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A Novel Design of Compact Monopole Antenna with Defected Ground Plane for Wideband Applications

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Abstract—In this paper, a design of compact monopole antenna with defected ground plane for wideband applications has been investigated. Initially, the partial ground plane is used which yields the impedance bandwidth ($S_{11} \leq -10\,\text{dB}$) of 23.87% and 17.54% ranging (4.00 GHz–5.11 GHz) and (8.48 GHz–9.84 GHz), respectively. The bandwidth of the proposed monopole antenna is enhanced by employing the defects in the partial ground plane. Antenna is designed and simulated by using Ansoft HFSS v13 simulator; moreover, the antenna is fabricated to validate the simulated results with the measured results. Measured proposed monopole antenna with DGP (Defected Ground Plane) exhibits the impedance bandwidth ($S_{11} \leq -10\,\text{dB}$) of 72.87% ranging (3.89 GHz–8.35 GHz), which covers different wireless standards such as WiMAX (3.3 GHz–3.7 GHz), WLAN (5.15 GHz–5.85 GHz), X-band satellite applications (7.1 GHz–7.76 GHz) and point to point high speed wireless communication (5.925 GHz–8.5 GHz).

1. INTRODUCTION

In modern communication system, the demand for compact size antennas is increasing because of their wideband and multiband characteristics [1]. This attracts researchers towards microstrip antennas due to their low weight, low cost, low profile and conformal shape [2, 3]. Modern systems support different wireless applications and can be operated on various frequency bands. Hence, there is a need for multiband/wideband antennas [4, 5]. Nowadays due to advancement in wireless technologies, the need for wideband antennas is increased. So different applications can be used on a single device, such as data-text, audio, video or multimedia streaming [6]. In wireless communication to increase the data rate, FCC (Federal Communication Commission) released the unlicensed radio communication band (3.1 GHz–10.6 GHz) [7]. This band is used for the Wireless Personal Area Networks (WPAN) [8]. The bandwidth of antenna should be $\geq$ 1.5 GHz (25%), to satisfy the UWB (Ultra-Wideband) operations [9]. Antennas designed for UWB can be useful to work under various applications such as WLAN (2.4 GHz–2.48 GHz, 5.15 GHz–5.85 GHz), WiMAX (2.5 GHz–2.7 GHz, 3.4 GHz–3.69 GHz, 5.25 GHz–5.85 GHz), X-band satellite communication (7.1 GHz–7.76 GHz) and point to point high speed wireless communication (5.925 GHz–8.5 GHz) [10, 11].

In recent years, a lot of research has been proposed by the researchers in the field of wideband antennas. Many techniques are used to achieve wideband characteristics such as defected ground plane, partial ground plane, monopole patch, fractal patch, and microstrip patch [6–8, 12–14]. A wideband dual-frequency CPW-fed triangular monopole antenna for DCS and WLAN application has been designed to achieve the bandwidth of 34.7% (4.08 GHz–6.03 GHz) [14]. A wideband fractal antenna with combination of fractal geometries is investigated to achieve the bandwidth of 72.37% (1.64 GHz–3.5 GHz) [13]. A microstrip patch antenna is designed for wireless application with bandwidths of 4.13%

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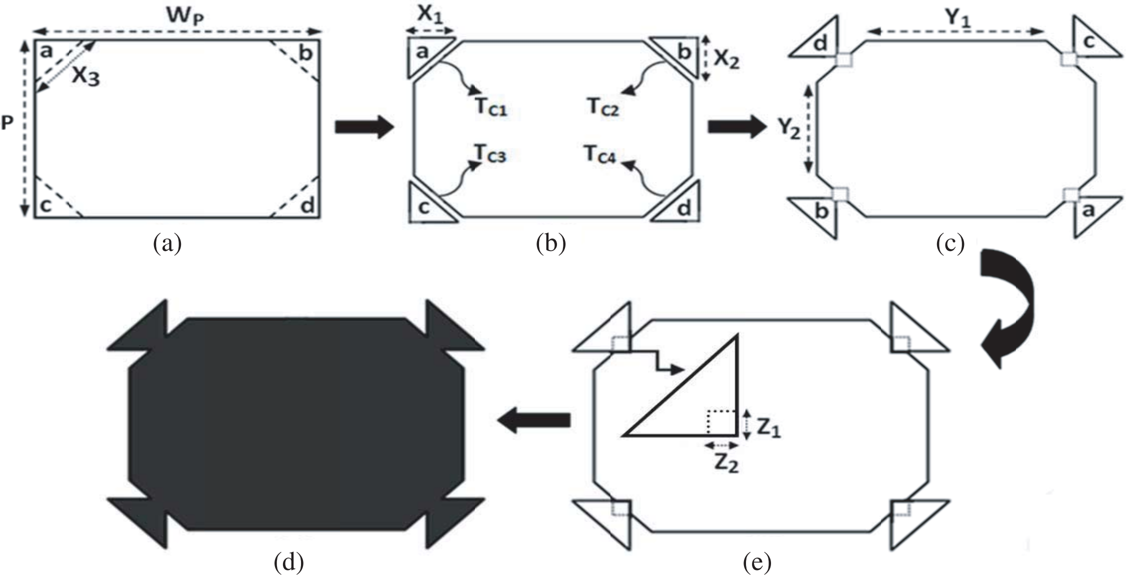
and 8.82% at the frequencies of 2.45 GHz and 5.125 GHz, respectively [2]. A CPW-fed slot antenna is designed to improve the impedance bandwidth to 52% (4.27 GHz–7.58 GHz) [15]. An L-shaped slotted patch antenna is designed with the wideband of 4.7 GHz [16], and a double L-slotted microstrip patch antenna is designed for broadband applications such as WLAN and WiMAX [17]. In this paper, a design of a compact monopole antenna with defected ground plane (DGP) for wideband applications is designed and fabricated. The wideband characteristics of antenna have been improved by employing the defects in the partial ground plane. The proposed antenna exhibits wide bandwidth and is capable of covering different wireless applications such as WLAN, WiMAX, X-band and satellite communication. The structural, simulated and experimental details are discussed in Sections 2 and 3.

2. ANTENNA DESIGN

The design and schematic configuration of the patch of proposed monopole antenna is shown in Fig. 1. The proposed antenna is designed using a low cost FR4 (glass epoxy) substrate with dielectric constant (ε_r) 4.4 and thickness (h) 1.6 mm. The initial geometry of antenna is composed of a rectangular patch as shown in Fig. 1(a), and the dimensions of patch ($W_P \times L_P$) are calculated by using following equations [20], where f_r (4 GHz) is the resonant frequency, c (3×10^8 m/s) the velocity of light, and h (1.6 mm) the thickness of substrate.



(a) (b) (c)

(d) (e)

Figure 1. Patch geometry of proposed antenna, (a) rectangular patch, (b) patch with truncated corners, (c) arrangement of triangular portions, (d) attachment of triangular portion on the truncated corners and (e) final geometry of the patch of proposed monopole antenna.

Width (W_P) of the rectangular patch is computed as 23 mm by using the equation given below:

$$W_P = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

The effective dielectric constant of the substrate is computed by using the equation given below, where W_P is the width of the patch. The value of ε_{reff} for the proposed monopole antenna is 3.284.

$$\varepsilon_{reff} = \left[\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\right]\frac{1}{\sqrt{1 + 12h/W_P}}, \quad 1 < \varepsilon_{reff} < \varepsilon_r \tag{2}$$

Extended incremental length (ΔL) of the proposed monopole antenna is calculated as 0.69 mm by using Equation (3) as shown below. Now the total length (L_P) of the patch is computed as 17 mm by using the relation as given below in Equation (4), where $1/\sqrt{\mu_o \varepsilon_o}$ is the speed of light in free space.

$$\Delta L = h * 0.412 \left[\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W_P}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W_P}{h} + 0.8\right)} \right] \tag{3}$$

$$L_P = \frac{1}{2 f_r \sqrt{\mu_o \varepsilon_o} \sqrt{\varepsilon_r}} - 2\Delta L \tag{4}$$

As shown in Fig. 1(b) the rectangular patch is modified by making the truncated corners (T_{C1}, T_{C2}, T_{C3} and T_{C4}), and the remaining triangular portions are named as a, b, c and d. These portions are arranged according to the design specification as shown in Fig. 1(c). In this figure, the vertices of the triangular portions a, b, c and d are connected to the boundary of the truncated corners T_{C4}, T_{C3}, T_{C2} and T_{C1}, respectively. Now these triangles are attached to the inner boundary of the truncated corners by the square dimensions of $(Z_1 \times Z_2)$ as shown in Fig. 1(d), to obtain the final geometry of proposed monopole antenna as shown in Fig. 1(e). The structures of patch such as rectangle (0th iteration), with truncated corners (1st iteration) and with triangular elements (2nd iteration) are fed by a transmission line $(W_F \times L_F)$ to analyze the performance parameters such as return loss, VSWR, gain and bandwidth as shown in Fig. 2.

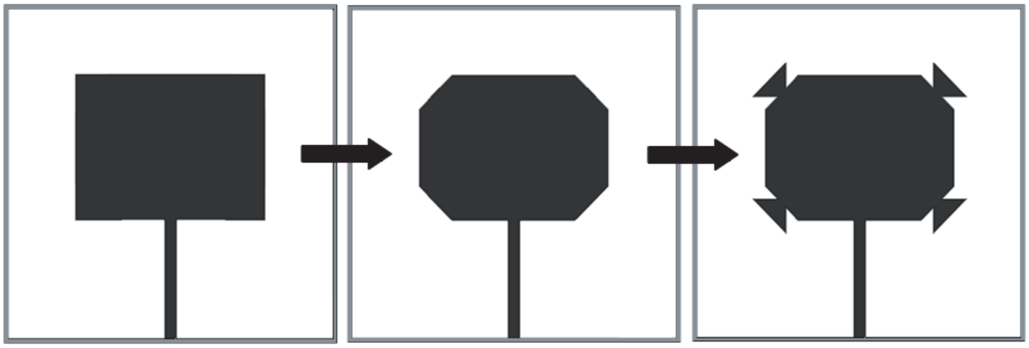
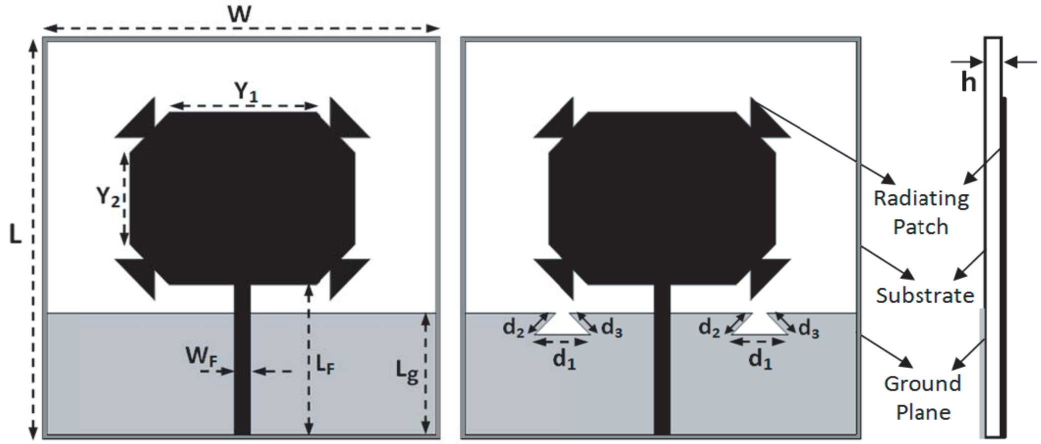

(a) (b) (c)

Figure 2. Proposed monopole antenna, (a) 0th iteration, (b) 1st iteration and (c) 2nd iteration.



(a) (b) (c)

Figure 3. Final geometry of proposed monopole antenna, (a) partial ground plane, (b) partial ground plane with defects, (c) side view of proposed antenna.

The 0th iteration, 1st iteration and 2nd iteration are designed by taking the length and width of the ground plane equal to the length (L) and width (W) of the substrate. The 2nd iteration of the proposed monopole antenna is classified as the final geometry of the proposed antenna as shown in Fig. 2(c). Further, for achieving the wideband characteristics, design of the antenna is modified by applying the partial ground plane ($W \times Lg$). The final geometry and the dimensions of the proposed monopole antenna as shown in Fig. 2(c) are further illustrated in Fig. 3(a). The design as shown in Fig. 3(a) is further modified to enhance the return loss and bandwidth of antenna at the frequency range of 1 GHz to 10 GHz, by employing the defects to the partial ground plane as shown in Fig. 3(b). The dimensions with partial ground plane as well as ground plane with defects (defective ground structure) of the proposed monopole antenna are mentioned in Table 1.

Table 1. Dimensions of final geometry of proposed monopole antenna.

Antenna design parameters	Dimensions
L	38.92 mm
W	40 mm
L_P	17 mm
W_P	23 mm
L_F	13.9 mm
W_F	1.4 mm
$X_1 = X_2$	4 mm
X_3	5.66 mm
Y_1	15 mm
Y_2	9 mm
$Z_1 = Z_2$	1 mm
Lg	12 mm
h	1.6 mm
d_1	5.66 mm
d_2	3 mm
d_3	3 mm

3. RESULT AND DISCUSSIONS

In this section, various parameters are investigated which influence the performance of the designed antenna. Frequency response and impedance characteristics strongly depend on the ground plane and the radiating patch of the design. Initially, the three iterations are developed by using the full ground plane as shown in Fig. 2. These iterations are designed to analyze the behavior of antenna in terms of return loss, VSWR, resonant frequency, gain and bandwidth. Simulated return loss versus frequency plots of the 0th, 1st, and 2nd iterations are shown in Fig. 4. Simulations of the antennas are carried out by using high frequency structure simulator (HFSS) V.13 based on finite element method (FEM). As seen in Fig. 4, the 0th iteration of the proposed monopole antenna resonates at frequency bands of (3.91 GHz, 6.01 GHz and 7.83 GHz) with -10 dB bandwidth of (150 MHz, 145 MHz and 335 MHz); the 1st iteration resonates at frequency bands of (6.22 GHz and 8.36 GHz) with -10 dB bandwidth of (181 MHz and 137 MHz); the 2nd iteration resonates at the frequency bands of (3.81 GHz, 5.83 GHz, 7.11 GHz and 7.60 GHz) with -10 dB bandwidth of (154 MHz, 145 MHz, 147 MHz and 253 MHz). Simulated results of the three iterations are mentioned in Table 2. According to the values of return loss and gain, performance of the proposed antenna is acceptable, but antenna bandwidth should be enhanced to achieve wideband characteristics.

The 2nd iteration of the proposed antenna is preferred as the final geometry, because it resonates on four frequency bands of operation. Further, this geometry has been modified to increase the bandwidth of antenna by employing the partial ground plane. The 'Lg' parameter of partial ground plane is

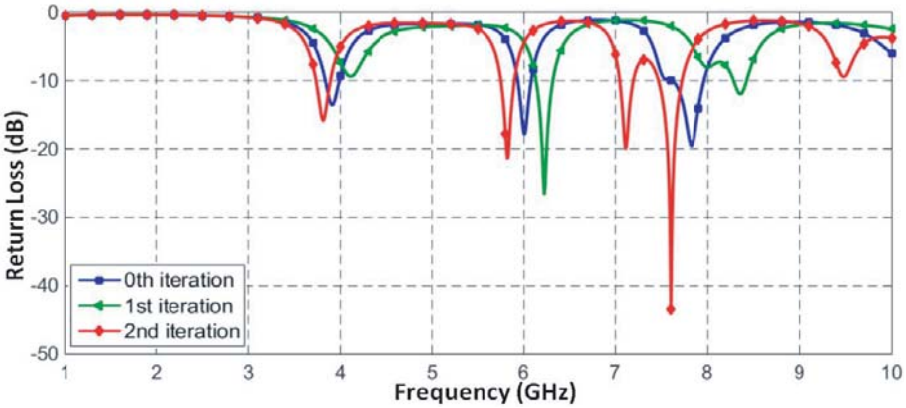


Figure 4. Simulated S_{11} characteristics of 0th, 1st and 2nd iteration of proposed monopole antenna.

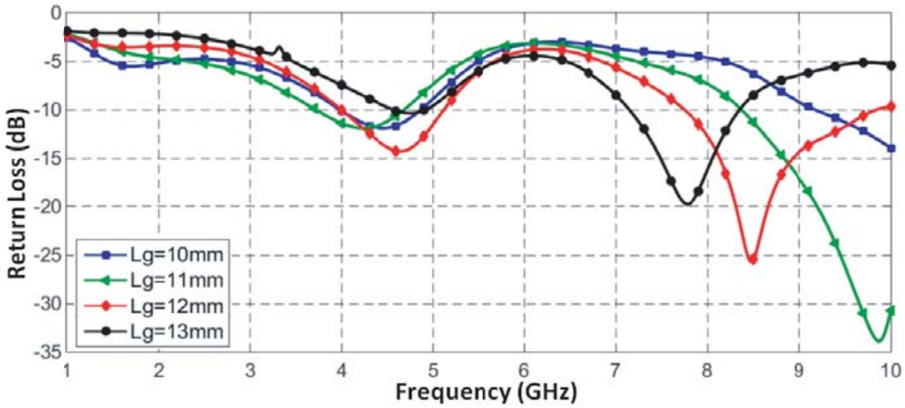


Figure 5. Simulated S_{11} characteristics of proposed monopole antenna for the variations of 'Lg'.

Table 2. Simulated results of 0th, 1st, and 2nd iteration of proposed antenna.

Iteration No.	Frequency (GHz)	Return loss (dB)	VSWR	Gain (dB)	Bandwidth (MHz)
0th	3.91	−13.59	1.52	3.38	150
	6.01	−17.80	1.29	3.98	145
	7.83	−19.57	1.23	6.96	335
1st	6.22	−26.71	1.09	4.76	181
	8.36	−11.93	1.67	3.60	137
2nd	3.81	−15.86	1.38	3.41	154
	5.83	−20.95	1.19	3.34	145
	7.11	−20.05	1.22	1.60	147
	7.60	−43.49	1.01	6.59	253

optimized to enhance the bandwidth of antenna with all other parameters fixed as shown in Fig. 3(a). Simulated return loss of the proposed antenna for different values of 'Lg' is shown in Fig. 5. The width of the ground plane which is equal to the width of the substrate is fixed and 'Lg' varied from 10 mm to 13 mm. From Fig. 5 it is found that the change in 'Lg' has significant effects on the bandwidth and impedance matching of the proposed monopole antenna. The proposed monopole antenna with $Lg = 12$ mm shows a much wider bandwidth at respective frequency bands than the other values.

Simulated results of the proposed monopole antenna with the variation in 'Lg' parameter are mentioned in Table 3.

In order to obtain more bandwidth, defects are employed in the partial ground plane with $Lg = 12\,\mathrm{mm}$. These defects increase the number of operating frequency bands and bandwidth of the proposed monopole antenna. The comparison of simulated S_{11} parameters of the proposed monopole

Table 3. Simulated results of variation in 'Lg' parameter of antenna with partial ground plane.

Variation of 'Lg' (mm)	Resonant Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
10	4.43	−11.88	880
	9.98	−13.83	810
11	4.24	−11.91	950
	9.88	−33.87	1630
12	4.65	−14.29	1110
	8.48	−25.66	2090
13	4.76	−10.36	340
	7.80	−19.71	1200

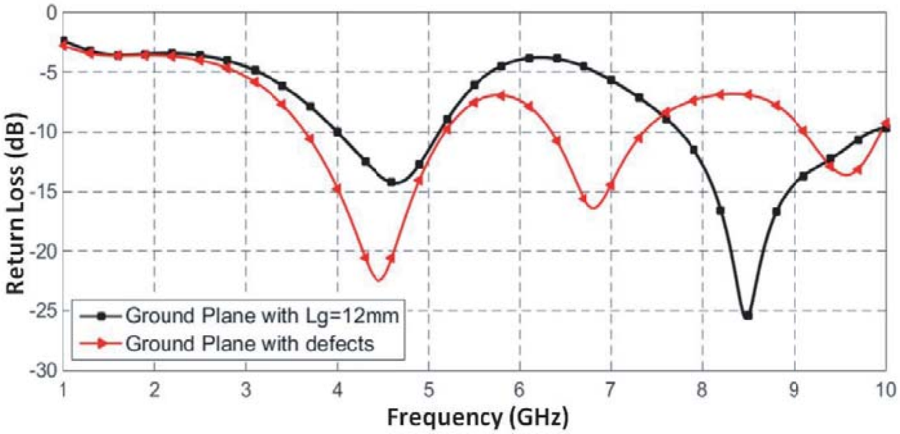
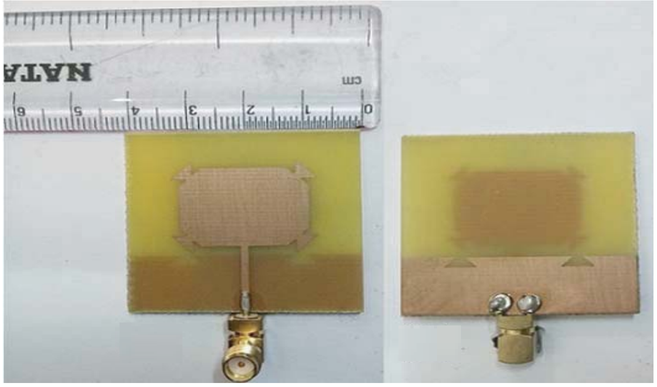


Figure 6. Simulated S_{11} characteristics of proposed monopole antenna with different ground plane structures.



(a) (b)

Figure 7. Fabricated prototype of proposed monopole antenna, (a) front view and (b) back view.

antenna with partial ground plane and ground plane with defects are shown in Fig. 6. It is evident from Fig. 6 that the antenna with defected ground plane resonates at three frequencies 4.4 GHz, 6.8 GHz and 9.6 GHz with return losses of −22.19 dB, −16.40 dB and −13.60 dB, respectively. Further, it has the bandwidth of 1.52 GHz at 4.4 GHz frequency band ranging from 3.65 GHz to 5.17 GHz, 1.01 GHz bandwidth at 6.8 GHz frequency band ranging from 6.34 GHz to 7.35 GHz and 0.83 GHz bandwidth at 9.60 GHz frequency band ranging from 9.11 GHz to 9.94 GHz. The final geometry of the proposed

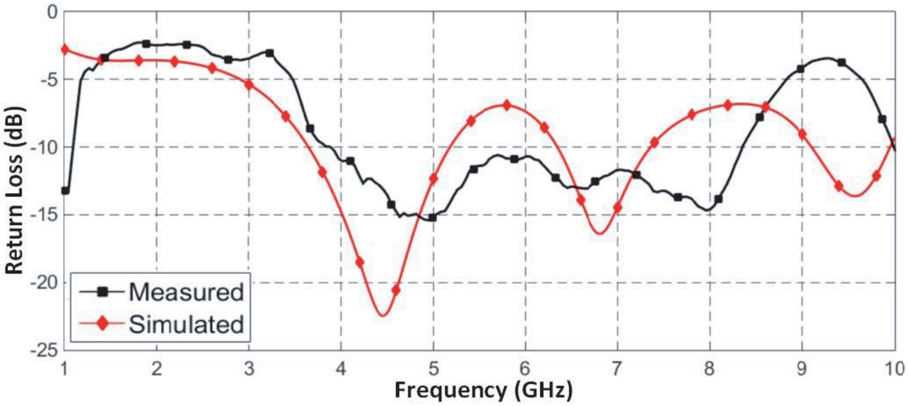


Figure 8. Comparison of simulated and measured S_{11} characteristics of proposed monopole antenna with DGP.

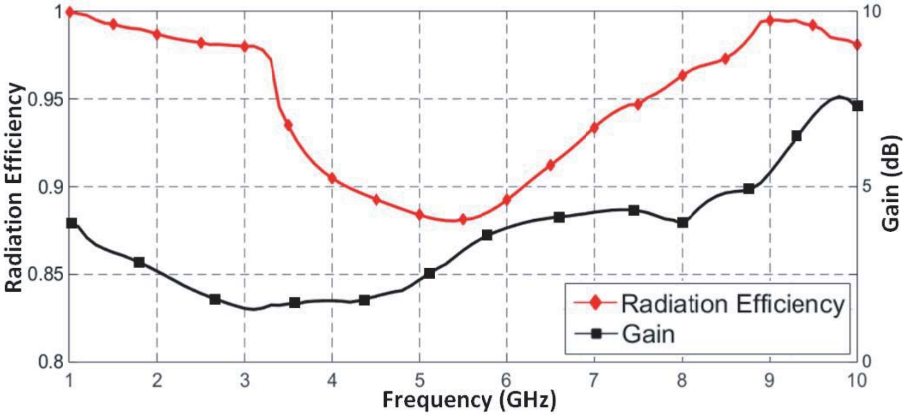


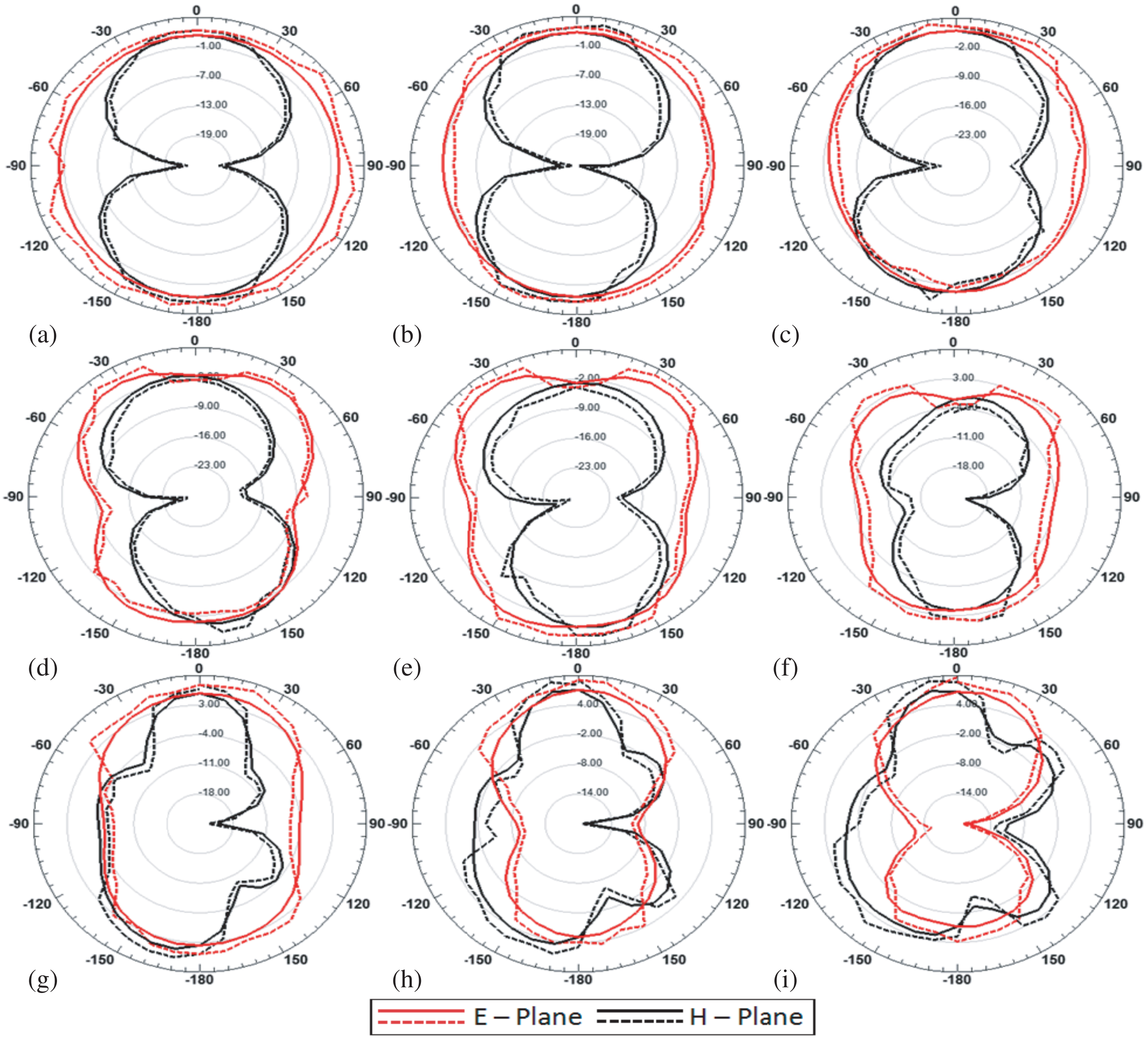
Figure 9. Radiation efficiency versus frequency plot of proposed monopole antenna with DGP.

Table 4. Simulated and measured values of proposed monopole antenna with DGP.

Proposed Monopole Antenna	Resonant Frequency (GHz)	Bandwidth (GHz)	Bandwidth (%)
Simulated	4.40	1.52 GHz (3.65–5.17 GHz)	34.54
	6.80	1.01 GHz (6.34–7.35 GHz)	14.85
	9.60	0.83 GHz (9.11–9.94 GHz)	8.64
Measured	6.12	4.46 GHz (3.89–8.35 GHz)	72.87

monopole antenna with Defected Ground Plane (DGP) is fabricated on an FR4 glass epoxy substrate to validate the simulated results with the measured ones.

Prototype of the proposed monopole antenna with DGP is shown in Fig. 7. The fabricated antenna is tested by using Anritsu MS46322A, VNA (Vector Network Analyzer) ranging from 1 MHz to 20 GHz. The comparison of simulated and measured return loss versus frequency plots of the proposed monopole antenna with DGP is shown in Fig. 8. It is very much clear from the simulated and measured S_{11} parameters of antenna that the measured results are much better than the simulated ones in terms of bandwidth. The measured S_{11} parameter exhibits bandwidth of 4.46 GHz ranging from 3.89 GHz to 8.35 GHz as compared to the simulated S_{11} curve. The measured return loss (S_{11} parameter) of monopole antenna with DGP is at an acceptable level ($S_{11} \leq -10\,\text{dB}$) for the entire frequency range of 3.89 GHz–8.35 GHz. Comparison of the simulated and measured values of antenna is shown in Table 4.



(a) (b) (c) (d) (e) (f) (g) (h) (i)

Figure 10. 2D radiation patterns of proposed monopole antenna with DGP simulated (solid line) and measured (dashed line) for (a) 3.65 GHz, (b) 4.4 GHz, (c) 5.17 GHz, (d) 6.34 GHz, (e) 6.8 GHz, (f) 7.35 GHz, (g) 9.11 GHz, (h) 9.6 GHz and (i) 9.94 GHz.

Table 5. Comparison of proposed monopole antenna with other published work.

References	Dimensions (mm^3)	Operating Frequency Range (GHz)	Bandwidth (GHz)	Maximum Gain (dB)
[4]	8000	2.3–2.52, 3.37–3.45 and 5.6–5.9	0.20, 0.08 and 0.30	6.5, 5 and 3
[12]	4000	1.68–4.07	2.39	5.8
[13]	2656.5	1.64–3.5	2.86	5.3
[15]	2667	4.27–7.58	3.31	4
[16]	6717.75	1.5–6.2	4.7	5.5
[18]	2400	2.425–4.075	1.65	5
[19]	2704	2.16–3.19	1.03	2.3
[21]	16000	3.25–8.85	5.6	16.12
[22]	1767.15	1.7–11.1	9.4	4.0
[23]	795.42	3.1–10.6	7.5	9.9
Proposed work	2490.88	3.89–8.35	4.46	7.50

The comparison of the proposed monopole antenna with other published works [4, 12, 13, 15, 16, 18, 19] is tabulated in Table 5. The size of the proposed antenna is compact as compared to the aforementioned references except [18], but if we contemplate [18] it exhibits less bandwidth of 1.65 GHz. So, we can claim that the proposed monopole antenna with DGP exhibits wideband characteristics and high gain.

Radiation efficiency variation with the frequency of the proposed monopole antenna with DGP is shown in Fig. 9. Antenna efficiency varies from 88% to 92%, 90% to 94% and 98% to 99% for the frequency ranges of 3.65 GHz–5.17 GHz, 6.34 GHz–7.35 GHz and 9.11 GHz–9.94 GHz, respectively. Similarly, the gain variation with frequency is also shown in Fig. 9. Gain of the antenna varies from 1.65 dB to 2.66 dB, 4.03 dB to 4.34 dB and 5.39 dB to 7.50 dB for the frequency ranges of 3.65 GHz–5.17 GHz, 6.34 GHz–7.35 GHz and 9.11 GHz–9.94 GHz, respectively. The proposed antenna shows the maximum gain of 7.50 dB at 9.9 GHz frequency and minimum gain of 1.65 dB at 3.6 GHz frequency. Figs. 10(a)–(i) show the simulated far-field radiation pattern in E and H planes at different frequencies 3.65 GHz, 4.4 GHz, 5.17 GHz, 6.34 GHz, 6.8 GHz, 7.35 GHz, 9.11 GHz, 9.6 GHz and 9.94 GHz, respectively. It is observed that the proposed antenna with DGP suitably radiates over a wide range of frequencies. Radiation pattern in E-plane ($\phi = 90^\circ$) gives a dipole like structure at all the frequency bands, and it is exactly dipole at the frequencies of 3.65 GHz and 4.4 GHz. H-plane ($\phi = 0^\circ$) pattern is exactly omnidirectional at 3.65 GHz, 4.4 GHz and 5.17 GHz frequencies, whereas it is slightly distorted at 6.34 GHz, 6.8 GHz, 7.35 GHz, 9.11 GHz, 9.6 GHz and 9.94 GHz frequencies.

4. CONCLUSION

A compact monopole antenna with defected ground plane for wideband applications is designed, simulated and fabricated for validating the experimental results. By employing defects in the partial ground plane, the proposed antenna exhibits more bandwidth than the antenna with partial ground plane. The simulated proposed antenna with DGP exhibits the bandwidths of 35.54%, 14.85% and 8.64% ranging (3.65 GHz–5.17 GHz), (6.34 GHz–7.35 GHz) and (9.11 GHz–9.94 GHz), respectively, whereas experimental results of the proposed antenna with DGP exhibit the bandwidth of 72.83% ranging (3.89 GHz–8.35 GHz). It is concluded that the antenna shows a good omnidirectional radiation pattern and also exhibits a high value of gain varying from 1.65 dB to 7.50 dB for the entire frequency range of 1 GHz–10 GHz. Enhanced bandwidth makes the proposed antenna suitable for different wireless standards such as WiMAX (3.3 GHz–3.7 GHz, 5.25 GHz–5.85 GHz), WLAN (5.15 GHz–5.85 GHz), X-band satellite applications (7.1 GHz–7.76 GHz) and point to point high speed wireless communication (5.925 GHz–8.5 GHz).

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