A Hexagonal-Shaped Fractal Antenna Array for Multiband Applications

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ABSTRACT
A innovative geometry of fractal microstrip antenna has proposed which can be used for various multiband applications. This hexagonal fractal antenna structure has designed to produce multiband characteristics or to achieve miniaturizations. Multiple hexagons of the proposed geometry of an antenna are interconnected to maintain conductivity and to preserve electrical self-similarity. The hexagonal fractal antenna is implemented in the corner fed dipole configuration with overlapping vertices to preserve the electrical self-similarity paramount in multiband design. Coaxial feeding has used to make the design of antenna versatile in term of impedance matching. This antenna has designed up to f iteration through miniaturization procedure. Proper and improved results has observed at fourth iterations of the antenna design.

Keywords
Fractal multiband antenna, hexagonal fractal multiband antenna, iterated function system, Resonant Frequency, size reduction.

1. INTRODUCTION
Advanced communication systems require antennas with more bandwidth and smaller dimensions compared to conventional antennas. Fractal geometry is a very good solution to fabricate these antennas. This causes wide spread researches on fractal antennas recently. Fractal antenna's response differs obviously from traditional antenna designs. It is capable of operating optimally at many different frequency ranges simultaneously [3]. This makes the fractal antenna an excellent design for broadband applications.

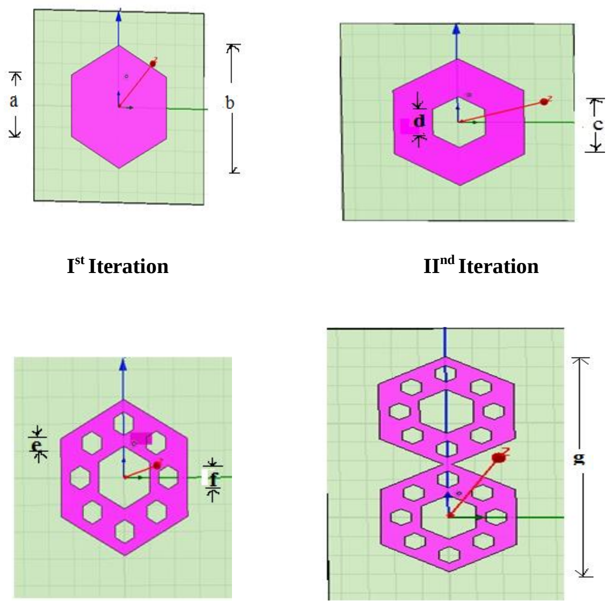
Recent efforts by several researchers around the world to combine fractal geometry with electromagnetic theory have led to a plethora of new and innovative antenna designs[1]. The most recent multiband antenna development is the incorporation of fractal geometry into radiating patch of microstrip antenna. Here a hexagonal geometry of microstrip antenna has constructed to achieve multiband applications[2]. Fractals create from self-similar elements, iterating in various directions that increasing iterations, does not change their total form; because their small sections are reduced-size copy of the whole. Self-similarity of fractals causes multi-band and broad-band properties of antennas [9].

Due to the concept of self-similarity and infinite complexities, the proposed geometry of an antenna is very versatile in term of polarization, radiation pattern, gain and bandwidth[2,3]. Through proper selection of the feed and slot-loading technique, and miniaturisation with higher iterations, significant bandwidth enhancement can be observed with proposed geometry.

ANTENNA GEOMETRY
The hexagonal fractal microstrip antenna for three iterations has shown in Fig. 1. Third iteration geometry of an antenna consists of eight small shaped hexagonal which are constructed by reducing and grouping these hexagon generator shape to one third its first iterations. Miniaturization ratio 1:3 has used to configure antenna. This miniaturization procedure is known as the iterated function system (IFS) and it is described by the matrix equation [4][5].

$$W\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix}\begin{bmatrix} e \\ f \end{bmatrix}$$

This antenna geometry is very useful in maintaining overall antenna conductivity and thereby electrical self-similarity can be easily achieved. Total length and width of an antenna is 59mm while the hexagon distance is 29mm.The hexagonal fractal antenna has designed with substrate height=1.6 mm, Loss tangent tan ɗ =0.019 and dielectric constant εr=4.4 second iteration a small hexagonal shaped slot has made at it's centre. In third iteration further miniaturization creates eight smaller hexagons around a central hexagon. Coaxial feeding has used for excitation of an antenna with probe diameter of 3.0mm Results has observed at centre frequency for 2.5GHz and around of it. Because of these smaller hexagons inside the radiator patch, it increase surface current length and thereby increases in total conductivity in the patch which results in strong radiation.



Ist Iteration IInd Iteration

IIIst Iteration IVth Iteration

Fig. 1 Hexagonal microstrip antenna with four iterations where a =29 mm, b = 59mm, c = 23.1 d = 11.6mm, e =4.35mm, f = 8.7mm, g = 114 mm.

2. ANTENNA CHARACTERISTICS
The hexagonal fractal antenna is implemented in the corner fed configuration with overlapping vertices to preserve the electrical self-similarity paramount in multi band design. When

viewed from the corner input, it is apparent the hexagonal fractal presents similar scale lengths of one third and, therefore, it can generate resonant frequencies with a power of three [6]. The proposed antenna design exhibits log periodic frequency nature. The smaller hexagons within the hexagonal fractal antenna are interconnected to maintain conductivity and to preserve electrical self-similarity. Due to this characteristics proposed antenna geometry resembles Sierpinski Gasket antenna. Although proposed design can be looks similar to that of Sierpinski Gasket fractal antenna, but the hexagonal fractal antenna resonant frequencies repeat with a factor of three whereas the Sierpinski gasket antenna resonant frequencies repeat with a factor of two.

Parametric analysis and fast sweep in HFSS yield the exact length at 2.5GHz. Next, using a small ground plane and an extra length, along with de-embedding, one can have the exact input impedance at the transition. This impedance can then be exported to any circuit simulator to design a suitable matching network. The structure is then put together, along with the SMA edge connectors and simulated in HFSS.

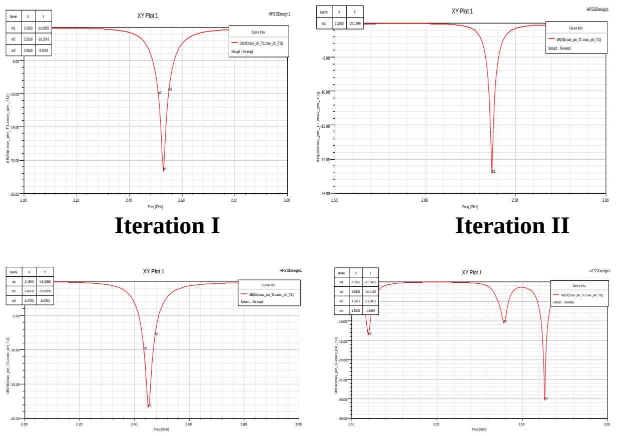
By connecting fractal shaped antennas, wideband coverage can be achieved [5]. Key benefits of Hexagonal fractal antennas are reduced size and compactness. Furthermore, this fractal antenna design allows controlling of characteristics such as location of frequency bands, radiation pattern and entire bandwidth owing to feeding technique and antenna geometry variations [8].

Circular equation was used to calculate the actual distance, *a* of the hexagonal radiating patch antenna to match at 2.5GHz and around of it which is given below.

$$a = \{[1 + (2h/\pi \varepsilon r F)]\ [(lnF/2h) + 1.7726]\}$$

3. SIMULATION RESULTS

The first three iterations of the corner-fed hexagonal fractal dipole are measured and have been examined using the finite element method (FEM). The reflection coefficients (Return Loss) for the first three iterations of the hexagonal fractal antenna are plotted in Fig. 2. The Hexagonal fractal Antenna produced a high return loss compared to the Sierpinski Carpet Fractal Antenna.



Iteration I **Iteration II**

Iteration III **Iteration IV**

Fig. 2 Return Loss of respective three iterations

Details of the resonant frequency are listed in following table for the second iteration of the hexagonal fractal antenna. Aside from the first resonant frequency, hexagonal fractal antenna produces recurring resonant frequencies with a factor of about 3.

TABLE I

Iterations	Centre Frequency(GHz)	Return Loss(db)	Return Loss Bandwidth(GHz) %
I[st]	2.53GHz	-21.89db	1.58
II[nd]	2.45GHz	-18.39db	1.63
III[rd]	2.37GHz	-22.17db	1.26
IV[th]	1.59 GHz	-13.78 db	1.88
	2.39 GHz	-10.58 db	0.83
	2.63 GHz	-30.41 db	1.52

Proper Return Loss has observed at third iteration, An approximate resonance frequency is selected for the proposed hexagonal fractal antenna by using following equation.

$$f_n \approx \frac{0.168.c}{[l.\delta^{n-2}]}, \quad 2 \le n \le k+1$$

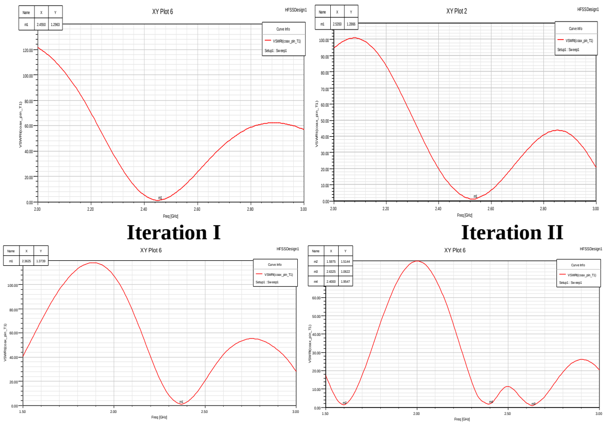
where *C* is the speed of light, *L* is the hexagon side length, *δ* is the scale factor, *n* is the resonance, and *k* the fractal iteration. Although resonance frequency 2.50GHz has considered according to the above equation, but due to various practical issues a centre frequency around 2.5 GHz has considered during the various observations. It has observed that proper impedance matching has obtained at 2.37GHzis used for third iteration.

Similar to that of Return Loss, voltage standing wave ratio (VSWR) has also observed for various iterations with various centre frequencies. These observations are tabulated in following table.

TABLE II

Iterations	Resonance Frequency(GHz)	VSWR	VSWR Bandwidth (%)
I[st]	2.53GHz	1.266	1.64
II[st]	2.45GHz	1.296	1.53
III[st]	2.37GHz	1.373	1.59
IV[th]	1.59GHz	1.514	1.93
	2.63GHz	1.062	0.70
	2.40GHz	1.954	1.83

It can be observed from table, VSWR at first iteration is very large and beyond the limit. At first iteration radiating patch is simply work as hexagonal radiating patch of a microstrip antenna and because of improper maintenances of conductivity in antenna, VSWR is inaccurate. VSWR plot of antenna for three iterations has shown below in Fig.III

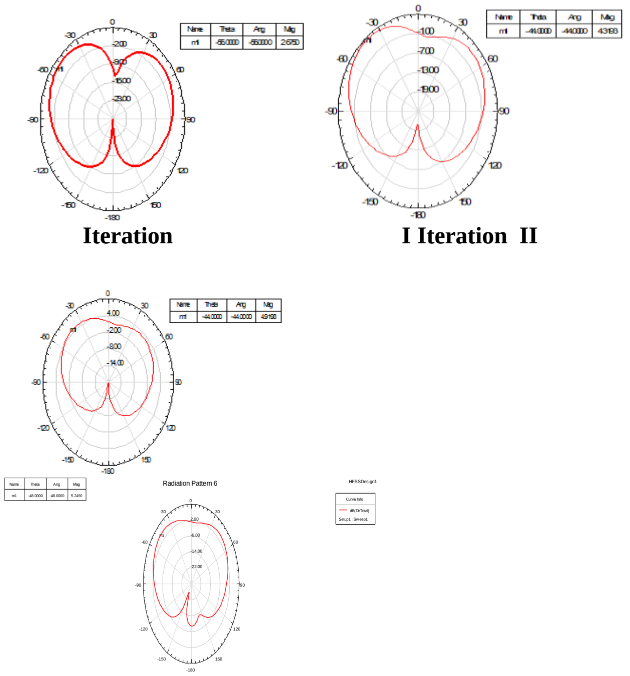


Iteration I **Iteration II**

Iteration III **Iteration IV**

Fig. 3 VSWR Plot of respective four iterations

It has observed from the simulations, radiation pattern for first and second iteration is spurious due to excess of back radiation. In second iteration, there is only one hexagon at centre because of it, proper conductivity has not achieved which results in improper impedance matching which results in this spurious radiation. Radiation pattern for various respective iterations has shown in Fig. IV.



Iteration **I Iteration II**

Iteration III **Iteration IV**

Fig. 4 Radiation pattern of respective four iterations

4. CONCLUSIONS

The hexagonal fractal microstrip antenna has designed and discussed. Characteristics of hexagonal fractal microstrip antenna are compared with Sierpinski Gasket fractal antenna..

The hexagonal fractal antenna is observed to possess multiband behaviour similar to the Sierpinski gasket antenna. This new fractal antenna allows flexibility in matching multiband operations in which larger frequency separation is required. It is possible with this fractal to shape and update the radiation pattern according to the environment in real time, with the aid of control algorithms, making it steerable. The simulated results have shown a good radiation structure, which has high directivity and gain, when compared to a simple patch antenna. The return loss measurements show an excellent dip and suitable bandwidth. The directivity and the gain are directly proportional to the number of fed array elements.

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