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Analysis and Designing of the Sierpinski Carpet Fractal Monopole Antenna

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Abstract
In this research paper we have represented the design and analysis of the Sierpinski Carpet Fractal Antenna. Here we have studied the properties of the antenna such as return loss and VSWR and design the sierpinski carpet up to third iteration. Here the FR4 substrate plays a very important role because all the proposed work designed on FR4 substrate.

Keywords
Fractal antenna, Sierpinski carpet antenna, VSWR loss, Return loss.

I. Introduction

Fractal is a very interesting concept that has been proposed by Mandelbrot. It has different and interesting features because of their geometrical properties. Fractal antenna is well-defined as that usages a fractal and self similar design to maximize the length which can transmit and receive electromagnetic radiation in a given total surface area or also volume. Space filling and self similarity both of the properties of the fractal antenna is used in the design of antenna itself, here self similarity means that an object is form of different subunits.

The surface mounted antennas used in the aircrafts, trains, cars, satellite etc. needs to be lighter in weight and reduced in size so that they consume less fuel. In the miniaturization of antenna, the space filling property plays a very significant role.

There are many profits of the fractal to develop various antenna features. The mixture of self similarity and complexity both are very important to design antenna for wideband performance, by applying fractals to antenna elements :

- Wideband frequency band
- Optimized for gain
- Resonance frequency is achieved that are multiband
- Can create smaller antenna size

1. Sierpinski Fractal Antenna

Waclaw sierpinski is one who described the Sierpinski carpet in 1916, it is a plane fractal. The method that is used in the sierpinski carpet fractal antenna is that sub-dividing a shape into smaller replicas of itself, removing one or more replicas (fig 1), and recursively can be extended to other shapes as can be seen in fig 1, as sub-dividing a rectangle into 9 similar rectangle and after that removing the middle rectangle and this is Sierpinski carpet (Fig 1).

(A) Sierpinski Carpet

Here as we can see in fig 1 the sierpinski carpet's structure starts with a square or rectangle. In this process, the square or rectangle is cut into nine similar sub-squares in a 3-by-3 grid after that the central sub-squares are removed as we can see in fig no 1, after that the same procedure is repeated to the remaining eight sub-squares also. Sierpinski carpet is a procedure of all the sets in this sequence i.e. in this process the construction is repeated many times. The various iterations of sierpinski carpet is shown by below Fig.

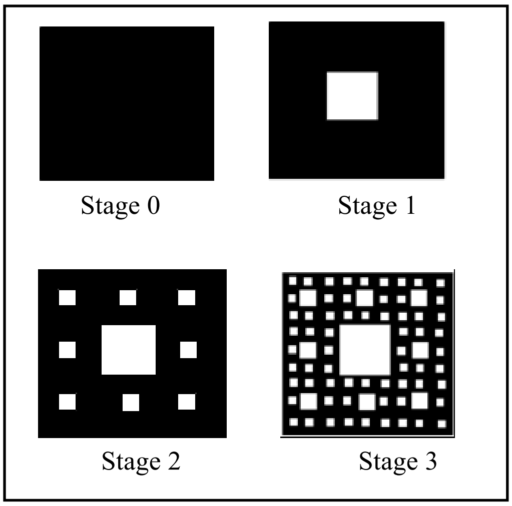

Fig 1. Sierpinski carpet fractal antenna up to third iteration

II. Sierpinski Carpet Antenna Design

The Sierpinski Carpet is the procedure of the Cantor set into the two dimensions, in the construction of this fractal, a square will be divided into nine smaller squares of which one of the squares in the middle will be drop as can see in fig 1. The process continue with subdivided the eight remaining squares in nine small congruent squares in each of which one in the middle will be drop. The process continue as long as the limitation of the subdivided is not too small.

Let N_n be the number of black boxes,
L_n The ratio for the length,
A_n The ratio for the fractional area after the nth iteration
dn is the capacity dimension. Then

$$N_n = 8^n \quad (1)$$
$$L_n = (1/3)^n \quad (2)$$
$$A_n = (8/9)^n \quad (3)$$
$$d_n = -\lim (\text{In } N_n / \text{In } L_n) \quad (4)$$

Here we are using the antenna size for operating frequency of 1.8 GHz is 38 mm x 38 mm. The 1st iteration of sierpinski carpet structure designed is by dividing the square into nine smaller squares and after that removed the square (as can see in fig 1) at the center so that the remaining square is eight. After that, If the scaling factor L1 =0.33, then multiply L, with 38 mm the

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length of the small square is equal to 12.54 mm.
From above equations the results of 1st iteration is:

$$N_1 = 8^1 = 8$$
$$L_1 = (1/3)^1 = 0.33$$
$$A_1 = (8/9)^1 = 0.889$$
$$d_1 = 1.89$$

The 2nd iteration of sierpinski carpet structured was designed by dividing each remaining eight into nine smaller squares. After that drop the whole center square for each remaining square. The remaining smaller square for this stage is 64 ~ is the scale factor for second iteration. When L2 is multiplied by 38 mm the length for the smaller squares is 4.2 mm. using equation (1) to (4)

$$N_2 = 8^2 = 64$$
$$L_2 = (1/3)^2 = 0.111$$
$$A_2 = (8/9)^2 = 0.791$$

The 3rd iteration of sierpinski carpet structured was designed further by dividing each remaining 8 into 9 smaller squares after that drop the entire center square for each remaining square. When L3 is multiplied by 38 mm the length for the smaller squares is 1.702 mm. using equation (1) to (4)

$$N_3 = 8^3 = 512$$
$$L_3 = (1/3)^3 = 0.037$$
$$A_3 = (8/9)^3 = 0.702$$

Here the design of sierpinski carpet is only up to 3rd iteration. This process has been stop due to a very small area. If the area is too small the fabrication will be difficult to be done.

III. Measurement Results

(A) Return loss

Finally the return loss of the sierpinski carpet fractal monopole antenna is achieved. Good performance is reached throughout the frequency band from 0-10 GHz. The best return loss is -27dB at 3.9GHz.

Table 1 : Comparison of return loss at various resonant frequencies for first, second and third iteration

Ref no	Resonating Frequency (GHZ)	Iteration1 Return Loss(db)	Iteration 2 Return Loss(db)	Iteration3 Return Loss(db)
1	1.6	-15	-17	-22
2	3.5	-8	-20	-24.50
3	3.9	-6	-12	-27
4	5.1	-11	-20	-25.50
5	6.3	-3.50	-14.50	-21
6	7.7	-5	-10.50	-22.50

(B) VSWR

VSWR is voltage standing wave ratio that tells about the impedance mismatch, increasing in VSWR indicates an increase in mismatch between the antenna and the transmission line. Decrease in VSWR means that there is a good matching with min VSWR. It is always required for VSWR to be always less than 2.

Table 2 : Comparison of VSWR loss at various resonant frequencies for first, second and third iteration

Ref no	**Resonating Frequency (GHZ)**	**Iteration 1 VSWR (db)**	**Iteration 2 VSWR (db)**	**Iteration 3 VSWR (db)**
1	1.6	3.25	2.50	1.40
2	3.5	7.25	1.75	1
3	3.9	10.50	4.25	0.80
4	5.1	11	1.75	1
5	6.3	12.75	3.25	1.40
6	7.7	11.75	5.50	1.30

IV. Conclusions

A sierpinski carpet fractal monopole antenna was constructed using fractal geometry for wideband applications. The design has been started using a single element equation from patch antenna. When the number of iterations increased the number of resonant frequency will increase. In this design the iteration is at third iteration with the return loss of -27 dB will cover a frequency range from 0 -10 GHz.

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