Overview on Recent Development of Fractal Antenna in Communication

Dhere Vidyashree
M.E Student, Electronics and Telecommunication Engineering Department
SVERI's College of Engineering, Pandharpur, Maharashtra, India

Mahesh S.Mathpati
Assistant Professor, Electronics and Telecommunication Engineering Department
SVERI's College of Engineering, Pandharpur, Maharashtra, India

ABSTRACT
Fractal antenna and their different geometry are been studied widely. This paper provides brief overview of recent development of fractal antennas. Fractal antenna are widely used in wireless applications because of it features and capabilities. Due to its space filling property the miniaturization of antenna structure is possible; while Similarity property make antenna to resonate at multiple frequency. It also provide improvement in performance such as multiband impedance, SWR, Polarization phasing and wideband frequency response, it do not require matching components.

Keywords
Fractal; multiband; self-similar; geometry; Space filling.

1. INTRODUCTION
Today's modern wireless communication system applications are effectively changing with wide variety of requirement, more in concern with miniaturizing of space, multiband and wideband behavior. Traditional antenna operates at a single frequency band, whereas a multiple antennas are required for different application. Therefore, large space is required for multiple antennas. Fractal geometry has been applied to many fields and results have been found. They have also been combined with theory of electromagnetic [1]. The radiation pattern using fractals are much better as compared to the traditional antennas fulfilling all these requirements [2]. Fractal antenna provides with multiband behavior where a single antenna can operate at many frequency bands due to its geometry. Many structures of fractal are based on a virtual combination of capacitors and inductors. Fractal antennas have features such as[3][4][5]:

i. Self similarity: antenna has the same structure but repeated with reduction in size successively.

ii. Space filling structure make antenna to resonate at multiple frequency which gives multiband and wideband behaviors.
iii. One of the fundamental property of antenna is frequency-independent. This ability retains the same shape under certain scaling transformation .i.e. iteration method; which compact the size and make it irregular with different shape geometry.

Fractals are classified in two major categories.

A. Deterministic Fractals:

The deterministic fractals consist of those shapes which determined with geometry. They take a 'generator' and apply it on successive size scales. Such as : Sierpinski carpet, Sierpinski gasket, Koch curve etc.

B. Random Fractals:

The Random fractals consist of those shapes which are statistically self-similar. They are familiar and many look like random walks (Brownian motion); dendrites; or lightning bolts.

2. BASIC FRACTAL GEOMETRY
2.1 Sierpinski Gasket Geometry
Sierpinski gasket geometry is shown in fig 1 [6]. It is based on property of self-similarity where antenna has the same structure but repeated with reduction in size successively, studied widely for applications of antenna. The Sierpinski gasket fractal is formed by iteration method repeated for infinite number of times. Initially a triangle is taken in required shapes. Black triangular areas represent a metal and the white triangular areas represent reduced size by removing white triangle as in fig 1 shows the 4 iteration construction. A Sierpinski dipole can be easily compared to a bowtie dipole antenna shown in Fig 2. The middle third triangle is removed from the bowtie antenna, leaves three equally sized triangles, which are half the height of the original bowtie.

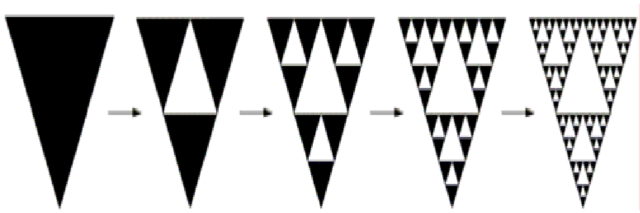


Fig 1. Construction of Sierpinski Geometry

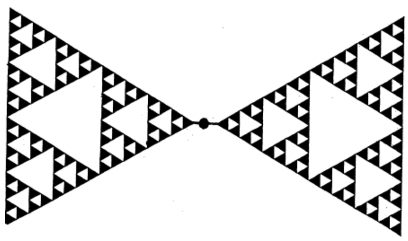


Fig 2. Seirpinski bowtie antenna

2.2 Sierpinski Carpet
The Sierpinski carpet structure is similar to the Sierpinski gasket[7], but it contains squares shapes instead of triangles as shown in fig 3 for 4 iterations. Initially it contains with a square in the plane, and then divides the square into nine smaller squares where the open central square is removed. Also the remaining eight squares are divided into nine smaller similar squares for second iteration and so on for 4 iteration shown in figure. It has efficient radiation-pattern computations and adaptive beam forming, especially for array with

multiple stages of growth which contain a relatively large number of elements.

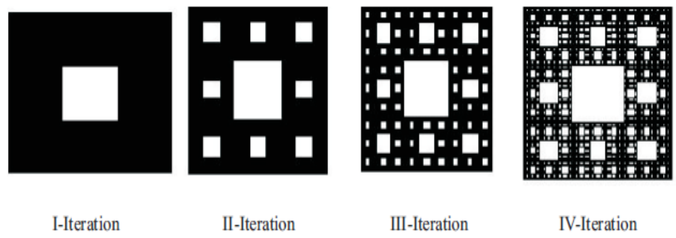


Fig 3. Construction of Sierpinski Carpet geometry

2.3 Koch Fractal – Dipole antenna.

The benefit of using a fractal as a dipole antenna is to miniaturize the total height of the antenna at resonance. Resonance means having no imaginary component in the input impedance. The fig. 4 shows geometry of fractal antenna used as a dipole. The construction of the standard Koch curve is simple [8]. Firstly the straight line as starting steps was considered and divided by factor 4/3. This straight line is divided into three equal parts, by replacing the middle part of straight wire with a bending of wire of triangular shape that covers the original third section. This is the first iterated version of the geometry called the generator. The process is repeated in the generation of higher iterations. The performance of Koch fractal monopoles is superior to that of conventional straight-wire monopoles, when operated in the small-antenna frequency region.

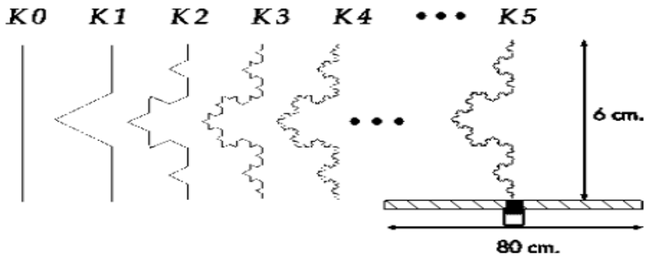


Fig 4. Geometry of Koch dipole

2.4 Minkowski Loop

Minkowski loop can be used to decrease the size of the antenna by increasing the efficiency with which it fills up its occupied volume with electrical length. The analysis is made, where the perimeter of Minkowski fractal wavelength is nearly one. Several iterations are compared with a square loop antenna to study the benefits of using a fractal antenna. Far field patterns for resonant fractal loop antennas for various indentation widths and fractal iterations are computed by the moment method as shown in fig.5. The pattern cut is orthogonal to the plane of the loop. Radiation pattern for Minkowski fractal antenna radiates in Omni-direction and also has low VSWR.

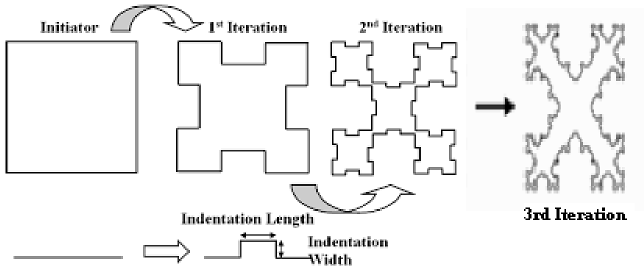


Fig 5. First three iterations of Minkowski loop

2.5 Hilbert Curve

Hilbert curve geometry contains a space-Filling property, with a large number of iteration fulfill the volume it occupies. Additionally the geometry also has the following properties: self -Avoidance, simplicity and self-similarity. The space-filling properties of the Hilbert curve as in fig 6, were investigated as an effective method for designing compact resonant antennas. The study on effect of the central feed-point location on the input impedance of a Hilbert antenna may result in a very small radiation resistance: a properly chosen of center feed point can always provide a 50ohm match, regardless of the stage of growth.

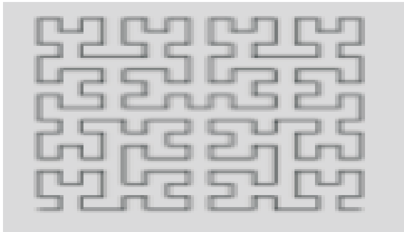


Fig 6. Hildert Curve

2.6 Fractal tree

The multi-hand characteristics of a deterministic fractal tree structure antennas, created by an electrochemical deposition process, were investigated by Puente[9][14]. It was found that these fractal tree antennas have a multiband behavior with a denser band distribution than the Sierpinski antenna. Antenna miniaturization is achieved by employing fractal tree geometries as end-loads by increasing the density of branches as shown in fig 7. (i.e., by using trees with a higher fractal dimension).

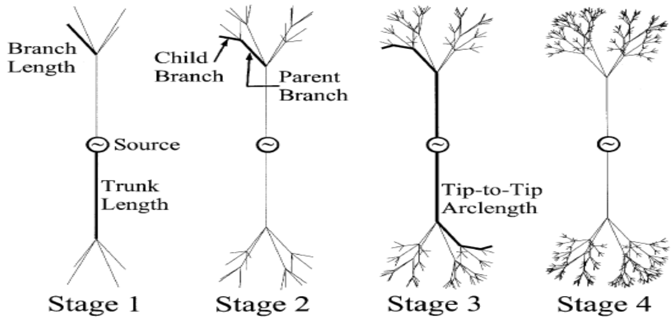


Fig 7. Fractal Tree

3. FRACTAL ANTENNA REVIEW

3.1 Koch island fractal boundary micro strip patch antenna by Rao Patnam (2003)

This antenna is a good example of the properties of fractal boundary microstrip antennas. In this Koch loop antenna is printed on a dielectric material with εr – 4.4 and a thickness of 1.58 mm shown in fig 8. At the fundamental mode, the antenna has a resonant frequency slightly lower than equivalent Euclidean shaped antennas, but with a considerable area reduction. It also has a higher quality factor Q that will result in a smaller bandwidth. One of the most interesting properties is the existence of higher order modes that result in directive patterns. The directive pattern behavior is obtained with a simple feeding scheme with broadside radiation patterns.

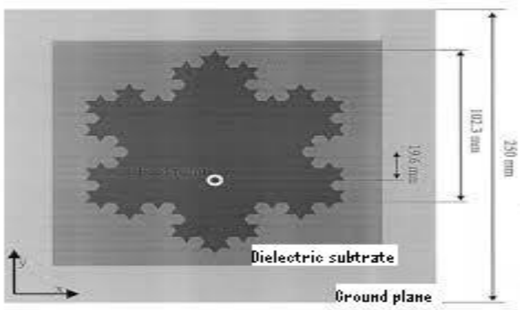


Fig 8. Koch Island Patch

3.2 Si fabricated Sierpinski carpet fractal antennas by Kikkawa and kimto (2005).

Sierpinski carpet fractal antennas fabricated on silicon substrates with the resistivity's of 2290, 79.6, and 10 ohm were investigated as shown in fig 9.[15]. The return loss lower than 10 dB was achieved in the frequency range from 18 to 26.5 GHz. The Gaussian monocycle pulse having 70-ps pulse width as a UWB signal was transmitted between antennas with 10-mm distance on the Si substrate. The voltage gains of the received Gaussian monocycle pulses were improved from -32 to -23 dB by increasing the Si substrates resistivity's from 10 to 2290 ohm.cm.

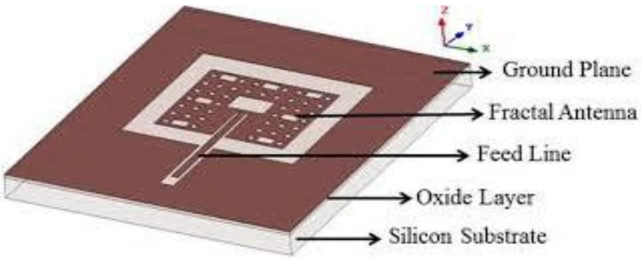


Fig 9. Seirpinski Carpet dipole antenna

3.3 Compact Frequency Notched UltraWideband Fractal Printed Slot Antenna by Lui (2005).

A novel compact frequency notched UWB fractal printed slot antenna employed with Koch fractal slot to achieve both size-reduction and frequency notched function[16]shows in fig 10. The antenna is fabricated on a thin dielectric substrate with low relative permittivity εr- 2.65, tan δ loss of 0.001, and thickness h - 1 mm. The operation bandwidth of the antenna is from 2.85 to 12 GHz, in which a frequency notched band from 4.65 to 6.40 GHz. Several properties of the antenna such as frequency notched characteristics, impedance bandwidth, radiation patterns and gain is achieved with relative stable and omni-directional performance. The antenna useful for compact broadband or UWB applications.

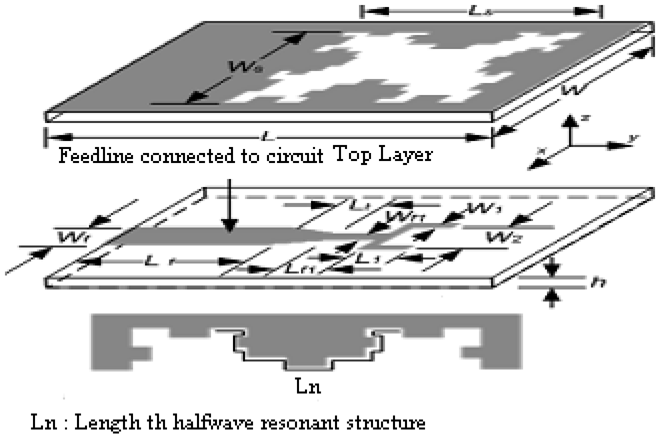


Fig 10. Fractal Printed Slot antenna

3.4 Koch-Fractal Folded-Slot Antenna designed by Ananth Sundaram (2007)

A Koch fractal folded-slot antenna is employed over a single-slot antenna with impedance matching to a 50 ohm feed[18]. With center-fed with a slot RT/Duroid 6002 substrate. The antenna is matched to a 50 ohm CPW feed line using a 76 ohm quarter wave transformer. For the simple folded-slot antenna, the measured return loss is around 40 dB at the operating frequency *fo* -10.45 GHz. Schematic layout of the first and second iteration Koch fractal folded-slot antenna is shown in fig 12. The bandwidth of the antenna obtained from the measured return loss is about1.211 GHz for a return loss better than 10 dB. For the first iteration Koch fractal antenna, the measured return loss is around 34 dB at the operating frequency of 8.05 GHz and the bandwidth obtained from the measured return loss is about 0.4 GHz for a return loss better than 10 dB. For the second iteration, the measured return loss is about 42 dB at the operating frequency of 7.9 GHz and the bandwidth of the antenna obtained from the measured return loss is about 0.34 GHz for a return loss better than 10 dB.

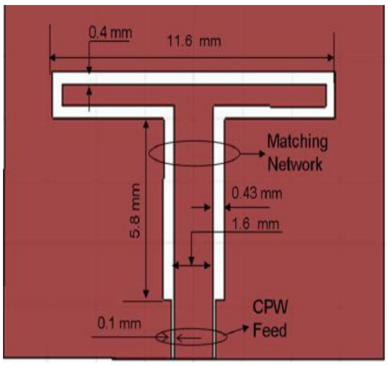
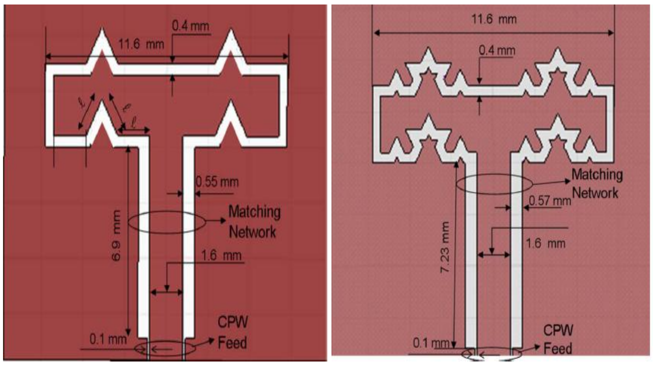


Fig 11. simple fold slot antenna



1st iteration 2nd iteration

Fig 12. Koch fractal folded-slot antenna

3.5 Planar Fractal Monopole Antenna by Mahdi (2008)

The planar PGK (Penta-Gasket-Koch) antenna is shown in figure. This antenna is constructed on Rogers RO4003 substrate with εr – 3.38, *h* – 1.5mm and Z0 - 50 ,Microstrip feed-line has been designed for approximately 50 ohm characteristic impedance[19]. The design achieves a good input impedance match and linear phase throughout the pass band 1.5–20 GHz and good impedance match. The slight mismatch and small phase distortion occurs at low frequencies. Applications :- used as multiband antenna in time domain and pulse communications Systems ,UMTS, Bluetooth, and WLAN systems.

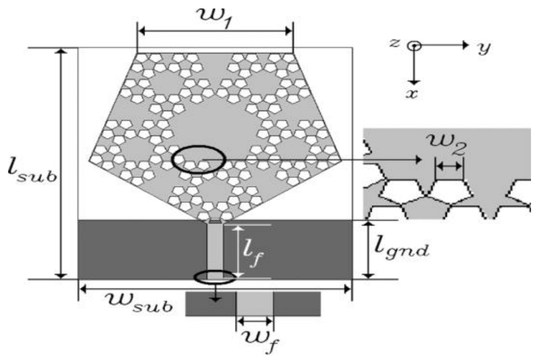


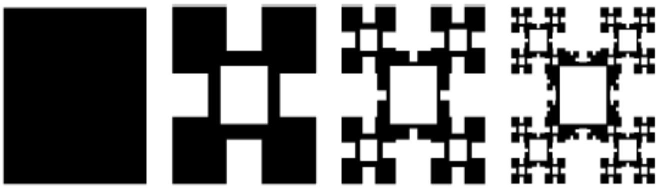
Fig 13. planar monopole antenna (PGK)

3.6 Small-Size Microstrip Patch Antennas Combining Koch and Sierpinski Fractal-Shapes by Wen-Ling Chen (2008)

There are many size reduction techniques proposed such as so far. Fractal shapes have applied to the edges of the patch gives 45% reduction. i. Loading the edges of the patch with inductive elements and inserting the slots into the patch gives 65% reduction. ii. Use of substrate with reduced dielectric constant εr , increase the antenna cost majorly. iv. Shorting posts technique gives 75% reduction in size but the radiation patterns of these compact antennas changed greatly as a result of the asymmetrical structures and high fabrication price.

In this technique the size of micro-strip patch antennas is reduced by etching the edges of the patch as Koch curves and the inner patch are fabricated on *h* - 0.5-mm- thick substrates with relative permittivity 2.65, and are matched by quarter wavelength transformers [20] as shown in fig 16. The decreasing of the antenna peak gains is inevitable when size of antenna get reduced. The size reduction of 77.1% is achieved without degrading the antenna performances, such as radiation patterns and return as the Sierpinski Carpet. The geometry can be obtained by replacing each sides of a square by a modified Koch curve whose iteration factor I s 1/4, and dropping the Sierpinski carpet elements whose iteration factor is 1/3.These antennas loss.

The main advantages of the proposed method are: great size reduction achieved (more than 4 times, the radiation patterns maintained, wider operating frequency bandwidth achieved, and easiness of the design methodology. Geometries of the proposed novel fractal shapes combined by Koch island shapes and Sierpinski carpet shapes. The geometry can be obtained by replacing each sides of a square by a modified Koch curve whose iteration factor is 1/4, and dropping the Sierpinski carpet elements whose iteration factor is 1/3. (a) KS0: Zeroth iteration operatin frequency *f*o -1.563 GHz & gain G - 5.2 dB (b) KS1: first iteration, *f*o - 0.89125 GHz & G - 1dB (c) KS2: second iteration, *f*o- 0.77125 GHz & G - -0.38 dB (d) KS3: third iteration *f*o - 0.77375 GHz & G - 1.1 dB.

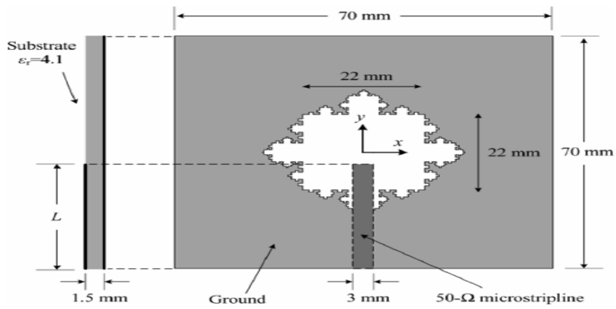


(a) (b) (c) (d)

Fig 14. Microstrip Patch Antennas with KS fractal shape

3.7 Microstrip-Line-Fed Printed Wide-Slot Antenna by Wen-Ling Chen (2009)

A printed wide-slot antenna fed by a 50 ohm microstrip line with a fractal shaped square wide slot for bandwidth enhancement were demonstrated as shown in fig 15. Results show that the impedance bandwidth can significantly be improved by properly selecting the iteration factor and the iteration order of the fractal shape [22]. The impedance bandwidth determined by -10 dB reflection coefficient can reach nearly 2.4 G Hz for operating frequencies 4.0 GHz. Gain variation less than 2 dB for bandwidth of 1.59 GHz. Good broadside radiation patterns of about 1590 MHz.



15 Fig -L. Microstrip ine-Fed Printed Wide-Slot Antenna

3.8 3-D Fractal Heat sink Antenna by Joaquin (2010)

Dual-function structure is presented, as 3-D fractal heat sink antenna[23]. It compares favorably to a patch antenna, improving radiation efficiency (up to 0.98) and directivity (up to 8.21 dB). As a heat sink, it decreases thermal resistance in comparison to a typical finned heat sink as shown in fig 16. A substrate of FR4 epoxy with (εr – 4.2, tan δ loss of 0.02) is used over a finite ground plane with dimensions of 2 wavelengths square. The finned heat sinks lower the resonant frequency from 5.8 to 5.5 and 5.3 GHz.

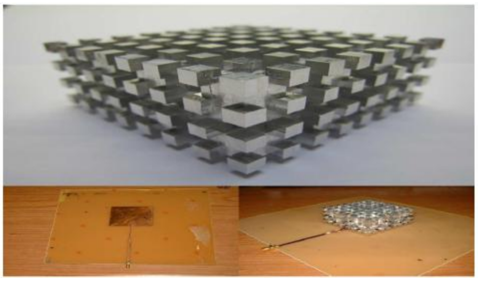
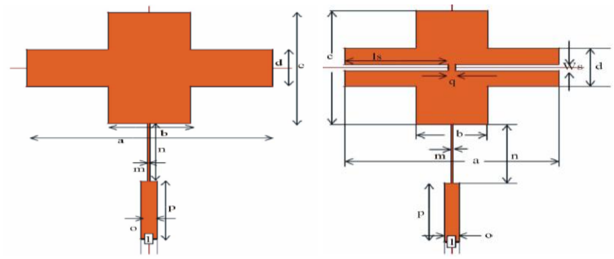


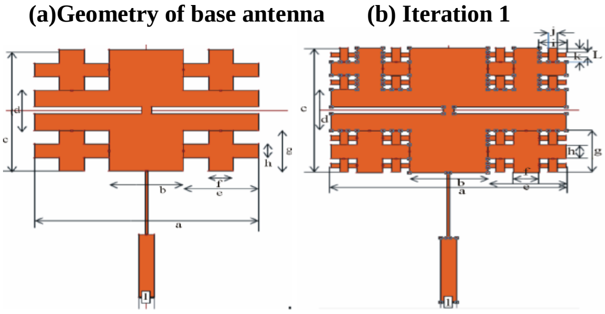
Fig 16. 3-D Heatsink Fractal Antenna

3.9 Plus Slotted Fractal Antenna (2012)

The plus shaped fractal antenna is designed on a substrate of dielectric constant εr = 4.4 and thickness 1.6 mm. This is the reference or base shape antenna [42]. This reference antenna is modified by inserting horizontal slots on both sides with respect to center of patch. The proposed antenna is characterized by a compact size. It is microstrip feed fractal patch of order 1/3. The antenna radiates at multiple resonant frequencies. The resonant frequencies gradually decreases from 2.2 GHz to 900 MHz after I & II iterations respectively. Thus the size reduction of 81.77% & overall bandwidth of 12.92% are achieved. Second iterations gives a good size reduction and enhanced band width then that of modified reference antenna with slot of first iteration.



(a)Geometry of base antenna **(b) Iteration 1**

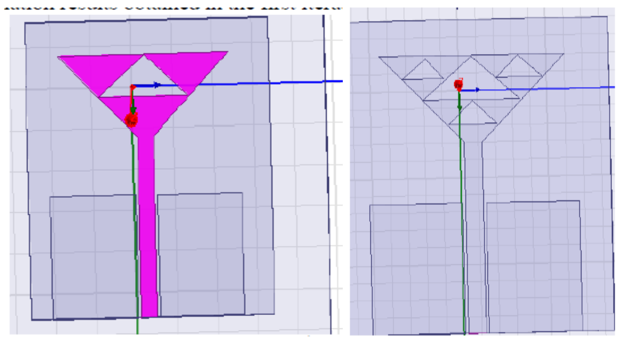


(c)iteration 2 **(d) iteration 3**

Fig 17. Plus Shape Slotted Fractal Antenna

3.10 Triangular fractal antenna compared with Plus Shape Slotted Fractal Antenna (2013)

The triangular fractal antenna is fabricated for 2nd iteration. The resonant frequencies are obtained at 4.4 GHz and 6.5 GHz respectively. When compared with plus shaped slotted fractal antenna obtained resonant frequencies at 0.94 GHz, 3.43GHz and 4GHz on 2nd iteration and operates at three resonant frequencies while the triangular fractal antenna operated at two resonant frequencies. Both antenna gives multiband behavior. These lineaments proved to be a boon as miniaturization with optimal behavior is achieved.



I iteration **II iteration**

Fig 18. Triangular fractal antenna

3.11 A Symmetrical Koch fractal antennas by V.V.Reddy and N.V.S.N.Sarma (2014)

A single-layer single-probe feed asymmetrical fractal boundary micro strip antenna is considered for triband circular polarization (CP) operation[41]. Asymmetrical Koch rectangular, single-band CP, fractal slotted antennas for multiband operation. The circular polarization radiation is achieved by optimizing feed point of the fractal slot, rotation and multiband. The parameters of the fractal slot are optimized to achieve better triband operation. The measured axial-ratio 3-dB CP bandwidths are 55, 78, and 174 MHz and 10-dB return-loss bandwidth 8.7%, 2.4%, 5% .Size is reduced due to use of fractal concept.

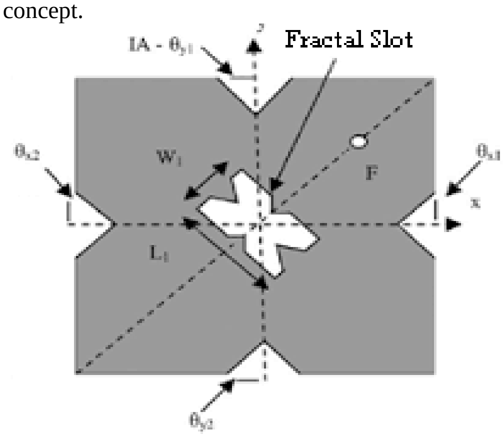


Fig 19. A symmetrical Koch fractal antennas

4. CONCLUSION

The review of fractal antenna presented gives an overview on the research area of fractal antenna in communication and result shows the better output of latest antenna using different technique .By using the fractal antenna, we can reduce the size of antenna and as well as get the better performance. The property of self-similar structures can be used as multiband antennas. The performance parameters such as frequency bandwidth, current density distribution, radiation resistance, radiation efficiency, quality factor, and resonant frequency of the fractals can be improved by total length of the antenna and changing the wavelength. Fractal antennas are modified to achieve omni-directional radiation patterns with high efficiency and good gain. Fractal antenna are used in In Building Communication applications, Wireless Networks: MIMO, WiMax, Mobile Devices, Telemetric, RFID (Radio frequency identification) The fractals field is still in stages of development and getting advance.

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7. AUTHOR PROFILE

Dhere Vidyashree V,Completed B.E(E&TC)in 2012 from Brahmdevdada Mane Institute of Technology, Solapur, Maharashtra, India and Pursuing M.E (E&TC) from SVERI’s, COE, Pandhrpur, Solapur University, Maharashtra, India. Her field of interests are Microwave, Antennas and Signal Processing.

Mahesh. M., Completed B.E (E&CE) in 2000 from the REC, Bhalki, Karnataka and M.Tech (Microwave Engg) in 2006 from Jadhavpur University, Kolkatta, Pursuing PhD from VTU, Belgaum, Karnataka. Working as Assistant Professor in SVERI’s COE, Pandhrpur. His field of interests is Microwaves, Antennas and Signal Processing.