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Research Article

A Polarization Dependent Electromagnetic Band Gap based Circularly Polarized Low Profile Dipole Antenna for WLAN Application

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Abstract: This paper presents circularly polarized dipole antenna operating at 5.8 GHz for WLAN applications. Normally dipole antenna radiates linearly polarized waves. Radiation of circularly polarized (CP) wave has been achieved through integration of a novel PDEBG with the antenna. PDEBG are artificial structures that show diversity in reflection phase depending on the polarization state of incident plane wave. This polarization dependent reflection phase feature of PDEBG is realized by modifying its rectangular unit geometry. It has been observed that proposed dipole antenna has an axial ratio less than 3 dB in frequency range from 5.58 GHz to 5.93 GHz (AR BW= 5.98%). The proposed PDEBG structure has 6.02% wider frequency bandwidth for linear to circular polarization and an overall size reduction of 15% as compared to previously proposed PDEBG structures. The proposed PDEBG can be used for reconfigurable polarization surfaces.

Keywords: WLAN, PDEBG, CP, axial ratio, dipole antenna, low profile

1. INTRODUCTION

Because of its simple structure, dipole antenna is widely used in wireless communication systems covering wider range of applications. One of common observation in these antennas is out of phase image current due to which they cannot radiate efficiently near Perfect Electric Conductor (PEC) ground plane. Therefore, these wire based antennas cannot be operated under low profile conditions [1]. Low profile dipole antenna configuration can be built by placing an Electromagnetic Band Gap (EBG) ground plane. EBG structures have raised substantial attention in modern era due to their attractive features namely, in-phase reflection and band-gap properties [2-5]. However, conventional EBG ground planes give identical reflection phase response irrespective of polarization state of normally incident plane wave. Recently Polarization dependent EBG (PDEBG) surfaces have been proposed. These surfaces exhibit reflection phase response which is a function of frequency as well as polarization state [6, 7]. PDEBG ground plane find applications in changing the linear polarization into circular polarization along with enhancement in radiation efficiency [8], dual band circular polarization conversion [9,10], Dual/Triple-Band Applications [11] and to increase the axial ratio bandwidth [10]. The design technique is the same as that of Sievenpiper surfaces [13]. Conventional dipole antenna radiates linearly polarized waves. Radiation of circular polarized wave is desired in several applications. One can use two dipole antenna having 90° feed phase [14]. Another mechanism of obtaining CP radiation pattern is through use of curl antenna [15]. However, the Axial Ratio (AR) bandwidth is generally narrow. The limitation of PDEBG structures is their large size.

This article presents a low profile circularly polarized single dipole antenna for WLAN application using a novel compact PDEBG structure. The proposed surface consists of unit cell having diamond shaped patch and four L shaped strips. With the optimized design approximately 6% 3dB AR bandwidth and about 15% reduction in overall size has been achieved. The paper is organized into the following sections:

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Section 2 explains radiation mechanism of CP dipole antenna. Simulation results are discussed in section 3. Section 4 is the conclusion of the paper. All simulations are carried out in CST which is a 3D EM tool.

2. RADIATION MECHANISM OF CP DIPOLE ANTENNA

Fig. 1 depicts geometry of a dipole antenna placed horizontally over ground plane. Orientation of antenna is kept at $\varphi<\pi/8$ with a gap of less than 0.1λ above the ground plane. Now total radiated field ($\vec{E}$) at broader side of integrated structure is the superposition of two fields i.e. directly radiated field ($\vec{E}^d$) and reflected field ($\vec{E}^r$) from ground plane [1].

Mathematically:

$$\vec{E} = \vec{E}^d + \vec{E}^r \qquad (1)$$

Where

$$\vec{E}^d = \frac{Eo}{2}(x^{\wedge}.e^{-jkz} + y^{\wedge}.e^{-jkz})$$

$$\vec{E}^r = \frac{Eo}{2}(x^{\wedge}.e^{-jkz-2jkd+j\theta_x} + y^{\wedge}.e^{-jkz-2jkd+j\theta_y})$$

E_o=Magnitude of the Electric field

k= Free space wave number

d= Height of Dipole Antenna from PDEBG

$(x^{\wedge}, y^{\wedge})$ = Unit vector

θ_x= Reflection phase of x polarized wave

θ_y= Reflection phase of y polarized wave

As dipole antenna is very close to ground plane so approximately 2 kd = 0. Now to ascertain behaviour of PEC, PMC and PDEBG, following three cases are considered.

***Case* 1**: In first case the ground plane is considered to be PEC. As PEC introduces a phase reversal therefore reflection phases are $\theta_x = \theta_y$=180˚.

By putting these values in (1) it can be observed that both fields ($\vec{E}^d$and $\vec{E}^r$) cancel out each other. Therefore, total radiating field becomes zero, i.e.,

$$\vec{E} = 0 \qquad (2)$$

***Case* 2**: Now in second case, ground plane is considered to be PMC that reflects the wave in phase to incident wave therefore reflection phases are $\theta_x = \theta_y$=0˚.

By putting these values in (1) it can be observed that total field is linearly polarized:

$$\vec{E} = E_o e^{-jkz}(x^{\wedge} + y^{\wedge}) \qquad (3)$$

***Case* 3**: In last case PDEBG structure is used as a ground plane for which the reflection phases are $\theta_x = 90°, \theta_y = -90°$. By putting these values in (1)

$$\vec{E} = \frac{E_o}{2} e^{-jkz}\left[\left(x^{\wedge} + y^{\wedge}\right) + j\left(x^{\wedge} - y^{\wedge}\right)\right] \qquad (4)$$

Here it can be observed that phase difference between directly radiated and reflected field is now 90˚, Therefore Right Hand Circular polarized (RHCP) wave is obtained from linearly polarized wave.

Equation (4) hence conceptually explains the radiation mechanism of the CP dipole antenna. A precise characterization to the dipole height and ground plane size is considered using full wave 3D EM tool.

3. EXPERIMENTAL RESULTS

For the operational mechanism of the radiator, A PDEBG unit cell is designed and the dipole antenna is integrated with this surface.

Rectangular patch with diamond shape geometry enclosed by L type slot is used as a base geometry. Fig. 2 presents geometrical configuration of unit cell along with its necessary parameters. The patch is connected to ground plane through central conducting via of radius 0.5 mm. Roger 5880 is used as a substrate material having permittivity of 2.2 and thickness of 3.175 mm. Periodicity along x and y axis is 15 mm and 11mm respectively. L1 is 3.5 mm long which is the shorter arm length of slot. L3 is the longer arm of slot and having value of 6 mm. L4 is 8 mm and L5 is 14 mm, which are the dimensions of diamond shape geometry. Patch length and width represented by L2 and L6 are 14 mm and 9 mm respectively. Ground plane of 5x5 rectangular patches is 65x85 mm, a size reduction of 35 % in the y and 15 % in the x direction as compared to [16], while resonant dipole length is 20 mm. Height of dipole antenna above PDEBG is less than 5 mm which satisfies the condition of low profiling.

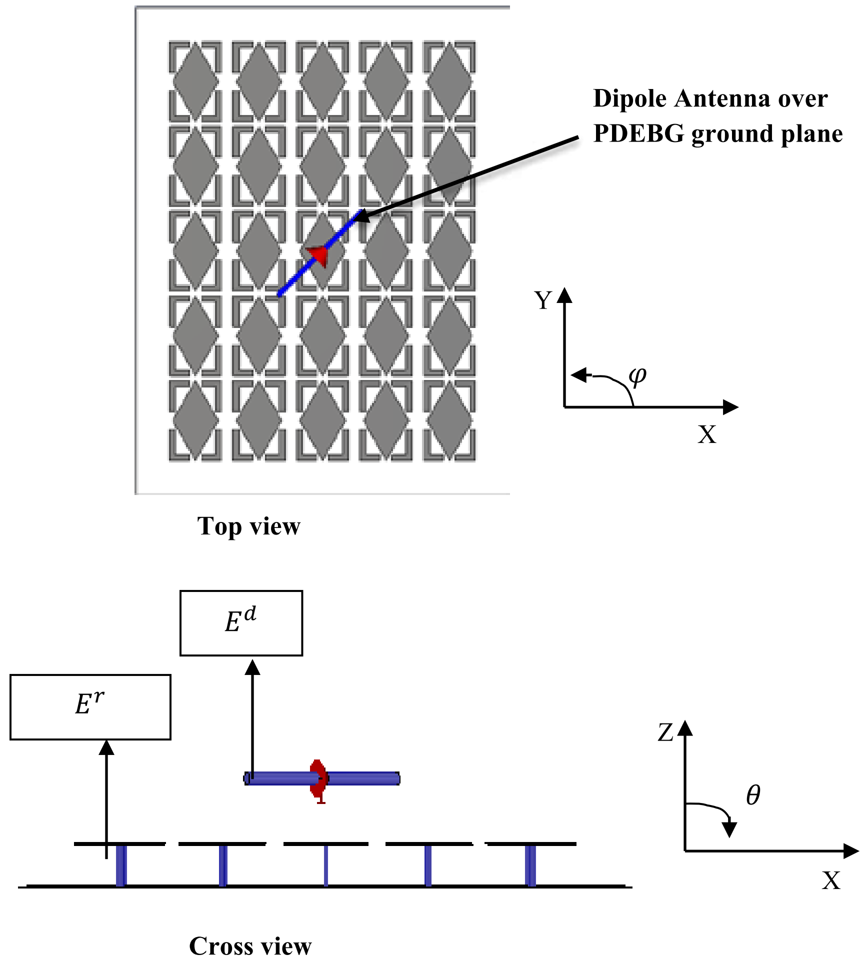


Fig .1. Dipole antenna integration with PDEBG, Orientation of the dipole antenna is $\boldsymbol{\varphi}$=45 direction.

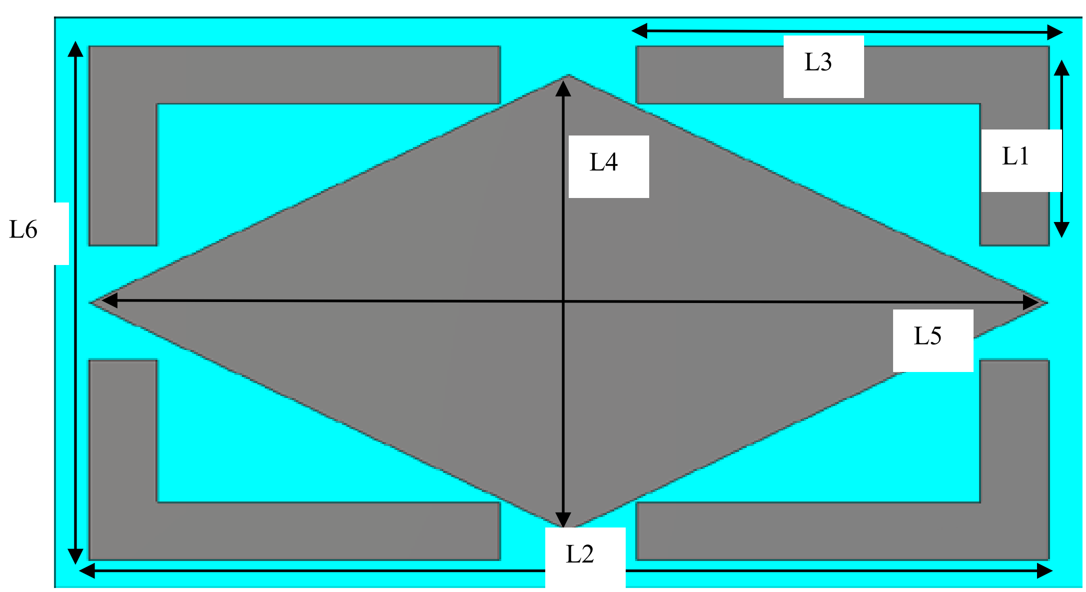


Fig. 2. Proposed PDEBG unit cell.

Table 1. Summary of unit cell in phase reflection coefficient.

Polarization of Incident Wave					
X Polarized			Y Polarized		
Reflection Phase in Degree	Frequency in GHz	% BW	Reflection Phase in Degree	Frequency in GHz	% BW
135	3.83	35.60 %	135	4.666	49.98 %
90	5.023		90	6.842	
45	5.618		45	8.082	
0	6.068		0	9.069	
-90	7.199		-90	11.398	

Table 2. Axial ratio (AR) beam width improvement at 5.8 GHz versus elevation angle in the XZ, YZ planes.

Plane	3 dB AR Beam width in [8]	3 dB AR Beam width using Novel PDEBG for φ=45˚	Improvement
XZ plane	30˚	53.3˚	23.3˚
YZ plane	30˚	35.6˚	5.6

Dimension of diamond shaped patch and slots length affect reflection phase of x and y field components of incident wave and resonant frequency of the PDEBG surface. Values of these parameters are optimized for best polarization dependent properties of the surface. By selecting appropriate dimensions of the structure, the reflection phase for x polarized wave is 0˚ degree at 6.068 GHz while for Y polarized wave it is 9.069 GHz.

The unit cell is simulated in CST MWS. In-phase reflection behaviour for x and y polarized plane wave of unit cell is given in Fig. 3. The ±90 degree AMC bandwidth is 36 % and 50 % for x and y polarized plane wave respectively as shown in Table 1. For low profile wire antenna applications, a reflection phase in the range 90±45˚ is the input-match frequency band [2] of a PDEBG surface which is also mentioned for x and y polarized linear wave in Table 1.

Return loss of dipole antenna with PEC and PDEBG is shown in Fig.4. The reflection coefficient less than -10 dB bandwidth is 18.80 % (5.46 GHz to 6.59 GHz) in case of PDEBG. Simulated return loss of antenna is 15.43% in case when no ground plane is used and is from 5.62 to 6.56GHz. And when using PEC ground plane with dipole antenna no operating bandwidth is seen because of strong mutual coupling between ground plane and antenna. It has been observed that return loss bandwidth in case of PDEBG is greater (18.80 %) as compared to when no ground plane is used.

Axial ratio bandwidth less than 3 dB which is from 5.58 GHz to 5.93 GHz (5.98 %) is shown in Fig. 5. The proposed PDEBG structure has 6.02 % wider frequency bandwidth for linear to circular polarization than [8], which completely covered the Wireless Local Area Network (WLAN) Band 5.725 GHz to 5.875 GHz with low profile configuration.

Fig. 6 shows the axial ratio at 5.8 GHz verses elevation angle in both XZ and YZ planes. The improvement in axial ratio 3 dB beam width for φ=45˚ is 23.3˚ and 5.6˚ at XZ planes and YZ plane. Table 2 explains the 3dB beam width improvement in XZ and YZ plane of the Fig. 6 as compared to [8]. Hence, it can be concluded that PDEBGs are useful in transformation of polarization of dipole antenna from linear to circular along with improved antenna performance after integration.

In comparison to Curl antenna on square patch EBG which also radiates CP waves, the prototyping of dipole antenna is simple. In addition to that, this antenna structure can be used for reconfigurable polarization diversity when the orientation of dipole is changed. Linear polarization is obtained when dipole is oriented along x or y direction. A Right Hand Circular polarized (RHCP) wave is obtained when the

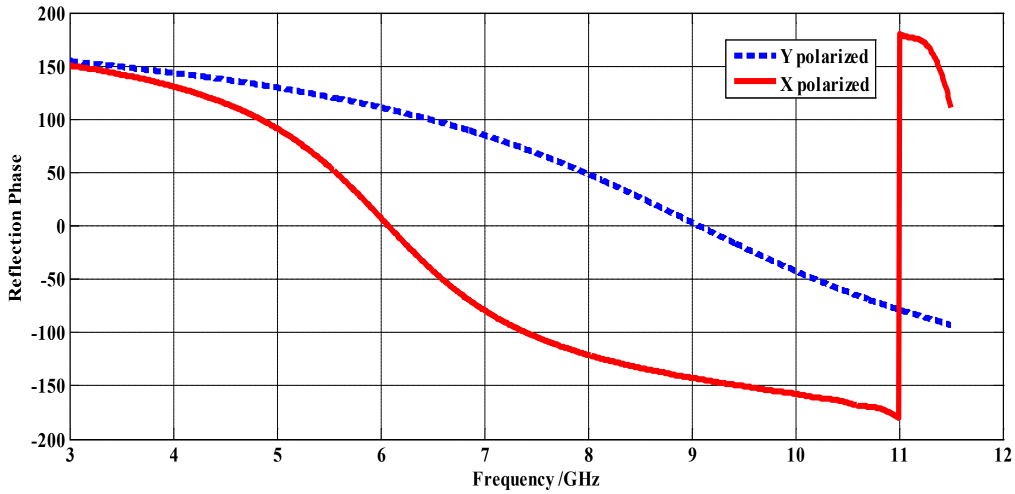


Fig. 3. In phase reflection coefficient of proposed unit cell.

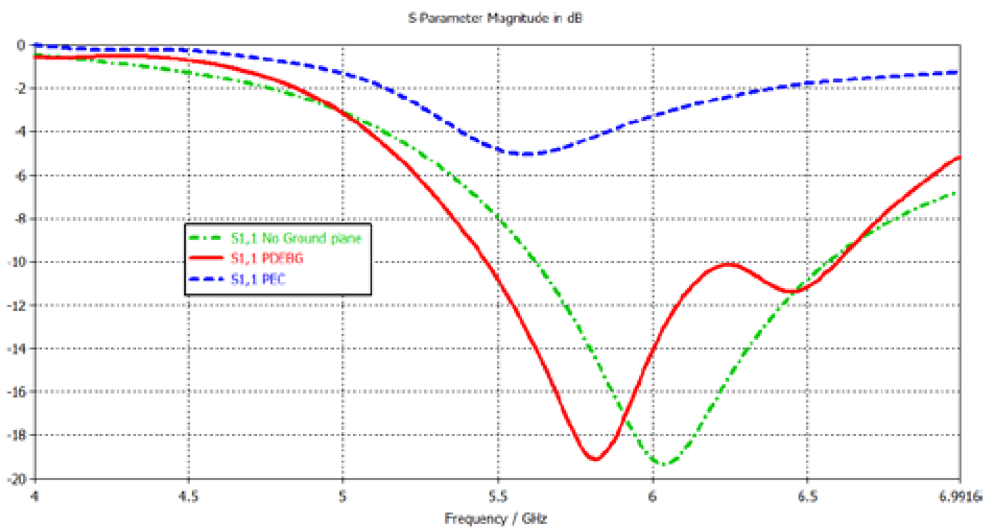


Fig. 4. Simulated return loss of the antenna with PEC, PDEBG and without ground plane.

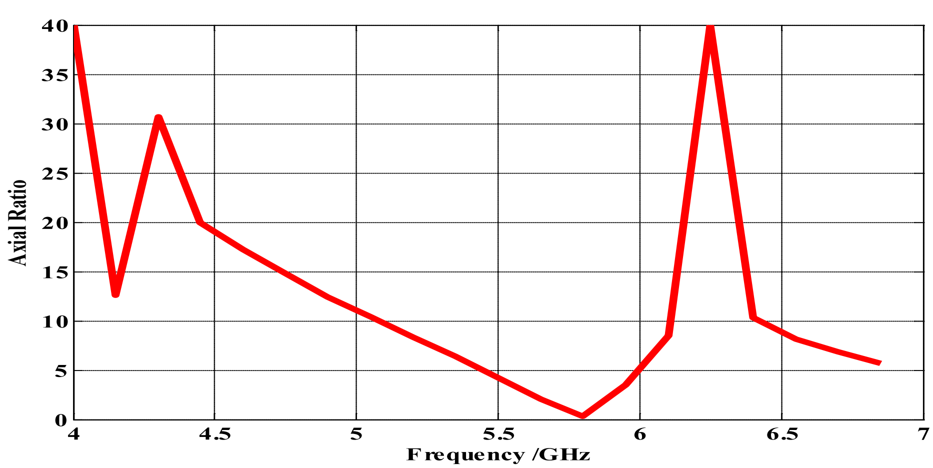


Fig. 5. Integrated dipole antenna Axial Ratio at φ= 45˚.

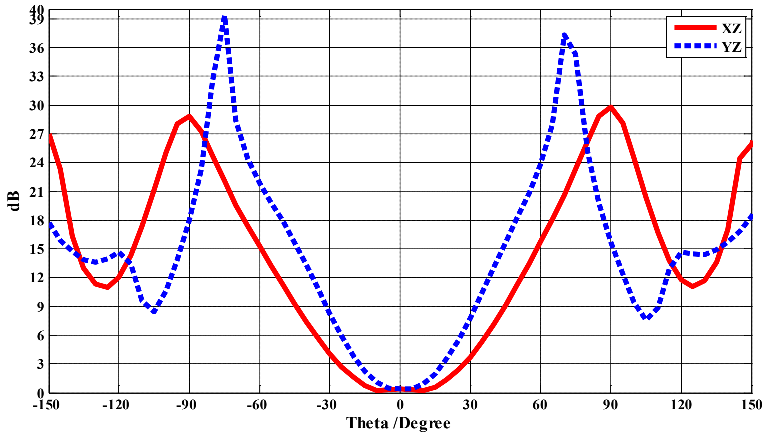
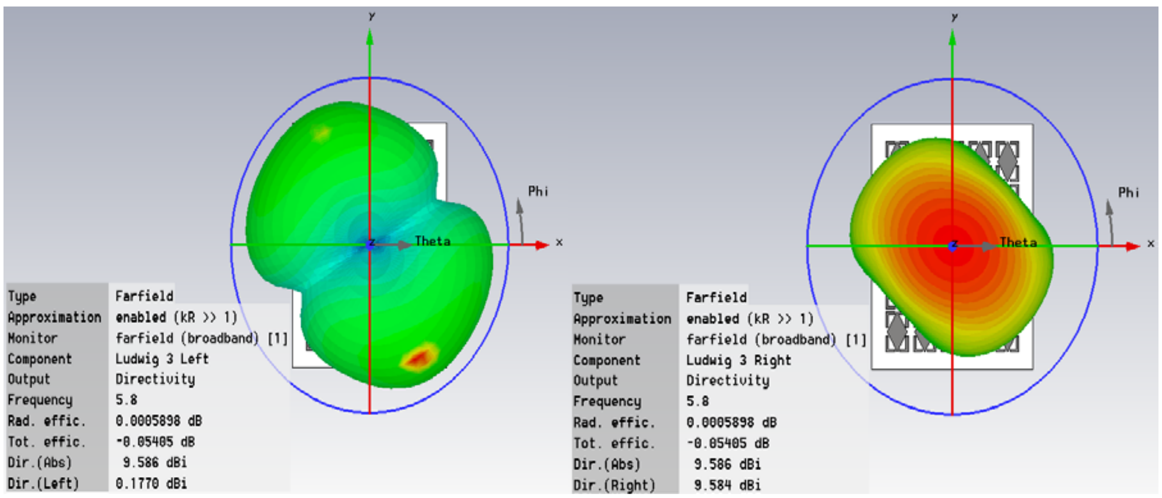
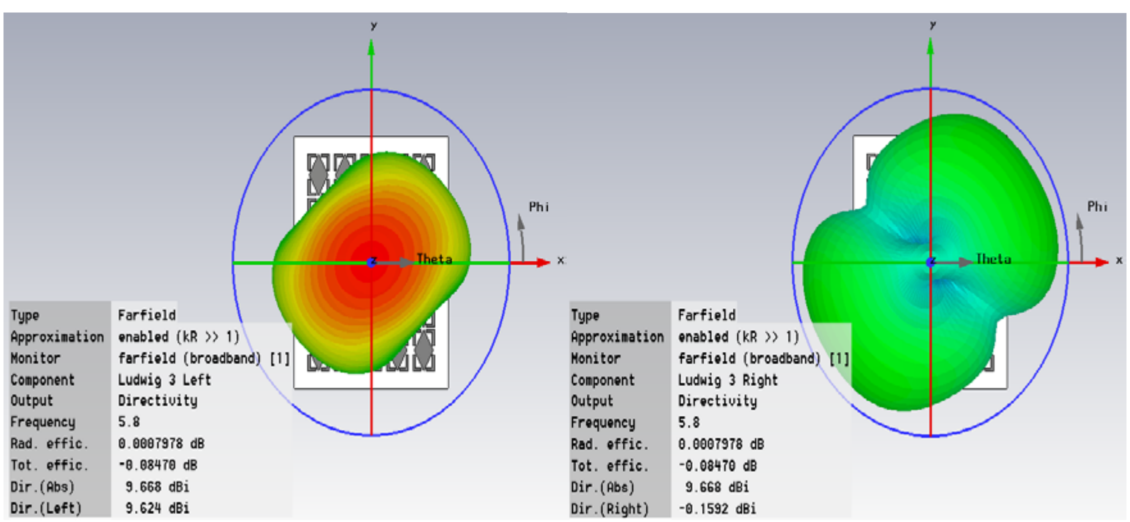


Fig. 6. Axial ratio at 5.8 GHz verses elevation angle in the XZ, YZ planes at$\boldsymbol{\varphi}$=45˚.



(a) (b)

Fig. 7. Radiation pattern of the dipole antenna (a) LHCP at $\boldsymbol{\varphi}$=45˚ (b) RHCP at $\boldsymbol{\varphi}$=45˚.



(a) (b)

Fig. 8. Radiation pattern of the dipole antenna (a) LHCP at $\boldsymbol{\varphi}$=135˚ (b) RHCP at $\boldsymbol{\varphi}$=135˚.

dipole orientation is 45˚as can be seen from the radiation intensity of Fig. 7. The intensity of radiation in Fig. 8 (a) shows that A Left Hand Circular polarized (LHCP) wave is obtained when the dipole orientation is 135˚.

4. CONCULSIONS

This article presents design of a novel dipole antenna radiating circularly polarized EM wave. CP behaviour of the design is achieved by incorporating a novel PDEBG ground plane to the antenna. In-phase reflection of this artificial ground plane results in better return loss with low profile configuration at the operating frequency. Polarization dependent property of the structure transforms polarization of the antenna from linear to circular one. It has been observed that integrated antenna is showing an axial ratio less than 3 dB in frequency range from 5.58 GHz to 5.93 GHz (5.98%) which completely covered the Wireless Local Area Network (WLAN) Band 5.725 GHz to 5.875 GHz with low profile configuration. Simulation results are obtained in CST MW Studio to verify the conceptual antenna design. Hence it is concluded that PDEBGs can be used to achieve low profile configuration of dipole antenna which is also capable of radiating CP wave at the operating frequency as desired in many wireless applications.

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