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Design and Improvement of Step Slotted Microstrip Monopolar Patch Antenna using Defected Ground Structure (DGS)

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Jovita Serrao [α] & Nirav Patel [σ]

Abstract- A new low profile and broadband monopolar patch antenna is proposed. Previously, long rectangular patch antennas have been designed with a compact structure and high gain, but these antennas do not have the required monopolar radiation pattern. On the other hand there have been patches designed to have wide bandwidth by employing thick substrates. However, the profile of such antennas may be too high for certain applications. We propose a low profile patch antenna with wide bandwidth, high gain, high directivity and monopole like radiation pattern. The proposed antenna has a bandwidth of 1.396% and gain of 4.75 dBi with monopole like radiation pattern at 5.156 GHz for an infinite ground plane. Using Defected Ground Structure (DGS) resonant frequencies are obtained at 3.836, 5.18 and 6.644 GHz, with bandwidth of 18.902% and gain of 8.66 dBi.

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I. Introduction

Monopole antennas are widely used in wireless communication system, since they can provide omnidirectional radiation patterns [1]. In recent years the demands on mobile communication have grown rapidly. So, indoor wireless networks consisting of numerous indoor base station antennas have been mounted on the ceilings of many buildings and malls, thus there are stringent requirements on an antennas impedance bandwidth and physical size. Many types of monopole antenna are attractive for present wireless communication systems.

A typical monopole antenna is the quarter wavelength monopole antenna, whose length is equal to a quarter of the wavelength at the resonance frequency. The profile of a conventional monopole antenna is too high for some devices that have limited space for hiding the antenna. Microstrip antennas are popular for their low cost, light weight, easy fabrication, mass production and planar structure with low profile [1][2]. Because of the merits it is expected that microstrip antennas can be used to replace monopole antennas that have a high profile of about quarter wavelengths. A microstrip patch antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. Radiation from the patch can occur from the fringing fields between the periphery of the patch and the ground plane.

This paper is organized as follows. Section 1 mentions a brief introduction to the applications of monopole antenna. Various methods that have been implemented to design monopolar patch antennas and their drawbacks, is mentioned in Section 2. Section 3 explains the design of a novel low profile monopolar patch antenna. The number of resonant frequencies and the bandwidth is increased using Defected Ground Structure (DGS). The simulation and results are shown in Section 4. In this section we have also mentioned the effects of DGS. The paper is concluded in Section 5.

II. Monopolar Patch Antenna

Monopole antennas are widely used since they provide a vertical polarization and a conical radiation pattern. However, the profile of a conventional monopole antenna that has a quarter wavelengths is too high for some devices or applications that have limited space for hiding the antenna. Many excitation modes have been studied for circular disc and annular ring patches. A circular microstrip antenna can be used to replace vertical wire monopole [3]. However, the radius of this antenna is very large. Microstrip antennas including ground wire which connects the patch of the antenna to the ground plane can be used to obtain monopole like radiation pattern [4].Such an antenna has total height much less than a quarter wavelength of the centre operating frequency. However, this type of monopolar wire patch antenna has a narrow impedance bandwidth. To improve the bandwidth a planar rectangular monopole top-loaded with a shorted square or circular patch can be used [5]. The wire monopole and the ground wires [4] can be replaced by a planar rectangular monopole and ground rectangular plates respectively [5]. The profile of such an antenna is around $0.09_{\lambda 0,}$ which is much lower as compared to the quarter wavelength dipole. The bandwidth can further be increased by using a circular patch, because of the

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relatively large patch size. The bandwidth of a probe fed patch antenna is limited by the inductance introduced by the coaxial feed in case of thick substrate. To improve the bandwidth and avoid drilling or soldering of the patch, a L-probe fed circular patch antenna can be used [6]. Such an antenna provides wide bandwidth and high gain with a profile of 0.13 λ_0. However, such antennas consist of air substrate, which are difficult to implement. Another inconvenience is that such antennas are larger in size as compared to quarter wavelength monopoles. The profile of the L-probe fed circular patch can be reduced to 0.092 λ_0 by shorting the circular patch to the ground plane by four copper wires [7]. The radius of this patch is also reduced due to the presence of shorting wires. The bandwidth can further be enhanced by connecting four trapezoidal plates orthogonally to the circular patch which is shorted to the ground plane by four copper wires [8]. A rectangular planar monopole with a bevel can further increase the impedance bandwidth. Nevertheless, owing to the asymmetry of the planar structure, its radiation patterns in the azimuth plane do not keep omnidirectional as the operating frequency increases [9]. A disk-loaded monopole reduces the profile to 0.08 λ_0. A monopole can also be created by connecting six triangle plates together. The regular hexagon is shorted to the ground plane by six wires [10]. The height of such an antenna is equal to 0.1 λ_0 at resonance frequency. Another type of monopolar patch is the sleeve monopole antenna [11]. This antenna is composed of a circular patch and a disc-conical sleeve, both of which are shorted to the ground plane through four shorting probes. The antenna has a low profile of 0.1 times the free space wavelength of the centre operating frequency. A circular sleeve structure can be added to improve the matching condition of the upper operating frequency edge and thus enhance the bandwidth [12].

The bandwidth enhancement for monopolar patch antennas were demonstrated [3] - [13] with/ without shorting wires. All these antennas have a profile of about 0.1 λ_0 (or even higher); nonetheless it is too thick for some applications such as the installation to an aircraft. Besides these antennas adopt an air substrate and their structures are not simple to be fabricated. A centre-fed circular microstrip patch with a coupled annular ring provides monopole-like radiation pattern [14]. Such antennas have low profile of 0.04 λ_0.

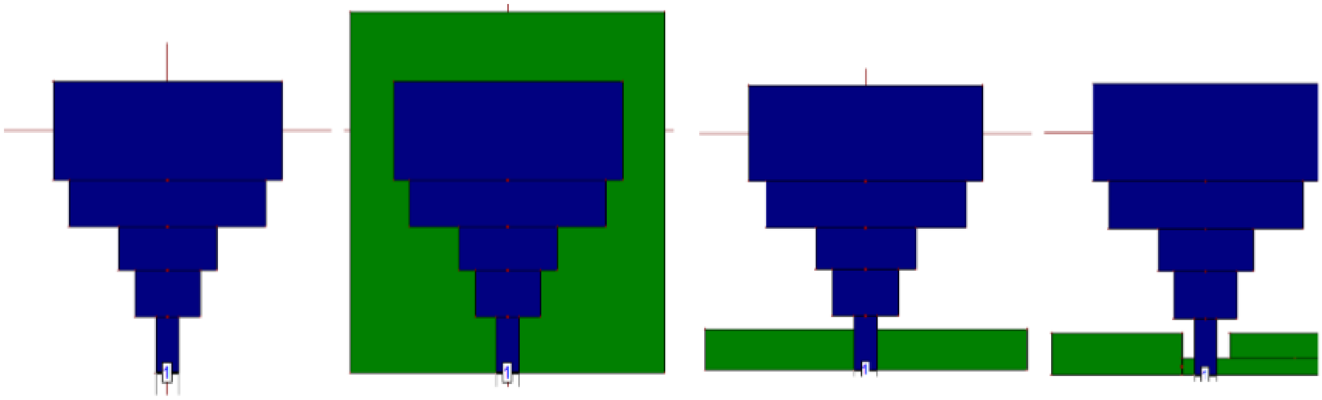
III. Antenna Design

In this paper we proposed a monopolar patch antenna. A step slotted antenna is designed. The parameters of the designed antenna are shown in Table no. 1. The antenna is printed on FR4 substrate with dielectric constant 4.4 and thickness 1.6 mm.

Table 1 : Dimensions of Slotted Step MSA

Antenna Parameter	Specification
Ground size	38.5 mm X 5 mm
Substrate size	38.5 mm X 44 mm
Patch steps	
W_p X S_1	28 mm X 12 mm
W_1 X S_2	24 mm X 5.75 mm
W_2 X S_3	12 mm X 5.25 mm
W_3 X S_4	8 mm X 5.75mm
Ground slot	6 mm X 3 mm
Feed Line Width	2.8 mm

Global Journal of Researches in Engineering (F) Volume XVI Issue IV Version I Year 2016



(a) (b) (c) (d)

Fig. 1 : Geometry of designed antenna (a) with infinite ground plane, (b) with finite ground plane, (c) with defected ground structure 1 and (d) with defected ground structure 2 (final prototype)

Table 2 : Comparison of output parameters of designed prototype

Parameters	Infinite ground plane (Fig.1.a)	Finite ground plane (Fig.1.b)	Defected ground structure 1 (Fig.1.c.)		Defected ground structure 2 (Fig.1.d)		
Resonant Frequency	5.156 GHz	4.69 GHz	4.124 GHz	5.204 GHz	3.836 GHz	5.18 GHz	6.644 GHz
Return Loss	-15.136 dB	-29.56 dB	-22 dB	-25 dB	-15 dB	-24 dB	-18.1 dB
Bandwidth	1.396%	12.15%	18.523%		18.902%		
Gain	4.75 dBi	5.22 dBi	5.23 dBi		8.66 dBi		
Directivity	7.346 dBi	8.48 dBi	7.823 dBi		11.586 dBi		

Table 3 : Comparision of fabricated antenna with previously designed antenna

Parameter	Circular patch with annular ring [14]	Concentrically shorted circular patch [15]	Rectangular patch with periodic vias [16]	New low profile monopolar patch antenna
Principle	Slots on patch	Periodic shorting vias	Periodic shorting vias	Step slotted MSA and defected ground structure (DGS)
Substrate	Duroid 6002	Duroid 5870	Duroid 5870	FR4
Dimension	Diameter = 150 mm	Diameter = 180 mm	62.4 x 30.4 mm	44 x 38.5 mm
Profile	0.029λ	0.024λ	0.030λ	0.028λ
Resonance	5.8 GHz	2.4 GHz	5.8 GHz	3.836, 5.18 and 6.644 GHz
Bandwidth	12.8%	18%	12.48%	18.902%
Gain	5.7 dBi	6 dBi	9 dBi	8.66 dBi

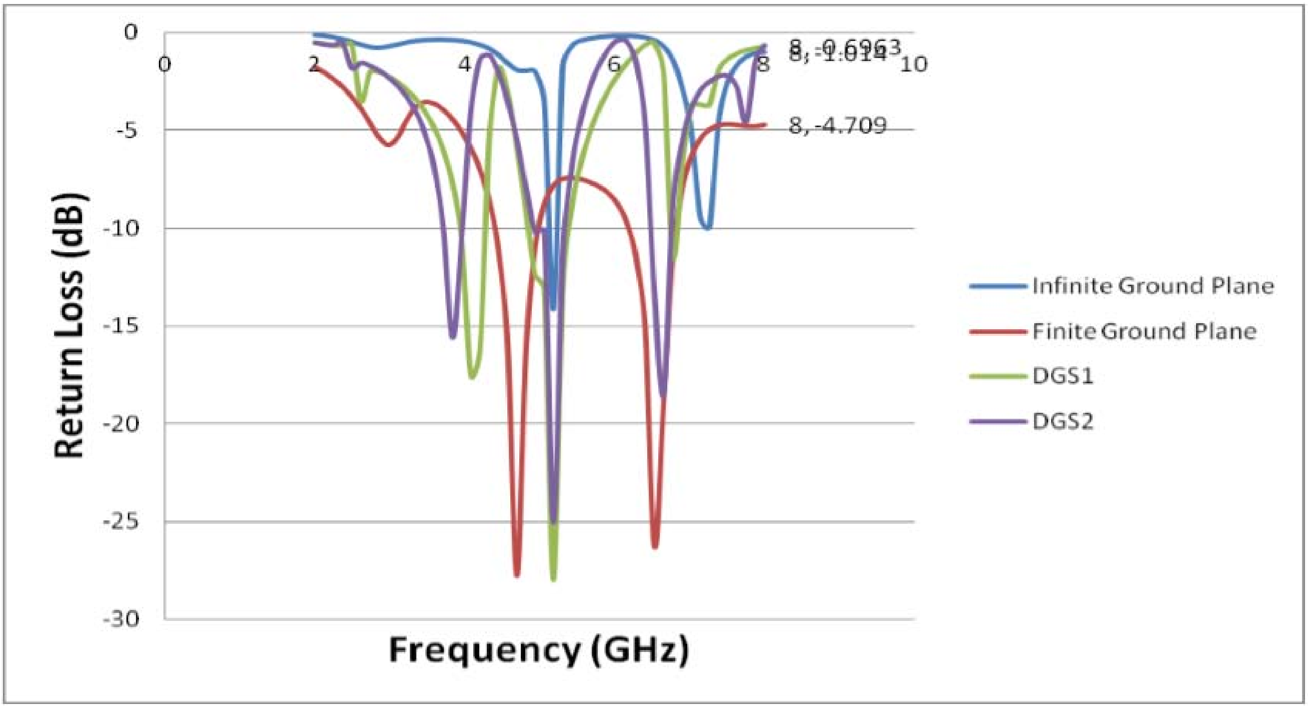


Fig. 2 : Comparison of return loss for the designed prototypes

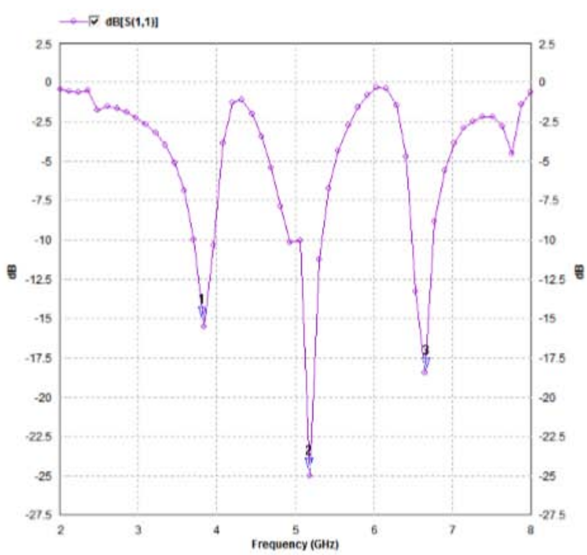


Fig. 3 : Return loss of proposed antenna with defected

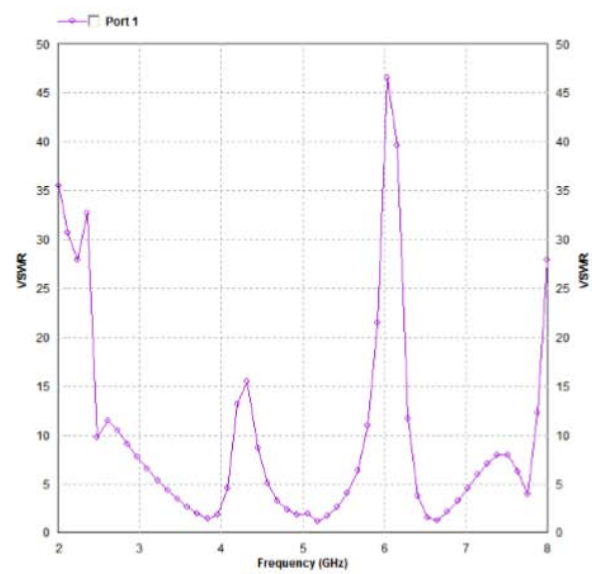


Fig. 4 : VSWR of proposed antenna with defected ground plane

The basis of the proposed antenna structure is a rectangular patch monopole, which has dimensions of length L and width W, and connected at the end of the CPW feed-line. The simulations were performed using IE3D software, a commercial full wave simulator based on Method of Moments (MOM).

IV. Results and Discussions

The dimensions for the prototype are finalized using iterative method. The designed monopolar patch has a profile of 0.027λ0 which is lower than that of a centre-fed monopolar patch [14]. The patch was initially simulated for an infinite ground plane. The antenna resonates at 5.156 GHz. Bandwidth of 1.396%, gain of 4.75 dBi and directivity of 7.346 dBi is obtained.

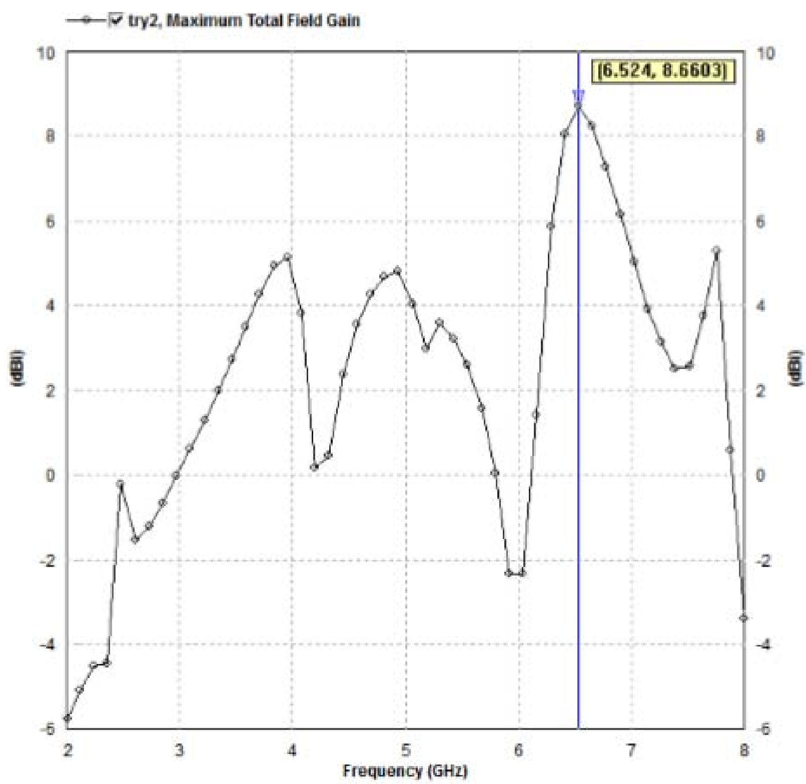


Fig. 5 : Gain of proposed antenna with defected ground plane

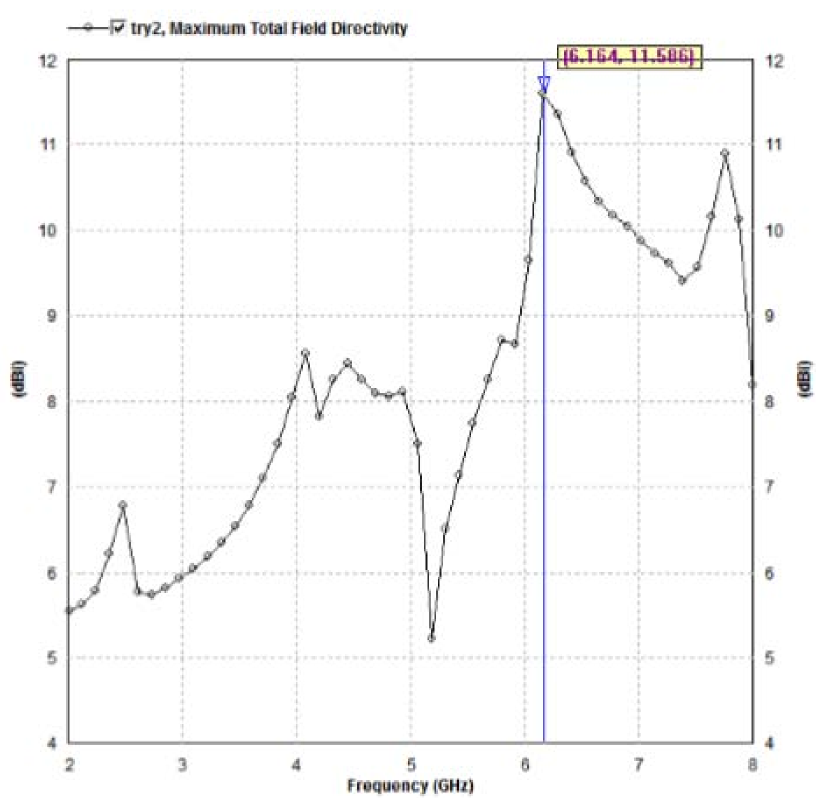


Fig. 6 : Directivity of proposed antenna with defected ground plane

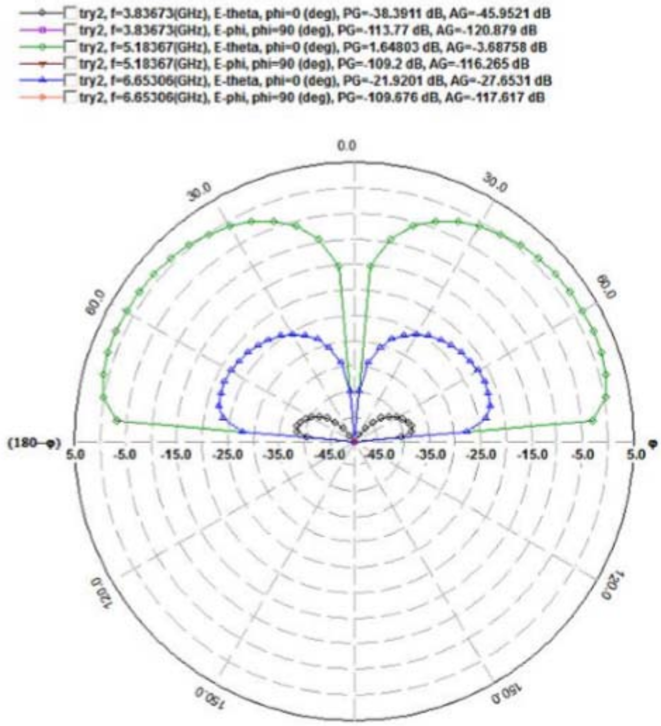


Fig. 7 : Elevation pattern of proposed antenna with defected ground plane

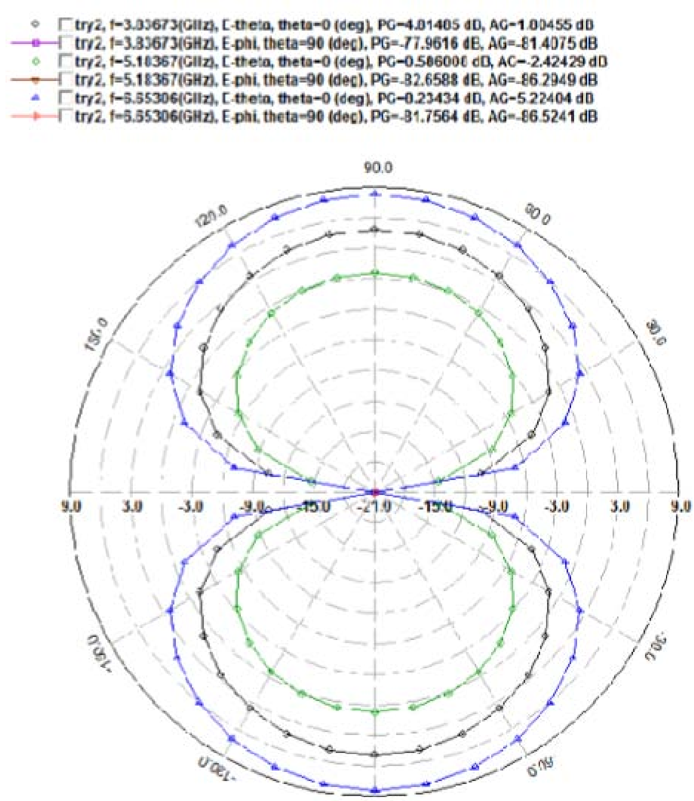


Fig. 8 : Azimuth pattern of proposed antenna with defected ground plane

Global Journal of Researches in Engineering (F) Volume XVI Issue IV Version I Year 2016

The antenna is simulated for finite ground plane, resonant frequency of 4.69 GHz is obtained, other parameters obtained are mentioned in table no. 2.Defected ground structure is used to increase the number of resonant frequencies and the bandwidth of the antenna. The parameters are shown in table 2. The return loss of the final prototype with DGS is shown in figure 2. Total bandwidth of 18.902% is obtained for the designed antenna. The comparative graph of return loss for all the four conditions is shown in figure 3. The VSWR plot for the final prototype is shown in figure 4. The VSWR is well below 2 for all the resonant bands. High gain of 8.66 dBi is obtained as depicted in figure 5. Figure 6 shows the directivity of the designed antenna. Directivity of 11.586 dBi is obtained as shown in figure 6. The cross polar and co-polar components of the elevation radiation pattern for all the resonant frequencies is shown in figure 7. The azimuth pattern is shown in figure 8. The three dimensional radiation pattern of the designed antenna at the resonant frequencies is shown in figure 9. The performance of the proposed antenna with that of the previously designed antenna is compared in table 3.

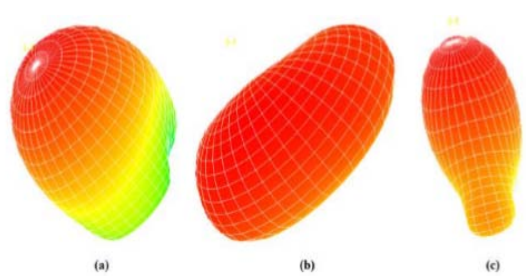


Fig. 9 : Radiation Pattern of Designed Antenna At (A) 3.836 Ghz, (B) 5.18 Ghz and (C) 6.644 Ghz

V. Conclusions

A broadband monopole antenna using step slotted microstrip patch has been designed. The design is improvised using defected ground structure (DGS). By the use of DGS we obtain higher number of resonant frequencies, high gain, high directivity and high bandwidth at a low profile. The antenna has been proposed, designed and simulated for WLAN operations. The simulated results show a bandwidth of 18.9%, gain of 8.66 dBi and monopole like radiation pattern at a low profile of 0.028 $_{\lambda 0}$.

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