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Design and Implementation of Fractal Antenna for SWB Applications

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***Abstract*—**This paper focuses the design and analysis of star triangular fractal antenna. The designed structure offers maximum gain and bandwidth ratio greater than 10:1 for SWB (2.18 to 44.5 GHz) applications. The purpose of the iteration is to reduce the size of the fractal antenna. The proposed antenna has been analysed for the part of SWB band from 1 GHz to 30 GHz. The proposed antenna structure can be designed using design equations and simulated using computer simulation technology (CST). Finally prototype has been developed and parameters are measure using network analyser. The observed results show that the proposed antenna structure can be used for wideband wireless communication applications with minimum loss and excellent radiation.

***Keywords*—** Super Wide Band Antenna, Microstrip patch, Fractal antenna, Return loss, Directivity, Gain.

I. INTRODUCTION

The miniaturized wideband antennas are used widely in modern communication systems. Fractal geometries can be used to fabricate multi-band and broad-band antennas. One of the main components of super wideband communication systems is a SWB antenna. Applying fractals to the antenna elements allows for smaller size, multiband and broad band properties. The term fractal, which means broken or irregular fragments, each of which having reduced size and copy of the whole. A fractal is a rough or fragmented geometric shape that can be subdivided into parts, each of which is reduced in size and copy of the whole. There are many mathematical structures that are fractals as Sierpinski's gasket, Cantors comb, von Koch's curve etc. Fractals also describe many real-world objects, such as clouds, mountains, turbulence and coastlines that do not correspond to simple geometric shapes [1-5]. The geometry of the fractal antenna encourages its study both as a multiband solution and also as a small antenna. First one can expect a self-similar antenna to operate in a similar way at several wavelengths. Small antennas are of prime importance in communication systems because of the available space limitation on devices and the deployment of diversity and multi-input multi-output (MIMO) systems.

The antenna geometry optimization includes modified ground plane leads miniaturization and to maintaining the good antenna performance in terms of bandwidth and efficiency. However the classical small antennas suffer from inefficient performance. Fractal geometry provides the solution by designing compact and multiband antennas in a most efficient and sophisticated way. A fractal can fill the space occupied by the antenna in a more effective manner than the traditional Euclidean antenna [6-7]. This leads to more effective coupling of energy from feeding transmission lines to free space in less volume. Fractal antennas show multiband or log periodic behavior that has been attributed to self-similar scale factor of the antenna geometry [8-9]. Fractal loop shows improved impedance and SWR performance on a reduced physical area when compared to non-fractal Euclidean geometries. In order to enable more operating bands within lower spectrum, a higher scaling factor is required. Fractal antenna represents a class of electromagnetic radiators where the overall structure is comprised of a series of repetition of a single geometry and where repetition is at different scale.

II. STRUCTURE AND DESIGN

Fractals have self-similar shapes and can be subdivided in parts such that each part is a reduced size copy of the whole. Self-similarity of fractals causes multi-band and broad-band properties and their complicated shapes provide design of antennas with smaller size. Fractals have convoluted and jagged shapes with many corners that these discontinuities increase bandwidth and the effective radiation of antennas [10-11].


Fig.1. Examples of fractals that can be found in nature

Fractals can be placed long electrical length in to a small area using their ability of space-filling. Fractal is a geometric shape that has the property of self-similarity which is each part of the shape is a smaller version of the whole shape. Fractals also model many natural objects and processes. The Figure1shows that the example of fractals that can be found in nature. A fractal is a mathematical set that has a fractal dimension that usually exceeds its topological dimension and may fall between the integers. Euclidean geometries are limited to points, lines, sheets, and volumes, fractals include the geometries that fall between these distinctions. Therefore a fractal can be a line that approaches a sheet. The line can meander in such a way as to effectively almost fill the entire sheet. These space filling properties lead to curves that are electrically very long, but fit into a compact physical space. This property can lead to the miniaturization of the antenna elements. Fractals are self-similar. They represent a class of geometry with very unique properties that can be enticing for antenna designers.

The fractals can be used in two ways to enhance antenna designs. The first method is in the design of miniaturized antenna elements. These can lead to antenna elements which are more discrete for the end user. The second method is to use the self-similarity in the geometry to blueprint antennas which are multiband or resonant over several frequency bands.Vorya Waladi etal (2014) describes the novel printed star-triangular fractal microstrip-fed monopole antenna with semi elliptical ground plane is presented for super-wideband (SWB) applications. In comparison to the previous SWB and fractal antennas, the antenna dimension has a compact size of 20x20x1mm^3 with the operating frequency band between 1 to 30 GHz for the acceptable voltage standing wave ratio less than two. In this paper existing star triangular fractal with outer loop shape antenna is modified by changing the regular geometry of ring into hexagonal one. By modifying the shape it will resonate at different frequencies so that it can be used for SWB wireless communication applications. Hexagonal microstrip patch antenna is one of the various shapes capable for circular polarization. The design of hexagonal microstrip antenna can be done by using variation of static energy below hexagonal circular ring patch. The relationship between the equivalent areas of circular and hexagonal patches [6] in given by the equation (1) and equation (2).

$$a_e = a\left[\left\{1 - \frac{2h}{\pi a \varepsilon_r}\left(\ln\frac{\pi a}{2h} + 1.7726\right)\right]\right]^{1/2} \quad (1)$$

$$\pi a_e = \frac{3\sqrt{3}}{2} s^2 \quad (2)$$

Where,

s is side of hexagonal patch.

ε_r is the relative permittivity of the substrate.

h is the height of the substrate.

a_e is effective radius of circular patch.

The geometry of the antenna composed of a microstrip triangular fractal (MSTF) patch with semi ellipse shaped ground plane. The proposed MSTF antenna with specified dimension of 20x20 mm^2 is printed on FR4 substrate with relative permittivity of 4.3, loss tangent of 0.02, and thickness of 1 mm. To achieve a better impedance matching that results in bandwidth enhancement, the technique of loading a rectangular notch with dimension of 2.6x2 mm at the feeding position in the ground plane is introduced. The width and length of the microstrip feed line to achieve 50Ω characteristic impedance is fixed at 2.1 mm and 4.8 mm, respectively. Due to the increasing fractal iteration on the fractal patch, it is expected that the bandwidth of the antenna will be increased. The fractal patch printed on the top surface of the substrate to the ground plane. Semi elliptical ground plane is used for impedance matching. The length of the ground plane is 6.6mm, and the width is 20 mm, which is equal to the width of substrate. The geometry of basic circular triangular patch fractal antenna is shown in the Figure2.

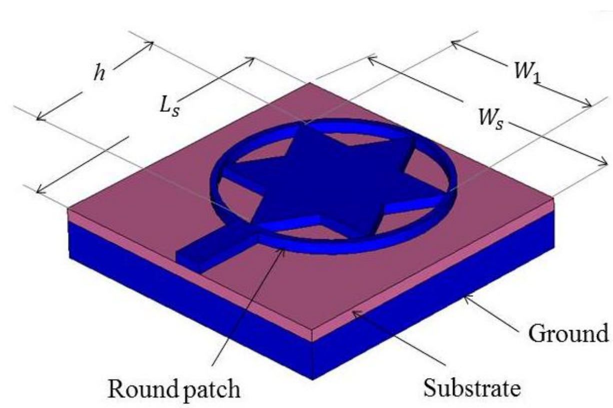

Fig.2. Geometry of circular triangular fractal antenna with normal ground plane

The Star triangular fractal antenna designed using CST STUDIO SUITE 2011. The main parameters involved in this design are, frequency of operation and the dimension of the antenna such as length of the substrate, width of the substrate and thickness of the substrate. The semi elliptical ground planes are used to improve the performance of proposed fractal antenna structure. The simple semi ellipse ground plane acts as an impedance-matching circuit [10]. The parameters and are two prominent factors of the proposed microstrip triangular fractal patch antenna's third iteration, which are optimized to obtain the most impedance bandwidth and better impedance matching. As the ground length increases, the impedance bandwidth increased up. The small changes in the width of the gap between the fractal patch and the ground plane has a great effect on the impedance matching of the fractal antenna's third iteration. Figure 3 shows the modified proposed micristrip triangular fractal patch antennas for SWB applications. Table 1 shows the designed parameters of the proposed star triangular fractal antenna during simulation. Figure 4(a-d) shows the proposed antenna structure with iterations, each iterations the performance of the antenna got improved. Previous works [7-8] concentrated only two iterations with circular patch.

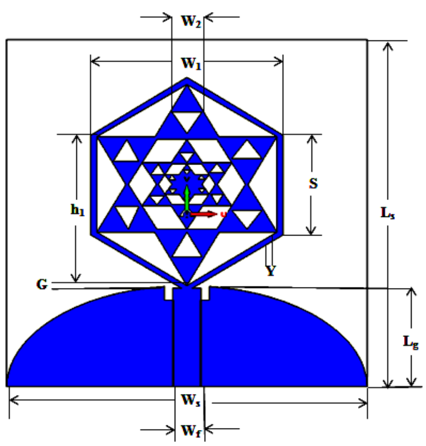

Fig.3. Geometry of circular triangular fractal antenna with semi elliptical ground plane

Table.1. Dimensions of hexagonal triangular fractal antenna with semi elliptical ground plane

Parameter	Description	Optimal value
W_s=W_g	Width of the antenna	20 mm
L_s	Length of the antenna	20 mm
S	Each side of the hexagonal	4 mm
Y	Space between two hexagonal	0.4 mm
G	Distance between patch and ground plane	0.2 mm
L_f	Width of the fed line	2.1 mm
W_1	Width of the element triangular	12 mm
W_2	One face of primary slot	1.7 mm
L_g	Length of the ground plane	6.6 mm
L_f	Length of the fed line	4.8 mm
H	Height of the element triangular	10.3mm

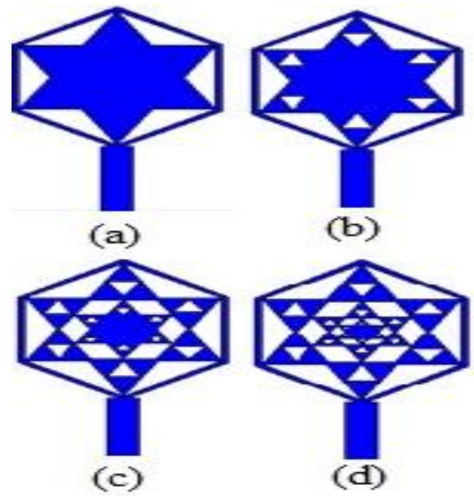

Fig.4. Structure of circular triangular fractal antenna a) without iteration b) iteration1 c) iteration2 d) iteration3.

III. RESULTS AND DISCUSSION

Figure 5 and Figure 6 shows the surface current distribution of the proposed hexagonal fractal antenna for different frequencies. The observed results show that the radiation is maximum at the bottom side of the hexagonal fractal microstrip patch antenna. Figure 5 to Figure 8 shows the electric and magnetic field distributions of proposed antenna structure for different operating frequencies. Figure 9 and Figure 10 shows the return loss and voltage standing wave ratio plot of proposed hexagonal fractal antenna, which shows that the losses are minimum with acceptable voltage standing wave ratio. Figure 11 to Figure 13 shows the three-dimensional radiation pattern of proposed fractal antenna with different operating frequencies. The observed results are tabulated in table 2, which shows that the radiation efficiency, directivity and gain are good for entire operating frequency for the proposed fractal antenna

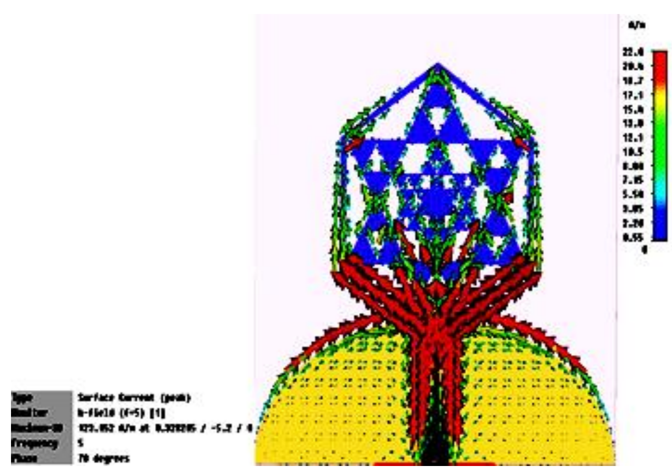

Fig.5. Surface current distribution of the proposed microstrip hexagonal fractal antenna at 5GHz

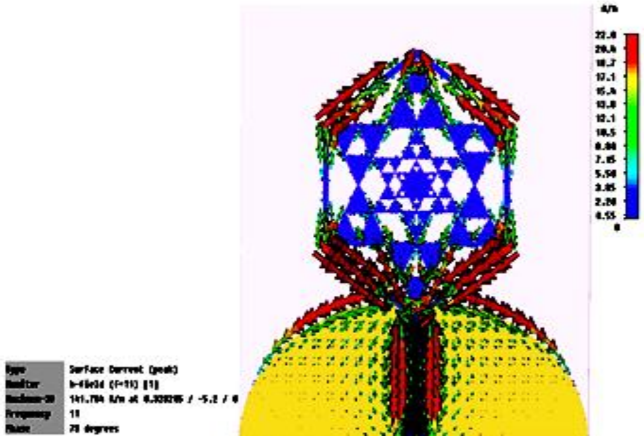

Fig.6. Surface current distribution of the proposed microstrip hexagonal fractal antenna at 9.3 GHz

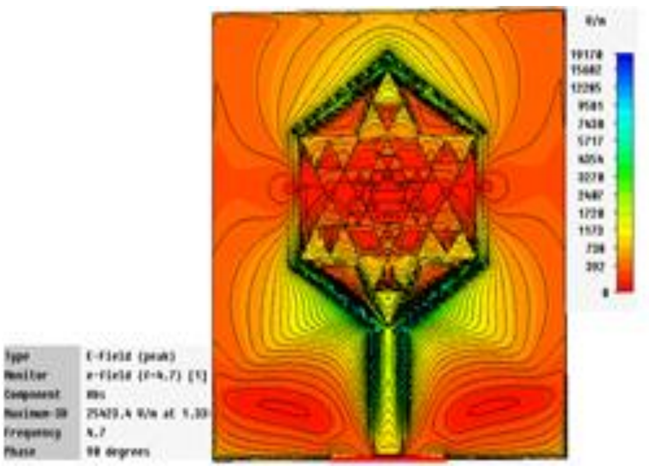

Fig.7. Electric field distribution of the proposed microstrip hexagonal fractal antenna at 4.7 GHz

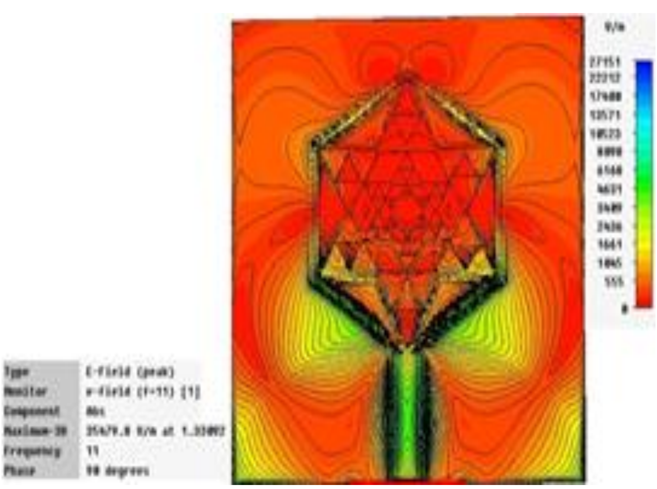

Fig.8. Electric field distribution of the proposed microstrip hexagonal fractal antenna at 11 GHz

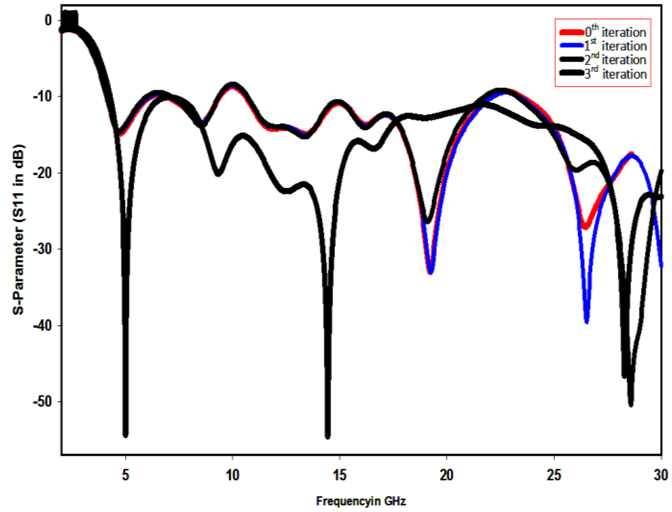

Fig.9. Return loss (S_{11}) plot of the proposed microstrip hexagonal fractal antenna with three iterations.

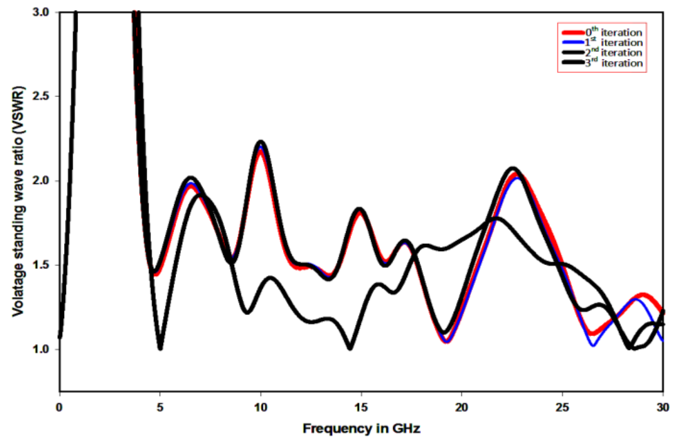

Fig.10. Voltage standing wave ratio (VSWR) plot of the proposed microstrip hexagonal fractal antenna with three iterations.

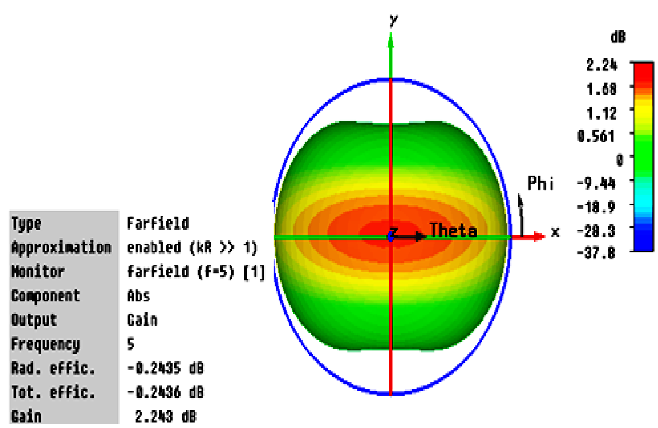

Fig.11. Three dimensional radiation pattern of the proposed microstrip hexagonal fractal antenna at 5 GHz operating frequency.

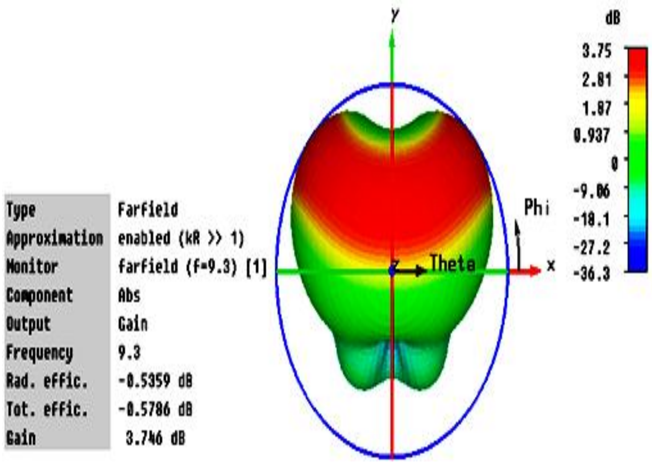

Fig.12. Three dimensional radiation pattern of the proposed microstrip hexagonal fractal antenna at 9.3 GHz operating frequency.

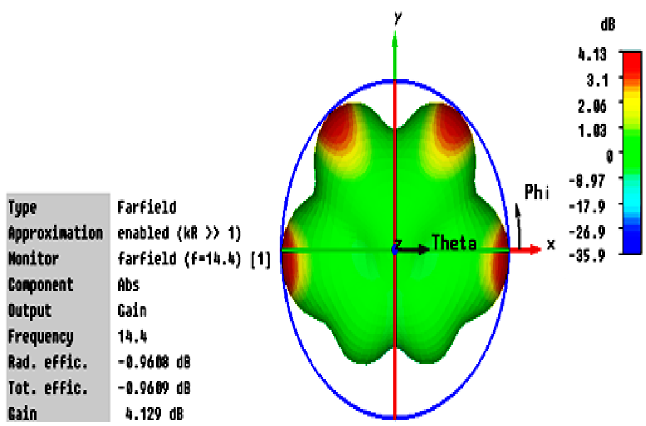

Fig.13. Three dimensional radiation pattern of the proposed microstrip hexagonal fractal antenna at 14.4 GHz operating frequency

Table.2. Extracted parameters of hexagonal triangular fractal antenna with semi elliptical ground plane

Frequency (GHz)	S 11 (dB)	Gain (dB)	Directivity (dBi)	VSWR
5	-55	2.2	2.48	1
9.3	-20	3.7	4.28	1.26
14.4	-55	4.12	5	1.26
28.2	-46	4.12	5.5	1.26

IV. PROTOTYPE OF PROPOSED FRACTAL ANTENNA

The designed hexagonal microstrip fractal patch antenna has been fabricated. Figure 14 to Figure 16 shows the prototype of the proposed fractal antenna (three iterations). The prototype shows that the proposed structure is very small in size compared to a coin. This miniaturized antenna is well suitable for super wide band applications. Figure 17 shows the testing of proposed fractal antenna using Network analyser. The return loss and voltage standing wave ratio results during three iterations are compared and shown in Figure 18 and Figure 19. The observed results shows that the return loss and voltage standing wave ratio are acceptable compared to previous results [1-10]. Figure 20 to Figure 22 shows the simulated and measured return loss during three iterations. There is a trade-off between simulated and measured results due to small fractal size. The observed results show that the proposed antenna structure works under super wide band frequency. Here the testing range of network analyser is only 14 GHz. So the measurement only taken up to 14 GHz, which covers Ultra-Wide Band frequency range. In future the proposed antenna structure can be tested using higher range network analyser to validate entire results. In future increase the number of iterations to improve the performance of the proposed antenna structure.

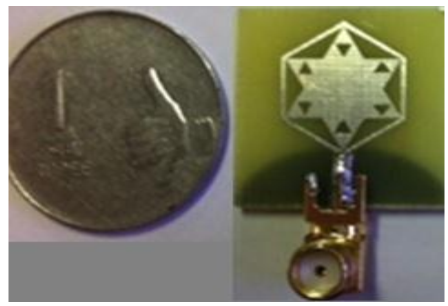

Fig.14. Prototype of the proposed microstrip hexagonal fractal antenna (iteration 1).

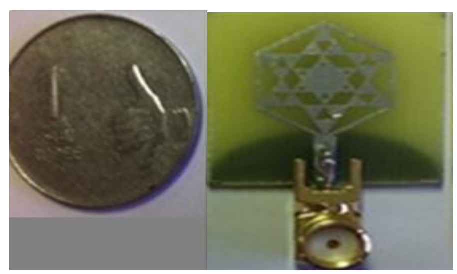

Fig.15. Prototype of the proposed microstrip hexagonal fractal antenna (iteration 2).

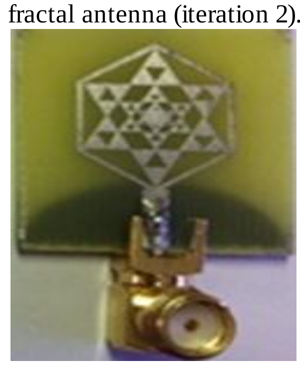

Fig.16. Prototype of the proposed microstrip hexagonal fractal antenna (iteration 3).

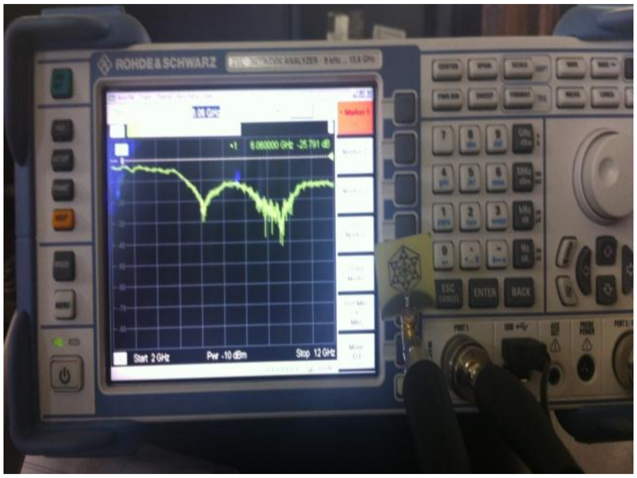

Fig.17. Testing of the proposed microstrip hexagonal fractal antenna using Network Analyzer.

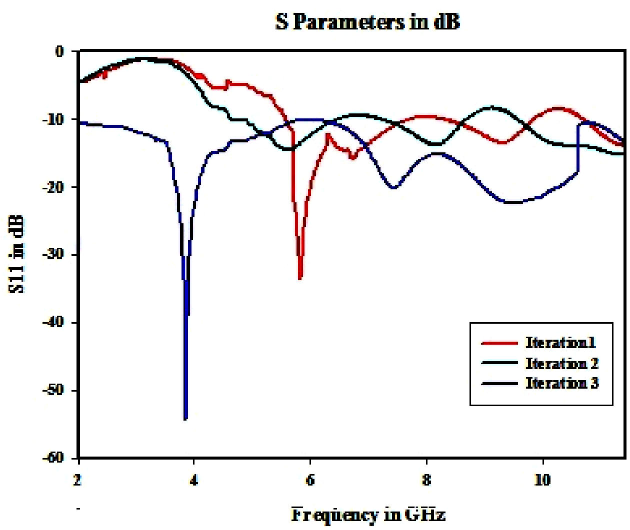

Fig.18. Measured return loss (S_{11}) comparison plot of the proposed microstrip hexagonal fractal antenna.

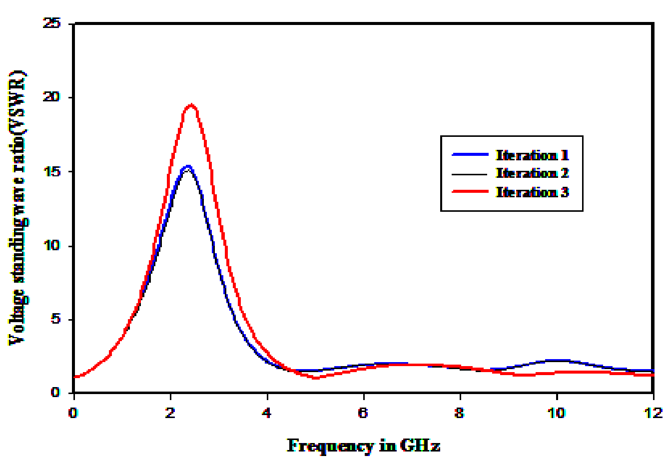

Fig.19.Measured voltage standing wave ratio comparison plot of the proposed microstrip hexagonal fractal antenna.

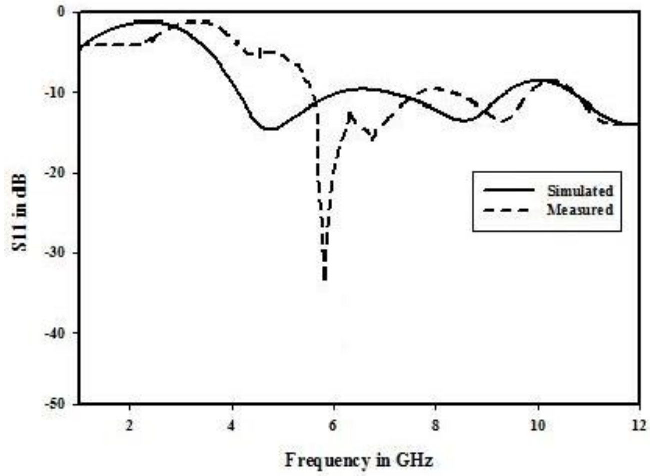

Fig.20. Comparison between simulated and measured return loss (S_{11}) during iteration 1.

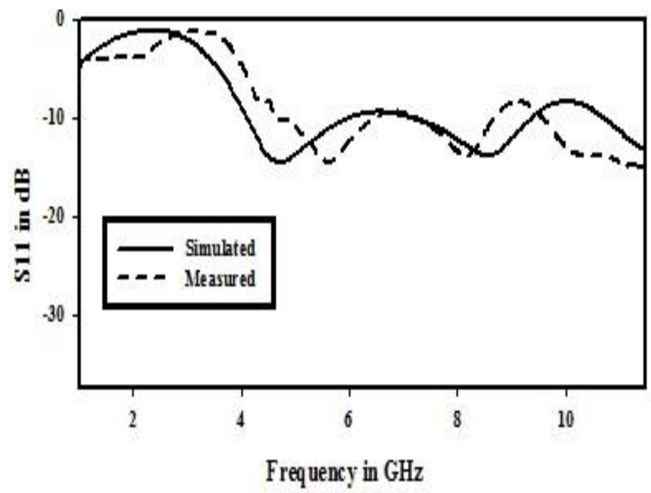

Fig.21. Comparison between simulated and measured return loss (S_{11}) during iteration 2.

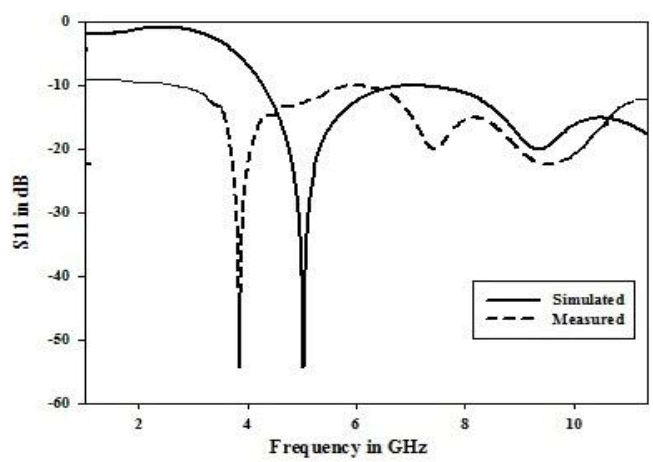

Fig.22. Comparison between simulated and measured return loss (S_{11}) during iteration 3.

V. CONCLUSION

This design focused the modified fractal antenna for wideband application such as Ultra-Wide Band (3.1 GHz to 10.6 GHz) and Super Wide Band (2.18GHz to 44.5GHz). In future the same structure can be undergone for higher order iterations and to improve the performance. The proposed antenna structure is well suitable for wideband military and defense applications.

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