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# Ultra Wideband Fan Shape Fractal Antenna for Microwave Application

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## Abstract

This paper describes the design and simulation of Fan shape fractal antenna using IE3D electromagnetic simulation software. The fractal structure is advantageous in generating multiple frequencies or enhancing bandwidth. fan shape fractal antenna gives better performance in return loss, efficiency and directivity. This fractal antenna can be used in the Wi-Fi. Fractal antenna are very odd in concept and very new in design for wideband applications, many discontinues in the structure add in radiating higher frequencies. This paper proposes the design and simulation of three stages of antenna and the performance characteristics of this three antennas reported in this paper.

**Keywords**: Wideband, fractal antenna, simulation, return loss.

## Introduction

Fractal antennas can be utilized in a variety of applications, especially where space is limited. An example of exploiting the benefits of fractal in antenna systems is the phased arrays, where fractals can reduce mutual coupling and allow for lower scan angles, mobile phone handsets and satellite communications [1].

Since the first fractal antenna was introduced, fractal geometries have been applied to the design of antennas especially for multiband antennas because of its self-similarity. If an antenna is much smaller than the operating wavelength, its efficiency deteriorates drastically, since its radiation resistance decreases and the reactive energy stored in its near field increases [2]. Antenna geometries and dimensions are the main factors determining their operating frequencies [3].

Fractal antennas [4], have very good features like small size and multiband characteristics. Most fractal objects have self similar shape, with different scale [5, 6]. Fractal antennas have shown the possibility to miniaturize antenna structures and to improve the input matching. Certain classes of fractal antennas can be configured to operate effectively at various frequency bands [7]. As a part of an effort to further improve modern communication system technology, researchers are now studying many different approaches for creating new and innovative antennas. One technique that has a received much recent attention involves combining aspects of the modern theory of fractal geometry with antenna design [8].

In this letter examine a novel antenna design which is based on the fan shape, which gives some desirable result for many wireless applications.

## Theory and Design of Small Antenna

The quest for smaller sized resonant antennas has been on for decades. Several of antenna design principles may have to be modified while dealing with small-sized antennas. By convention, a small antenna is defined as one occupying a fraction (typically <1/6) of the wavelength [9]. The primary concern in their design is in the impedance matching. As the length of an antenna is reduced, the real part of its input impedance approaches zero, while the imaginary part tends to be an extremely large negative number. This causes major reflections at the input terminal as the transmission line connected to it generally has a standard characteristic impedance (50Ω).

The reactive part of the impedance is contributed by the induction fields in the near-zone of the antenna [10]. The resistive part on the other hand may be attributed to various loss mechanisms present in and around the antenna, including the radiation “loss”. Losses due to the finite conductivity of the antenna structure, and that due to currents induced on nearby structures including ground contribute to the antenna input resistance.

## Issues in Design of Small Antennas

It is often preferred to operate an antenna around its resonance to obtain proper impedance match with the transmission line. There are several artificial ways of obtaining similar input characteristics without actually increasing the length of the antenna. One is to use reactive elements at the input that cancel out the reactance of the antenna. However this approach often limits the bandwidth of operation of the antenna.

Another method extends the length of the antenna, without actually making it longer. Meandered and zigzag lines are examples of this approach. Bends and corners introduced by this modification adds to the inductance of the line, but does not significantly impact the real part of impedance. Hence the study on small resonant antennas is still ongoing and antenna applications of several fractal geometries have been approached with this objective.

An important issue that remains is the low bandwidth, which in other words is a high quality factor. At resonance, the quality factor is defined as [11], [12]

$$Q = \frac{2\omega W}{P}$$

where *W* is larger of *We* or *Wm* are the time averaged electric or magnetic energy stored in the near field of the antenna. *P* is the radiated power from the antenna. The factor of 2 is used to incorporate the effects of adding additional network components required to make the antenna resonant. This value is reduced by the losses in the tuning elements. It is also stated that for large *Q*, the antenna bandwidth is defined as the reciprocal of *Q* [11]. The minimum *Q* of a small antenna is obtained as [13]:

$$Q_{min} = \frac{1}{2(\beta a)^3} + \frac{1}{(\beta a)}$$

where *a* is the smallest possible sphere that encloses the antenna. In general *Q* is evaluated by treating the antenna as a one port device and obtaining its RLC equivalentcircuit [14].

Another issue that concerns the design of small antennas is radiation efficiency. This is defined as [9]

$$\text{Radiation efficiency} = \frac{Radiation\ PF}{Radiation\ PF + Loss\ PF}$$

Several techniques are available for evaluating the radiation efficiency of small antennas. One of the improved techniques is to enclose the antenna is a special waveguide fixture, by a transmission measurement using a reference antenna [15]. The efficiency is calculated from measured S-parameters.

## Fundamentals of Modeling Techniques Used

This research work relies to a great extent on the modeling studies using commercially available EM simulation softwares such as IE3D,G-NEC and XFDTD. An understanding of the fundamental theory behind these numerical techniques is essential in creating the antenna models and to evaluate the results obtained with them. Hence a brief exposition into the theory behind these techniques is presented in this section.

***A. Method of Moments (MoM)***

The electromotive force (emf) method for calculation of antenna impedance is applicable to a very limited number of antenna configurations. Numerical techniques are essential in more general antenna structures, especially when complicated geometry such as fractals is involved. One very common method in electromagnetics, suitable for antenna analysis as well as for scattering and diffraction problems is the method of moments (MoM) [16]. MoM is a very powerful and versatile technique which can be applied to linear, planar, as well as three-dimensional structures[17]. The method involves segmentation of the antenna structure and choosing suitable basis functions to represent currents on these segments. A set of equations is generated by enforcing the boundary conditions with a suitable set of testing functions. This results in a matrix whose order is proportional to the number of segments on which the current distribution is represented. The solution to the problem is found by inverting this matrix.

***B. Finite Difference Time Domain (FDTD) method***

Although MoM based software is convenient for several cases, it does not incorporate the effects of the dielectric support, if present. Some of the antenna configurations studied during this work used dielectric substrates to improve the antenna bandwidth. Since the properties of these novel materials could be varied by a large order of magnitude, the simulation package to be used should be able to handle these accurately. For example, the moment method based simulation packages such as G-NEC do not handle dielectric materials. In contrast finite difference time domain (FDTD) approaches rely on Maxwell's equations in the difference equation form, and hence are not expected to cause major problems as the dielectric constant of material systems is increased. With this view an FDTD based commercial EM simulation package XFDTD from Remcom Inc. in State College, PA was used in some of the antenna simulations.

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## Antenna Design

In this model, the proposed antennas were designed using FR4 EPOXY substrate. In this fractal antenna height and substrate are same that is h = 2.5 and Ɛr = 4.6 . For feeding, Probe feeding method is used. In all iteration feeding point is same and radius of feeding point is 0.25mm.

In the present work, a fan base is taken and another shape of sierpinski gasket is cut from it. Same procedure is repeated and the result of simulation studies is presented up to second iteration.

In the base shape a fan shape of radius 9mm is taken as shown in figure 1. For the first iteration one sierpinski gasket geometry is cut from every leaf of the geometry as shown in figure 2. In the second iteration three sierpinski gasket geometry is cut from the geometry as shown in figure 3.

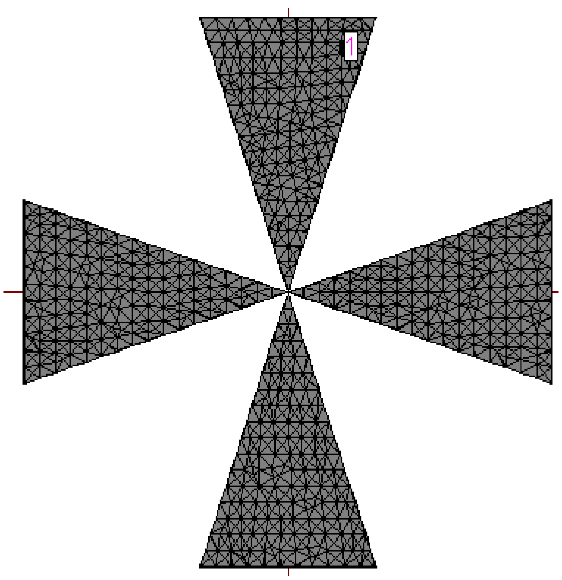

**Fig. 1. Base shape of fan shape fractal antenna**

In the first iteration sierpinski gasket geometry has length and width of 2mm and 3mm respectively. The shape of the sierpinski gasket geometry in second iteration is same as of the first iteration.

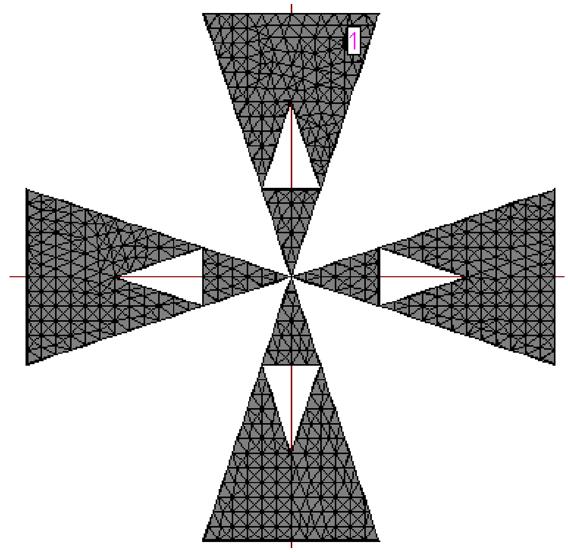

**Fig. 2. First iteration of fan shape fractal antenna**

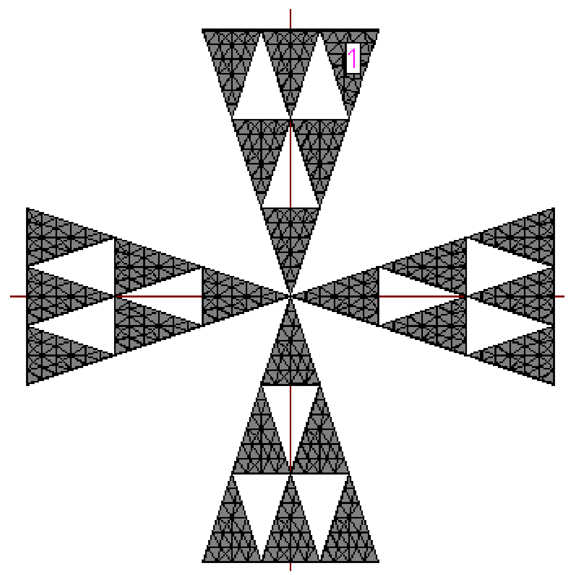

**Fig. 3. Second iteration of fan shape fractal antenna**

## Computer Simulation and Result

For the simulation of RF component design, there exist many types of software, such as HFSS, CST, Fidelity, SuperNEC etc. The structure is designed and simulated using zeland's IE3D simulation software. The resonant frequency for which minimum return loss occurs for various bands with increase in number of fractal since successive iterations.

Figure 4 shows the Return loss versus frequency for base shape. Figure 5 shows the variation of VSWR versus frequency for base shape and figure 6 shows smith chart for base shape. Similar results for successive iterations are shown in figure 7 to figure 12. It is observed that as the number of iterations are increased;

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bandwidth also increase. For the base shape, and first iteration there is no operating band. For second iteration one ultra wideband occurs at 11.5 GHz. As shown in figure 10, in the second iteration, we got the minimum resonant frequency with return loss -32.34 dB at11.5 GHz, whose bandwidth is 52.44 %.

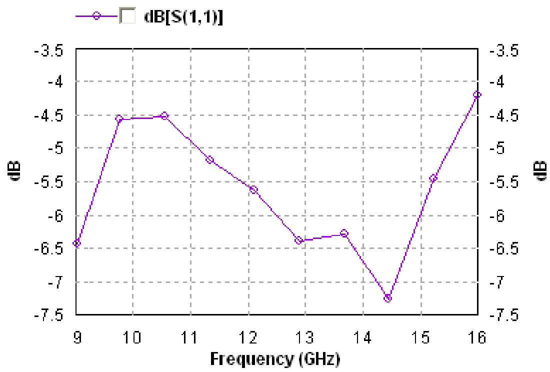


**Fig. 4. Return loss versus frequency plot for base shape**

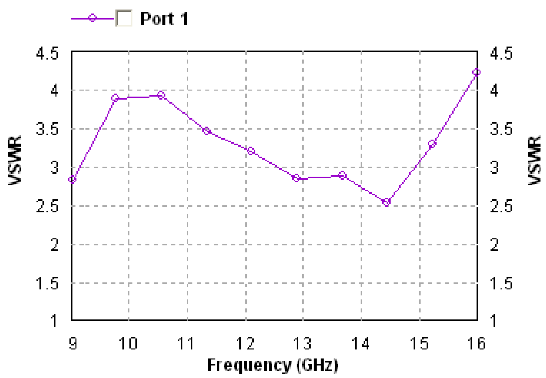


**Fig.**
**5.VSWR versus frequency plot for base shape**

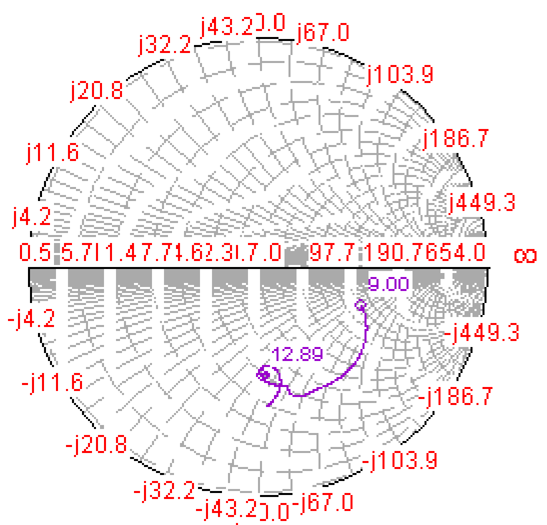

**Fig. 6. Smith chart for base shape**

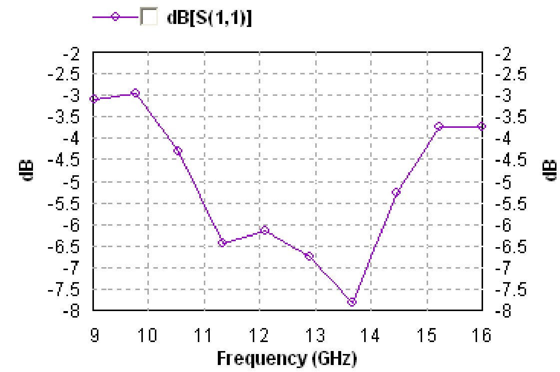


**Fig. 7. Return loss versus frequency plot for first iteration**

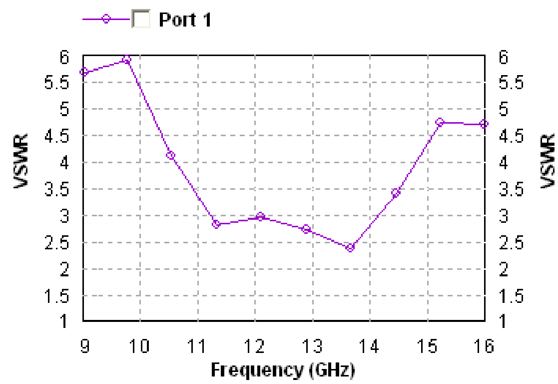


**Fig. 8. VSWR versus frequency plot for first iteration**

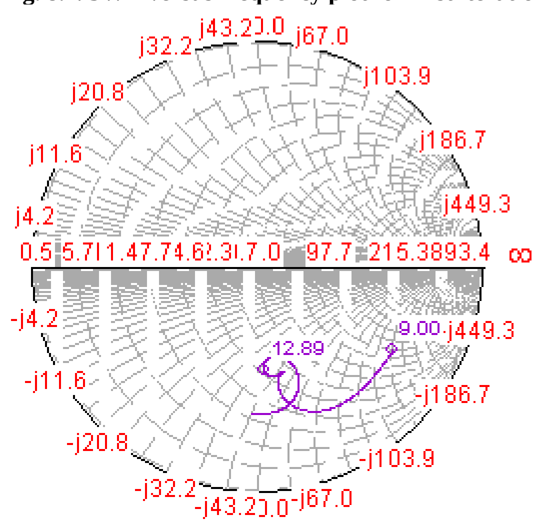

**Fig. 9. Smith chart for first iteration**

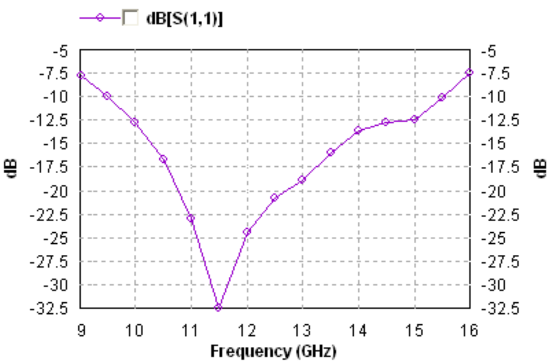


**Fig. 10. Return loss versus frequency plot for second iteration**

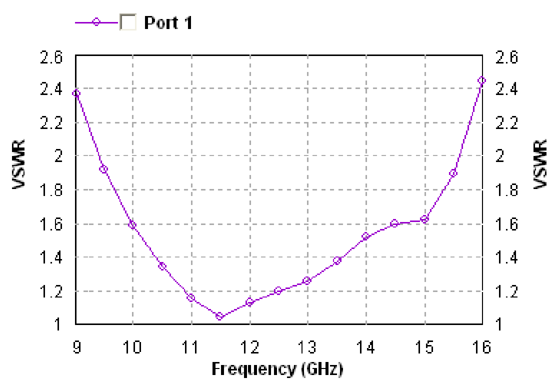


**Fig. 11. VSWR versus frequency plot for second iteration**

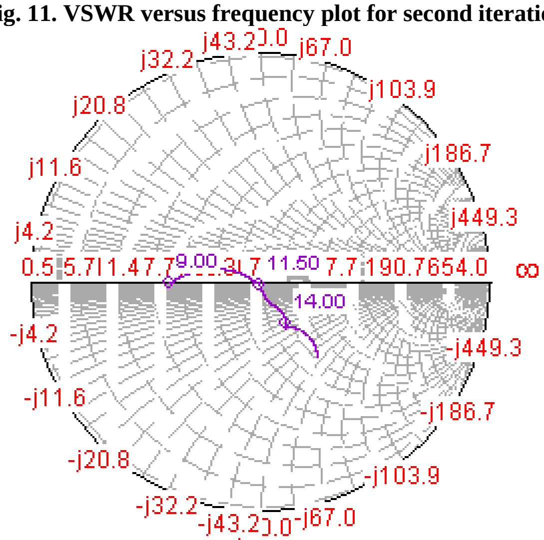


**Fig. 12. Smith chart for second iteration**

## Conclusion

The proposed fractal antenna seems to be an interesting configuration for use in application where a large frequency separation is required. The bandwidth effect changes with the change in resonant frequencies and VSWR is within the accepted level. The second iteration in this paper presents the best performance at frequency 11.5 GHz. At the 11.5 GHz, we got the minimum resonant frequency with -32.34dB return loss and 52.44% band width. This antenna has best performance as comparison with other conventional antennas.

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