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Design and Analysis of Sierpinski Carpet Fractal Antenna

Parthsarthi Namdeo[1], Navneet Agrawal[2], Pankaj Yadav[3], Rahul Vishwakarma[4] Gaurav Chaitanya[5]

Department of Electronics & Communication Engineering, A.I.T.R Indore, R.G.P.V Bhopal, Indore (M.P.), India[1,2,3]

Abstract: The combination of fractal geometry with electromagnetic theory has led to useful and innovative antenna designs. This paper presents the design of Sierpinski carpet fractal antenna up to third iteration. The proposed antenna is designed on FR4 substrate with dielectric constant of 4.4. The antenna have been optimized to operate in multiple bands between 5-20 GHz. Sierpinski Carpet Fractal Antenna (SCFA) have been analyzed in term of various parameters like return loss, Total Field Gain, Directivity, Radiation pattern & VSWR etc.

Keywords: Patch Antenna, Fractal, Sierpinski Carpet Fractal Antenna (SCFA),Hyperlynx 3D EM.

I. INTRODUCTION

Fractal is a new class of geometry that was proposed by Mandelbrot.[1] Fractal shape antennas have different and interesting features due to their geometrical properties. A fractal antenna is an antenna that uses a fractal, self similar design to maximize the length, or increase the perimeter of material that can receive or transmit electromagnetic radiation within a given total surface area or volume. [2] Self similarity and space filling properties of fractal antennas is utilized in the design of antennas with characteristics like multiband behavior and miniaturization. Self similarity means that an object is build of sub units and Subunits on multiple levels which try to figure out the Structure of entire object.[3]

Surface mounted antennas in cars, trains, aircrafts, satellite etc., needs to be smaller in size, light weight so that it consumes less fuel. Here space filling property of fractal antenna plays a vital role in the miniaturization of antennas. [4]

There are many benefits when we apply this fractals to develop various antenna elements. The combination of infinite complexity and detail and self similarity makes it possible to design antennas with very wideband performance. By applying fractals to antenna elements [6]:

- We can create smaller antenna size
- Achieve resonance frequencies that are multiband
- May be optimized for gain
- Achieve wideband frequency band

II. SIERPINSKI FRACTAL ANTENNA

The Sierpinski carpet is a plane fractal first described by Wacław Sierpiński in 1916.The technique of subdividing a shape into smaller copies of itself, removing one or more copies, and continuing recursively can be extended to other shapes. Like subdividing a rectangle into 9 congruent rectangle and removing the middle rectangle and this leads to the Sierpinski carpet.[8]

2.1. Sierpinski Carpet

The construction of the sierpinski carpet begins with a square or rectangle. The square or rectangle is cut into 9 congruent subsquares or sub rectangle in a 3-by-3 grid, and the central subsquares or sub rectangle is removed. The same procedure is then repeated to the remaining 8 subsquares. The Sierpinski carpet is the intersection of all the sets in this sequence, that is, the set of points that remain after this construction is repeated infinitely often. The figures below show the first four iterations.[8]

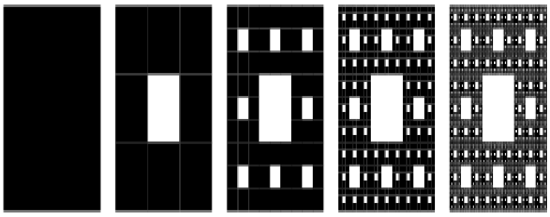

FIG. 2.1 SIERPINSKI CARPET[10]

III. ANTENNA DESIGNING

The design of this antenna starts with a base rectangle of length equal to 27.99mm and width of 37.25mm. Then we removed the rectangle of length 9.33 and width of 12.4 from the centre of base rectangle to get next iteration. This will divide the base in 3 by 3 grids. The size of removed rectangle is 1/3 of the base rectangle now again subdivide remaining of the eight solid rectangles into 9 equal rectangles and remove the center rectangle of length 3.11 mm and width of 4.13 mm from each to obtain second iteration.

Continue the same procedure to get a decreasing sequence and next iteration by using this procedures we have designed three iterations as shown in Figure 2. This basic rectangular patch is designed on a FR4 substrate of thickness 1.59mm. The dimensions of the patch are calculated using the formulas given below [5] [7]:

For base rectangle patch antenna, the area (A(0)) is 27.99x37.25 mm^2. The area of the small square at the center is 9.33x12.4= 115.692 mm^2.This smaller rectangle is ejected out and hence the effective area becomes

A (0) = 1042.6275
A (1) = A (0)-115.692
A (1) = 1042.6275-115.692=926.9355

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Area1= A (1)/A (0)
= 926.9355/1042.6275
= 0.889
Hence the area is reduced by 11.1%.

Similarly after second iteration size is further reduced by 20.8%. [9]

Table I: Designing Parameters

Dielectric substrate(FR4)	4.4
Substrate height	1.59 mm
Width $= \frac{c}{fo}\sqrt{\frac{2}{\varepsilon r+1}}$	37.25 mm
$\varepsilon reff = \frac{(\varepsilon r+1)/2+(\varepsilon r-1)/2}{[1+12\frac{h}{w}]}$	4.08
$\Delta L = 0.412h\frac{[\varepsilon reff+0.3][\frac{W}{h}+0.264]}{[\varepsilon reff+0.258][\frac{W}{h}+0.8]}$	0.732 mm
$Leff = \frac{c}{2fo\sqrt{\varepsilon reff}}$	29.46 mm
L=Leff-2ΔL	27.99 mm

IV. SIMULATION RESULTS & DISCUSSION

The designed antenna is simulated over Hyperlynx 3D EM software as simulation tool, characteristics of Iterated Sierpinski Carpet Fractal Antenna (SCFA) have been analyzed in term of various parameters like return loss, Total Field Gain, Directivity, Radiation pattern & VSWR etc.

4.1 First Iteration

The first iteration of the fractal antenna is designed and its simulated results are shown in figure 4.1.1, 4.1.2 and 4.1.3. After first iteration the Sierpinski carpet antenna resonates at three different frequencies namely 5.3 GHz 7.986 GHz and 14.3 GHz with the return loss of -16.5452 dB, -23.6184 dB and -22.63 dB respectively.

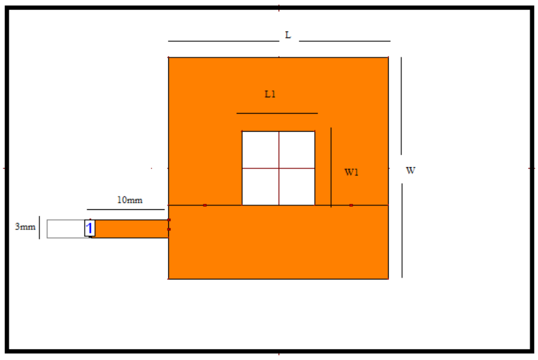

Fig 4.1.1 Iteration 1

L=27.99 mm W=37.25 mm
L1=9.33 mm W1=12.4 mm

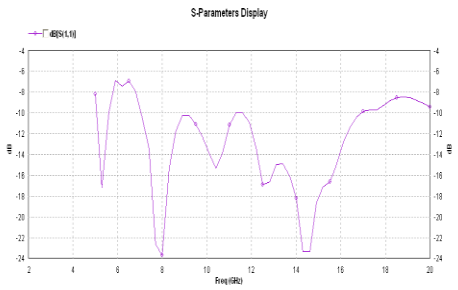

Fig. 4.1.2 Iteration 1 S-Parameters

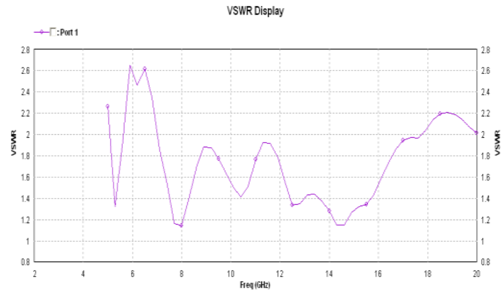

Fig. 4.1.3 Iteration 1 VSWR

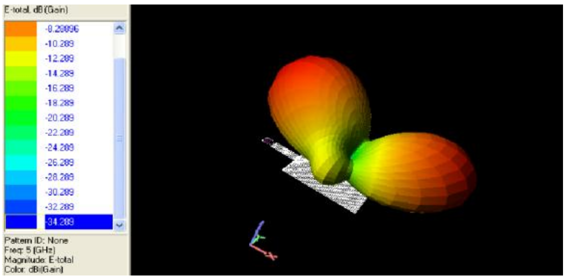

Fig. 4.1.4 Iteration 1 Radiation Pattern

4.2 Second Iteration

The second iteration of the fractal antenna is designed and its simulated results are shown in figure 4.2.1, 4.2.2 and 4.2.3.At second iteration Sierpinski carpet antenna exhibits the multiband characteristics at 5.3GHz, 7.4 GHz and 14.6 GHz with the return loss of -17.7146 dB, -24.7308 dB and -23.3808 dB respectively.

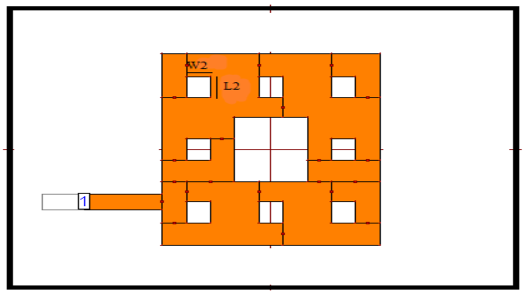

Fig. 4.2.1 Iteration2

L2=3.11 mm W2=4.13

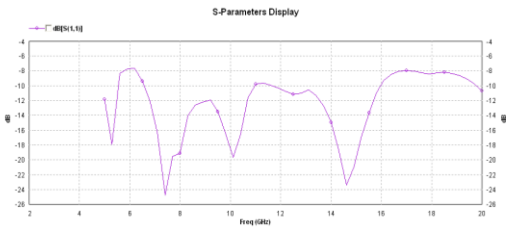

Fig. 4.2.2 Iteration 2 S-Parameter

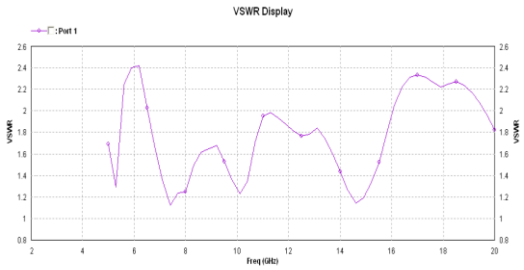

Fig. 4.2.3 Iteration 2 VSWR

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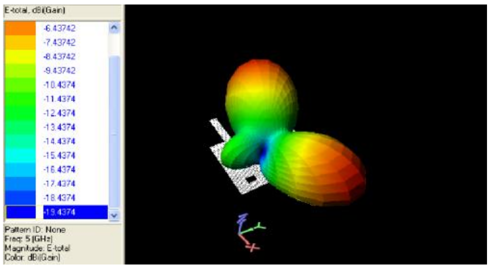

Fig. 4.2.4 Iteration 2 Radiation Pattern

4.3 Third Iteration

The third iteration of the fractal antenna is performed and its simulated results are shown in figure 4.3.1 and 4.3.2. At third iteration the Sierpinski carpet antenna resonates at three different frequencies namely 5.3 GHz 7.4 GHz and 14.6 GHz with the return loss of -15.8802 dB, -26.3595 dB and -26.598 dB respectively.

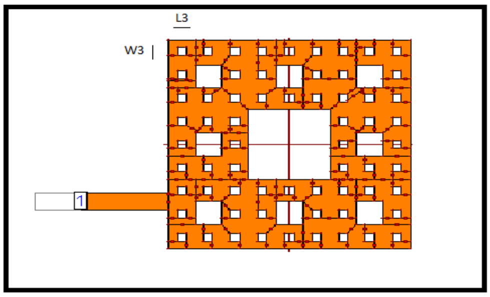

Fig. 4.3.1 Iteration 3

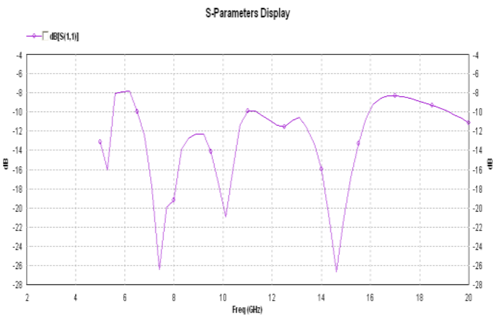

Fig. 4.3.2 Iteration 3 S-Parameter

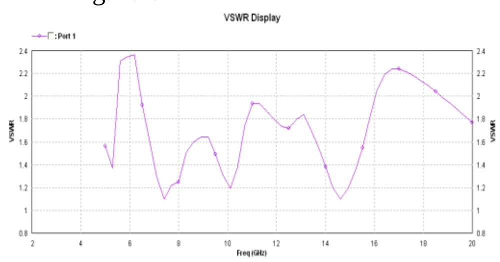

Fig. 4.3.3 Iteration 3 VSWR

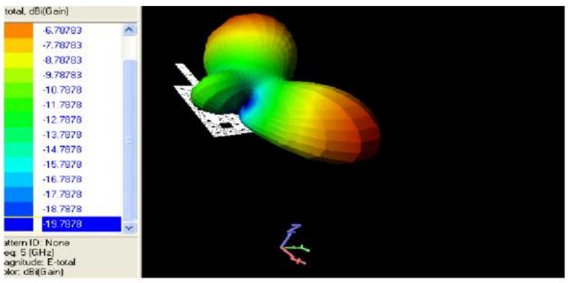

Fig. 4.3.2 Iteration 3 Radiation Pattern

V. TABLE OF RESULTS

Iterations	Frequency point (GHz)	Gain (dB)	VSWR (dB)
1	5.32	-16.5452	1.37624
	7.986	-23.6184	1.14122
	14.307	-23.3215	1.14644
2	5.3	-17.7146	1.31252
	7.4	-24.7308	1.12315
	14.6	-23.3808	1.14537
3	5.3	-15.8802	1.39493
	7.4	-26.3595	1.10103
	14.6	-26.598	1.10463

VI. CONCLUSION

Sierpinski's carpet antenna is an extension of micro strip patch antenna. In this paper, micro strip Sierpinski carpet antenna is designed and iterated up to third iteration to exhibit multiband behavior. The simulated result shows that the antenna is suitable for 5.3/7.4/7.9/14.3/14.6 GHz wideband applications. As the iterations increase, the gain of antenna increases and VSWR decreases. Proposed antennas can be used for secure communication purpose and in applications like Wi- Max and Wi-Fi. They are also easy to fabricate and smaller than conventional antennas of similar performance, thus being optimal for pocket-sized mobile phones.

Sierpinski carpet with 1/3 iteration factor the size of the patch decreases by 33.9% of the base micro strip antenna.

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