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Design and Implementation of Sierpinski Carpet Fractal Antenna for Wireless Communication

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ABSTRACT

The need of multiband, larger gain and low profile antennas to support multiple wireless applications led to the design of Fractal Antennas. Fractal antennas due to their self similar design take less area and are thus low profile. Further they can obtain radiation pattern and input impedance similar to a larger multiband antennas.

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 and fed with 50 ohms microstrip line. By optimizing the width microstrip feed and its location the antenna can be optimized to operate in multiple bands between 2-14GHz.

Keywords - *Microstrip Antenna, Fractal, Sierpinski Carpet Fractal Antenna (SCFA), HCR Principle.*

I. INTRODUCTION

Antennas enable wireless communications between two or more stations by directing signals toward the stations. An antenna is defined by Webster's Dictionary as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves". The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145–1983) defines the antenna or aerial as "a means for radiating or receiving radio waves" [2].

For wireless communication system, antenna is one of the most critical components. A good design of the antenna can thus improve overall system performance. Microstrip patch antennas are widely implemented in many applications due to their attractive features such as low profile, light weight, conformal shaping, low cost, high efficiency, simplicity of manufacture and easy integration to circuits. However the major disadvantage of the microstrip patch antenna is its inherently narrow impedance bandwidth.

Further the tremendous increase in wireless communication in the last few decades has led to the need of larger bandwidth and low profile antennas for both commercial and military applications. One technique to construct a multiband antenna is by applying fractal shape into antenna geometry.

II. FRACTAL ANTENNAS

Mandelbrot offered the following definition: "A fractal is by definition a set for which the Hausdorff dimension strictly exceeds the topological dimension", which he later retracted and replaced with: "A fractal is a shape made of parts similar to the whole in some way". So, possibly the simplest way to define a fractal is as an object that appears self-similar under varying degrees o f magnification, and in effect, possessing symmetry across scale, with each small part of the object replicating the structure of the whole [3].

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. [3].

Fractals are complex geometric designs that repeat themselves, or their statistical properties on many scales, and are thus "self similar." Fractals, through their self-similar property, are natural systems where this complexity provides the sought-after antenna properties. Some key benefits of fractal antennas area:

1) Fractal Antennas radically alter the traditional relationships between bandwidth, gain and size, permitting antennas that are more powerful, versatile and compact [5].
2) Fractal Antennas produces fractal versions of all existing antenna types, including dipole, monopole, patch, conformal, biconical, spiral, helical and others, as well as compact variants of each only possible through fractal technology.

3) Fractal Antenna's technology affords unique improvements to antenna arrays, increasing their bandwidth, allowing multiband capabilities, decreasing size load and enabling optimum smart antenna technology.

4) Increased bandwidth/multi-band and gain in addition to smaller size.

5) The inherent qualities of fractals enable the production of high performance antennas that are typically 50 to 75 percent smaller than traditional ones.

6) Additionally, fractal antennas are more reliable and lower cost than traditional antennas because antenna performance is attained through the geometry of the conductor, rather than with the accumulation of separate components or separate elements that inevitably increase complexity and potential points of failure—and cost. The result is one antenna able to replace many at a high value offering to our customer.

III. RUMSEY'S PRINCIPLE AND HCR CONDITION

Rumsey's Principle: Another attribute of fractals emerged upon Rumsey's Principle, all antennas, whose structures are solely defined by angles, are "frequency independent," or "frequency invariant." This rule dominates the design of all wideband antennas to date, and is a valid electromagnetic fact. This includes all log periodic antennas, spiral antennas, sinuous antennas, and Dyson spirals and so on, previously defined by Rumsey's Principle. However, log periodic and these other examples are a restricted subclass of the larger class of self-similar about- a-point geometries [5].

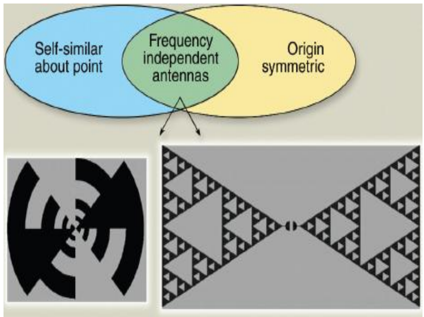

Fig 1: Hohlfield-Cohen-and-Rumsey (HCR) Conditions.

HCR condition: In 1999, Hohlfeld and Cohen found that all frequency invariant antennas must be self similar (fractal) about a point, and origin symmetric about that point. The finding of Rumsey's Principle is a special, albeit proven useful, case of the now more general and complete finding now referred to as the "Hohlfeld-Cohen-and-Rumsey" (HCR) conditions [6][7].

IV. ANTENNA DESIGN

In order to use same antenna for different applications required the antenna to be a multiband antenna and miniaturized to suite different wireless applications. The geometry of Sierpinski Carpet Antenna up to 3rd iteration is presented in Figure 2. The Polish mathematician Waclaw Sierpinski (1882–1969) presented the Sierpinski carpet in 1916 [10].

The design starts with Sierpinski Carpet Planar Monopole Antenna. The first basic rectangular patch is designed. In the first iteration the basic square patch is segmented by removing the middle square from it, by taking scale factor 1/3. For second iteration segments are done on remaining eight squares following the scale factor of 1/3. The same procedure is used for further iterations with same scale factor. By using this method we have designed three iterations as shown in Figure 2.
This basic rectangular patch is designed on a FR4 substrate of thickness 1.6 mm and relative permittivity of 4.4. The dimensions of the patch are calculated using the formulas given in Balani's book [11] and are as shown in table I below:

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Table I: Design Considerations

Dielectric substrate(FR4)	ε_r=4.4, tanδ=0.09
Substrate height	1.59mm
$W=\frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_r+1}}$	37.25mm
$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}$	4.08
$\Delta L=0.412h\frac{(\varepsilon_{reff}+0.3)\left[\frac{W}{h}+0.264\right]}{(\varepsilon_{reff}+0.258)\left[\frac{W}{h}+0.8\right]}$	0.732mm
$L_{eff}=\frac{c}{2f_0\sqrt{\varepsilon_{reff}}}$	29.46mm
$L=L_{eff}-2\Delta L$	27.99mm

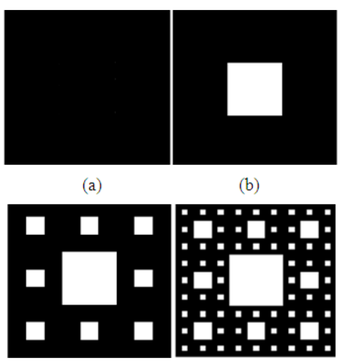

Figure 2. Schematic of proposed Sierpinski Carpet Antenna

In this work, microstrip feeding technique is used. The location of microstrip feed to the patch is adjusted to match with its input impedance (usually 50 ohm). An industry-standard simulation tool for 3D full-wave electromagnetic field simulation, Ansoft HFSS has been used to model and simulate the proposed antenna

V. SIMULATION RESULTS

To design the Sierpinski carpet antenna, has been simulated by varying two parameters, (i) position of the feeding line from the edge of the substrate. (ii) Width of the microstrip feed. By selecting these parameters, the proposed antenna can be tuned to operate within the frequency range 2GHz –14 GHz. Figure 3(a) shows simple design of the simple rectangular patch antenna. Figure 3(b) shows its S11 graph.

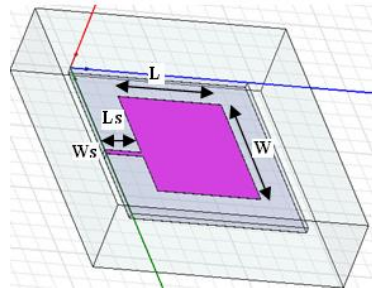

Figure 3(a). Simple RMSA Design. W=37mm, L=28mm, Ls=10mm, Ws=3mm

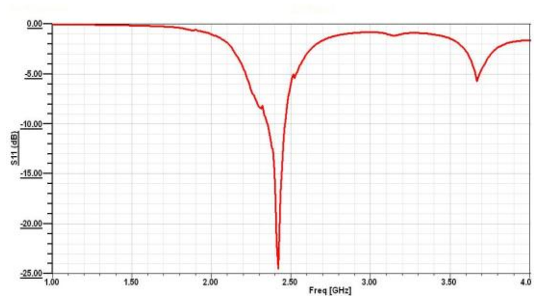

Figure 3(a). S11 graph for RMSA Design.

Figure 4(a) shows the design of 1st iteration of Sierpinski carpet microstrip antenna (SCFA). Same analysis is carried out by varying the feed location and the width of the microstrip feed for the 1st iteration SCFA. Figure 4(b) shows the reflection coefficient for the best result on variation of feed location and its width Ws.

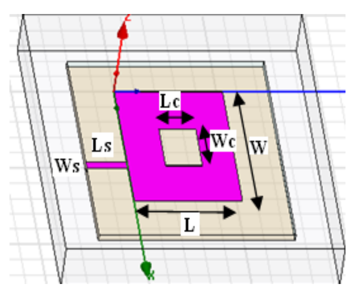

Figure 4(a): 1st Iteration SCFA Design. Wc=12.4mm, Lc=9.4mm, Ls=10mm, Ws=3mm.

Figure 5(a) shows the design of 2nd iteration SCFA which is obtained by further inserting slots 1/3 times that of the center slot. Same analysis is carried out by varying the feed location and the width of the microstrip feed for the

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1st iteration SCMSA. Figure 5(b) shows the reflection coefficient for the best result on variation of feed location and its width Ws.

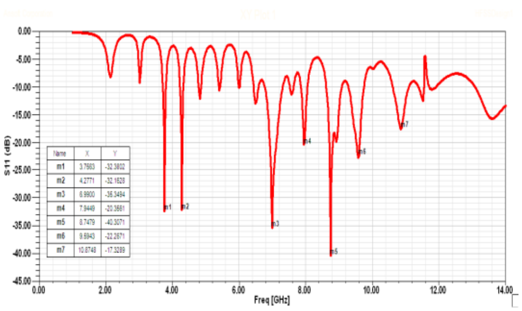

Figure 4(b): S11 graph for 1st Iteration Design.

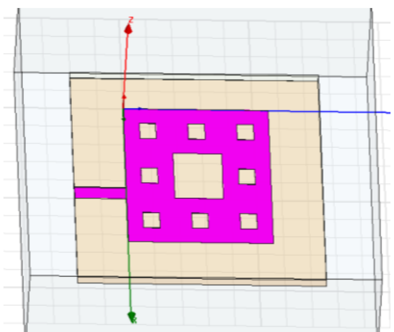

Figure 5(a): 2nd Iteration Design.

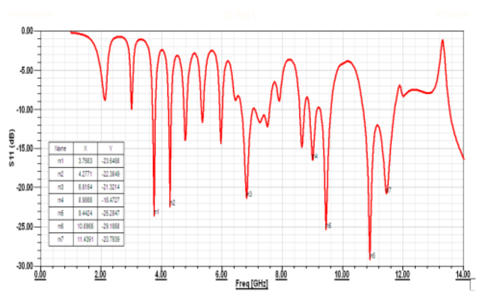

Figure 5(b): S11 graph 2nd Iteration Design.

Figure 6(a) shows the design of 3rd iteration of SCFA which is obtained by further inserting slots 1/3 times that of the slots in 2nd iteration. Figure 6(b) shows the reflection coefficient for the best result on variation of feed location and its width Ws.

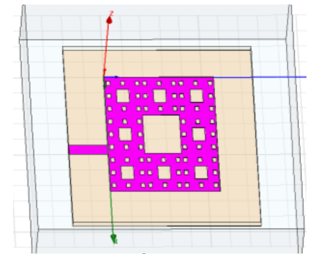

Figure 6(a): 3rd Iteration Design.

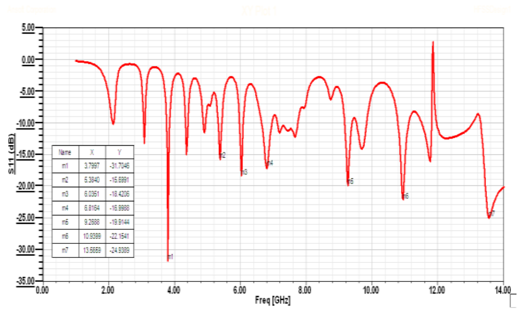

Figure 6(b): S11 graph 3rd Iteration Design.

Table 2 below shows the comparison of above designed antennas. It is observed that with ,every iteration there is a slight increase in the frequencies.

Table 2: Comparison of simulated results.

Iteration	**Frequency Bands (GHz)**	**Gain (dB)**
RMSA	2.45	1.237
1st	3.75, 4.23, 6.81, 8.98, 9.44, 10.89, 11.43	2.682
2nd	3.75, 4.27, 6.81, 7.51, 9.03, 9.44, 10.89, 11.46	3.312
3rd	3.79, 5.38, 6.05, 9.68, 10.94, 11.7, 13.56	3.831

VI. FABRICATION RESULTS

3rd iteration SCFA has been fabricated using FR4 substrate. N-type female (SMA) connector is soldered at the microstrip feed end. Fig. 8 shows the front and back view of the fabricated antenna.

Figure 8: Front and back view of fabricated 3rd iteration SCFA.

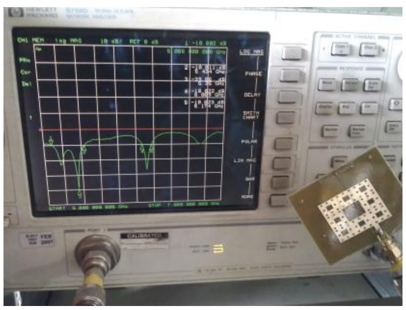

Figure 9: Testing using VNA of fabricated 3rd Iteration SCFA

Figure 9 above shows the testing of fabricated 3rd iteration SCFA using a Vector Network Analyzer (VNA). Figure 10 shows the S11 graph for the fabricated antenna and Table 4 shows the comparison between simulation and fabrication results. From table 3 it can be seen that resonating frequency for simulated results are 3.79, 5.38 and 6.05GHz and those for fabricated results are 3.13, 3.87, 5.43 and 6.17 GHz; which are in good match.

Table 4: Comparison of simulated and fabricated results for 3rd iteration SCFA

Frequency bands	Simulated	Fabricated
Band 1	3.79	3.87
Band 2	5.38	5.43
Band 3	6.05	6.17

VII. CONCLUSION

In this paper a microstrip fed Sierpinski carpet fractal antenna (SCFA) is designed and implemented up to 3rd iteration. Sierpinski carpet with 1/3 iteration factor the size of the patch reduces by 33.9% of the conventional microstrip antenna. As the iterations go on increasing the loading causes multiple resonance and a shift down in frequency. The fabricated 3rd iteration SCFA results are in good match with the simulation results.

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