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Characterization of CP Radiations in a Planar Monopole Antenna Using Tuning Fork Fractal Slot for LTE Band13/Wi-Max and Wi-Fi Applications

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ABSTRACT In this paper, a novel antenna design comprising planar monopole with fractal slot defected ground structure for circularly polarized radiation is proposed. In the proposed antenna geometry, circular polarization radiation characteristics are obtained by defecting the ground structure with fractal slot. In this approach, CP characteristics are achieved by intensifying the level of cross polar component of the linearly polarized antenna upto a certain level by means of fractal slot inserted in ground structure. Antenna prototype with third order iterative tuning fork shaped fractal slot is fabricated and tested for the validation of simulated results. Parametric studies are also performed to exemplify the process of CP radiations. From the simulated and measured results, it is confirmed that the proposed antenna can be proficiently produced 10 dB return loss bandwidth (BW) nearly $\approx$ 37.4%, while 3-dB AR bandwidth (ARBW) is 15.5%, respectively. The proposed antenna can be a credible applicant for LTE Band 13/ cellular/ PCS /ASW/ WiMAX and Wi-Fi applications.

INDEX TERMS Circular polarization, axial ratio bandwidth (ARBW), modified ground structure (MGS), fractal structure, planar monopole CP antennas.

I. INTRODUCTION

Over the past decades, the microstrip antennas are widely employed in the wireless and satellite communication systems for the reason that they offer countless advantages likewise light weighted, small in size, ability of to be integrated with microwave integrated circuits on conformal surfaces. The circularly polarized microstrip antennas (CPMSA) are vastly preferred in RADAR tracking, satellite and mobile communication systems, GPS and WLAN systems due to advantages of better mobility, reduction in multipath reflections and stable signal quality between the transmitting and receiving devices in comparison of conventional (MSA) microstrip antennas. Usually in CPMSA, CP radiation can be realized with the practices of single feed, dual feed or hybrid feed excitation techniques [1]. In comparison of dual feed or hybrid feed antenna designs, microstrip antennas designed with single feed technique are extensively chosen as they have simplex structure to achieve CP radiation [2], [3].

CP microstrip antennas with defected ground structure (DGS) are highly attention-grabbing for the reason of their miniature size and wider return loss BW. Apart from above specified merits, DGS accords with reduction of higher harmonics, decreases the mutual coupling effect, and also reduces the effects of cross polarization [4], [5]. As a result, several antenna designs have been foreseen to improve the performances of microstrip antennas employed with defected ground structure.

Similar to the antennas with DGS, antennas with fractal ground structure (FGS) are extensively utilized for the enhancement of various performances of antennas like miniaturization, BW enhancement, reduction in mutual coupling etc. [6], [7]. When fractal slots are introduced in the ground plane of any antenna; it adds the equivalent capacitive and inductive elements to the antennas, which improves the characteristic impedance of the antennas. Several microstrip antenna with fractal ground structures have been reported

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in literature [8]–[15], which are envisioned for improving the performances of the antennas like impedance bandwidth and CP characteristics. In [8], [9], fractal antennas were presented for improving the impedance bandwidth by utilizing fractal structure with metasurface. A compact hexagonal shaped CP antenna with triangular fractal slots on the ground structure for wide-band applications [10], a linearly polarized CPW-fed octagonal fractal antenna with defected ground structure for super-wideband [11], A low-profile fractal antenna for wearable on-Body WBAN applications [12], an array antenna using defected ground structure shaped with fractal form generated by Apollonius circle [13], and another CP antenna with fractal ground structure [14] have been addressed. These CP antennas with fractal structure produce reasonably narrow return loss (RL) and axial ratio bandwidth typically $\leq$ 10 % and $\leq$ 5%, respectively with comparable gain profile between 2- 5 dB/dBic. Besides, a proximity coupled asymmetric cross slotted circular patch with Koch curve fractal structure has been reported to improve the antenna performances [15]. In this antenna design, the gain profile of the antenna is improved but this antenna has similar limitation like relatively bigger size, narrow AR bandwidth typically less than 1.5%. In this antenna design, CP radiation is generated by inserting two asymmetric length rectangular shape slots on circular patch which are perpendicular to each other.

In this paper, an antenna design with single feed technique is characterized for CP radiation. In proposed antenna, CP characteristic is achieved by raising the level of cross polar component of the linearly polarized antenna upto a certain level by inserting fractal slot. In "Antenna design" section the geometrical structure of antenna with fractal ground structure is described; while detailed discussion on simulated and measured results is explained in section "Results and Discussions" followed by conclusive remarks and applications of the proposed in "Conclusion" section.

II. ANTENNA CONFIGURATION AND ANALYSIS

The geometrical design of the proposed CP antenna with third iterative fractal slot operates at 2.11GHz frequency is shown in Figure 1. The geometry of the proposed antenna employs an inverted L-shaped monopole radiating patch joined with ≈50Ω microstrip feed line at upper surface of the substrate; whereas the bottom side of the substrate comprises modified partial ground plane loaded with third iterative fractal slot. Initially, an inverted L-shaped planar monopole with partial ground plane is designed. Further, a nearly a square shaped conductor patch is combined with the partial ground plane. In order to get the CP operation, a third iterative fractal slot is inserted on the modified ground structure. The proposed antenna is fabricated on most commonly available composite material FR-4 substrate; having dielectric permittivity ε_r = 4.4; tangent loss tan δ = 0.02; and thickness t=1.6 mm. The snapshots of fabricated antenna are shown in Figure 2. The total length and width of the proposed antenna is taken as W and L; while the length and width of third iterative fractal slot is chosen as l_t and W_t. The other different optimized values of third iterative fractal slot and antenna parameters are given in Table 1 and Table 2, respectively.

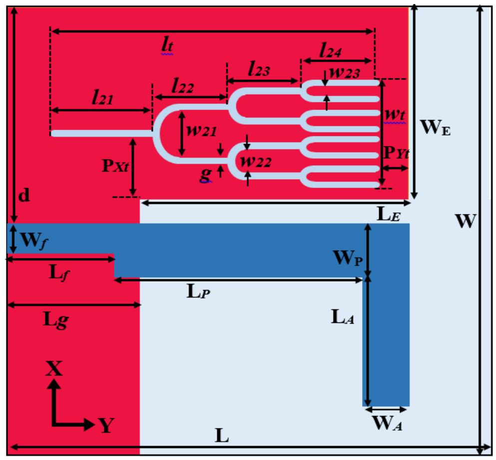


FIGURE 1. Geometrical design of proposed CP antenna.

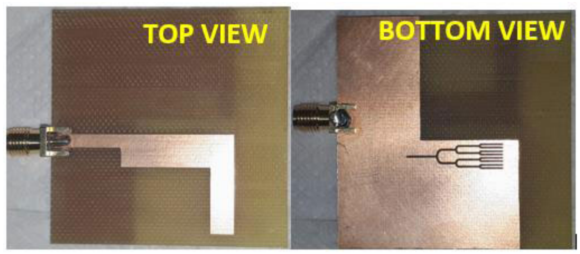


FIGURE 2. Snapshot of fabricated structure of the proposed antenna.

TABLE 1. Optimized values of parameters of third order iterative fractal structure (in mm).

l_t	20.4	l_{21}	6.3	l_{23}	5.1
W_{21}	2.6	W_{22}	1.2	W_{23}	0.4
g	0.3	P_{Xt}	2.9	P_{Yt}	3.5
l_{24}	4.9	W_t	5.4	l_{22}	4.10

TABLE 2. Optimized values of various parameters of proposed antenna design (in mm).

L_f	15	L_P	19	L_A	13
L_E	21	W_f	3	W_P	7.1
W_A	7.1	W_E	23.5	Lg	18
L	50	W	50	d	26.5

III. FMGS GEOMETRIES AND THEIR ANALYSIS

A. EVOLVEMENT OF FINAL GEOMETRY OF THE PROPOSED ANTENNA

Here in this section, geometrical progress to achieve the final antenna design is outlined as shown in Figure 3. In the beginning, a simple microstrip feed patch with rectangular monopole strip is printed on the upper surface of the FR-4 substrate whose one end is connected with

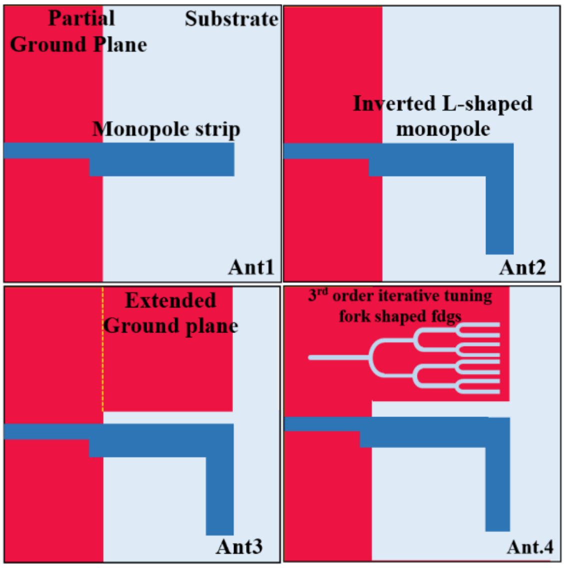


FIGURE 3. Different steps of antenna evolution process.

SMA connector; and backside of the substrate is taken as a partial ground plane (Ant.1). Moreover, the rectangular monopole strip of Ant1 is converted to inverted L-shaped monopole by connecting another rectangular strip (Ant.2). In the next step of antenna progression, the partial ground plane is extended by joining a nearly a square shaped conductor patch of 23.5 mm x 21 mm size with the partial ground plane of Ant.2 (Ant.3). To sum up the final antenna design, a third order iterative tuning fork shaped fractal defected ground structures is introduced (Ante.4). The simulated S_{11} responses of all four structures are shown in Figure 4. The following interpretations have been concluded.

For ant.1, no evidences of resonance occurrence ($S_{11} < -10$ dB) have been observed. In ant.2, when an inverted L-shaped patch is coupled with the microstrip feed patch, a considerable excellence is seen in the simulated S_{11} response ($S_{11} < -10$ dB) varied from 1.80 GHz to 2.21 GHz with minima of -24 dB. In ant.3, a substantial growth in the S_{11} response (from 1.82 GHz to 2.39 GHz) has been witnessed when nearly square ground plane is combined with partial ground plane. Further for ant.4, with the introduction of third iterative fractal slot; the S_{11} bandwidth is significantly expanded to 760 MHz (from 1.72 GHz to 2.48 GHz), which is wider than the antenna without fractal slot. The reason for significant improvement in the S_{11} bandwidth can be attributed to the existence of two resonant modes which is also leading the double minima in the frequency behavior.

As far as concerning about the CP operation and respective axial ratio responses achieved from evolved antenna geometries, Figure 5 represents the axial ratio performances of all geometries. Initially from ant.1 to ant.3, there have no confirmation of circular polarization operation (AR < 3dB) been observed due to non-excitation of two orthogonal modes. In ant.4, when third iterative fractal slot is introduced; axial ratio response crosses the level of acceptable range

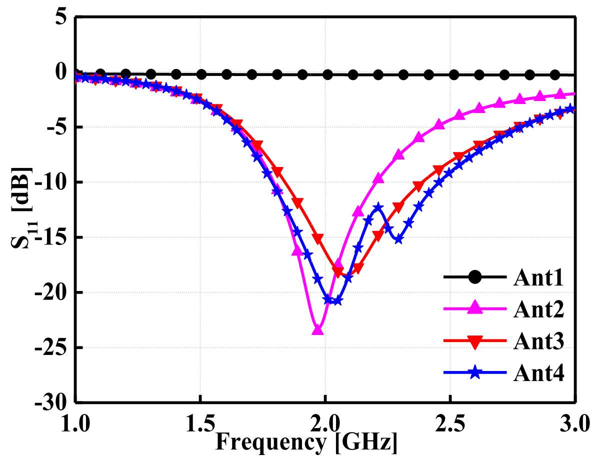


FIGURE 4. The S_{11} responses of all evolved antenna geometries.

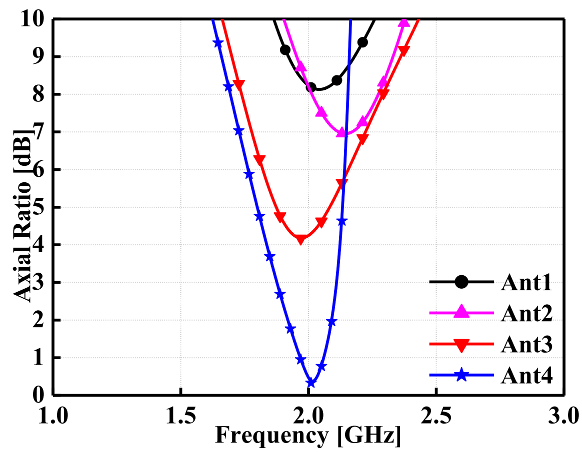


FIGURE 5. Axial ratio responses of all evolved antenna geometries.

(AR < 3dB level). Here, insertion of fractal structure on the ground structure intensifies the level of cross polarisation to the desired level. The intensified cross polarization level has the same magnitude and with 90° phase difference as in co-polar component, which results the CP operation in proposed antenna structure.

B. EVOLVEMENT OF FRACTAL GEOMETRIES AND THEIR RESPONSES

The proposed CP antenna design is simulated and analysed with High Frequency Structure Simulator (HFSS-14). Initially, a long and very thin straight line slot is inserted on the modified ground plane as a zero order iterative fractal slot. The shape of first order iterative fractal slot is inspired from shape of tuning fork 'an acoustic resonator'. In order to obtain the first iterative fractal, the long and thin straight line slot is bent in to the U-shaped tuning fork. The S_{11} and AR responses for proposed antenna either with no fractal slot or with all fractal slots are shown in Figure 7 and Figure 8. From the referred figure, it can be seen that more or less identical responses of S_{11} are produced with the antenna loaded with

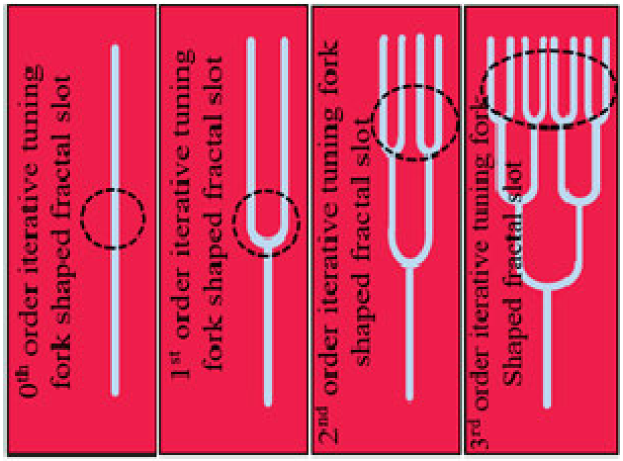


FIGURE 6. Sequentially evolved all fractal geometries.

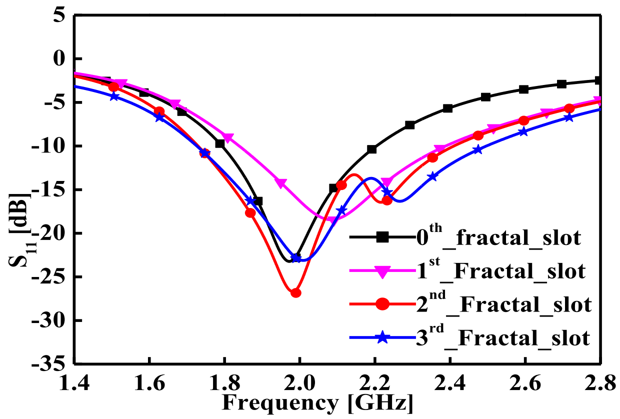


FIGURE 7. The S_{11} responses obtained for all fractal designs.

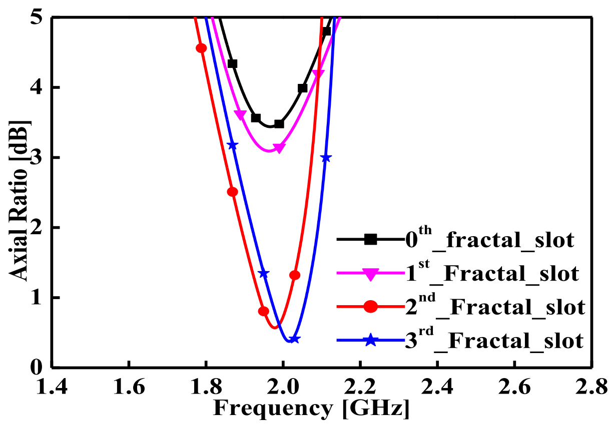


FIGURE 8. Axial ratio responses for all fractal designs.

zero and first iterative fractal slots. As far as concerning about the AR performances; the AR values are stagnated around 3.5dB and 3dB in both the cases, respectively. Furthermore, the second iterative fractal is obtained by changing single level tuning fork segment in to double level tuning fork segment. As soon as, the iteration order of fractal slot is changed to second order iteration from first iteration, the antenna

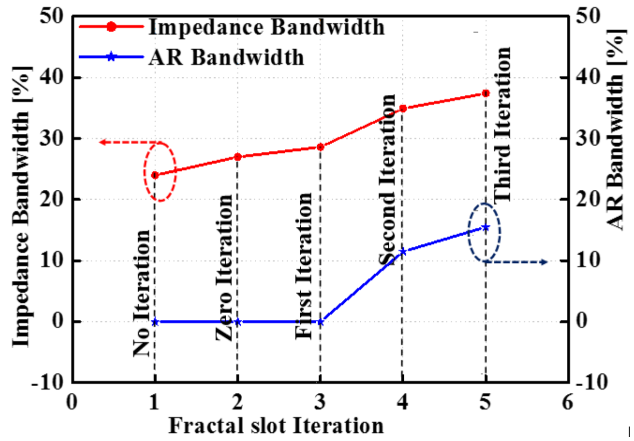


FIGURE 9. Relative impedance & AR bandwidth for all fractal designs.

responses are significantly improved in terms of impedance and AR bandwidth. The S_{11} performance is enhanced due to the existence of two resonant modes which is also leading the double minima in the frequency response. For this case, simulated impedance BW is ≈690MHz spreaded over 1.72-2.41GHz; while the corresponding AR bandwidth is around 210 MHz ranged from 1.82- 2.03GHz.

Finally, to analyze and improve the performances of the proposed antenna, higher order iterative fractal slot is introduced on the ground structure. The third order iterative fractal slot is obtained by changing double level tuning fork segment in to quad level tuning fork segment. The third iterative fractal slot is positioned at P_{Xt} and P_{Yt} distance away from the edge of ground plane. Here, the overall length and width for third iterative fractal slot is chosen as l_t and W_t, respectively; while the slot gap between fractal arms is chosen as '*g=0.3mm*'.

The S_{11} BW of the antenna with third fractal structure is around 760 MHz (1.72GHz to 2.48 GHz). The S_{11} bandwidth achieved from antenna with higher order iterative fractal is much wider than the bandwidth produced by antenna without fractal slot. As far as concerning about the AR performance, the excellent AR response is appreciated. The wide AR bandwidth around ≈310 MHz (1.86 GHz to 2.17 GHz) with excellent purity of polarization is appreciated as the minimum value of axial ratio in 3-dB AR bandwidth reaches to 0.2dB. Figure 9 demonstrates improvement observed in impedance bandwidth and AR bandwidth for the proposed antenna integrated with different iterative fractal slots. From the referred figure, it is clearly seen that when the antenna is integrated with one after the other fractal slots, a consistent improvement in both the bandwidths is witnessed. Further, if the order of fractal iterations are kept iterated to higher order of iterations (fourth or fifth order), then no motivated results of antenna performances have been made.

C. MECHANISM OF CP GENERATION IN PROPOSED GEOMETRY

In order to understand the role of defects created in the ground plane, one has to understand the physics behind

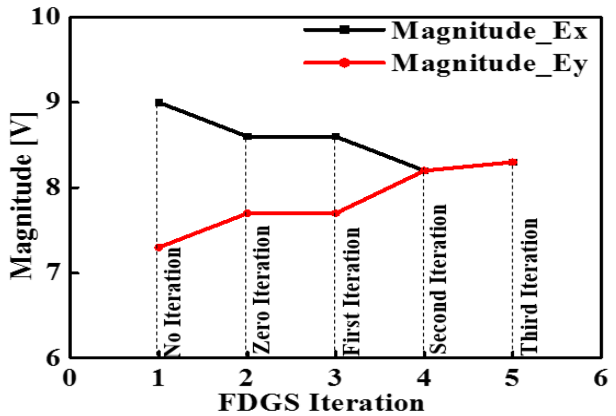


FIGURE 10. Magnitude variation response of E_X and E_Y field components w.r.t. fractal slot iteration order.

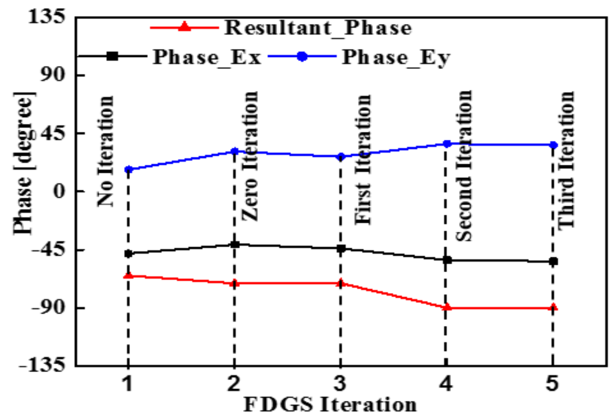


FIGURE 11. Phase variation response of E_X and E_Y field components w.r.t. fractal slot iteration order.

the DGS [16], [17]. The cross polar component level of the linearly polarized microstrip patch antenna is oftenally increased if defective structures are created in the ground plane below (not under) the microstrip patch. If the magnitude of the increased cross pole mode is equivalent as of the original resonant mode, then the basic principle of CP generation is accomplished. However, it is not possible to increase the level of cross-polar component to the desired level in the conventional antennas having defective ground structures (DGSs) like U-shaped and dumbbell DGS etc. Now, the major concern for achieving the CP operation in the proposed antenna by DGS is designing a slot structure in the ground plane which can increase the cross polar level to the desired level. Hence, to generate the CP radiations by the proposed antenna, fractal slots of different iterative orders are sequentially inserted in the ground plane as shown in Figure 6. These fractal slots are inserted purposely to increase the cross-polar component level for the accomplishment of CP characteristics.

When the Zero and first order iterative fractal slots are inserted; as such no promising conditions accountable for CP operations are seen. Almost identical results are also seen in both the cases. Now, the magnitudes of Ex and Ey field vectors are observed very much dissimilar; while corresponding phase shift (Φx-Φy) between both the field components are seen as −72° and −71°, respectively.

Figure 10 demonstrate the magnitude changing response of Ex and Ey electric field vectors, when the antenna is either with no fractal slot or with various fractal slots sequentially inserted on the ground structure from zero to third iteration. From the referred figure, it can be clearly seen that for the zero and 1st iterations, magnitude of both the electric field vectors are not similar but as soon as, the fractal iterative order changes to higher order iterative fractal slots (second or third order), both electric field vectors attain the equal magnitudes(Ex=Ey). Figure 11 shows the phase responses (Φx and Φy) of the both the electric field vectors for all the fractal geometries. From this figure, it can be easily understood that as soon as the fractal iteration

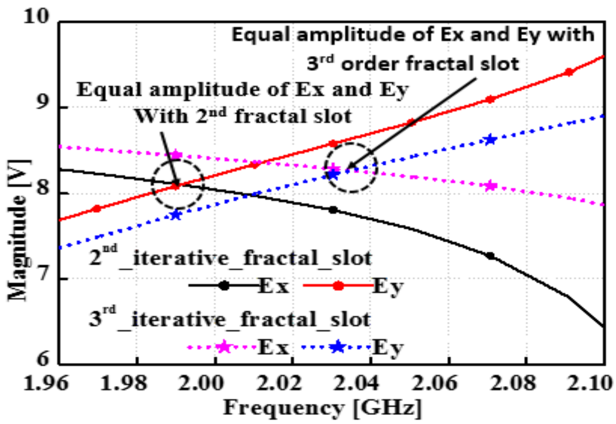


FIGURE 12. Magnitude response of fields E_X and E_Y against the resonance frequency.

changes from first to higher order iterative (second or third), both the electric field vectors accomplish the 90° phase shift (Φx-Φy= −90). Besides this, on insertion of higher order iterative fractals on the ground structure; the cross polar component level of the linear polarized antenna is intensified to the certain level, consequently the proposed antenna produces CP radiations.

Figure 12 demonstrate the magnitude variation diagrams of two radiated field vectors Ex and Ey excited in the boresight direction. Here first of all, the original resonant mode generates an electric far-field vector (Ex) in the X- axis direction. When a second or third order iterative fractal slots are introduced on the ground structure, the augmented x-pole (cross pole) produces second electric far-field vector (Ey) orthogonally in the direction of y-axis. Almost equivalent amplitude of both electric field vector (Ex and Ey) is observed at the resonant frequency.

Figure 13 demonstrate phase variation responses of two electric far-fields i.e. Ex and Ey radiated in broadside direction. From the referred figure, it can be clearly seen that both the radiated fields have 90° phase shift in both cases; when second or third iterative fractals are introduced. Here, phase of electric field (Φx) lags the phase of electric field (Φy) by

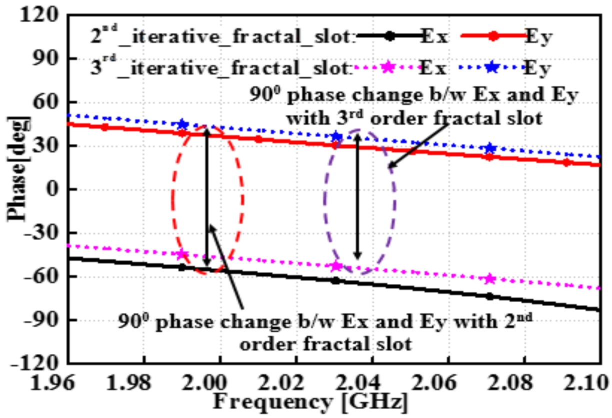


FIGURE 13. Phase changing response of fields *Ex* and *Ey* filed vectors with respect to second and third iteration of fractal structures.

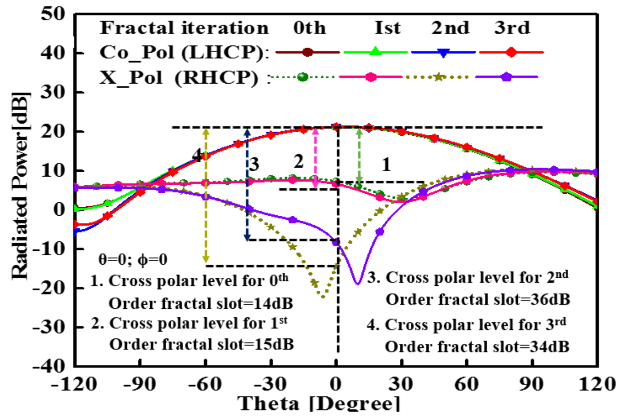


FIGURE 16. Cross polarization responses and radiation patterns observed for all fractal sots.

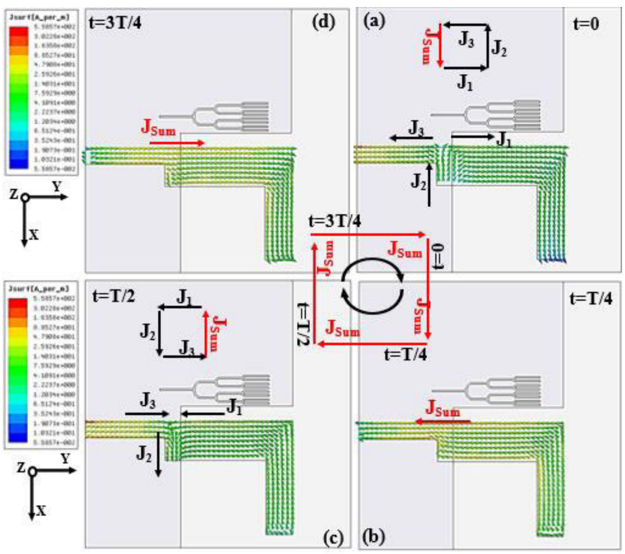


FIGURE 14. The surface current distributions on monopole patch and ground plane with third iterative tuning fork shaped fractal slot at (a) t=0 phase (b) t=T/4 phase (c) t=T/2 phase (d) 3T/4 phase.

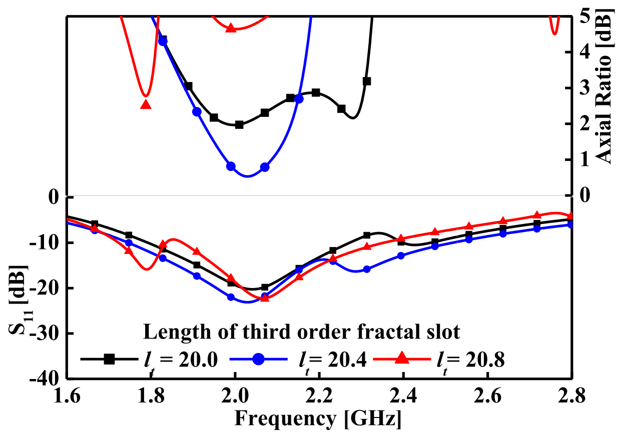


FIGURE 17. The S_{11} responses on tuning overall length (l_t) of third order iterative fractal slot.

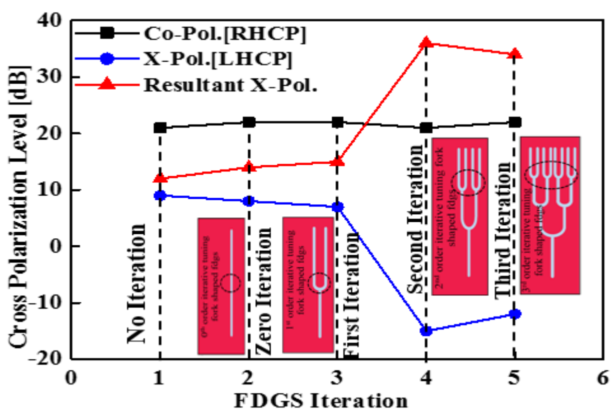


FIGURE 15. Cross polarization level with respect to fractal iterations.

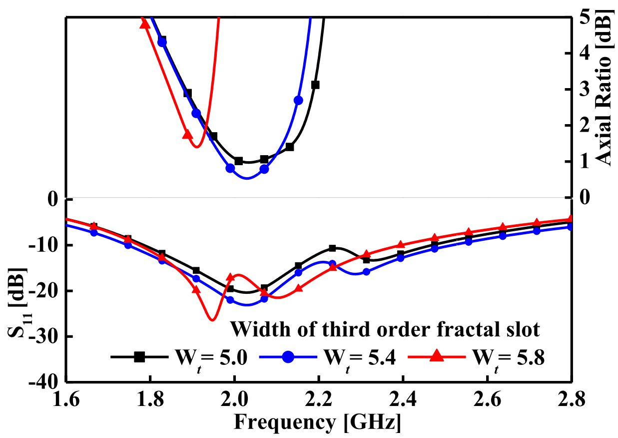


FIGURE 18. Axial ratio responses on tuning overall width (W_t) of third order iterative Fractal slot.

90° approximately. Hence, left hand sense of circular polarization is perceived. To validate the sense of polarization, the variation of the dominant surface current (J_{sum}) has been observed in the radiator.

Figure. 14 shows the surface current distribution at 2.03GHz for four different phases (ωt) change from t=0 to t=3T/4 with an interval of T/4(where T is the time period). As time progresses from t=0 to t=3T/4, the predominant

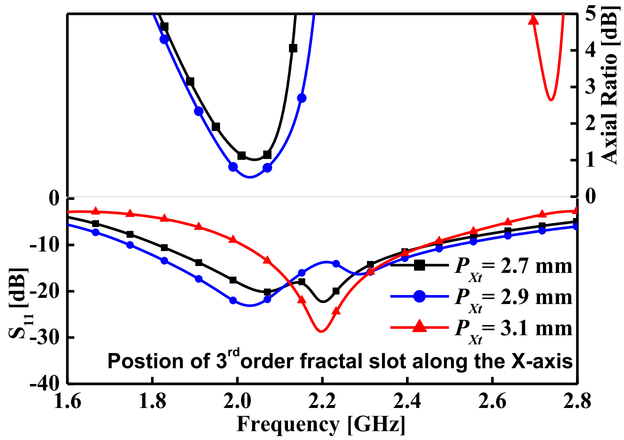


FIGURE 19. The S_{11} and AR responses on tuning placing position (P_{xt}) of third iterative fractal slot.

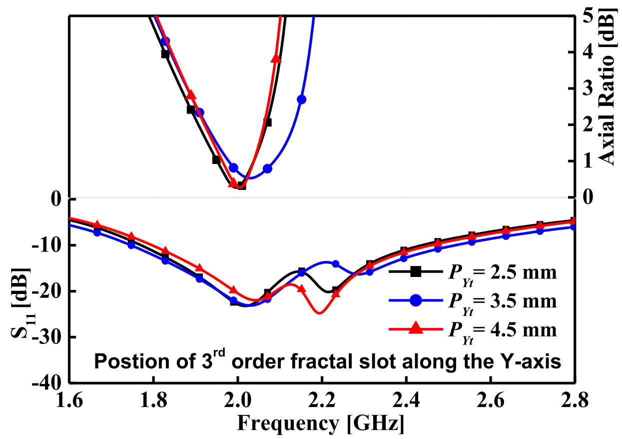


FIGURE 20. The S_{11} and AR responses on tuning placing position (P_{Yt}) of third iterative Fractal slot.

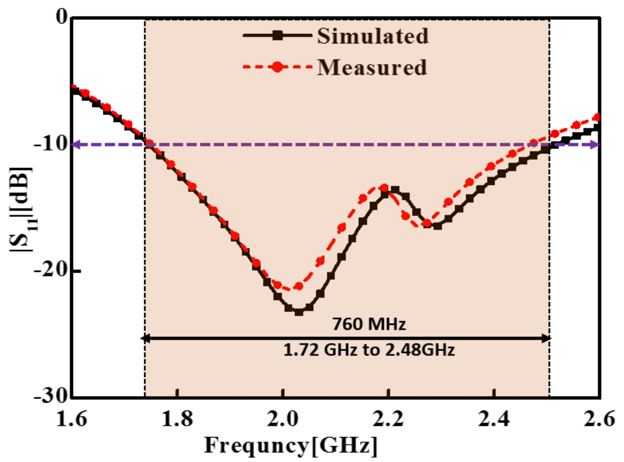


FIGURE 21. Simulated and measured impedance bandwidth response of the proposed antenna.

surface current rotates in clockwise direction as the wave propagates in +z-axis direction. Hence, for the proposed antenna structure; LHCP sense of polarization of wave has been witnessed in the +z direction.

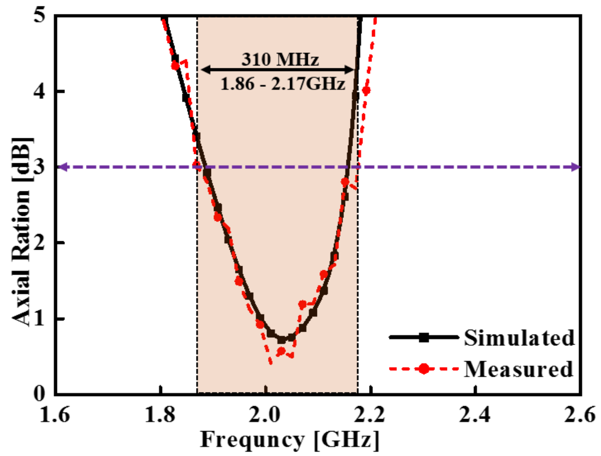


FIGURE 22. Simulated and measured axial ratio bandwidth responses of the proposed antenna.

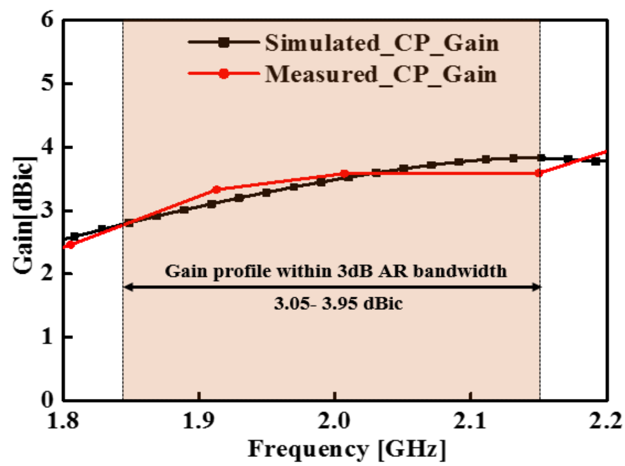


FIGURE 23. Simulated and measured gain profile of the proposed antenna with in the −10 dB bandwidth.

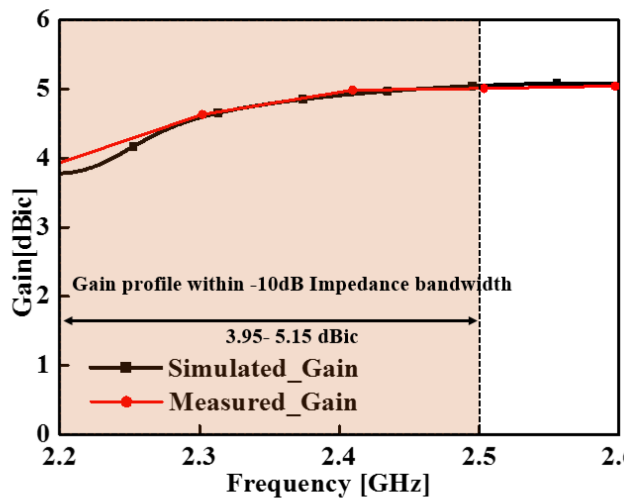
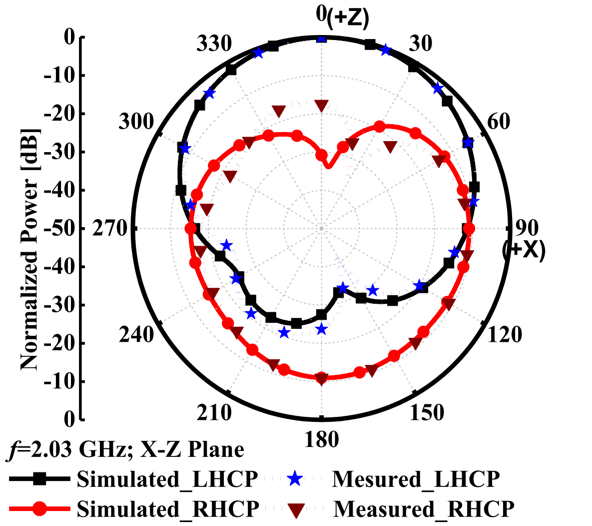
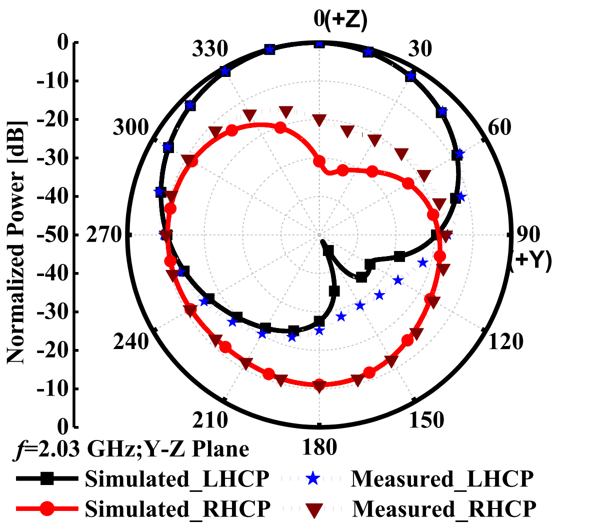


FIGURE 24. Simulated and measured gain profile of the proposed antenna with in the 3-dB axial ratio bandwidth.

Figure 15 shows the level of co-polar, cross polar component with resultant polarization level; while the Figure 16 demonstrates the radiation characteristics of the

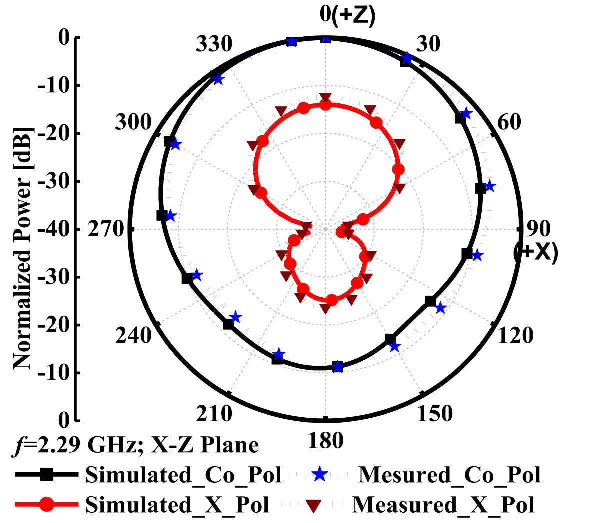


(a) Circular Polarized radiation pattern in X-Z Plane at 2.03GHz frequency

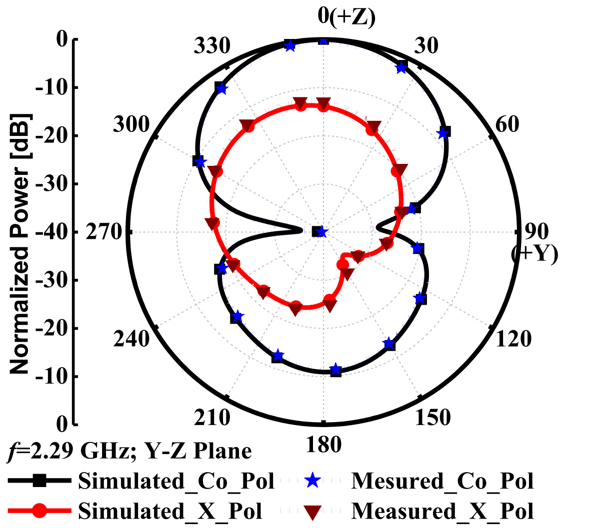


(b) Circular Polarized radiation pattern in Y-Z Plane at 2.03GHz frequency

FIGURE 25. Simulated and measured normalized circularly polarized radiation patterns at 2.03 GHz frequency.



(a) Linearly polarized radiation pattern in X-Z Plane at 2.29GHz frequency



(b) Linearly polarized radiation pattern in Y-Z Plane at 2.29Hz frequency

FIGURE 26. Simulated and measured normalized linearly polarized radiation pattern in Y-Z plane at 2.29GHz frequency.

proposed antenna loaded with or without different fractal slots in its ground plane. When the proposed antenna does not comprise any fractal slot in its ground plane, the co-pol and cross-pol levels are recorded as 21dB and 09dB (in both E and H planes), respectively. At this point, the total cross-pol difference is seen around ≈12dB in both planes. Further, if antenna is loaded with zero and first order iterative fractal slots, polarization level of cross polar component is increased marginally. As soon as, the higher iterative fractal slots are loaded on the ground structure of the antenna, the polarization level of cross polar component is aggressively increased to the certain desired level. Hence, it can be evidently concluded that the cross polar component having the equal magnitude (Ex=Ey) and 90 degree shift (Φx-Φy) as obtained for main co-polar component, is accountable for CP operation.

D. PARAMETER STUDIES OF ANTENNA WITH THIRD ITERATIVE FRACTAL SLOT

In order to observe the good purity and mechanism of CP operation in the proposed antenna, the parametric studies are conducted on parameters of third iterative fractal slotted in the ground plane of proposed antenna. The concern parameters of the fractal slot which have sound impact on antenna performances are: length ‘l_t’ and width ‘W_t’ along with other parameters of the fractal like slotting position of fractal in the ground plane along the X and Y axis at coordinates (P_{Xt}, P_{Yt}). Figure 17 & Figure 18 display the S_{11} and AR responses, when overall length (l_t) and width (W_t) of the fractal slot is tuned. The planar monopole antenna with the third iterative fractal slot has two resonant modes. Here, first resonant mode is originated in the direction of x-axis and almost stationary in the lower side of frequency band; while

TABLE 3. Comparison of various figures of merits of proposed and referenced antennas.

Ref.	Antenna geometry	*Size	CF/RF (GHz)	IBW (%)	ARBW (%)	Gain (dBic/dB)
[8]	circular slot antenna with 4 rectangular slots on fractal meta surface	$0.20\lambda_0$x$0.20\lambda_0$	3.3	63	--	3.6
[9]	microstrip slot antenna with fractal Koch on Metamaterial surface	$0.31\lambda_0$x$0.31\lambda_0$	3.5	14	--	3.75
[11]	CPW fed octagonal antenna with octagonal fractal slots	$0.23\lambda_0$x$0.25\lambda_0$	3.8	179	--	≈10
[12]	triangular patch with Koch fractal DGS and meandering slits	$0.32\lambda_0$x$0.32\lambda_0$	2.45	7.75	--	2.06
[14]	Single feed square patch with fractal slot ground structure	$0.19\lambda_0$x$0.19\lambda_0$	1.575	2.0	0.4	2.3
[15]	Proximity coupled Circular patch with Koch curve fractal DGS	$0.44\lambda_0$x$0.44\lambda_0$	1.5	9.27	1.28	5.41
[17]	Square patch slotted with 4 V-shaped corner and cross slot at center with DGS plane	$0.28\lambda_0$x$0.28\lambda_0$	1.5	6.65	1.06	3.9
Proposed antenna	***Monopole antenna with Tuning Fork Shaped fractal slot***	$0.29\lambda_0$x$0.290\lambda_0$	***2.110***	***37.4***	***15.5***	***3.95/5.15***

$^*\lambda_0$ is calculated at the lowest frequency(f_l), CF/RF: Centre/Resonance Frequency, IBW: Impedance Bandwidth, ARBW: Axial ratio Bandwidth

the second mode is originated in the direction of y-axis due to intensification of polarization level of cross polar component on introduction of fractal slot. When the fractal slot length increases, this second resonant mode moves toward the lower side in the frequency band. As far as concerning about the axial ratio responses, axial ratio responses are deteriorated when fractal slot length is tuned from the optimized value i.e. $l_t = 20.4$mm.

Figure 19 & Figure 20 display the S_{11} and AR responses when the slotting position of the fractal structure P_{Xt} and P_{Yt} are tuned. Both the resonant modes became slightly unstable when fractal slot is moved from the edge of ground plane along the x-axis and positioned at $P_{Xt} = 2.7$mm and 2.9mm turn by turn. Moreover, if the value of P_{Xt} is further increased to 3.1mm; lower mode is shifted towards the upper side in the frequency band, while the second higher mode is wiped out. Corresponding axial ratio responses are also changed when fractal structure is moved along the +x-axis. When the fractal structure is relocated along the y-axis from the corner edges of ground plane, both the resonant modes are remained more or less stable at 2.05GHz and 2.25GHz frequencies, respectively but when the fractal structure is further kept relocated after $P_{Yt} = 3.5$mm, then the higher resonant mode is slightly shifted to the lower side in the frequency band. For this case, the corresponding AR performance is deteriorated if the fractal structure is relocated from the optimized value i.e. $P_{Yt} = 3.5$mm. By tuning the fractal parameters (length, width and slotting position), two orthogonal modes with equal amplitude and 90° phase difference at certain frequency are produced. From referred figures, it can be understood that both the resonant modes are independent to each other for the CP radiation. Any change in Fractal dimension within the restricted limit, no effect on the basic resonant mode has been seen. This is the major advantage of this approach used for design of CP antenna.

IV. RESULTS AND DISCUSSIONS ON CP ANTENNA WITH THIRD ITERATIVE FRACTAL SLOT

The parameter values of the proposed antenna with third iterative fractal slot are best optimized and fabricated to validate the simulated results. Various characteristics of the fabricated antenna prototype like Far field and 3-dB AR etc.; were measured in anechoic chamber using ENA series network analyzer make E5071C (300 KHz – 20 GHz). Figure 21 & Figure 22 show the comparison between simulated and measured results of S_{11} and AR performances. The measured S_{11} results are well agreed with simulated S_{11} results. The measured impedance BW is produced about 760 MHz varied from 1.72 GHz to 2.48 GHz centered at 2.11 GHz frequency. The produced ARBW is around 310 MHz spreaded over 1.86 GHz to 2.17 GHz centered at 2.03 GHz frequency. The maximum measured CP gain is around 3.95 dBic with in the ARBW as shown in Figure 23. However, the measured total gain responses are varied from 2 dBic to 5.15 dBic in entire impedance BW as shown in Figure 24. The measured and simulated normalized radiation patterns (at $\Phi = 0°$, $\Phi = 90°$) of CP antenna are plotted at 2.03 GHz resonant frequency as shown in Figure 25 and Figure 26. From the referred Figures, it can be evidently seen that the measured radiation patterns are almost comparable to the simulated results. The 3-dB beamwidth is about 91° along with more than 90% antenna efficiency. Several merits of the proposed antenna are compared with the previously published work as shown in Table 3.

V. CONCLUSION

A new antenna design comprises of fractal structure for CP radiation is proposed. In this approach, cross polarization level of linearly polarized antenna is increased to the desired level for achieving CP radiation characteristic. Here, CP antenna with 3rd iterative fractal DGS is simulated, fabricated and experimentally examined. Proposed antenna shows the measured impedance BW and corresponding ARBW as 760 MHz and 310 MHz respectively. The measured CP gain is almost stable across the entire CP band with 3.95 dBic peak value. Proposed radiator can be applicable for LTE Band 13/ cellular/ PCS /ASW/ WiMAX and Wi-Fi applications.

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