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WideBand Compact Rectangular Patch Antenna Using Artificial Dielectrics

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***Abstract*- In this paper the work presented is on performance enhancement of rectangular microstrip patch antenna achieved by use of an array of conducting cylindrical pins embedded in the substrate. Parametric study has been carried out on the radius of the obstacle (i.e. cylindrical pins) and the obstacle spacing. The configuration presented leads to 28% compactness along with 142.4% increase in bandwidth in comparison with an antenna on reference dielectric. An impedance match of -36dB has been obtained as compare to -12dB on reference dielectric. Cross polarization level obtained is below -35dB in both E and H-plane.**

***Index Terms*- artificial dielectrics, conducting cylinders, patch antenna**

I. INTRODUCTION

Demand for compact radiator with sufficiently high bandwidth is rapidly increasing in wireless and space borne applications. Microstrip antennas due to their inherent capabilities of low cost and light weight are widely used in these applications. Antenna miniaturization using high permittivity materials as substrate has been attempted in the past [1]-[2]. The miniaturization can be achieved by using high dielectric constant materials but there are two drawbacks. First, the field remains highly concentrated around the high permittivity region, which results in low antenna efficiency and narrow band characteristics. The second drawback pertains to the fact that characteristic impedance in a high permittivity medium is rather low which creates difficulties in impedance matching of antenna. Another approach for miniaturization uses either shorting wall [3]-[4] or a shorting pin [5]. The shorting wall leads to a quarter wave patch, while a shorting pin near the feed can reduce the size even further. However the cross polarization levels are quite high due to asymmetric structure of the patch. Moreover the patch with shorting pin can only provide impedance bandwidth of about 2% [5].

During recent years there developed a great deal of interest in the use of metamaterials in electromagnetic wide band applications. An artificial dielectric is a specified class of metamaterials, obtained by arranging a large number of identical conducting obstacles in a regular three dimensional pattern. Under the action of the externally applied electric field, the charges on each conducting particle are displaced and simulate the behavior of the molecules in an ordinary dielectric. The original application of the artificial dielectrics was to replace the heavy natural dielectric material in lens antennas [6]. More recently, various versions of artificial dielectrics have been used to modify the properties of material in the ways that are not attainable otherwise. Specifically in microstrip patch antenna, miniaturization has been reported with the use of artificial materials and surfaces [7]-[9]. The use of artificial magneto dielectric for miniaturization has also been proposed while approximately retaining the bandwidth [10]-[11].

In this article the work presented is on the microstrip patch antenna embedded on cylindrical pin structure. The proposed structure exhibits wideband characteristics along with compactness. The bandwidth enhancement of 12% and weight reduction factor of 3 using cylindrical pin structure has been attempted in past for Global Navigation Satellite System (GNSS) antenna application [12]. But no reference is available in the literature for its use in high frequency region which lies in C and extended C Band. Also there is no study available which reflects the effect on antenna parameters like bandwidth and gain by varying pins dimensions and grid spacing. Simulation results presented here are obtained with the finite element based Ansoft High Frequency Structure Simulator (HFSS). The parametric study has been presented on the radius of pins and grid spacing. Performance comparison of proposed antenna design with that of reference dielectric also has been presented.

II. ANTENNA STRUCTURE AND ANALYSIS

The structure of the proposed antenna is shown in Fig. 1. Rectangular array of closed conducting cylinders (obstacles) are embedded in the host medium which in the present case is FR_4 epoxy. The simple rectangular patch (designated as Antenna A) is designed to operate in extended C-Band. The dimensions chosen are length (L=8mm) and width (W=15.8mm). The coaxial feed is used to excite the microstrip patch. The height of the substrate taken is 1.6mm and heights of the cylindrical pins chosen is 1.56mm above the ground plane. There is a gap of 0.04mm to avoid the shortening of patch. Ground plane size is 50 x 50mm. Obstacle size and the spacing are obtained through parametric study which is explained in detail in the later section. The loaded Antenna designated as Antenna-B is shown in Fig 1.

The substrate behaves as an anisotropic medium characterized by permittivity and permeability tensors [13] as given below

$$[\varepsilon] = \begin{bmatrix} \varepsilon_x & 0 & 0 \\ 0 & \varepsilon_y & 0 \\ 0 & 0 & \varepsilon_z \end{bmatrix}$$

$$[\mu] = \begin{bmatrix} \mu_x & 0 & 0 \\ 0 & \mu_y & 0 \\ 0 & 0 & \mu_z \end{bmatrix}$$

For TM^z field configuration the passbands for the medium are defined by the relation [13]

$$\cos(\eta\theta) = \cos\theta + \frac{A}{\theta}\sin\theta \qquad (1)$$

Where η is the refractive index,
$\theta = k_d a$ is the electrical spacing,
k_d is the wave number in embedding medium and
$A = \frac{\pi}{\ln\frac{a}{\pi d}}$ for square grid case.
Where $'a'$ is the grid period and $'d'$ is the diameter of pins.

For eqn. 1 to remain valid the grid spacing must satisfy the condition [13]

$$d \ll a < \frac{\lambda_d}{2} \qquad (2)$$

where λ_d is the operating wavelength in the embedding medium. The pins dimensions and grid spacing are chosen in such a way so that the entire operating region is well above cutoff [13]. This ensures that there is no propagation of waves along the dielectric surface.

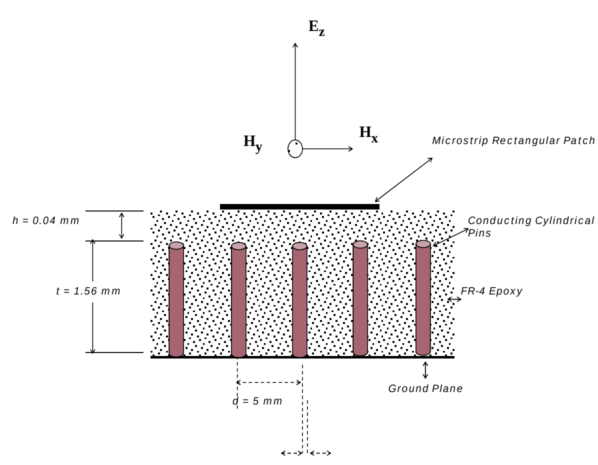

Fig. 1 Structure of proposed antenna (Antenna B)

III. RESULTS AND DISCUSSION

A. *Parametric Study and Performance Comparison*

Simulations are performed in the frequency range 5-9GHz. The unloaded antenna resonates at frequency 7.76GHz and has bandwidth of 330MHz (4.15%) on -10dB criterion. Parametric study is first done on the grid spacing ($'a'$) keeping the size of the obstacle i.e. radius (r) fixed at 0.3mm. Using (2) the maximum value of 'a' is limited by the minimum operating wavelength. Fig. 2 shows the return loss variation with frequency for different antenna configurations.

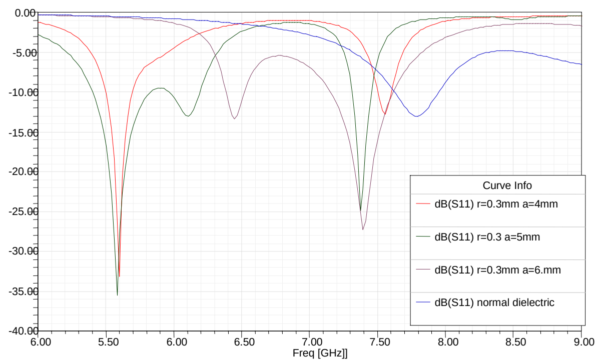

Fig. 2 Simulated return loss curves for different antenna configurations with obstacle spacing ranging from 4mm to 6mm and also for normal dielectric.

For the purpose of good and clear illustration the results are shown only for three configurations which correspond to the obstacle spacing of 4, 5 and 6mm and they are compared with return loss of the unloaded antenna. It is observed that for the fixed radius as the distance between the obstacle decreases frequency corresponding to first resonant mode also start decreasing. This is due to increase in the interaction field in the array [14] which in turn increases the permittivity in the transverse direction and thereby led to the decrease in the resonant frequency. The maximum value of $\frac{d}{a}$ for which eqn (1) holds is taken here as 0.2. The motivation behind this consideration is the value of gain of the antenna. The antenna gain suffers badly when $\frac{d}{a}$ becomes more than 0.2. This fact is observed from repeated simulations. For reference dielectric only one resonant mode excite in 5-9GHz band and mode resonant frequency is 7.76GHz. For the loaded antenna, two or even three modes excited depending upon the distance between the obstacles but in all cases there is a shift in dominant mode frequency and antenna is downsized. Table 1.1 and 1.2 shows the numerical values of the resonant frequency and impedance bandwidth obtained after simulations.

Table 1.1 Resonant frequency of patch antenna on simple dielectric

Resonant frequency(GHz)	Frequency range (GHz)	Impedance BW (MHz)	% BW
7.76	7.61 – 7.94	330	4.15

Table 1.2 Resonant frequency and impedance bandwidth for various obstacle spacing keeping size of obstacle fixed (r=0.3mm)

Obstacle Spacing (mm)	Resonant Frequency (GHz)	Frequency Range	BW (MHz)	%BW
4	5.56	5.48- 5.90	220	3.8
5	5.59	5.39–6.19	800	13.81
6	6.40	6.38–6.51	130	2.0

As shown in Table 1.2, more insight is given to the case when the radius r=0.3mm and obstacle spacing $'a'$=5mm, resonant frequency decreases to 5.59 GHz which implies 28% compactness. Moreover bandwidth obtained is 800MHz this is 142.4% greater than bandwidth of the same patch antenna on simple dielectric as shown in Table1.1. Hence both compactness and wide band characteristics are achieved in this configuration.

Now the parametric study is perform on the size of obstacle by keeping the obstacle spacing fixed at 5mm and by varying the radius of the conducting cylinders (obstacles). Again for the purpose of clear illustration parametric results are divided into two groups Fig. 3 and Fig. 4.

Fig. 3 shows the simulated return loss when the radius of the obstacle is between 0.09 to 0.4mm.

The value of $\frac{d}{a}$ is less than 0.2 for these configurations. % bandwidth enhancement and compactness as compared to the unloaded antenna can be clearly observed from Fig. 3. Numerical values are tabulated in Table 1.3.

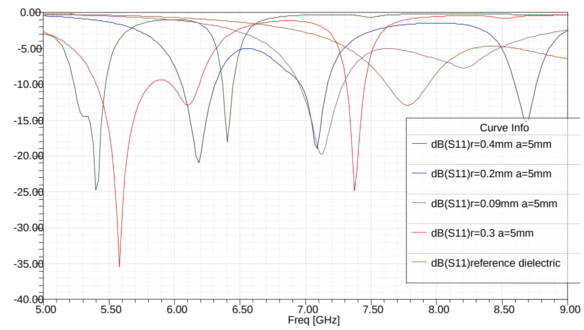

Fig 3 Simulated return loss curves for the antenna configurations with size of obstacle ranges from 0.09 to 0.4mm.

Table1.3 Impedance bandwidth for the various antenna configurations for fixed obstacle spacing a=5mm.

Radius of Obstacle (mm)	Resonant frequency (GHz)	Frequency range (GHz)	Impedance BW (MHz)	% BW
r=0.09mm	7.11	6.94–7.29	350	4.8
r=0.2mm	6.18	6.03–6.32	290	4.6
r=0.3mm	5.59	5.39–6.19	800	13.81
r=0.4mm	5.39	5.22–5.47	250	4.5

Fig. 4 shows the return loss vs frequency with radius ranging from 0.5 to 1.5mm. The value of $\frac{d}{a}$ is greater than 0.2 for these configurations. It is clear from the return loss curves that for these configurations compactness is achieved but at the cost of bandwidth. Also gain and radiation efficiency suffers badly due to conductor loss. Table 1.4 shows the decrease in the resonant frequency as the obstacle size increases from 0.09mm to 1.5mm for the fixed obstacle spacing of 5mm. For r=1.5mm resonant frequency is 2.39GHz thereby providing 70% compactness. But it is clear from Fig. 4 that as radius increases from 0.5mm to 1.5mm bandwidth suffers due to increase in the stored energy in the medium which led to the increase in quality factor.

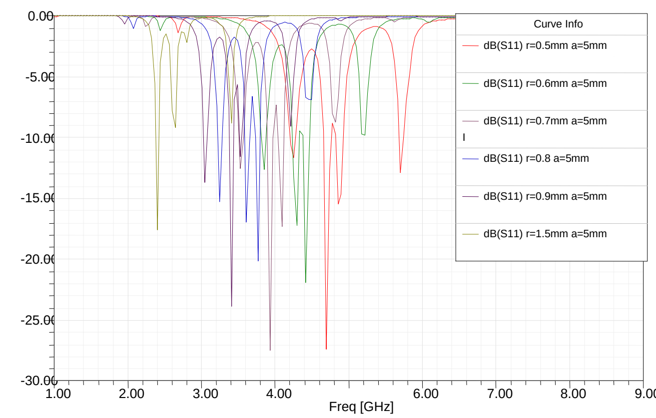

Fig. 4 Simulated return loss curves for the antenna configurations with size of obstacle ranges from 0.5 to 1.5mm

Table 1.4 Parametric study o f the loaded antenna for fixed obstacle spacing and radius ranging from 0.09mm to 1.5mm

Radius(r) of obstacle (mm)	Obstacle spacing (mm)	Resonant frequency (GHz)
0.09	5	7.11
0.2	5	6.18
0.3	5	5.56
0.4	5	5.39
0.5	5	4.25
0.6	5	3.83
0.7	5	3.51
0.8	5	3.23
0.9	5	3.03
1.5	5	2.39

B. Radiation Pattern

Fig. 5 shows the Simulated Gain patterns for Antenna A and Antenna B. Maximum gain in the broadside direction is around 4.49 dB in antenna A which decreases to 3.15dB in antenna B. Reduction in gain is due to the dispersive nature of the medium.

Fig. 6 and Fig. 7 show the normalized simulated E-theta and E-phi radiation pattern in E-plane and H-plane respectively for antenna B at 5.59GHz. The ratio of the co-polarization to cross polarization level is higher than about 35db in E-plane and about 36db in H-plane and maintains the same level within the bandwidth.

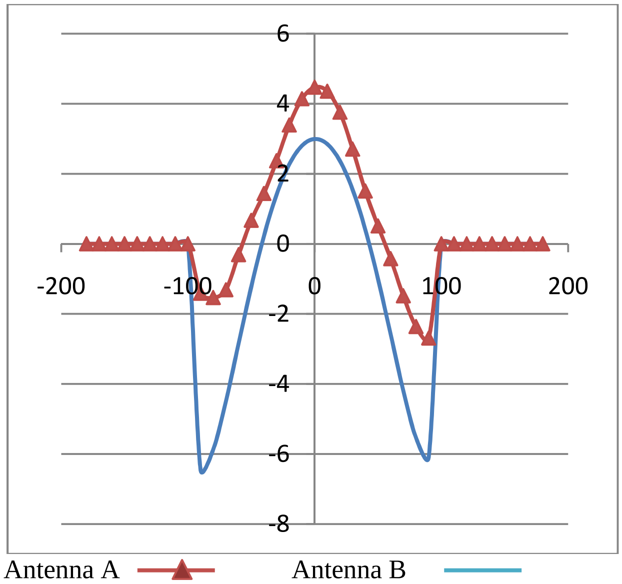

Fig. 5 Simulated Gain vs theta for Antenna A and Antenna B

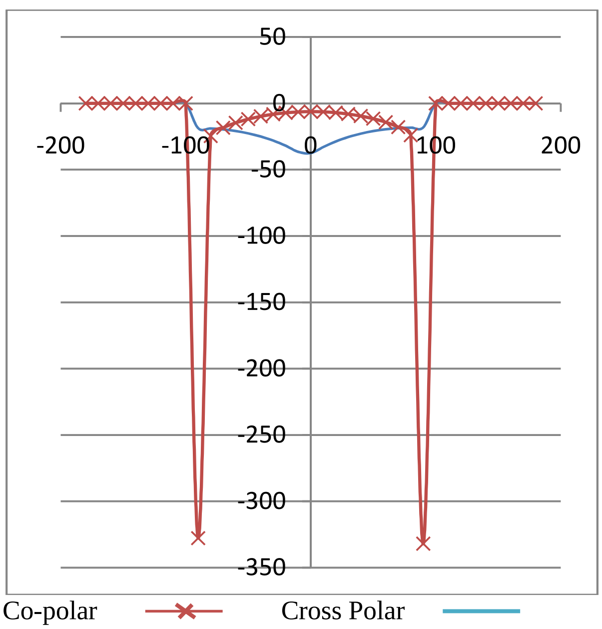

Fig. 6 Simulated radiation pattern for antenna B (E-Plane)

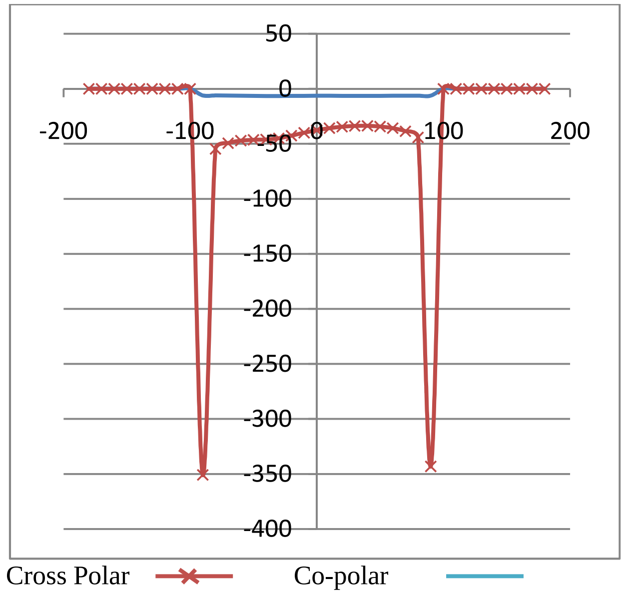

Fig.7 Simulated radiation pattern for antenna B (H-Plane)

V. CONCLUSION

This paper presented the rectangular microstrip antenna on artificial dielectric. Due to full shape of the patch without any shorting pin, slot loading or shape modification the proposed patch antenna gives good broadside pattern shape with low cross polarization levels. Small reduction in antenna gain is also reported. For further improvement in bandwidth, optimization can be applied to pins dimensions and grid spacing.

REFERENCES

[1] D.M.Pozar and D.H.Schaubert, *Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays.* NewYork: IEEE Press, 1995.

[2] J.R. James and P.S. Hall, Handbook of Microstrip Antennas London, U.K.: Peter Peregrinus, 1989.

[3] S.Pinhas and S. Shtrikman, "Comparison between computed and measured bandwidth of quaterwave microstrip radiators," IEEE Trans. Antenna Propagation., vol. 36,pp. 1615-1616, Nov., 1988.

[4] R.Chair, K.F.Lee, and K.M. Luk, "bandwidth and cross polarization characteristics of quaterwave shorted patch antennas," Microwave Opt.Technol. Lett.,vol. 22, pp. 101-103, July 1999.

[5] R.B. Waterhouse. “Small microstrip patch antennas,” Electron. Lett., vol.31, pp. 604-605, 1995.

[6] W.E. Kock,“Metallic delay lenses,” Bell System Technical J., vol. 27, pp. 58–82, 1948

[7] S-S. Zhong and J.H. Cui, “Compact circularly polarized microstrip antenna with magnetic substrate,” in Proc. IEEE AP-S Int. Symp., San Antonio, TX, Jun.2002, vol1 pp.793-796.

[8] D.Psychoudakis, Y.H. Koh, J.L.Volakis, J.H. Halloran, “Design method of aperture coupled microstrip patch antennas on textured dielectric surfaces,” IEEE trans. Antennas Propag., vol.52, no. 10, pp. 2763-2766, Oct. 2004.

[9] H. Mosallaei and K. Sarabandi, “Antenna miniaturization and bandwidth enhancement using reactive impedance substrate,” IEEE Trans Antenna Propag., vol.52,no.9, pp. 2403-2414, Sep. 2004.

[10] K. Buell, H. Mosallaei, and K. Sarabandi, “Embedded-circuit magnetic metamaterial substrate performance for patch antennas,” in IEEE Antennas Propag. Soc. Int. Symp., Monterey, CA, Jun. 20–25, 2004, pp. 1415–1418.

[11] M. E. Ermutlu, C. R. Simovski, M. K. Kärkkäinen, P. Ikonen, S. A. Tretyakov, and A. A. Sochava, “Miniaturization of patch antennas with new artificial magnetic layers,” in Proc. IEEE Int. Workshop on Antenna Technology, Singapore, Mar. 7–9, 2005, pp. 87–90.

[12] Enhanced Bandwidth patch antennas with artificial dielectric substrates for high precision satellite positioning. Antenna Technology,2009, iWAT 2009.

[13] R. J. King,D.Thiel and K.Park et al., “The synthesis of surface reactance using an artificial dielectric,” IEEE Trans. Antennas Propagat. vol. 31, no. 3, pp. 471–476, 1983

[14] R. E. Collin, Field Theory of Guided Waves. New York: McGraw-Hill, 1960, ch 12.