHz) worldwide, and 9 GHz (57 to 9 GHz) in Europe. So, 60 GHz license free frequency band is the solution to the problems in the present wireless systems because of very high frequency as compared to the present wireless system frequency band. Many more advantages of 60 GHz frequency band have been described in [16].

In this paper, we present a design of rectangular microstrip antenna for 60 GHz communication. The air gaps are incorporated in the substrate and the bandwidth of the antenna is increased. Various parameters of the antenna such as return loss, VSWR, radiation pattern, directivity, radiation efficiency etc. are presented; the return loss of the antenna is less than -10 dB for the frequency range 51.83 GHz to 63.69 GHz. The presented antenna can be used for 60 GHz applications. Rest of the paper is organized as follows: the geometrical configuration of the designed antenna is given in Section 2. The simulated results with discussion are presented in Section 3. Finally, Section 4 concludes the work.

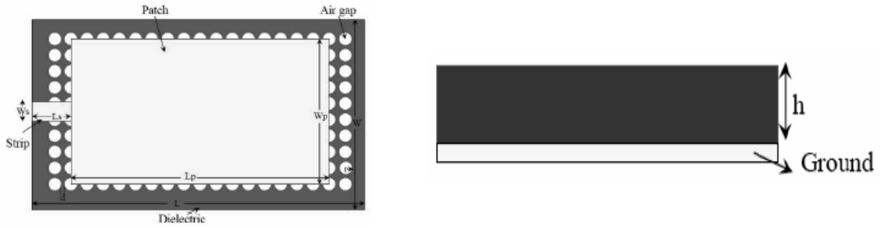
2. ANTENNA CONFIGURATION

The geometrical configuration of the designed rectangular microstrip antenna with photonic band gap structure is depicted in Fig. 1. The rectangular patch of length 'L_p' and width 'W_p' is placed on a substrate with photonic band gap structure as shown in Fig. 1. The height and relative permittivity of the substrate is 'h' and 'ε_r', respectively. The separation between two consecutive air cylinders is 'd', and the radius of the each cylinder is 'r'. The antenna is fed by microstrip line feeding technique. The length and width of the microstrip feed line is 'L_s' and 'W_s' respectively.

3. RESULTS AND DISCUSSION

The designed antenna configuration of Fig. 1 is simulated using the CST microwave studio simulator. Using this simulator, the designed model of the antenna is optimized. The optimized dimensions of the microstrip antenna are given in Table 1.

The return loss of the proposed antenna is shown in Fig. 2. The antenna has been designed for operation in the 60 GHz frequency band that ranges from 51.83 GHz to 63.69 GHz (20.53%) is achieved as shown in Fig. 2. The voltage standing wave ration (VSWR) of the designed rectangular microstrip antenna is shown in Fig. 3. From Fig. 3, it can be seen that the 2 : 1 bandwidth is 20.53%. The radiation pattern of the designed antenna is shown in Fig. 4. The radiation pattern of the designed antenna shows the omnidirectional nature in the upper hemisphere as shown in Fig. 4. The directivity, radiation efficiency and total efficiency at various frequencies are shown in Table 2. The designed microstrip antenna can be used for 60 GHz applications.



(a) Top view

(b) Side view

Figure 1: Geometrical configuration of rectangular microstrip antenna with photonic band gap structure.

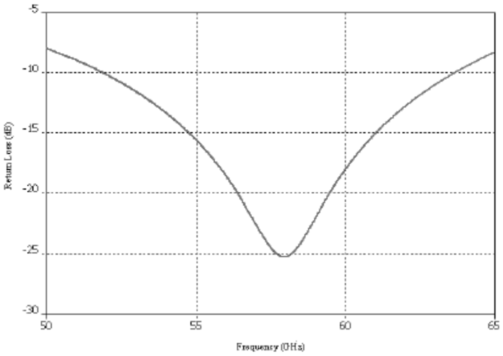


Figure 2: Return loss of the antenna.

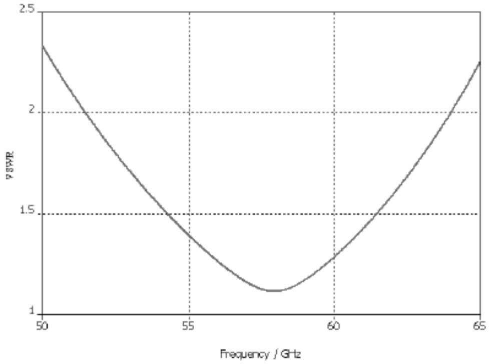
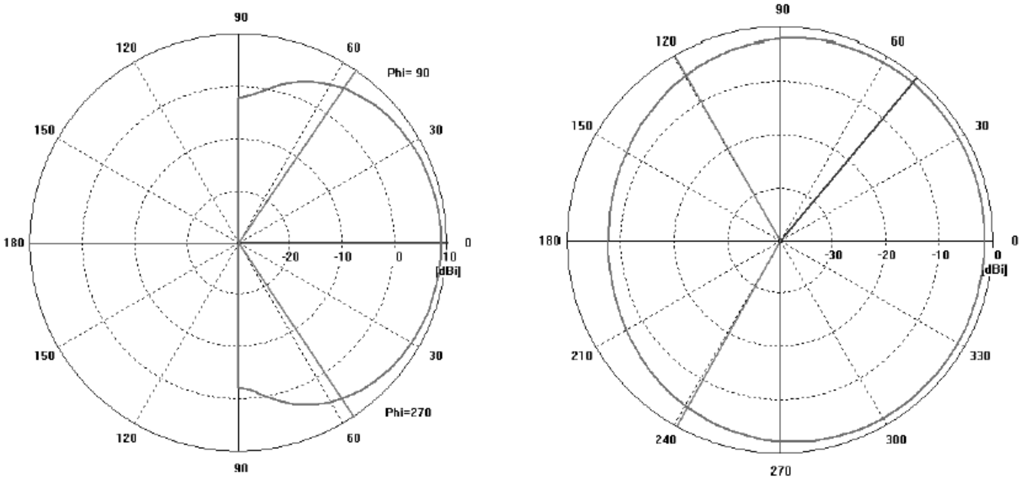


Figure 3: Voltage standing wave ratio (VSWR) of the antenna.

Table 1: Dimensions of the proposed microstrip antenna.

Parameter	**Value**
Length of the patch (L_p)	2.00 mm
Width of the patch (W_s)	0.80 mm
Dielectric substrate (ε_r)	2.2
Distance between two air gap (d)	0.02 mm
Length of microstrip feed line (L_s)	0.45 mm
Width of microstrip feed line (W_s)	0.02 mm
Length of dielectric substrate (L)	2.50 mm
Width of dielectric substrate (W)	1.50 mm
Height of substrate (h)	0.40 mm
Radius of cylinder (r)	0.04 mm



(a) (b)

Figure 4: Radiation pattern of the antenna, (a) theta plane, (b) phi plane.

Table 2: Various parameters of the antenna.

Frequency	Directivity	Radiation Efficiency	Total Efficiency	3 dB Angular Width (theta plane)	3 dB Angular Width (phi plane)
57.5 GHz	8.937 dBi	0.7627	0.7599	112.1°	238.8°
57.9 GHz	8.970 dBi	0.7634	0.7611	112.4°	237.5°
60 GHz	9.143 dBi	0.7674	0.7553	114.1°	231.0°

4. CONCLUSIONS

A design of rectangular microstrip antenna for 60 GHz communication has been presented. The photonic band gap structure is utilized to enhance the bandwidth and gain of the antenna. The designed antenna model has been optimized for 60 GHz applications using the CST Microwave studio. The return loss as well as the radiation patter has been presented. The radiation pattern of the antenna shows the omnidirectional nature. The designed rectangular microstrip patch antenna with photonic band gap structure can be used for various applications of 60 GHz technology.

REFERENCES

1. Mailloux, R. J., et al., "Microstrip antenna technology," *IEEE Trans. Antennas and Propagation*, Vol. 29, 2–24, 1981.
2. Kumar, G. and K. P. Ray, *Broadband Microstrip Antennas*, Artech House Inc., MA, England, 2003.
3. Garg, R., P. Bhartia, I. Bahl, and A. Ittipioon, *Microstrip Antenna Design Handbook*, Artech House Inc., MA, England, 2001.
4. Pozar, D. M., "A review of aperture coupled microstrip antennas: History, operation, development, and applications," *IEEE Letters*, 1996.
5. Targonski, S. D., R. B. Waterhouse, and D. M. Pozar, "Design of wide band aperture coupled stacked microstrip antennas," *IEEE Trans. Antennas and Propagation*, Vol. 46, 1245–1251, 1998.
6. Kumar, P., G. Singh, T. Chakravarty, S. Bhooshan, S. Khah, and A. De, "Numerical computation of resonant frequency of gap coupled circular microstrip antennas," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 10, 1303–1311, 2007.
7. Kumar, P. and G. Singh, "Theoretical investigation of the input impedance of gap-coupled circular microstrip patch antennas," *Journal of Infrared, Millimeter and Terahertz Waves*, Vol. 30, 1148–1160, 2009.

8. Kumar, P., G. Singh, S. Bhooshan, and T. Chakravarty, “Gap-coupled microstrip antennas,” *Proc. of IEEE Sponsored International Conference on Computational Intelligence*, 435–438, Sivakasi, India, 2007.
9. Yablonovitch, E., “Inhibited spontaneous emission in solid-state physics and electronics,” *Physical Review Lett.*, Vol. 58, 2059–2062, 1987.
10. Joannopoulos, J. D., P. R. Villeneuve, and S. Fan, “Photonic crystals: Putting a new twist on light,” *Nature*, Vol. 386, 143–149, 1997.
11. Lin, S. Y., E. Chow, V. Hietala, P. R. Villeneuve, and J. D. Joannopoulos, “Experimental demonstration of guiding and bending of electromagnetic waves in a photonic crystal,” *Science*, Vol. 282, 274–276, 1998.
12. Fan, S., P. R. Villeneuve, J. D. J. Oannopoulos, and H. A. Haus, “Channel drop tunneling through localized states,” *Physical Review Lett.*, Vol. 80, 960–963, 1998.
13. Ikuno, H., Y. Naka, and A. Yata, “Analysis of optical waveguide devices using the FDTD method based on the principles of multidimensional wave digital filters,” *Radio Science*, Vol. 35, 595–605, 2000.
14. Akkermans, J. A. G., “Planar beam-forming antenna array for 60-GHz broadband communication,” *Technische Universiteit Eindhoven*, 2009.
15. Segura, N., et al., “On-wafer radiation pattern measurements of integrated antennas on standard BiCMOS and glass processes for 40–80 GHz application,” *IEEE Int. Conference on Microelectronic Test Structures*, Vol. 18, 2005.
16. Koh, C., “The benefits of 60 GHz unlicensed wireless communications,” *YDI Wireless Whitepaper*, 2004.