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Original scientific paper

DUAL WIDEBAND AND HIGH GAIN MICROSTRIP ANTENNA FOR WIRELESS SYSTEM

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Abstract. *In this paper dual wideband high gain circular shaped microstrip antenna with modified ground plane is presented for wireless communication systems. The overall dimension of the proposed antenna is 50 x 40 x 1.6 mm*^{3}*. The radiating element consists of circular shaped patch which is excited by microstrip feed-line printed on FR4 epoxy substrate. The ground plane is on the other side of the substrate having a rectangular ring shape to enhance the peak gain of the antenna. The proposed antenna exhibits two wide fractional bandwidths (based on ≤ -10 dB) of 61.1% (ranging from 2.0 to 3.8 GHz, centred at 2.88 GHz) and 53.37% (ranging from 5.48 to 9.6 GHz, centred at 7.44 GHz). The measured peak gain achieved is 8.25 dBi at 8.76 GHz. The measured impedance bandwidth and gain suffice all the commercial bands of wireless systems such as 4G LTE band-40, Bluetooth, Wi-Fi, WLAN, WiMAX, C-band, and X-band. The measured results are experimentally tested and verified with simulated results. A reasonable agreement is found between them.*

Key words: *High gain, monopole, wide bandwidth, WLAN, WiMAX, X-band*

1. INTRODUCTION

Recently, wireless communication systems have played an important role in the development and advancement of modern technology. Microstrip Patch Antennas (MPA) are widely used in wireless systems due to inherent features such as low cost, light weight, conformal, ease of integration with microwave circuits [1]. However, microstrip patch antennas suffer from the limitation of narrow bandwidth and low gain problems in the last decade. For short range high speed data connectivity of wireless systems (WLAN, Wi-Fi, Bluetooth) requires wide bandwidth, whereas in long range point to point communication for C-band and X-band needs high gain also. However, narrow bandwidth problem can be solved to some extent by monopole antenna. The bandwidth enhancement of monopole antennas has been reported in [2]-[9]. Wideband L-shaped printed monopole antenna with

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impedance bandwidth over 4.7 GHz has been reported in [2]. In [3] presented dual wideband monopole antenna with split ring resonators having impedance bandwidth of 280 MHz and 3100 MHz. In [4] demonstrated bandwidth enhancement of planar monopole microstrip patch antenna with curved slot having 109% fractional bandwidth. In [5] developed a novel CPW-fed wideband printed monopole antenna with DGS exhibits impedance bandwidth of 3.18 GHz and peak gain of 4.5 dBi. In [6] mentioned a technique of adding small fractal elements to the polygon shaped radiator of a CPW-fed monopole antenna leads to coverage of bandwidth (3.1-10.6 GHz). In [7] presented dual wideband monopole antenna for UMTS, WLAN, and WiMAX applications. An inverted question mark broadband high gain patch antenna has been designed [8], which exhibits -10 dB impedance bandwidth of 250 MHz and 8.07 GHz. In [9] reported CPW feed dual band and wideband antennas using crescent shape and T-shape stub for Wi-Fi and WiMAX application.

Besides these, few researchers have developed some designs [10]-[14] in which the gain of the monopole antenna may be increased. In [10] proposed arrow shaped broadband high gain monopole antenna, percentage bandwidth of 133% with peak gain 5.2 dBi. In [11] demonstrated a high gain ultra wide band monopole antenna exhibits 154% impedance bandwidth with maximum gain of 8 dBi. In [12] reported high gain dual-band antenna having maximum gain with the values of 6.2 dBi and 10.4 dBi. The disadvantage of this antenna is its lager size (109.03 mm x 77.88 mm). In [13] proposed ACS-fed dual band antenna with truncated ground plane for 2.4/5 GHz WLAN application with peak gain of the antenna is 4.85 dBi. Planar stair-like UWB monopole antenna serve to enhance the boresight gain has been presented in [14]. Indeed, there are many other promising techniques [15]-[17] proposed for enhancing gain of MPAs. Aforementioned gain enhancement techniques are bulky and much complex structure which are not usable for portable devices.

In this paper, a wide band microstrip antenna with high gain is presented for the applications of wireless communication systems. The configuration of the proposed antenna is very simple. It consists of circular shaped patch excited through a microstrip feed line which acts as a radiating element on the top of the substrate and a rectangular ring is loaded on the ground plane, which enhanced the impedance bandwidth as well as the gain. The proposed antenna has two wide bands with resonant frequencies at 3.36 GHz, 6.88 GHz, and 8.76 GHz. The measured -10 dB impedance bandwidth of the 1st band is 1800 MHz (from 2.0-3.8 GHz) and that of 2nd band is 4120 MHz (from 5.48-9.6 GHz). The peak gains at the specified resonant frequencies are 4.5 dBi, 5.5 dBi and 8.25 dBi. The bandwidth of the lower and upper bands may cover all the commercial bands (such as 4G LTE, Wi-Fi, Bluetooth, WiMAX, C-band, and X-band). The detail evolution of the proposed antenna structure is given in the consecutive sections.

2. ANTENNA STRUCTURE

The structural configuration of the proposed antenna is very simple which is illustrated in Fig. 1. The radiator consists of a circular patch and 50 Ω microstrip feed-line (W_f x L_f) on the top of the substrate. The low cost FR4-epoxy substrate (ε_r = 4.4, tan δ = 0.02, thickness = 1.6 mm) is used for construction of the proposed antenna. The overall dimension is 50 x 40 x 1.6 mm^3. The values of the antenna parameters are optimized with the help of HFSS v.15 electromagnetic simulator. The proposed monopole antenna evolution is done by two steps shown in Fig. 2. Instead of a partially ground plane on one of the sides of the substrate, an almost rectangular ring (or square slot) is loaded at the ground plane, which enhanced the gain as well as reformed the impedance characteristics of the antenna. The conventional circular shape patch antenna (without ring on ground plane) produces a dominant TM_{11} mode at 4.64 GHz. The radius is taken 9 mm (r) [W_{f1} x L_{f1} = 1.8 x 12 mm^2], and the resonant frequency is estimated by the theoretical equations [1]:

$$f_r = \frac{1.8412c}{2\pi R_e \sqrt{\varepsilon_r}} \tag{1}$$

$$R_e = R\sqrt{1 + \frac{2h}{\pi R \varepsilon_r}\left[\ln\left(\frac{\pi R}{2h}\right) + 1.7726\right]} \tag{2}$$

Where, R = physical radius (mm), R_e = effective radius (mm), c = speed of light in free space (m/s), fr = resonant frequency (GHz), ε_r = relative permittivity and h = thickness of the substrate. The theoretical resonant frequency is similar to the simulated resonant frequency obtained by HFSS simulator. However, the desired characteristics could not be achieved from this configuration. Therefore, the ground plane has been modified by adding a strip of length L_1, Z_g, and W_g, it makes the ground plane as a rectangular ring. The length L_1(or L_2), Z_g and L_g excites a resonant frequency at ~6.95 GHz and ~9.65 GHz, which are determined by the following equations [1]:

$$f_{TMmn} = \frac{c}{2\sqrt{\varepsilon_{eff}}}\sqrt{\left(\frac{m}{L_e}\right) + \left(\frac{n}{W_e}\right)} \tag{3}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{4}$$

Where, f_{TMmn} = resonance frequencies of different resonant TMmn modes, ε_{eff} = effective permittivity. At the second resonance frequency (~6.95 GHz), the $TM_{2.50}$ mode is present as two half-wavelength variations in the field is appeared along the length L_e and Z_g of the ground plane. Therefore, L_e becomes (L_1+Z_g), and We is equal to zero at $TM_{2.50}$ mode. At third resonance frequency (~9.65 GHz), the TM_{34} mode is present as three half-wavelength variations along the length of (L_1+Z_g) and four half-wavelength variations in the field is occurred along the width W_g of the ground surface. Therefore, L_e becomes (L_1+Z_g), and W_e becomes W_g at TM_{34} mode. The reflection coefficient and gain comparison of two antenna structure are depicted in Fig. 3 and Fig. 4, respectively. Figure 4 it is clearly visualized that the proposed antenna has better gain characteristics. The gains have been improved by introducing a rectangular ring on the ground plane. This improvement may happen because of the increment of the directivity as compared to the antenna without rectangular ring on the ground plane. Whereas in Fig. 3 the reflection coefficient is slightly reformed (in term of resonant frequency and impedance bandwidth). The final dimensions of the antenna parameters are finalized after large number of simulation. The parameters are as follows (in millimetre): R = 7, W_f = 1.6, L_f = 12, W_{f1} = 1.8, L_{f1} = 12, s = 4, p = 4, Z_g = 10, W_g = 40, L_g = 11, g = 10.5, r = 9, L_1 = 29, L_2 = 29, d = 1, t = 1.5, h = 1.6.

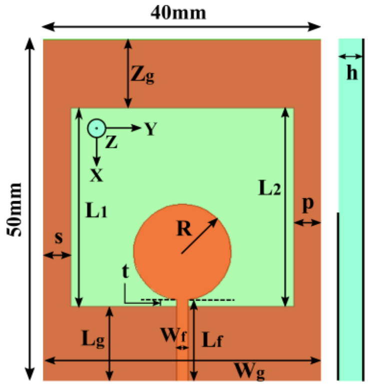


Fig. 1 Geometry of the proposed antenna (a) top view (b) side view

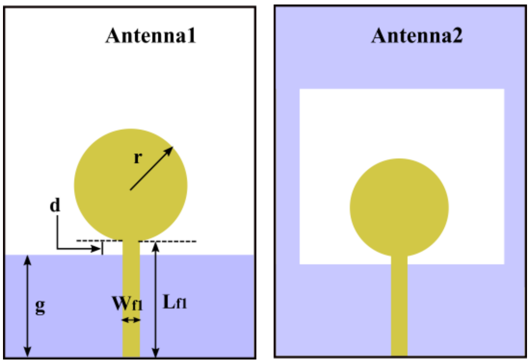


Fig. 2 Evolution of the proposed antenna (a) without ring on ground plane (b) with rectangular ring on ground plane

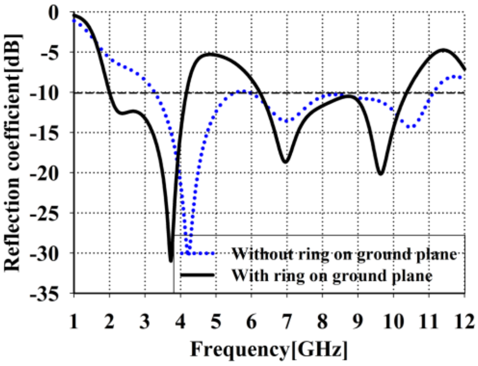
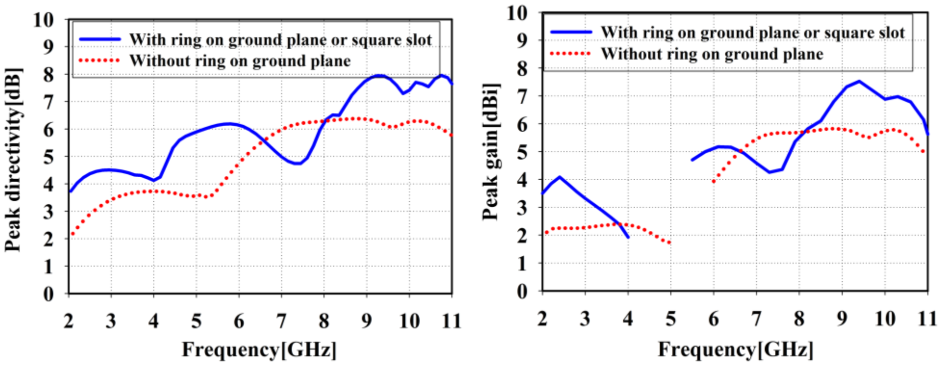


Fig. 3 Simulated reflection coefficient of proposed antenna with and without ring on ground plane



(a) (b)

Fig. 4 Simulated (a) directivity and (b) peak gains of proposed antenna with and without rectangular ring

3. SIMULATED AND MEASURED RESULTS

The antenna prototype has been fabricated on the basis of optimal dimension, depicted in Fig. 5. After fabrication, the |S11| of the proposed antenna is measured with the help of Rohde and Schwarz ZNB 20 vector network analyzer. Figure 6 and Table 1 illustrates that the measured |S11| agrees with simulated result with small discrepancy. This may be due to fabrication tolerance, dielectric inconsistency, and/or SMA connector (low cost). From measured |S11| parameter it is exhibited that the -10 dB impedance bandwidth of lower band is 1800 MHz and of upper band is 4120 MHz. So, it is clear to observed that the proposed antenna can comprise the band of 4G LTE, Bluetooth, Wi-Fi, WiMAX, C-band.

(a) (b)

Fig. 5 Photograph of the proposed (a) top view (b) bottom view

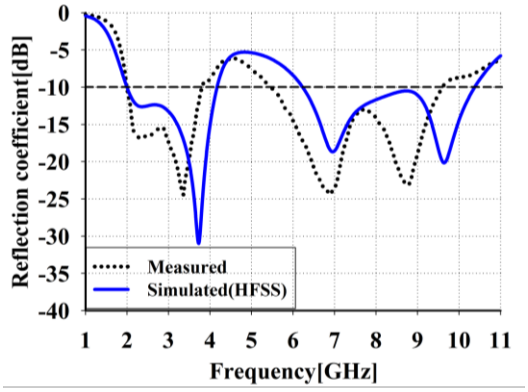


Fig. 6 Simulated and measured S_{11}(dB) versus frequency (GHz)

Table 1 Comparison of simulated and measured S_{11}(dB)

	Resonant frequencies (GHz)	Impedance bandwidth (MHz)
Simulated	3.73, 6.98, 9.64	2160, 4130
Measured	3.36, 6.88, 8.76	1800, 4210

The far field radiation patterns on the E-plane and H-plane for 2.36 GHz, 3.5 GHz, and 6.9 GHz are shown in Fig. 7, Fig. 8 and Fig. 9, respectively. It is clearly noticed that the proposed antenna exhibits a bi-directional E-plane and omnidirectional H-plane pattern, and cross-pol values are fairly small in broadside direction which is most desirable for monopole antenna radiation. It is also noticed that the cross-polar values are significantly small due to the symmetrical configuration with respect to feedline. The cross-pol values are obtained at 2.36 GHz < -20 dB, 3.5 GHz < -30 dB and 6.9 GHz < -30 dB, in broadside direction. The simulated 2D and 3D radiation pattern at 9.65 GHz is illustrated in Fig. 10. It is found that the 3 dB beam-width is about 35° at 9.65 GHz.

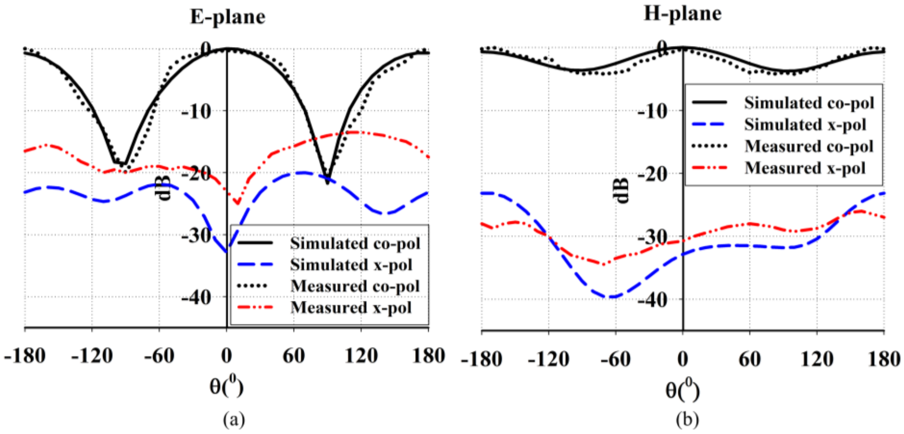
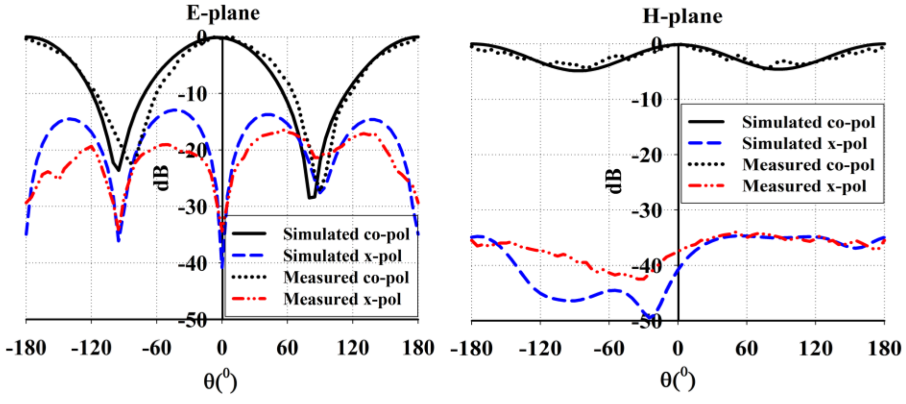
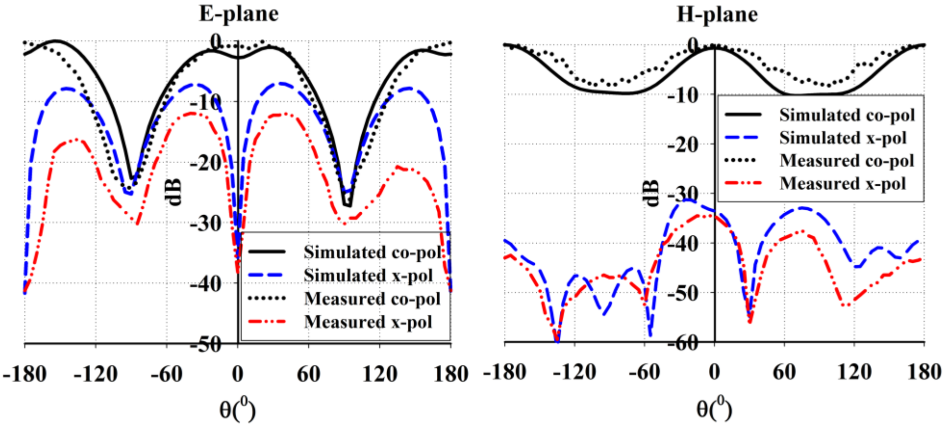


Fig. 7 Measured and simulated far-field radiation patterns at 2.36 GHz of (a) E-plane (b) H-plane



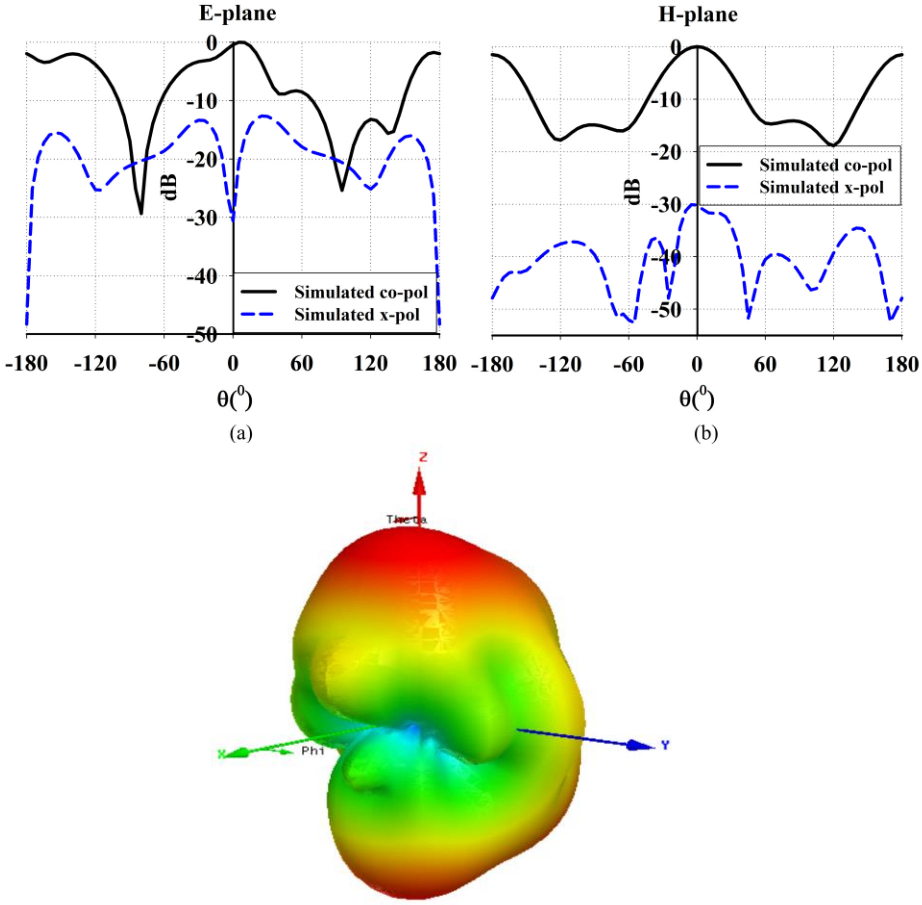
(a) (b)

Fig. 8 Measured and simulated radiation patterns at 3.5 GHz of (a) E-plane (b) H-plane



(a) (b)

Fig. 9 Measured and simulated far-field radiation patterns at 6.9 GHz of (a) E-plane (b) H-plane



(a) (b)

(c)

Fig. 10 Simulated far-field radiation patterns at 9.65 GHz of (a) E-plane (b) H-plane (c) 3D pattern

The measured and simulated gains are compared in Fig. 11 over the operating bands. It is observed that the measured peak gain can be reached maximum to 8.25 dBi at 8.76 GHz. The peak gains at the other frequencies are 4.5 dBi, and 5.5 dBi corresponding to frequencies of 3.36 GHz, and 6.9 GHz, respectively.

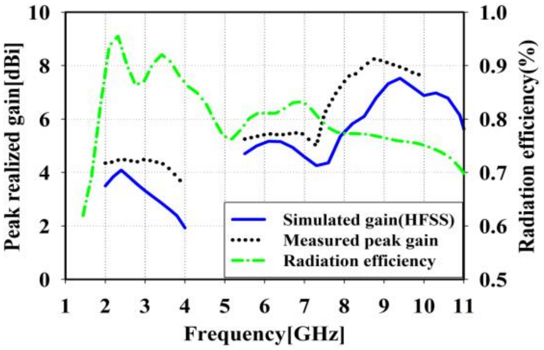


Fig. 11 Simulated and measured realized gains of proposed antenna

The proposed monopole antenna and some other monopole antennas are compared which is given in Table 2. The references of [4], [8], [10] and [11] have larger impedance bandwidth but lower peak gain compared to proposed antenna.

Table 2 Comparison of various monopole antennas with proposed antenna

Ref. no.	Size (mm^3)	Operating bands (GHz)	Impedance bandwidth (MHz)	Peak gain (dBi)
[3]	25x40x0.635	2.4/5.2/5.8	280, 3100	-2, 4
[4]	50x55x1.5	2.4/3.5/5.2/5.8	4800	4.8
[7]	42x51x1.6	2.4/3.5/5.2/5.8	2120, 1540	5.03, 1.94
[8]	30x20x1.6	2.4/5.2/5.8	200, 8070	5.5
[10]	40x43x1.6	2.4/3.5/5.2/5.8	6500	5.2
[11]	48x32x1.6	3/5/11	1.82–14.07	8
[13]	25x17.5x1.6	2.4/5.2/5.8	250, 2590	4.85
[18]	45x40x1.6	2.4/2.5/5.2/5.8	5500	6.8
[19]	30x30x1.56	2.4/2.5	180, 1080	1.49, 3.23
[20]	60x60x1.6	3.6/5.8/8.5	309, 270, 310	6.4, 7.52, 7.32
[21]	30x23x1.575	5.8/10	160, 680	4.11, 7.15
[22]	21x17x1.6	2.74/ 6.34	20, 79	4.43, 5.37
[23]	48x25x1.6	5.8	500	6.85
Proposed antenna	50x40x1.6	2.35/2.4/5.8/6.9	1800, 4120	8.25

4. CONCLUSION

In this paper dual wide band and high gain microstrip monopole antenna has been proposed for wireless systems. The antenna is moderate in size and simple in configuration. The measured result shows that the proposed antenna has two wide frequency bands ranging from 2 GHz to 3.76 GHz (1800 MHz) and 5.48 GHz to 9.6 GHz (4120 MHz) with a high peak gain of about 8.25 dBi achieve at 8.76 GHz. The peak gain of the proposed antenna has been enhanced by modifying the ground surface (introducing a rectangular ring or square slot) without hampering radiation characteristics (standard monopole type) too much. The measured bandwidth exhibits that the antenna can sufficiently cover all the commercial bands such as 4G LTE band-40 (India), Bluetooth, Wi-Fi, WLAN, WiMAX, C-band, and X-band.

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