2. LITERATURE REVIEW: A BRIEF OF THE WORK ALREADY DONE IN THE FIELD

This section will present a brief overview of some of the more common fractal geometries that have been found to be useful in developing new and innovative designs for antennas.

**Sierpinski Gasket:** The most popular fractal antenna is Sierpinski gasket named after the Polish mathematician Sierpinski who described some of the main properties of this fractal shape in 1916 [Tian Tiehong, Zhoe Zheng, Zhou Zheng, April 2003]. The original gasket is constructed by removing a central inverted triangle from a main triangle shapes as shown in figure 1.4.

![Stages of Sierpinski Gasket](image)

Figure 1.4 Several stages in the construction of a Sierpinski gasket fractal antenna.

The Sierpinski gasket is a self-similar structure as each one of its main three parts is exactly equal to the whole object, but scaled by a factor of two and so is each of the three gaskets that compose any of those parts. The self similar properties of the fractal shape are translated into its electromagnetic behavior and results in a multiband antenna [Carles Puente-Baliatda, April 1998]. This multiband fractal antenna is first introduced by Puente who also gave an iterative transmission line model [Baliarda, C.P., Borau, May 2000] that models the Sierpinski fractal antenna by following the same iterative process that is employed in the construction of the Sierpinski gasket. Puente also suggested a method for perturbing the Sierpinski structure in such a way as to control the position of multiple bands where necessary [Puente.C, Romeu.J, Bartoleme, R., Pous, R., Nov 1996].

George F. Tsachtsiris presented a modified Sierpinski gasket monopole antenna [Tsachtsiris, G.F, Soras, C.F.; Karaboikis, M.P., Makios, V.T , Oct 2004] that possesses a small physical size, high efficiency and the ability to allocate both the 2.4 and 5.2 GHz Industrial Scientific and Medical bands without the need of a matching network. J.M.Gonzalez showed that current
distribution of Sierpinski fractal antenna shows a self-similar behavior determined by the self-similar properties of its geometry [Gonzalez, J.M.; Navarro, M.; Puente, C.; Romeu, J.; Aguasaca, feb2002].

**Crown Square Fractal Antenna**

Another popular fractal antenna is Crown square microstrip fractal antenna. This antenna is introduced by P. Dehkhoda & A. Tavakoli [Dehkhoda, P.; Tavakoli, 2004]. This antenna is shown in figure 1.5. This antenna is constructed by removing a square shape from an original square as shown in figure. After this a same shape with a scale of is added after (n-1)th iteration. Generally only two iterations are considered since higher order iterations do not make significant affect on antenna properties.

![BASE SHAPE FIRST ITERATION SECOND ITERATION](image)

**Figure 1.5 Crown Square Fractal Antenna**

This antenna is simulated with a=2.6 mm and b/a=1.0526 where a and b are the sides of nearly square and a substrate with \( \varepsilon_r = 2.52 \) and 1/8 inch thickness is assumed [Dehkhoda, P., Tavakoli, 2004]. Feed is applied at one corner of Original Square. This antenna gives a size reduction as compared to a nearly squared antenna but in exchange bandwidth is reduced.

**Sierpinski Carpet Fractal Antenna**

Next fractal antenna is Sierpinski carpet antenna. Configuration of a Second order Sierpinski carpet fractal antenna is shown in figure 1.6. This antenna was simulated by S. Wong [Wong, S., Ooi, B.L., Kooi, P.S., Leong, M.S., 2001]. This third order Sierpinski carpet gasket is printed over a thin duroid substrate of relative permittivity \( \varepsilon_r = 2.2 \) and thickness h=0.25 mm. Fractal shape is constructed with two iterations. That is Sierpinski carpet appears at two different scales within main structure. There is a factor of three between scales. This patch gave resonance
frequency at 1.45, 3.21, 5.33 and 7.2 GHz and its measured bandwidth is about 1% at each band. In this simulation boundary integral method have been used to analyze Sierpinski carpet antenna. Measured values of resonant frequencies and input return loss for these antennas have been found to agree well with the theoretical prediction. Basile Panoutsopoulos [Panoutsopoulos, B,2003] also simulated same geometry for different feed locations like center feed, corner feed and transmission line feed to achieve optimum position for matching conditions and gave results that center probe feed was best.

![Figure 1.6: Four stages in construction of Sierpinski carpet Antenna](image)

**Hilbert curve fractal antenna**

Next fractal antenna is Hilbert curve fractal antenna introduced by K.J.Vinoy [Vinoy, K.J., Jose K.A., Varadan, V.K.; Varadan, V.V.2001], [Vinoy, K.J., Jose K.A., Varadan, V.K.; Varadan, V.V.2001]. Fractal Hilbert curve geometry results in an antenna with low resonant frequency compared to other configurations. This antenna consists of line segments arranged in a predictable fractal order. This can be modeled using wire segments. This antenna is shown in figure 1.7. It is clear that as the fractal order increases, the total length of the line segments contributing to the geometry increases in almost geometric progression, as the area it encompasses remain the same. Thus within a small area, a resonant antenna with very large line length can be accommodated. Hilbert curves are capable of reducing the antenna size further. Compared to other antennas like Sierpinski carpet and Koch curves Hilbert curve antennas have the additional feature of shrinking the antenna size significantly. These antennas have the capability to change their radiation characteristics adaptively and are generally classified as reconfigurable antennas.
Koch Monopole fractal Antenna

Next fractal antenna is Koch monopole antenna (figure 1.8) introduced by C.Puente [Baliarda, C.P.; Romeu, J.; Cardama, A,2000]. Constructed after an iterative procedure the length of curve increases by a factor of 4/3 at each stage, yet always maintains the same height. The limit object obtained after an infinite numbers of iterations is an ideal fractal curve with no derivative at any point.

This antenna was simulated for different iterations and some interesting conclusions were derived [Puente, C.; Romeu, J.; Pous, R.; Ramis, J.; Hijazo, 1998]. The input resistance is increased each time the length (Not the size) of antenna is increased. Also the resonance frequency is shifted towards longer wavelengths becoming resonant antennas even in small region. Analogously, the Q-factor is reduced at each iteration, tending to the fundamental limit. These results show that the Koch fractal monopole can improve the behavior of common monopoles. Further S.H. Zainud-Deen [nud-Deen, S.H.; Awadala, K.H., Khamis, S.A.; EL shalaby, N.A,2004] examined the electromagnetic characteristics of a Koch fractal antenna. He used method of moments to analyze the antenna structure. He also showed that use of Koch fractal monopole in portable radio equipment can reduce the length of antenna, decreases the current flowing along the body of the handheld device and improves the impedance matching to the feed line of the antenna.
Figure 1.8: Koch Monopole antennas with first three iterations

**Fractal Tree antenna**

Next fractal antenna is fractal tree antenna [W.J. Lui and C.H. Cheng and H.B. Zhu, 2006]. Fractal tree structures can be exploited in antenna designs to produce multiband characteristics or to achieve miniaturization. Dipole antennas use fractal tree structures as end loads to achieve a resonant frequency than a standard dipole of comparable length. Fractal tree antennas in figure 1.9

In case of fractal trees, generator is defined as a junction from whom several smaller branches, called child branches, split from a parent branch. Every branch, with the exception of the first and final branches, has a generator connected to it at each end: one from which it is a child and the other to which it is connected is the parent. The child branches are the half the length of the
parent branches from which they separate from, also child branches bend 30 degree from the direction the parent branch is aimed. All child branches have equal angles separating them. The distance from a tip of the wire at one end of the dipole to the tip of other end is 7.5 cm. The antenna is directly fed by a voltage source at the centre of the antenna. Radiation characteristics of these antennas were evaluated using method of moments and it was found that resonant frequency decreases with an increase in the fractal stage of growth. Joshua S.Petko [Ahmed Ibrahiem, Anthony Ghiotto, Tan-Phu Vuong and SmailTedjini,2006] showed that the density and elevation angle of the branches play an important role in the effective design of miniature 3-D fractal tree antennas. He varied the angle between child branches and parent branches over a range of angle from 10° to 90° in place of taking it 30°. He found that fractal tree antennas with small elevation angles have a lower VSWR but a higher resonant frequency than those with large elevation angles. The resonant frequency continues to move lower as the elevation angle increases until it reaches approximately 50°. From that point resonant frequency begins to increase again.

**Minkowski Fractal Curve Antenna**

Next fractal antenna is Minkowski fractal curve antenna introduced by Adam Lamecki [Renzo Azaro, Edoardo, Paolo Rocca and Andrea Massa,2007]. Figure 1.10 shows the method of iterative construction. In every iteration total length of this curve is multiplied by two.

![Figure 1.10 : Minkowski Fractal Curve Antenna](image-url)
Great advantage of Minkowski fractal shape is that it is easy to approximate it by rectangular grid used in most of full wave electromagnetic simulators. Antennas with iterations n=1, 2, 3 were successively simulated. On low frequency range analyzed structure is a narrow band antenna, and the behavior is analogue to a straight dipole. In this frequency range input impedance increases with every iteration. Radiation patterns of n=1, 2 fractal antennas remain like the radiation pattern of straight dipole. For higher frequencies antenna input impedance looses resonant circuit character and opportunity of a broadband impedance match appears. In result a broadband match can be achieved at higher frequency.

NOTEWORTHY CONTRIBUTION IN THE FIELD OF PROPOSED WORK:

Lot of work has been reported on fractal antenna as discussed in the previous section. The following are the significant contributions reported recently.

Kikkawa et al [T. Kikkawa, K.K. Kimoto and S. Watanabe, 2005] investigated ultra wide band Sierpinski Carpet dipole antenna, return loss less than -10dB was achieved in the frequency range from 18 to 26.5 GHz.


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Angera [Jaume Anguera, E.M. Ortigosa, Carles Puente and Carmen Borja and Jordi Soler, 2006] et al developed a triple band microstrip patch antenna and the bandwidth of each operating band was enhanced to achieve triple frequency broadband microstrip antenna. Sierpinski fractal geometry was used to achieve the desired response.

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Lui, Cheng and Zhu [W.J. Lui and C.H. Cheng and H.B. Zhu, 2006] reported a compact frequency notched ultra wide band printed slot antenna. Koch fractal slot has been employed to
achieve both size reduction and frequency notched function. Ultra wide band performance with frequency notched characteristics was obtained along with relative stable and omni directional performance.

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Hwang [Kuem C. Hwang,2007] proposed a broad band planar fractal antenna that consists of a flared Sierpinski gasket and slotted ground plane for multiband communication services. Two iteration Siepinski patch and slotted ground plane was used to enhance the band width performance.

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![Figure 1.8: Koch Monopole antennas with first three iterations](image)

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Figure 1.9: The generation of a three dimensional fractal tree. At each iteration the branches split into four segments in two orthogonal planes.

In case of fractal trees, generator is defined as a junction from whom several smaller branches, called child branches, split from a parent branch. Every branch, with the exception of the first and final branches, has a generator connected to it at each end: one from which it is a child and the other to which it is connected is the parent. The child branches are the half the length of the parent branches from which they separate from, also child branches bend 30 degree from the direction the parent branch is aimed. All child branches have equal angles separating them. The distance from a tip of the wire at one end of the dipole to the tip of other end is 7.5 cm. The antenna is directly fed by a voltage source at the centre of the antenna. Radiation characteristics of these antennas were evaluated using method of moments and it was found that resonant frequency decreases with an increase in the fractal stage of growth. Joshua S.Petko [Ahmed Ibrahim, Anthony Ghiotto, Tan-Phu Vuong and SmailTedjini, 2006] showed that the density and elevation angle of the branches play an important role in the effective design of miniature 3-D fractal tree antennas. He varied the angle between child branches and parent branches over a range of angle from $10^0$ to $90^0$ in place of taking it $30^0$. He found that fractal tree antennas with small elevation angles have a lower VSWR but a higher resonant frequency than those with large elevation angles. The resonant frequency continues to move lower as the elevation angle increases until it reaches approximately $50^0$. From that point resonant frequency begins to increase again.
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