



A Miniaturized Printed Antenna with Extended Circular Patch and Partial Ground Plane for UWB Applications

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Abstract

A miniaturized printed antenna with extended circular patch and partial ground plane for ultra-wideband applications is designed and investigated. The overall structure volume of the antenna is $15 * 20 * 1.6 \text{ m}^3$. Proposed antenna's reflection coefficient ($S_{11} < -10 \text{ dB}$) is 3.1–20 GHz with the Impedance B/W of 146.3%. The values of the peak gain and antenna efficiency stand at 4.8 dB and 67% respectively, both of which are achieved in the operational frequency band of the design. The suggested antenna with stable far-field pattern satisfies the monopole conditions. The both measured and simulated Co-pol. and (X)-pol. are relatively good agreement. The CST simulator is used to make the proposed structure. The frequency shifted to 3.1 GHz by making a partial ground plane and higher frequency shifted to 20 GHz by introducing a circular parasitic element is placed in the circular ring slot of the patch. The proposed structure is tested to validate the results of the simulations thus, a good agreement between measured and simulated results is satisfactory that proves the structure's validity for UWB applications. The proposed antenna finds application in WiMAX-band of 3.5, 5.5 GHz, WLAN-band of 5.2, 5.8 GHz, X-band of 8–12 GHz.

Keywords Miniaturized · Ultra-wideband · Circular patch · Partial ground plane · Multiple applications

1 Introduction

As per the need of advancements in wireless communication, broadband partial ground plane antenna with compact size will provide several possibilities to the researchers worldwide. Broadband partial ground plane antenna radiator have large bandwidth, high efficiency, high gain, and provide ease of fabrication. A microstrip elliptical slot structure have been attention in the field of UWB band and achieved the ultra-wideband for multiple applications, circular ring in the patch has been reported [1]. Many compact structure have been reported for UWB applications, mentions as circular shaped ring, circular slot

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and L-shaped slots, cutting rectangular, printed curved slot, triangular, U-shaped, semi-circular slot, in [2–5]. Bandwidth enhancement is reported by S-slot rectangular patch [6]. Wideband antenna achieved 4.5 dB gain due to truncation in the circular model [7]. Broad-band behaviour have been proposed due to cutting; triangular, U-shaped rectangular and L-shaped slots [8, 9]. Dual-frequency ranges are observed by the added parasitic slot in the patch, by adding circles in the back side plane [10, 11]. 44% fractional bandwidth has been obtained by applying fractal slot in circular patch [12]. Enhanced bandwidth with dual frequency by introduced gap coupling (technique) have been reported in [13]. To achieve broadside radiation-pattern by sweeping of ‘E’-shaped element in radiator has been suggested [14]. A ladder-shaped structures in the back plane resulting increased wide band resonance as reported in [15]. By using rubber as a substrate, ultra-wide band has been reported [16]. Ultra-wide band applications has been achieved due to create multi-slots in the planar antenna [17]. By creating small fractal element in planar antenna, bandwidth enhancement is reported [18]. Low order frequency modes is observed by making defective ground structure [19]. UWB applications have been reported due to; rectangular parasitic patches near to the stripline, modified patch with defective back plane, miniaturized antenna with printed ground plane and dumbbell shaped planar structure [20–22]. Lower side frequency is excited due to a defective backplane, higher side frequency is excited by added a rectangular-shaped parasitic element in circular patch [23].

Bandwidth enhancement, in this case, is achieved in the lower frequency band due to impedance matching. The comparison analysis of earlier published monopole designs are mention in Table 1. It is noticed that the presented antenna exhibits UWB behavior (3.1–20 GHz) and impedance bandwidth of 146% in a very small size of 300 mm². A miniaturized printed design with an extended circular patch and the incomplete ground plane is proposed in this paper. Bandwidth expands at the higher and lower frequencies because of the higher order and lower order modes. This fulfils the dual purpose of bandwidth enhancement and miniaturization. Most of the structures reported above are complex in nature and have a larger dimension (typically of the size of 27 * 24 * 1.6 mm³). In this article, a compact antenna (15 * 20 * 1.6 mm³) with very large impedance B/W is

Table 1 A comparison of presented antenna with recently published in references

| Refs. | Overall volume (mm ³) | Peak gain (dBi) | Peak efficiency (%) | Physical size L _{sub} * W _{sub} (mm ²) | Fractional B/W (%) |
|----------------------|-----------------------------------|-----------------|---------------------|--|--------------------|
| Azim et al. [1] | 39 * 40 * 1.6 | 2.14 | 75 | 1560 | 130 |
| Li et al. [3] | 27 * 24 * 1.6 | 1.7 | NA | 648 | 150 |
| Telsang [4] | 53.3 * 40 * 1.5 | 6.1 | NA | 2132 | 146 |
| Baudha et al. [5] | 53 * 40 * 2.2 | 2 | 60 | 2120 | 109 |
| Aneesh [6] | 35 * 45 * 15 | 8.1 | 92 | 1575 | 118 |
| Kurniawan et al. [7] | 50 * 33 * 1.6 | 4.5 | 62 | 1650 | 127 |
| Goswami [11] | 15 * 20 * 1.5 | 2 | 78 | 300 | 76 |
| Awad et al. [17] | 30 * 35 * 1.6 | 6 | NA | 1050 | 109 |
| Fallahi et al. [18] | 25 * 25 * 1.5 | 3.2 | 91 | 625 | 109 |
| Yadav et al. [20] | 20 * 25 * 1.5 | 5.1 | 89 | 500 | 110 |
| Baudha et al. [21] | 15 * 20 * 1.5 | 3.5 | 76 | 300 | 130 |
| Presented | 15 * 20 * 1.6 | 4.8 | 67 | 300 | 146 |

reported which is having a four-stages. Antenna's all stages is unique and represents the different simulation (S_{11}) results. The suggested design is represented by stage 04. The higher-modes resonances are created by introduced the incomplete ground plane whereas the lower-modes resonances are achieved by extended circular patch. The following sections are discussed in this article: In Sect. 2, the optimum dimension of the suggested design with all parameters, 04-stages evolution, and variations in return loss results due to the change in the stages, various important parametric parameters studies are taken up. In Sect. 3, the relative analysis of the (S_{11}) measured curve and (S_{11}) simulated curve, simulated I/P impedance curve, measured and simulated far-field pattern, simulated of gain, and antenna efficiency, analysis of antenna's surface current is presented.

2 Antenna Geometry, Evolution and Parameter Study

The FR4 substrate is used to fabricate the suggested design. The specification of the flame retardant (FR4) material is 4.4 permittivity, 1.6 mm thick and a loss tangent equal to 0.025 with physical volume of $15 * 20 * 1.6 \text{ mm}^3$ and antenna is fed by a 50Ω line. The suggested design's geometry with optimum parameters is shown in Fig. 1. Circular patch, circular slot and parasitic circular element with microstrip line makes a front view of the suggested antenna. The diameter of the circular patch is denoted by 'c', 'd' represents the slot diameter, 'e' represents the parasitic element diameter and 'w' represents the width of the microstrip line.

The backside of the design has a partial ground plane with semi-circular slot, where 'p' is a diameter of semi-circular slot, 'k * q' represents the area of ladder pattern element, 'i' represents the upper plane height and other elements in the back plane is represented by 'r * k', 'j', 'm * n', 'f', 'w', and 'o'. 'b' represents the complete length and 'a' represents the complete breadth of the design. 'h' denotes the thickness of the assigned substrate. Table 2 shows the parameter values (reported in mm) of the design.

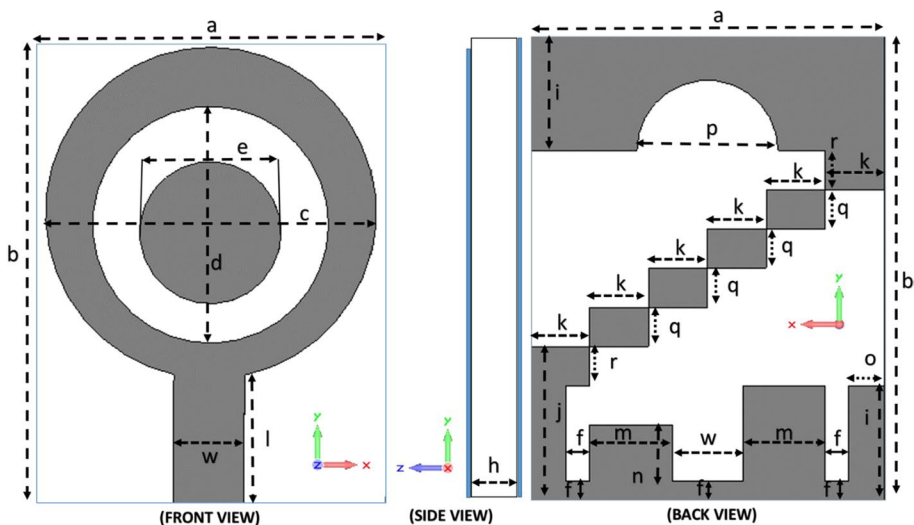


Fig. 1 The proposed antenna geometry configuration and parametric values (all values are in mm)

Table 2 Design parameters of the presented antenna (all values are in mm)

| Parameters | a | b | c | d | e | f | h | i | j |
|-------------|-----|-----|-----|------|-----|---|-----|---|-----|
| Values (mm) | 15 | 20 | 14 | 10 | 6 | 1 | 1.5 | 5 | 6.8 |
| Parameters | q | k | m | n | o | p | r | w | l |
| Values (mm) | 1.6 | 2.5 | 3.5 | 3.34 | 1.5 | 6 | 1.8 | 3 | 4 |

The evolution of the presented design in various stages have been presented in Fig. 2. Stage 01 shows the circular-shaped patch and an incomplete ground plane with microstrip line. Stage 02 shows the unique design in the backside with semi-circular slot and multiple rectangular designs are introduced causes excitation of higher frequency. Stage 03 shows that better resonance is observed by introduced a circular slot in the main patch with the same backplane. Stage 04 is the proposed antenna design, by adding parasitic circular-shaped element in the main patch causes impedance matching and resonances in lower and higher frequencies are excited.

Proposed design development from stage 01 to stage 04 along with their respective reflection coefficient (S_{11}) is shown in Fig. 3. The first stage (stage 01) has a defined ground plane and simple circular patch. The operating bandwidth for this stage is from 3.5 to 6.2 GHz and 8 to 12 GHz. The second stage is having a (PGP) partial ground plane and a simple circular patch. The operating bandwidth for this stage is from 2.8 to 3.3 GHz, 3.8 to 6.5 GHz and 7.5 to 20 GHz. In this stage the antenna covers three distinctive frequency bands. The third stage is having an additional slot in the main patch, with operating bandwidth is from 3.2 to 7.2 GHz and 8 to 20 GHz. The frequency shifted to 3.1 GHz by making a partial ground plane, and higher frequency shifted to 20 GHz by introducing a circular parasitic element is placed in the circular ring, as visible in the final stage (stage 04).

In the parameter study section, the variation of four parameters and optimized the result on this basis by observing their effects on S-parameter results. Firstly, the parameter (c) is sweeping from 12 to 15 mm, change the diameter, resulting in a change in results. When 'c' is < 14 mm multiband occurs after 6 GHz. The proper impedance

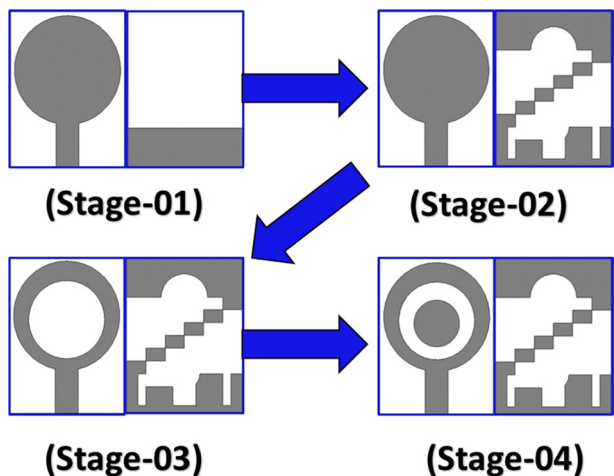
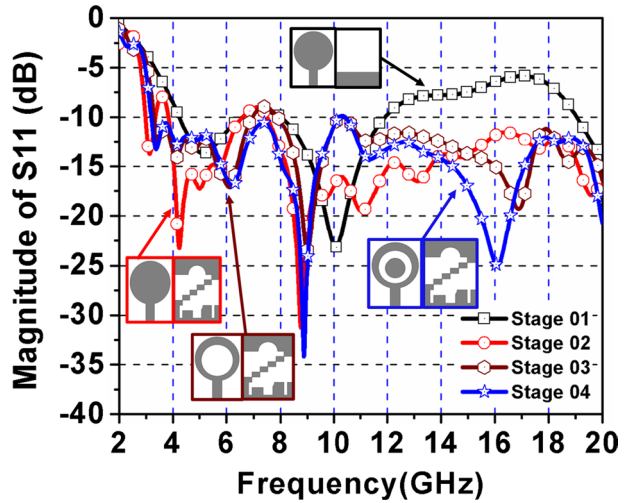
Fig. 2 Evolution of the proposed antenna structure from stage 01 to stage 04

Fig. 3 Simulated return loss (S_{11}) of stage 01, stage 02, stage 03, and proposed antenna (stage 04)



matching is obtained in the UWB band at an optimum value of 14 mm size as shown in Fig. 4. When the size of the circular slot (d) is increased from 9 to 11 mm, it gives different result at different size, when ' d ' is less than 10 mm size entire band mismatched, lower order oscillations visible at optimum value of 10 mm and it shows the full impedance matching as shown in Fig. 5. Another parameter (e) is sweeping from 4 to 7 mm and it provide return loss ($S_{11} < -10$ dB) at optimum value of 6 mm. This parameter is very important because it provides lower band impedance matching which shown in Fig. 6. Figure 7 shows parametric study of semi-circular slot (p), the parameter ' p ' are varied from 5 to 7 mm and optimum results are obtained at 6 mm due to perfect impedance matching at this dimension. The final proposed antenna exhibits an overall fractional bandwidth greater than 146.3%. Results are discussed and elaborated in the next section.

Fig. 4 Simulated return loss of proposed antenna with various values of first circle ' c '

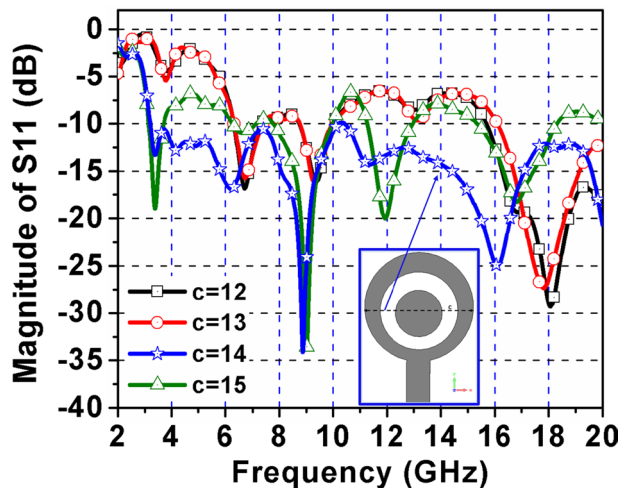


Fig. 5 Simulated return loss of proposed antenna with various values of circular slot 'd'

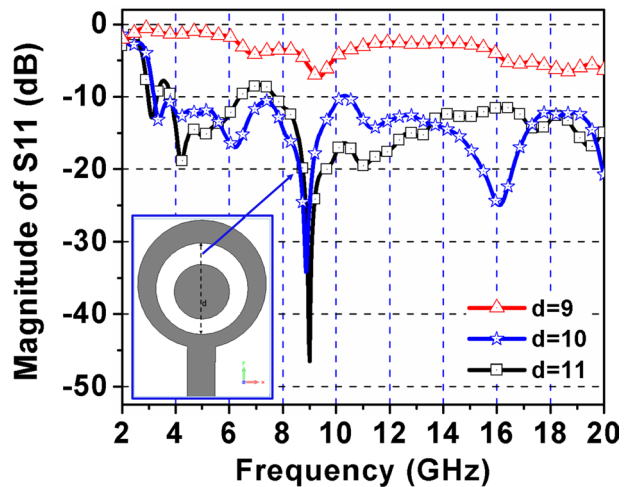
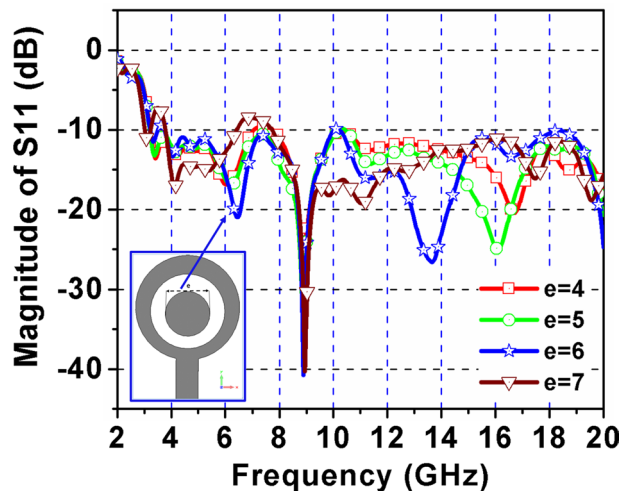


Fig. 6 Simulated return loss of proposed antenna with various values of third circle 'e'



3 Results and Discussion

The presented extended circular patch antenna has an extremely compact structure of 300 mm². The proposed antenna is a low profile ultra-wideband (UWB) antenna, therefore it could be useful for multiple applications. Drafting of the suggested design and all results are simulated using CST Tool. The fabrication of the suggested design is manufactured on substrate (FR4) using LPKF ProtoMat E-44 milling machine.

Figure 8 shows the testing setup of the suggested design in anechoic chamber. Proposed antenna testing is conducted by using VNA (Agilent) and the microstrip line is connected with 50 Ω (SMA) connector inside an anechoic chamber.

Figure 9 shows the relative analysis of the measured (S_{11}) curve and simulated (S_{11}) curve for the suggested design. The graph shows measured (S_{11}) curve result are in good acceptance with the simulated (S_{11}) result. The small deviation arises in some

Fig. 7 Simulated return loss of proposed antenna with various values of fourth circle 'p'

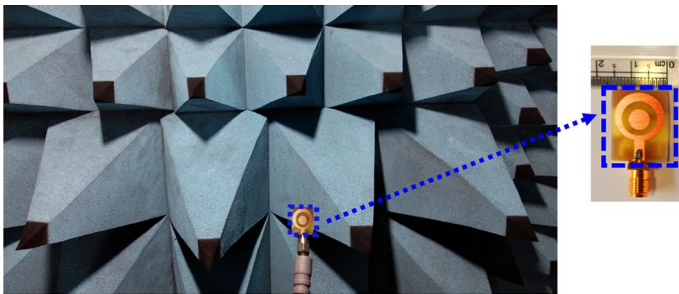
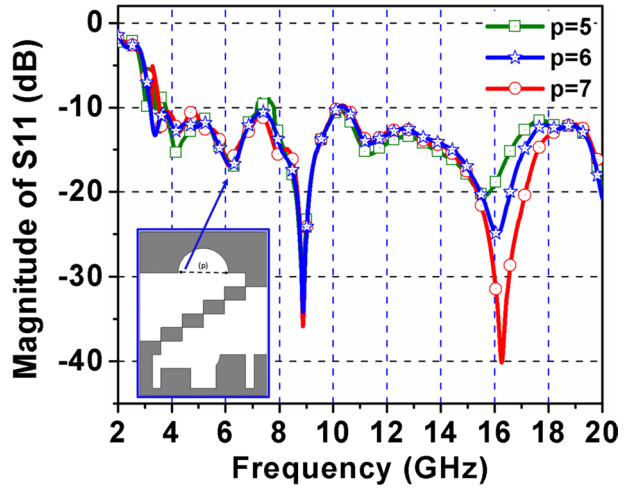


Fig. 8 Antenna measurement setup of proposed antenna structure in an anechoic chamber

Fig. 9 Comparison of simulated and measured return loss of the proposed antenna (stage 04)

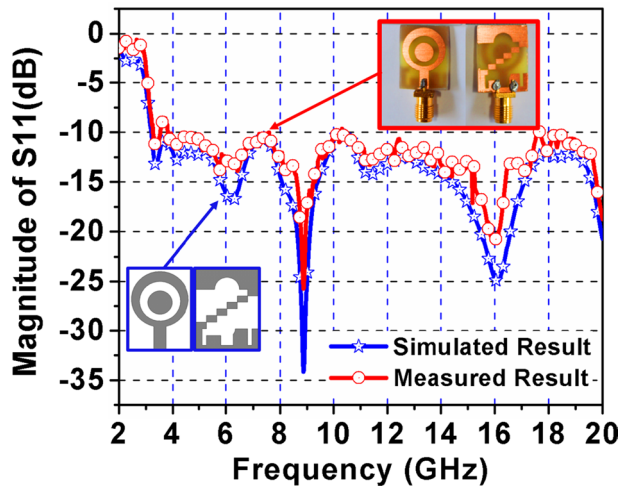


Fig. 10 Input impedance of proposed antenna (real part and imaginary part)

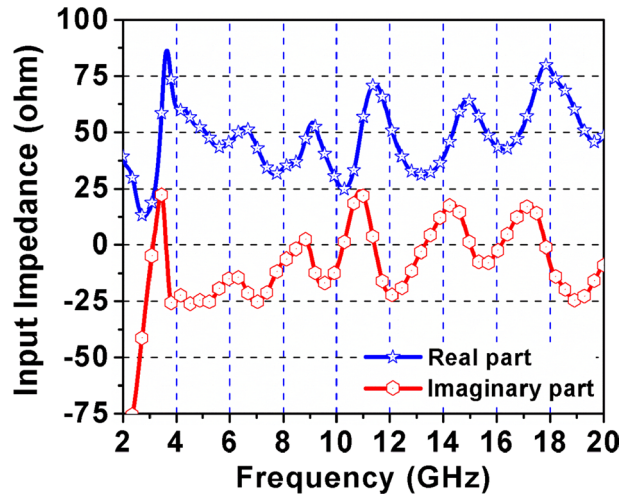
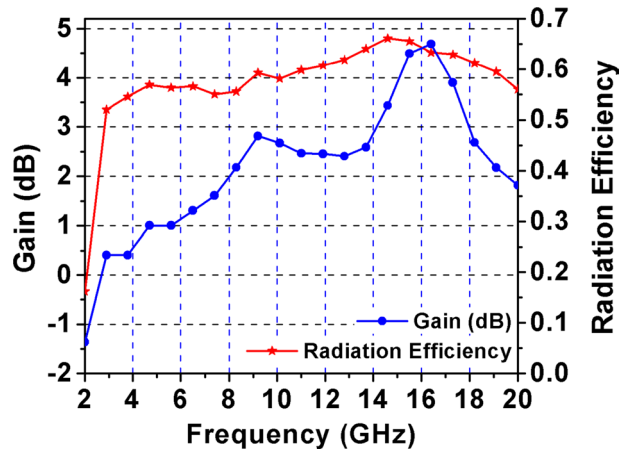


Fig. 11 Simulated gain and radiation efficiency of the proposed antenna



frequencies because the size of the suggested design is compact and 50 Ω SMA A-type connector is comparably big which accounts for the manufactured tolerances.

Figure 10 shows I/P impedance curve which represents the simulated real and imaginary components versus the frequency curve for the suggested design. The real impedance is sustained at 50 Ω throughout the proposed band and shows optimum impedance matching. The imaginary impedance shows the behavior of the antenna, initially it behaves like inductive (due to +ve polarity from 3.1 to 3.6 GHz), and after that antenna shows capacitive behavior (due to -ve polarity from 3.6 to 10 GHz) and again it further fluctuates to inductive or capacitive behaviour's at higher frequencies as shown in Fig. 10.

Figure 11 shows simulated antenna efficiency and gain versus frequency curve of the suggested design. Peak gain is observed at 16.2 GHz with a value of 4.8 dB. The peak radiation efficiency is observed at 14.4 GHz with a value of 67%, as frequency increases losses increase causes the antenna efficiency becomes decreases at higher frequency.

Figures 12 and 13 shows the comparative analysis of measured and simulated Co. and (X)-pol. at four selected frequencies. The H-polar pattern is defined by XoZ-plane, $\Phi=0^\circ$

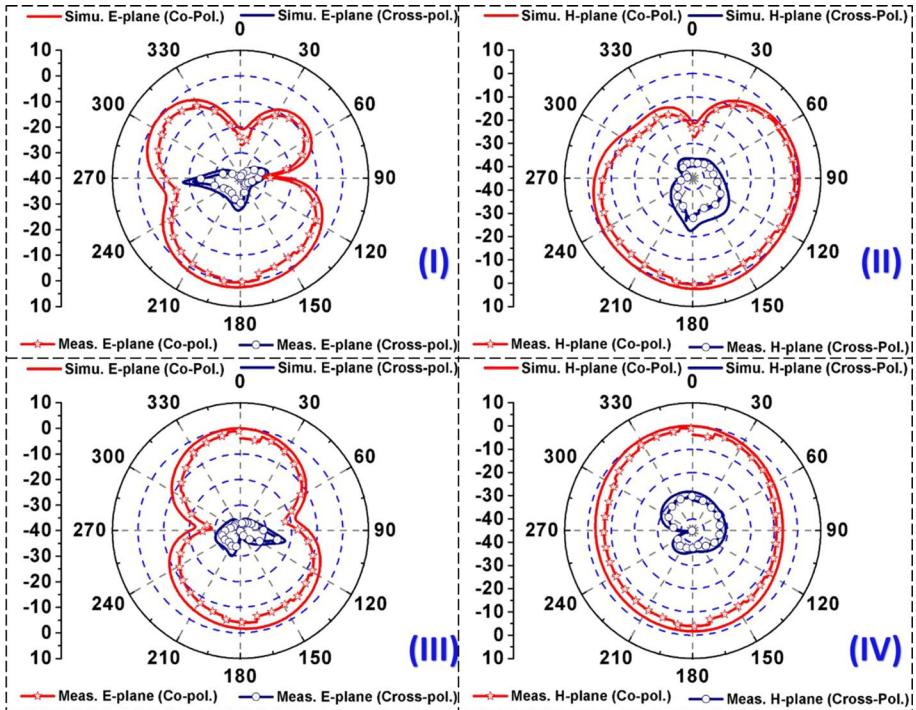


Fig. 12 Simulated and measured Co-pol. and cross-pol. of the proposed antenna at (I) 3.3 GHz E-plane, (II) 3.3 GHz H-plane, (III) 6 GHz E-plane and (IV) 6 GHz H-plane

and E-polar pattern by YoZ- plane, $\Phi=90^\circ$. Polar pattern of Co/(X)-pol. of H and E-plane at (3.3 and 6 GHz resonance) is shown in Fig. 12. The stable Co-pol. Omni and bi-directional polar pattern is observed with a good agreement of (X)-pol. at the lower frequency modes, whereas at (8.8 and 16 GHz frequencies) is shown in Fig. 13. The distorted occurs at higher frequencies due to the fact that ohmic losses increase.

Antenna’s surface current (front view) is visible in Fig. 14 at a constant phase (178°) for selected 04 frequencies. As evident from Fig. 14; I and II at (3.3 and 6 GHz frequencies) as the current signal strength is higher with the high current value of 167 and 61.7 A/m and in Fig. 14; III and IV at (8.8 and 16 GHz frequencies) the current signal strength is higher with the high value of 171 and 82.4 A/m. Mainly current strength due to the surface of the main circular patch, circular slot and circular parasitic element as well as due to ladder structure in partial ground plane.

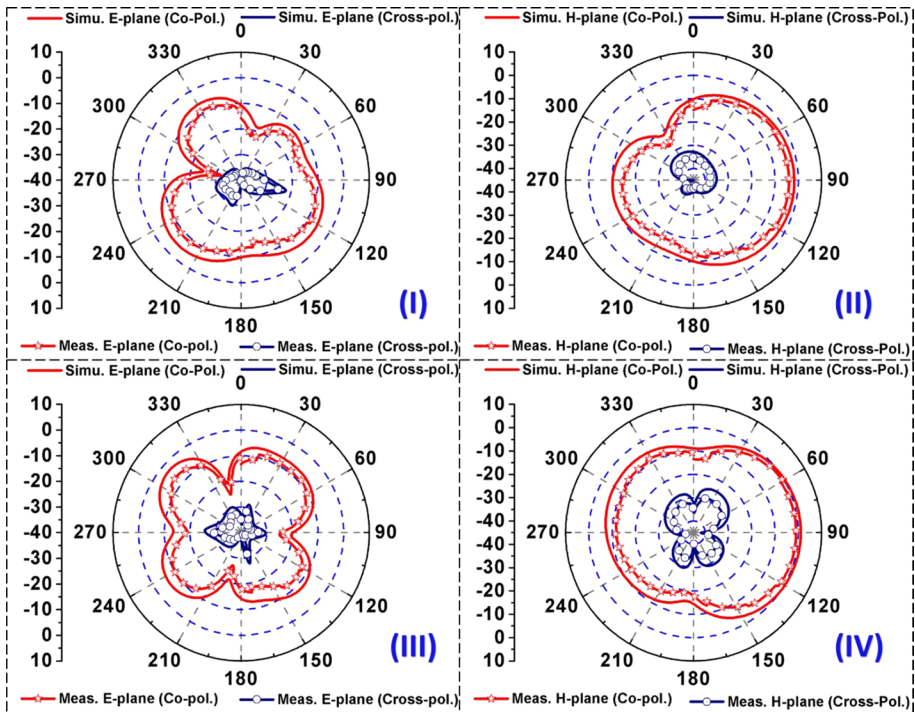


Fig. 13 Simulated and measured Co-pol. and cross-pol. of the proposed antenna at (I) 8.8 GHz E-plane, (II) 8.8 GHz H-plane, (III) 16 GHz E-plane and (IV) 16 GHz H-plane

4 Conclusion

A miniaturized antenna with extended circular patch and partial ground plane is proposed. A suggested antenna has been designed, fabricated and investigated. The impedance bandwidth ($S_{11} < -10$ dB) is 146% running from 3.1 to 20 GHz with a size of 300 mm². Antenna's peak gain is 4.8 dB and antenna efficiency is 67% have been obtained. The suggested design exhibits stable polar pattern (H-plane with omni-directional at $\Phi = 0^\circ$) and (E-plane with Bi-directional at $\Phi = 90^\circ$). The surface current shows good signal strength at (3.3, 6, 8.8, and 16 GHz frequencies). All above properties show that the presented structure is useful for broadband applications which includes 3.5/5.5 GHz (WiMAX), 5.2/5.8 GHz (WLAN), 8–12 GHz (X-band), the field of satellite communication and numerous other wireless uses.

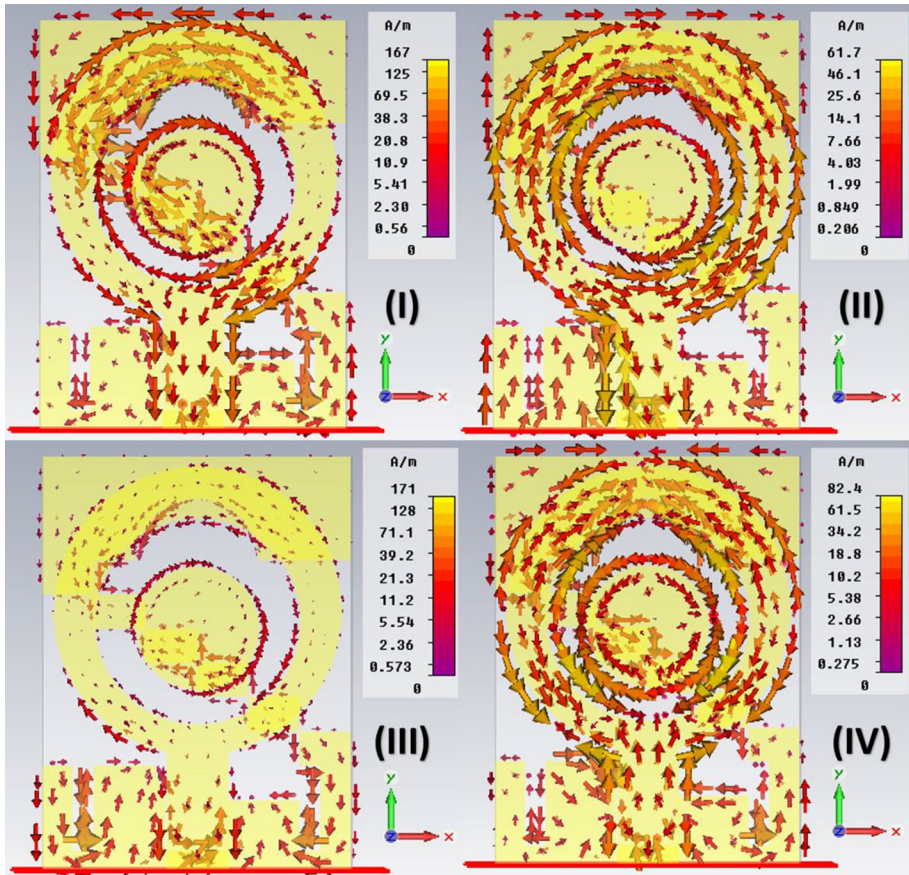


Fig. 14 Surface current distribution of the proposed antenna (stage-04) at (I) 3.3 GHz, (II) 6 GHz, (III) 8.8 GHz and (IV) 16 GHz

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