Design of Koch Fractal Antenna with Defected Ground Structure for S-band Applications

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Abstract- **The proposed article presents a wideband characterized antenna with fractal geometry. To improve the impedance bandwidth a second-order iterated Koch fractal curve is incorporated on the lower and upper edges of the main radiator. The operating frequency of the antenna spans from 1.9 GHz to 4.3 GHz. The impedance bandwidth of 77% is achieved due to the implementation of the defected ground structure. The overall geometry configuration is built on a FR4 substrate. The monopole is powered on a line feed attached to the fractal patch with a matched impedance of 50Ω. The dimensional compactness of the proposed fractal antenna measures $0.641\lambda_0 \times 0.434\lambda_0 \times 0.016\lambda_0$ (f_r = 3.1 GHz). A maximum realized gain measures to 4 dBi at 4.22 GHz with better X-Pol level and stable radiation characteristics covering the entire operational band adds to the merits of this investigation. Thus, the proposed monopole can be considered suitable for application in the S-band.**

Keywords— Koch fractal, Realized gain, Linear polarization, Cross polarization, Wideband.

I. INTRODUCTION

The present scenario focuses on the requirement for lightweight, compact, high performing and efficient antennas elements. These are the major areas attracting a lot of attention in sensing and wireless communication systems. Less metallization for cost-effectiveness and system integration are the main constrains [1]. Over the conventional antennas the fractal-based antennas are gaining much attention for their radiation stable properties and application in almost every wireless device. Compact size, high gain factor and better polarization (linear, and circular) are the characteristics of greater importance in the aviation, defense and space industries. Features like wide and multi operational bandwidth, stable gain response, impedance matching, low mutual coupling etc., have made its waysto numerous applications in the field of wireless technologies such as Satellite Communications, Radars, WLAN, GPS, MIMO, and Remote sensing etc.

Fractal geometry-based antennas has advantages over conventional antennas in terms of better radiation properties. Several types of fractal-based antenna designs of various applications are given in the literature [1-4]. Two essential properties of the fractals are (i) Space-filling, and (ii) Self-similarity. To a greater degree, these dimensional parameters govern the antenna’s radiation characteristics [1-5]. In work [1] the authors have implemented a Minkowski fractal geometry in the antenna element with an asymmetric slot at the top of the monopole. They have obtained a complimentary structure with notch load structure in the ground. The radiator yields the IBW ranging from 700 MHz to 4.71 GHz. The base structure of the design is octagonal. The fractal antenna has a larger dimension with an average gain of 3.93 dBi. In [2] fractal defected ground structure is implemented on a line feed basic patch antenna. The design shows -40 dB of S11 ≤ -10 dB response. The operating frequency of 30 MHz ranging from 1.558 GHz to 1.588 GHz is observed. A 2nd and 3rd order iteration of fractal defected ground structure are implemented to achieve linear polarized (LP) to circularly polarized (CP) radiation. The axial ratio (AR) bandwidth of 6 MHz with the gain response varies from (1.7 dBi - 2.2 dBi). Authors in another investigation [3] have successfully incorporated a Koch curve fractal geometry with second-order of iteration to design a miniaturized MIMO wideband antenna. The IBW of the fractal antenna ranges from 2 GHz to 10.6 GHz. To achieve better isolation four element monopoles are placed mutually orthogonal to each other on the same substrate. A maximum realized gain obtained is 4 dBi. The radiation performance of the patch is stable with positive gain response over the entire S_{11} band thus making it a fit for wireless device applications. In another work [4] researchers have implemented Koch fractal geometry on a circularly polarized central radiator with a coaxial feeding on the ground. The operational range of the antenna ranges from 891 MHz to 928 MHz. Arrow shaped slots are incorporated on the radiating patch diagonally. The axial ratio bandwidth is found to be 907 MHz to 915 MHz. The fractal element has compact dimension with a gain maximum response of 5.5 dBic in the impedance bandwidth (IBW).

By implementing Koch fractal geometry on a regular antenna element, the physical dimensions of the radiator remain unaltered even when the electrical length measure of the antenna element is increased [2-7]. The proposed investigation effectively addresses this concept and the need for antenna applications in the S-band.

II. KOCH CURVE ITERATIONS

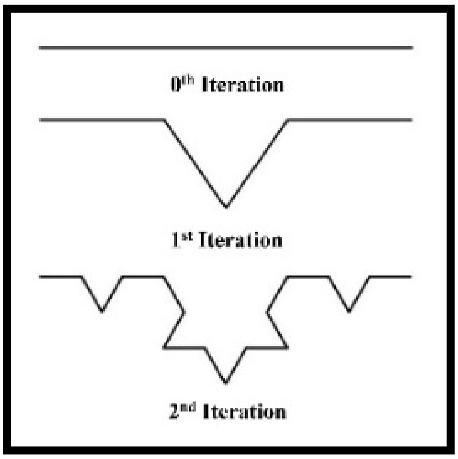


Fig. 1. Koch curve iterations

Koch fractal iterated geometry is generated by taking one third (1/3) of a line segment taken as P. The initial order of iteration is referred as the initiator. Two-line segment of equal length and a bent angle of 60^0 on the central segment constitutes 1st iteration of the Koch curve. Fig. 1 shows two consecutive steps of the Koch fractal iteration which is denoted as n = 2. The curve maintains a constant value of one-third segment of the initiator for each fold of iteration with successive n value. Hence, a total of four-line segments are derived. Therefore, the length P of the unbent curve for the n^{th} order iteration of the Koch curve is given by equation no. 1.

$$P = (4/3)^n \tag{1}$$

The idea of creating a Koch curve serves as the basis for the design of the presented antenna. The radiator's electrical length of is improved by the incorporation of Koch fractal iterations. It significantly retains the antenna's present size while maintaining better radiation performance. Here, a basic metal patch is placed on an FR4 substrate material with relative permittivity of 4.4 and loss tangent 0.02. The design and simulations are carried out through High- Frequency Structure Simulator (HFSS) - 2020. The operating frequency of the designed fractal antenna spans from 1.9 GHz to 4.3 GHz. The wideband monopole shows a positive gain response in the entire IBW. The proposed patch yields a significant radiation characteristic in the S-band.

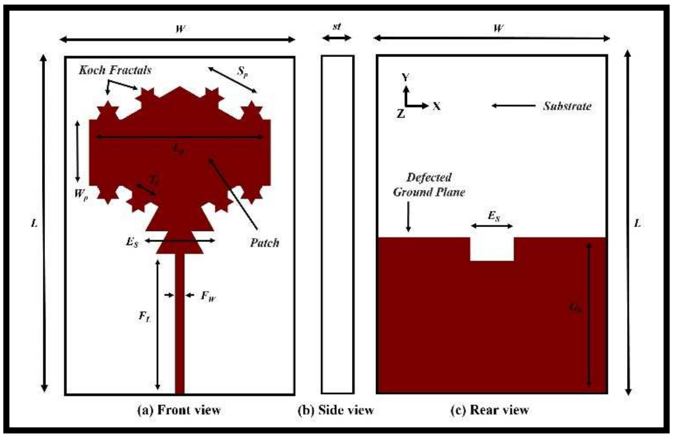


Fig. 2. Fractal antenna design overview

III. ANTENNA CONFIGURATION

The compact monopole features wideband characteristics and the antenna configuration setup is built on an FR4 substrate with relative permittivity 4.4 and loss tangent of 0.02. The overall design dimensions are measured to $0.677\lambda_0 \times 0.611\lambda_0 \times 0.034\lambda_0$ (f_r = 6.55 GHz). A 2nd order Koch fractal protrusions are incorporated on the upper and lower edges of the central radiator. As a result, the metal content on the radiator is reduced with successive iteration of fractal curves, leaving it with more number of metallic bents on the patch element. Fig. 2. shows the overview schematic of the presented fractal antenna. Along with fractal curves two consecutive triangular notches are implemented on the connecting end of the feed line. These notches are responsible for the enhancement of the impedance bandwidth. The S_{11} curve goes below -10 dB line and covers the entire S-band. The central radiator along with the fractal extension on both upper and lower side of the patch results in the generation of two resonant frequencies 2.17 GHz and 4 GHz. The monopole is powered through line feeding, connecting the fractal patch with the best impedance match of 50 Ω. The radiation properties like better X-pol differences and gain stability along with tuning the IBW defected ground structure is incorporated on the ground plane. Approximately 60% of the grounded area from the bottom is retained to obtain the optimized dimension for the antenna. Additionally, a rectangular cut of dimension 8mm × 4.4mm is implemented on the defected ground structure. As a combined effect it leads to the development and further enhancement of the wideband characteristics of the antenna and the operational frequency band reached to 77% of the IBW. The optimized design parameters of the fractal patch are given in Table. 1.

TABLE I.
PARAMTERS OF THE FRACTAL ANTENNA

Parameters	Variables	Values (mm)
Substrate length	*L*	*62*
Substrate width	*W*	*42*
Patch length	L_P	*33.4*
Patch width	W_P	*12.2*
Antenna thickness	*st*	*1.6*
Ground cut	E_S	*8*
Feed length	F_L	*25.8*
Feed width	F_W	*1.6*
Defected ground length	R_1	*28.5*
Defected ground width	R_2	*42*

IV. RESULTS AND DISCUSSION

A 2nd order Koch fractal antenna element is fabricated and the prototype is shown in the Fig. 3. The measurement of the results is carried out in the anechoic chamber. The measurement setup of the transmitter antenna and the antenna under test is put in line of sight configuration. The proposed antenna is positioned at a distance of $2D^2/\lambda$, where D is the dimension of the antenna under test. The antenna result parameters are discussed in this section.

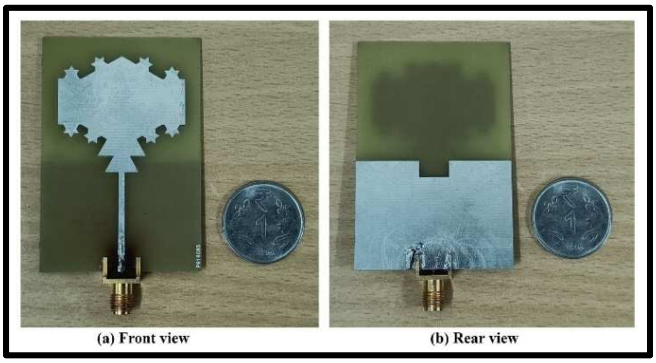


Fig. 3. Fabricated prototype

A close comparison of measures and simulated reflection coefficient is shown in Fig. 4. The measured S_{11} of the fractal monopole remains in between 2 GHz to 4.3 GHz covering the complete S-band. The S_{11} at two resonant frequencies reaches down to -16 dB and -24 dB at 2.25 GHz and 3.9 GHz respectively. Essentially the proposed design covers the ISM band at 2.4 GHz. The overall impedance band of the antenna is calculated to be to be 77%. Essentially the proposed design covers the ISM band at 2.4 GHz. The simulated and measured results are in good agreement.

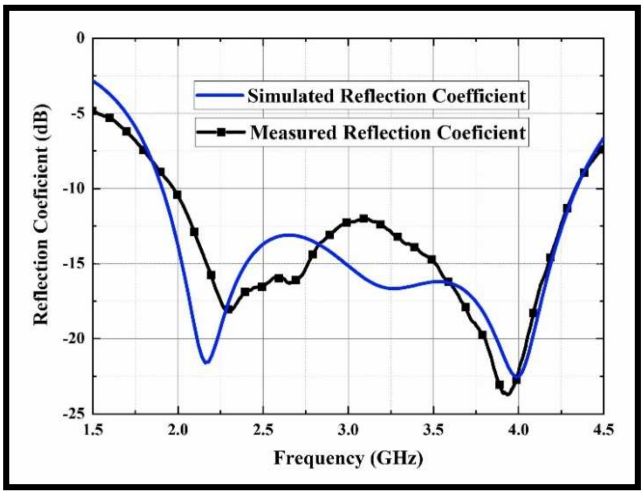


Fig. 4. Reflection coefficient

The fractal antenna's gain response over frequency is shown in Fig. 5. A highest gain measure of 4 dBi is found at 4.22 GHz. The realized gain response varies from 1.6 dBi to 4 dBi in the impedance bandwidth. The central radiator with Koch fractal protrusion along with defected ground structure resulted in the optimization of the antenna in achieving positive gain response.

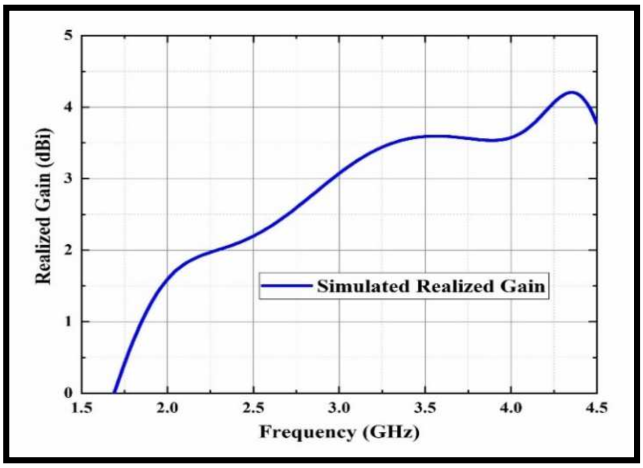


Fig. 5. Realized gain response

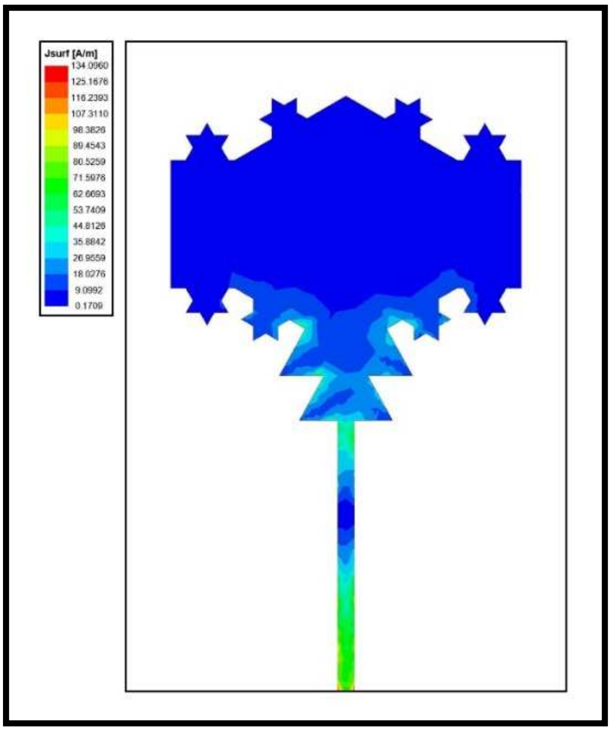
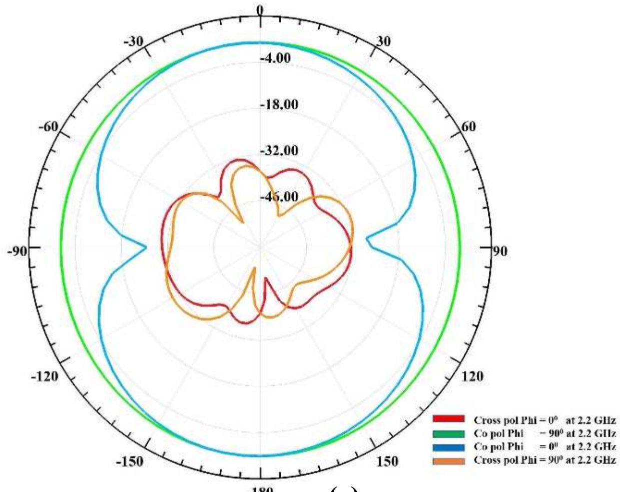
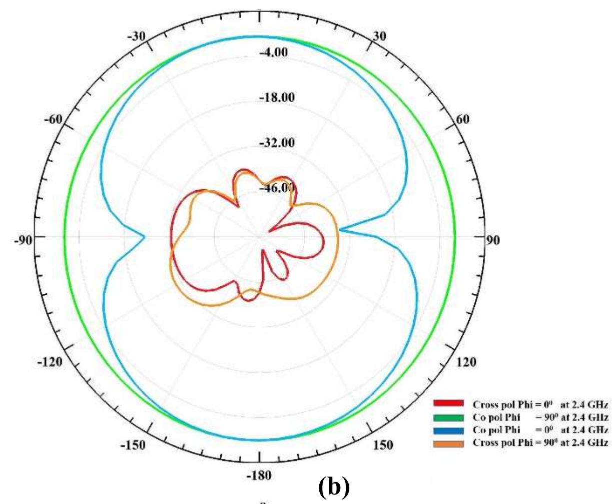


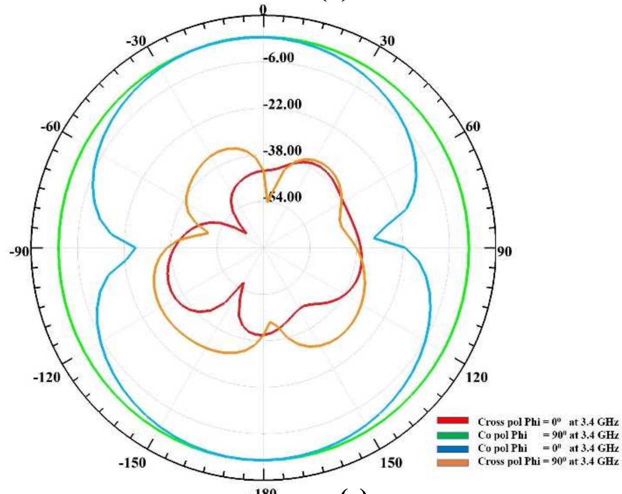
Fig. 6. Surface current plot



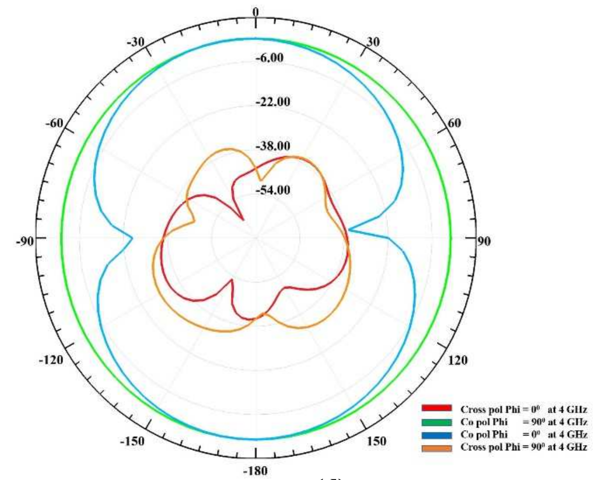
(a)



(b)



(c)



(d)

Fig. 7. Radiations pattern plots of the antenna at (a) 2.2 GHz, (b) 2.4 GHz, (c) 3.4 GHz, (d) 4 GHz.

Fig. 6. shows the current distribution plot of the investigated fractal antenna. From the given plot it can be observed that most part of the patch is radiating with prevailing current. Similar plots have been observed at resonant and other frequencies in the IBW. The lower part of the antenna element is radiating with higher current magnitude whereas, the upper edge shows low current magnitude. Due to the incorporation of Koch fractal extension along the boundary of the central radiator, the electrical length of the antenna element increases resulting current accumulation in the metal patch.

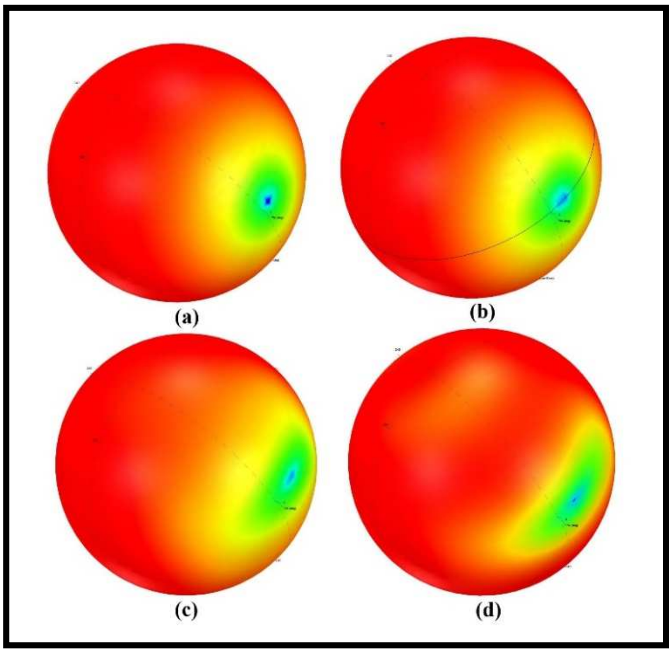


Fig. 8. 3D Radiations pattern plots of the proposed antenna at 2.2 GHz, (b) 2.4 GHz, (c) 3.4 GHz, (d) 4 GHz.

The 2D patterns plots of X-Pol in both the plane E & H of the presented fractal radiator are shown in Fig. 7. The patterns are recorded at four different frequencies i.e., 2.2 GHz, 2.4 GHz, 3.4 GHz, and 4 GHz. The results are shown in the Fig. 4. (a - d). Due to the incorporation of defected ground structure along with a rectangular cut, better cross polarization is found in the operational band. The X-Pol differences in the given frequencies are observed to be more than 40 dB for Φ=0o and Φ=90o. From the three-dimensional polar radiation patterns as shown in the Fig. 8. the monopole shows an omnidirectional nature of 3D patterns with approximately 120o beam- width.

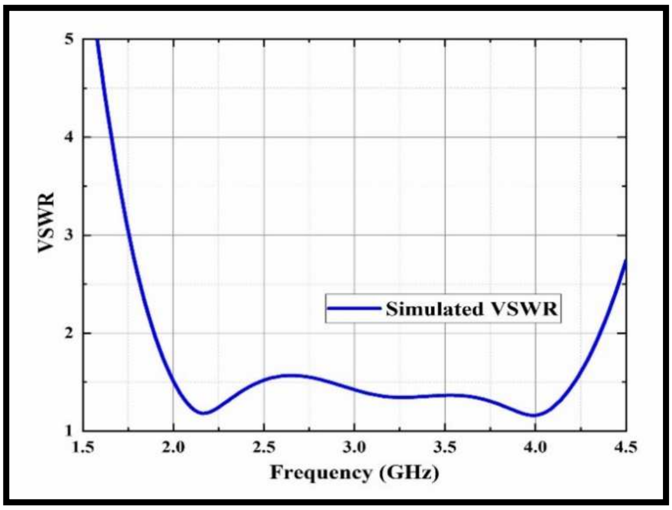


Fig. 9. VSWR plot

Fig. 9. Shows the voltage standing wave ratio (VSWR) response of the presented fractal antenna. The curve is observed close to 1 covering the impedance bandwidth. At the lower and upper resonant frequencies 2.25 GHz and 3.9 GHz the ratio is found to be 1.18 and 1.16 respectively.

A comparison analysis from similar work presented in the literature with respect to the investigated antenna is presented in Table II. In [6], the monopole has a comparable dimension with average radiation performance. It resonates at 3.4 GHz with a nominal gain of 2.3 dBi. The second reference [7] in the table shows a wider IBW up to 3.3 GHz. A maximum gain of 2.9 dBi is reached with 5.8 as the center frequency. In the work [8] the size of the antenna is the largest among all the compared works. It has less operating band coverage of 0.915 GHz with a lowest gain of 1.19 dBi. Similarly, in [9] the antenna configuration is built on a substrate having dielectric constant 2.2 and has an average dimensional area. It also has a low coverage of IBW and a lower gain of 2.06 dBi.

The proposed fractal antenna element outperforms all the compared works tabulated in the comparison table in terms of compactness, higher gain, wide bandwidth covering in the IBW and stable radiation properties throughout the S-band.

TABLE II.
COMPARISION ANALYSIS

Ref.	ε_r	Size (mm^3)	f_r (GHz)	Operating Frequency (GHz)	Gain (dBi)
[6]	4.4	55 × 50	3.4	2.75	2.3
[7]	4.4	22.2 × 18.6	5.8	3.3	2.9
[8]	4.4	80 × 64	0.915	0.033	1.19
[9]	2.2	55 × 48	2.45	0.19	2.06
This work	**4.4**	**72 × 42**	**3.12**	**2.44**	**4**

V. CONCLUSION

A Koch fractal antenna with linear polarization is investigated in this work. The simulated S11 ≤ -10 dB is found to be 77% covering the range of 1.9 GHz to 4.3 GHz. It also covers the ISM band of 2.4 GHz. The Koch fractal protrusions along the boundary of the central radiator and the defected ground structure with a rectangular cut yields stable radiation characteristic throughout the impedance bandwidth. The antenna features a peak gain response of 4 dBi at 4.22 GHz and an omnidirectional nature of radiation patterns with 120^0 beam. The fractal monopole has better X-pol levels up to 40 dB with a positive gain response ranging through the IBW. The simulated and measured results are in good agreement. Hence, it can be concluded that the proposed fractal antenna can be a good fit for S-band applications.

REFERENCES

[1] F. Wang, F. Bin, Q. Sun, J. Fan and H. Ye, "A Compact UHF Antenna Based on Complementary Fractal Technique," IEEE Access, vol. 5, pp. 21118-21125, 2017, doi: 10.1109/ACCESS.2017.2756672.

[2] K. Wei, J. Y. Li, L. Wang, R. Xu and Z. J. Xing, "A New Technique to Design Circularly Polarized Microstrip Antenna by Fractal Defected Ground Structure," IEEE Transactions on Antennas and Propagation, vol. 65, no. 7, pp. 3721-3725, July 2017.

[3] S. Tripathi, A. Mohan and S. Yadav, "A Compact Koch Fractal UWB MIMO Antenna With WLAN Band-Rejection," IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 1565-1568, 2015, doi: 10.1109/LAWP.2015.2412659.

[4] A. Farswan, A. K. Gautam, B. K. Kanaujia and K. Rambabu, "Design of Koch Fractal Circularly Polarized Antenna for Handheld UHF RFID Reader Applications," IEEE Transactions on Antennas and Propagation, vol. 64, no. 2, pp. 771-775, Feb. 2016, doi: 10.1109/TAP.2015.2505001.

[5] V. V. Reddy and N. V. S. N. Sarma, "Triband Circularly Polarized Koch Fractal Boundary Microstrip Antenna," IEEE Antennas and Wireless Propagation Letters, vol. 13, pp. 1057-1060, 2014.

[6] K. Ding, C. Gao, Y. Wu, D. Qu and B. Zhang, "A Broadband Circularly Polarized Printed Monopole Antenna With Parasitic Strips," in IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 2509-2512, 2017, doi: 10.1109/LAWP.2017.2728124.

[7] T. K. Das, D. Prasad Mishra, S. Pandav and S. K. Behera, "Design of a Wideband Pythagorean-tree shaped Fractal Monopole Antenna for RFID Applications," 2019 IEEE Indian Conference on Antennas and Propogation (InCAP), Ahmedabad, India, 2019, pp. 1-4, doi: 10.1109/InCAP47789.2019.9134662.

[8] C. -Y. -D. Sim, J. -H. Zhuang, W. -S. Liao, J. -R. Liou, C. -C. Hsu and J. -Y. Huang, "A Coupled-Feed Monopole Antenna for UHF RFID Reader Application," 2018 International Symposium on Antennas and Propagation (ISAP), Korea (South), 2018, pp.1-2.

[9] L. Zhang, Y. -C. Jiao, Y. Ding, B. Chen and Z. -B. Weng, "CPW-Fed Broadband Circularly Polarized Planar Monopole Antenna With Improved Ground-Plane Structure," in IEEE Transactions on Antennas and Propagation, vol. 61, no. 9, pp. 4824-4828, Sept. 2013, doi: 10.1109/TAP.2013.2267719.