Microstrip Fed Multiband Hybrid Fractal Antenna for Wireless Applications

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Abstract ─ A hybrid fractal multiband antenna is designed by integrating Koch curve and meander antenna. Scripting method (*.vbs) is adopted to obtain the hybrid fractal structure using IFS and MATLAB. Final structure is obtained by perturbing the reference fractal shape. Proposed antenna exhibits multiband characteristics capable of operating in four different wireless frequency bands including very popular Bluetooth (2.4 GHz), WiMAX (3.4-3.7 GHz), WLAN 802.11 a/b/g (5.3-6.1 GHz) and Aeronautical radionavigation (8.68-9.05GHz). The antenna has a planar structure, compact size of 39 mm × 32 mm × 1.58 mm and is suitable for wireless applications. Prototype of the proposed structure is developed on easily available and low cost FR4 substrate. The antenna has acceptable values of return loss, VSWR and gain. Measured characteristics are in good agreement with the simulated one.

Index Terms ─ FR4, hybrid fractal, IFS multiband.

I. INTRODUCTION

Progress in the modern wireless communications systems has generated the demand for compact, multiband, wideband and cost effective antennas. Fractal antennas have the capability to fulfill these requirements due to their self-similarity, space filling properties and ability of miniaturization [1]. Fractal geometries were 1st proposed by Mandelbrot in 1953 [2] which were later widely adopted in various engineering fields. Due to self-similarity, fractal structures are generated by repeated recursive process which further increases the effective electrical path length and generates a wide surface area in a limited space. This helps in achieving multiband behavior and also reduction in size and volume [3]. Even in USB (Universal Serial Bus) applications the remedy to space limitation makes the fractal geometries an interesting case of study. By perturbing the reference geometrical parameters one can tune the antenna to the desired frequency bands [4-5]. So antenna geometries and their dimensions are deciding factors to determine their operating frequencies [6]. Wireless standards like bluetooth, Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) are becoming more popular for wireless applications and data sharing, hence, there is huge demand for antennas with moderate gain, compact size, light weight and single-fed feed lines [7].

The proposed antenna has an advantage of compact size and simple structure which makes it better choice for wireless applications. Hybrid fractal geometries are generated by combining of two different fractal antennas or a fractal and a non-fractal antenna to form a hybrid antenna, this combination can be at generator level or at final stage of compete antenna structure [8-11].

The combination process to design the proposed hybrid antenna structure is shown in Fig. 1. Koch like microstrip structure with indention angle θ = 60° and meander like microstrip structure [12] with indention angle θ = 90° are combined to form the desired generator structure. Both Koch and meander are widely used antenna elements in wireless communication standards like ISM, GSM, UMTS, WIFI, WLAN, Bluetooth etc. Number of segments in the proposed hybrid structure (Fig. 1 (c)) is 7, whereas in case of Koch it is 4 and 5 in case of meander. This helps to achieve more miniaturization and increased effective electric length as compared to individual Koch curve or meander like structures.

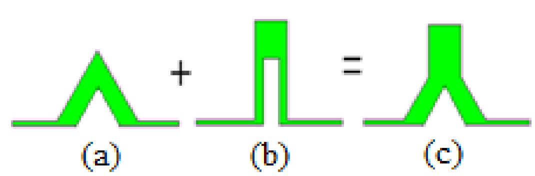

Fig. 1. (a) Koch curve, (b) meander antenna, and (c) hybrid fractal structure used as generator (n=1).

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II. IFS - ITERATED FUNCTION SYSYTEM

IFS is a versatile mathematical representation to describe a fractal structure. It is used to define a generator structure by creating a series of self-affine transformation *w* [13] which can be formulated as:

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

where *a*, *b*, *c*, *d*, *e* and *f* are real numbers. The *a*, *b*, *c* and *d* control the rotation and scaling, while *e* and *f* control linear shift or translation. Assuming w_1 w_2 … w_n as series of linear affine transformations and let *A* be the initial geometry. By applying set of transform on *A*, it can be expressed as follows:

$$W(A) = \bigcup_{n=1}^{N} W\ n(A). \quad (2)$$

Here, *W* is called Hutchinson operator which is used to obtain the final geometry. The transformations to obtain 7 segments of the proposed generator geometry are as follows:

$$W_1\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 1/5 & 0 \\ 0 & 1/5 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \quad (3)$$

$$W_2\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 1/5 & -1/4 \\ 1/4 & 1/5 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} 1/5 \\ 0 \end{pmatrix}, \quad (4)$$

$$W_3\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 0 & -1/4 \\ 1/4 & 0 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} 2/5 \\ 1/4 \end{pmatrix}, \quad (5)$$

$$W_4\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 1/5 & 0 \\ 0 & 1/5 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} 2/5 \\ 1/2 \end{pmatrix}, \quad (6)$$

$$W_5\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 0 & 1/4 \\ -1/4 & 0 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} 3/5 \\ 1/2 \end{pmatrix}, \quad (7)$$

$$W_6\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 1/5 & 1/4 \\ -1/4 & 1/5 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} 3/5 \\ 1/4 \end{pmatrix}, \quad (8)$$

$$W_7\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 1/5 & 0 \\ 0 & 1/5 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} 4/5 \\ 0 \end{pmatrix}, \quad (9)$$

where, W_1 *to* W_7 are set of linear affine transformations. The generator is then obtained by union of all above transformations:

$$W(A)=W_1(A)\cup W_2(A)\cup W_3(A)\cup W_4(A)\cup W_5(A)\ W_6(A)\cup W_7(A). \quad (10)$$

The process can be repeated if higher iterations are needed. As there are 7 segments in the generator structure located in 5 vertical divisions so fractal similarity dimensions can be calculated [14] using the equation:

$$D = \frac{\log(n)}{\log(r)} = \frac{\log 7}{\log 5} = 1.20906. \quad (11)$$

The proposed design is based on the 2nd iteration of the new generator to form a hybrid fractal structure antenna as shown in Fig. 2.

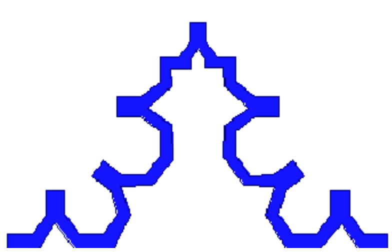

Fig. 2. Proposed hybrid fractal geometry for 2nd iteration.

The total length *l* of the structure is given by the function:

$$l = h\left(\frac{N}{r}\right)^n, \quad (12)$$

here, *N* represents the number of segments the geometry has, *r* the number that each segment is divided on each iteration and *h* the height of the curve and *n* is the number of iterations resulting in $l = h\left(\frac{7}{5}\right)^2$. The effective electrical path length is increased by each iteration, hence, for 1st iteration the length increases by a factor of 1.4.

III. ANTENNA DESIGN AND STRUCTURE

A. Methodology

Fractal structures are complex in nature and contains large number of corners, bends and edges so it is difficult to draw fractal shapes manually in HFSS. For easy understanding of the entire procedure used in designing the proposed hybrid fractal antenna structure, the procedure is shown in Fig. 3.

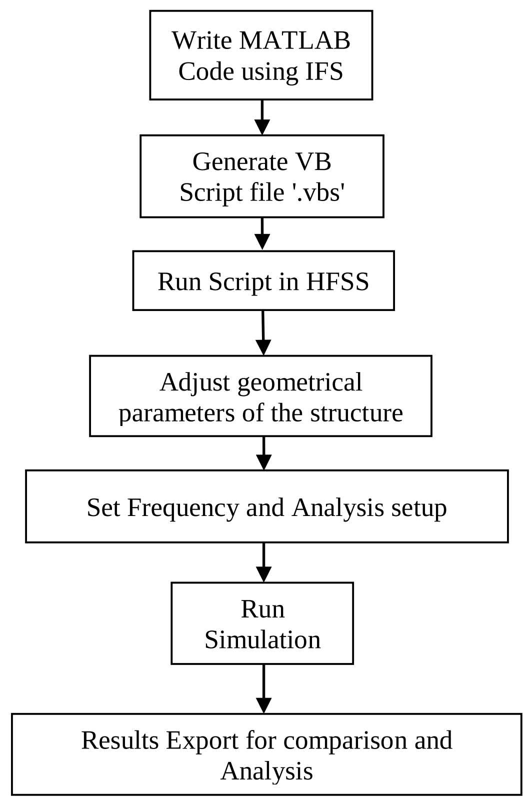

Fig. 3. Flow chart showing the various steps followed in designing and simulation of the proposed antenna.

It shows various steps starting from writing a MATLAB [15] code using IFS and generating a *.vbs script [16-17] file to draw the structure in HFSS simulator. This geometry is further used as a reference structure for completing the final proposed antenna structure. Step 4 can be repeated to obtain desired results.

The initial design shown in Fig. 2 is used to make the final structure by combining the similar structure on a rectangular substrate.

B. Structural schematic

A Novel hybrid fractal structure is presented in this article. The purpose of designing this hybrid fractal antenna is to obtain multi-band characteristics for wireless applications. The antenna is fed through a edge connected SMA coaxial connector using microstrip feed line feed. Figure 4 shows the detailed structure of the proposed geometry along with the coordinates. In order to reduce the stray fringing fields and to improve the radiation efficiency, proposed antenna has been designed by following basic rules L1/h>>1 (L1 is length of patch), W1/h>>1 (W1 is width of microstrip feed and h is thickness of substrate), $\mathcal{E}_r >> 1$ and $1 < \mathcal{E}_{reff} < \mathcal{E}_r$ [18].

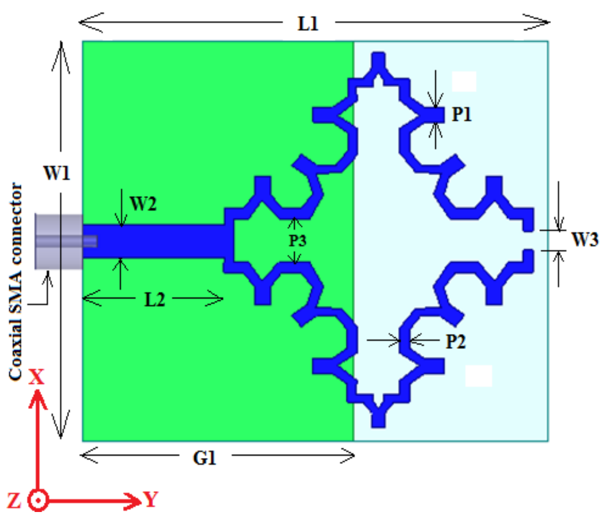

Fig. 4. Structural details of complete antenna schematic.

The antenna is designed on easily available and cost effective FR4 substrate, which is sandwiched between copper layers of radiating antenna structure and defected ground structure. It has dielectric constant $\mathcal{E}_r = 4.4$ and dielectric loss tangent 0.02 and mass density 1900 Kg/m^3, thickness of the substrate (h) = 1.58 mm. Length L1 and width W1 of the substrate is 39 mm and 32 mm, respectively.

G1 represents the length of ground conductor layer, L2 & W2 represents length and width of microstrip feed line, whereas W3 shows the minimum gap between the two hybrid fractal arm ends. P1 shows the width of crown head and P2 shows the width of connecting arm, whereas P3 represents the maximum gap between the two hybrid fractal arms. Table 1 shows the detailed dimensional distribution of the proposed antenna geometry.

Table 1: Dimensions of the proposed hybrid fractal structure

Parameters	Dimensions (mm)
L1	39
L2	11.8
W1	32
W2	2.6
W3	1.498
P1	1.152
P2	0.85
P3	3.45
G1	22.7

All the simulations are carried out using Ansoft HFSS simulator. Proposed antenna is fed through a 2.6 mm wide and 11.8 mm long microstrip line feed. Values of effective dielectric constant and impedance is calculated using (13) and (14) [18]:

$$\mathcal{E}_{reff} = \frac{\mathcal{E}_r+1}{2} + \frac{\mathcal{E}_r-1}{2}\left[1\Big/\sqrt{1+12h/w}\right], \quad (13)$$

$$Z_0 = \frac{120\pi}{\sqrt{\mathcal{E}reff}\left[\frac{w}{h}+1.393+0.667ln\left(\frac{w}{h}+1.444\right)\right]}. \quad (14)$$

Calculated values of $\mathcal{E}_{reff}$ and Z_0 form Equation (13) and (14) are 4 and 50 Ω for the proposed geometry.

To achieve the desired multiband characteristics while maintaining the compact size of the antenna, several design parameters of the antenna are optimized which includes varying the width of the antenna radiator (P1 and P2) structure, varying the thickness of substrate (*h*) and varying the length of ground plane (G1). Variation of all these parameters have a significant effect on the S_{11} characteristics and correspondingly on bandwidth and gain also. Geometrical values given in Table 1 are optimized values selected after taking a large number of trials of simulations and analysis of results. After comparison of various variations in ground length 'G1' optimized value 22.7 mm is observed and selected.

The proposed antenna has a radiating structure containing many bends, corners and edges which not only increases the total electric length of the antenna, it also causes the change in the current path which leads to more radiation and more number of resonant frequencies [19].

IV. RESULTS AND DISCUSSION

The prototype of the optimized structure is developed on easily available FR4 substrate. Figure 5 shows the complete prototype structure (top as well as bottom view) with soldered coaxial edge mounted (with clipped mounts on top) coaxial SMA connector.

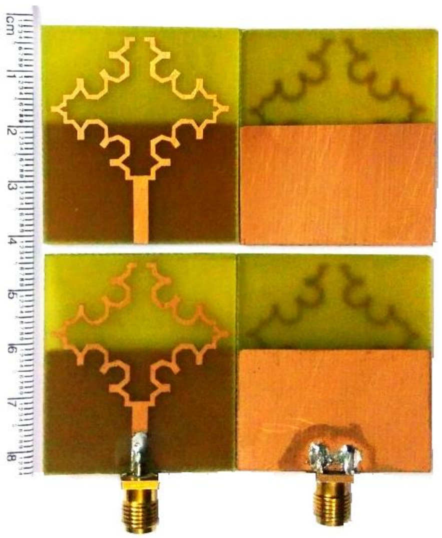

Fig. 5. Top and bottom view of fabricated hybrid fractal antenna structure.

Figure 6 shows the comparison of simulated return loss for different available and widely used substrate materials. It shows that best results are obtained by using the FR4 substrates as we get resonance in useful frequencies like 2.4 GHz, 3.4 GHz, 5.57 GHz and 8.82 GHz, whereas other substrates may show good results but they do not resonate in useful frequencies range.

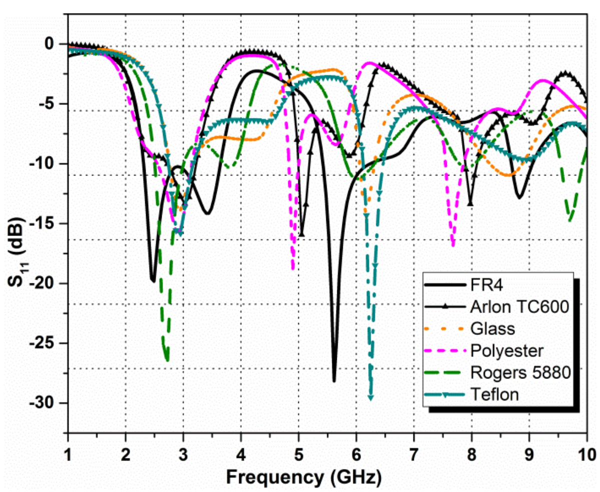

Fig. 6. Comparison of return loss for different substrates materials.

For 1st iteration, two resonating frequency bands are obtained having resonating frequencies at 3.7 GHz and 5.9 GHz having return loss values of 13 dB and 14.8 dB respectively. For 2nd iteration, four resonating bands are obtained .Table 2 shows the distribution of the obtained frequency bands along with their lower, upper and center frequency values. It also shows the associated values of S_{11} in decibels and bandwidth. The proposed antenna follows the constraint values of VSWR ≤ 2. All resonating frequencies have values of VSWR ranging from 1.08_{min} to 1.59_{max}. It suggests that the number of resonating bands increases with the level of iteration however the number of iterations for practical feasibility is limited to 2nd iteration only as further increase can lead to more complex structure and hence, diminishes the possibility to fabricate the structure with required precision.

Table 2: Distribution of frequency bands showing associated bandwidth and VSWR for N=2

Freq. Band No.	F_L (GHz)	F_C (GHz)	F_H (GHz)	S_{11} dB	B.W. (MHz)	VSWR
1.	2.3	2.4	2.89	-19	590	1.23
2.	2.89	3.4	3.6	-16.9	710	1.48
3.	5.35	5.57	6.1	-25.3	750	1.08
4.	8.68	8.82	9.05	-12.8	361	1.59

Figure 7 shows the 2D far-field radiation pattern with elevation planes for φ=0° (taken for reference purpose only), 90° and 180° for centre frequencies 'F_c' for each frequency band.

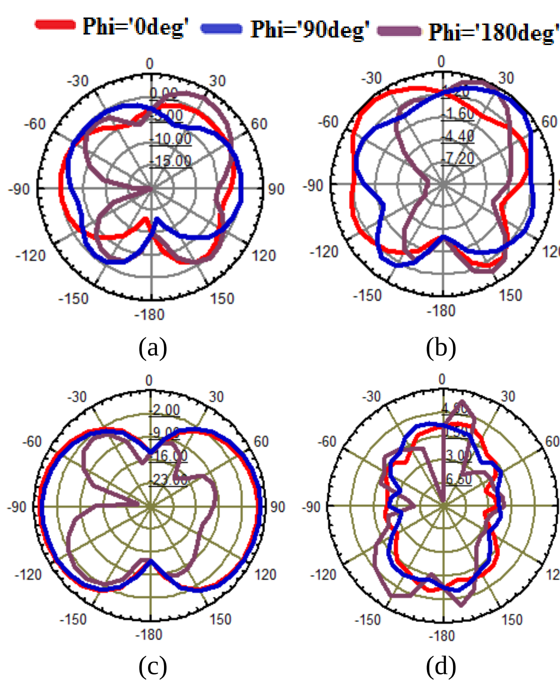

Fig. 7. Simulated E-plane (x-z) 2-D radiation pattern of proposed antenna at frequencies: (a) F_c = 2.4 GHz, (b) F_c = 3.4 GHz, (c) F_c = 5.57 GHz, and (d) Fc = 8.8 GHz.

It is seen that the fractal antenna provides almost stable patterns nearly in the form of figure-eight in the E-plane (x-z plane). The radiation pattern (as in Fig. 7 (d)) is distorted at higher frequencies as compared to lower ones. This is due to change in the nature of current due to edge reflection resulting from standing waves from lower frequencies to a travelling wave at higher frequencies [20]. Total simulated gain of the proposed antenna is 7 dB_{max} and 3-D radiation pattern obtained at 9 GHz is almost omnidirectional as shown in Fig. 8.

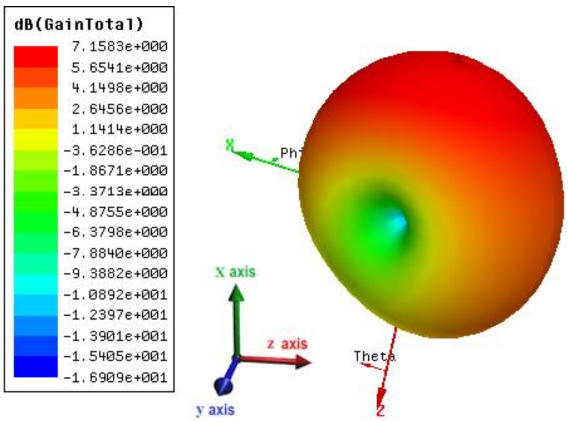

Fig. 8. Simulated 3-D radiation pattern of proposed antenna and gain total in decibels.

The prototype of the proposed structure of hybrid fractal multiband antenna is tested on Agilent's vector network analyzer (VNA). Figure 9 shows the comparison of simulated and tested return loss graphs.

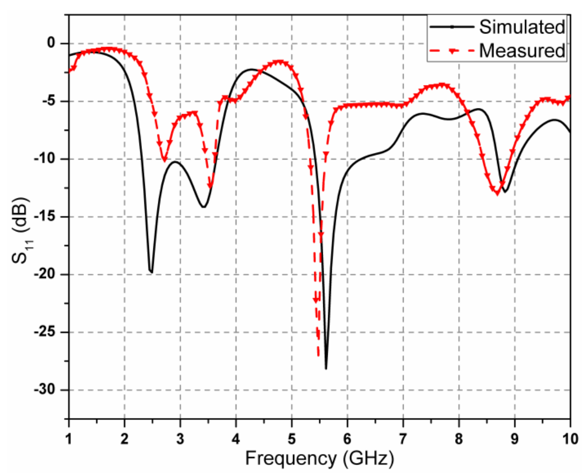

Fig. 9. Simulated versus measured return loss results of proposed antenna at different frequencies for N=2.

Both the simulated and tested return loss graphs are in good agreement with each other; however, the variation in the tested results is due to some factors in the measuring environment which includes fabrication tolerance, solder bumps, losses due to SMA connectors, losses in connecting cable etc., which are not considered in the simulation environment.

A comparison for the compactness, gain and number of frequency bands of the proposed antenna with previous work on similar fractal antennas and hybrid fractal antennas is shown in Table 3.

Table 3: Comparison of proposed antenna with other similar fractal antennas

Author	Frequency Bands	Gain dBi (max)	Size (mm^2)
S. K. Behera [3]	2	6	25 × 66
R. Azaro [5]	3	5	40 × 40
A. Jamil [6]	2	3.87	38 × 10
S. K. Sharma [8]	4	4	100 × 50
Y. Kumar [11]	7	4	28 × 15
R. A. Kumar [20]	3	4.7	30 × 25
This work	4	7	39 × 32

V. CONCLUSION

The hybrid fractal antenna exhibiting multiband behavior is analyzed and investigated. The amalgamation of Koch-Meander geometry generates a novel design which not only provides desired multiband behavior it also provides miniaturization due to increase in effective length of the antenna. Number of segments in generator structure increases to 7, whereas individual Koch curve has only 4 segments. Optimized antenna parameters are selected after taking large number of trials by varying different parameters of the antenna structure. Proposed hybrid fractal antenna resonates at four frequencies including important wireless standards like Bluetooth (2.4 GHz), WiMAX (3.4-3.7 GHz), WLAN 802.11 a/b (5.3-6.1 GHz) and Aeronautical radionavigation (8.68-9.05 GHz). Proposed antenna has acceptable values of return loss (S_{11}), VSWR (1.08_{min} to 1.59_{max}), gain (7 dB_{max}) and bandwidth (361 MHz, 750 MHz and 1300 MHz). Proposed antenna fulfills all the requirements to be used in handheld devices due to its compactness and light weight. The measured results are in good agreement with the simulated results.

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