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A Novel Hexagonal Shaped Fractal Monopole Antenna for Multiband Application

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Abstract: *This proposed work describes about a design of novel printed multiband antenna with fractal pattern for multiband applications. The fractal antenna is designed with Hexagonal monopole as an initiator for the design frequency band of 1GHz. FR4 substrate with a dielectric constant value of 4.6 is used for this design and fed with 50-ohm micro strip feed line. The three iterations of the hexagonal antenna and its position, location of the antenna can be enhanced to function in multiple bands of 1 to 3 GHz is obtained and VSWR of the prototype antenna is achieved<1.5. The prototype antenna tested results are obtained through Agilent VNA – N9923A and the values are in good agreement with that of the simulation results in Ansoft HFSS.*
Keywords: *Fractal antenna, multiband antenna, micro strip antenna, iterative methods, slot antenna.*

I. INTRODUCTION

Antennas play a crucial part in radio frequency and microwave wireless communication systems, including cell phones, radar, television transmission, and other systems utilizing electromagnetic waves. The search is on for an antenna that can operate across many frequency bands. The antenna design is always important in certain applications need the antenna to be as small as possible [1]. The performance of an antenna can be improved with appropriate design. The stringent requirements of wireless communication systems have necessitated the design of compact multiband antenna [2]. The most requirements of wireless communication systems have necessity of designing compact multiband antenna [3]. Antennas for modern wireless communication systems must be multiband and smaller in size than classic antennas [1]. Due to benefits like fast data rates and insulation from electromagnetic interference, multi-band antennas are of tremendous interest. Numerous methods have been developed to increase monopole antenna bandwidth, including expanding the substrate and altering the radiator, ground, and feed structures. [2].

The extraordinary progression in mobile communication systems has proportionally led to the expansion of antenna system development in the recent years. There has been enormous technology of furnishing the mobile devices with extra components with more functionality while sinking the size. Recently antennas with multiband and wideband characteristics have been developed for wireless applications such as slot antenna with parasitic elements, and additional resonator, [2]. Even though they are working in wide range of frequency bands, it consists of complexity in design. However, a technique which has pulled out the research community attention which involves the combination of the theory of fractal geometry to attain the multiband operation with fractal antenna design. Fractal antenna should be an exceptional replacement solution for compact size antenna with multiband. Broadband and multiband frequency reactance properties of the fractal antenna can be derived from the inherent properties of the geometry of that antenna [25]. Fractal antennas are great beneficiary over the classical antennas because the mutual coupling is less, they are compact in size, and also having multiband or wideband behavior.

II. FRACTAL ANTENNA

In 1975, Benoit Mandelbrot used the term "FRACTAL," which is a word derived from the Latin for broken or uneven bits [4]. A fractal means subdividing into multiple parts in a rough manner or fragmented geometric shape, each part should be of at least a copy of the complete structure. Fractals are commonly a structure of self-similar design and free of scale. Unique mathematical characteristics seen in fractal geometry include branching in tree leaves and other natural phenomena. Self-similarity and space-filling exist the two basic primary geometries used in fractal design [5]. Fractals are self-similar structures with an unlimited level of complexity. This implies that the structure repeats itself when the focus is increased. Antennas that can function at many bands of frequencies might be designed using this technique. Each component of a fractal geometric shape is a smaller replica of the entire shape, which lacks any distinguishing scale [1], [2]. A low-profile antenna has been designed using a self-similarity idea, which allows for versatility in creating a miniaturized antenna [3]. Each fractal is made up of several variations of the same form. The fractal field development is in infant stage and getting advanced day by day. These antennas, which are smaller than those of traditional designs, emit and detect very well throughout a wide frequency spectrum [3]. Also, these antennas maintaining a good to excellent return loss, VSWR, gain, mechanical simplicity and robustness. To achieve multiband features, many antennas have been constructed employing the concepts of self-similarity and self-affinity [6]. In order to develop a low-profile antenna with flexibility in order to get a miniaturized antenna, a self-affine idea has been utilized. [7] The antenna may resonate at many frequencies by selecting the right scaling factor, and by optimizing the feed location and ground. A compact wideband fractal cantor antenna is made to work with wireless applications in the ISM band, Bluetooth, DCS, and WLAN [4]. The inscribed triangular circular fractal antenna is designed to achieve UWB applications by using CPW-fed [5]. The sierpinski gasket designed is to achieve multiband and mobile applications [8]. The hexagonal boundary sierpinski carpet designed is to operate in UWB with band rejection functionality [9]. The star-triangular fractal monopole antenna is designed by using Fr4 substrate and it achieved super wideband applications [7]. To enable extreme wide band applications, the monopole structure of this antenna is developed on the FR4 substrate with a coplanar wave guiding feed structure, a hexagonal radiator, and six additional tiny hexagonal components [8]. [2, 3] designed fractals with self-affine properties, analyzed them for multiband features, and implemented them on an RT duroid substrate on the opposite side using microstrip line feeding. When compared to RT duroid, the price of fr4 substrate is incredibly cheap.

III. ANTENNA GEOMETRY AND OPERATION PRINCIPLE

The dimensions (L) and (W) are particularly crucial when building a microstrip patch antenna. The antenna construction is particularly crucial when utilizing the Fractal approach to produce several frequency bands in a single antenna. This study proposes a hexagon-shaped fractal structure.

A. Antenna Design

The suggested antenna structure is made on FR4 epoxy material which is having a dielectric constant of 4.4 and a 1.6 mm thickness. Using Ansoft HFSS 13 3D tool a hexagonal is drawn with radius of 10mm. and a hexagonal monopole antenna is drawn in the base of the diameter of the circle as revealed in Figure 1(a). The figure 1(b) illustrates the creation of a slot in between the two designs and the 2mm reduction in hexagonal size from the zeroth iteration design for the first iteration. To produce the second iteration, which is seen in Figure 1(c), one more iteration is created in a similar manner. The number of iterations can be adjusted for multiband purposes. The suggested antenna has self-affine characteristics. The substrate's rear side is covered with the ground plane. The antenna is 50 x 22 mm. The following equations (1, 2, 3, 4, and 5) are used to get the Patch Antenna Dimensions [9].

Using equation (1), choose the dielectric material and thickness of ground and substrate. [1,4] With the help of the values of Ɛr, fr, and h.

$$\mathrm{f} = \frac{\mathrm{c}}{2\mathrm{l}\sqrt{\varepsilon_\mathrm{r}}} \tag{1}$$

Where c = veolcity of light.

For effective radiation, the width w is given by equation (2). In this Fr4 proxy dielectric is chosen with $\varepsilon_\mathrm{r} = 4.4$.

$$\mathrm{w} = \frac{\mathrm{c}}{2\mathrm{f}}\sqrt{\left(\frac{2}{\varepsilon_\mathrm{r}+1}\right)} \tag{2}$$

The (3) Equation provides the hexagonal patch antenna's effective dielectric constant

$$\varepsilon_\mathrm{reff} = \frac{\varepsilon_\mathrm{r}+1}{2}\frac{\varepsilon_\mathrm{r}-1}{2}\left[1+12\frac{\mathrm{h}}{\mathrm{w}}\right]^{-\frac{1}{2}} \tag{3}$$

The length of the extension patch is given by equation (4).

$$\Delta\mathrm{l} = 0.412\mathrm{h}\frac{(\varepsilon_\mathrm{r}+0.3)\left(\frac{\mathrm{w}}{\mathrm{h}}+0.264\right)}{(\varepsilon_\mathrm{r}-0.258)\left(\frac{\mathrm{w}}{\mathrm{h}}+0.8\right)} \tag{4}$$

The Equation (5) yields the patch antenna's length.

$$l = \frac{c}{2f\sqrt{\varepsilon_{reff}}} - 2\Delta l \tag{5}$$

Where c = free space velocity.
ε_r = dielectric constant of the proposed substrate.
w = width of the Patch
Δl = extension patch length

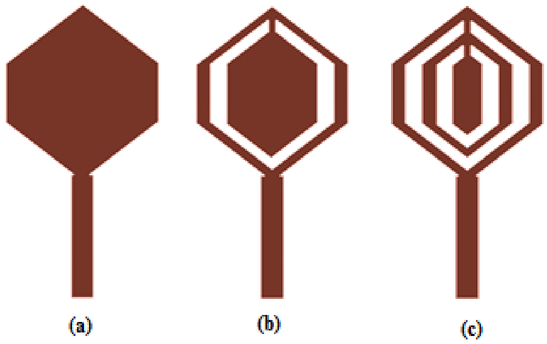

Figure 1. Proposed antenna with respect to each iteration

Figure 2 depicts the proposed antenna's layout design along with its dimensions, and Table 1 lists the values.

Table 1: Dimensions of the Conventional and The Novel Fractal Antenna.

Sl. No.	*Title*	*Novel Fractal Dimension*
1	Height of the antenna (L)	50mm
2	Width of the antenna (W)	22 mm
3	Height of the feed line (LF)	21mm
4	Width of the feed line (WF)	3mm
5	Height of the ground plane (LG)	10.5mm
6	Width of the ground plane (WG)	22mm

IV. SIMULATION RESULTS

Using the Ansoft HFSS 13 simulator tool, the proposed antenna is modelled. Below is a discussion of the simulation findings for three iterations.

A. Monopole Initiator

Microstrip line feeding was used to feed the antenna. Up to two iterations have been completed. The radiating element in the design is a copper-clad FR4 substrate with a dielectric constant value of 4.6 and a 1.6mm thickness.

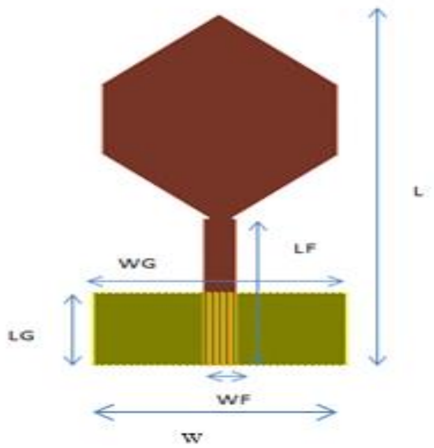

Figure 2. Shows the layout for Zeroth iteration

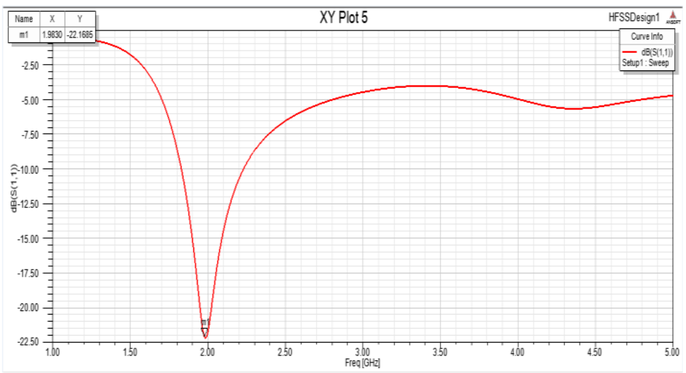

Figure 3. Return loss for monopole initiator

After simulating the zeroth iteration, a single frequency of 1.98 GHz was achieved. The simulation plot is shown in figure 3.

B. First Iteration

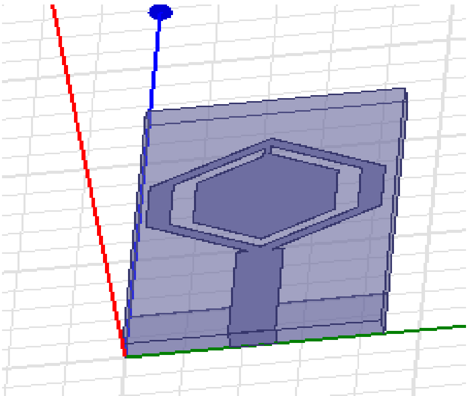

Figure 4(a). Design for first-iteration

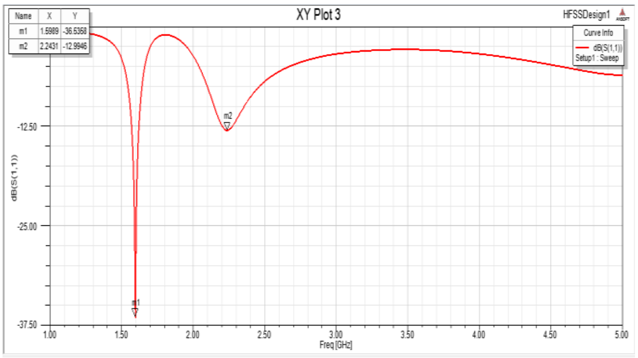

Figure 4(b). Return-loss of the proposed first-iteration model

The simulation work of the proposed antenna's first-iteration model is shown in figure 4(a), and concern result for the return loss for the same is shown in figure 4(b) with an achievement of dual frequency in 1.59 GHz and 2.2 GHz.

C. Second Iteration

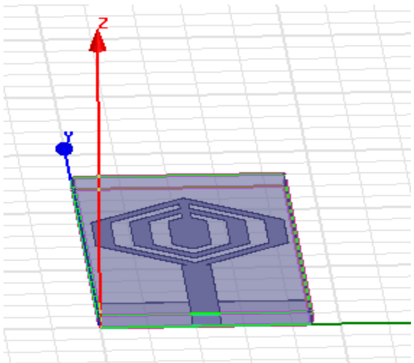

Figure 6. Shows the layout for second iteration

After the simulation process for the Second iteration is shown in figure 6. And with a return loss achievement of 1.6 GHz, 2.1 GHz, 2.98 GHz respectively in zero, first and second iterations as exposed in the figure 7.

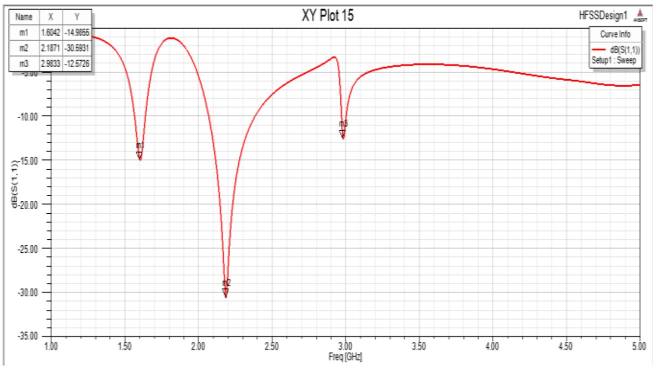

Figure 7. Return loss for the second iteration

The return loss is calculated by reflection coefficient using the equation 6.

$$\text{Return loss} = 20 \log_{10} |\Gamma| = 20 \log_{10} |S_{11}| \qquad (6)$$

D. Effect of Different Fractal Iteration Levels

The structures are simulated using HFSS in order to examine the performances of the proposed antenna at various iterations and the efficacy of the fractal shape. As the iterations are increased, multiband behaviour appears as in figure 8. The third iteration exhibits multiband behaviour and has great VSWR and gain based on the comparative results.

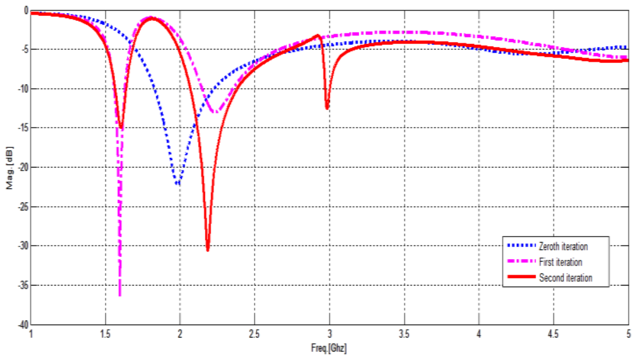

Figure 8. Comparison up to second iterations

Table 2 Comparison of simulated results

Iterations	*Resonant frequency (GHz)*	*Return losses (dB)*	*VSWR*
Zeroth	1.6	-14.98	1.3
First	1.59	-36.5	1.12
	2.24	-12.99	1.4
Second	1.6	-14.48	1.1
	2.17	-26.75	1.5
	2.98	-11.5	1.3

In table 2 the comparison of resonant frequency, return loss, VSWR for zeroth, first and second iterations is being cited.

E. 3d Radiation Pattern

Radiation pattern is about the antenna characterize like gain, beam width, polarization etc., normally energy leaving the antenna that energy need to be radiate at 360 degree.

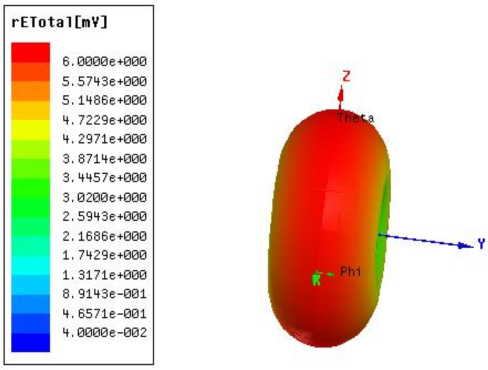

Figure 9. Radiation pattern for second iteration

In figure 9 shows that in second iteration the total gain of 6dBi is achieved.

V. HARDWARE RESULTS

The Figure 10 shows the Prototype model of Hexagon Fractal Antenna in FR4 substrate with respect to 2nd iteration.

Figure 10. Fabricated prototype model

A. Hardware Results – Return Loss

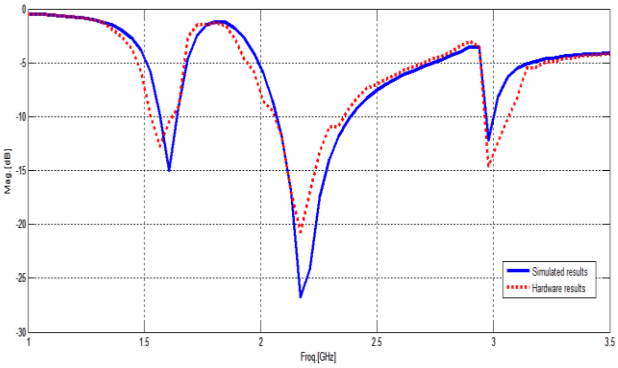

Figure 11. S11 hardware result for second iteration

The antenna is tested with Agilent N9923A – VNA (Vector Network Analyzer). In network analyzer, the antenna performance can be measured with the help of connector. Figure 11 displays the fabrication antenna's return loss performance relative to the second iteration.

B. Hardware Results – VSWR

$$\text{vswr} = \frac{\text{Max}}{\text{Min}} = \frac{1+r}{1-r} \qquad (7)$$

Where, r– reflection coefficient of voltage sent/ voltage reflected.

The equation 11 given the VSWR measurement formulae, by knowing the reflection co-efficient of the antenna the VSWR can be easily calculated. The hardware VSWR result is shown in figure 12.

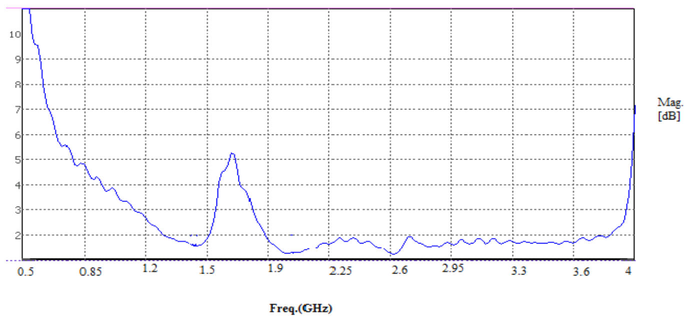

Figure 12. Return loss for second iteration

Table 3 compares the frequency and return loss for the second iteration between the simulated and prototype model measured values. The results are consistent with the simulation since there is no dissimilarity between the simulated and prototype model measured frequencies owing to different factors like fabrication error and the testing environment for produced antennas.

Table 3 Comparison of simulated & Fabricated Results for second iterations

DESCRIPTION	RESULRS ATTAINED FROM PROTOTYPE		
Frequency simulated	1.6GHz	2.1GHz	2.98GHz
Return loss simulated	-14.98dB	-30.5dB	-12.5dB
Frequency measured	1.5GHz	2.08GHz	2.9GHz
Return loss measured	-17dB	-25dB	-14dB

VI. CONCLUSION

A novel multiband antenna with fractal pattern is designed up to 2nd iteration for multiband applications. Furthermore, the structure is customized for multiband wireless applications. Ansoft HFSS 13 is used to design, model, and build the novel fractal antenna. Results have been analyzed for operating frequencies in the 1.6GHz, 2.1GHz, and 2.98GHz ranges. It has been shown that frequency increases as the number of iterations increases. It has found use in GPS receiver, 3G, and WLAN Video application because it demonstrates strong multiband capabilities. By applying fractals into antenna, it has many benefits such as it achieves resonance frequencies that are multi band and it achieves multiband frequency band. The fabricated hexagonal fractal antenna is tested using Agilent N9923A – VNA and theoretically results are plotted. In order to minimize the size of the whole system, fractals may potentially be used in the design of antenna feed lines and related components in the future upcoming works. For wireless application and mobile appliances this fractal antenna is well- suited.

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