A Novel Metamaterial Inspired 2\textsuperscript{nd} Iteration Koch Fractal Antenna for Wi-Fi, WLAN, C band and X band Wireless Communications

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Abstract. The rapid advancements in wireless technology desires compact, miniaturized, multiband and ultra wideband antennas. Fractal antennas have been proved as a source for fulfilling these demands. In this paper a 2\textsuperscript{nd} order Koch fractal antenna of size 29.6 x 35.7mm\textsuperscript{2} designed on FR4-epoxy substrate material of dielectric constant (\(\varepsilon_r\)) 4.4 with a height of 1.6mm. This antenna is named as ANTENNA\textsuperscript{-1}. To increase this antenna’s performance a meta material unit cell has been placed on the ground plane to serve multi band applications and is named as ANTENNA\textsuperscript{-2}, which is the proposed antenna in this paper. The simulations have been carried out for both the antennas using ANSYS HFSS tool over the frequency sweep of (1-12GHz). The simulation results of proposed antenna producing 7 frequency bands which serves Wi-Fi, WLAN, C-band, and X band wireless communications. The simulation results like return loss, VSWR values have a good matching with the measured return loss, VSWR results of the fabricated antenna.

Keywords: iteration, Koch Fractal Geometry, Scaling Factor, Metamaterial, SRR unit cell, DNG material

1. Introduction
Micro strip Patch antenna is the primary source for designing cost effective compact, miniaturized, flexible multiband antennas but its limited narrowband characteristics diverted the attention of many antenna designers towards Fractal Antennas. Different patch antennas based on Euclidean geometry are presented for Multiband and Broadband Applications [1-3]. Modern communication gadgets require UWB, multiband antennas. Frequency independent nature of fractal antenna analyzed for multiple frequencies are due to self similar scaled or rotated copies [4]. The iteration analysis is obtained for multi bands considering parametric models using Method of Moments [5]. A Fractal is a self similar structure generated by repeated iteration process. Fractals have some advantages like self similarity, space filling, compact, low profile. Some of the popular Fractal geometries are Sierpinski gasket, Sierpinski Carpet, Koch curve, Koch snow flake, Minkowiski [6]. A snowflake wideband antenna designed for 28 GHz band with dual beam applications. A multiband fractal antenna designed for UWB, Bluetooth, with a band rejection for WLAN [7]. Octagonal shaped fractal antenna designed for Multiband purpose and has 48GHz Bandwidth with a sweep of (1-50GHz) [8]. A Koch fractal shape is combined with the Sierpinski fractal for multiband applications with smaller size and good radiation characteristics [9]. A modified Koch Fractal antenna with U slot at the centre of the patch presented for WiMAX, WLAN applications using CPW feed technique [10]. A novel one dimensional Koch fractal geometries are designed on the patch in series and are subtracted from the patch. A wider bandwidth has obtained by maintaining the proper ratio of Koch fractal period and its radius [11]. A Koch snowflake generated on the patch and the tapering of dimensions allow the antenna to resonate at multiple bands [12] within (0-8GHz) range. On the Bowtie antenna Koch shape
is carved such that it resonates for DCS/PCS/UMTS/WLAN and WiMAX bands [13]. A circularly polarized Koch Fractal antenna developed for tri band applications covering WLAN and WiMAX [14]. A hybrid antenna developed using Murkowski geometry and its results are compared for traditional SPK, Koch antennas [15]. The novel SPK gasket antennas were designed for L, S, C and X band communications with DGS, CSIR techniques [16-19]. An OSRR is placed on the defected ground which improves miniaturization and covers WLAN, WiMAX and X bands [20]. A metamaterial triangular multiple SRRs positioned on the patch to make the antenna resonates for WLAN/WiMAX/ITU band applications [21].

2. Geometries Of ANTENNA-1 and ANTENNA-2
In this work two antennas are being compared for their performance characteristics like Return loss, VSWR, Gain, %BW. Hence their patch and ground Geometrical shapes are presented in the Fig.1. Here Antenna-1 is a 2nd iteration Koch Fractal Antenna with Full Ground and Antenna-2 is the proposed antenna which is a modified version of Antenna-1 by changing its ground structure with a SRR Unit cell.

![Figure 1. Geometries of Koch Fractal antennas (a) Antenna-1, (b) Antenna-2](image)

3. Design procedure of ANTENNA-1: The geometry of Antenna-1 with top view, ground plane view are shown in the Figure.1, which needs to follow the two design steps named as 0th iteration and 1st iteration as illustrated in Figure.2. An edge feed technique is used for exciting all the antennas to match with 50 ohm port impedance and its dimensions are calculated from a microstrip line online calculator.

3.1 Designing of 0th iteration Koch structure
A patch of 19.98mm x 26.08 mm developed on the FR-4 epoxy substrate, which is known as basic structure or iteration-0. The traditional MPA formulas are used for the designing of basic structure as below.

For designing iteration-0, the width and length of the basic MPA can be calculated by the following Equations

The patch Width is given by
\[ w = \frac{C}{2\pi f_r \sqrt{\varepsilon_r}} \left(\frac{\varepsilon_r + 1}{\varepsilon_r} \right) \]  
\[ (3.1) \]

Where \( \varepsilon_r \) specifies relative permittivity and \( C \) is the light velocity

The patch Length is given by
\[ L = \frac{c}{2\pi f_r \sqrt{\varepsilon_r}} - 2\Delta L \]  
\[ (3.2) \]

Where \( \varepsilon_e \) is the effective relative permittivity, and \( \Delta L \) is the effective length determined by the below formulas
\[ \mathcal{E}_t = (\mathcal{E}_r + 1)/2 + (\mathcal{E}_r - 1)/2[1 + (12h/w)]^{1/2} \]  

\[ \Delta L = 0.42h \frac{(\mathcal{E}_t + 0.3)(W/h + 0.264)}{(\mathcal{E}_t - 0.258)(W/h + 0.8)} \]

3.2 Designing of 1st iteration Koch structure

The Koch fractal curve is shown in the Figure.2. A Koch curve divides the straight line into 4 line segments, out of which middle two line segments are arranged such that they intersect and form a triangle. The same processes extended for generating next order iterations.

*The Fractal dimension of Koch curve is defined as \( D = \log(N)/\log(S) \)*

Where \( N \) denotes the number of sub sections in each iteration and \( S \) is the Scaling factor. So \( N=4, S=1/3 \)

\[ \text{Hence } D = \frac{\log(4)}{\log(1/3)} = 1.28 \]  

**Figure.2. Koch Fractal Geometry**

By following the above Koch principal, 3 equilateral triangles are created and etched from the patch in the 1st iteration. The side length of the triangle is considered as \( 1/3 \) of the patch Length. In the further process 3 more triangles of same side length are rotated by 180 degrees about z direction and are superimposed on the triangular slots. Further they are etched to get the star shaped slots along 3 sides of the patch. This iteration-2 Koch geometry increases the electrical path length and enhances the radiation characteristics and makes the antenna to exhibit more number of bands. The two stages involved in Koch 2nd iteration antenna are iteration-0 and iteration-1 as shown in the below Figure.3.
Figure 3. Koch Fractal antenna iterations (a) Iteration-0, (b) Iteration-1, (c) Iteration-2

Table 1 Basic antenna parameters

| Antenna parameter          | Size (mm)   |
|----------------------------|-------------|
| Substrate                  | FR4-epoxy   |
| Dielectric constant ($\varepsilon_r$) | 4.4         |
| Substrate length ($L_s$)   | 29.6        |
| Substrate width ($W_s$)    | 35.7        |
| Substrate thickness ($h$)  | 1.6         |
| Ground length              | 29.6        |
| Ground width               | 35.7        |
| Length of the Patch ($L$)  | 19.98       |
| Patch width ($W$)          | 26.08       |

4. Geometry and Design procedure of ANTENNA-2 (Proposed Antenna)

The geometry of patch is same as that of the ANTENNA1, but there is a modification in the ground structure as shown in the Figure 5. A metamaterial inspired unit cell known as SRR 35.7mmx26.9mm is placed on the ground with a 5mm width to increase the number of resonant frequencies for promoting multiple bands. The dimensions of the SRR unit cell are presented in Table 2. The gap of the SRR ring “a” is responsible for creating capacitance effect and exhibiting left hand material properties. The parametric study performed to fix the gap dimensions as 3mm.
Table.2 Proposed Antenna-2 Geometrical parameters

| parameter                  | Length(mm) |
|----------------------------|------------|
| L                          | 29.6       |
| W                          | 35.7       |
| L₁, L₂, L₃                 | 6.66       |
| W₁, W₂, W₃                 | 8.693      |
| Feed length (L_f)          | 4.81       |
| Feed width (W_f)           | 3.0        |
| Triangle1,2 side length(S_L)| 6.66       |
| Triangle 3 side length(S_W)| 8.693      |

Figure.4. Geometry of Metamaterial inspired 2nd Iteration Koch fractal antenna (a) Patch on the substrate, (b) Metamaterial on the ground plane

5. Results and Discussions

5.1 Simulation results of Antenna-1
It involves two iterations named as 0th iteration antenna and 1st iteration antenna. So After simulation using HFSS tool their return loss graphs are compared to conclude that the 2nd iteration antenna exhibit good radiation characteristics with more number of resonant frequencies as shown in the Figure.5. For better understanding the dB S(1,1), VSWR vs. Frequency plots are individually plotted in the Figure.6
Figure 5. Comparison of Return loss plots of 0th Iteration antenna, 1st iteration antenna with 2nd iteration Koch Fractal antenna (Antenna-1).

The simulation results for ANTENNA-1 are carried out using ANSYS HFSS software, which extracts results in terms of S(1,1)dB plot and VSWR plot shown in the Figure 6. It exhibits 4 resonant frequencies designated as 2.7, 6.7, 8.1, 11.6 with minimum value of S(1,1)dB about -10.275, -12.2401, -11.533 and -34.760 dB. The VSWR values at all these centre frequencies are attaining value < 2. The gain values reported at these resonant frequencies are 0.98, 1.96, 3.33 and 11.3 dB respectively.

Figure 6. Simulation Results of Antenna-1 (a) Return loss plot (b) VSWR plot

5.2 Simulation results of Antenna-2
A Split Ring Resonator structure developed on the ground for the designing process of ANTENNA-2. Hence a parametric study done to fix the gap between the two ends of the ring. When a = 3 mm more number resonant frequency bands were obtained as shown in Figure 7. The red colour long dash curve shows 7 bands when gap a = 3 mm.
Figure 7: Parametric study to determine the gap of SRR on Ground plane of Antenna-2

Figure 8 depicts the return loss, VSWR plots for the proposed Antenna-2, which reports 7 frequency bands centered at 2.4, 5.2, 6.7, 7.5, 8.5, 9.4, 11.4 GHz with VSWR < 2. The deep peaks of $S(1,1)$ dB are reported as -11.82, -18.79, -12.28, -12.55, -14.01, -17.25, -11.42 dB respectively. The simulated gain values at these bands are reported as 7.52, 5.217, 4.60, 6.51, 3.85, 2.1, and 2.89 dB respectively.

Figure 9: Comparison of simulated Return loss plots of Antenna-1 & 2
After comparison of Performance parameters of both Antenna-1 and Antenna-2 are superimposed in Figure.9. The reported results are tabulated in the Table-3. Antenna shows better performance and are suitable for Wi-Fi, WLAN, C-band, and X-band Applications.

Table.3. Comparative study of simulated radiation parameters of Antenna 1 and 2

| S.No | Resonant Frequencies (f_r) GHz | Frequency S(1,1) (dB) | VSWR | Gain (dB) | BW | %BW | Applications |
|------|-------------------------------|-----------------------|------|----------|----|-----|--------------|
|      | Iteration-2                   |                        |      |          |    |     | C-band, and X band |
| Koch Fractal | 2.7                          | 6.7                    | 10.275 | 1.64   | 1.96 | 200 | 2.9 | Wi-Fi, WLAN, C-band, and X band |
| Fractal          | 6.7                          | 8.0-8.1                | -12.24 | 1.72   | 3.33 | 80  | 0.98 |
| Antenna 1        | 11.6                         | 11.1-11.7              | -11.53 | 1.00   | 11.3 | 600 | 5.26 |
| Antenna 2        | 2.5                          | 2.43-2.62              | -13.18 | 1.69   | 0.032 | 190 | 7.52 |
| Iteration-2      | 5.1                          | 5.04-5.31              | -10.84 | 1.25   | 2.752 | 270 | 5.21 |
| Koch Fractal     | 6.7                          | 5.57-6.88              | -13.48 | 1.64   | 4.52 | 310 | 4.60 |
| Fractal          | 7.7                          | 7.43-7.93              | -23.24 | 1.61   | 4.138 | 500 | 6.51 |
| Matamaterial(proposed antenna) | 8.6                        | 8.40-8.73              | -12.88 | 1.49   | 5.627 | 330 | 3.85 |
|                  | 9.5                          | 9.40-9.60              | -14.17 | 1.31   | 4.748 | 200 | 2.1 |
|                  | 11.3                         | 11.13-11.46            | -26.09 | 1.73   | 4.7  | 330 | 2.89 |

Figure 10. Simulated gains of Antenna-2 (Proposed antenna) (a) at 2.5 GHz 7.52 dB (b) at 5.1 GHz 5.217 dB (c) at 6.7 GHz 4.60 dB (d) at 7.7 GHz 6.51 dB (e) at 8.6 GHz 3.85 dB (f) at 9.5 GHz 2.1 dB (g) at 11.3 GHz 2.89 dB
From the Figure.10 it is inferred that the simulated gain values are more at higher frequencies. The maximum value of gain is 5.62 dB at 8.6 GHz. The same concept is shown in Figure.12(a). The radiation patterns shown in Figure.11, which depicts the distributed power at all resonant bands for all directions of Θ. Here E-plane pattern represented by dotted lines and corresponds to Φ=0 degrees and H-plane pattern corresponds to Φ=90 degrees drawn in solid lines. The Figure.11 illustrates that E, H radiation patterns are bidirectional at lower resonant frequencies but these are distorted at higher resonant bands. In Fig 12(a) Gain values are plotted for entire frequency sweep from (1-12) GHz range and Current density distribution at 8.7 GHz is presented in Figure 12(b), which shows more electric distribution takes place at the edges of the patch with a current density distribution of 47.3 Amp/m. 
6. Proposed Fabricated Antenna Validation

The fabricated Prototype is shown in the below Figure.13 and is validated using Vector Network Analyzer for examining Return loss, VSWR results shown in Figure.14. Furthermore, the comparison between simulation and measured results verified and all the results are tabulated in Table.5. The measured results showing 7 frequency bands which are same as simulated results with a little change in S(1,1)dB and VSWR values as listed in Table.5 at center frequencies 2.4, 5.0, 6.9, 7.8, 8.7, 9.5, 11.8 GHz. The screen shots of measured results are shown in Figure 14. There is a good matching of numerical simulation results with the experimental measured results.

(a) (b)

Figure 13 Prototype of proposed ANTENNA-2 (Met material inspired 2nd iteration Koch Fractal Antenna) Patch and Ground planes, (b) Experiment set up for Testing antenna with VNA

(a) (b)

Figure 14. Experimental suts on VNA of ANTENNA-2 (Met material inspired 2nd iteration Koch Fractal Antenna) (a) Return loss plot (b) VSWR plot
Table 5. Comparison of Simulation results of proposed antenna with its Measured results

| Simulation Results using HFSS | Measurement Results using VNA |
|------------------------------|------------------------------|
| $f_r$(GHz) | S(1,1)dB | VSWR | $f_r$(GHz) | S(1,1)dB | VSWR |
| 2.5 | -13.18 | 1.69 | 2.4 | -15.12 | 1.56 |
| 5.1 | -10.84 | 1.25 | 5.0 | -20.05 | 1.78 |
| 6.7 | -13.48 | 1.64 | 6.9 | -12.7 | 1.58 |
| 7.7 | -23.24 | 1.61 | 7.8 | -11.56 | 1.43 |
| 8.6 | -12.88 | 1.49 | 8.7 | -35.7 | 1.24 |
| 9.5 | -14.17 | 1.31 | 9.5 | -22.6 | 1.35 |
| 11.3 | -26.09 | 1.73 | 11.8 | -20.2 | 1.24 |

**Conclusion:** This paper presented with a novelty and new approach in carving Koch 2$^{nd}$ iteration fractal geometry on the FR-4 substrate. ANTENNA-1 is designed first and its simulation characteristics are verified using ANSYS HFSS tool for a frequency window of (1-12GHz). To design the multiresonant proposed antenna, the ground structure of ANTENNA-1 is modified by using a metamaterial multiband technique with SRR cell on the ground. This modified geometry is named as Antenna-2 which covers Wi-Fi, WLAN, C-band, and X-band simultaneously with reasonable gain values. This ANTENNA-2 is fabricated and examined for validation of return loss, VSWR values. The simulated results obtained from HFSS tool and measured results examined from VNA are matching with each other.

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