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A Review : Microstrip Fractal antenna geometries

***Abstract**. With the rapid development of wireless communication system, the main objective is to design of wideband, multiband and small size antenna. To obtains these requirements the fractal antenna is used. The term "fractal" came into the existence in 1975 which means non-regular and never ending pattern. Fractal geometry has advantages of reducing antenna size and obtains multi-band or wideband behaviour; while it's on the other hand drawback is increasing the complexity of antenna design when increasing the iteration number without notifies any enhancement in antenna performance. Also, fractal geometry has two important properties such as space filling and self-similarity. One of the most hopeful areas of fractal-geometry is its application to the design of antenna to produce miniature size and wideband antenna take advantages from their unique properties of self- similarity property and space-filling.*

Streszczenie.** Wraz z szybkim rozwojem systemów komunikacji bezprzewodowej, głównym celem jest projektowanie anten szerokopasmowych, wielopasmowych io niewielkich rozmiarach. Aby spełnić te wymagania, stosuje się antenę fraktalną. Termin „fraktal" powstał w 1975 roku, co oznacza nieregularny i niekończący się wzór. Geometria fraktalna ma zalety polegające na zmniejszeniu rozmiaru anteny i uzyskaniu zachowania wielopasmowego lub szerokopasmowego; z drugiej strony wadą jest zwiększenie złożoności konstrukcji anteny przy zwiększaniu liczby iteracji bez powiadamiania o zwiększeniu wydajności anteny. Ponadto geometria fraktalna ma dwie ważne właściwości, takie jak wypełnienie przestrzeni i samopodobieństwo. Jednym z najbardziej obiecujących obszarów geometrii fraktalnej jest jej zastosowanie do projektowania anten o miniaturowych rozmiarach, a anteny szerokopasmowe czerpią korzyści z ich unikalnych właściwości samopodobieństwa i wypełniania przestrzeni.* (Geometrie anten Microstrip Fractal***)

Keywords: *Fractal antenna, fractal technique, iteration factor,* microsrtrip.
Słowa kluczowe: anteny fraktalne, iteracja, mikrostrriop - mikropasek

Introduction

Recently, fractal geometry has witnessed a wide development in all branches of engineering and scienceIt is interested with the properties of fractal things, known as fractals. The fractal was coined by Benoit Mandelbrot; Mandelbrot perceived that when using Euclidean geometry only cannot describe nature, which is in terms of circles, cubes and straight-lines [1]. He suggested fractal geometry to utilized could be characterize real objects for example coastlines and trees. The easiest way to define fractal is as the same object replicates at differing phases of miniaturization, where that fractal object is regarded as a self similar object which replicated several terms with the smaller size and same shape, the object that is not repeated with the same shape will not be considered as a fractal objec [2].

Fractal Geometry

Fractal can be classified into two main forms such as random and deterministic, random fractal can be found in nature and it constituted randomly from a set of non-determined steps such as tree and cloud. While, deterministic fractal constituted from a set of mathematic steps[3].

In order to design any kind of fractal antenna, two main steps must be accomplished are initiator and generator, the initiator represent the base state of antenna design and it has a zeroth iteration number, while the advantage of generator is about the subsequent iteration number which generated from the area of initiator that starts from 1st iteration to a certain number of iterations. The iteration number is selected depending on the task that the antenna should perform such as multiband or wideband behavior. The fractal that utilized in the design of the antenna is not a mathematically fractal with infinite scale, but it is usually a quasi-fractal or pre-fractal. Therefore, a quasi-fractal with certain iteration number can be used to design wideband antenna[4].

There are two types of possessing; self-similarity to natural fractal are statistical self-similarity and exact self-similarity, in statistical self-similarity the same object will repeat with the same size such as the boundary of clouds and wall cracks[1],[2].

Fractal Dimensions

Fractal has no integer dimensions while Euclidean has integer dimension and fractal dimension is less than its Euclidean dimension(DE) and it is greater than its topological dimension(DT). DT used to refer the familiar intuitive idea of dimensions. As shown in Fig.1, a point, a line, a plane and a cube have topological dimensions of 0D, 1D, 2D, and 3D, respectively. These intuitive dimensions are always expressed as integer dimensions [5], [6].

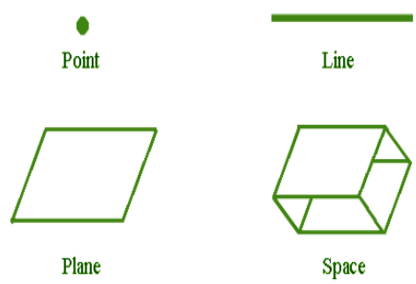

Fig. 1: Euclidean geometries [1]

The simplest way to constitute a figure which contains fractal dimensions is using the general formula to calculate fractal dimensions FD as given by [5], [6]:

$$\text{FD}= \frac{Log\ (n)}{Log\ (\frac{1}{r})} \quad (1)$$

where r is the value of the reduction factor, which represents the new-side length compared to the length of the original-side and n is the total number of copies.

The fractal dimension FD of any shape or figure which exhibits a self-similar property of fractal geometry can be calculated by splitting the shape into n parts and the size reduction factor r used to make a relationship between the size of each split part and the size of original one. For any Euclidean shape such as line, circle and other shapes, the fractal dimension FD is the same as topological dimension DT of that shapes, while fractal dimension(FD) may be estimated for any non standard forms which have self similarity property of fractal geometry [5], as shown in Fig.2. The dimensions some of geometrical shapes are summarized in Table 1, where, the fourth column of Table 1 includes the value of fractal dimension FD for every geometric shape [5].

Table 1: FD of geometrical forms

Shape Name	n	r	Fractal dimension
Line	2	1/2	1
Square	4	1/2	2
Cube	8	1/2	3
Minkowski island	5	1/3	1.46
Cantor	2	1/3	0.63
Sierpinski	3	1/2	1.58

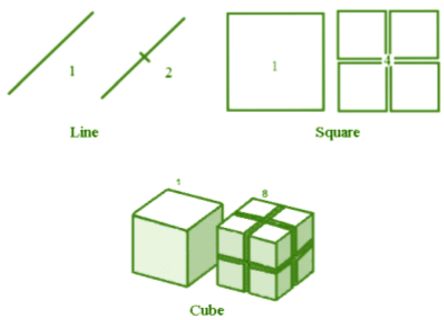

Fig. 2 Euclidean geometrical forms of a cube, square and line [5]

Fractal Properties

Fractal antenna engineering is a raising field that applies fractal geometry for advancing new types of antennas with special characteristics such as wideband,multi band high directive antennas and compact size. The space filling property of fractal geometry will reduce the size to be taken by the antenna while self-similar property will repeat the same object in a less size over the exact occupied space and it leads to a multi-band or wideband behavior of antenna [5]. In past years, many kinds of research have been made on the size of fractal antenna engineering. The fractal technique has been employed to monopole, dipole, slot, patch, and loop antennas. Space-filling: Space-filling property of fractal geometry will offer size reduction of the antenna and increase of effective electrical-length of the antenna via which the current travels by increasing the iteration number while remaining the same occupied area as shown in Fig.3[5].

Also, fractals have abilities of space-saving and which make an obvious benefit of using fractal antennas. Self-similarity: Self-similar property of fractal geometry will offer wideband by lapping various resonance frequencies together to constitute antenna with wider bandwidth, also, it offers multi-band antenna. The main idea of self-similarity is to create mini shapes for the same main shape within the same space utilised to make the antenna, as illustrated in Fig.4, which represent Sierpinski-gasket and Koch curve for the third iteration [5], [6].

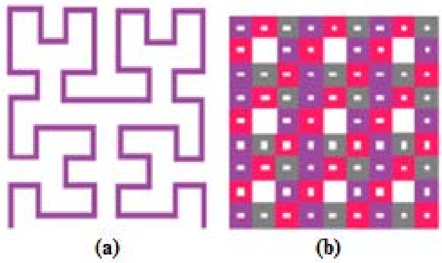

Fig.3: Fractals of space-filling (a) Hilbert-curve (b)Sierpinski-carpet [5]

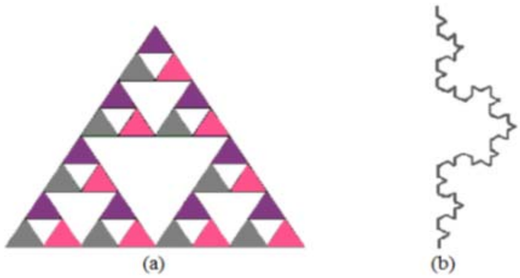

Fig.4: A fractal of (a) Sierpinski-gasket (b) Koch-curve[5]

Related for microstrip antenna

In [7], A proposed propeller-shaped antenna for SWB application is presented, as shown in Fig.5 . The designed antenna provides a wide band (3-35) GHz with average gain 4.5dBi and ratio bandwidth of 11.6:1. The designed antenna structure is not appropriate for L band wireless applications. The proposed antenna has fair impedance bandwidth however it suffers from a lower BDR value (809) due to its large electrical dimensions.

Fig.5 : Propeller shaped monopole radiator with CPW feed [7]

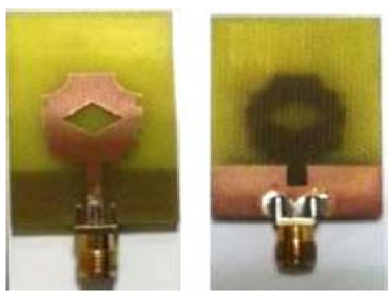

Fig.6: Hut-shaped antenna [8]

In [8], A novel antenna hut-shaped with a diamond slot-shaped at its core is created for super wideband applications. To achieve the enhanced bandwidth, a parial ground with a rectangular structure is proposed, as shown in Fig.6 . The designed antenna works in the frequency band of (0.92 - 22.35) GHz. Gain degrades with an increase in frequency from 2 GHz to 12 GHz.

In [9], In order to refine the performance bandwidth, the triangular sector has been replaced by a circular sector in the proposed antenna. The full structure of circular sectors is utilized to directly match the impedance to the 50-ohm feed-line. By appropriately optimizing the geometrical parameters of the antenna, the bandwidth achieved is (1.0-19.4) GHz. Also, the proposed antenna has dimensions of 135 mm × 135mm. Impedance matching over the entire range of frequency band is not good especially in the range of 9 GHz to 11 GHz as VSWR > 2 which results in poor return loss. Gain reduces with an increase in frequency between 3 to 4.5 GHz and 6.5 to 8.5 GHz, as shown in Fig.7.

Fig.7: Circular coupled sectorial loop radiator for SWB applications [9]

In [10], To attain wide bandwidth of (2.18-44.5) GHz a novel design of circular-hexagonal fractal antenna with asymmetrical patch towards the substrate and partial ground plane has been introduced. The average gain of 4.38dBi is obtained. The presented antenna has a good efficiency over the entire range of frequency bands, a large BDR of 2461, and a high ratio bandwidth of 20.4:1. Cross polarization level increases at higher frequencies and thus radiation characteristics become unstable at those frequencies.

In [11], A novel SWB antenna with functional section block techniques is introduced to acquire the desired performance. The proposed antenna structure provides a broad bandwidth from 5 GHz to 150 GHz. In spite of this wide impedance bandwidth, the designed antenna is not appropriate for low-frequency band applications.

In [12], the proposed antenna consists of an inverted triangle above which includes two notches and a parasitic element of rectangular shape which is placed to improve the reflection coefficient at a lower frequency, as shown in Fig.8. The ground plane contains a slits notch at the sides which improves the impedance matching at a higher frequency. The proposed antenna works the frequency range of 3.06-35 GHz. The efficiency and gain of the designed antenna are not discussed. Inconsistency between the measured and simulated result shows, poor impedance matching between 10 GHz to 20 GHz due to which omnidirectional radiation patterns are not recognized over the entire range of frequency and also at a frequency above 10 GHz cross-polarization level increases.

In [13], a Semicircular shaped patch with a trapezoid ground plane which is top rounded at the corner to obtain good impedance bandwidth matching is proposed. The antenna is fed with a tapered feedline to shift the lower operating frequency and to provide SWB characteristics. It covers the frequency spectrum (1.30 – 20) GHz and provides a gain of 2 dBi at 1.3 GHz to 5 dBi at 20 GHz. The efficiency of 98 % is reported over the whole operating band. Impedance matching is good only in the range of 4.90 GHz to 10.95 GHz. At frequency higher than 10 GHz current density is not equally spread on the ground and the patch plane, which results in an increased level of cross-polarization. Also, the phase difference across the whole band is not linear, leading to pulse distortion. Gain fluctuations in-between frequencies are also observed. Input impedance phase variation is not linear at 17.50 GHz which may lead to pulse distortion.

Fig.8: CPW fed inverted triangular shaped patch antenna [13]

In [14], Novel SWB monopole antenna design has been presented to obtain a broad impedance bandwidth from 2.5-80 GHz with measured gain of 6 dBi at 25 GHz and 2 dBi at 2.5 GHz. The proposed design consists of expanding tapered feed region and a triangular tapered feeding line. Variation in group delay is observed between 18 - 19 GHz due to improper impedance matching. In spite of this, wide bandwidth of 77 GHz the presented antenna structure is not applicable to low-frequency wireless applications like Global Positioning System, and Global system for mobile application.

In [15], A novel design of transparent antenna has been reported. A staircase approach on the rectangular patch is adopted to achieve wide bandwidth of 3.15 GHz to 32 GHz. The CPW fed partial ground is modified by quarter-circle slots to reduce the capacitance effect. In order to enhance the lower resonant frequencies and to increase the bandwidth, two symmetrical major and minor rectangular stubs were placed above the quarter-circle slot ground by virtue of the dual-axis. Gain varies over the entire range of frequencies and negative gains are observed throughout the bandwidth. Lower BWR is reported as compared to other references.

The authors Dorostkar and Firouzeh (2014) [16]presented a design of a novel multiband and wideband triangular-circular fractal antenna. The proposed antenna is using Rogers (Duroid 5870) substrate of (80×90) mm2 with permittivity 2.3mm, loss tangent 0.0012 and 1.575 mm thickness with elliptical shape partial ground plane. Simulation results indicate the operating bandwidth covering the range of frequencies for dual band at (0.9-2.5) GHz and (5.4-32) GHz, stable gain and omnidirectional radiation pattern make this antenna a good candidate for many wireless communications.

In study, Abraham and Mathew (2015) [17] presented dual band Microstrip antenna for WiMAX and GSM applications. The antenna based on fractal geometry is introduced to obtaining dual-band behavior. The type of substrate used is FR4 (72×84) mm2, a loss tangent of 0.002 with a relative permittivity of 4.4 and thickness of 1.6 mm, the type of feeding used is proximity coupled fed. Simulation results indicate this antenna has two resonant frequencies at 1.8GHz and 3.4GHz with reflection coefficient values of -18.7dB and -14.3dB respectively. The proposed antenna has good performance in (3.37 - 3.415) GHz and (1.754 - 1.816) GHz bands, good radiation patterns and gain of 5.3dB therefore, it is appropriate WiMAX and GSM applications. The 1st iteration of the proposed antenna is fabricated and compares its results with simulated one; it observed an agreement between measured and simulated results.

Another study of authors, Kishor and Yadava (2016) [18]presented a design of a Chaucer fractal microstrip antenna integrated with a split ring structure for the mobile application. They used FR4 substrate with a 1.6 thickness; a loss tangent of 0.02. The obtained result specifies the antenna of operating frequency at 2.4 GHz. The proposed antenna offers multi band operation with good gain, wide bandwidth, and low value of return loss.

In [19], A circular-shaped patch with rectangular-slot ground fed by a microstrip feed line is presented to operate at a frequency range from 2.4-28.4 GHz with a bandwidth ratio of 12:1. Negative gains at lower frequencies are observed. Impedance bandwidth matching is not fairly good between 16-24 GHz which results in a decrease in gain with an increasing frequency above 16 GHz.

Authors Singhal and Singh (2016) [20], In order to achieve wide bandwidth of 3.5- 37.2 GHz, a π-shaped radiator is designed with the modification of the traditional elliptical monopole radiator and CPW fed ground plane, as shown in Fig.9. Simulation results show gains of 8 dBi and 2 dBi at 37.2 GHz and 3.5 GHz respectively. With an increase in frequency, efficiency is observed to be decreased up to 55% due to improper impedance bandwidth matching at a higher frequency and also due to varying SMA connectors, substrate and performances of the radiating structure at a different frequency.

In [21], Authors proposed a crescent shaped radiating patch with rectangular-slotted partial ground, fed by a microstrip line to achieve wide bandwidth of 2.5 GHz to 29.0 GHz with an overall dimension of 32 mm × 22 mm and bandwidth ratio of 11.6:1 which results in a BDR of 3462.02. The minimum and maximum gains are 2 dBi and 6.10 dBi at 7 GHz and 16 GHz respectively. Measured efficiency of 75% and simulated efficiency of 81% are achieved. Radiation Efficiency decreases at a frequency above 7 GHz. An omnidirectional pattern of the antenna becomes directive at frequencies above 14.5 GHz.

Fig.9: CPW Fed-Phi-shaped patch antenna [20]

The researchers Shareef, Seleh and Shaalan (2017) [22] proposed a pentagon fractal antenna. The type of feeding used is coaxial feed. Simulation results show four resonance frequencies at 7GHz, 8.4 GHz, 11.1 GHz and 11.9 GHz through frequency range (6.5-12.5) GHz and VSWR<2 which indicate good impedance matching. It has high gain and directivity with good values of radiation efficiency at four resonance frequencies. This antenna is appropriate for applications above 6 GHz such as fixed wireless link, science, and smartphone through the promising applications of 5 GHz technology.

In [23], The authors reported a 30 mm × 30 mm design of microstrip monopole antenna for band notch rejection by carving a rectangular slot on the patch radiator. The author proposed that impedance matching bandwidth and characteristics of radiation pattern can be enhanced, using tapered microstrip feed-line and modification in the lower edge of the patch. The average gain of the proposed radiator is 5dbi. The proposed antenna has an operating frequency over the range of 3-50 GHz having a band-notch frequency from 4.85-5.83 GHz. The presented antenna is incapable to cover lower frequency bands. Above 30 GHz, the cross-polarization level increases. In order to ensure the receive pulse is the correct copy of the transmit pulse.

In [24], Band notch SWB antenna with tapered feedline has been designed. Band notch function has been achieved by placing C shaped parasitic element near the ground plane and by etching two L-shaped-slots on the ground plane. The proposed antenna provides a large impedance bandwidth with a bandwidth ratio of 111.1:1. At frequency above 20 GHz, as shown in Fig.10.

Fig.10: Tapered radiating patch with chamfered ground plane band notched SWB antenna [24]

Another researchers Kaur and Sivia (2018) [25] designed F-shaped fractal MPA for C and X-band application, .it printed on two types of the substrate such as Roger RT/duriod and FR4. Three iterations are utilized to design this antenna and microstrip line feed is used to excite it. The parameters of the proposed antenna such as reflection coefficient, VSWR, bandwidth, and gain for two types of the substrate is compared and found when using Roger RT/duriod, it can obtain increased gain and reduced reflection coefficient. it observed rapprochement between simulation and measurement results in term of reflection coefficient and VSWR. The measurement results of proposed antenna with Roger RT /duroid substrate offer a gain of 7.22dB, 5dB, 2.9dB, 8.3dB, 1.29dB for resonance frequencies at 5.6GHz, 7.7GHz, 9.3GHz, 11.26GHz and 13.5GHz, respectively.

Xue, Jiang and Gong (2018) [26] invested fractal Quasi-Fractal structure for a wide operating band of 5.4- 14.2 GHz linearly polarized and large size of 158 mm × 158 mm × 3.6 mm Sirpinski and Minkowski geometry used in designing rectangular dielectric resonator antenna reported in [27]. The fractal antenna has an operating band of 3.5-7.2 GHz.

In [28], A bevel-shaped radiator with a tapered antenna feed-line is designed and analyzed to achieve SWB performance. A partial ground on the bottom side and two ground planes on the top side are used to present wideband characteristics. The presented design provides a ratio bandwidth of 66:1 with an impedance bandwidth of 0.3-20 GHz, as shown in Fig.12. An average gain of (7 dBi) is seen over the entire frequency band of 0.3-17 GHz. Due to high dielectric losses gain decreases as the frequency increases above 17 GHz. In the radiation pattern of the proposed antenna, a large number of ripples are observed at frequencies above 7.85 GHz. Also, the electrical dimension of the proposed antenna is large (80 mm × 80 mm).

Fig.12: Bevel shaped patch radiator [28]

In [29], A circular metallic patch nested of Apollonius circles is designed and analyzed. In order to greatly enhance the bandwidth, the ground is loaded with two semicircular notches. The antenna is fed by a tapered microstrip feedline to achieve better impedance matching overall around the frequency range of 3 GHz to 60 GHz. Although the peak gain increases with increasing frequency, however experimental design validation of the proposed antenna is not obtained.

In [30], Planar monopole SWB antenna based on Hanning window function is designed to provide wide band of (2.5-110) GHz. In order to improve radiation and reduce reflection, the line is narrowed at the feeding point, as shown in Fig.13. The gain is about 40 GHz on operiting band. However, according to the measured result impedance matching is not fairly good over the entire defined frequency range.

Fig.13: Hanning function based tapered microstrip monopole antenna [30]

In [31], A compact polygonal-shaped patch antenna of 40 mm × 38 mm dimension which covers the frequency range of 2.25-11.05 GHz is designed. The ground plane consists of a circular and rectangular-shaped-slot to helps expand the bandwidth and gain of the designed antenna. A peak gain of the designed antenna is 5.05 dBi. However, the efficiency of the designed antenna drops with an increase in frequency, as shown in Fig.14.

Fig.14: Polygonal-shaped antenna [31]

In [32], A Compact SWB trapezoid-shaped radiator with a triangular tapered feedline and a semicircular ground plane is designed and investigated, as shown in Fig.16. The antenna structure covers a frequency (1.42 -90) GHz band and provides a gain of 7.67 dBi. In spite of support for wide bandwidth, the omnidirectional radiation pattern becomes distorted at higher frequencies.

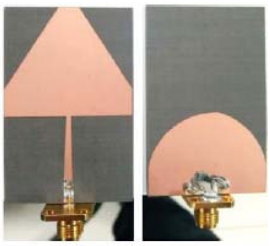

Fig.16: Trapezoid shaped patch antenna with semicircular ground plane [32]

Verma and Ansari (2015) [33] presented an analysis of rectangular-shaped MPA, the patch contains a pair of the truncated corner and U-shaped slot to obtain better impedance bandwidth, also truncated corner with U-shaped slot and without it is studied and compared. A foam substrate is used (26×37.5) mm2 with a permittivity of 1.07 and a thickness of 5.5 mm. Simulation results indicate 80.4% impedance for bandwidth (2.58-6.05)GHz with gain of 9.78dBi and efficiency of 89.68%. They conclude that the bandwidth of the antenna is controlled by U-shape slot, truncated corners length, and substrate thickness. This antenna is proper for multi-functional modern wireless communication C-band and S-band applications.

All researches previously mentioned in the literature survey are aimed to design an antenna with compact size, wide bandwidth, and good gain. In order to design a suitable MPA with optimum specification and best results such as size miniature, wide bandwidth, low cost, high gain and reduced input reflection coefficient (S11), it is designed a proper prototype to be integrated with many communication systems. Table 2 shows another number of designs recently published for the fractal-shaped microstrip antenna.

Table 2:The fractal-shaped microstrip antenna

Ref.	Antenna Geometry	Area (mm^3)	B.W (GHz)	Gain (dBi)
[34]	Hanning function based tapered microstrip monopole antenna	40×50 ×0.254	2.5 – 110	5
[35]	Polygonal shaped patch radiator with circular slotted ground plane	40×38×1.6	2.25 - 11	4.68
[36]	Koch Snowflake fractal	60 × 70 × 1.6	8.2–12.4	-
[37]	Minkowski fractal	27.5 × 45 × 1.6	1.49-1.518	0.3694
[38]	Sierpinski Carpet and Minkowski fractal	4 0 × 40 × 1.6	3.4-3.6 5.5-6.4	2.75
[39]	Hetero Triangle Linked Hybrid Web fractal	26 × 46 × 1.6	3.4-3.48 5.15–5.35 5.72–5.82	4.35
[40]	Hexagonal-Triangular Fractal	25 × 30 × 0.8	3–25.2	6.2
[41]	Mandelbrot fractal	263 × 164 × 2.3	2-2.7	-
[42]	Octagonal Sierpinski fractal	25 × 19 × 1.6	3.68 - 31.6 7.86-11	3.1
[43]	Compact CPW-fed Semi-circular triangular antenna	15×20×1.6	4.9 – 25	4
[44]	Trapezoid shaped patch antenna with semicircular ground plane	57×34× 1	1.42 - 90	4.77
[45]	Peano and Cantor fractal	26 × 21 × 1.6	2.44 - 5.8	5.74
[46]	Eliptical fractal	170 × 150 × 1.6	0.65- 35.6	3.13
[47]	Planar fractal	26 × 27 × 1.6	2.19-13.95	5
[48]	Hilbert Curve	50 × 60 × 3	0.68–0.99,	3.15

	fractal		8.04–10.9 12.7–14.6	
[49]	Minkowski fractal	20 × 20 × 1.6	4.4-6.1	5
	Pentagon Fractal Antenna	-	7.5-8	6.34
[50]	Sierpinski fractal	24.5 × 20 ×1.6	3.1 - 10.6	3
[51]	Koch fractal	80 × 40 × 1.58	1.5-4	3.3
[52]	Hexagonal tree shepd fractal	39.6 × 43.5 ×1.6	2.5–16	4
[53]	Hourglass shaped fractal	16.9 × 14 × 1.6	3.75-19	1.51
[54]	Fern fractal leaf antenna	50.8 × 62 × 1.6	1.3-20	10
[55]	Octagonal Sierpinski fractal	25 × 19 × 1.6	3.87-35 (Band rejection is from 7.24-11.1)	5.8
[56]	F-shape fractal antenna	-	7.22 - 9.44	1.2998
[57]	Quasi-Fractal	25 × 30 × 0.8	5.4-14.2	-
[58]	circular-patch antenna	52×42×1.575	0.96 - 10.9	2.37
[59]	Square-patch antenna	52×46×1.6	0.95 - 13.8	3.75
[60]	Bevel shaped patch radiator with modified ground plane	80×80×1.57	0.3 - 20	7
[61]	Circular-shaped patch	19×31×1.6	3 - 60	6.5

Conclusion

This paper presents the different types of microstrip fractals that can be used to design an antenna and these fractals play a very vital role to reduce the size of the antenna and optimizing the gain. If the number of iterations of the fractal was increasing, then the resonant frequency also increases and it gives lower return losses. By using Fractal geometry, the multiband and wideband characteristics were achieved which are used for different applications like military and wireless communication by using different feeding techniques.

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