Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

Fractal Array Antenna: A Review of the State of the Art

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Abstract:
Possible array antennas with programmable multibeam, broadband, high end of coverage, high gain, less side-lobe level with wider side-lobe level angles, improved signal-to-noise ratio, and small size are required for modern astronomical and other advanced wireless communication systems. This has sparked numerous schools of thought on the subject of array antennas, one of which employs fractal array antennas. This paper provides an in-depth analysis of current developments in fractal array antenna design. To better understand how fractal antennas function, a primer on the theory behind them is presented. In addition, comparative research of the present state-of-the-art in antenna miniaturisation, gain, and Bandwidth augmentation with fractal array are performed.

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Keywords: Fractal Antenna, Array Antenna, Cantor linear array, Circular Polarization, Side lobe level(SLL)

1. INTRODUCTION

When it comes to antenna theory, microstrip antennas are the most active right now. Microstrip antennas are comprised of a metallic patch printed on a thin, grounded dielectric substrate. Microstrip antennas provide benefits such as portability, small size, cheap cost, flexibility, and simple integration with active devices. However, they have drawbacks such as low power, limited bandwidth, poor polarization purity, and spurious feed radiation **[1].** That's why improving both bandwidth and gain presents such a problem for microstrip antenna design **[2].**

When the gain, bandwidth, and power handling capabilities of a single microstrip antenna

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

element prove insufficient, an array design may be employed to boost performance. Each patch in this array has to be fed properly **[3, 4]** for the array as a whole to function as an efficient radiator. One or more lines may be used as the feed arrangement. A network with a single feed line is called a series feed network, whereas a network with numerous feed lines is called a corporate feed network. Corporate feed networks allow for flexible power distribution across antenna components. Beam may be steered across the corporate feed network by adding a phase change **[5].**

Multiple small antennas working together as an array may provide the same functionality as a single, bulky one. Antenna arrays are preferred because of the superior directivity and gain they provide, features crucial for many uses. These include communications; radars; satellites; electronic warfare; and radio astronomy. Linear, rectangular, circular, triangular, spherical, and other geometries can all be used to form an antenna array from a collection of identical elements. The radiation pattern of a phased array antenna may be electronically scanned, which is a very useful and novel capability. The array's radiation pattern may be steered electronically and adjusted in terms of shape by adjusting the amplitude and phase of the excitation of all radiating components. The electric field produced by the array is the vector sum of the electric fields of each individual radiating component. When the fields of the antenna arrays work together in a good way, an effective directional pattern is made. One of the most important parts of today's communication and industrial systems using radio frequency (RF), microwave, or millimeter wave frequencies is the antenna array. Devices able to dynamically manipulate the electromagnetic field are necessary for contemporary and future communication systems to meet the problems they confront. Antenna arrays are the best and most adaptable way to make these gadgets work.

1.1 Fractal Technology in Antenna

A pattern that never comes to an end is known as a fractal structure. These structures are made up of patterns that are both infinitely complex and self-similar on a variety of different scales [6]. Because of their ability to repeat themselves, fractals may be used in a wide variety of contexts, including science and engineering. The word "fractal" comes from the Latin word "fractus," which refers to a surface with a broken or irregular pattern. Some examples of naturally occurring fractals are the coastline of the ocean, the mountains, sea shells, snowflakes, leaves, and the eye train of a peacock [7]. All natural fractals may be classified as random fractals since there is no deterministic mechanism that can be used to generate them and also because they exist on non-integral surfaces. They are also referred to as "stochastic fractals" in certain circles. In the study of fractal development, several statistical approaches of various sorts are used. The degree to which these fractals behave in an unpredictable manner differs from structure to structure, as well as from one technique of creation to another way of manufacture. The Brownian motion of microscopic particles in fluid is also the best instance of random fractal behaviour, as can be shown in Figure1.

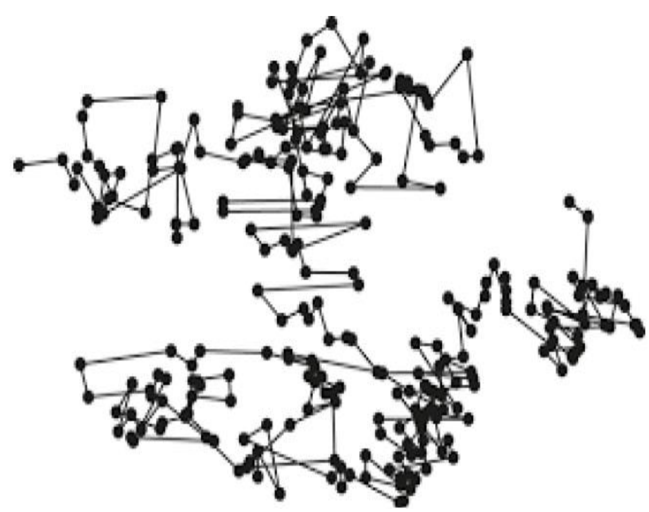

Figure 1. The Brownian motion of microscopic particles

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

This can be noticed by looking at the diagram. Geometric structures known as deterministic fractals are characterised by their ability to recur at a variety of sizes. In contrast to fractals that are generated at random, these ones have dimensions that have been accurately measured for their development. The construction of deterministic fractals always involves the use of iterated function systems (IFS) and complex number approaches. Scaling, twisting the plan axes, and dislocating the source are the three steps involved in the generation of a fractal structure employing these approaches. The Koch curve, Sierpinski triangle, Julia sets, and Sierpinski square are only a few of the examples of well-known IFS and complex number fractals.

Within these deterministic fractal structures, the fundamental generator, also known as the seed, duplicates itself indefinitely [8-10].

2. LITERATURE REVIEW

When it comes to long-range communication systems, array antennas are a better option than aperture antennas. Since the emission pattern can be fine-tuned with a larger number of antenna components, side lobes are reduced and scanning beams may be made more directed. These basic characteristics [12–15] are what make array antennas so useful in military settings. Traditional array antennas' performance is inadequate for modern wireless communication systems. Due to their new ideas about antenna properties like reconfigurable multi-beams, excellent array factor properties, reduced mutual coupling losses, ultra-wide band, and multiband characteristics, fractal array antennas have recently become a candidate for use in both military and civilian fields [16, 17].

Y. Kim, et.al., [18] In this paper, constructed random fractal array antennas using fractal geometric technology to cut down on unwanted side lobes were discussed. The technique presented here combines the best features of both random array antennas and periodic array antennas. For this purpose, the idea of self-similarity is integrated into the theory of random array antennas to control the sidelobe levels. Strong and with a reasonable number of side lobes, fractal random array antennas are an excellent option for large thinning array antennas.

Carles Puente-Baliarda, et.al., [19] Multiband operation and reduced side lobe levels were shown in Figure3. using a fractal Cantor array antenna. This article discusses and analyses two approaches to building multi-frequency fractal array antennas. A fractal design of array antennas is introduced, and the relative current distribution function of such a fractal array is derived; in addition, the fractal distance between array components is studied.

Dwight L. Jaggard, et.al., [20] in this paper Cantor array antenna of fractal nature was described, which had an expansion factor of three for multiband operation and lower side lobe levels than other antennas. This article examines two potential approaches to the fabrication of multi-frequency fractal array antennas and evaluates, compares, and contrasts the benefits offered by each of these approaches. In this study, authors investigate the fractal distance between array components. Additionally, authors introduce a fractal design of array antennas and derive the relative current distribution function of such a fractal array shown in Figure 2.

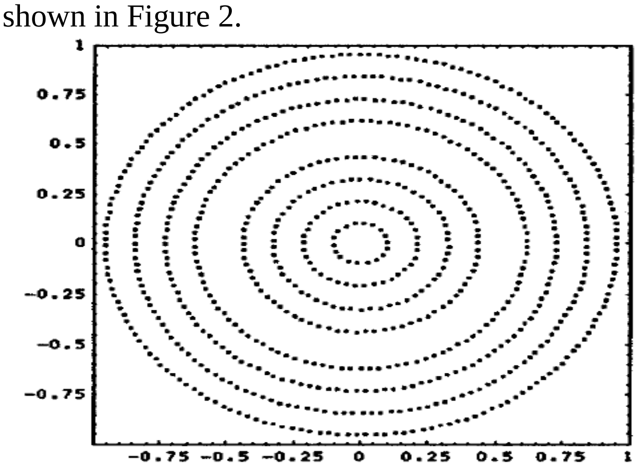

Figure 2. The Ring Array

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

D. H. Werner, et.al., [21] this paper discuss and designed a methodical strategy for the process of developing linear and planar fractal array antennas. This geometric method, which is based on the concept of sub-array concentric circular rings, may be used to construct any kind of polygon shape imaginable. Cantor linear, Sierpinski triangular, square, and hexagonal fractal array antennas are some types of fractal array antennas that may be designed using this geometric design technique. Other examples include. They demonstrated numerous essential characteristics of fractal array antennas by making use of the recursive structure of fractal geometric technology. Some of these characteristics include multiband behaviour, methods for getting lower sidelobe levels, and thinning. Because of the recursive nature of this design process, developing algorithms for it is a very straightforward task.

Douglas H. Werner, et.al., [22] Peano-Gosper fractal array antennas are the name given to a new order of self-similar fractal array antennas that has been developed. All of the antenna's elements are arranged in a straight line following a Peano-Gosper curve that allows them to avoid colliding with each other. In comparison to more conventional periodic planar array antennas, which typically have square or rectangular shapes and regular boundary borders, the frequency range of these fractal array antennas is relatively wider, which is just one of the many benefits that come along with using these antennas. These arrays do not display any grating lobes, and this is true even when the distance between antenna components is as close as physically feasible (at least one wavelength apart). Radiation patterns of Peano-Gosper fractal array antennas have been described, along with a well-organized iterative technique that can be used to quickly calculate radiation patterns up to an infinite number of stages of development. This technique can be used to determine the radiation patterns of Peano-Gosper fractal array antennas.

W. Kushirun, et.al., [23] The authors offer a concentric circular design process for creating antennas with a fractal array shape, such as a pentagon, an octagon, or a honeycomb, with an expansion factor of 2. Iterative improvements in these arrays' directional performance. The impact of the array's centre antenna element has also been studied. The suggested fractal arrays' centre element enhanced the behaviour of the array's factors. Additionally, a technique for designing conformal fractal array antennas (3D) using concentric spheres is presented. Broadband antenna arrays employing the Menger sponge and Sierpinski gasket conformal fractal designs are created with this 3D design process. Designing such arrays is a difficult task.

Pingjuan L. Werner, et.al., [24] have designed a class of antennas they name Peano-Gosper fractal array antennas because of their self-similar structure. In order to prevent the various components of the antenna from coming into contact with one another, they are arranged in a row that follows a Peano-Gosper curve in a straight line. The frequency range of these fractal array antennas is rather extensive in comparison to that of more common periodic planar array antennas, such as those with square or rectangular geometries and regular boundary borders. Fractal array antennas also have regular boundary bounds. Even when the spacing between the antenna components is made as small as is practically possible, these arrays still do not exhibit any symptoms of grating lobes (at least one wavelength apart). We have defined the radiation patterns of Peano-Gosper fractal array antennas and coupled them with a streamlined iterative approach that can be used to rapidly compute radiation patterns up to an infinite number of stages of evolution. This approach will be discussed in more detail in the following section.

Anirban Karmakar et.al., [25] Microstrip fractal planar array antennas using a Sierpinski carpet structure were proposed for use in spacecraft as shown in Figure 3. As a result of their geometrical make-up, the mutual coupling

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

between the antenna components dropped to below -20dB, and low side lobes began to form.

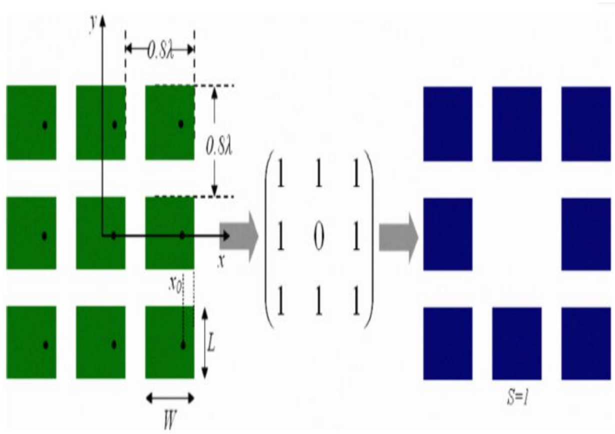

Figure 3. Illustration of the procedure for converting a *3x3* rectangular microstrip planar array in to a first stage (5'=1) of Sierpinski carpet based thinned array by removing the central element.

Jabbar, A. N., [26] this paper showed off three different forms of new fractal array antennas for use in space and high-tech wireless networks. They outperform the widely-used Uniform Square array, as well as random conventional array antennas and the Sierpinski fractal array antenna. Antenna arrays inspired by Twig, Dragon, and Flap fractal structures are presented.

N. Deepika Rani, et.al., [27] compare the Cantor fractal linear array antenna's benefits to those of more traditional arrays. Fractal structures like those used in Cantor linear arrays allow them to outperform more traditional linear array antennas in terms of all of the array factor attributes. Over time, narrower beams and fewer side lobes may be achieved by increasing the expansion factor and iteration count.

V. S. Rao, et.al., [28] The Cantor linear array was developed as a solution to the problem of having an odd number of antenna components. Cantor arrays normally consist of three different components, however at any given moment only two of those elements will be functioning. In this case, the authors suggest making use of four different components, with two of them being in the "on" position and the other two being in the "off" position. Because of this, there is an indirect change in the quality of the array factor as a consequence of the varying distance between the antenna components. The array that is detailed in this paper has obtained greater resolution and side lobes in comparison to both the Cantor fractal array and the standard linear array antenna.

R. T. Hussein, et.al., [29] explain the idea of fractal patterns, which are used in antenna arrays to provide multiband behavior. In designing multiband fractal linear array antennas, the Cantor set is a key component shows in Figure 4. The characteristics of array factors are compared to those of the more common linear array.

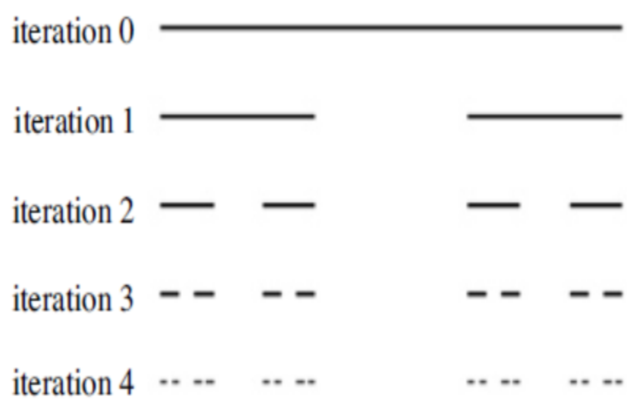

Figure 4. The first four iterations in the construction of the Cantor set array.

M. Levy, et.al., [30-31] a quick method for smart antenna applications that presents itself via the use of fractal array antenna theory, time and location tag algorithms, and beam shaping algorithms. The new techniques that have been suggested continue to enhance the distribution of computational sources for the progression of rapid beams, and the method that has been suggested significantly reduces the amount of time that is required for scheming the array factor. It also considerably reduces the amount of reliance placed on the user's memory.

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

Mounissamy Levy, et.al., [32-33] a conceptual study of fractal array antennas for use in optical communication systems has been presented. Both the diverging and converging optical fractal antennas, in addition to the non-linear one, are suggested and investigated. The arrays that have been described have great potential for a variety of forthcoming applications, including efficient quantum light sources, nano-scale spectroscopy, and high speed data transmission systems.

S. Hebib, et.al., [34] Cantor spiral thinning was presented as a way for achieving both lower side lobe levels and narrower main beams simultaneously in a thinned array antenna as shows in Figure 5. Thinner by roughly 10%, this array yet exhibits the same array factor behaviour as a standard Cantor circular array antenna.

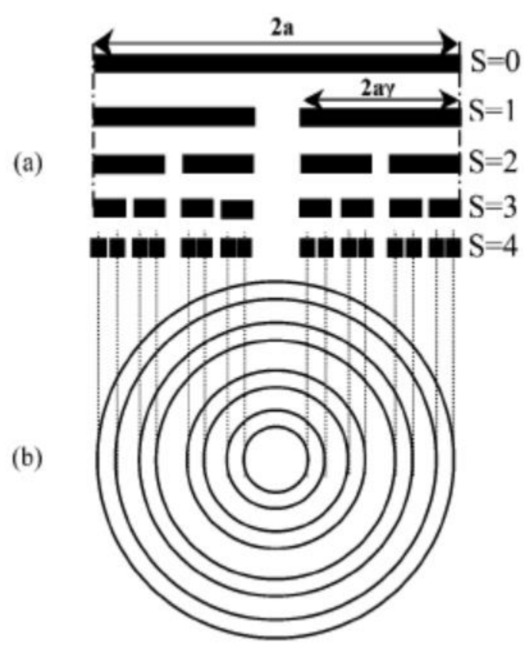

Figure 5. (a) Symmetric polyadic Cantor set at stage of growth S = 1; 2; 3; and 4. (b) Resulting concentric rings at stage S = 4.

Anirban Karmakar, et.al., [35] have presented a novel thinning array antenna form to reduce unwanted side lobes. For the reduction of the side lobes, this paper proposes a new technique using the Sierpinski square design, which is called sequential elimination of components. For the purpose of showing the suggested thinning method, a 99 array with micostrip patch antenna components has been explored.

Carsten Metz, et.al., [36] presented effective thinning strategies using non-linear multiplicative processing of array antennas for high resolution digital beam-forming radar applications. These sub-array-based, nonlinear multiplicative thinning processing algorithms show off very promising properties, such as thinning by as much as 80% with very minor sacrifices in picture detail.

Carlo Bencivenni, et.al., [37] have presented a novel thinning procedure for linear array antennas used in satellite systems. This technique reduces the size of the array antenna by "Switching off" the antenna components with the lowest weights in the "weight vector" that get the maximum gain. The method's efficacy is validated by comparing it to a precise combinatorial search strategy for finding the best solution for designing irregular array antennas of varying sizes.

Ovidio Mario Bucci, et.al., [38-39] novel tapering strategies have been suggested to address the shortcomings of local and global optimization techniques currently employed in satellite communications. It turns out that local optimization techniques aren't very useful for huge arrays, and global optimization requires intensive computer procedures. In this paper, one- and two-dimensional tapering strategies, respectively, are presented for linear and circular array antennas. The analytical methods take into account the geometry of the array antenna's central node and the array antenna's components. These approaches are helpful in computing the whole geometry of density tapered linear and concentric circular arrays quickly, iteratively, and deterministically.

K. Ulichny, et.al., [40] The thinned array antennas have been developed by randomly

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

eliminating 22 array antennas (meaning, four neighboring elements) in large aperture arrays, with varying degrees of success. Roughly 5-to-10% of the antenna elements may be thinned in this way without compromising the array factor qualities of the rest of the antenna.

Alessandro Ramalli, et.al., [41] antennas with a density tapered array configuration have been developed for use in ultrasonic imaging. A method is presented in this article for designing the layout of medium, big, and very large circular array antennas with a minimal number of antenna components that conform to Fermat's spiral seeds, and spiral density that tapers off toward the centre. Because of characteristics like aperiodic and deterministic geometry, a special effort is made to guarantee consistent performance throughout a broad range of wheel orientations.

Noor Ainniesafina Zainal, et.al., [42] antennas for 5G mobile applications with high density tapering were explored. Density tapered arrays of two different forms are shown, one optimized for low side lobes and the other for broad band applications. Instead of turning off certain antenna components, electrical tapering has been employed here by adjusting the space between them.

Will P. M. N. Keizer, et.al., [43] have implemented thin circular arrays on a vast scale, with a wavelength range of 25 to 133, to create a synthesis with a low side lobe. Synthesis of a low-level side lobe by use of amplitude-only taping applied to the "ON" components of a large circularly thinned array antenna.

Efri Sandi, et.al., [44] have presented two new methods for simplifying the design and lowering the price of linear sparse array antennas. The first way is combinatorial, using integer cyclic difference sets to greatly decrease the initial set size. To mitigate the impact of side lobes, the second procedure employs amplitude tapering using a binomial array. This hybrid method considerably reduces the number of antenna components required, the time required for calculation, and the size of the array antennas. Optimizing array antennas is a tried-and-true practice that has been around for at least four or five decades. However, because to the dynamic nature of algorithms, this process of applying optimization strategies to array antennas continues until now. Numerous methods for synthesizing array antennas, including those that optimize the amplitude, phase, and distance between the antenna components, may be found in the literature. In this study, we focused on reducing the size of antenna components by adjusting their amplitude. This article presents the existing literature on amplitude optimization of antenna arrays, as well as fractal array antennas, and highlights the dearth of research into the practical use of optimization methods, notably thinning, in the context of fractal array antennas.

R. L. Haupt, et.al., [45-48] to realize the advantages of tiny antenna arrays, was an early user of optimization methods such as genetic algorithms, particle swarm optimizations, and adaptive algorithms. To attain low side lobe levels, a thin array antenna is required, which is a challenging goal to meet. The production of non-uniform arrays via the use of traditional statistical methods is very inefficient. Using conventional techniques of optimization, it is possible to synthesize large arrays of antennas. The person who came up with the genetic algorithm did so because he saw fundamental flaws in the methods that came before it. This approach determines which of an array antenna's components have to be disabled in order to get the fewest amount of side lobes that are feasible. In this particular piece of research, both linear and circular antenna arrays are given a more streamlined appearance.

Rajesh Bera, et.al., [49-51] explained the process of thinning concentric hexagonal and cylindrical elliptical array antennas with evenly stimulated isotropic antenna components that are able to provide a directional beam with a low amount of relative side lobes. In order to reduce

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

the size of the array antenna's individual antenna components, the particle swarm and craziness-based particle swarm optimization approaches were used. Because of these optimization approaches, roughly "60%" of the antenna elements were able to become thinner while maintaining the same beam width and reducing the degree of side lobes.

P. Lombardo, et.al., [52] offered for the purpose of optimizing the design of a planar thinned array antennas with varying characteristics. The method that has been presented may either function with individual antenna components or with more compact groupings of a variety of subarray kinds that are positioned on a flat surface. The strategy that has been suggested centers on lessening the intensity of the side lobes while also taking into account a fixed number of active antenna components or subarrays. The approach that is being proposed is suitable for a variety of different forms of the output array antenna that is chosen, which makes it possible to achieve the required directivity attributes on the corresponding antenna pattern. In the context of industrial production, the use of subarrays with a limited number of distinct form variants is suitable. This would result in lower costs for both the design and the mechanization of the process. The modularity that is produced as a consequence makes it possible to scale antenna designs to suit a variety of applications.

U. Singh, et.al., [53] a biogeography-based optimization approach was given for the purpose of thinning bulky multiple concentric circular array antennas. The objective is to construct an array antenna with evenly excited current amplitudes using isotropic antenna components in order to produce pencil beams with minimal amounts of side lobes. Because of this optimization, over half of the antenna components have been reduced in thickness while maintaining or improving their array factor behavior.

Urvinder Singh, et.al., [54] application of the Firefly optimization algorithm to the design of thinned concentric circular array antennas was presented in this paper. The goal is to build an array antenna consisting of evenly stimulated isotropic components. This kind of antenna is designed to generate a pencil beam pattern with minimal levels of side lobes. Within the scope of this research project, two particular use cases for the suggested technique to thin down concentric circular array antennas were described. The main example use an inter-element spacing that is uniform and is either fixed at 0.5 microns or one of its multiples, while the secondary case utilizes an inter-element spacing that is either optimal or one of its multiples. Better array factor characteristics have been attained in both of these examples, and the results of this research make it abundantly evident that the firefly method is appropriate and easy to use for any kind of array antennas.

Douglas H. Werner, et.al., [55] in this paper synthesis of a fractal radiation pattern was used to describe a combined approach to the design of multiband array antennas. This innovative approach to the design of multi-band array antennas has a number of advantages, including a significant reduction in the amount of mutual coupling losses, the fact that only a minimal amount of element switching is necessary, and the ability to easily realize the design in the form of reconfigurable apertures. Additionally, a thinning procedure that safeguards all of the benefits provided by the band switching architecture was established. This process is predicated on the selection of an appropriate window function. There were several other window functions that were taken into consideration, such as the Blackman–Harris, Kaiser–Bessel, rectangular, and Blackman.

A.N. Bondareako, et.al., [56] a new synthesis approach has been given for the creation of various array antennas of Sierpinski gasket nature. This technique is based on the theory of atomic function. A significant advancement may

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

be attributed to the use of this synthesis method to these arrays.

D. H. Werner, et.al., [57] addressed nature-based optimization methodologies for the construction of polyfractal antenna arrays, such as the genetic algorithm and the covariance matrix adaptation evolutionary approach. These arrays make use of compact direct techniques, raised power series, and aperiodic tiling. The working frequency bandwidths of polyfractal array antennas may reach up to 30:1 and beyond, and they have no grating lobes and extremely low sidelobe levels.

Anirban Karmakar, et.al., [58] The Sierpinski fractal array antenna optimization utilizing the differential evolutionary method was taken into consideration. In a normal situation, fractal array antennas like Sierpinski carpet structures may suffer from an elevated side lobe level, in addition to suffering from complicated array factor calculation, which isolates it from the application of any evolutionary optimization strategy. A novel iterative feed matrix is proposed, and it is based on the Sierpinski carpet array. Its insertion simplifies the computation complexity of the Sierpinski fractal array antenna at different iterations and expansion factors, and it makes them suitable for the application of any evolutionary optimization methods.

Chen W-L, et.al., [60] in this paper, research on a proposed wide-slot antenna with a fractal-shaped slot for bandwidth improvement is presented. Experimental results show that operating bandwidth can be greatly increased by etching the wide slot as fractal shapes, and that there is a correlation between bandwidth and iteration order (IO). The experimental investigation of the fractal shapes' scale factor (IF) continues. At operating frequencies around 4 GHz, the proposed fractal slot antenna achieves an impedance bandwidth of 2.4 GHz, defined by a 10 dB reflection coefficient. This is roughly 3.5 times that of a conventional microstrip-line-fed printed wide-slot antenna. In addition, it has a 1.59 GHz bandwidth with a 2-dB gain.

3. RESULTS AND DISCUSSION

Table 3.1 Comparisons between previous related fractal antennas

Reference No.	BW (GHz)	Gain(dB)	SLL (dB)	Mutual Coupling (dB)	Directivity (dB)	Size (mm)	Efficiency %	Array Size	Type	Weak points
[19]		1.1-1.7					30	64 Element	Koch	Not cover all bands, complex geometry
[20]							40	754 Elements	Cantor ring array	complex geometry,
[21]							60	64 Elements	Sierpinski	Not cover all bands
[22]					21.27		70	19x19 array	Koch	Large size
[23]					22.5		60	3x3 ARRAY	Koch	Not cover all bands
[24]								1024 Elements	Flap Fractal	Not cover all bands
[25]			-18	-20				9x9	Sierpinski	
[56]	2.1-3.2	7							Sierpinski gasket	

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

[57]										
[58]	10.25-10.75	5							Sierpinski	Elevated side lobe level
[60]	(2.7–4) (4.3–5.2)	3~5.5				70×70×1.5	-		Fractal Slot	Large size, LP, does not cover all required bands,
[61]	(2.1–6)	2~5				48×40×1	80–90		Sierpinski	LP, complex design
[62]	(3–12)	-				31×28×1.6	80–90		Koch	Does not cover 2.4 GHz band, LP, no gain values
[63]	(2.4–2.49)	(1.9~7)				120×120×1.6	-		H-Fractal	Large size, does not cover all required bands, LP,
[64]	(5.1–5.8) (2.4–2.48) (3.4–3.6)	1.1~3.1				100×100×5	50–72		Minkowski	Large size, LP, low efficiency at lower band.
[65]	(5.1–5.8) (1.5–4)	2.2~2.4				80×40×1.58	60–79		Koch-snowflake	LP, does not cover the (5-6) GHz band, complex geometry
[66]	(1.3–20)	−2~10				62×50.8×0.8	20–90		Fern Leaf	LP, low gain and efficiency at lower band
[67]	(2.4–2.5)	-				35×35×2.5	48–62		Koch	LP, no values of gain, low efficiency values
[68]	(2.5–2.7)	-				263×164×2.3	-		Mandelbrot	Large size, LP, does not cover all required bands, no values of gain and efficiency.
[69]	(5.4–14.2)	-				158×158×3.6	-		Quasi-Fractal	Large size, LP, does not cover all bands requirement, no values of gain and efficiency.
[70]	(3–25.2)	3~9.8				25×30×1	-		Hexagonal-Triangular	LP, no efficiency values, does not cover all required frequencies.

4. CONCLUSION

Many of the capabilities that can be used in conjunction with fractal antenna arrays have not yet been developed, and the technology is still in its infancy. The radiation patterns of individual elements are diffuse and have a low directivity (gain). Sometimes, antennas with particularly directional properties are needed to meet the needs of long-distance communication (quite high gains). The antenna's electrical size must be increased for this purpose. Increasing the size of a single element of an antenna can often lend it more authoritative qualities. The collection of radiating devices arranged in a certain electrical and geometrical arrangement is another method to increase the antenna's overall dimensions without increasing the size of the individual elements. This new antenna is an array because it is made up of many separate parts. It's safe to assume that each item in the array is equivalent to every other item in it. Although this isn't mandatory, it is often the most efficient use of your time. Elements of an array can take any form (wires, holes, etc.). Researchers are inspired to look for new ways to improve the

Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

functionality of implanted antennas by studying this topic. For high-frequency tasks, a fractal antenna array is a viable option. It is essential to have a highly directional and high-gain antenna array for milimeter wave communication. Attempting to do so is a constant difficulty in this industry. Metamaterials could be used to increase the antenna's size, gain, or bandwidth in antenna design. The greatest apparent benefit would be the miniaturisation of antennas, and smaller antennas that use metamaterials are already commercially available.

ACKNOWLEDGEMENTS

Nill

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Section A-Research paper
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Fractal Array Antenna: A Review of the State of the Art

Section A-Research paper
ISSN 2063-5346

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