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A Survey on Fractal Wearable Antennas With Different Substrate Materials

M.Sangeetha , Dr.B.Elizabeth caroline

Abstract**—** This paper provides survey on koch fractal antenna for different substrate materials.Wearable antenna bonds cloth into the communication system, making electronic devices less obtrusive. In this paper a brief overview of fractal Antenna along with a survey on different geometry is presented and compared for different antenna radiation parameters. It can help one understand the survey of research work going on in the area of the fractal antennas. Due to the recent advancement in broadband technologies different types of antennas were developed, a microstrip patch antenna was developed to meet the need for a cheap, low profile, broadband antenna. This antenna has wide range of applications such as assistance to emergency services such as police, paramedics and fire fighters, military applications including soldier location tracking. This paper presents the study of a compact patch antenna to operate in the frequency range of X band i.e. 8 GHz to 12 GHz. Several techniques have been studied to achieve desired frequency band and considerable bandwidth.Wearable antennas find profound applications:. The investigations are to characterize the antenna not only in flat condition, but also under different bending and crumpling conditions.The proposed Koch fractal antenna is close to the proximity of the body, and the absorption of electromagnetic power on human body is also examined. It is found that the Specific Absorption rate (SAR) is much below a safety level of 0.119 W/kg and hence suitable for wearable applications.

Keywords— Specific Absorption rate (SAR), Fractal, wearable Antenna, bending, crumpling

I. INTRODUCTION

The primary motivation of fractal antenna engineering is to extend antenna design and synthesis concepts beyond Euclidean geometry. In this context, the use of fractals in antenna array synthesis and fractal shaped antenna elements have been studied. Obtaining special antenna characteristics by using a fractal distribution of elements is the main objective of the study on fractal antenna arrays. It is widely known that properties of antenna arrays are determined by their distribution rather than the properties of individual elements. Since the array spacing (distance between elements) depends on the frequency of operation, most of the conventional antenna array designs are band-limited. Self-similar arrays have frequency independent multi-band characteristics. Fractal and random fractal arrays have been found to have several novel features. Variation in fractal dimension of the array distribution has been found to have effects on radiation characteristics of such antenna arrays. The use of Random fractals reduces the fractal dimension, which leads to a better control of side lobes. Synthesizing fractal radiation patterns has also been explored. It has been found that the current distribution on the array affects the fractal dimension of the radiation pattern. It may be concluded that fractal properties such as self-similarity and dimension play a key role in the design of such arrays.

M.Sangeetha, Applied Electronics, IFET College of Engineering,Villupuram, India. (Email : geethu.sparkles@gmail.com)
Dr.B.Elizabeth caroline , Department of ECE , IFET College of Engineering, Villupuram, India. (Email : bcaroline05@yahoo.com)

II. COMMON SHAPES OF FRACTAL ANTENNA

This section will present a brief overview of some of the more common fractal geometries that have been found to be useful in developing new and innovative designs for antennas.

A. Koch Curve

The von Koch curve was initially presented by the Swedish mathematician Helge von Koch. The Koch curve was created to demonstration how to construct a continuous curve that did not have some tangent line.

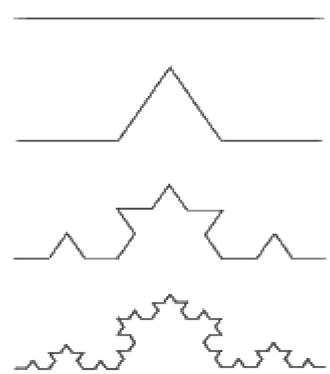

Figure 1: Three iterations of Koch fractal

It is built by starting with a straight line. Divide the line in three parts. Substitute the center part by a regular triangle with the base detached. This process is repeated on every straight line ongoing in an infinite procedure resulting in a curve with no smooth sections.

B. Sierpinski gasket

Sierpinski gasket geometry is the most widely studied fractal geometry for antenna applications. The steps for constructing this fractal are described.1st a triangle is taken in a plane. Then in next step a central triangle is removed with vertices that are located at the midpoint of the sides of the triangle as shown in Figure.2. The process is then repeated for remaining triangles as shown in figure. The Sierpinski gasket

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fractal is formed by doing this iterative process infinite number of times.

Figure 2: Four iterations of the Sierpinski fractal

C. Sierpinski Carpet

The Sierpinski carpet is constructed similar to the Sierpinski gasket shown in Fig.3, but it use squares instead of triangles. In order to start this type of fractal antenna, it begins with a square in the plane, and then divides it into nine smaller congruent squares where the open central square is dropped.

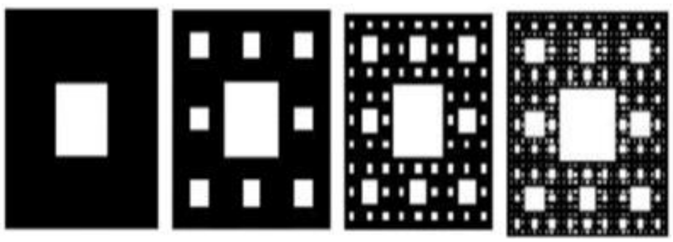


Figure 3: Steps of Iteration to get Carpet geometry

III. LITERATURE SURVEY

The various approaches of fractal antenna are described in this section

Mai et al [1] proposed three different structures of UWB antennas using clothing materials and suitable for wearable application were fabricated. The antennas were designed using jeans as substrate, while radiating element and ground plane are made out of copper tape. The operating frequency of all three designs is between 3 GHz and 12 GHz. The simulated and measured results showed that the proposed antennas have (|S11| <= 10 dB) at UWB frequency ranges, constant gain, high efficiency and stable radiation pattern over its whole frequency band. In addition, the compact size of the antenna confirms its suitability for portable UWB devices.

Jalil et al [2]had simulated Triple-band Fractal Koch Textile antenna using first iteration of Koch geometry of a dipole antenna structure for wearable applications. The antenna designed using denim textile as substrate. While radiating elements are made of copper fabric. The flare angle of the antenna design is varied to three different values which are 30, 45 and 60 degree respectively.The proposed antennas are simulated in CST Studio and optimized to operate within the ISM frequency bands (0.902-0.928 GHz, 2.4-2.5 GHz and 5.725-5.875 GHz).

Mohd et al [3] presented aMultiband Fractal Koch dipole textile antenna was fabricated by for wearable applications. The antenna designed using denim textile as substrate.Three different comprehensive analyses are taken into consideration: measurement antenna with different bending sizes, on-body measurement and under wet conditions. The antenna is designed to operate at 0.9 GHz, 2.45 GHz and 5.8 GHz.Good performance is observed when the textile antenna is less than 2% of water absorption.A suitable placement on the body has been discovered between the chest and backside.

Eng Gee Lim et al [4] presented a Rectangular microstrip antenna was fabricated by with 4 different textile substrates.The short circuit pins method was proposed to reduce antenna size by approximately 68%. Simulations were carried out over the frequency range 2 GHz to 3 GHz. The resonant frequency of the patch antenna (i) wash cotton as a substrate is 2.396 GHz and the returnloss is -42.125 dBand with curtain cotton as a substrate is 2.398 GHz and the return loss is -41.572 dB.with polyester as a substrate is 2.398 GHz and the return loss is -30.152 dB.with curtain cotton as a substrate is 2.404 GHz and the return loss is -33.3792 dB.

Mohammad Monirujjaman Khan, [5]The antenna is dual band at 2.45 GHz (ISM band) with omnidirectional radiation pattern over the body surface to communicate power efficiently with other co-located body worn devices and at 1.9 GHz (PCS band), it has directive radiation pattern towards off the body to communicate from on-body device to off-body devices. The free space and on-body performances of the antenna are investigated by both simulation and experiment. The antenna shows very good on-body radiation efficiency of 58% at 2.45 GHz and 61% at 1.9 GHz. Good on-body gain is noticed at both frequency bands. Results show that the gain of the proposed antenna increases by 4.7% at 2.45 GHz and 3.2% at 1.9 GHz when placed on the body.Dimensions of the dual band and diverse radiation pattern antenna components are shown in Table 1. The Schematic diagram and Fabricated antenna are shown in Fig.4 a andb.

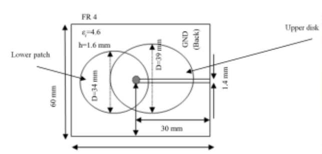


Fig.4 a. Schematic diagram of The dual band and diverse radiation pattern

b. Fabricated antenna

Table 1. Dimensions of the dual band and diverse radiation pattern antenna components.

Components	Unit (mm)
Top disk diameter	39
Lower patch diameter	34
Height of inner ring	2.23
Ground plane size	60 × 60

Syed UvaidUllah et al[6] Presented wearable electro-textile patch antenna is designed by using Minkowski fractal geometries with tuning hole for 0th, 1st and 2nd iterations.

The size of antenna is reduced to 20.212% at second iteration from the predictable patch. Hence, the designed antenna is compact enough to be placed in typical wireless devices frequency of 2.4 GHz. The designed antenna provides gives good performance characteristics in all the three frequency bands.

MuayadKodet al[7] Presented A dual broadband flexible butterfly loop antennais designed to be worn on a human body which covers severalimportant bands for wearable applications including theMedRadio band 402-406 MHz and ISM bands (433-434, 902-928and 2400-2483.5) MHz. It covers several desired bands in two wideband ranges from 400 to 1000 MHz and from 2 to 2.7 GHz.This antenna is flexible and robust against the detuning effect so that it useful for different flat and curved body partsare shown in Fig.5. Furthermore, it shows good performance at the low bands 405 and 433 MHz are shown in Fig.6 a and b where it radiates mainlytowards the body so that an effective communication link with implantable devices can be established with very low powerconsumption.

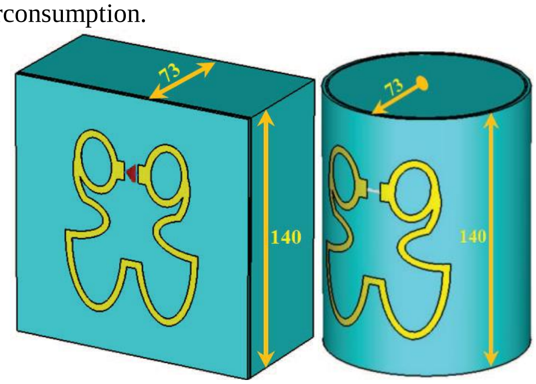


Fig.5Testing the proposed antenna on the flat and bending surfaces, all dimensions in mm.

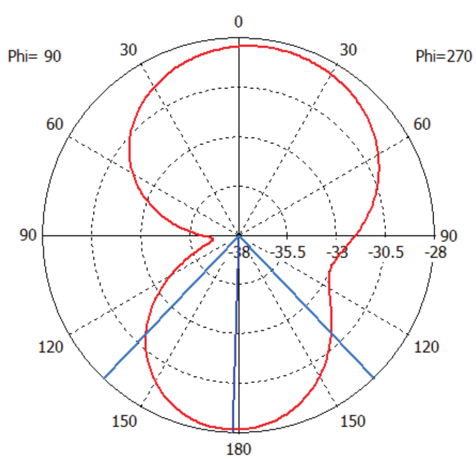
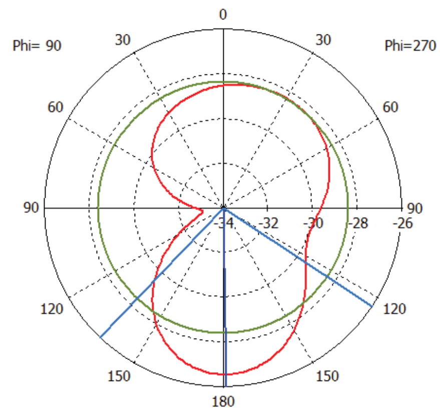


Fig.6 a.405 MHz



b.433MHz

Shorav Khan et al[8]Presentedthe textile wearable antenna with major applications of monitoring a human body is achieved by using a jeans substrate. The proposed antenna is made of jeans fabric of dimension 90mm × 86 mm. The Geometry of proposed textile antenna is shown in Fig.7. The proposed antenna gives three different wide bands with the gain of 3.353 dBi, 4.237 dBi, and 5.193 dBi which are best suitable for different wireless communication systems. The simulations were carried out using CST Microwave Studio software. The Simulated Gain & Efficiency of Proposed Antenna is shown in Table.2

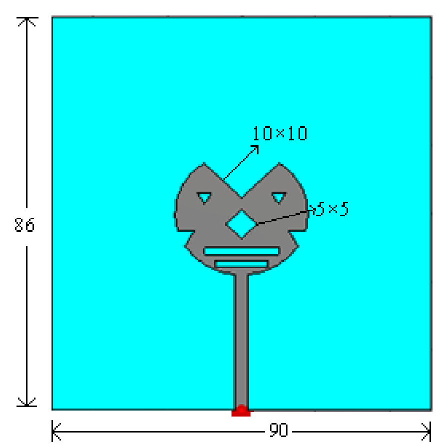


Fig.7 Geometry of proposed textile antenna

Table.2 Simulated Gain & Efficiency of Proposed Antenna

Frequency	**Directivity**	**S11**	**Efficiency**
2.1366 GHz	3.353 dBi	-22.23231 dB	87.2%
4.7563 GHz	4.237 dBi	-38.10731 dB	87.4%
11.495 GHz	5.193 dBi	-20.79123 dB	89.6%

R. Poonkuzhali1 et al[9] Presented the design and development of Koch fractal dipole antenna for wearable applications at 450MHz. Common jeans cotton is used as a flexible substrate material having a dielectric constant of 1.6

for the design and fabrication of the proposed antenna. Koch geometry with the antenna bandwidth of 10% and the return loss of −25 dB is achieved under the flat condition. Bending and crumpling condition is also investigated. This design is 32% reduction in size compared to the conventional antenna.

M. N. A. Karimet al[10]Presented the Log Periodic Fractal Koch antennas with three different structuresSuch as the 0th, 1st and series iterations have been designedUltra High Frequency (UHF) bandapplications, simulatedand fabricated. The size of the antennas has been reduced up to 7% for the1st iteration and up to 26% for series iteration antenna compared to the 0th iteration in Table.4. The Computer Simulation Technology (CST) software has been used to analyze the performances of the designed antennas such as return loss, radiation patterns, current distribution and gain in Table.3.

Table.3 Design specifications of the UHF Fractal Koch Antennas.

Types	**0th Iteration**	**1st Iteration**	**Series Iteration**
Operating Frequency (GHz)	0.5-3 GHz	0.5-3 GHz	0.5-3 GHz
Bandwidth (BW)	>200%	>200%	>200%
Gain	6-8 dBi	6-8 dBi	6-8 dBi
Radiation Pattern	Directional	Directional	Directional
Polarization	Linear	Linear	Linear
Scaling factor	0.85	0.85	0.85

Table.4 Comparison of size reduction of UHF Fractal Koch Antenna.

Antenna Type	**Dimension (*L* × *W* × *t*) mm**	**Size reduction (%)**
0th iteration	244 × 360 × 1:6	-
1st iteration	227 × 360 × 1:6	7%
Series iteration	183 × 360 × 1:6	26%

Kulbir Singh et al[11] Presented a comprehensive overview of fractal antenna engineering. Increasing the fractal dimension of the antenna leads to a higher degree of miniaturization. Also it is possible to use fractal structure to design small size, low profile, and low weight antennas.The analysis of a Koch monopole is also done and the results showed that as the number of iterations is increased, there is an increase in the effective length in Table.5 and decrease in resonant frequency

Table.5 Effective length of Koch monopole

Antenna	**Effective length (6cm)**	**Effective length (8cm)**	**Effective length (12cm)**
K0	6	8	12
K1	8	10.67	16
K2	10.67	14.22	21.33
K3	14.22	18.96	28.44

Deepti Das Krishna et al[12] Presented the Design of a CPW-fed modified Koch fractal printed slot antenna, suitable for WLAN 2.4/5.2/5.8 GHz and WiMAX 2.5/3.5/5.5 GHz operations.The operating frequency of a triangular slot antenna is lowered by the Koch iteration technique resulting in a compact antenna. Koch fractal slot antenna has an impedance bandwidth from 2.38 to 3.95 GHz and 4.95–6.05 GHz covering 2.4/5.2/5.8 GHz WLAN bands and the 2.5/3.5/5.5 GHz WiMAX bands. The antenna exhibits omnidirectional radiation coverage with a gain better than 2.0 dBi in the entire operating band.

Sankaralingamet al [13] Presented the miniaturization of wearable electro-textile antennas is achieved by the use of Minkowski fractal geometries of the 1st and 2nd iterations. Two electro-textile materials namely Flectron and Shieldit fabrics have been employed for the design of Minkowski fractal shaped wearable antenna. zeroth iteration, the antennadimensions are chosen to suit for WLAN applications. In the 1st and 2nd iterations the fractal geometry parameters are tuned for optimal performance in the WiBro and GSM 1900 bands respectively. In all the three frequency bands, the designed antenna gives good performance characteristics.The performances of the designed antennas such as frequency, efficiency, directivity and gain in Table.6.

Table.6 Design specifications ofMinkowski fractal antenna

Parameter	**Iteration No.**		
	0th	**1st**	**2nd**
ResonantFreq. (GHz)	2.44	2.29	1.93
Imp.Bandwidth (MHz)	130	100	63
Gain (dB)	5.9	5.0	1.65
Directivity (dBi)	8.4	8.2	7.59
3 dB beamwidth (E)	73	75.7	78.1
3 dB beamwidth (H)	61.8	62.5	67.5
Efficiency (%)	55.33	40.55	25.7

Manish Sharma et al [14]Presented a Multiband rectangular Fractal antenna designed And Analysis with Multiband Koch Fractal Monopole Antenna. This antenna is microstrip line fed and its structure is based on fractal geometrics.Antenna properties such as return loss, gain, VSWR, Directivity and Bandwidth are analyzed.Frequency bandwidth (0.8 GHz to 3 GHz) used in this project.This antenna for mobile antenna and Wi-Fi antenna. Return loss is -10 to -25 db and VSWR – 1-2 and impedance- 48 to 50 ohm.

A. H. Ramadan et al[15] Presented a hybrid antenna design approach which combines fractal shapes and electronic reconfigurability. The antenna is based on a U-slotted rectangular patch. Koch fractal geometry was applied to the patch and slot sides to increase the electrical length of the antenna without increasing its overall size, thus leading to resonance at a lower frequency. Reconfigurability is achieved by mounting RF switches at selected locations across the slot. Ansoft HFSS, which is an EM simulator based on the Finite-Element Method (FEM), was used to check and compare the following three cases: 1) Design before applying Koch fractal, 2) design when first-iteration Koch is applied to the edges of the patch and the U-slot, and 3) design when second-iteration Koch is applied to internal edges of the U-slot. For Case 1, a narrow resonance is obtained at 1.9 GHz, in addition to two wide bands in the 2.7- 6.6 GHz range. For Case 2, the lower narrow resonance is shifted to 2.1 GHz, and there exists a wide band covering the 2.4-6.7 GHz range. The switching condition of Case 3 removes the lower narrow resonance, and results in a wide band in the 2.5-6.7 GHz frequency span.

NaynaDandgavhalet al [16]Presented the design and simulation of Koch Snowflake antenna up to second iteration. The bandwidth of the antenna gets increased with increase in the number of iterations. As the fractal iteration increases, perimeter of patch increases and effective area of antenna increases with improve multiband application. The designed antenna have some favorable characteristics such as; compact size, directional radiation pattern, multiband , satisfactory return loss less than -10 db and operate at desired frequency 1.24 GHz for GPS (Global Position Systems) applications, 1.42GHz for L-band applications & 2.92 GHz for S-band applications.

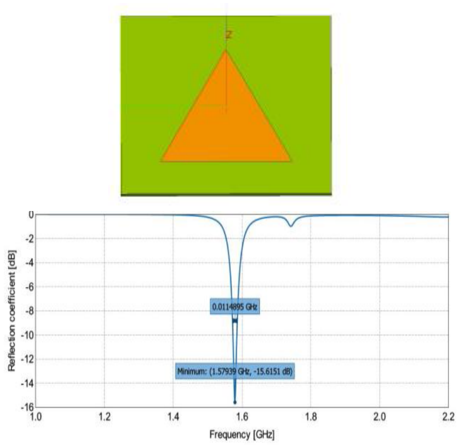


Fig.8 Structure and return loss of iteration – 0

Above Fig.8 shows structure return loss of basic TMSA. The triangular patch resonates at the frequency 1.57 GHz having bandwidth 25.25 MHz with a return loss of -15.61 dB

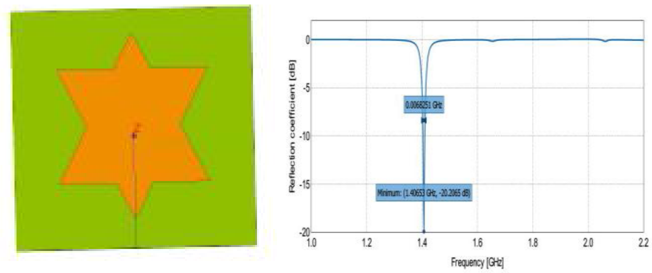


Fig.9 Structure and return loss of iteration – 1

Above Fig.9 shows structure return loss of basic TMSA.In which antenna resonate at 1.4 GHz frequency with 20.04 MHz bandwidth and -20.2 db return loss.

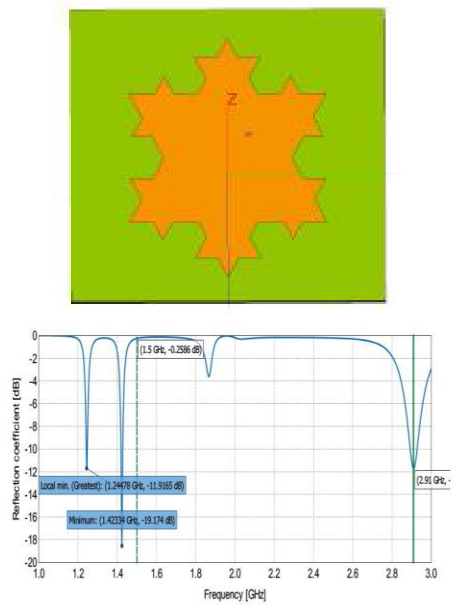


Fig.10 Structure and return loss of iteration – 2

Above Fig.10 shows structure return loss of basic TMSA.This shows that antenna can resonate at three different resonant frequencies 1.24 GHz, 1.42 GHz and 2.91 GHz with 7.88 MHz, 10.43 MHz and 41.22 MHz bandwidth respectively.

Rajeev Mathur et al [17] Presented a novel prototype structure for Koch Loop Antenna was developed and experimentally proven to be adequate in terms of return loss. Seven resonant bands have been obtained by simulation & measurement on VNA, for this antenna. The performance of the proposed antenna design is analyzedand the results are compared with the simulations using IE-3D tool.The VSWR of the designed antenna is less than 2 for all 7 resonant bands of 135MHz, 1160 MHz, 2030 MHz, 3170, 4171 MHz, 5910

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MHz. and 8190MHz.Table.7 shows Comparison between Simulated results and Measured Return Loss

Table.7Comparison between Simulated results and Measured Return Loss

Band No	Simulated results		Measured Results	
	Centre Freq.	S11 in dB	Centre Freq.	S11 in dB
I	0.135	-15.761	0.135	-15.04
II	2.01	-33.304	2.03	-30.04
III	1.56	-32.047	1.16	-27.85
IV	3.00	-30.845	3.17	-18.14
V	4.2	-29.70	4.17	-13.36
VI	5.625	-23.13	5.91	-14.01
VII	8.19	-14.554	8.19	**

Nirzara Sable et al [18] Presented a design of Koch monopole fractal antenna to be used in wireless communications at the ISM frequency band. The antenna is simulated for 2.4 GHz frequency. The property of self-similarity that fractal shapes possess has been successfully applied in other types of antennas Return losses of first three iteration of Koch monopole antenna are shown in Fig.11. For second iteration at 3.5 GHz frequency return loss is -12.2508 dB and for first iteration at 1.27GHz frequency return loss is -6.6950dB.Gain of first three iterationof Koch monopole antenna are shown in Fig.12.

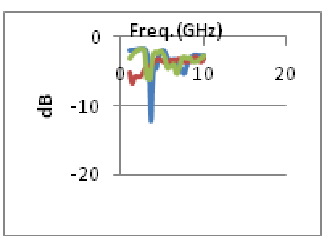


Fig.11 Return losses of first three iterations

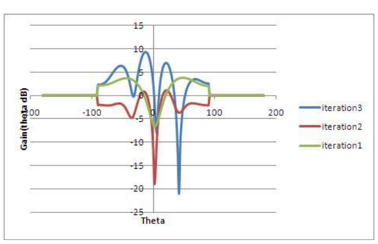


Fig.12 Gain of first three iterations

Deepal Gupta et al [19] Presented a novel Sierpinski carpet based fractal antenna for Wimax frequencies for three iterations, is proposed are shown in fig.13 a,b and c. The given antenna is composed of a rectangular patch antenna loaded with rhombus structures. The antenna is designed for resonating between 2-6 GHz frequency range for Wimax application. The proposed antenna is simulated on CST version 10 and the results are in good agreement.

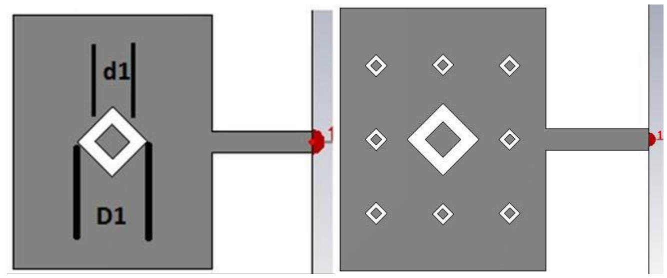
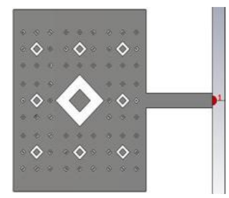


Fig.13 a.First Iteration b. Second Iteration



c.Third Iteration

AnujAttriet al [20] Analysed the performance of Sierpinski Carpet antenna and correspondingly its stacked configuration.Fractal Antennas can help in meeting the requirements of more compact and mutiband antennas for Personal Communication Systems. The designed antennas are simulated with the help of simulation software Ansoft HFSS. This antenna is showing resonance at frequencies 4.1, 6.3, 7.6 and 8.3 GHz. frequency resonance is from 4.4 to 4.8 GHz i.e a bandwidth of 400 MHz

IV. CONCLUSION

A flexible wearable Koch fractal dipole antenna is constructed using fractal geometry for above 450 MHz **band** of operation with different substrate material. The initial design is started by using a single element equation of dipole antenna with scaling factor of 1/3. In this design, the highest iteration is Koch second iteration, and the overall simulated result is verified with the measured one under flat condition. The performance of the antenna under bending and crumpling condition is also investigated in two perpendicular planes, *x-z* plane and *y-z* plane. In all the cases, the reflection coefficient of the antenna is changed and a significant shift in resonant frequency designed above 450MHz with different substrate material. The above study shows that the antenna can be operated at VHF band suitable for military application. The main contribution of this design is 32% reduction in size compared to the conventional antenna.

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