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Design of Optimized Koch Based Fractal Patch Antenna for Multiband Wireless Applications

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An optimized Koch based fractal patch antenna with twin lower leafs has been designed for appropriate wireless communication applications and capable of exhibiting penta-band behavior. The proposed structure has been created by introducing modified Koch curve on a rhombus shaped fractal patch having compact dimensions of 60 mm×50 mm×1.6 mm with defected ground structure. The reflection coefficient (S_{11}) values of the proposed antenna are -11.97 dB, -20.29 dB, -25.38 dB, -13.91 dB and -23.48 dB at resonating frequencies of 2.8649 GHz, 6.3514 GHz, 7.1622 GHz, 8.2973 GHz, and 8.9459 GHz, respectively. It has values of VSWR at all resonating frequencies within acceptable range of 1 to 2. The prototype of the proposed structure has been designed on easily available and low cost FR4 epoxy substrate material. The bandwidths of 1.39 GHz, 3.30 GHz, 10.19 GHz, 1.93 GHz and 2.23 GHz has been obtained at all resonating frequencies. The measured results has been analyzed and compared with simulated results and bears a close approximation. The developed prototype can be utilized for applications in S, C, and X frequency band which can further be used for various communication applications like radar, satellite communication and wireless computer networks.

Keywords: CPW, FR4, HFSS, IFS, Koch Fractal, VSWR

1 Introduction

Modified Koch fractal has been imposed on fractal patch to enhance its characteristics as compared to conventional fractal patch[1]. The word fractal comes from the Latin word *fractus* that means broken, uneven, irregular curves or form that repeats themselves at any scale on which they're examined[2-3]. It maximizes the length or increases the perimeter (within sections or the outer structure) of material which can receive or transmit electromagnetic waves among a given total extent or volume[4-5]. The recent developments in the wireless technology functional at multiple frequency demands multiband or multifunctional antennas with broader bandwidth[6-7]. The main advantages of fractal antennas are its reduced size and multiband operation[8]. Furthermore, the fractal antennas allow controlling of characteristics such as location of frequency bands, radiation pattern and entire bandwidth owing to feeding technique and antenna geometry variations[9]. Self-similarity is achieved by applying sizable amount of iterations and multiple reduction and replica method like Koch curve[10-11] and Sierpinski gasket[12].

The patch of proposed antenna has been shaped by an iterative mathematical process referred as iterative function system (IFS), exploiting geometry like Koch curve[13]. An initial baseline has been replaced with a series of 4 similar size line segments, 2 finish segments lying on the first line and sharing its termination points and 2 other line segments forming a spike that protrudes removed from this baseline, formation of Koch curve is truly an efficient step as shown in Fig. 1, for every iteration, the length of a plane decreases by an element of three. Conventional Koch curve has been initially designed with an iteration angle of 60°[11]. It was initial delineated by Helge von Koch in 1904[14]. The options of the Koch curve can be advantageous to overcome the drawbacks of other conventional antennas[15].

The expected good thing about employing such a shape as an antenna is to miniaturize the full height of antenna at resonance[16]. Various researchers have tried to achieve this by modifying fractal patch Koch curve[17] and tried to design a compact single layered

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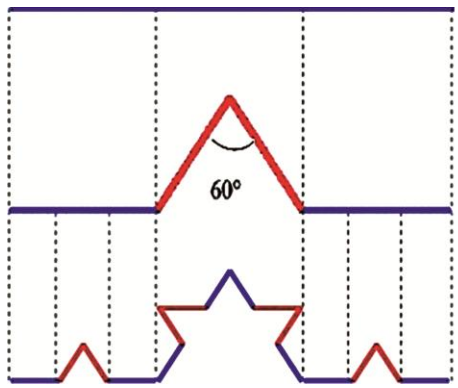


Fig. 1 — Conventional Koch curve iterations[8].

multiband antenna with Defected Ground Structure (DGS) which can be used for WLAN, WiMAX and LTE applications[18].

2 Materials and Methods

The proposed structure consists of dielectric material substrate FR4 which is widely used by researchers for planar antenna design, easily available and cost effective also. Proposed structure had nature inspired design. Modified Koch curve and defective ground had been used to get multiple resonance. A rhombus shaped microstrip patch was carefully selected with calculated dimensions. The dimensions of the ground plane were 54 mm × 44 mm and the thickness of the material layer is 1.6 mm. The dielectric constant of the dielectric material layer was 4.4. The diagonal dimensions of the rhombus shaped patch were 37.4 mm × 26.18 mm respectively as illustrated in Fig. 2. The overall dimensions of the substrate were 60 mm × 50 mm. Co-axial feeding was employed by a through hole SMA coaxial connector[19].

2.1 Dimensions of the Flower Shaped Patch

A rhombus shaped initiator patch was designed on FR4 epoxy substrate material substrate by carefully calculating the dimensions[20]. The larger diagonal length of the patch was 37.4 mm and smaller diagonal length was26.18 mm as shown in Fig. 2. The length of each side was 22.82 mm.

2.2 Iterated Function System (IFS)

IFS had been a widely used mathematical tool mainly used for the design of fractal geometries[21]. The affine transformation of the proposed antenna is represented by:

$$W\begin{pmatrix}x\\y\end{pmatrix}=\begin{pmatrix}a & c\\b & d\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}e\\f\end{pmatrix} \quad \dots (1)$$

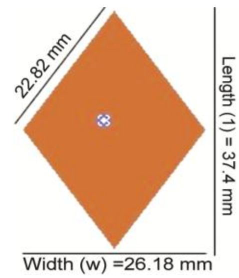


Fig. 2 — Rhombus shaped initiator patch.

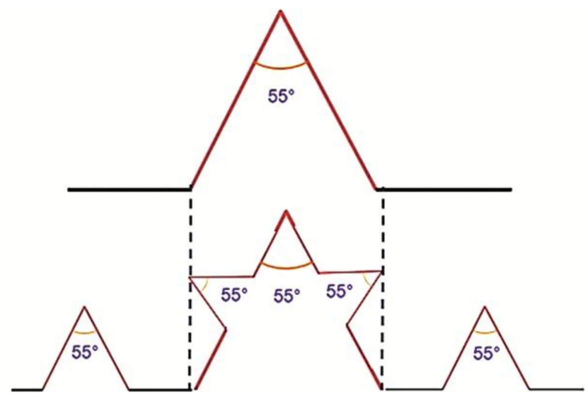


Fig. 3 — Proposed Koch fractal with modified 55° angle.

where *a*, *b*, *c*, *d*, *e* and *f* are real numbers. *a*, *b*, *c* and *d* controls the rotation and scaling while *e* and *f* control linear shift or translation. Assume W_1, W_2 … W_n as series of linear affine transformations. The first iteration for the Koch curve consists of taking four copies of the horizontal line phase, each was scaled by r = 1/3. In proposed antenna structure modified Koch curve was used in which two segments are turned to 55°, one clockwise and one anti clockwise as shown in Fig. 3 as compared to 60° in conventional Koch fractal. In conjunction with the specified translations, this yielded the subsequent IFS[11]. The transformations for getting generator structure were expressed by the subsequent function[22]:

$$W_1\begin{pmatrix}x\\y\end{pmatrix}=\begin{pmatrix}0.25 & 0.00\\0.00 & 0.25\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}0.00\\0.00\end{pmatrix} \quad \dots (2)$$

$$W_2\begin{pmatrix}x\\y\end{pmatrix}=\begin{pmatrix}0.25 & -0.55\\0.55 & 0.25\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}0.25\\0.00\end{pmatrix} \quad \dots (3)$$

$$W_3\begin{pmatrix}x\\y\end{pmatrix}=\begin{pmatrix}0.25 & 0.55\\-0.55 & 0.25\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}0.50\\0.55\end{pmatrix} \quad \dots (4)$$

$$W_4\begin{pmatrix}x\\y\end{pmatrix}=\begin{pmatrix}0.25 & 0.00\\0.00 & 0.25\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}0.75\\0.00\end{pmatrix} \quad \dots (5)$$

where, the W_x is termed as Hutchinson operator. W_1, W_2, W_3 and W_4 were set of affine linear transformations. The transformations to obtain the segments of the generator of our proposed geometry is given by:

$$W(A) = \bigcup_{n=1}^{N} W_n(A) \quad \ldots (6)$$

In order to achieve higher order of iterations an iterative recursive code was written in MATLAB based on equations (2-6).

The patch had been designed with Koch curve iterations in the HFSS electromagnetic simulator. The modified angle in Koch curve patch was 55°. The construction of iteration from simple patch is shown in Fig. 4 (a) and various iteration stages to construct modified patch proposed geometry is shown in Fig. 4 (b) and (c) respectively. Modified Koch curve shaped portion had been removed from the sides of the patch and subsequently such parts were removed from the remaining segments. This process was repeated up to 3rd iteration. Final structure was obtained as shown in Fig. 4(d). Higher iterations were also possible but they limit the practical feasibility of the prototype. As it can be seen clearly in Fig. 4 (d) which had large number of corners, edges and segments as compared to Fig 4 (a) which definitely helped in achieving multiband operation[11].

2.3 Final Proposed Geometry

Fractal geometries were widely known for their self-similarity structures in which each basic shape was repeated again and again at different levels of iterations. In Fractal iterations we got a very unique geometry having a large number of segments/edges/corners which helped to achieve multiple resonances (multiband approach). Final proposed geometry had a nature inspired design, additional twin lower leaf like monopole structures had been added along with the modified Koch curve fractal patch. Lower leafs were also designed by using the modified Koch curve as shown in Fig. 4(b) up to 1st iteration. The advantage of the twin lower leafs in this proposed antenna was to obtain resonance at lower frequency and gain enhancement[23]. The length of leaf branch is 7.7 mm and width of this leaf branch is 0.6 mm.Final radiating structure of proposed antenna is shown in Fig. 5(a).

Carefully done structural calculations are described in Table 1 which shows all parameters along with the substrate material dielectric constant. The ground of proposed antenna had been chosen as defected ground to reduce the out of band harmonics[24]. It had edge spacing of 3 mm, length of ground is 54 mm and breadth is 44 mm as shown in Fig. 5(b). A hole had been drilled in the substrate to accommodate the coaxial connector pin so that base can be soldered with ground and pin should be soldered with the radiating structure on the other side of the substrate.

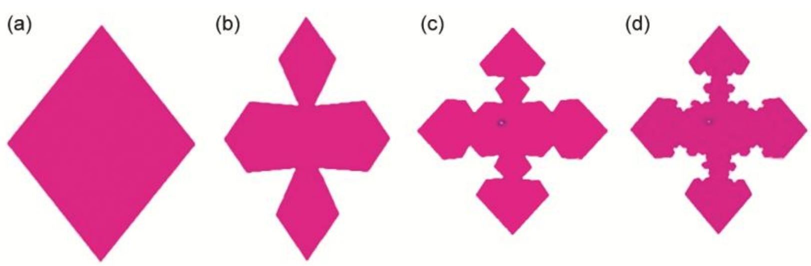


Fig. 4 — (a) Initial fractal patch, (b) 1st iteration in patch, (c) 2nd iteration in patch, and (d) 3rd iteration in patch.

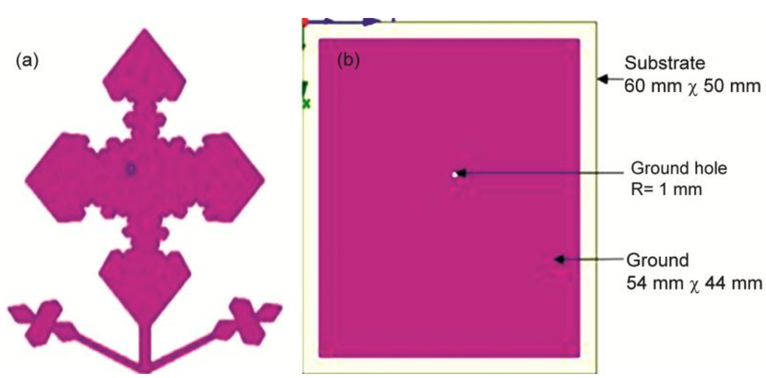


Fig. 5 — (a) Top view of the proposed antenna with modified Koch curve, and (b) Back view defective ground dimensions.

Table 1 — Dimensions of Proposed Antenna Geometry

Antenna Design Parameters	Dimensions
Length of Substrate (L_S)	60 mm
Width of substrate (W_S)	50 mm
Substrate Material	FR4 Epoxy
Dielectric Constant(ε_r)	4.4 mm
Thickness of Substrate	1.6 mm
Modified Angle(Θ)	55°
Length of Ground	54 mm
Width of Ground	44 mm
Number of Iterations (Patch)	3

Table 2 — Comparison of Different Feeding Techniques

Feeding Technique	Resonant Frequency (GHz)	Return loss (dB)	VSWR
Coaxial	2.8649	-11.97	1.72
	6.3514	-20.29	1.40
	7.1622	-25.38	1.30
	8.2973	-13.91	1.89
	8.9459	-23.48	1.92
Microstrip	10.00	-18.29	1.95
CPW feed	1.75	-10.70	1.70
	2.19	-18.63	1.45
	4.72	-21.26	1.25

2.4 Feed Technique

There were different feeding techniques like microstrip line feed, CPW feed, aperture feed etc which can be used for providing high frequency signal to the antenna structure in search of good results. Coaxial probe feed had been used in the proposed structure. Such feed was purposefully and carefully chosen after comparing the results with other feeding methods in proposed antenna for ohmic resistance matching. Coaxial technique had good results as compare to other methods so it had been selected for proposed design. It was found that S_{11} parameters and other parameters had improved by using coaxial technique[25]. The different feeding techniques were evaluated and comparison results are shown in Table 2.

2.5 Antenna Prototype Development

The prototype of the proposed antenna structure had been designed, developed and analyzed for the performance. Fig. 6(a) shows the top view of developed/fabricated prototype of the modified Koch based patch fractal antenna and Fig. 6(b), shows back view of the prototype with defected ground along with the soldered SMA coaxial connector for providing signal to the antenna. All measured results show close similarity with simulated ones.

Proposed modified Koch fractal antenna was compared with various other existing multiband antennas as shown in Table 3 and it shows good results in terms of compactness, gain and numbers of resonant frequency bands.

Table 3 — Comparison of Proposed Microstrip Koch Curve Geometry with similar reports.

Sr. No.	Reference Work	No. of frequency resonance obtained	Gain (max) in dB	Size (in mm)
1	[23]	3	3.23	56 x 59
2	[26]	NA	NA	36 × 22
3	[27]	4	4	18.5 × 39
4	[28]	5	5.18	25 × 17
5	[29]	3	5.90	40 × 40
6	[30]	4	3.12	25 × 9
7	[31]	1	NA	29 × 29 (Size of patch)
8	Proposed antenna	5	7.65	60 x 50

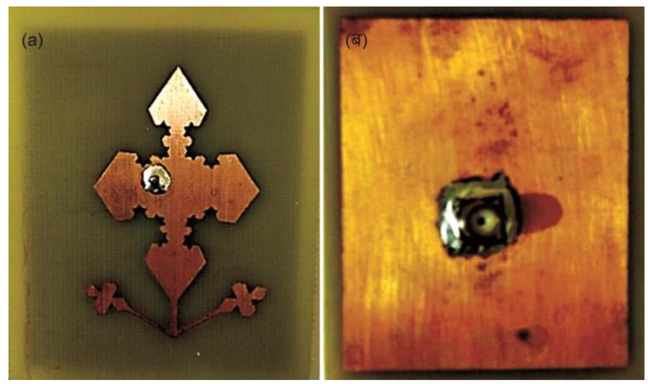


Fig. 6 — (a) Top view of fabricated (b) Back view of fabricated antenna.

3 Results and Discussion

Proposed structure exhibited multiband behavior by resonating at five different frequencies 2.86 GHz, 6.35 GHz, 7.16 GHz, 8.29 GHz and 8.94 GHz with acceptable values of reflection coefficient -11.97 dB, -20.29 dB, -25.38 dB, -13.91 dB and -23.48 dB respectively. It exhibited penta-band behavior and it can operate in 3 different band spectrums like *L*, *C* and *X*. The results of proposed antenna were measured on VNA (vector network analyzer). The results exhibit the close agreements between measured and simulated results as shown as Fig. 7. Measured VSWR was also in smart estimate with the simulated ones and satisfies the condition for all resonating frequencies and confirms ohmic resistance matchings for proposed antenna. Any minor difference in the measured and simulated results can be due to soldered bumps, mismatch in the connector and cable joints etc. which were not considered during simulated in the simulation software.

3.1 Radiation Patterns

2D-simulated radiation patterns are shown in Fig. 8 (a to f) for all resonating frequencies which represents the radiation in the H plane and E plane. It was found that the proposed antenna had radiation patterns similar to non planar wire antennas. The radiation patterns at H-plane were almost isotropic and in E-plane they exhibit broadside radiation patterns. All these radiation patterns show the antenna's directivity in the far-field region in both azimuth and elevation plane. There was variation noticed in the near-field pattern as we move to higher frequency due to reflection at the edges and deviation in the nature of current arising from reflections due to standing waves[6].

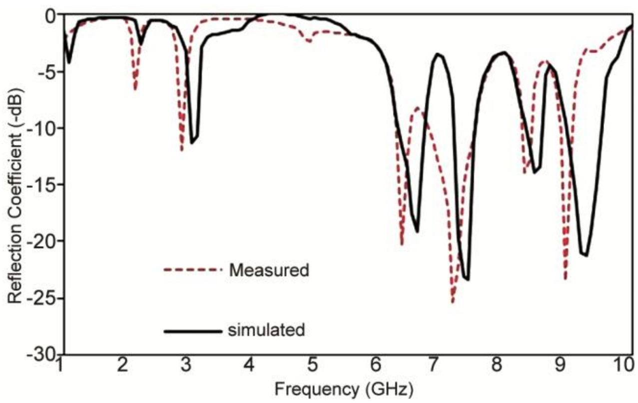


Fig. 7 — Comparison of measured and simulated return loss.

Polarization, single plane cut andthe radiation characteristics may also be described in terms of field pattern. Since a fractal patch antenna radiates ordinarily to its patch surface therefore the patterns were given in polar or linear type with a dB strength scale.

3.2 3D Radiation Pattern and Gain at Various Resonating Frequencies

The gain along with 3-Dimensional radiation pattern of the proposed antenna is presented in Fig. 9 for every resonating frequency, which undoubtedly indicates that the maximum experimental peak gains within resonating frequencies was 7.65dB (at 8.29 GHz) and minimum gain was 1.32 dB (at 2.86 GHz).

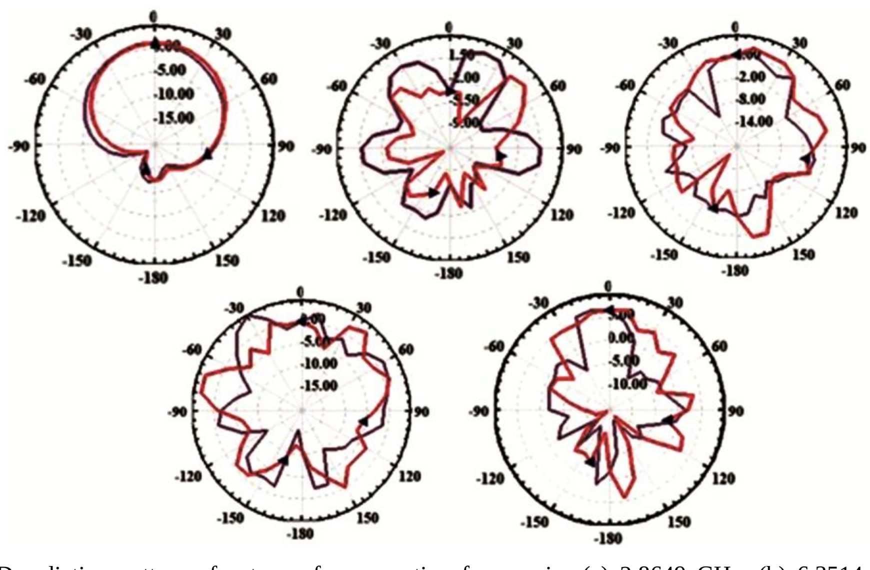
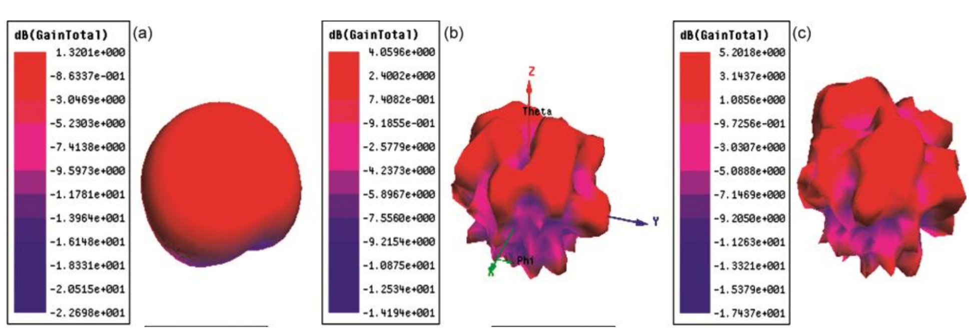


Fig. 8 — Different 2-D radiation pattern of antenna for resonating frequencies (a) 2.8649 GHz, (b) 6.3514 GHz, (c) 7.1622 GHz, (d) 8.2973 GHz, and (e) 8.9459 GHz, respectively.



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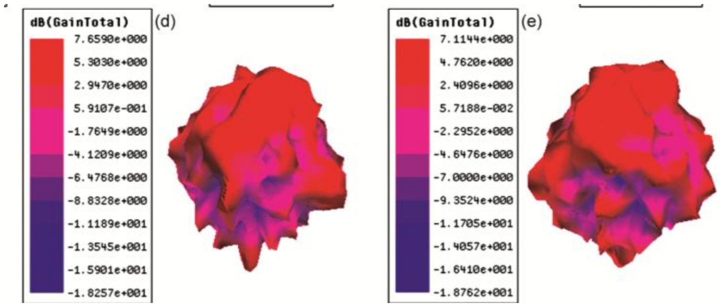

Fig. 9 — (a to e) 3D radiation pattern and gain of proposed antenna at various resonating frequencies (a) 2.8649 GHz, (b) 6.3514 GHz, (c) 7.1622 GHz, (d) 8.2973 GHz, and (e) 8.9459 GHz, respectively.

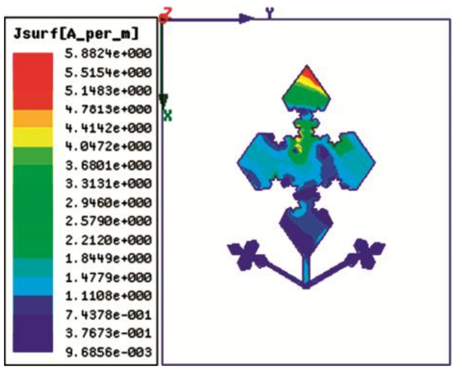

Fig. 10 — Current distribution of the proposed antenna at 8.9459 GHz.

3.3 Current Distribution at Different Working Frequencies

The average current density is shown in different colors in the legend alongside the proposed antenna prototype along with density meter for multiple frequencies. We can see the average current distribution on the surface of the antenna. Current distribution of proposed antenna at various operating frequencies was 2.81 A/m (2.8649 GHz), 5.30 A/m (6.3514 GHz), 3.27 A/m (7.1622 GHz), 2.79 A/m (8.2973 GHz) and 5.88 A/m (8.9459 GHz); respectively as shown in Fig. 10.

4 Conclusion

An optimized Koch based fractal patch antenna supported by Koch curve has been designed and simulated on FR4 substrate and results are investigated. The proposed structure has compact dimensions of 60 mm x 50 mm x 1.6 mm and exhibits penta-band operation by resonating at different frequencies 2.8649 GHz, 6.3514 GHz, 7.1622 GHz, 8.2973 GHz and 8.9459 GHz along with acceptable values of reflection coefficient -11.97 dB, -20.29 dB, -25.38 dB, -13.91 dB and-23.48 dB respectively. Maximum values of Gain achieved is 7.65 dB at 8.29 GHz and minimum value is 1.32 dB at 2.86 GHz and VSWR for all resonating frequencies is less than 2. The 2-D far-field radiation pattern is acceptable for all working frequencies and current distribution of proposed antenna at various operating frequencies is 2.81 A/m (2.8649 GHz), 5.30 A/m (6.3514 GHz), 3.27 A/m (7.1622 GHz), 2.79A/m (8.2973 GHz) and 5.88 A/m (8.9459 GHz) respectively. Proposed antenna can be used for various wireless applications.

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