Design and Analysis of E-Shape Sierpinskis Fractal Antenna

Sukhveer Singh¹, Savina Bansal² and Sukhjinder Singh³
¹Research scholar, ²Professor and ³Assistant Professor
Department of Electronics & Communication Engineering
Giani Zail Singh PTU Campus, Bathinda (Punjab), India, 151001

ABSTRACT – An E-shape Sierpinski Fractal antenna has been designed & analyzed in this paper using High Frequency Structure Simulator (HFSS). The Sierpinski Carpet geometry has been modified to design the antenna upto 3rd iteration using 1.8 GHz operating frequency. The space filling property of fractal and coaxial probe feed are used to design above said antenna. The feed position is set manually for matching input impedance, positive gain and low return loss. Performance has been analyzed in terms of return loss, VSWR, peak gain, peak directivity and radiation efficiency in the 1 GHz to 10 GHz frequency range. The antenna designed can be used in wide-band and ultra wide-band frequency applications.

Index Terms - E-shaped Sierpinski antenna, Fractal antenna, Microstrip patch, Multiband antenna, Sierpinski carpet.

I. INTRODUCTION

Antenna is the foremost part of wireless communication system used for transmitting and receiving the electromagnetic signal. The antenna types can be classified based on frequency band of operation, physical structure and electrical/electromagnetic design. The requirements of modern wireless communication system are small size, low profile multiband antenna, lesser cost and wider bandwidth. Researchers have suggested the fractal shape used in microstrip patch antenna to meet above said requirements. Many approaches have evolved over the years, which can be used to achieve one or more of these design objectives [9] [5]. Fractal based antenna has gathered lot of attention recently.

The microstrip patch antenna consists of a metallic radiate patch on one side of the dielectric substrate and ground on other side. There are various types of radiation patch shapes etched on substrate such as square, circular, rectangular, triangular, sectoral, annular ring, semicircular, octagon, dipole and elliptical.

The paper is arranged as follows. The Section 2 defines the fractal antenna, different geometries and advantages. The basic concepts behind the design of propose antenna is described in Section 3 and Section 4 presents the simulation results of E-shape sierpinski fractal antenna. The conclusion of the paper is presented in last Section 5.

II. FRACTAL ANTENNA

The Fractal term was firstly used by B. B. Mandelbort (French mathematician) in 1975, also called the father of fractal. The fractal is a Latin word which means broken or fragmented into various irregular shapes or curves [2]. Fractal shapes demonstrate some typical features to meet the requirements of modern antenna such as low profile, multiband behavior, small size, low cost and wider band width. Fractal characterized properties are space filling and self-similarity. Self similarity property denotes that the pattern develops into similar if the portion of the pattern is expanded by a long way. Space filling properties show the way to curves that are electrically very long but fit into compressed physical shape. This can lead to decrease of antenna size and more transformation of energy from transmission line to free space in less volume. Fractal antennas can be designed in many shapes using fractal geometries such as Sierpinski Carpet, Sierpinski Gasket, Minkowaski Loop, Koch Island Mandelbrot Set, Julia Set and Bifurcation Diagrams [4]. Initially the developments of fractal geometry
came from the study of figure 1. For example fractal has been used to model complex nature objects such as galaxies, clouds boundaries, coast lines, forest etc. After the initial work of Mandelbrot and others wide range of applications for fractals developed in many branches of science and engineering. Fractal geometry is mixed with electromagnetic theory for the purpose of discovering new class of radiation, propagation and scattering problems. One of the recent areas of fractal electrodynamics research is in its application to antenna theory and design of antenna.

Researchers have used various fractal geometries for improving the antenna parameter with varying degree of performance [1][3][6][8][10]. In this work E-shape sierpinski fractal antenna has been designed using Sierpinski Carpet class of fractal antenna discussed below.

III. ANTENNA DESIGN

Antenna design for modern wireless applications demands compact size, low cost, simple radiating element, good performance, simple and easy fabrication and suitable feeding configuration. The E-shape Sierpinski Fractal Antenna with coaxial probe feed is designed in this paper to meet above said requirements. The detail for the same is briefly discussed in the following sub-sections.

A. Rectangular Microstrip Patch Antenna

To design E-shape sierpinski fractal antenna firstly rectangular microstrip patch antenna is designed at 1.8GHz operating frequency using High Frequency Structur Simulator (HFSS), substarte material used is with dielectric constant 2.2 and height of substrate is taken as 1.6 mm. The antenna design depends upon dielectric constant of substrate material ($\varepsilon_r$), resonant frequency ($f_c$) and height of substrate (h). The length (L) and width (W) of rectangular patch of RMPA can be determined using following relation [4]:

$$W = \frac{Va}{2f_c} \left[ \frac{\varepsilon_r + 1}{2} \right]^{\frac{1}{2}}$$

(1)

Where

- $Va = speed of light in the vacuum$
- $f_c = resonant frequency$
- $\varepsilon_r = dielectric constant of substrate$

As the waves move through substrate and air, an effective dielectric constant comes into account for the fringing and wave propagation in the line and is given as [4]:

$$\varepsilon_{eff} = \left[ \frac{\varepsilon_r^{+1}}{2} \right] + \left[ \frac{\varepsilon_r^{-1}}{2} \right] \left[ 1 + 12 \frac{\varepsilon_r}{\varepsilon_0} \right]^{\frac{1}{2}}$$

(2)

$$\Delta l = 0.412h (\varepsilon_r + 0.3) \frac{W}{\pi} + 0.264 (\varepsilon_r - 0.258) \frac{W^2}{\pi} + 0.8$$

(3)

$$L = \frac{1}{2f_c \sqrt{\varepsilon_{eff} \sqrt{\mu_0 \varepsilon_0}}} - 2\Delta l$$

(4)

Where

- $f_c = resonant frequency$
- $\varepsilon_{eff} = effective dielectric constant of material$
- $\mu_0 = 4\pi \times 10^{-7} \text{ H/m permeability of free space}$
- $\varepsilon_0 = 8.854 \times 10^{-12} \text{ F/m permittivity of free space}$
- $\Delta l = change in length by fringing effect$

Moreover, ground and substrate length (Ls) and width (Ws) can be determined as [11]:

$$Ws = 6h + W$$

(5)

$$Ls = 6h + L$$

(6)

B. Fractal Design

Fractal antenna geometries are inspired by nature i.e. it possess features of fractals that exists naturally. Sierpinski Carpet geometry [11] has been used here to design E-shape sierpinski fractal antenna upto 3rd iteration. To achieve above objective, firstly Microstrip Rectangular Patch antenna is designed using equations shown in figure 2(a). Next the rectangular patch antenna is divided into 9 equal sub-rectangles and inner most sub-rectangle has been modified (as shown in fig 2(b)) to E-shaped modified sierpinski carpet E-shape iteration 1. Similar steps have been carried out for iteration 2& 3 as shown in
Fig 2(c) and Fig 2(d) respectively and to achieve the design the proposed antenna.

![Fig 2(c) and Fig 2(d)](image)

**Fig. 2 E-shape fractal antenna upto 3rd iteration**

**C. Feeding technique**

Antenna performance depends upon the feeding technique and its suitable position. A feeding technique can be chosen based on factor power transformation between patch and feed point for proper impedance matching. Basically feeding technique can be classified into various categories and some of them are Coaxial Probe Feeding, Microstrip Line Feeding, Proximity Coupled Feeding and Aperture Coupled Feeding [7].

In this work, the coaxial probe feeding techniques has been used because it is easy to fabricate and match, and it has low spurious radiation. In coaxial probe feeding, the inner conductor of the coaxial is attached to the radiation patch while the outer conductor is connected to the ground plane.

**IV. SIMULATION RESULTS**

Simulations of E-shape sierpinski fractal antenna upto 3-iteration has been carried out in terms of return loss, VSWR, peak gain, peak directivity and radiation efficiency at 1.8 GHz using HFSS software in this work. HFSS is a special tool used for the accurate and fast 3D EM (electromagnetic wave) simulation of high frequency range problems.

Experimental results for different iteration represented and briefly discussed below:

**Iteration 0:**

Firstly, simple rectangular patch antenna has been designed using HFSS software (refer figure 3 (a)). After designing, it has been simulated in the range 1GHz to 10 GHz for different parameters (Table 3(b)). It has been observed that there are 7 resonant frequencies ranging between 1GHz to 7 GHz on which antenna can radiate efficiently. At these frequencies antenna gain and return loss is above 3 dB and greater than -13 dB respectively and VSWR lies between 1 and 2. This frequency range can be thus used for different applications of wireless communication systems. Figure 3 (c) and 3 (d) shown return loss vs frequency and VSWR vs frequency for iteration 0 respectively.

![Fig 3(a) HFSS design for iteration 0](image)

**Table:**

<table>
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<tr>
<th>Sr No</th>
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<th>Return Loss (dB)</th>
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<th>Peak Gain (dB)</th>
<th>Peak Directivity (dB)</th>
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**Iteration 1:**

In iteration 1 the one E-slot is cut into the rectangular patch as depicted in Fig 4(a). Table 4(b) represents simulation for iteration 1. There are 16 resonant frequency range between 1 GHz to 10 GHz on which antenna can radiate efficiently. Fig 4(c) and Fig 4(d) shown return loss, VSWR vs frequency for iteration 1 respectively.

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<table>
<thead>
<tr>
<th>Sr No</th>
<th>Resonant Frequency (GHz)</th>
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<th>VSWR</th>
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**Iteration 2:**

The design of iteration 2 is depicted in Fig 5(a), the antenna has been simulated for different parameters ranging from 1 GHz to 10 GHz. Table 5(b) represents simulation for iteration 2. There are 11 resonant frequencies between 3 GHz to 10 GHz on which antenna can radiate efficiently. Fig 5(c) and Fig 5(d) shown return loss, VSWR vs frequency for iteration 2 respectively.

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Fig. 4(a) HFSS design for iteration 1 (b) Table of simulated Result (c) Return loss vs frequency (d) VSWR vs frequency

Fig. 5(a) HFSS design for iteration 2 (b) Table of simulated (c) Return loss vs frequencies (d) VSWR vs frequency
Iteration 3:
The design of iteration 3 for E-shape sierpinski fractal antenna is depicted in Fig 6(a) after extending the 2nd iteration antenna. Table 6 (b) represents of simulation for iteration. There are 10 resonant frequency range between 1 GHz to 9 GHz on which antenna can radiate efficiently. Fig 6(c) and Fig 6(d) shown return loss vs frequency and VSWR vs frequency for iteration 3 respectively.

V. CONCLUSION
E–shape Sierpinski Fractal Antenna at 1.8 GHz frequency has been designed up to 3rd iteration in this paper using High Frequency Simulation Software (HFSS). It has been analyzed for parameters such as return loss, VSWR, peak gain, peak directivity and radiation efficiency. It can be concluded from above simulation results (Iteration 0 to Iteration 3) that E-shape sierpinski fractal antenna can be used as multiband antenna in this range ranging from 1 GHz to 10 GHz.
Moreover it is also observed that E-shape Sierpinski Fractal Antenna possesses wide band characteristics that can be exploited for ultra wide band frequency applications.

References