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A Survey on Fractal Antenna Design

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Abstract

Fractal structure is implemented in such a way to maximize the effective length of material that can receive or transmit electromagnetic radiation within a given total surface area or volume. Fractals have unique property by making the copies of itself at different scales. Fractals found its applications in two fields: 1. For the analysis and design of fractal antenna elements and 2. To the design of antenna arrays. Self similarity and Space filling are the key properties of fractal geometries which are used for the design of fractal antennas and arrays. This paper presents the survey on the existing categories of Fractal Antennas and their applications. Types of Fractal Geometries are listed in this survey. A brief summary of works incorporated and the advantages of those proposed methods and the findings and shortfalls have been discussed.

Keywords:Fractal, Sierpinski Gasket, Sierpinski Carpet, Koch curves, Minkowski Geometry, Hilbert.

1 Introduction

Fractal geometry is a very popular method which has unique properties to improve the characteristics of the patch antennas. Fractal was first defined by Benoit Mandelbrot in 1975 and snowflake curve was the first example of fractal given by him. Fractal shapes are complex in structure and they can be generated by using recursive procedures which exhibit large surface area in limited space [1]. Even though there are various mathematical structures may be termed as fractals [2]. So, geometries and dimensions of fractal structures are important key factor for the operative resonant frequencies. The self similarity of fractal shapes can be obtained by applying the infinite number of iterations to achieve multiband characteristics [3]. The space filling property is used to decrease the antenna size or to achieve the miniaturization of antenna. The miniaturization of antenna is also achieved by increasing the effective permeability and permittivity of the substrate [4]. The fractal antenna is more powerful, compact and versatile [5]. The self-similar property of fractal can be explained with the help of an example of a fern leaf. If we observe a fern leaf carefully then we will notice that each small leaf which is a part of the big leaf has the same shape as that of the whole fern leaf. The fern leaf is self-similar [6]. The generally used fractals are Sierpinski Gasket, Sierpinski Carpet, Koch curves, Minkowski Geometry, Hilbert etc.

2 TYPES OF FRACTAL GEOMETRIES

The Classification of Fractal Antennas can be explained in Fig.1

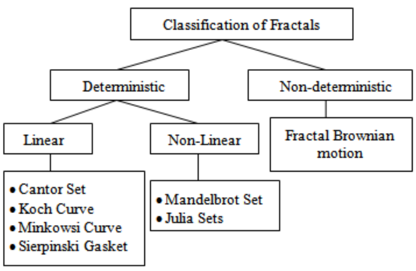

Fig.1 Classification of Fractal Antennas

2

A. Sierpinski Gasket

The widely used fractal geometry is Sierpinski Gasket for antenna applications. The Self-similar current distribution on this antenna exhibits the multi-band characteristics. Two different approaches like multiple-copy and decomposition can be used to generate the Sierpinski Gasket antenna with the help of self-similarity and space-filling properties, as shown in the Fig.2. As illustrated in Fig.3, the Sierpinski Gasket shape is attained by extracting the central part of main triangle with inverted equilateral triangle from the main triangle and this process can be repeated to attain the desired geometry

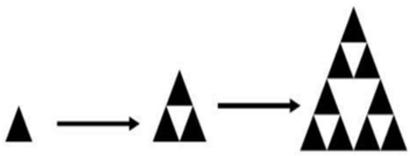

Fig.2 Sierpinski Gasket-Multiple Copy Generation Approach

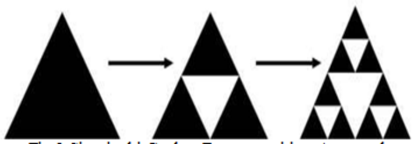

Fig.3 Sierpinski Gasket-Decomposition Approach

B. Sierpinski Carpet

The Sierpinski Carpet geometry is obtained by using the rectangular patch. The rectangle of one-third size is subtracted from the centre of the main rectangle and this process is repeated number of times to attain the desired geometry [9]. The self-similarity property of fractal antenna is used with varying iterations to design this antenna [10] [11]. The Sierpinski Carpet fractal antenna with four iterations is shown in Fig.4.

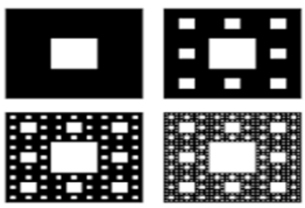

Fig.4 Sierpinski Carpet Fractal Antenna

C. Koch Curve

The Koch curve is the simplest fractal. It is generated by dividing the straight line into three parts a, b and c. The middle part of the straight line bends into the triangular shape as shown in Fig.5, with flare angle 60o and indicated as b [12]. The same process can be repeated for the fractal geometry up to finite number of iterations. Iteration adds length to the curve and results in a total length i.e.; four-third size the original geometry. [13]:

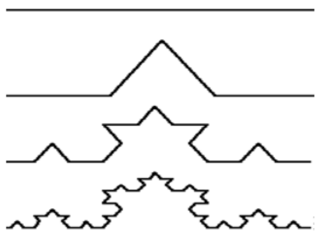

Fig.5 Koch Fractal Curves

D. Minkowski Geometry

The geometric shape of Minkowski curve is designed by taking the straight line (initiator) and the generator structure is shown in Fig.6 [14]. This recursive process is repeated up to 2nd iteration. The Iterated Function System (IFS) can also be used to obtain the required Minkowski fractal shape. It is somehow similar to Koch curves where equilateral triangles are used but in Minkowski geometry, the rectangles are used.

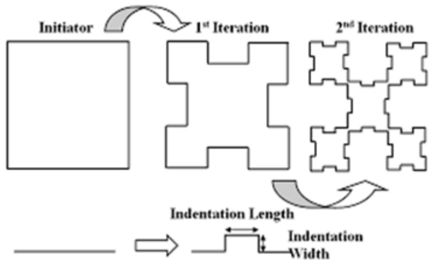

Fig.6 Minkowski curve

E. Hilbert Curve

Hilbert curves are given the name after David Hilbert in 1891. These curves consist of various stages where each following stage contains four copies of the previous one, along with one extra line segment as shown in Fig.7. The geometry of Hilbert curve is space filling i.e; with the large number of iterations [15].

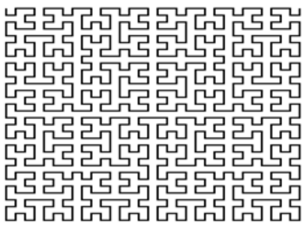

Fig.7 Hilbert Curve

3 LITERATURE REVIEW

Research work has been done by the distinguished researchers to enhance the performance parameters of a fractal antenna. This paper mainly deals with the motivation to carry the research on antennas, study of work that has been done by the various researchers and the challenges faced by distinguished researchers. The study of the research work carried out by various researchers is listed below:

Landeau et al., [5] investigate the optimization of modified Sierpinski fractal antenna. The Particle Swarm Optimization and curve fitting techniques are able to convert the dual band antenna to broadband antenna. The proposed antenna can be used for WiMAX, WLAN, Public safety band and point-to-point high speed communication.

Singh and Kumar [13] describe a design of compact size Multiband hybrid fractal antenna by the combination of Koch and Minkowski curve. The simulated antenna resonates at seven frequency bands and covers the wireless applications such as GPS, Bluetooth, ISM band, WLAN, aeronautical navigation and Mobile/fixed satellite.

Abdullah et al., [14] premeditates the design of Minkowski fractal antenna for dual band applications. The designed antenna operates on two different frequencies and reports maximum return loss is -20.62dB. The reference frequencies occur in GPS (1.5 GHz) and GSM (1800 MHz).

Azaro et al., [15] anticipates the design of log-periodic square

fractal antenna for Ultra Wide Band applications. In the desired band, the proposed antenna indicates the constant and stable gain. The radiation pattern is broadside and it is suitable for medical imaging and UWB radar applications.
Kumar et al., [16] premeditates the frequency reconfigurable antenna with moving feeding technique. Sierpinski monopole gasket is connected with microstrip line feed which is also attached with flexible coaxial feed. The connected feed line slides with the help of Computer controlled mechanism. While sliding the feed line with the help of computer controlled mechanism, the various operational frequencies are observed.
Choukiker et al., [17] proposes a hybrid fractal shape planar monopole antenna that can be operated at different frequencies which is very useful for Multiple Input Multiple Output (MIMO). The discussed hybrid structure is the integration of Minkowski and Koch curve with edge to edge separation of at 1.75 GHz. To improve the isolation and impedance matching of antenna, T-shaped strip is inserted into the structure and rectangular slot is incised towards upper side of the ground plane.
Kumar and Singh [19] explains Hybrid fractal antenna by the combination of the Koch curve and Meander geometry. The antenna resonates at four frequencies are Bluetooth (2.12-2.95 GHz), 4.07 GHz, WLAN (4.82-5.95 GHz) and 7.3 GHz. They can be used for wireless applications.
Singh and Singh [20] explain the modified Sierpinski fractal antenna by using compact high frequency coaxial probe feed. The broadband behavior occurs in the frequency band as 12.213.4 GHz and 21 30 GHz. The experimental gain varies in between 8 to 22 dB. The implemented antenna is useful for the satellite receiver, mounted earth station, mobile space research activity, passive sensors and active sensors.
Gurpreet Bharti et al., [21] presents the design of triple band compact microstrip patch antenna with fractal elements. The antenna has been designed on FR4 substrate with thickness 1.6mm, dielectric constant 4.4 and resonant frequency of antenna is 3.2 GHz. Gain of antenna is improved by addition of fractal elements to the nine corners of the nonagon patch. The designed antennas covers the frequency bands of WLAN, WiMax and other wireless applications which comes under the frequency ranges of S-band, C-

band and X-band.

Sumanpreet Kaur Sidhu et al., [**22**] illustrates the rectangular patch with half rectangular fractal geometry is designed. The proposed antenna is fabricated on RT/duroid 5880 with relative permittivity 2.2 and having dimensions 40mm x 30mm x 1.56mm. It operates at four frequency bands 3.19-3.29 GHz, 3.98-4.09 GHz, 5.4-5.46 GHz and 5.97-6.06 GHz. The proposed design has return loss 18.5061 dB, -22.1394 dB, -4.7404 dB and -36.2199 dB in frequency bands 3.19-3.29 GHz, 3.98-4.09 GHz, 5.4-5.46 GHz and 5.97-6.06 GHz. The proposed antenna can be used in the military for meteorological purpose and satellite communications.

Narinder Sharma et al., [**23**] deals with the miniaturization of fractal antenna by using novel Giuseppe peano fractal antenna for wireless applications. The antenna is designed on FR4 glass epoxy substrate with dielectric constant 4.4 and thickness 1.6mm. The resonant frequency of 4 GHz is used to design the proposed antenna. The 1st iteration of antenna resonates on 3.61 GHz, 6.20 GHz and 8.43 GHz frequency band and 2nd iteration resonates on 2.10 GHz, 2.85 GHz, 5.158 GHz and 9.11 GHz. The designed antenna can be used for different wireless applications such as WLAN (4.82-5.95 GHz), Bluetooth (2.12-2.95 GHz), X-band (8-12 GHz) etc.

Kaur et al., [**24**] anticipates the design of Plus Slotted Fractal Antenna Array by combining the fractal antenna and antenna array. They can be used for S, X and C band applications. The Proposed antenna operates at 2.5 GHz and designed upto 2nd iteration. The designed antenna array operates at five different frequencies and exhibits maximum gain 10.26 dB at 6.9 GHz and depicts multiband characteristics.

Pandey and Shanmuganantham [**25**] propose a wideband compact sized slotted MPA with enhanced bandwidth using coaxially fed. The proposed antenna exhibits increased -10 dB impedance bandwidths of 500 MHz, 400 MHz and 550 MHz, and practically used for WLAN and WiMAX applications.

Guru Prasad Mishra et al., [**26**] presents the design and simulation of multiband Sierpinski fractal antenna with different patch (rectangular, circular and triangular) geometries. To validate the effect of fractal on microstrip array, a 2 x 2 fractal antenna array is also designed. The proposed multiband antenna and its array are optimized to operate at 28 GHz, considering a FR-4 substrate material. They can be used in Ka band and other wireless communications.

Shanu Patel et al., [**27**] presents the design and simulation of dual-band Minkowski fractal antenna by the coupling technique. The proposed antenna is suitable for wireless local area network applications. The material used for substrate is FR4 with relative permittivity of 4.4 and thickness is about 1.6mm, and loss tangent of 0.0013. The antenna is fed by 50 Microstrip line feed.

Chatterjee et al., [**28**] presents the design and fabricate a compact four-element linear array of microstrip patch antennas to be operated at dedicated short range communication service (DSRCS) band. The array is designed in a particular direction by reducing the peak side lobe level (peak SLL) in its beam pattern. In order to reduce the array size and also to increase its gain, a modified-Cantor square-fractal based design has been employed as an element of the array. Optimum values are obtained using Differential Evolution (DE) algorithm. The corporate feed network of the array is designed using the optimum values of the parameters.

Varamini et al., [**29**] describes a compact antenna based on fractal and metamaterial loads techniques. The microstrip patch antenna is assumed as a basic antenna and then the effect of fractal structures is implemented. The fractal patch is considered as a right-handed element and then by adding a left-handed element. The antenna miniaturization is achieved by using the metamaterial loads technique. By adding reconfigurable characteristic to the proposed antenna, the gain and radiation pattern can be controlled. The patch antenna has low bandwidth and gain and so we have developed the patch antenna with defected ground is used to achieve higher gain and bandwidth. The final antenna is covering 2.4, 3.5 and 5.5 GHz with higher gain than the patch antenna.

Shubha Gupta et al., [**30**] describes the inverted pyramid-shaped Sierpinski fractal Dielectric Resonator Antenna (DRA) is designed and investigated. The geometry is a Sierpinski Gasket with rectangle as a base element. Proposed fractal is applied on Rectangular DRA (RDRA) and bandwidth variation with three different orientations of DRA is investigated. Proposed structure with inverted geometry gives the optimized bandwidth and gain. The material used for investigation is Rogers RT/Duroid 6010, which is a ce-

ramic PTFE composite material having dielectric constant 10.2. The maximum gain obtained is 6.56 dBi at 10.1GHz and the efficiency is above 81% for the entire band of operation.
Sankar Ponnapalli et al., [31] illustrates the fractal arrays (Repetitive-geometry-based smart arrays). They have the impressive array factor properties by degrading the large number of antenna elements at higher expansion levels. The thinning of Sierpinski fractal arrays will be applicable balance between all array factor properties by using two types of bounded binary-fractal-tapering techniques known as Sierpinski and Haferman carpet anti-diagonal tapering techniques.
Jagtar Singh Sivia et al., [32] describes the design of Modified Sierpinski Carpet Fractal Antenna which resonates at six frequencies 4.825, 5.455, 6.265 GHz and 6.805, 8.02 and 9.145 GHz. The FR4 glass epoxy with relative permittivity 4.4 and height 1.6 mm is used as substrate material. Antenna is fed by coaxial probe feed. Investigation is done between 1 and 10 GHz frequencies.
Ullah et al., [33] demonstrates the design of monopole antenna which depicts three different frequency bands. The radiating patch of antenna comprises of two parts, the upper part is flower-shaped and lower part is leave- shaped. Lower part comprises of two identical leaves. It exhibits acceptable simulated antenna efficiency (¿70) and can be used for GPS and Mobile WiMAX applications.
Mohd G. Siddiqui et al., [34] proposes the microstrip antenna is based on fractal techniques and designed for wireless applications. The radiating element is an A-shaped triangle on which fractal concept is applied. Fractal concept is applied on the proposed A-Shaped Fractal Microstrip Antenna (ASFM-Antenna. Von Kochs snowflake concept is used in which a single line is divided into four new lines, and it is done at each side of the triangle. The antenna resonates at 11.44 GHz, 13.178 GHz, 15.482 GHz, 19.902 GHz and 23.529 GHz. Hence, X-band [8.212.4 GHz], Ku-band [12.418 GHz] and K-band [1826.5 GHz] are the frequencies of operating bands.
Sumeet Singh Bhatia et al., [35] presents an optimal design of fractal antenna with modified ground structure for wideband applications. The proposed antenna has been designed by taking numerous iterations started from 0th to 3rd. The maximum value of bandwidth has been adorned in the final iteration as 1.88 and 0.20 GHz. Further, this bandwidth has been improved and em-

bellished as 2.48 GHz within the frequency range of 36 GHz by employing horizontal and vertical extensions in the partial ground plane. The maximum value of gain is reported as 5.1 dB and radiation pattern is also omnidirectional. The proposed antenna is useful for the wireless applications as WiMAX (3.43.69 GHz) and WLAN (5.155.35 GHz and 5.725.82 GHz).

Bandhakavi S. Deepak et al., [36] demonstrates the design and analysis of a novel wide-band covering, hetero triangle linked hybrid web fractal antenna. The hetero triangle linked hybrid web structure has been designed through multiple iterations and it is fabricated on FR4 dielectric of r = 4.4 with height of 1.6 mm. The proposed antenna offers a comprehensive bandwidth of 18.055 GHz, covering from 1.945 GHz to 20 GHz. It supports various applications starting from 3G, LTE, ISM, Bluetooth, Wi-Fi, WLAN (2.42.48 GHz) and 5.2/5.8 GHz (5.155.35 GHz/5.725.82 GHz), WiMAX operating in the 2.3/2.5GHz (2.3052.36 GHz/2.52.69 GHz), 5.5GHz (5.255.85 GHz) and Satellite communication (Ku band: Uplink of 14GHz and Downlink of 10.912.75 GHz). The proposed antenna provides peak realized gain of 7.17 dB with efficiency more than 78% in the operating band.

Arpan Desai et al., [37] focuses on design and analysis of hexagon inspired fractal geometry and defected ground plane to evaluate the performance of patch antenna for wireless applications. It also emphasizes by increasing the antenna bandwidth by incorporating novel rectangular Defected Ground Surface (DGS) structure with CPW feed. In the proposed work, antenna is simulated and fabricated for wireless applications using FR4 as the substrate, and it covers wide band with high gain. The proposed antenna suitable for Wi-Fi, cordless phone, wireless devices and wireless sensor networks applications.

Gnanaharan Irene and Anbazhagan Rajesh [38] present a novel compact hexagonal shaped ultra-wideband multiple-input multiple output (UWB-MIMO) Koch fractal antenna is designed with penta-band rejection characteristics. A spiral shaped slot is introduced inside the fractal hexagonal monopole to introduce band reject characteristics. The band suppression and widening of the impedance bandwidth are achieved by using defected ground structures. The antenna has very low envelope correlation coefficient of less than 0.17 and low capacity loss of 0.254 which proves that the

MIMO antenna shows good diversity performance.

Roman Kubacki et al., [39] presents microstrip patch antennas are based on the fractal antenna concept by the usage of planar periodic geometries. The properties of the fractal structure were used in a single-fractal layer which employs fractals on both the upper and bottom layers of the antenna. The antenna could support an ultra-wide bandwidth ranging from 4.1 to 19.4 GHz. It demonstrates the higher gain with an average value of 6 dBi over the frequency range and a radiation capability directed in the horizontal plane of the antenna.

Madhav et al., [40] describes the compact conformal antenna is proposed for vehicular communications applications. It is fabricated on a transparent and flexible poly vinyl chloride material of size 55mm x 40mm x 3mm. The proposed antenna is intended to operate in GSM-1800/1900, Digital Communication System (DCS-1800), Personal Communication Service (PCS-1900), Universal Mobile Telecommunications System (UMTS), Long-Term Evolution (LTE2600), Industrial, Scientific, and Medical radio band (ISM 2.4G), Wireless local area network (WLAN), Bluetooth, World Interoperability for Microwave Access (WiMAX), IEEE802.11p protocol based Vehicle-to-everything, Dedicated short-range communications (DSRC) and Wireless Access in Vehicular Environments (WAVE) communications bands.

Susila Mohandoss et al., [41] presents a bandwidth enhanced, compact planar ultra-wideband antenna design for the usage of wireless personal area communication (WPAN) applications. The proposed fractal based antenna has an impedance bandwidth from 2.9 GHz to 15 GHz with low profile configuration and is fabricated on FR4 substrate. Furthermore, the antenna is validated for its applicability in WPAN for the calculation of fidelity factor through time domain analysis along with the transmission coefficient and group delay measurements.

Yagateela P. Rangaiah et al., [42] determines the single feed circularly polarized microstrip antenna with Koch curve as boundary is presented. The two pairs of rectangular microstrip antenna edges are replaced by a Koch curve of 1st stage and 2nd stage with different indentation angles to get circular polarization. The dependency of aspect ratio and fractal dimension of the boundary on the performance of the circularly polarized antenna is discussed.

Singh Bangi and Singh Sivia [**43**] describes the two types of fractal antennas are designed one by superimposing Hilbert curve on Minkowski curve known as Hilbert Minkowski Antenna (HMA) and other by superimposing Minkowski curve on Hilbert curve known as Minkowski Hilbert Antenna (MHA). FR4 material is used as a substrate material. It is found that Hilbert Minkowski Antenna has better performance in terms of Gain while Minkowski Hilbert Antenna is better in terms of number of frequency bands.
Gohar Varamini et al., [**44**] develops the slot microstrip antenna with Sierpinski carpet and Minkowski formation by placing the metamaterial loads in the slot area of the antenna. The reflection/transmission method has considered by obtaining the permittivity and permeability of the split ring resonator (SRR) as a metamaterial. We show that the antenna has two resonance frequencies that matched with the metamaterial Double Negative (DNG) characteristic.
Narinder Sharma et al., [**45**] initiates two Moore Antennas are designed which are different from each other in terms of 50 microstrip transmission line only. To improve the multiband behavior of Moore Antenna, it is being fused with Koch curve and resultant antenna is named as Moore Koch Hybrid Fractal Antenna (MKHFA) where Koch curves are superimposed on Moore curve. Two distinct MKHFAs are designed as MKHFA with LFL and MKHFA with RFL. Results of Moore Antenna has been compared with MKHFA and found that MKHFA exhibits multiband behavior.

4 CONCLUSION

This paper summarizes a brief literature survey about the fractal antenna. Small size, wideband and multiband antennas are most widely required so that they can be added on cellular phones, airplanes, space crafts and missiles. They are less bulky and capable of resonating at different bands but suffer from disadvantages like low bandwidth and low gain. There are number of techniques for improving these factors like cutting slots in patch by using fractal geometry and then the size of the antenna reduces. The metallic portion is reduced due to the use of various fractal geometries. Hence they can reduce the overall size of antenna. Multiband/wideband can be produced by making use of a single antenna. Fractal geometry also helps in the improvement of bandwidth. Hence large bandwidth can be achieved. It can be used for various wireless applications like Bluetooth, GSM, Satellite, GPS RFID, WiMAX, WLAN, RADAR, Point-to-point high speed wireless communication, ISM band.

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