Journal of Advances in Science and Technology
Vol. 12, Issue No. 25, (Special Issue) December-2016, ISSN 2230-9659

Size Reduction and Multiband Operation of Microstrip Antennas Using Fractal Geometry for Wireless Applications: A Review

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Abstract – With rapid advancement in communication technology over the past decade, there is an increasing demand for small size, cost effective and multi frequency antennas. Fractal antenna designs can be used in meeting the requirements of designing a multi band, low profile and small size. Various techniques and geometries have been introduced for size reduction and multi band operation of micro strip fractal antennas. The reason behind popularity of these antennas is their electrically large structure which adjusts very efficiently into compact size. This paper describes about a review of different geometries already used to design antennas of various techniques of compactness by fractal geometry on micro strip patch antenna for multi band wireless application.

Keywords: Fractals, Multi Band Antennas, Resonant Frequency, Space-Filling, Plus Shape Antenna and Size Reduction.

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INTRODUCTION

There has been a tremendous ever-growing demand, in the both defence as well as the consumer global markets, for antenna designs and fabrications that possess the following highly desirable attributes:

1. Small size
2. Very Thin
3. Conformal
4. Operating in multi-band or broad band

There are a number of approaches that have been developed over the years [1], which can be used to achieve one or more of these design objectives. Recently, the possible way of developing antenna designs that makes use in some of the properties of fractal geometries to achieve above attributes. Since conventional micro strip antennas have a conducting patch printed on a grounded dielectric substrate and operates as resonant cavity elements therefore its operation leads inherently to narrow impedance bandwidth which is a barrier for micro strip antennas applications in wireless communications [7]. Moreover in many of these applications, as further requirement would be a multi-frequency operation and size reduction. Therefore, the enhancement of the bandwidth, the achievement of multi frequency operation and size reduction are major challenges for the antenna designer and many techniques have been proposed for this purpose.

Antennas with low profile, small size and multi band are in great insist in modern communication[10]. Traditionally each antenna operates at a single frequency band, where a different antenna is needed for different application. Therefore large space is required for different antennas.

In order to overcome this problem, multi band antenna can be used where a single antenna can operate at many frequency bands. So multi band behavior can be achieved by fractal antenna. Fractal concepts have been increasingly applied to the design of various antennas in recent years because of their self-similar characteristic and space-filling capability.

Fractal antennas are simple, light weight and compact in size. In 1970, Dr B. Mandelbrot first time used the term Fractal. Fractal symbolizes broken or irregular fragments. He investigated the relationship between fractals and nature using discoveries made by Gaston Julia, Pierre Fatou, and Felix Hausdorff. He was able to show that many fractals exist in nature and can be used to accurately model certain phenomena. Fractals explains a family of complex shapes that possess an inherent self-similarity in their geometrical structure. Fractal has various properties like recursive, infinite, space filling and self-symmetry.

In this study, fractal geometries such as Sierpinski gasket, Koch curves and few designs of some of these are explored for size reduction and multi band operations of fractal antennas.

2. FRACTAL GEOMETERY

Fractals are structures and maintain their shape at different scales. Prof. Cohen was the first to develop an antenna element using the concept of fractal geometry. Fractals are geometric structures which have a high degree of symmetry. The fractal concept can be used to reduce the antenna size or it can be used to achieve multiple band and increase of each single band due to the self-similarity in the geometry [2-4]. Micro strip printed Antennas based on fractal based structures have been known for their multi-band operation. The function iterated technique is one of the popular methods of generating fractal structures. A series of affine transformations are applied to generate a fractal structure. Affine transformation involves three operations, viz., scaling, translation and rotation. Using this approach, it is possible to generate highly complex but regular geometric figures with the help of a few parameters. Fig. 1(a),(b),(c) and (d) shows some of these unique geometries. Most of these geometries are infinitely sub-divisible, with each division a copy of the parent. This special nature of these geometries has led to several interesting features uncommon with Euclidean geometry. A large number of fractal antenna design approaches have been proposed for multi band wireless applications. The overgrowing body of the literature suggests the design of patch antenna using fractal geometries techniques for wireless application and the purpose of the survey is carried out to a remarkable growth of antenna design techniques in wireless applications.

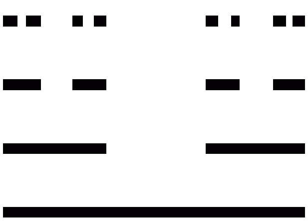

Fig 1(a) Cantor Set

Fig 1(b) Kochi Curve

Fig.1(c)Sierpinski Gasket

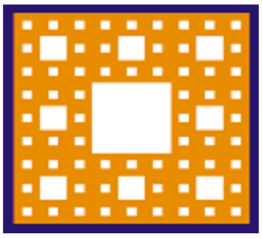

Fig. 1(d) Sierpinski Carpet

Fig,1:(a),(b),(c) and (d): Different types of Fractal geometries used as antennas.

3 MULTI BAND I SHAPED FRACTAL ANTENNA

This paper presents multi band I shaped square fractal patch antenna. Proposed antenna is designed using IE3D and results are analyzed in terms of return loss, gain, directivity, bandwidth and VSWR. The presented antenna is designed with new fractal geometry which is in I shaped [3]. It has been designed for C band (4 GHz to 8 GHz) and X band (8 GHz to 12 GHz) band applications, where antenna can be used for satellite communication and RADAR application. The dimensions of the square patch are 37.6218 mm x 37.6218 mm. The antenna is placed on Rogers RT duroid 5880 substrate with εr =2.2, loss tangent =0.0009 and thickness 0.26mm. A coaxial feed with feed point coordinates (16.7, 16.7, 0) are selected for impedance match[3]. When second iteration is applied modified I- shaped patch has been obtained by removing two squares of length 4.1802 mm from each square of length 12.5406 mm is obtained.

The third iteration is found to have improved antenna parameters compared to the first and second. It is observed that the return loss characteristics reduce as the number of iteration increase. In 4GHz – 12GHz, a wide bandwidth of 1.2 GHz is obtained in the range of 4.7GHz –8.5GHz for the third iteration. It is observed that after the third iteration of the fractal antenna the number of bands increase from one to four, effective area decreased and gain & bandwidth gets increased. This type of antenna finds application for defence and secure communication. The geometry of antenna is described in fig. 2.

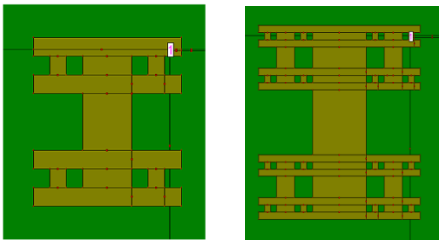

Fig. 2: I shaped square micro strip fractal antenna

4. PLUS SHAPE SLOTTED FRACTAL ANTENNA

A plus shape slotted fractal antenna was designed for wireless telecommunication application. Antennas with slot exhibit wider bandwidth, smaller dispersion and low radiation loss than micro strip patch antennas. Since fractal geometry antennas are characterized by self-similarity and space filling properties which reduces considerable size of antenna and provides multi band operation as compared to conventional micro strip printed antenna. This paper outlines a multi band antenna design and analysis based on fractal geometry concepts. The antenna using fractal geometry of plus shaped has been designed on a substrate with dielectric constant εr = 4.4 and thickness 1.6 mm. The slot length Ls is varied on either side of the edge as 5 mm, 10 mm, 15 mm, 20 mm, 21.175 mm, 21.675 mm and the changed frequency has been studied. The optimum length obtained is Ls = 21.675 mm and is taken for as optimized length of the slot for the further number of iteration. The following table1 shows change of slot length v/s resonant frequency.

Table1 Slot length v/s resonant frequency.

Slot length (Ls) variation in mm	Resonating frequency (GHz)
0	2.22
5	2.197
10	2.155
15	1.93
20	1.436
12.175	1.34
21.675	1.27

It is found that the resonant frequency of the antenna 1 i.e., modified base antenna with slot with fr = 1.27 GHz which is lower compared to the base antenna without slot (fr = 2.199 GHz). Therefore the size reduction obtained is 66.85%. The antenna 2 i.e. the modified antenna with slots and first iteration gives multiple bands with lowers frequency of 0.99 GHz. The size reduction obtained for antenna 2 is 79.88%. Further antenna 3 i.e., with slot and second iteration (fig 3) gives multiple bands with lower resonant frequency of 0.90 GHz. The 81.77% size reduction was obtained for antenna 3 which is more compared to all other proposed antennas structures.[2].

It is observed that the antenna is radiating at multiple resonant frequencies. The resonant frequency is reduced from 2.2 GHz to 900 MHz after I & II iterations respectively. Thus considerable size reduction of 81.77% & overall bandwidth of 12.92% are achieved. The proposed antenna is simulated using the method of moment (MOM) making use of antenna software (IE3D) and verified practically by Vector analyzer Rohde model and Schewarz, XVK model No. 8651, German make equipment. Such type of antennas may find uses in wireless telecommunication systems. The geometry of the antenna is shown in fig 3.

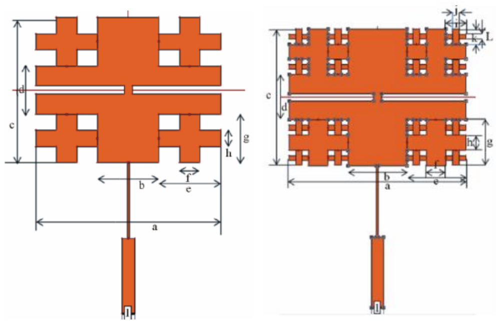

Fig. 3: Plus shaped slotted fractal antenna

5: MULTI BAND FRACTAL ANTENNA BASED ON THE SIERPINSKI CARPET GEOMETRY

This paper presents Seirpinski Carpet Geometry fractal antenna.. Proposed antenna is designed using CST microwave studio EM simulator and results are analyzed for multi band operation and size reduction in terms of gain, return loss, Bandwidth, and VSWR. Here Probe Feed technique is used for the designed antenna.

The total length and width of ground plane is 70 mm each and the presented antenna is designed with Seirpinski Carpet fractal geometry which is in square shaped. The total length and width of ground plane is 70mm. The length and width of probe fed carpet patch are 63 mm each. The substrate used is FR4 with εr =4.4, and PEC as a conducting material for probe. The second and third iteration designs achieve results at frequencies of 4.4GHz, 8.2GHzand 11GHz and acts as multi band antenna [11].

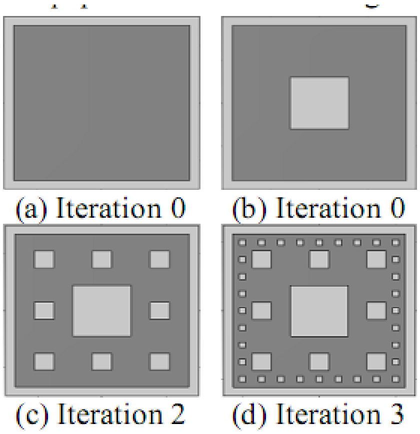

Fig.4: Multi band Seirpinski Carpet Fractal antenna

The Antenna size is reduced by 44.4% in second iteration and 52.1% in third iteration. Bandwidth is enhanced by 2.09% for band 4.54 4 GHz and 2.54% for band of 4.7GHzat the end of third iteration. The achieved gain is 7.417db at 4.544 GHz and 1.252db at 4.706GHz The return loss is more than -15db and VSWR is less than1.3.The designed antenna can be used for fixed microwave and aviation applications. The proposed antenna geometry of Seirpinski Carpet fractal antenna is shown in fig4.

6. MULTI BAND KOCH FRACTAL MONOPOLE ANTENNA

This paper presents the design and investigation of the Koch monopole antenna using fractal geometry to obtain multi band behaviour and to minimise size. Antenna parameters, bandwidth, rerun loss and radiation field patterns are studied and analyzed with respect to planar monopole antenna and Koch fractal monopole antenna. All the investigations are carried out by CST microwave studio software and experimentally in PCB fabrication lab. Performance of third iteration Koch monopole is studied in detail and compared to a conventional planar monopole. Parametric study was done on monopole on (1) the length of the substrate (Ls); (2) Length of the ground plane (Lg); (3) width of the substrate, Ws, and (4) thickness of the monopole trace line (t). All the investigations have been carried out using CST Microwave Studio software. Both antennas have been fabricated on an FR-4 board with dielectric constant, εr = 4.7, and substrate thickness, t = 1.6 mm.

The simulated and measured S11 for planar monopole found at 2.45GHz are -11.68 dB and -11.06dB, for fractal Koch monopole antenna -12.33dB and -11.10 dB respectively. Both measured antennas operate well in 2.45GHz frequency range. The measured monopole antenna resonates at a single frequency, while three resonance frequencies, 2.45 GHz, 6.85 GHz and 9.82 GHz are achieved by the third iteration Koch fractal antenna [3]. It is observed that number of resonant frequencies relates to the increase in the fractal iteration number. Electrical length of the proposed antenna shortens by 20%. The size compactness and multi resonant antenna behaviours are particularly significant in line with the miniaturization of today's electronic devices. The geometry of the proposed antenna is shown in fig 5.

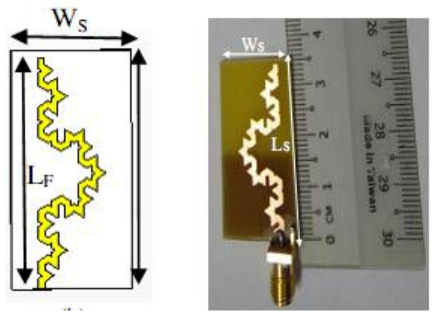

Fig.5: Multi band Koch Fractal monopole Antenna

7. DEVELOPMENT OF A SELF-AFFINE FRACTAL MULTI BAND ANTENNA FOR WIRELESS APPLICATIONS

This paper deals with design of a compact multi band fractal antenna with self-affine property. The antenna has been fabricated with a substrate of dielectric constant εr = 4.4 and thickness 1.6mm. Simulation is carried out using IE3D software. A conventional rectangle of dimension 40 mm x 30 mm is mounted on substrate having a ground plane of dimension 50mm x40mm. A SMA connector of 50 ohm is used to feed the antenna and probe feed technique was adopted. The suitable feed location is obtained at (-4,-8) through optimization process [5]. Antennas are optimized resulting in the following parameters. h = 1.6mm, L = 30mm,W = 40mm, Lg = 40mm, Wg = 50mm, La = 10mm, Wa = 7.5mm, Lb = 2.8mm, Wb = 4mm. The geometry of reference and its first and second iterative antenna with scaling of four are shown in Figure 6.

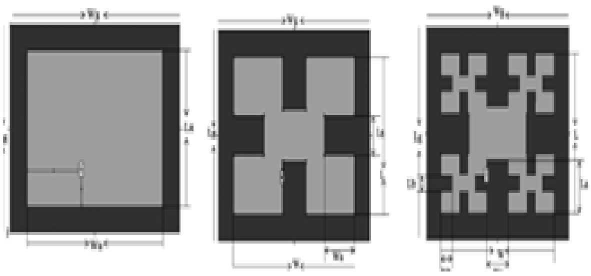

Fig.:6(a): Geometry of Fractal Reference Antenna,6(b) First Iteration Fractal Antenna, 6(c) Second Iteration Fractal Antenna.

The resonant frequencies of second iteration patch resonating at 1.26 GHz, 1.51GHz, and 3.6 GHz respectively provides a bandwidth of 2.36GHz, 1.3GHz and 5GHz at these resonant frequencies. In this proposed antenna a size reduction of 48% with Bandwidth of 8.6% with broadside radiation pattern is achieved.

8. COMPACT MODIFIED SIERPINSKI FRACTAL MONOPOLE ANTENNA

This paper demonstrates Sierpinski fractal antenna used for multiband wireless applications. It is having a three-stage Sierpinski fractal geometry as the radiating patch element. The designed fractal antenna has compact dimension of 75x89.5x1.5 mm3. The proposed antenna's multiband characteristic for a return loss less than l0dB is achieved. The model is applied to predict the properties of fractal antenna when the height of the antenna is varied. It is printed on a 1.58 mm thick substrate, dielectric constant εr = 4.4, with the size 75x89.5 mm^2, the radiating element consists of a three stage modified Sierpinski fractal geometry diagonal lengths of the diamonds d,=28 mm, d2 = 15 mm, d=38. 87 mm, L,= 66.2 mm, L2= 75 mm, h,= 40 mm, h2= 63.52 mm, h3 = 76.74, H=21 mm, w=3 mm, g = 2.3 mm. The proposed antenna after iteration provides reasonable impedance matching at 900 MHz for GSM, UHF-RFID, 2.4 GHz for Bluetooth, and at 5.8 GHz for WLAN. It is observed that the proposed antenna gain lies between 2dB to 7dB with maximum gain of 8 dBi . The parametric study for different height H of Sierpinski antenna, shows that with increase in frequency, the number of lobes also increases implies behaviour of multiband fractal antenna[4]. It is observed that when, the height of the ground plane increased the impedance bandwidth of the proposed antenna well below -l0dB was obtained. It is observed that the proposed antenna gain lies between 2dB to 7dB with maximum gain of 8 dBi . The Sierpinski diamond antenna, with three iterations levels reduced the volume of the antenna and behaves as multiband operation. The antenna is having approximates unidirectional radiation patter. The antenna is useful for low profile, low-cost and supporting multiband operation such as GSM, Bluetooth, WLAN applications. The geometry of the antenna is shown in fig 7.

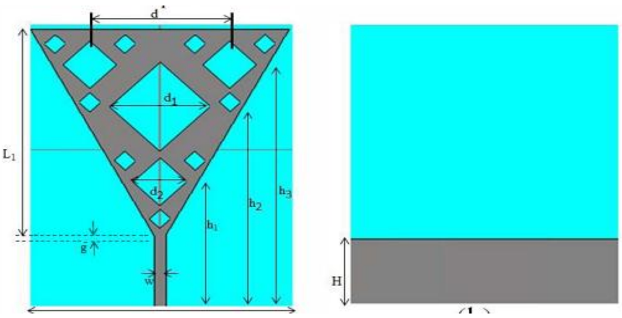

Fig.7: Front and backside of Compact Modifed Sierpinski Fractal Monopole Antenna

10. KOCH ANTENNA DESIGN FOR UHF/SHF APPLICATION

This paper represents the analysis and design of multiband square Koch fractal dipole antenna, where it is shown that as the iterations are increased, the band of frequencies also increase. The designed antenna has operating frequencies for first iteration are of 496 MHz and 1430 MHz, and for second iteration are of 460 MHz, 1248 MHz, 1926 MHz and 4390 MHz with acceptable bandwidth. The radiation characteristics, SWR, reflection-coefficient, input impedance and gain of the proposed antenna are described with 4NEC2 Software package. The Method of Moment (MOM) is used to calculate the current distribution along the square Koch curve [12]. The feed source point of this antenna is placed at the origin (0, 0, 0), and this source is set to 1 volt. The length of the λ/2 dipole antenna is 20 cm, For the first iteration at 496MHz and 1430MHz the various parameters are tabulated as follows in table 2.

Table 2: Resonant Frequencies and Input Impedances, SWR, reflection coefficients and gain for Proposed Antenna

Frequency (MHz)	SWR	Reflection-coefficient (dB)	Gain (dB)	Input Impedance	
				R	X
496	1.42	-15.048	1.88	35.362	3.750
1430	1.31	-17.292	4.91	65.817	0.181

After the second iteration it is found that the antenna has four frequency bands at the resonance frequencies 460 MHz,1248 MHz,1926 MHz and 4390 MHz with acceptable bandwidth, at these frequencies SWR<2, the various parameters are tabulated as follows in table 3.

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Table 3. Resonant Frequencies and Input Impedances, SWR, reflection coefficients and gain for Proposed Antenna

Frequency (MHz)	SWR	Reflection-coefficient (dB)	Gain(dB)	Input Impedance	
				R	X
460	1.20	-20.747	0.58	41.622	-0.711
1248	1.23	-19.643	4.36	40.568	0.299
1926	1.07	-28.506	1.26	46.397	-0.360
4390	1.59	-12.841	8	78.942	-5.297

It is observed that after the second iteration the simulation results show that this antenna can be efficiently operated as a multiband antenna. According to these frequencies, this antenna can operate as a multiband antenna in the UHF/SHF. The proposed antenna geometry is shown in fig 8.

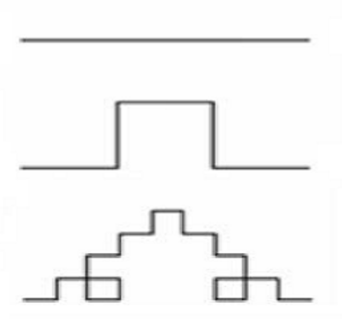

Fig. 8.: First Three Iterations of the Construction of the Square Koch fractal structure.

10. CONCLUSION

Fractal geometry has been demonstrated to be useful to design multi band micro strip antenna and for size reduction. Their properties have been combined with slot cutting, space filling and self-similar techniques to enhance bandwidth and multi band operation. Micro strip antenna having fractal geometry have been useful to obtain broad side radiation patterns with a larger directivity than that of conventional micro strip antennas.. This is an advantage for certain wireless communications applications design. We have analyzed the following key benefits of fractal in antenna geometry:

i) With increasing number of iterations of fractal, resonant frequency increases which results in lower return losses.

ii) Multiband and broadband frequency response which is due to the inherent properties of the antenna's fractal geometry.

iii) Compact size compared to the antennas having conventional designs, while maintaining good to excellent efficiencies and gains

iv) Simplicity and mechanical robustness.

v) Characteristics of fractal antenna are obtained due to its geometry and not by the addition of discrete components.

vi) Ability to design for particular multi-frequency characteristics.

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