A New Approach to Fractal Antenna Design for UWB Applications: An Analysis

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Abstract
There are many efforts done by the several researchers around the world, to combine fractal geometry with electromagnetic theory have led to a world of new and innovative antenna designs. In this report, we provide a research on the fractal antenna in the field of fractal antenna engineering. The research for the fractal antenna is focused in the two areas: the first deals with the design of fractal antenna elements, and the second deals with the applications of the fractal antenna. From the previous research it was shown that Fractals have no characteristic size, and are generally composed of many copies of themselves by different scales. This unique property of the fractal antenna plays a very significant role in the size reduction and enhancement of bandwidth.

In this paper, we used Meta material to attain the better results and the antenna can be used for ultra wide band applications. By the use of the meta material antenna attains a impedance bandwidth of 98.6%.the value of the mutual coupling is observed to be -25dB and the radiation pattern shows us that the antenna can be used for the ultra wide band applications. Antenna attains a diversity gain of greater than 9.97dB and ECC is less than 0.06. The applications of this antenna cover WLAN, WIMAX, UWB applications etc.

HFSS software is used for the simulation and FR4 epoxy material is used to design the substrate.

Keywords: Fractal antenna, HFSS (high frequency structure simulator), ultra wide band (UWB), Metamaterial.

INTRODUCTION

Fractal antenna is used to provide better characteristics as compared to the simple micro strip antenna. The word fractal is derived from the Latin word “fractus” meaning broken, uneven, any of various curves which repeat itself at any scale on which they are examined. By using the fractals in any antenna will maximizes the length, or increase the perimeter (on inside sections or the outer structure), of material that can receive or transmit electromagnetic radiation within a given total surface area or volume.

Fractals are geometrical shapes, which are self-similar, repeating themselves at different scales. The geometry of the fractal antenna is very important because we can increase the effective length of the antenna by keeping the area parameters same. The shape of fractal antenna can be formed by an iterative mathematical process called, Iterative Function Scheme (IFS).

Rumsey, a well-known scientist, established that an antenna with shapes only defined by angles would be frequency independent, since it would not have any characteristics size to be scaled with wavelength.

Fractal antenna design has two things:

1) Initiator (0th stage)*:* It is basic shape of the geometry. It can be any shape either triangle, rectangle or any other quadrilateral.

2) Generator: It is the shape which is obtained by scaling the initiator and will be repeated either inside or outside on the initiator to obtain subsequent stages to reach final fractal geometry. Generator is obtained from the initiator itself.

Below figure shows the different stages of the fractal antenna.

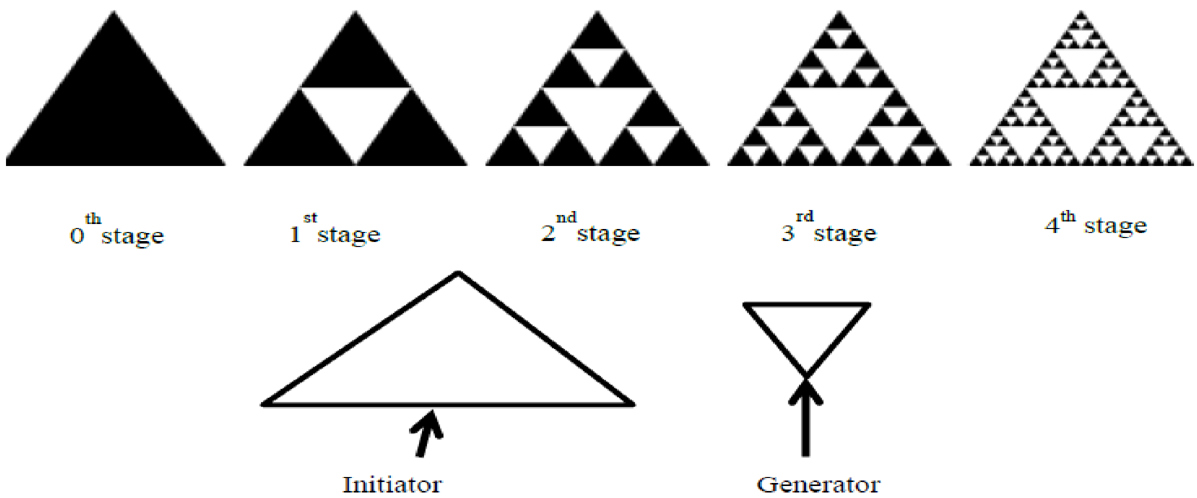

Fig. 1 different stages of fractal antenna

Koch loop and Minkowski loop —.The Koch curve can also be used to form a loop of reduced size. Another example of this type of loop we can take as the Minkowski loop formed with a 90-degree bend. Both types of fractal loops can reduce the diameter of the loop and achieve approximately the same performance as a regular single wire loop.

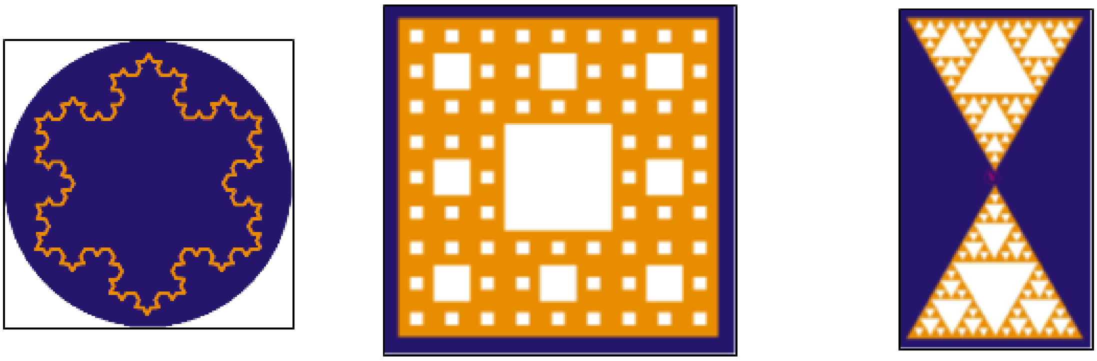

Fig.2 types of the fractals

Sierpinski monopole and dipole — The Sierpinski gasket is a self-similar structure. In an ideal Sierpinski gasket, each of its three main parts is exactly a scaled version of the object (scaled by a factor of two). The self-similarity properties of the fractal shape are translated into its electromagnetic behaviour and results in a multiband antenna. The variation on the antenna's flare angle shifts the operating bands, changes the impedance level, and alters the radiation patterns.

Cantor slot patch — The Cantor slot patch is another example of multiband fractal structure. This type of patch has been applied in multiband micro strip antennas and multiband frequency selective surfaces.

Fractal Tree — various fractal tree structures have been explored as antenna elements and has been found that the fractal tree usually can achieve multiple wideband performance and reduce antenna size.

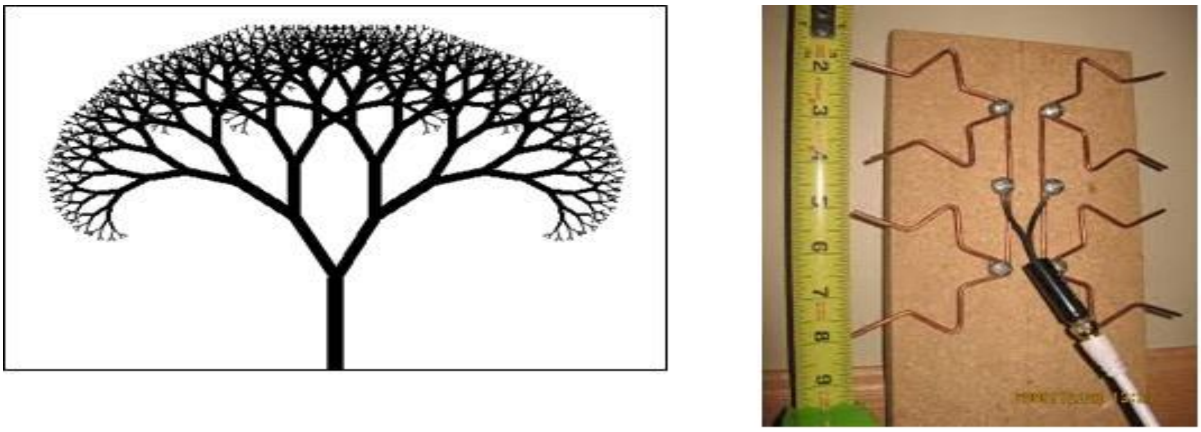

Fig.3 fractal antenna tree

Printed circuit fractal loops — the printed circuit fractal loop antenna is designed to achieve ultra wideband or multiple wideband performance and significantly reduce the antenna dimensions. The antenna has a constant phase centre, can be manufactured using printed circuit techniques, and is readily conformable to an airframe or other structure.

Koch monopole and dipole — The Koch curve has been used to construct a monopole and a dipole in order to reduce antenna size.

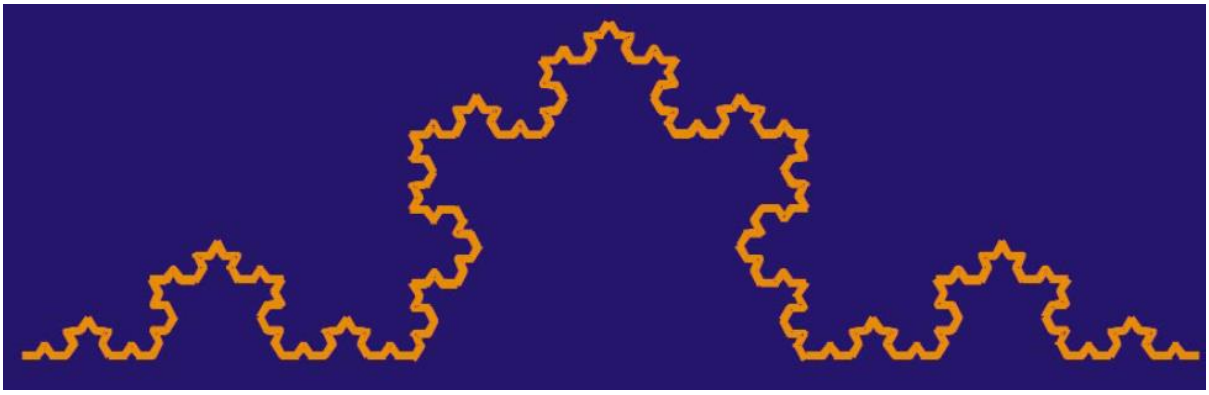

Fig. 4 Koch antenna

Features	Application
Small dimension	Electrically small antenna
Self-similarity	Useful in designing the multiband antenna
Increasing the no. Of iteration	Useful to decrease the resonant frequency while electrical length will increase
Space filling ability	Useful for miniaturization of an antenna by increasing the electrical length into
Sharp, edges& discontinuities	Helps to make antenna radiate frequently

MIMO TECHNOLOGY

This technology is being used in all over the world for high rate data transmission. MIMO plays a very important t role in the wireless world. MIMO stands for multiple inputs multiple outputs so by using this concept MIMO can use various antenna elements. We can increase the communication capacity by the use of the MIMO technology.

Today we are looking for those devices and technologies which can be used for the short as well as the long range communication. As we know that narrow ban d in the micro strip patch antenna is a big limitation in the communication system. Many researches had been done to overcome this limitation. From these researches some focused only in the enhancement of the bandwidth but at same time the parameters of the antenna got degraded.

So, from the above observation it was clear that we should need a technique in which both bandwidth and parameters helps us to attain better results. So, after this UWB plays a significant role in the enhancement of the bandwidth but it also has a limitation of multipath path feeding. To improve this limitation, MIMO technology was generated.

Fractals were used to achieve the better result. Fractals have a property of self- similarity and with this property they help to achieve a better impedance matching. Meta materials based antennas are very useful in enhancing the bandwidth with the better efficiency

FRACTAL FEOMETRY

Benoit Mandelbrot described the term 'fractal' and he has described the relationship between fractal and nature using discovery made by Gaston Julia and Pierre fatuous. Its Latin name is fractus means 'broken'. Some of part has same shape as whole object but on a different scale. Fractus concept has been applied to many branches of science and engineering including fractal electrodynamics for radiation and propagation. Fractal geometry has been used to determine the object in nature that is tough to define with Euclidian geometry. Fractal geometry formed using an iterative process that leads to self similarity and self affinity structure.

Fractal can be classified in two categories: deterministic and random. Deterministic are those that are generated several scale and rotated copies of themselves. Random fractal contain element of randomness that allow simulation of natural phenomenon. Fractal antennas are addition of classical antenna which utilizes fractal geometry and antenna theory plays an important role in the fractal antennas.

In this antenna a hexagonal iterative slot and a transmission line is made. The dimension is explained in the table 1.FR4 epoxy material is used for the substrate and having a thickness of 1.6mm. The loss tangent for the substrate is given as 0.02 and the value of εr=4.4.

As we can see from the below figure the structure is designed in the four steps.

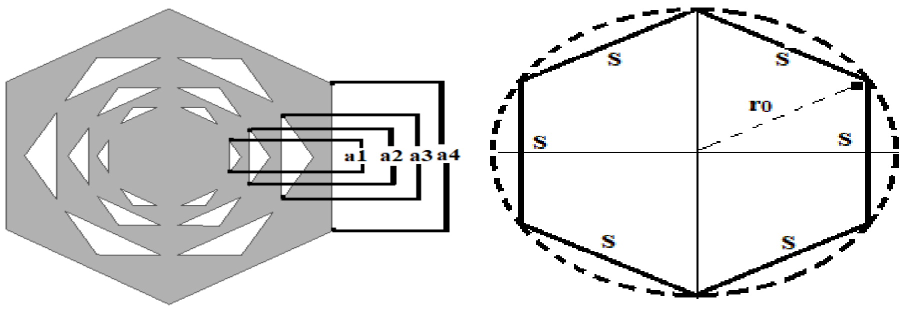

Fig.6 fractal geometry and hexagonal circular generator

TABLE 1. PARAMETERS FOR THE PROPOSED ANTENNA

DIMENSIONS	PARAMETER	VALUE	VALUE
LENGTH	A_1	3.5	30
WIDTH	A_2	4.5	30

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GAP	R_o	6.5	3
T_L	A_3	5.5	2
T_W	A_4	6.5	13

CONCEPT AND TERMINOLOGIES

The concept and terminologies are very clear in this research. A UWB- MIMO antenna is designed with the use of the Metamaterial and ring resonator is used to obtain the ultra wide band spectrum and to reduce the mutual coupling.

Metamaterials is a combination of Greek and Latin words. In Greek terms Meta means "beyond" and in Latin word material means "matter" or "material". They are made from assemblies of multiple elements fashioned from composite materials such as metal and plastic. The material is arranged in a repeating pattern.

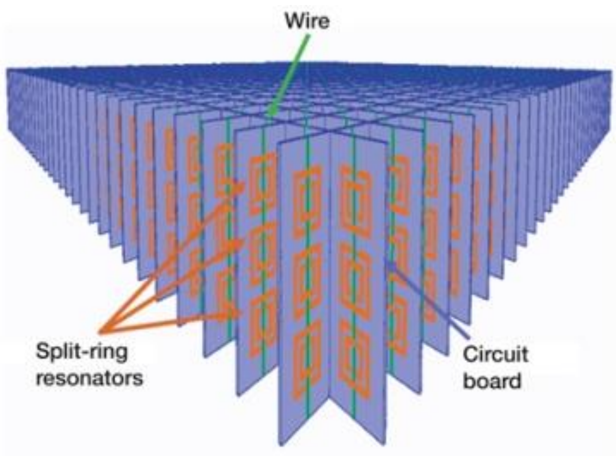


Fig. 6 Metamaterial

A split ring is an artificial structure in the Metamaterials. The purpose of the split ring resonator is to produce the desired magnetic susceptibility in various types of the Metamaterials up to 200 terahertz. Split ring resonator consists of a pair of concentric metallic rings, etched on a dielectric substrate with slits etched on the opposite side. Each split ring resonator has an individual tailored response to the electromagnetic field.

Table 2 previous fractal antenna result reports

SIZE OF THE ANTENNA	MUTUAL COUPLING	ECC	BAND-WIDTH	GAIN	PEAK GAIN	RADIATIO N
60×41	<-17	<0.25	11.07	>9	6.5	>70%
48×48	<-17	<0.1	12	NA	5	>75%
55×33	<-18	<0.019	10.6	>9.95	NA	>91%
36 × 40	<-19	<0.03	12	>9.5	4	>70%

40×40	<-15	<0.1	6	>9.95	4.3	>69%
50×40	<-15	<0.02	11	>9.65	NA	>91%
35×38	<-20	<0.035	11.2	NA	4.5	NA
50×25	<-17	<0.15	12	>9.95	5.8	>85%
30×30	<-25	<0.013	15	>9.98	6.2	>88%
34×30	<-16.3	<0.06	12.6	>9.99	4.8	NA

METHODS OR APPROACHES

Iterative function systems

Iterative functions are used to make the fractals of the antenna. These iterated function system are based on the application of the series a affine transformers, w, defined by

$$w\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix}, \qquad (1)$$

Or equivalently by,

$$w(x, y) = (ax + by + e, cx + dy + f), \qquad (2)$$

Where a, b, c, d and f are the real numbers. Hence the affine transformation, w is represented by six parameters.

$$\left(\begin{array}{cc|c} a & b & e \\ c & d & f \end{array}\right), \qquad (3)$$

Such that a, b, c and d control rotation and scaling, while e and f control linear translations.

Now suppose we consider w1,w2, ...wn as a set of affine linear transformations, and let A be the initial geometry. Then a new geometry produced by applying the set of transformation to the original geometry, A and collecting the result from w1(a), w2(b), ...wn(a), can be represented by

$$W(A) = \bigcup_{n=1}^{N} w_n(A), \qquad (4)$$

Where w is known as the Hutchinson operator. Fractal geometry can be obtained by repeatedly applying w to the previous geometry. For example if the set Ao represents the initial geometry, then we will have

$$A_1 = W(A_0),\ A_2 = W(A_1),\ \cdots,\ A_{k+1} = W(A_k). \qquad (5)$$

An iterated function system generates a sequence that converges to a final image, A∞ in such a way that

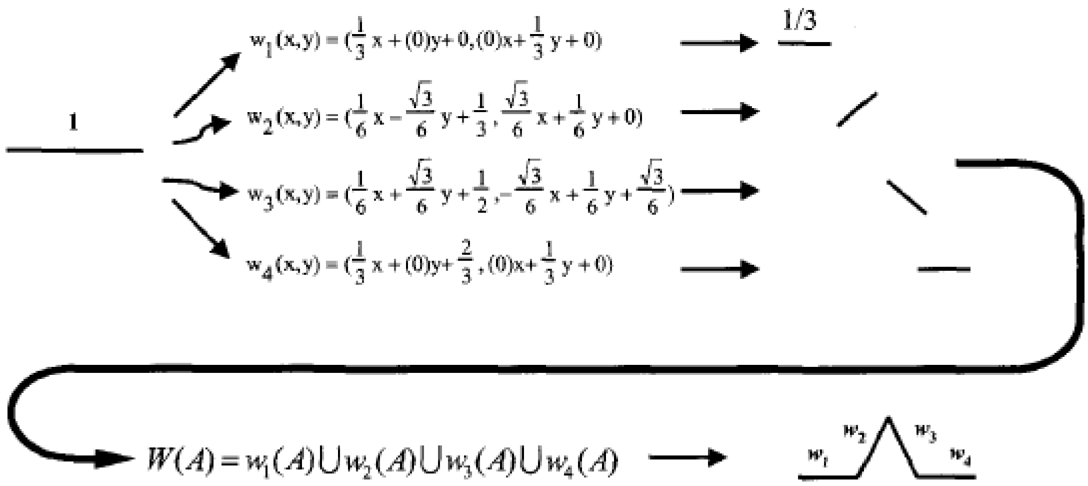
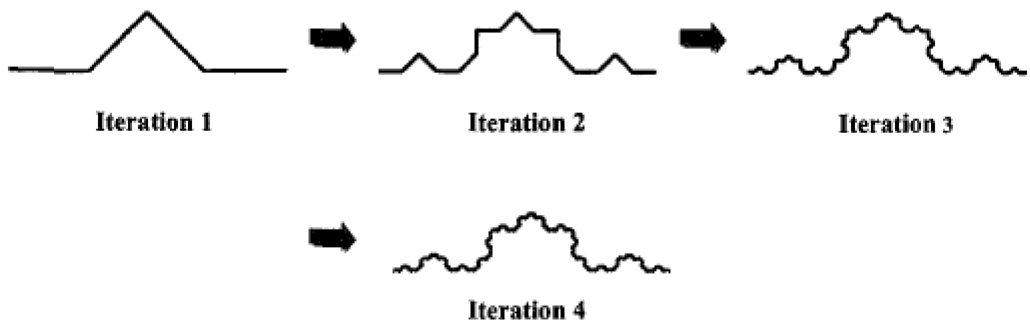


Figure 6. The standard Koch curve as an iterated function system (IFS).

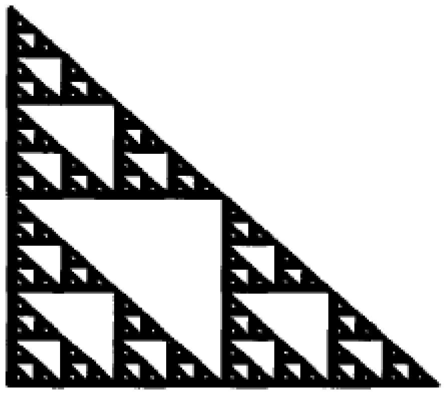


$$W(A_\infty) = A_\infty. \qquad (6)$$

In the above equation w is the fixed point and the attractor for the iterative function is shown in the above figure

The above figure shows the process of generating the Koch fractal curve. In this case, the initial set, *A*,, is the line interval of unit length, i.e., *A*, = **{x:x** ~[0,1]). Four affine linear transformations are then applied to *A*,, as indicated in Figure ti. Next, the results of these four linear transformations are combined together to form the first iteration of the Koch curve, denoted by A,**.** The second iteration of the Koch *A*>, may then be obtained by applying the same four affine transformations to *A*,. Higher-order version:; of the Koch are generated by simply repeating the iterative process until the desired resolution is achieved. The first four iterations of the Koch curve are shown in Figure 7. We note that these curves would converge to the actual Koch fractal, represented by &, as the number of iterations approaches infinity.

a	b	c	d	e	f
0.500	0.000	0.000	0.500	0.000	0.000
0.500	0.000	0.000	0.500	0.500	0.000
0.500	0.000	0.000	0.500	0.000	0.500



a	b	c	d	e	f
0.195	-0.488	0.344	0.443	0.4431	0.2452
0.462	0.414	-0.252	0.361	0.2511	0.5692
-0.058	–0.07	0.453	-0.111	0.5976	0.0969
-0.035	0.07	-0.469	-0.022	0.4884	0.5069
-0.637	0.0	0.0	0.501	0.8562	0.2513

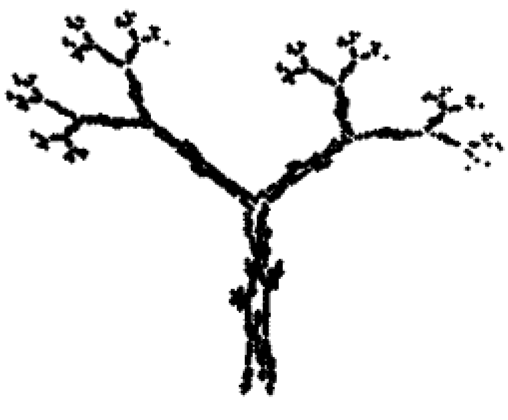


Fig Coding for the fractal tree.

DATABASE AND PERFORMANCE MEASURE

Return loss for the iterative structure or repeated fractals as shown in the figure 7. As soon as we increase the iterative structures later we attain very good results of better impedance matching. As we can see from the figure that the bandwidth attain for the third repeated iteration is given as 8.9GHz. The antenna is designed in such a way so that its size can be reduced and attains better results.

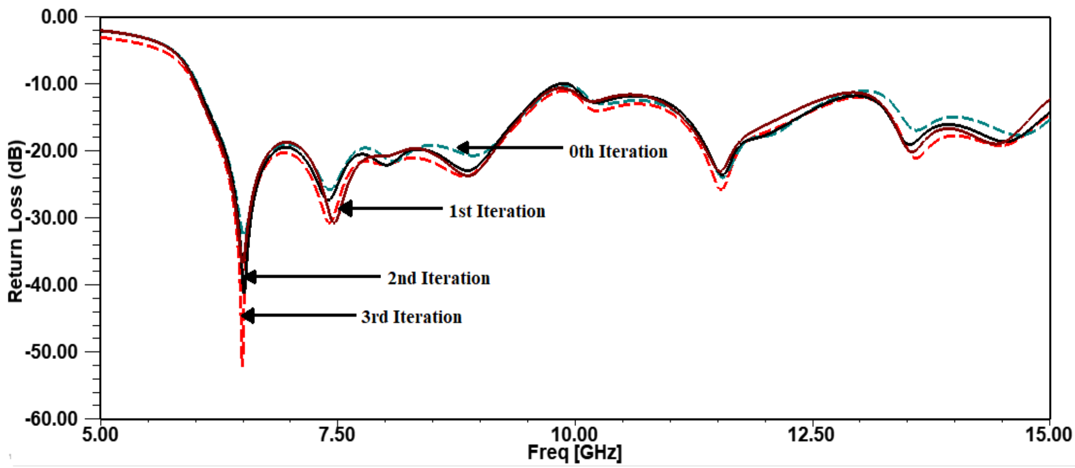


fig. 7 return loss for the repeated shape(fractals)

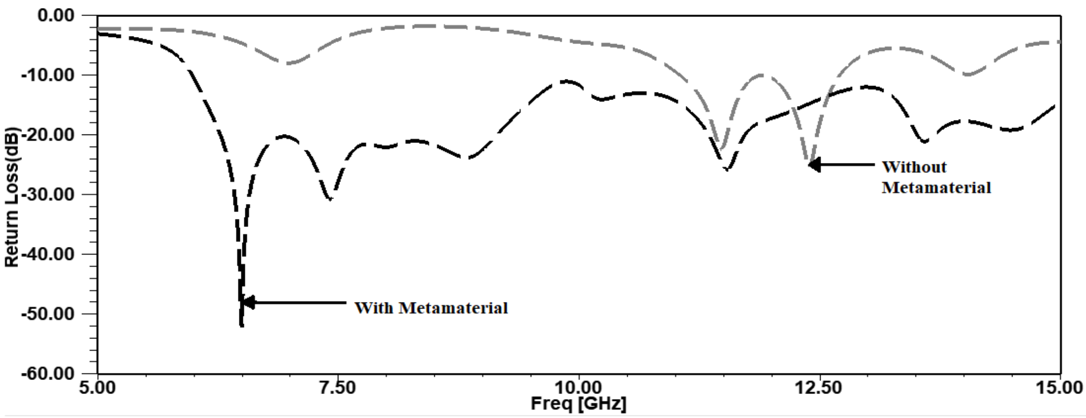


fig 8 return losses with and without the metamaterial

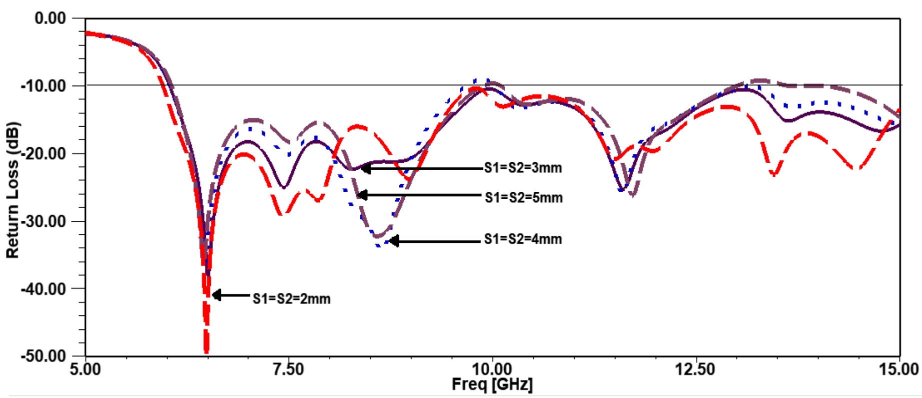


fig 9. return loss due to the presence of two split rings

The parameters (width) of split rings are very important to attain the perfect impedance matching. Above figure shows the change in return loss due the presence of the split rings. We increase and decrease the width of the split ring resonator to attain the better results. From the observations and results we found that, at the width of 2mm better impedance matching is achieved.

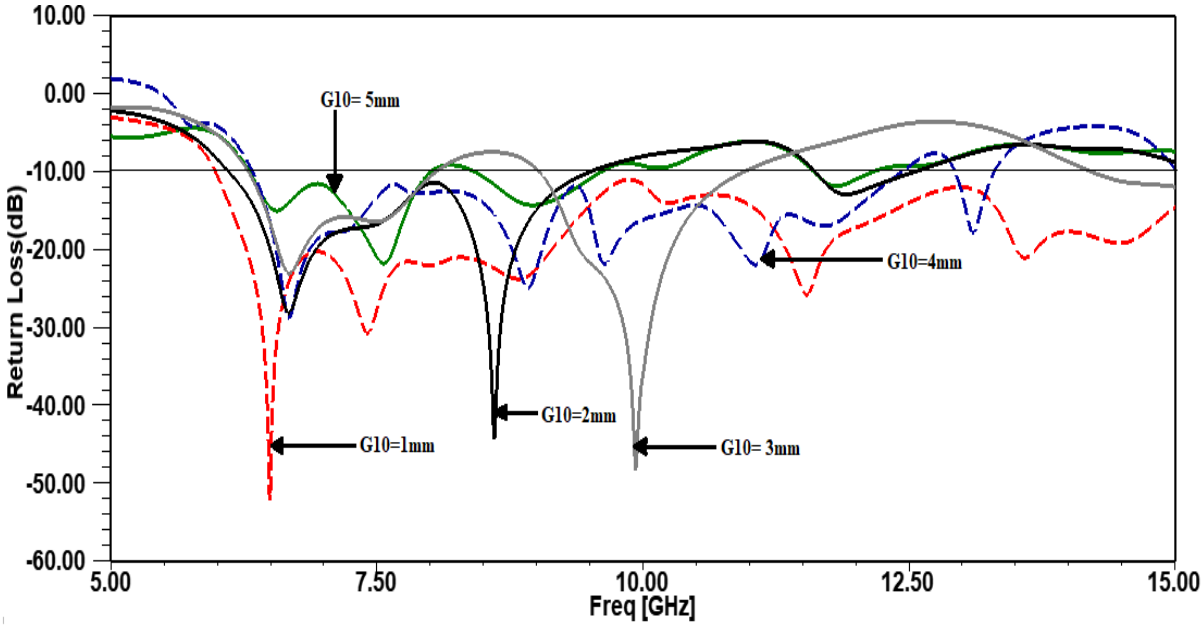


fig10. Presence of gap in the return loss

As shown in the above figure the gap plays a very important role in attaining the UWB and this gap lies between the two split ring resonators. Changes in the value of the return loss due to the presence of the gap are shown in the above figure. The split width is taken to be 2mm and the value of gap between the two resonator lies between 1mm to 4mm but we are taking the gap value 1mm because it gives us the perfect impedance matching. So if we try to increase or decrease the value of the gap then perfect impedance matching is not achieved

CONCLUSION

In this research we have designed a new Metamaterial MIMO based fractal antenna with the various parameters. The simulated result of the fractal antenna is shown in the above figure. A compact size fractal antenna is designed. After watching the simulated result we found that the fractal antenna attains impedance bandwidth of 9.1 GHz and the radiation pattern shows us that the antenna can be used for the ultra wide band applications. Antenna attains a diversity gain of greater than 9.97dB and ECC is less than 0.06. The applications of this antenna cover WLAN, WIMAX, UWB applications etc.

FUTURE CHALLANGES AND DIRECTION IN FRACTAL ANTENNA

In future technology, Regarding high data rates and short range transmission the ultra wide band plays a very important role. Recently many UWB antennas have developed and established. Many researchers have focused on the MIMO antenna and this requires a several transmitters and receivers antennas. This UWB spectrum frequency helps to overcome multipath propagation with non-line-of-sight (NLOS), which results in the more accuracy of data. The MIMO antenna enhances the channel capacity by increasing the spectrum efficiency of the channel. However, significant issues/ challenges have overcome to enhance the effectiveness of MIMO. We can use this antenna in the portable devices and in ultra wide band applications.

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