Design and Analysis of a Broadband Low Profile Monopolar Patch Antenna with Defected Ground Structure (DGS)

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Abstract- Patch antennas have gained popularity in present scenario of technological advances. In this paper a new design of low profile and broadband monopolar patch antenna has been proposed. The existing design of long rectangular patch antennas have been designed with a compact structure and high gain, but do not have the required monopolar radiation pattern. On the other hand there have been some patches designed to have wide bandwidth by employing thick substrates. However, the profile of such antennas may be too high for certain applications of employed frequency range. The proposed low profile patch antenna is with wide bandwidth, high gain and monopole like radiation pattern, which has a bandwidth of 9.4% and gain of 7 dBi with monopole like radiation pattern for an infinite ground plane. By the use of Defected Ground Structure (DGS) bandwidth of 15.3% and gain of 5 dBi is obtained at a low profile of $0.027\lambda_0$.

Keywords- Excitation modes, low profile, monopolar patch antenna, coplanar waveguide fed (CPW), omnidirectional.

1. Introduction

Antennas are the integral part of the communication systems. 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 with increase in services. This has also made possible to have 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 in practice and have proved to be useful antenna for present wireless communication systems, which are gaining its popularity. A typical monopole antenna is the quarter wavelength monopole antenna, whose length is equal to a quarter of the wavelength at the resonance frequency of interest. 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 generally consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side of the substrate with certain specific dielectric constant. Radiation from the patch can occur from the fringing fields between the periphery of the patch and the ground plane.

The organization of this paper is 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. Defected Ground Structure (DGS) is used to increase the bandwidth of the designed antenna. The simulation and results are shown in Section 4. In this section we have also mentioned the effects of a finite ground plane. The paper is concluded in Section 5 with its outcome and prospective results.

II. Monopolar Patch Antenna

Monopole antennas have widely gained popularity and have been used since they can 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 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.**

2. ANTENNA DESIGN

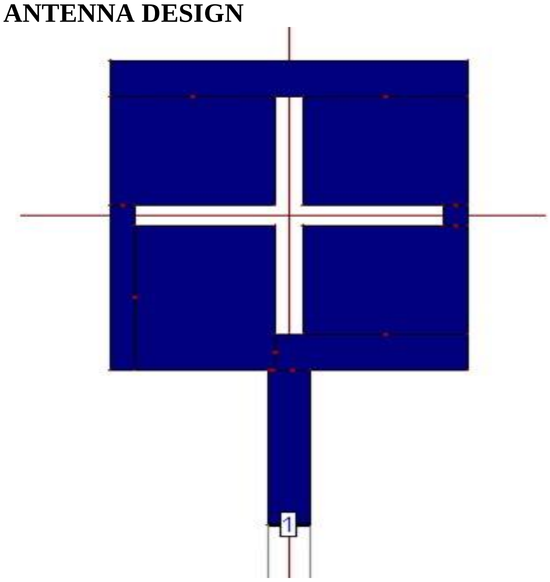

Fig. 1: Proposed antenna with infinite ground plane

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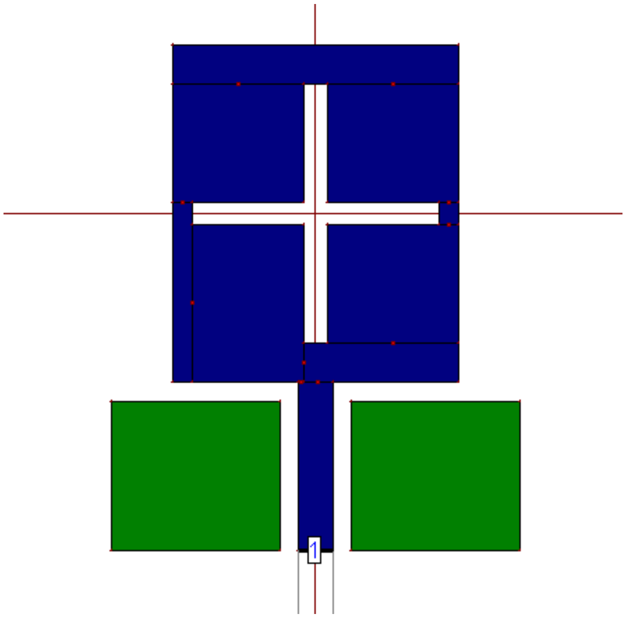

Fig. 2: Geometry of proposed antenna with DGS

In this paper we propose a coplanar waveguide fed monopolar patch antenna. Initially a rectangular patch antenna for the WLAN 2.4 GHz band was designed using basic design equations [1] for a microstrip patch antenna design. Vertical and horizontal slots were then introduced on the patch to obtain resonance in the 5 GHz band (5.25 GHz to 5.35 GHz and 5.47 GHz to 5.725 GHz). Fig. 1 shows the geometry of the rectangular patch antenna with horizontal and vertical slots. The effect of addition of these slots is shown in fig. 2. The bandwidth of the designed antenna is increased by using DGS. Fig. 3 shows the geometry of the final proposed monopole antenna. The antenna is printed on FR4 substrate with dielectric constant 4.4 and thickness 1.6 mm. 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 optimized geometric parameters of the proposed antenna are: length of rectangular patch L= 29.63 mm, width of rectangular patch W= 25 mm, ground plane length Lg = 13.12 mm, ground plane width Wg = 14.8 mm, feed-line width Wf =3 mm, slot length L1 = 22.7.5 mm, slot length L2 = 21.53 mm, slot width Ws =2 mm, spacing between ground plane and feed length d = 1.65 mm and spacing between rectangular patch and ground plane s = 1.72 mm. The simulations were performed using IE3D software, a commercial full wave simulator based on Method of Moments (MOM).

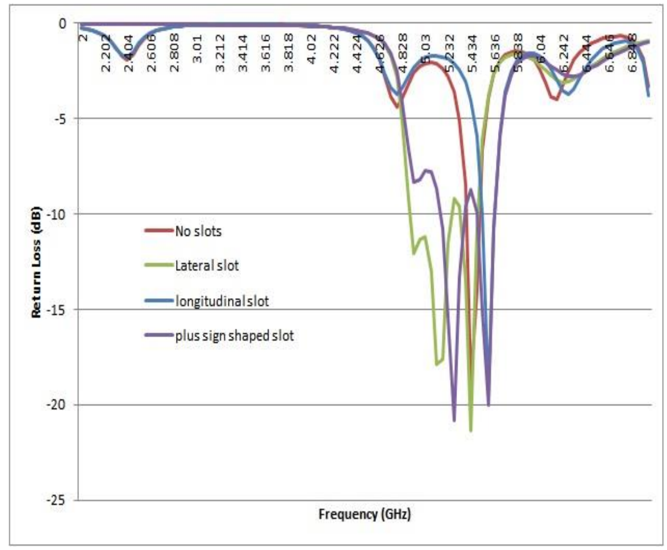

Fig. 3: Effect of adding slots on the antenna

III. Results And Discussions

The dimensions for the plus sign on the rectangular patch are finalized using iterative method. The designed monopolar patch has a profile of $0.027\lambda_0$ which is lower than that of a centre-fed monopolar patch [14]. The final prototype of the antenna is shown in fig. 3. The return loss obtained is shown in figure 4. The antenna resonates at 5.236 GHz and 5.58 GHz, which is same as the resonant frequency using infinite ground plane. Bandwidth of 15.3% is obtained using the proposed antenna. VSWR is well below 2 in the range 5 to 5.7 GHz as shown in figure 5. As shown in figure 6, the gain lies in the range of 4 to 5 dBi. The gain obtained is almost twice times higher than that obtained by a circular patch with annular ring. As shown in figure 7, directivity lies between 6.5 to 7 dBi. Fig. 8 and 9 depict the radiation pattern of the designed antenna. The proposed antenna has monopole like radiation pattern in the elevation plane and omnidirectional pattern in the azimuth plane. The performance of the proposed antenna with infinite ground plane, finite ground plane and ground plane with DGS are compared in table 1. The performance of the fabricated antenna are compared with the previously designed antennas is shown in table 2.

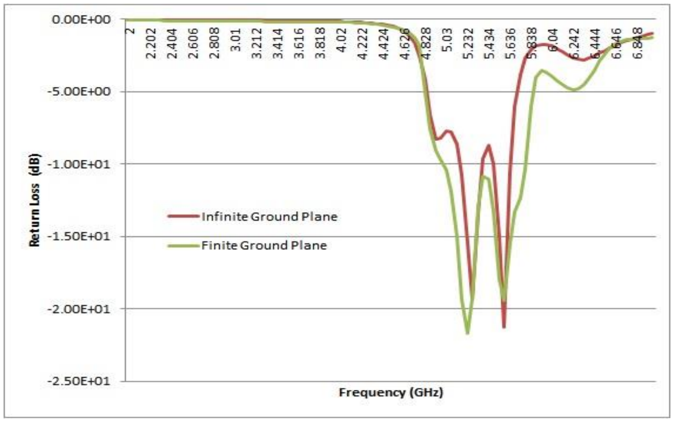

Fig. 4: Return loss of proposed antenna with finite ground plane

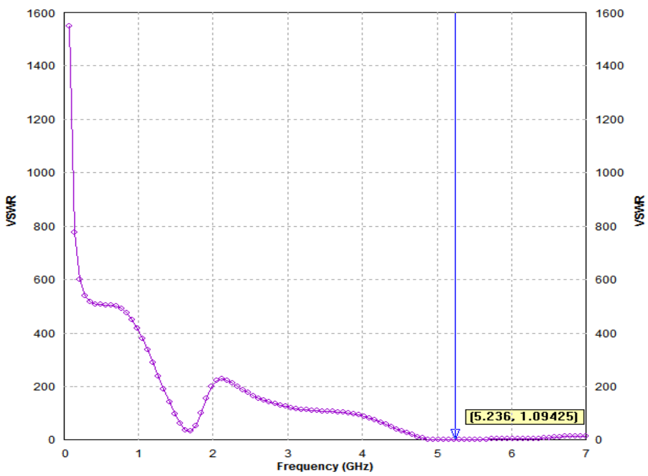

Fig. 5: VSWR of proposed antenna with finite ground plane

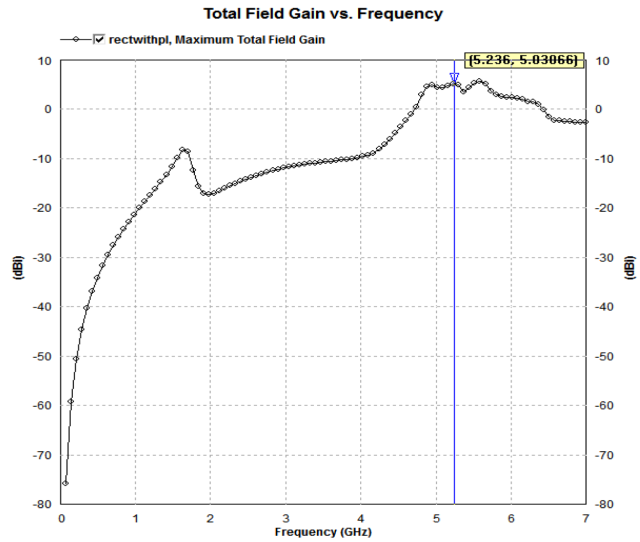

Fig. 6: Gain of proposed antenna with finite ground plane

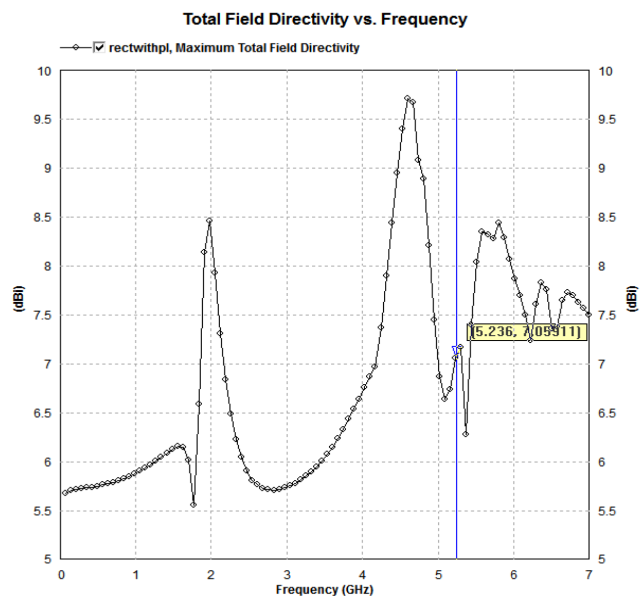

Fig. 7: Directivity of proposed antenna with finite ground plane

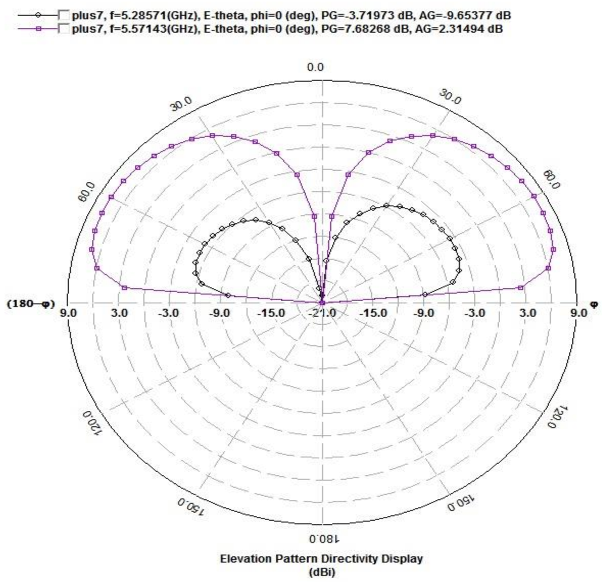

Fig. 8: Elevation pattern of proposed antenna with finite ground plane

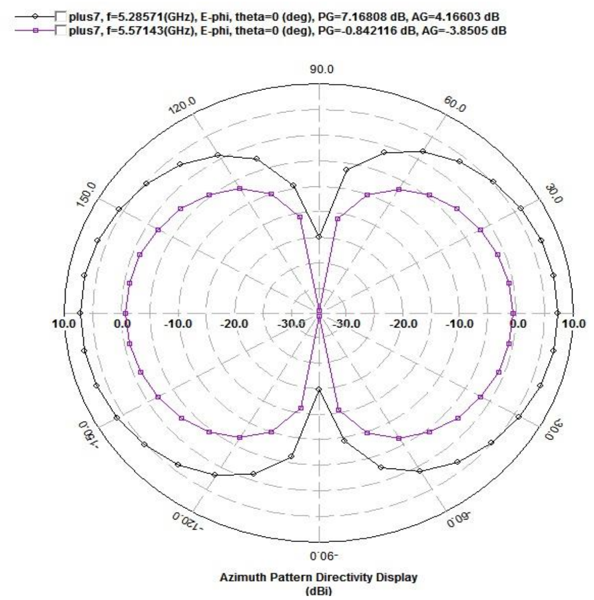

Fig. 9: Azimuth pattern of proposed antenna with finite ground plane

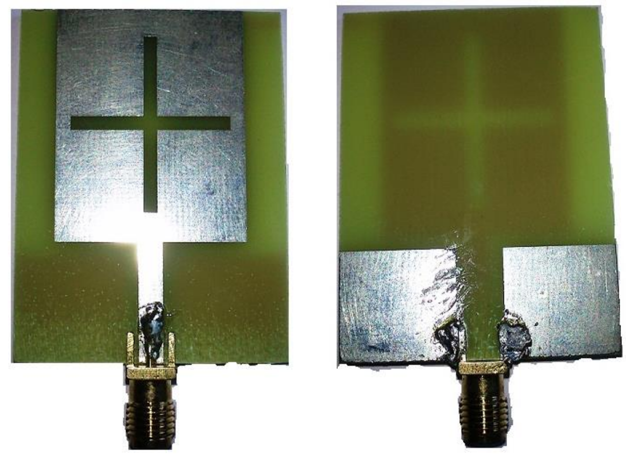

Fig. 10: Front and back view of the fabricated antenna

Table 1: Comparision of proposed antenna with infinite ground plane, finite ground plane and ground plane with DGS

Parameter	Monopolar Patch with infinite ground plane	Monopolar patch with finite ground plane	Monopolar patch with DGS (Simulated)	Monopolar patch with DGS (Fabricated)
Resonant frequency	5.278 and 5.572 GHz	5.25 and 5.576 GHz	5.23 and 5.58 GHz	5.25 and 5.48 GHz

Return loss	-28.12 dB	-25.6 dBi	-21.73 dB	-23.5 dBi
Bandwidth	9.4%	10%	12.3%	15.71%
Gain	6.83 dBi	6.57 dBi	5.586 dBi	5.586 dBi
Directivity	8.139 dBi	8.236 dBi	8.3 dBi	8.3 dBi
Profile	0.028λ	0.028λ	0.028λ	0.028λ

Table 2: 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	Slots on patch 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	44.47 x 35.9 mm
Profile	0.029λ	0.024λ	0.030λ	0.028λ
Resonance	5.8 GHz	2.4 GHz	5.8 GHz	5.25 and 5.48 GHz
Bandwidth	12.8%	18%	12.48%	15.71%
Gain	5.7 dBi	6 dBi	9 dBi	5.586 dBi

The front and back view of the fabricated antenna is as shown in figure 10. The antenna has been experimentally tested. The return loss of the fabricated antenna is shown in Figure 11. It can be seen that similar results have been obtained on fabrication. The fabricated prototype has a bandwidth of 15.5% with resonance at 5.25 GHz and 5.48 GHz.

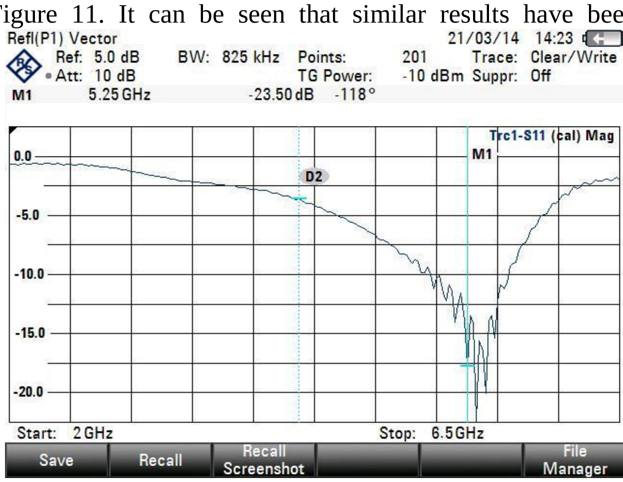

Fig. 11: Return loss of the fabricated antenna

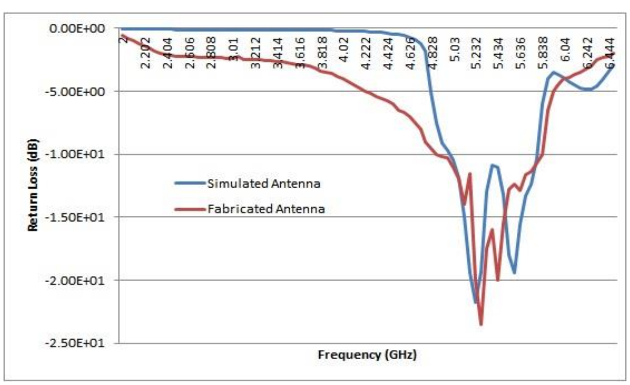

Fig. 12: Comparision of return loss of simulated and fabricated antenna

IV. Conclusions

A broadband monopole antenna with single plus sign has been proposed, designed, simulated, fabricated and experimentally tested for WLAN operations. The simulated results show a bandwidth of 12.3%, gain of 5 dBi and monopole like radiation pattern at a low profile of $0.028\lambda_0$. The designed prototype has been fabricated and a bandwidth of 15.71% is obtained. The results obtained on fabricating the antenna are similar to those obtained on simulation.

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Biography

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