Design and Analysis of Multiband Sierpinski Carpet Fractal Antenna for Wireless Communications

Rajiv Krishna Prasad[1], Architha Kishore[2], P Nagaraju[3]

[1, 2]B.E Students, Dept. of Telecommunication Engineering, R. V. College of Engineering, Bengaluru, India

[3]Associate Professor, Dept. of Telecommunication Engineering, R. V. College of Engineering, Bengaluru, India

Abstract: ***In modern wireless communication systems, antennas that are robust, mechanically simple and yet compact are increasing in demand. Likewise, antenna systems with multiband properties are greatly desired over the traditional types. This has stimulated antenna investigation in various fields; one among them being usage of the fractal shaped antenna elements. Fractal geometries radiate electromagnetic energy effectively and have features that have an added advantage over conventional antennas. In this paper a Multiband Sierpinski Carpet fractal antenna is constructed for four iterations at an operating frequency of 2.40 GHz. ANSYS HFSS firmware has been utilized for simulation and analysis. The antenna parameters; VSWR, Gain, Directivity and Radiation Efficiency have been attained. In addition, improvement in Return Loss property was observed with increase in iterations. But this improvement begins to disappear after the third iteration.***

Keywords: Fractal MPA, Iteration, Return Loss, Sierpinski Carpet

1. Introduction

The progression of wireless technology in the recent times has led to a greater need for prudent, sturdy and compact multiband antennas for industrial and commercial applications. Fractal antenna systems provide a feasible solution to this requirement as they integrate self-similarity as well as self-affinity in their geometry. Fractal patch antennas noticeably miniaturize the patch antenna, thus improving the compactness of the system [3]. In terms of performance as antenna elements, fractal shaped geometries when incorporated in antenna systems, result in multi-band and wide-band characteristics. Consequently a single fractal antenna can be used to operate over a spectrum of frequencies.

In orthodox microstrip patch antennas, multiple frequency band operations can be obtained by using multiple radiating elements or reactively loaded patch antennas. Even so the usage of a fractal patch antenna, whose self-similarity property is used to achieve multiband operations, yielded a vast improvement. The major assets of fractal patch antennas over classical antenna designs are;

- Multiband Operation
- Miniaturization Property.

Owing to fractal geometry, inductive and capacitive loading can be incorporated sparing the usage of additional reactive components.

2. Fractal Antenna Design

Low profile antennas are developed using the infinite complexity of most fractal shapes.

The Sierpinski Carpet geometry has been used to design the fractal patch antenna and this will be further elucidated in this section.

This geometry is a plane fractal which was first described by Wacław Sierpinski in 1916 [5]. Construction begins with a square which is further split into nine petite congruous squares. The midmost square is then discarded while the other eight are subdivided once again. This procedure is applied to the remaining eight sub squares that can be replicated for multiple iterations [2].

Antennas are designed using a scaling factor. The chosen model has a scaling factor of 3, which means that with every successive iterations the coordinates and dimensions get scaled down by a factor of 1/3 as depicted in Figure 1.

Here, N=8 is the total number of distinct copies present in the design, therefore Fractal dimension, Ds = log(N) / log(r) = log(8) / log(3) = 1.893.

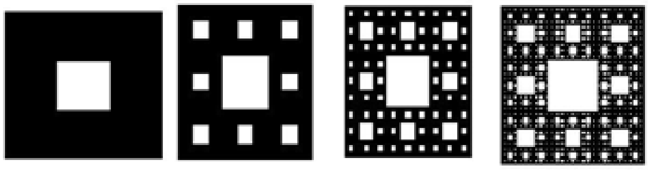

Figure 1: Steps of Iterations to get Carpet Geometry [2]

To make sure that our antenna works uniformly well at all frequencies, we check for two criteria [1];

- The design must be symmetrical over a point
- It must be self similar in nature i.e. must have the basic appearance at every scale, in other words; it has to be fractal in nature.

The reference antenna is a line fed fractal MPA which is designed on FR-4 Epoxy substrate with a Dielectric constant, ϵ_r **= 4.4**, Loss Tangent, **δ = 0.0025** and thickness, **h = 1.6 mm**. The design parameters i.e. Width of Patch (W), Effective dielectric constant (ϵ_{eff}), Effective length (L_{eff})

and Operating frequency (f_r) are calculated using the following;

$$W = \frac{c}{2f_r\sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{\frac{-1}{2}} \quad (2)$$

$$f_r = \frac{c}{2\sqrt{\epsilon_{eff}}\,(L + 2\Delta l)} \quad (3)$$

$$\Delta L = 0.412h\left(\frac{\left(\epsilon_{r_{eff}} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{r_{eff}} - 0.258\right)\left(\frac{W}{h} + 0.8\right)}\right) \quad (4)$$

$$L_{eff} = L + 2\Delta L \quad (5)$$

Length of patch (L) is equal to the Width of the patch (W), which is computed to be 27mm, since the carpet geometry has been chosen. The transmission line model is generally applied for ground planes that are infinite. Nonetheless, when considered for practical situations, having a finite ground plane is necessary. The dimensions for the ground plane are calculated such that it is larger than the patch dimensions by six times the substrate thickness [4]. The antenna patch and the ground plane have been assigned material PEC, i.e., 'Perfect Electric Conductor' [3]. A perfect conductor or perfect electric conductor (PEC) is an idealized material that exhibits infinite electrical conductivity.

The antenna is designed, modeled and simulated for the radiation characteristics in (1 to 10) GHz frequency range.

3. Results

The Return Loss is plotted with respect to Frequency in the X Axis and Return Loss in the Y Axis. Figures 2, 3, 4 and 5 illustrate the Return Loss graphs obtained for four iterations. It can be noted that the Return Loss values have improved in the second iteration in contrast to first iteration by reason of reduced reflections. The multiband characteristics are seen most predominantly in the third iteration. Further, these values tend to become more consistent with increasing iterations. But the improvements begin to diminish from the fourth iteration onwards.

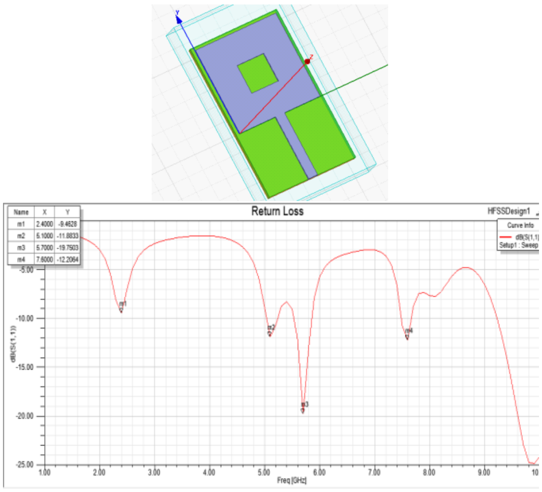

Figure 2: First Iteration

Table 1: First iteration Return Loss Values

Frequency (GHz)	2.4	5.1	5.7	7.6
Return Loss (dB)	- 9.463	- 11.883	- 19.760	- 12.206

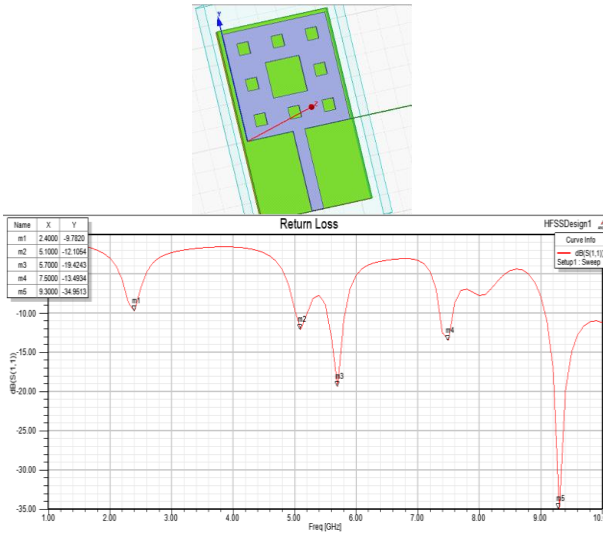

Figure 3: Second Iteration

Table 2: Second iteration Return Loss Values

Frequency (GHz)	2.4	5.1	5.7	7.6	9.3
Return Loss (dB)	- 9.782	- 12.106	- 19.424	- 13.493	- 34.951

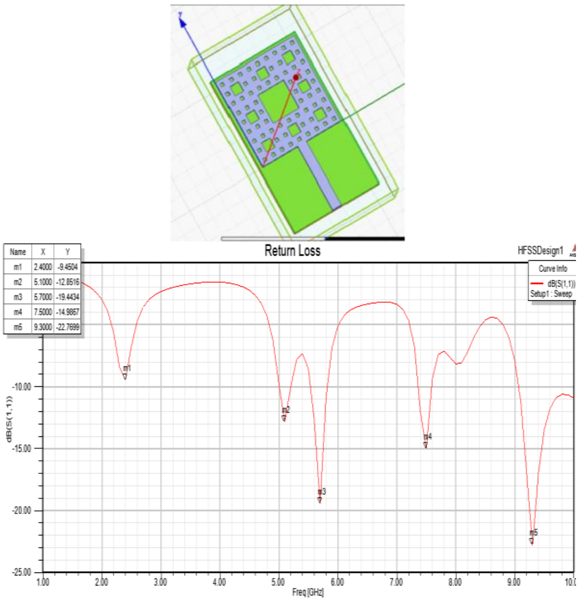

Figure 4: Third Iteration

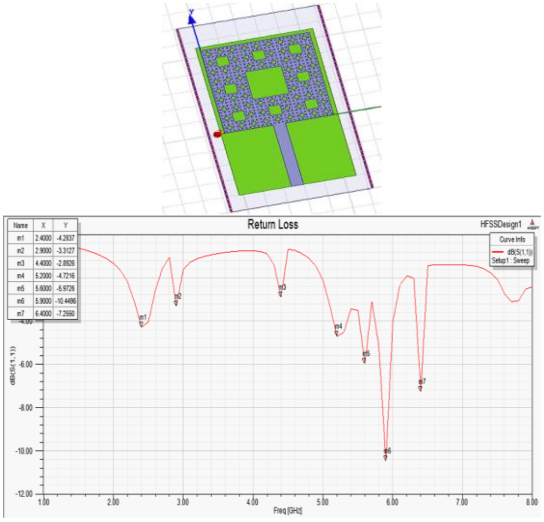

Figure 5: Fourth Iteration

Table 3: Third iteration Return Loss Values

Frequency (GHz)	2.4	5.1	5.7	7.6	9.3
Return Loss (dB)	-8.644	-10.909	-17.786	-11.421	-22.770

Table 4: Fourth iteration Return Loss Values

Frequency (GHz)	2.4	2.9	4.4	5.2	5.6	5.9	6.4
Return Loss (dB)	-4.284	-3.313	-2.893	-4.721	-5.973	-10.450	-7.255

Whilst Table 1, 2, 3 and 4 depict the return loss values for the four iterations chosen, Table 5 gives us the values for other antenna parameters such as Gain, Directivity and Power.

As mentioned earlier, the Return Loss values tend to diminish by the fourth iteration and this is justified by the values obtained.

Table 5: Simulation Results

Peak Directivity	0.4166
Peak Gain	0.2512
VSWR	1.2
Incident Power	1 (W)
Radiated Power	0.298 (W)
Accepted Power	0.495 (W)

Further;

- Radiation pattern shows minimum loss in side lobes.
- Efficiency of antenna, calculated by efficiency = gain/directivity, is found to be approximately 60%.
- Maximum intensity, defined as the peak power per unit solid angle, is found to be 0.01249 W/sr.

4. Conclusion

The fractal patch antenna was designed and simulated using HFSS software v13.0. The four sets of fractal antennas were designed having the same rectangular base geometry with varying square slots and the Return Loss values of these have been compared. The simulation results depict that as the dimensions of the square slot on the patch decreases, the performance of the fractal patch antenna improves with respect to three factors; (i) multi-band properties (ii) operational frequency and (iii) Return Loss values. With the next step forward being towards fabrication, the parameters of the antenna can be made more optimal using computing tools. Therefore, use of fractal geometry in patch antenna results in a compact and economical antenna that has multi-frequency and wide-bandwidth properties. Selection of optimal feed positions can boost the results further. This antenna can be utilized in wireless and handheld devices.

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Author Profile

Rajiv Krishna Prasad is a final year Telecommunication engineering student. He is pursuing B.E from R.V. College of Engineering, Bengaluru.

Architha Kishore is a final year Telecommunication engineering student. She is pursuing B.E from R.V. College of Engineering, Bengaluru.

P Nagaraju, associate professor at R.V. College of Engineering, has 20 years of teaching experience in the Telecommunication field.