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Planar Arrangement of Modified Concentric Rings with Defected Ground for Mobile and Wireless Communication Systems

Neelam Choudhary, Ajay Tiwari, Jaswant S. Saini, Virender K. Saxena, and Deepak Bhatnagar*

Abstract—This paper reports the design and performance of a compact planar arrangement of concentric rings designed with defected ground plane. The radiating circular patch and ground plane of antenna are modified in several steps to achieve a broadband circularly polarized antenna. In each stage of modification, antenna is simulated by applying CST Microwave Studio simulator, and finally, a prototype is developed and tested in free space. The developed prototype efficiently operates at frequencies 2.34 GHz and 4.41 GHz, and provides an overall impedance bandwidth close to 2.31 GHz or 67.45% with respect to central frequency 3.425 GHz. This antenna provides nearly flat gain in the desired frequency band with maximum measured gain close to 2.94 dBi at frequency 3.02 GHz. It also provides circularly polarized radiations in the frequency bands extended from 2.67 to 3.05 GHz and 3.44 to 3.57 GHz. The co-polar and cross-polar radiation patterns of the antenna in azimuth and elevation planes are obtained at frequencies 2.316 GHz and 4.41 GHz. The proposed antenna can be used for mobile and lower bands of Wi-Max and UWB communication systems.

1. INTRODUCTION

Modern day communication systems are compact in size, and hence they require compact antennas with larger bandwidth and higher gain. Microstrip antennas in their conventional form are compact in size, light in weight, have low manufacturing cost on mass production, can be easily integrated with other circuit elements and may be put directly inside the handset without protruding out. However planar antennas in their conventional form have narrow bandwidth, low gain and generally operate at resonance frequency corresponding to their dominant mode of excitation [1, 2]. These antennas may prove to be very useful structures for modern communication systems on attaining the desired features. Extensive efforts to improve their overall performance have been made in recent times so that they may find application in modern communication systems, military applications, global positioning systems, direct broadcast satellite systems etc. These efforts include application of high permittivity, low loss ceramic substrate [3], shifting of null voltage points on patch [4], application of narrow slots at appropriate location on patch to have compact antennas [5], exciting two modes having closely spaced resonance frequencies [6], putting patches under stacked arrangement [7–9], using reactive loading for dual frequency operation [10, 11], making co-planar arrangement with parasitic patches to attain broadband operation [12] and using high permittivity superstrate to have improved antenna gain [13]. A limited improvement in the performance of planar antennas was realized with these techniques [6–13], but this improvement is not sufficient knowing the requirements of modern day's communication systems. In recent times, the modifications in ground planes of planar structures were proposed [14–18] to achieve further improved performance which include the application of finite ground plane [14], application of defects in the ground plane [15–17] and application of a CPW feed arrangement [18].

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* Corresponding author: Deepak Bhatnagar (dbhatnagar2010@gmail.com).
The authors are with the Department of Physics, University of Rajasthan, Jaipur 302004, India.

These changes in the ground plane modify the current distribution on patch geometry which in turn improves the overall performance of antenna.

In this paper, we start work by first considering a microstrip line feed circular patch geometry having finite ground plane and then modify the patch and ground plane of this geometry in several steps. The performance of the antenna in each stage of development is simulated, and suitable prototypes were developed and tested in free space.

2. ANTENNA DESIGN AND RESULTS

Initially a circular conducting patch antenna having patch radius R is simulated using a finite size glass epoxy FR-4 substrate material. The length and width of ground plane of this structure are L and W, respectively. The substrate material has relative substrate permittivity $\varepsilon_r = 4.4$, substrate height $h = 1.59$ mm and loss tangent $= 0.025$. A 50 ohm microstrip line having length L_f and width W_f is used to feed this antenna which on the other end is connected with a 50 ohm cable through SMA connector as shown in Figure 1(a). The design parameters of this antenna are tabulated in Table 1. The performance of this circular patch antenna having finite ground plane is simulated in the frequency range 1 to 6 GHz by using CST Studio suite 2013 simulator. The simulated resonance frequency of this circular patch antenna corresponding to its dominant TM_{11} mode is 2.35 GHz. This antenna matches well with the applied feed line at frequencies 2.55 GHz and 4.22 GHz, as shown in Figure 2. The simulated bandwidths

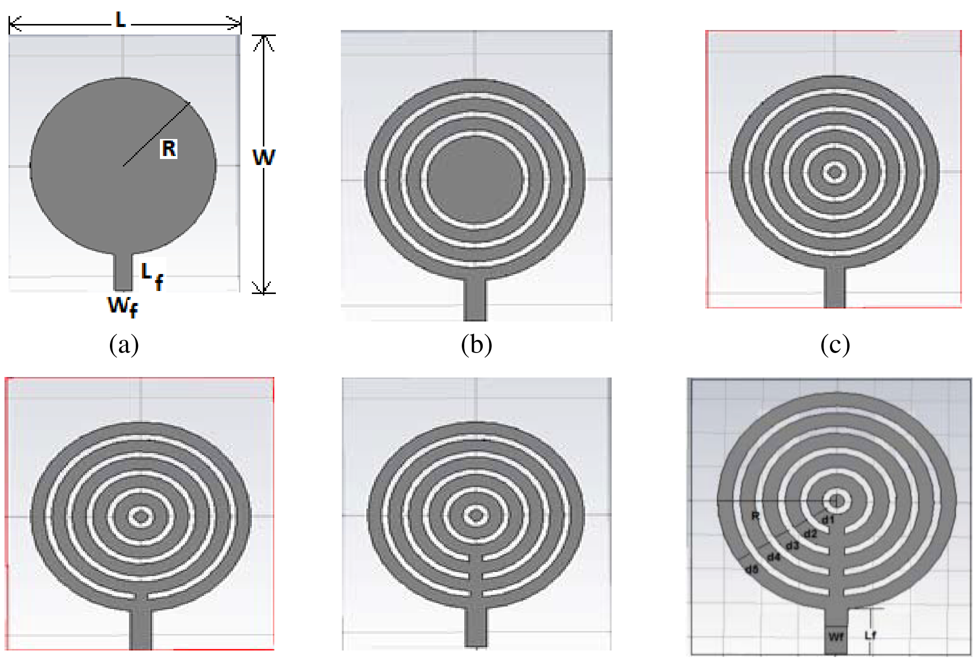


Figure 1. Stepwise modifications in circular patch antenna with finite ground plane.

Table 1. Optimized dimensions of proposed antenna.

Dimension of proposed antenna	Value (in mm)
Dimensions of Ground Plane ($L \times W$)	39 mm × 46 mm
Dimensions of the substrate material	39 mm × 46 mm
Radius of the Patch (R)	16 mm
Dimensions of microstrip line ($L_f \times W_f$)	6.5 mm × 3 mm

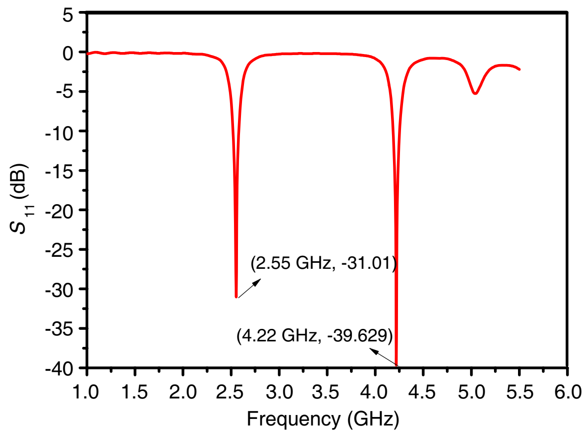


Figure 2. Variation of S_{11} parameter for circular patch with finite ground plane.

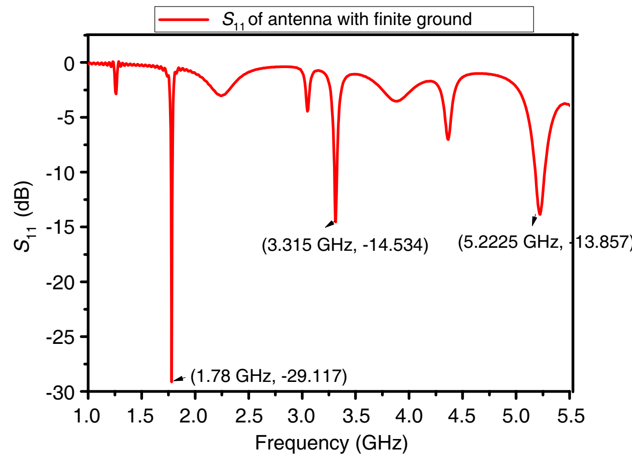


Figure 3. Simulated reflection coefficient of antenna with finite and infinite ground plane.

are very narrow, and the maximum gain of this antenna is close to 1.37 dBi. The radiation patterns have dumbbell shape with more power directed towards normal to patch geometry. This antenna is modified in two steps to improve its overall performance. In the next section, the details of modifications in patch geometry and obtained results are reported.

2.1. Modification in Patch Geometry

Retaining the finite ground plane mentioned above, the circular patch is modified by introducing concentric circular rings one by one on the patch geometry. Two such cases are shown in Figures 1(b) and 1(c) which have three and five concentric rings, respectively. The radii of innermost circles shown in Figures 1(b) and 1(c) are 7.0 mm and 1.0 mm, respectively. The width of each concentric ring shown in these figures is 2.0 mm while the separation between two consecutive rings is 1.0 mm.

The simulated resonance frequencies corresponding to dominant mode for the two modified structures mentioned above are almost identical and close to 2.27 GHz and 2.25 GHz, respectively. This suggests that on inserting concentric rings one by one, the resonance frequency of antenna corresponding to dominant mode decreases marginally, or in other words, effective size of antenna marginally increases. The final geometry shown in Figure 1(f) is obtained by connecting the planar circular concentric copper rings to the adjacent one with the help of a small copper strip of width 1.0 mm. The stepwise connecting process is shown in Figures 1(d) to 1(f).

Table 2. Optimized dimensions of radiating patch of proposed antenna.

Dimension of proposed antenna	Value (in mm)
Dimensions of Ground Plane ($L \times W$)	39 mm × 46 mm
Dimensions of the Substrate	39 mm × 46 mm
Radius of the Patch (R)	16 mm
Dimensions of microstrip line ($L_f \times W_f$)	6.5 mm × 3 mm
Radius of inner most circle (i) With three concentric rings (ii) With five concentric rings	 7 mm 1 mm
Width of each concentric ring	2 mm
Separation between two consecutive rings	1 mm

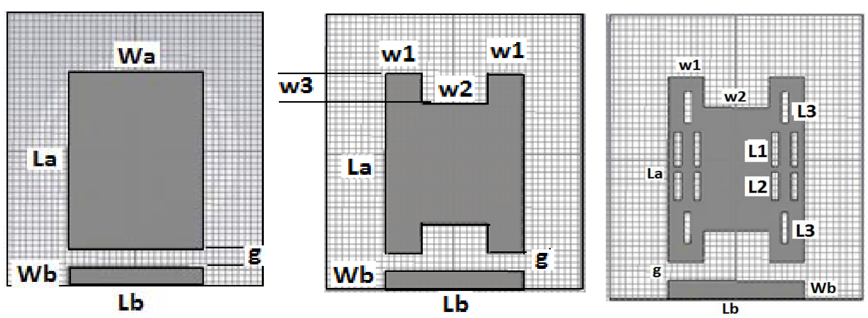
The resonance frequencies for the geometries shown in Figures 1(d) to 1(f) corresponding to their dominant modes are 1.92 GHz, 1.83 GHz and 1.78 GHz, respectively. At frequency 1.78 GHz, the real part of input impedance (Z_{in}) of geometry as shown in Figure 1(f) is 52 ohm while imaginary part of input impedance is close to zero. It is realized that in addition to dominant mode, good matching between antenna and feed line is also obtained at frequencies 3.31 GHz and 5.23 GHz, but the impedance bandwidths at all these frequencies are narrow. The realized frequencies 3.31 GHz and 5.23 GHz are suitable for wireless communication systems while frequency 1.78 GHz may be used for mobile communication. The impedance bandwidth values at these frequencies are still narrow, and maximum realized gain of antenna is close to 1.82 dBi.

In the next step, ground plane is modified for further improvement in the performance of antenna.

2.2. Modification in Ground Plane

After achieving optimum performance with considered geometry shown in Figure 1(f), the ground plane of antenna is modified in steps for further improvement in the performance of antenna. The applied modifications in steps are shown in Figures 4(a)–4(c). The size of ground plane is reduced from 39 mm × 46 mm to 21 mm × 36 mm, and then it is divided into two parts having lengths L_a & L_b and widths W_a and W_b, respectively as shown in Figure 4(a). These two rectangular parts of ground plane are separated by a gap g. In the next step of modification, equal edge truncations of sizes ($w_2 \times w_3$) are introduced in opposite sides of upper part of ground as shown in Figure 4(b). Finally, narrow slits of lengths L_1, L_2 and L_3 with equal width W_1 are introduced one by one in the upper part of ground plane at appropriate locations as shown in Figure 4(c). The details of design parameters are included in Table 3. In each stage of modifications, antenna parameters were carefully simulated.

A comparison of simulated S_{11} parameters for three considered steps of modification in ground plane



(a) (b) (c)

Figure 4. Modified ground in three considered steps.

Table 3. Optimized dimensions of ground plane of proposed antenna.

Dimension of proposed antenna	Value (in mm)
Dimensions of Ground Plane ($L_a \times W_a$)	30 mm × 21 mm
($L_b \times W_b$)	21 mm × 3 mm
Separation in two parts of ground plane 'g'	3 mm
Truncations applied in upper part of ground ($w_2 \times w_3$)	10 mm × 5 mm
Other dimensions of upper part of ground 'w_1'	5.5 mm
Dimensions of introduced slits in upper part of ground plane	
$L_1 \times W_1$	5.5 mm × 1 mm
$L_2 \times W_1$	4.5 mm × 1 mm
$L_3 \times W_1$	5 mm × 1 mm

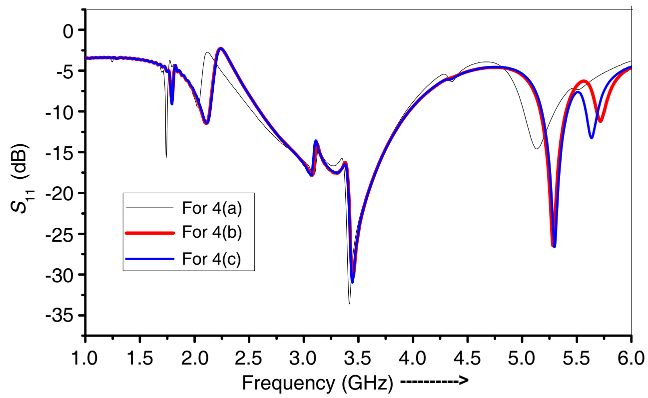


Figure 5. Simulated reflection coefficient of antenna with modified ground plane.

Table 4. Optimized dimensions of matching stub in the ground plane.

Dimension of proposed antenna	Value (in mm)
Dimensions of applied stub ($L_s \times W_s$)	8 mm × 1 mm
Dimensions of applied teeth in stub ($L_t \times W_t$)	3 mm × 1 mm
Separation between teeth	1 mm

is shown in Figure 5. With these modifications, matching of antenna with feed line at frequency 3.5 GHz is almost uneffected, but a nice matching between radiating element and feed is found at frequency 5.27 GHz. The simulated impedance bandwidth with defected ground plane shown in Figure 4(c) is close to 1.35 GHz which is spread in the frequency range 2.71 GHz to 4.06 GHz. The maximum realized simulated gain of antenna is close to 3.36 dBi.

In the final stage of modification, the two considered parts of the ground plane are connected through a matching stub or a narrow line. This strip line has six narrow teeth as shown in Figure 6(b). The length and width of this connecting stub are L_s and W_s, respectively while length and width of each of six introduced teeth are L_t and W_t, respectively. The separation between two successive teeth is 1 mm. The design details of matching stub are included in Table 4.

The front and back views of the simulated and developed prototype are shown in Figures 6(a)–6(e). The simulated current distributions on patch in two conditions namely antenna with finite ground plane and antenna with defected ground plane are given in Figures 7(a) and 7(b), respectively. With modification in the ground plane, the current density on patch increases significantly.

A comparison between measured and simulated variations of S_{11} parameter with frequency is shown in Figure 8 while measured variation of input impedance of antenna as a function of frequency is shown in Figure 9. For the considered antenna geometry, the simulated resonance frequency of excited dominant mode is 1.765 GHz. The first measured frequency where fair matching between antenna and feed line is achieved is close to 1.78 GHz which is in fine agreement with simulated frequency as shown in Figure 8. Both measured and simulated impedance bandwidths at frequency 1.78 GHz are close to 60 MHz or 3.37% with respect to central frequency 1.78 GHz. The simulated and measured gain values of proposed antenna at this frequency are close to 1.07 dBi and 1.16 dBi respectively. At two other frequencies namely 2.316 GHz and 4.41 GHz, good matching between antenna and feed line is achieved and both these frequencies are lying in the frequency band extended between frequencies 2.27 GHz to 4.64 GHz. The measured and simulated input impedances at frequency 2.316 GHz are $(49.67 - j7.67)$ ohm and $(50.13 - j2.03)$ ohm respectively while at frequency 4.41 GHz these are $(54.56 - j12.02)$ ohm and $(52.16 - j6.13)$ ohm respectively. The simulated impedance bandwidth realized with this antenna is close to 2.21 GHz or 64.29% with respect to central frequency 3.45 GHz. The measured impedance bandwidth is close to 2.31 GHz or 67.45% with respect to central frequency 3.425 GHz. The obtained band (2.27 GHz to 4.64 GHz) covers the frequency bands allocated for several applications including

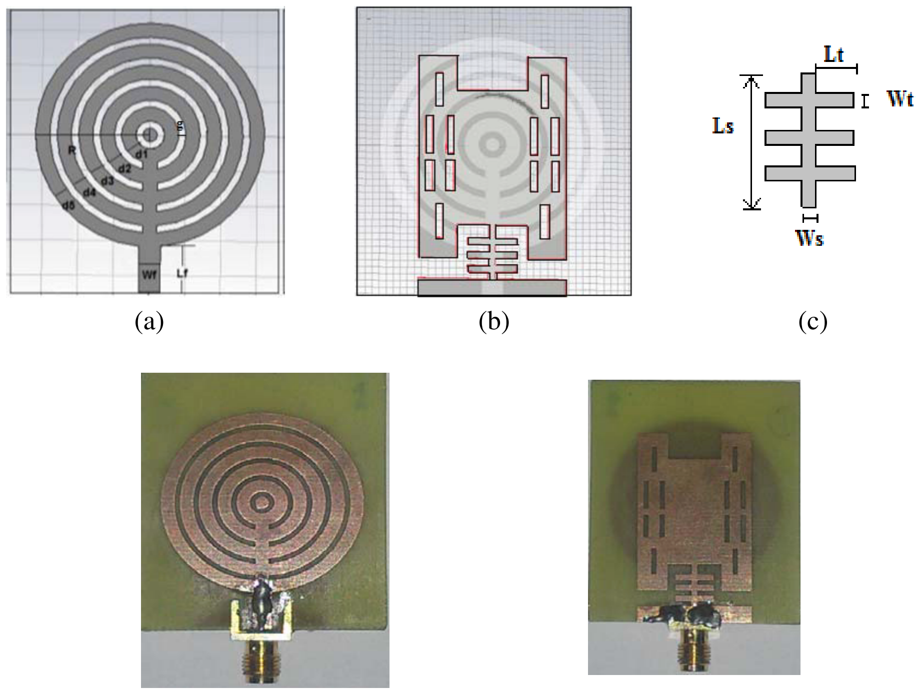
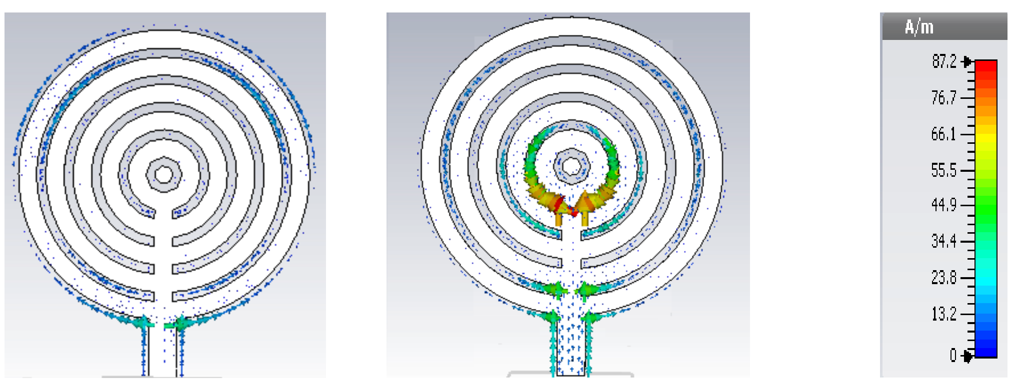


Figure 6. (a) Front view of simulated antenna. (b) Back view of simulated antenna. (c) Dimensions of connecting stub and teeths in ground. (d) Front view of developed prototype. (e) Back view of developed prototype.



(a) (b)

Figure 7. (a) Current density distribution on patch for antenna with finite ground plane. (b) Current density distribution on patch for antenna with defected ground plane.

those for mobile communication and lower bands of Wi-Max and UWB communication systems.

The simulated axial ratio variation of proposed antenna in the direction $\theta = 85°$ and $\phi = 240°$ is shown in Figure 10. The axial ratio in the frequency range 2.67 to 3.05 GHz and 3.44 to 3.57 GHz is lower than 3 dB. The minimum axial ratio values are obtained at frequencies 2.97 GHz and 3.5 GHz which are close to 0.72 dB and 0.22 dB respectively. The axial ratio bandwidths at these two central frequencies are close to 12.9% and 3.7% respectively. The testing for circular polarization is performed at several (θ, ϕ) values and finally with $\theta = 85°$ and $\phi = 240°$ the best performance (maximum axial ratio bandwidth) of antenna is obtained. This wideband circular polarization in two bands is achieved

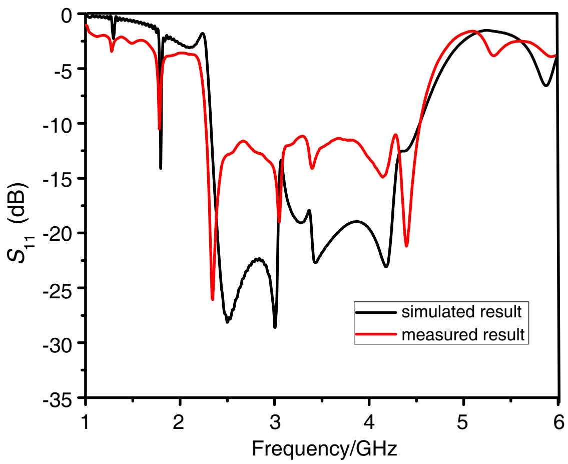


Figure 8. Simulated and measured reflection coefficients of antenna with diffective ground.

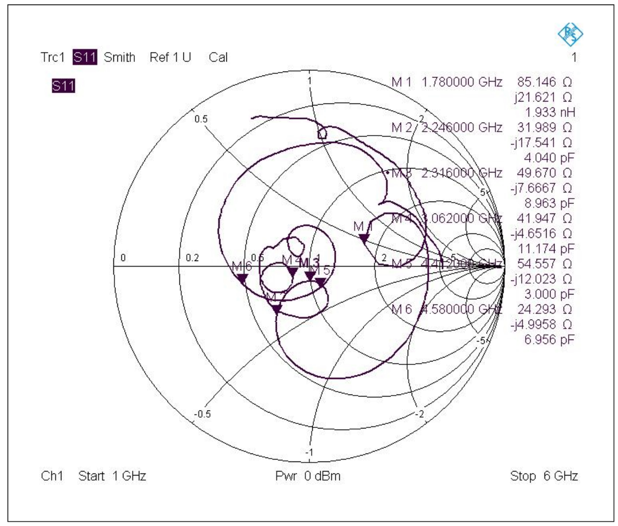


Figure 9. Measured input impedance of developed prototype.

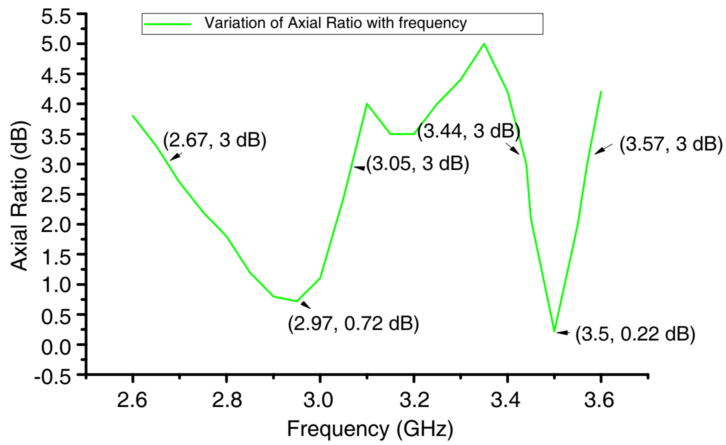


Figure 10. Simulated axial ratio variation of antenna with frequency.

Table 5. Simulated and measured gain of antenna geometry.

Frequency (GHz)	Measured Gain (dBi)	Simulated Gain (dBi)
1.78	1.16	1.07
2.65	3.18	2.86
3.02	2.85	2.94
3.25	2.65	2.91
3.5	2.33	1.75
3.75	1.93	1.52
4.35	0.97	0.783

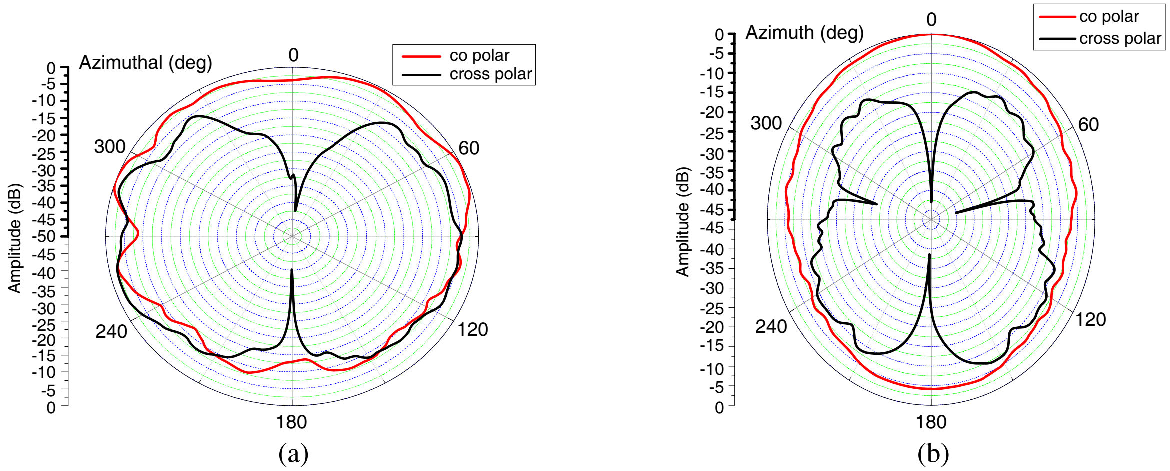


Figure 11. Azimuthal plane co and cross polar patterns. (a) 2.316 GHz. (b) 4.41 GHz.

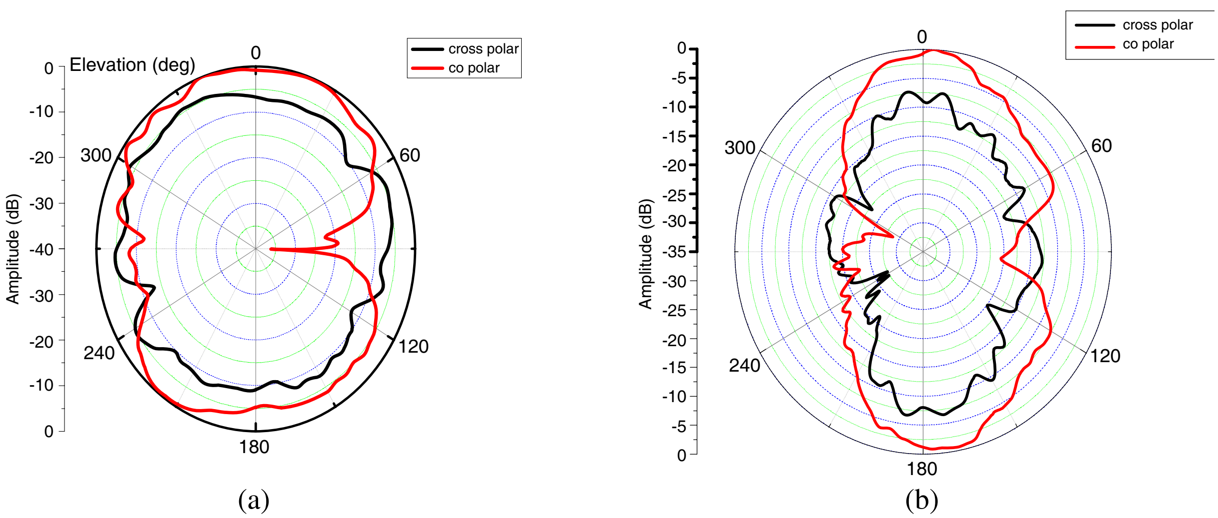


Figure 12. Elevation plane co and cross polar patterns. (a) 2.316 GHz. (b) 4.41 GHz.

only after shape optimization of tuning stub and introduced teeth and adjustment of separation between considered teeth.

The simulated and measured gain values of the proposed antenna are compared in Table 5. The maximum measured and simulated gain values of antenna are 2.85 dBi and 2.94 dBi respectively which are realized at frequency 3.02 GHz. The measured and simulated gain values at 1.78 GHz are 1.16 dBi and 1.07 GHz respectively. Within frequency range 2.6 GHz to 3.7 GHz, the variation in simulated gain values is less than 1 dBi while variation in measured gain values is less than 1.25 dBi. Since the gain bandwidth product remains constant, the low gain values obtained in this work are on expected lines. In the present work, the main focus is on impedance bandwidth and axial ratio bandwidth enhancement with acceptable gain values. The gain value can be improved further by applying suitable techniques [4] and by applying better substrate material.

The measured co- and cross-polar patterns of the proposed antenna in azimuthal and elevation planes at two frequencies, where good matching with feed line is obtained, are shown in Figures 11 and 12 respectively. These patterns suggest that co polar patterns are broader than cross polar patterns in both azimuthal and elevation planes. In elevation plane, maximum radiations at frequencies 2.316 GHz and 4.41 GHz are almost normal to patch geometry while in azimuthal plane, patterns are quite symmetric in all the four quardrants. Obtained radiation patterns resemble those of the dipole antenna operating under similar conditions.

3. CONCLUSIONS

In this paper, design and performance of a compact planar annular ring antenna with defected ground plane is discussed. The proposed antenna provides broader impedance bandwidth close to 2.31 GHz or 67.45% with respect to central frequency 3.425 GHz with nearly flat gain in the frequency range extended between frequencies 2.6 GHz to 3.7 GHz. The maximum measured gain is close to 2.94 dBi at frequency 3.02 GHz. The designed antenna also provides circularly polarized radiations in the two desired frequency bands and covers the frequency bands allocated for lower bands for Wi-Max and UWB communication systems. The radiation patterns resembles somewhat with those of a dipole antenna. The proposed antenna also resonates at frequency 1.78 GHz that is applicable for mobile communication and provides impedance bandwidth close to 3.37% with respect to central frequency. Since the gain of the antenna in this band is low, efforts for the improvement of gain for mobile applications are currently underway.

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