CHAPTER I

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Modern celestial and other advanced wireless communication systems require feasible array antennas with reconfigurable multi-beams, broadband, high end of coverage, high gain, less side lobe level with wider side lobe level angles, better signal to noise ratio and small in size than conventionally attainable. This has instigated array antenna design research and development in different tracks, one of which is by using fractal array antennas. The research work on repetitive shaped antennas is basically focused on two essential areas like the analysis and design of fractal antenna elements and the design of array antennas using fractal geometric technology. These recursively generated antennas provide new insights into the antenna properties due to their self-similar behavior. Owing to the feasible geometric construction and advanced properties, fractal antennas are find applications in advanced wireless communications, MIMO radars, satellite communications, multi-frequency wireless local area networks and space observation. The research work concentrated here is primarily aimed on the design of fractal array antennas using novel fractal geometric design methodologies and the reduction of total number of antenna elements at higher expansion factors (S) of both conventional and proposed fractal array antennas with different evolutionary optimization and new fractal density tapering techniques.

Various random and deterministic fractal array antenna designs and their design methodologies depending on fractal geometric technology have been discussed in recent years. These array antennas are designed for better array factor properties rather than conventionally available array antennas. In this work a novel geometric design methodology developed for the generation of different kinds of fractal array antennas with special emphasis on the improvement of array factor behavior and the reduction of total number of antenna elements at higher expansion factors (S) have discussed. Furthermore, different types of novel fractal and semi fractal density tapering techniques are introduced and some evolutionary optimization techniques are applied to proposed and conventional fractal arrays to reduce the number of antenna elements at higher expansion
factors and iteration levels. To set foundations for the understanding of the performance of such array antennas, the behavior of fractal geometric technology and applications of fractals in the field of science and engineering is explained first, before presenting the status of literature on fractal array antennas using such geometries.

1.1 FRACTAL GEOMETRIC TECHNOLOGY

A fractal structure is a never-finishing pattern. These structures are infinitely complex patterns that are self-similar across diverse scales [1]. Due to this self-similar performance, fractals find diverse applications in both science and engineering. The word fractal has its origin in the Latin word fractus, meaning an irregular surface. Coastal line of sea, mountains, sea shells, snowflakes, leaves, and eye train of a peacock are some of the naturally existed fractals [2]. Figure 1.1 shows some of the naturally existed fractals in the nature. By their geometrical constructions, fractal patterns come in two main variations.

- Random Fractals
- Deterministic or Geometric Fractals

All natural fractals come under random fractals because they don’t have a particular deterministic way of generation and they are non-integral surfaces. These are also known as stochastic fractals. The generation of these fractals is analyzed by different statistical techniques. The randomness of these fractals varies with structure to structure and way of generation. The Brownian motion of microscopic particles in fluid is also the best example for random fractal behavior as shown in Figure 1.2. Deterministic fractals are geometry based structures having scaled repetitive nature. These fractals have exact dimensions for the expansion unlike random fractals. Generally, all deterministic fractals are generated using iterated function system (IFS), recurrent iterated systems (RIFS), and complex number methods. In these methods of generation fractal structures are created on the source of scaling, plan axes rotation, and dislocation. The most popular IFS and complex number fractals are the Koch curve, the Sierpinski triangle, Julia sets, and the Sierpinski square are shown in Figure 1.3. In these deterministic fractal structures the basic generator or seed copied itself up to infinite iterations (p) [3-5]. The design methodology proposed in this thesis for the generation of various fractal array antennas is also having deterministic way of generation.
Figure 1.1: (a) Eye train of a peacock (b) Fractal shaped leaf

Figure 1.2: The Brownian motion of microscopic particles
Figure 1.3: (a) Koch curve up to three iterations. (b) Sierpinski square or carpet up to four iterations. (c) Sierpinski triangle up to four iterations.

1.2 APPLICATIONS OF FRACTALS

Fractal geometric technology has permeated numerous areas of science and engineering, such as astrophysics, image processing, biological sciences, bioinformatics, antenna engineering, computer graphics, and medical applications.

- Image compression using fractal image coding have led to a major fall in memory requirements and processing time than conventional techniques [6]. Figure 1.4 exemplifies the process of fractal image compression. The output images of shape “A” unite to the Sierpinski triangle. This last image is called ‘attractor’ for this photocopying mechanism. Any original image will be transformed to the attractor if the mechanism runs repetitively. This characteristic is the advantage to the fractal image compression.
Figure 1.4: fractal image compression using Sierpinski triangle

- The fractal structures inspired from human blood vessels of fractal nature offers an easy low-pressure network to achieve a silicon chip to allow a cooling fluid to uniformly flow across the surface of the chip and this keeps the computer cool.

- The human body is also having fractal nature. DNA, retina, blood vessels, and lobes of the lungs are self-similar structures. Euclidean geometry is powerless to study and analyze abnormalities in these structures. Fractal geometric technology and fractal analysis tools are more useful to diagnose irregularities in the human body [7], and Figure 1.5 shows the retina network of fractal nature.

Figure 1.5: The retina network of fractal nature
Fractal mesh invention has divulged to diminish memory requisites and CPU time for finite element analysis of quivering problems [8].

Bridges, cables and different zones in cities like industrial, commercial and residential places are designing using this repetitive fractal geometric technology as shown in Figure 1.6[9].

The largest use of fractals exists in computer graphics. Many image processing schemes use fractal algorithms to create natural and artificial fractal structures digitally [10].

![Figure 1.6: Triangular and circular landscape of a city zone.](image)

### 1.3 Fractal Geometric Technology in Antenna Engineering

The concept of fractal geometric technology to the antenna engineering was pioneered by Kim and D. L. Jaggard. They introduced random fractal array antennas for less side lobe levels. Conventional methods to the design and analysis of antennas have their base in Euclidean geometric methodology. There has been a substantial amount of current interest, however, in the option of developing antennas and array antennas that utilize fractal geometric technology in their
design methodologies. Actually designing of antennas using Euclidean geometry are based on certain formula and analytical equations, but in this fractal geometry, designing of antennas are depends on iterative functions and their recursive algorithms.

Fractal antenna engineering is having two main branches of antenna design methods to fulfill the requirements of wireless based communication systems. Figure 1.7 shows the two main branches of “Fractal Antenna Engineering.” Depending on their properties and designing parameters, both fractal shaped radiators and fractal array antennas are again classified into various types. Both types are playing a significant role in the advanced communication systems owing to their magnificent radiation characteristics and miniaturized design techniques.

**Figure 1.7: Basic classifications of fractal antennas**

### 1.4 FRACTAL SHAPED RADIATORS

The multi-band behavior of fractal shaped antennas was introduced by C. P. Baliarda. In that study, Sierpinski and Koch monopole antennas were initiated and these fractal antennas have multi-band performance over different frequency bands as shown in Figure 1.5. Such performance is based on the repetitive nature of the fractal structures, bends and corners [12-15] and some more fractal antennas like modified Sierpinski monopole, modified half-Sierpinski gasket, Mod-P Sierpinski fractal antennas were introduced for multi-band applications in[16-18]. Like Sierpinski
fractal gasket antennas, Sierpinski fractal carpets structures have also been used in the designing of antenna elements [19]. One of the serious setbacks with a small loop antenna is that the input resistance is very small, building it hard to couple power to the antenna. By using a fractal loop, input impedance of the antenna increases. Koch Island, Minkowski, and hexagonal geometry with triangular loop are the best examples for the fractal loop antennas [20-24].

Fractal geometric technology was also introduced in microstrip patch antennas instead of conventional rectangular, circular, and square geometries and this leads improved gain of those antennas with multi-band, and ultra wide band behavior [25]. The analogous insight of raising the electrical length of a radiator can be applied to a patch antenna [26]. The patch antenna can be analyzed as a “Microstrip Transmission Line”. So, if the current will be forced to pass through the convoluted path of a fractal structure rather than a conventional Euclidean pathway, the area needed to engage the resonant transmission line will be reduced. This method has been applied to patch antennas in a range of forms [27–29]. Recently, novel patterns of fractal antennas are projected for miniaturization applications, and miniaturized Giuseppe Peano microstrip patch is shown figure 1.6. [30-32].

![Image](image.png)

**Figure 1.8:** Logarithmic frequency response of from Sierpinski fractal structure
1.5 FRACTAL ARRAY ANTENNAS

The research work proposed here is completely focused on the design and analysis of fractal array antennas through new design methodologies, fractal tapering, and optimization techniques. An array antenna is one of the best solutions for the long range communication systems rather than aperture antennas. The multiplicity of antenna elements allows more particular control of the radiation pattern, thus resulting in lower side lobe level and high directive scanned beams. Due to these fundamental properties, array antennas play a vital role in military, defense and other space applications. Owing to novel insights into array antenna parameters like low side lobe level with narrow beams and wider side lobe level angles, ultra wide band, multi-beams, feasible and simple design methodologies, and algorithms of fractal array antennas, usage of these arrays increases quite commonly in the antenna literature from past two to three decades. Due to these properties, fractal array antennas are find applications in celestial and other advanced communication systems.
Random and deterministic fractal array antennas are the two basic types of fractal arrays based on their geometric construction. Again deterministic fractal array antennas are also divided into three types based on their geometric patterns.

- Linear (1D) Fractal Array Antennas
- Planar (2D) Fractal Array Antennas
- Conformal (3D) Fractal Array Antennas

This work focused on the design, and novel design methodologies of deterministic fractal arrays. Detailed discussion, and literature on fractal array antennas, application of tapering, and optimization techniques of these arrays are discussed in the literature survey.