IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 9, Issue 6, Ver. II (Nov - Dec. 2014), PP 01-08
www.iosrjournals.org

Design and Implementation of Printed Micro strip Fractal Antennas for Wireless Applications

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Abstract: *The need for miniaturized antenna is ever growing in view of the advancements in wireless communication technology. The conventional micro strip antennas take any shape like square, rectangular, triangle and so on. They provide normally single resonance frequency with high quality factor because of narrow bandwidth. However, the fractal antennas are able to provide either multi-band resonances or broad bandwidth because of the self-similar and space-filling properties. In this work, design of a Hilbert curve fractal antenna, sierpinsik gasket carpet fractal antenna is considered for single and multiband applications. Design and simulation is done using HFSS 13.0 software and fabrication is done using on FR-4 clad substrate. For second iteration and third iteration of both the fractal antennas are considered. For Hilbert curve of 2^{nd} iteration return loss is -19dB at 3.5 GHz and for 2^{nd} iteration carpet fractal antenna the return loss is -22dB at 3.5 GHz and -15dB at 7.1GHz which is a dual band characteristics.By using vector network analyzer E5071C the designed antennas are tested and various plots like return loss, VSWR, smith chart and polar plot are verified.The designed antennas are used in implantable medical (IMD) applications and other wireless applications.*
Index Terms: *microstrip, HFSS, HCFA, IMD*

I. Introduction

As already mentioned the fractal antennas employ the fractal geometry for their design as compare to classical antennas which employ Euclidean Geometry[1]. The two basic properties of fractals provide distinguish features to these fractal designed antennas, these are discussed with appropriate application areas below:

1. Any good antenna system requires antenna scaling which means that the different parameters (impedance, gain, pattern etc.) remain same if all the dimensions and the wavelength are scaled by same factor. Since due to self-similarity possessed by fractals, the fractal structure appear to be same independent of size scaling and thus it can be interpreted that the fractal structures can be used to realize antenna designs over a large band of frequencies . The antenna can be operated similarly at various frequencies which mean that the antenna keeps the similar radiation parameters through several bands.

Application: In modern wireless communications more and more systems are introduced which integrate many technologies and are often required to operate at multiple frequency bands. Thus demands antenna systems which can accommodate this integration. Examples of systems using a multi-band antenna are varieties of common wireless networking cards used in laptop computers. These can communicate on 802.11b networks at 2.4 GHz and 802.11g networks at 5 GHz. Use of fractal self-similar patterns offers solution.

2. Another requirement by the compact wireless systems for antenna design is the compact size. The fractional dimension and space filling property of fractal shapes allow the fractal shaped antennas to utilize the small surrounding space effectively. This also overcomes the limitation of performance of small classical antennas.

Application: The fractal antenna technology can be applied to cellular handsets. Because fractal antennas are more compact, they fit more easily in the receiver package [4]. Currently, many cellular handsets use quarter wavelength monopoles which are essentially sections of radiating wires cut to a determined length. Although simple, they have excellent radiation properties

II. Fractal Geometry

Fractal geometries have two common properties: Self-similar property, Space filling property. The self-similarity property of fractals gives results in a multiband behavior of an antenna. Using the self-similarity properties a fractal antenna can be designed to receive and transmit over a wide range of frequencies because it acts as a multiband[2]. While using space filling properties, a fractal make reduce antenna size. Hilbert curve fractal geometry has a space filling property.

A. Sierpinski Carpet

The Sierpinski carpet is constructed analogously to the Sierpinski gasket, but it use squares instead of triangles. In order to start this type of fractal antenna, it begins with a square in the plane, and then divided it into nine smaller congruent squares where the open central square is dropped. The remaining eight squares are divided into nine smaller congruent squares which each central are dropped

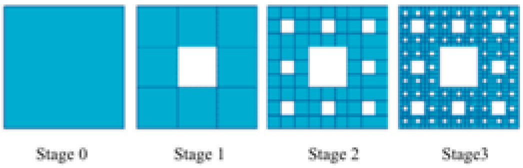

Figure 1.1: Sierpinski carpet stages

B. Koch Curve

The geometric construction of the standard Koch curve is fairly simple. It starts with a straight line as an initiator. This is partitioned into three equal parts, and the segment at the middle is replaced with two others of the same length. This is the first iterated version of the geometry and is called the generator[3]. The process is reused in the generation of higher iterations. By this fractal shape, we can construct monopole as well as dipole antenna.

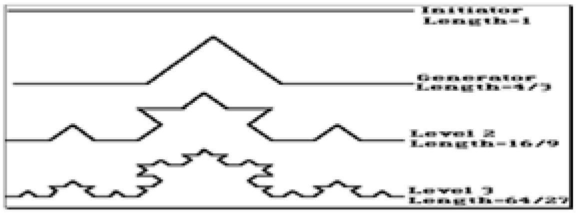

Figure 1.2: Koch curve

C. Sierpinski Gasket

Sierpinski gasket geometry is the most widely studied fractal geometry for antenna applications. Sierpinski gaskets have been investigated extensively for monopole and dipole antenna configurations. The self-similar current distribution on these antennas is expected to cause its multi-band characteristics. Sierpinski gasket shape also used to make monopole and dipole antenna.

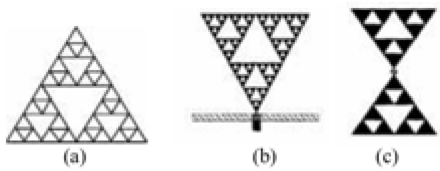

Figure 1.3: Sierpinski gasket geometry

D. Hilbert Curve

The space-filling properties of fractal geometries make them attractive candidates for use in the design of fractal antennas. This appealing attribute of fractal shapes can be used to miniaturize classical antenna elements such as dipoles and loops and overcome some of the limitations of small antennas[3]. The line that is used to represent the fractal geometry can meander in such a way that effectively fills the available space, leading to curves that are electrically long but compacted in a small physical space . Figure demonstrates the first four stages in the construction of a HCFA.

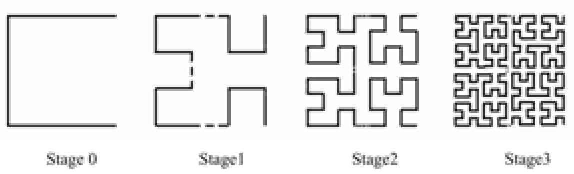

Figure 1.4: Hilbert curve stages

Compared to other fractal shapes, the Hilbert curve can pack longer curves in a given area. The self-similarity and space filling properties allow many iterations of the fractal shaped micro strip antenna possibly to be created. The multiple square curves are the main reasons to make the antenna work at multiple frequencies.

However; the coplanar waveguide (CPW) system has been widely used recently as feeding networks. Varieties of works have been reported utilizing the CPW feed system. CPW lines provide many advantages such as negligible radiation leakage, less dispersion, little dependence on the characteristic impedance on substrate height and uni-plane structure.

E. Plus Shape Fractal Antenna

Plus shape slotted antenna is designed based on fractal concepts for multiband behavior. A plus shape patch is taken as a base shape and in first iteration four other plus shape patches of the order of 1/3 of base shape are placed touching the base shape. Similarly second iterations are taken by further placing plus shaped patches at even reduced scales. It is found that as the iteration number and iteration factor increases, the resonance frequencies become lower than those of the zero iteration, which represents a conventional plus shape patch.

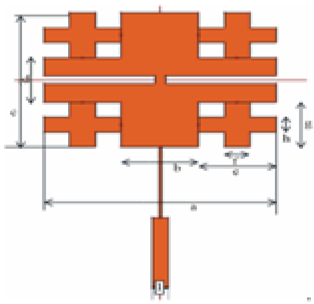

Figure 1.5: Plus shape slotted fractal antenna

III. Applications Of Fractals

1. Medical advances: Lungs, AIDS, cancer, bone fractures, and heartbeats arefractal in nature
2. Science:Scientists now work with fractal geometry to locate oil, identify geologic faults, and possibly predicting earthquakes.
3. Industry:The spring industry uses fractal geometry to test spring wire in 3 minutes instead of 3 days.Statistical models using fractal geometry are used to test for stress loading on oil rigs and turbulence effects on aircraft.Image compression algorithms for storing images and retaining definition uses fractal geometry. Both the weather and the money market are very fractal in nature.Acid rain and corrosion can be modelled using fractal geometry. Even the big bang theory and understanding the structure of the universe can be improved with fractals.
4. Military: A fractal "footprint" can be used to identify manmade versus natural features on aerial mappings and tracking submarines.
5. Mother Nature: Nature fractals Romanesque cauliflower. Here is a funny fractal hand
6. Fractal landscapes: Fractals are used in movies for landscapes, dinosaur skin textures, etc. For instance, the raindrop on the skin of the dinosaurs in Jurassic Park was done using a fractal model.

There are many applications that can benefit from fractal antennas. Discussed below are several ideas where fractal antennas can make a real impact. The sudden growing the wireless communication area has sprung a need for compact integrated antennas. The space saving abilities of fractals to efficiently fill a limited amount of space create distinct advantage of using integrated fractal antennas over Euclidean geometry. Examples of these types of application include personal hand-held wireless devices such as cell phones and other wireless mobile devices such as laptops on wireless LANs and networkable PDAs. Fractal antennas can also enrich applications that include multiband transmissions[5]. This area has many possibilities ranging from dual-mode phones to devices integrating communication and location services such as GPS, the global positioning satellites. Fractal antennas also decrease the area of a resonant antenna, which could lower the radar cross-section (RCS). This benefit canbe exploited in military applications where the RCS of the antenna is a very crucial parameter.

IV. Empirical Model And Design Equations

It is now possible to obtain approximate design equations for this type of antenna. The approach for the design formulation is based on that followed for resonant meander line antennas. The generation algorithm of this geometry is commonly expressed in terms of L-systems. Finally the data has been analyzed resulting in an empirical model formula at resonance stage n

$$f_n = 0.21\frac{c}{h}\delta^n \qquad (1)$$

Where fn = the resonance frequency at stage n
c= speed of electromagnetic wave= 3×10^8 m/s
h = the highest dimension size of antenna
n = integer number at stage n (1,2,3,.,.)
δ = log period = 1.38

The resonant frequencies are obtained through the above formulation by use the numerical method. We can find the empirical model equation by using the basic concept of antenna that state the resonance frequency vary inversely with the size of the antenna as shown in the Fig. 1.6 (a)

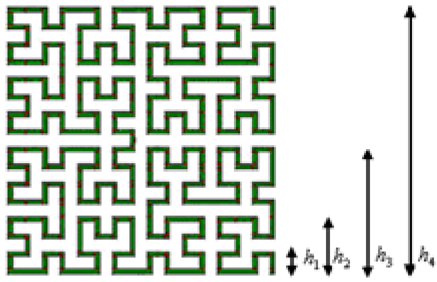

Figure 1.6 (a) Dimension of Hilbert Curve Fractal Antenna iteration 4 at the first fourth resonance

For an HCA with outer dimension of l and order of fractal iteration n, the length of each line segment d is given by

$$d = \frac{l}{2^n - 1} \qquad (2)$$

The number of short circuit terminations forparallel wire section be founded that

$$m = 4^{n-1} \qquad (3)$$

The segments not forming the parallel wire sections amount to a total length is

$$S = (2^{n-1})d \qquad (4)$$

The approach we introduce to derive the condition for the resonant properties of Hilbert curve antennas printed on a dielectric substrate, is to consider sections of the strip as terminated parallel strip transmission lines. The characteristic impedance of two parallel strips of negligible thickness (t) printed on a dielectric of height (h), and dielectric constant ε_r, as shown in Fig.11 in terms of complete elliptic integral of the first kind (K) is given by [7]:

$$Z_0 = \frac{\eta}{\sqrt{\varepsilon_{eff}}}\frac{K(k)}{K(k')} \qquad (5)$$

where the effective dielectric constant is

$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2}\frac{K(k')}{K(k)}\frac{K(k_1)}{K(k'_1)}$$

$$k = \frac{a}{b} \quad k_1 = \frac{\sinh(\frac{\pi a}{4h})}{\sinh(\frac{\pi b}{4h})}$$

$$k' = \sqrt{1-k^2} \quad k_1' = \sqrt{1-k_1^{\,2}}$$

and the pure inductance is

$$L_{in} = \frac{Z_0}{\omega}\tan\beta d = \frac{\eta}{\omega\pi}\log\frac{2d}{b}(\tan\beta d) \qquad (6)$$

The self-inductance due to a straight line of length s as

$$L_s = \frac{\mu_0}{\pi} s(\log\frac{8s}{b} - 1) \quad (7)$$

Substituting (5) in (6) and using (7), the total inductance is therefore

$$L_{total} = L_{in} + L_s$$

$$= \frac{\mu_0}{\pi} s(\log\frac{8s}{b} - 1) + m\frac{\eta}{\pi\omega}(\log\frac{8d}{b})(\tan\beta d) \quad (8)$$

It should however be noted that regular meander line antennas resonate when the arm length is a multiple of quarter wavelength. Thus, by changing the resonant length related terms on the RHS of equation, we can obtain all the resonant frequencies of the multi-band HCA. Therefore the first few resonant frequencies of the HCA can be obtained from the formula model:

$$m\frac{Z_D}{\omega}(\tan\beta_m d) + \frac{\mu_0}{\pi} s(\log\frac{8s}{b} - 1) = \frac{\mu_0}{\pi}\frac{k\lambda}{4}(\log\frac{8}{b}\frac{k\lambda}{4} - 1) \quad (9)$$

where k is an odd integer (1,3,5,…) and

$$\beta_m = \frac{\beta}{\sqrt{\varepsilon_{eff}}}$$

=propagation characteristics of the transmission line.

V. Implementation Of Hcfa Using Hfss

The purpose of this is to design and analyze Hilbert curve fractal antennas to get the empirical and electrical model. We use the Zealand program for simulating antennas. The antennas receive and transmit in many frequency resonances. We design a small Hilbert curve fractal antenna. We analyze this antenna by using the concept of the CPW transmission line and the mathematical definition of fractal to yield the models for Hilbert curve fractal antenna. From these models we can predict the multi resonance frequency. In the experiment we found that the least percent of difference for electromagnetic formulae model with the experiment (0.4%) is lower than the least of the difference for empirical model (4.43%) because the electromagnetic model used the transmission line model while the empirical model used the numerical method. These models will be helpful for design and making Hilbert curve fractal antenna.

The name HFSS stands for High Frequency Structure Simulator. Ansoft pioneered the use of the Finite Element Method (FEM) for EM simulation by developing / implementing technologies such as tangential vector finite elements, adaptive meshing, and Adaptive Lancozos - pade Sweep (ALPS)[6].

The first few iterations of Hilbert curves are shown in Fig.1.4 It may be noticed that each successive stage consists of four copies of the previous, connected with additional line segments. The segments used to connect copies of the previous iteration are shown in dashed lines. The generation algorithm of this geometry is commonly expressed in terms of L-systems. In this representation, a string of symbols with the following notations are used, leave two blank lines between successive sections as here.The fractal shaped structures possess space filling and self-similarity properties. The proposed antenna is able to provide better bandwidth while retaining all primary characteristics appreciably.

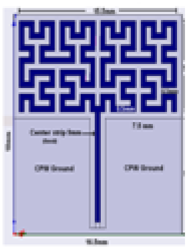

Figure 1.6: HCFA

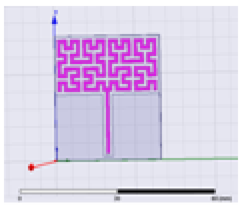

Figure 1.7: HFSS design for HCFA antenna (3rd iteration)

This HCFA makes use of a CPW feed system which is seen to provide improvement in the overall performance. The HCFA is designed to fit a size of 15.5mm x 7.5mm with micro strip width of 0.5mm and spacing of 0.5mm. Instead of separate ground plane, a CPW is used to feed this HCFA.

Now the micro strip width and spacing is 1mm it is resonated at two frequencies 3.2GHz, 6.9GHz with return loss values as -21dB and -15.9dB respectively.

VI. Simulation Results

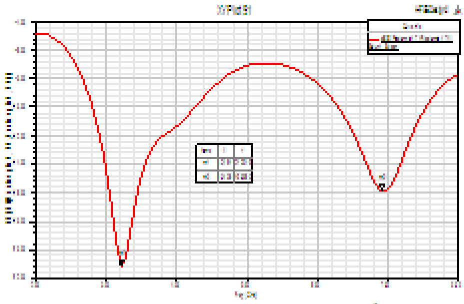

Figure 1.8: Return loss curve for 3rd iteration

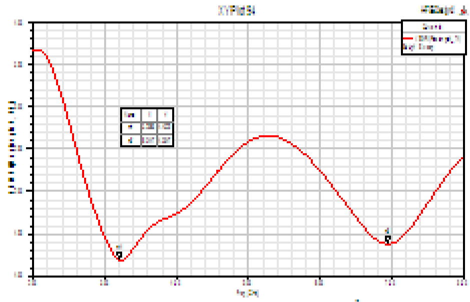

Figure 1.9: VSWR curve for 3rd iteration

VII. Practical Results

The vector network analyzer, VNA is a form of RF network analyzer widely used for RF design applications. A vector network analyzer is a test system that enables the RF performance of radio frequency (RF) and microwave devices to be characterized in terms of network scattering parameters, or S parameters.

The basic architecture of a network analyzer involves a signal generator, a test set, one or more receivers and display. In some setups, these units are distinct instruments. Most VNAs have two test ports, permitting measurement of four S-parameters (s_{11}, s_{12}, s_{21} ands_{22}), but instrument with more than two ports are available commercially

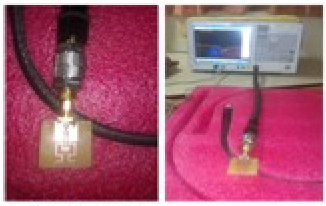

Figure 1.11(a): Experimental setup of fabricated Hilbert curve fractal antenna 2nd iteration

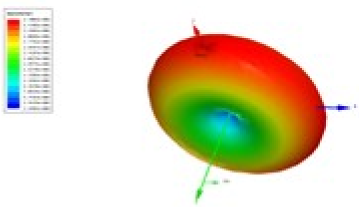

Figure 1.10: Gain curve for 3rd iteration

Figure 1.11(b): experimental setup of fabricated Hilbert curve fractal antenna 3rd iteration

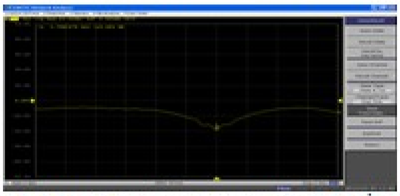

Figure 1.12(a): Return loss curve for 2nd iteration

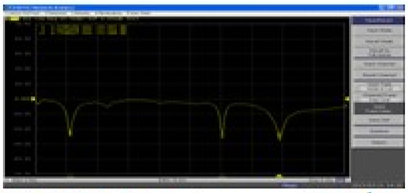

Figure 1.12(b): Return loss curve for 3rd iteration

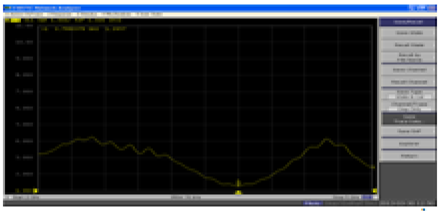

Figure 1.13(a): Impedance Chart curve for 2nd iteration

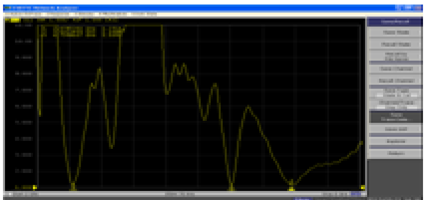

Figure 1.13(b): VSWR curve for 3rd iteration

VIII. Result Analysis

2nd iteration:

1) For the 2nd iteration, the antenna is resonating at frequency 4GHz which is obtained from simulation and the practical result the antenna is resonating at the frequency 3.79GHz.By comparing both the results there is slight deviation between the simulated and practical values, but this deviation is within the acceptable limit.
2) The VSWR value for the simulation and practical results is at 1.7 and 1.3 respectively. Hence the VSWR value is between 1 and 2, which states that the antenna is working properly.
3) The upper and lower frequencies denote the frequency where return loss crosses -10 dB point and center frequency is where minimum return loss is observed. The percentage bandwidth obtained is 18%

3rd iteration:

1) For the 3rd iteration, the antenna is resonating at frequency 3.2GHz and 6.9GHz which is a dual band obtained from simulation and the practical result the antenna is resonating at the frequency 2.7GHz, 5.6GHz and 6.7GHz which is a triple band.By comparing both the results there is slight deviation between the simulated and practical values, but deviation is due to surrounding disturbances.
2) The VSWR value for the simulation and practical results are in between 1 and 2, which states that the antenna is working properly.

3) The upper and lower frequencies denote the frequency where return loss crosses -10 dB point and center frequency is where minimum return loss is observed. The percentage bandwidth obtained is 40% and 16% at 1st and 2nd resonating frequencies.

IX. Conclusion

This work presents designing, simulating, fabricating, and testing of various multiband fractal antennas. The design and simulation is done using HFSS simulation software.

Hilbert curve fractal antenna is designed for 2nd and 3rd iterations. Second iteration of this antenna is resonated at 3.8GHz and third iteration of this antenna is resonated at three frequencies 2.7GHz, 5.6GHz and 6.7GHz with return losses -21dB, -22dB and -26dB respectively.

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