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Design and Development of Sierpinski Carpet Microstrip Fractal Antenna for Multiband Applications

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Abstract: The rapid growth of wireless technologies has drawn new demands for integrated components including antennas. Antenna miniaturization is necessary for achieving optimal design of modern handheld wireless communication devices. Numerous techniques have been proposed for the miniaturization of microstrip fractal antennas having multiband characteristics. A sierpinski carpet microstrip fractal antennas is designed in a centre frequency of 2.4 GHz which is been simulated. This is to understand the concept of antenna. Perform numerical solutions using HFSS software and to study the antenna properties by comparison of measurements and simulation results.

Keywords: fractal; sierpinski carpet; multiband.

I. INTRODUCTION

In modern wireless communication systems wider bandwidth, multiband and low profile antennas are in great demand for various communication applications. This has initiated antenna research in various directions. Nowadays microstrip antenna becomes very crucial for the communication world. Different types of antenna have been designed for various wireless applications. Among those antennas microstrip fractal antenna plays an important role in communication areas.
Fractals were first introduced by Benoit Mandelbrot in 1975.This is as a part of classifying structures whose dimensions were not whole numbers. Fractal concepts are defined in the field of antenna engineering for developing new types of antennas having prolific characteristics. Due to their geometrical properties the fractal shaped antennas exhibits some specific features. Fractals are also been applied in the field of analysis of high altitude lightning, image compression. Fractals are originated as geometric forms that are found in nature, and obtained after millions of years of evolution, selection and optimization. The necessity of wireless technology has motivated many designers to make new antenna design that can cover wide range of frequencies. Due to its low cost, low profile and complex configuration it has gained interest for many important applications. Here, an antenna is designed that will be useful for multiband application. Fractal geometry is used for designing antenna that has been successfully applied to get wide range of bandwidth.

Fractal antenna is widely used due to the following important facts:

- Multiband frequency response that derives from the inherent properties of the fractal geometry of the antenna.
- Compact size compared to conventional antenna designs, while maintaining excellent efficiency and gain.
- Robustness and mechanical simplicity.
- Design for particular multi frequency characteristics containing specific stop bands and also specific multiple pass bands.

The Sierpinski fractal antenna is traditionally well known for the multiband behaviour. Compound fractal antennas have the potential to provide multi-band solution through the property of self-similarity that its fractal shape poses. Using a combination of fractal structures we can provide better bandwidth than traditional and conventional microstrip fractal antennas. Infractal geometry, repetition of patterns occurs in an iterative manner. Fractal geometry provides better impedance matching and sizeminiaturization of antenna. This allows the antenna to operate at different frequencies thus minimizing the number of antennas required. It also reduces mutual coupling in fractal arrays. Microstrip antenna consists of 3 layers which are patch, ground and substrate.

The design of an efficient wide band small size antenna, for recent wireless applications, is a major challenge. In applications like high performance aircraft, satellite, missile, mobile radio and wireless communications small size, low-cost fabrication, low profile, conformability and ease of installation and integration with feed networks are

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the main design constraints. Designing a sierpinski microstrip fractal antenna requires a combination of designing steps. The first step involves designing an antenna to operate at a given frequency. This frequency is selected according to the required specifications of the antenna to be designed.

High Frequency Structure Simulator (HFSS) is a computer software that is used for antenna model design. Numerical simulations can be performed using HFSS software to obtain different specific design parameters of the microstrip fractal antenna and also different antenna characteristics are obtained.

II. MICROSTRIP ANTENNA

In telecommunication, amicrostrip antenna usually known as a printed antenna is fabricated using microstrip techniques on a printed circuit board (PCB). They are mainly used at microwave frequencies. The use of microstrip structures to radiate electromagnetic waves was described in 1950's.The earliest form of antennas was developed by Deschamps. Later it was formally introduced by Munson as planar antennas on missiles. By early 1970's, the importance of microstrip radiators was realized when researchers noted that almost half of the power in a microstrip radiator escapes as radiation. With the evolution of design technology, microstrip antennas have achieved higher bandwidth, improved polarization pattern and wider impedance bandwidth. Since printed circuit technology is currently used to provide low profile antennas for personal and mobile communication devices, this paper will embark on designing a microstrip antenna for specified bandwidth purposes.

An individual microstrip antenna consists of a patch of metal foil on the PCB surface and on the other side of the boarda metal foil ground plane is found. Microstrip antennas mostly consists of multiple patches in a two-dimensional array. The antennas are connected to the transmitter or receiver throughmicrostrip transmission lines. A radio frequency current is applied between antenna and ground plane. Microstrip antennas have become very popular in recent decades due to their thin planar profile which can be incorporated in to the surfaces of many consumer products, missiles and aircrafts.

The microstrip antenna can be designed with different topologies to meet the desired requirements of variety of wireless application, such as high gain, ultra wide band (UWB), miniaturization, rectangular, circular polarization, multipolarization, feeding techniques, etc.

A. Microstrip Fractal Antenna

The combination of fractal geometry used inmicrostrip configuration is termed as "microstrip fractal antenna". As the iteration order increases, the resonant frequency decreases more to lower side and thus indicates more size reduction. Fractal microstrip antenna structures show great promise in handling wide bandwidths at microwave frequencies with excellent return-loss and moderate gain performances. This antenna can be easily fabricated due to their light weight and low profile characteristics so that it can be demonstrated for multiband operations.

Self-similarity is an important property of fractals. A self-similar object is exactly or approximately similar to a part of itself. Here, the whole structure has the same shape as one or more of its parts. A fractal dimension is termed as a ratio which provides a statistical index of complexity comparing how detail a pattern changes with the scale at which it is measured. It has also been characterized as a measure of the space-filling capacity of a pattern that tells how a fractal scales differently than the space it is embedded. A fractal dimension does not have to be an integer. Fractals are generally made by IFS (iterative function system). A fractal antenna's response differs from that of a traditional antenna design such that it is capable of operating with excellent performance at different frequencies simultaneously. This makes the fractal antenna an excellent design for wideband and multiband applications. The construction of a fractal is based on an iterative process.

III. SIERPINKI CARPET GEOMETRY

The Sierpinski carpet is a plane fractal antenna first described by WacławSierpinski in 1916. The construction of theSierpinski carpet begins with a square. The square is cut into 9 congruent sub squares and the central sub square is removed. The same procedure is then applied recursively to the remaining 8 sub squares, and this can be repeated for multiple iterative levels.

A. First iteration

The design of the micro strip Sierpinski carpet fractal antenna follows the approach of different parameter considerations. First a microstrip patch at the required operating frequency is designed, then the first iteration of the Sierpinski carpet fractal antenna proceeds by dividing the microstrip patch into nine equal squares and removing the centre square. The feed location is adjusted so as to connect to the metallic portion of the patch.

B. Second iteration

In the second iteration of microstripSierpinski carpet fractal antenna, each of the eight remaining square is divided into nine equal squares, and the centre square is removed.

C. Third iteration

In the third iteration of microstripSierpinski carpet fractal antenna, remaining square is divided into nine equal squares, and the centre of each square is removed.

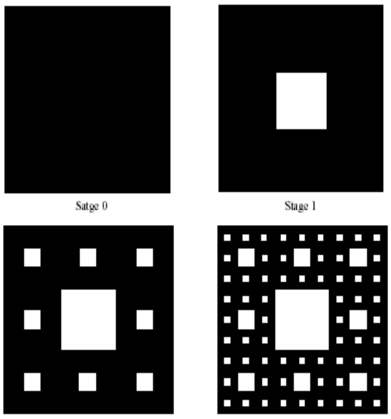

Fig. 1Sierpinski Carpet Antenna up to three iterations

D. Design Approach.

In the typical design procedure of rectangular Microstrip fractal antenna, three essential parameters are:

- Frequency of operation (f_0): The resonant frequency of the antenna must be selected appropriately. The antenna designed should be useful for the wireless communication system. The ISM frequency band is 2400MHz to 2483.5MHz, which is used for Bluetooth, WLAN and other applications. Hence the resonant frequency selected for the design is 2.4 GHz.
- Dielectric constant of the substrate (ε_r): The dielectric constant of substrate (ε_r) material plays an important role in the antenna design. A substrate having a high dielectric constant reduces the dimensions of the antenna but it also affects the antenna performance. So, there is a trade-off between size and performance of antenna. The dielectric material selected for design is FR4 epoxy having dielectric constant of 4.4. A substrate having high dielectric constant should be selected because higher the dielectric constant smaller the dimensions of the antenna.
- Height of dielectric substrate (h): For the microstrip fractal antenna to be used in communication systems, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate should be less.

The design of the antenna was start with single element using basic square patch microstrip antenna. The dimensions of an antenna at a given operating frequency describing its Length, L and width, W can be calculated by using equations given below:

Width,

$$W = \frac{c}{2f_0}\sqrt{\frac{\varepsilon_r+1}{2}}$$

Effective dielectric,

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{2}\left(\frac{1}{\sqrt{1+\frac{12d}{W}}}\right)$$

Fringing field,

$$\Delta l = 0.412\, d\, \frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{d} + 0.262\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{d} + 0.823\right)}$$

Length,

$$L = \frac{v_0}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta l$$

Where,

v_0 = Velocity of light in free space.

fr = Operating resonant frequency.

ε_r = Dielectric constant of the substrate used.

ϵ_{eff} = effective dielectric constant.

d = height of the substrate.

The generalized formulas for iteration n are as follows:

N_n = the number of black box.

L_n = the ratio for length.

A_n = the ratio for the fractal area after the nth iteration.

n = the iteration stage number.

$$N_n = 8n$$

$$L_n = \left\{\frac{1^n}{3}\right\}$$

$$A_n = \left\{\frac{8^n}{9}\right\}$$

E. Software Used

HFSS (High Frequency Structure Simulator) software is selected as simulating software. HFSS is an industry standard tool for simulating 3-D full-wave electromagnetic fields. It simplifies the process of inputting the structure by providing a powerful solid 3D modelling front end. The software was studied by simulating different types of patch antennas. The study was initiated with the designing of a simple square patch antenna.

F. Substrate Selection.

The substrate used is FR4 epoxy.FR-4 (or FR4) is a grade designation assigned to glass reinforced epoxy laminate sheets, tubes, rods and printed circuit boards (PCB). FR-4 is a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant. The material is known to retain its high mechanical values and electrical insulating qualities in both dry and humid conditions. These traits along with good fabrication properties, provide utility to this grade for a wide variety of electrical and mechanical applications.

G. Feeding Technique Used

The design of the feed mechanism forms the most critical part of the antenna design. It essentially determines the bandwidth of the antenna. The feeding technique influences the input impedance and the characteristics of the antenna, and is an important design parameter. The most common methods for feeding the microstrip patch antennas are: stripline, coaxial, aperture-coupling and proximity-coupling. Among this inset microstripline

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feeding technique is used here for the design. This feed arrangement has the advantage that it can be etched on the same substrate, so the total structure remains planar. An inset cut can be incorporated into the patch in order to obtain good impedance matching without the need for any additional matching element.

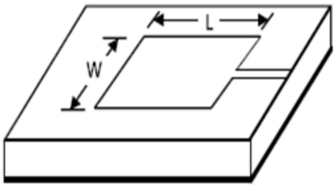

Fig. 2Microstrip Line Feed

Microstrip line feed is one of the easier methods to fabricate as it is a just conducting strip connecting to the patch and therefore can be consider as extension of patch. It is simple to model and easy to match by controlling the inset position. However the disadvantage of this method is that as substrate thickness increases, surface wave and spurious feed radiation increases which limit the bandwidth.

H. Antenna Structure and Design
The essential parameters required to design an antenna are the frequency of operation (f_0), dielectric constant (ε_r) of substrate and thickness (h) of the substrate. The frequency of operation is selected based on the application areas. Dielectric constant is usually chosen in the range 2.2 <ε_r< 12. When thickness of the substrate increases it improves the bandwidth and more power will be radiated.So choosing these essential parameters accordingly is an important and at the same times a risky task.

The procedure for designing a single rectangular microstrip patch antenna can be summarized in the following steps:

1. Choose a substrate material. Here, the material used is FR4 epoxy with ε_r =10.2.
2. Decide a frequency range and resonant frequency where the antenna want to resonate. That is f0=2.43 GHz within S band (2 to 4 GHz).
3. Select height of a substrate (h) and a patch material (t). They are always $h \leq 0.05\ \lambda_0$ and $t \leq 0.05\lambda_0$.
4. Calculate widths and lengths of patch and ground plane using the specific equations.
5. Decide a feeding technique which is well suited for the design. Here microstrip line feeding technique is used.
6. Design an antenna using HFSS simulation software using all the above values.
7. Observe simulated return loss by varying different parameters until get desired return loss at the resonant frequency.
8. Observe other simulation results such as gain, bandwidth, directivity, VSWR etc.

TABLE I DESIGN PARAMETERS

Parameters	Value
Frequency of operation, f_0	2.4 GHz
Dielectric Constant, ε_r	4.4
Substrate Thickness, h	1.6 mm

IV. RESULTS AND DISCUSSION

A. Microstrip Patch Antenna
A microstrip patch antenna is designed with a microstrip line feed s designed at a centre frequency of 2.4 GHz. A microstrip path antenna is designed with a dielectric constant, ε_r = 4.4 and substrate thickness, h = 1.6.

TABLE II DESIGN PARAMETERS OF MICROSTRIP PATCH ANTENNA

Parameters	Value
Frequency of operation, f_0	2.4 GHz
Dielectric constant, ε_r	4.4
Substrate Thickness, h	1.6 mm
Length of substrate, L_s	39.02 mm
Width of substrate,W_s	47.61mm
Length of ground, L_s	39.02 mm
Width of ground, W_g	47.61 mm
Length of patch, L_s	29.42 mm
Width of patch, W_p	38.01 mm

A single rectangular microstrip patch antenna is been simulated by using HFSS software. The simulated microstrip patch antenna is shown in fig 3.

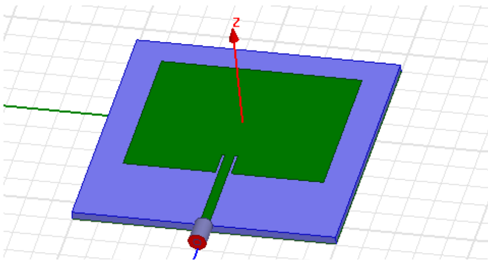

Fig. 3 Simulated single microstrip patch antenna

From simulated results, fig.4 shows the simulated return loss plot. Return loss is the difference between forward and reflected power, in dB. If the power transmitted by the source is PT and the power reflected back is PR, then the return loss is given by PR divided by PT. For maximum power transfer the return loss should be as small as possible. This means that the ratio PR/PT should be small as possible, or expressed in dB, the return loss should be as large as a negative number as possible. Here S11 parameter value obtained is -29 dB.

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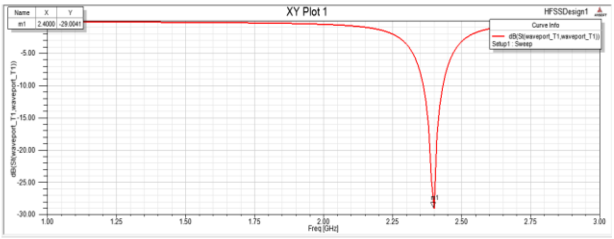

Fig. 4 Return loss plot of a single microstrip patch antenna

Voltage Standing Wave Ratio is the ratio of maximum radio-frequency voltage to minimum radio-frequency voltage on a transmission line. The VSWR can also be calculated from the return loss (S11) which means that it is also an indicator of antenna efficiency. It is given by:

$$VSWR = \frac{V_{max}}{V_{min}}$$

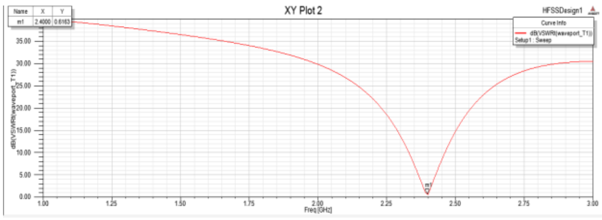

Fig. 5 VSWR plot of microstrip patch antenna.

Here, the VSWR obtained is 0.61.

An antenna radiation pattern or simply antenna pattern is defined as "a mathematical function or graphical representation of the radiation properties of the antenna as a function of space co-ordinates". The antenna pattern is mostly determined in the far field and represented as a function of the directional co-ordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity phase or polarization. The radiation property of most concern is the two or three dimensional spatial distribution of radiated energy as a function of observer's position along a path or surface of constant radius.

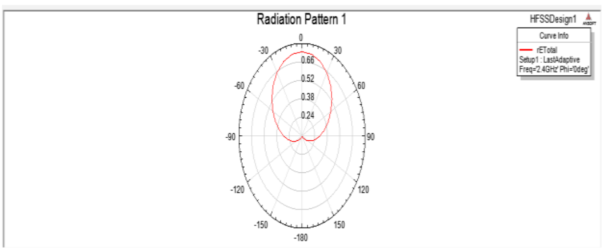

Fig. 6 Radiation pattern of microstrip patch antenna

Absolute gain of an antenna (in a given direction) is defined as, "the ratio of intensity in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. Here, the gain obtained is 1.0354 dB

$$Gain = \frac{Intensity\ \ of\ radiation}{Total\ \ input\ \ accepted\ \ power}$$

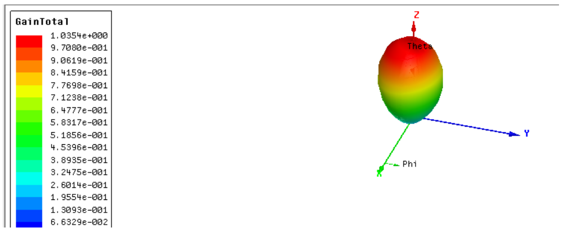

Fig. 73D Gain plot of microstrip patch antenna.

B. Sierpinski Carpet Antenna

Sierpinski carpet antenna is an extension of microstrip patch antenna. Here, microstripSierpinski carpet antenna is designed and iterated up to third iteration to exhibit multiband behaviour. The square patch microstrip antenna was selected for the initial design. The dimension of the antenna was determined from the equation of the microstrip patch antenna design equation. For the fractal design, a microstripsierpinski carpet antenna was selected. This antenna was design until third iteration. Square shape is cut down from the centre of microstrip patch antenna which shows the first iteration.

C. First Iteration

First a microstrip patch at the required operating frequency, 2.4 GHz is designed, then the first iteration of the Sierpinski carpet fractal antenna proceeds by dividing the microstrip patch into nine equal squares and removing the centre square. The feed location is adjusted so as to connect to the metallic portion of the patch.

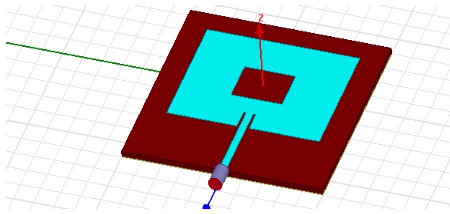
Fig. 8 Simulated sierpinski carpet antenna iteration 1 stage

The return loss for first iteration of sierpinski carpet antenna is obtained as multiple bands. The return loss obtained are -29.17 dB and -31.18 dB at frequencies 2.1 GHz and 3.7 GHz respectively.

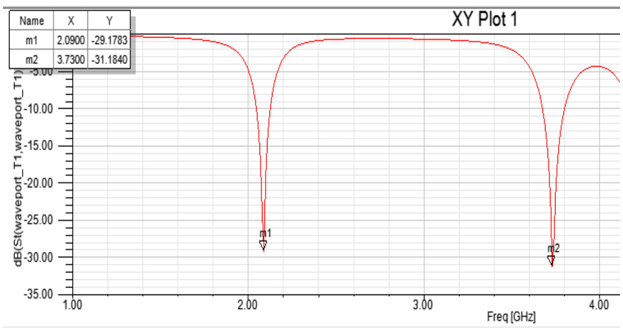

Fig. 9Return Loss Plot of Sierpinski Carpet Antenna Iteration 1 Stage

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The VSWR can also be calculated from the return loss (S11) which means that it is also an indicator of antenna efficiency. The VSWR obtained for first iteration are 0.6 at 2.1 GHz and 0.74 at 3.7 GHz.

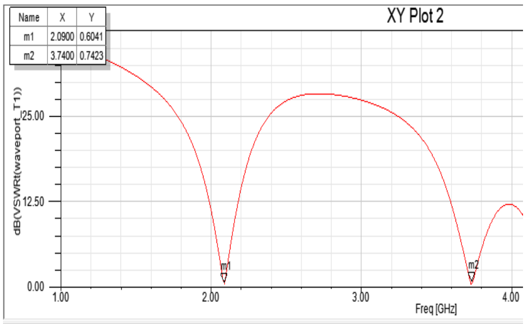

Fig. 10 VSWR Plot of Sierpinski Carpet Antenna Iteration 1 Stage.

In antenna design the term radiation pattern (or antenna pattern or far-field pattern) refers to the directional (angular) dependence of the strength of the radio waves from the antenna or other source. So, the radiation pattern for first iteration of sierpinski carpet antenna are given below.

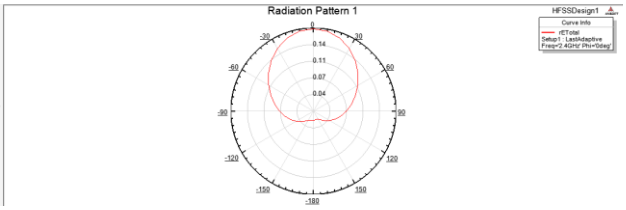

Fig. 11 Radiation Pattern of Sierpinski Carpet Iteration1 Stage.

A relative measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern. The gain obtained for first iteration is 3.1229 dB

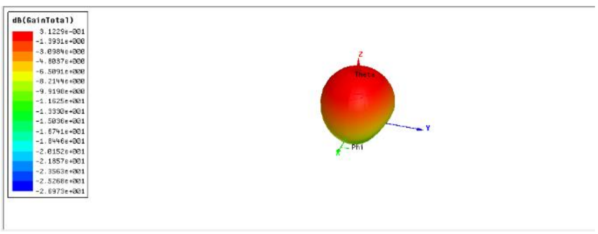

Fig. 12 3DGain Plot ofSierpinski Carpet Iteration1 Stage.

C. Second iteration

In the second iteration of microstripSierpinski carpet fractal antenna, each of the eight remaining square is divided into nine equal squares, and the center square is removed. This is done after the first iteration where the microstrip patch is divided into nine equal squares and the center square is removed. The feed location for the iteration is adjusted so as to connect to the metallic portion of the patch.

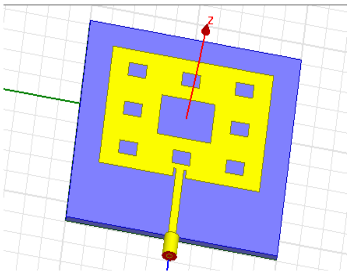

Fig. 13 Simulated Sierpinski Carpet Iteration 2 Stage

The return loss obtained during the second iteration of sierpinski carpet antenna are -21.57 dB at 2.1GHz and -33.36 dB at 3.7 GHz. The return loss is obtained at multiple bands.

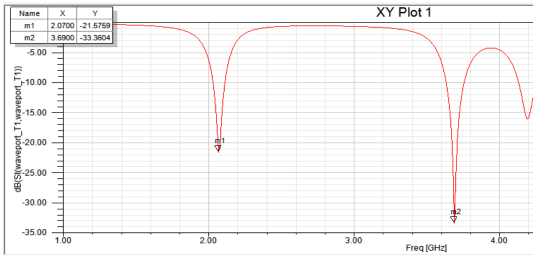

Fig. 14 Return Loss Plot of Sierpinski Carpet Iteration 2 Stage.

The VSWR obtained for second iteration is 1.45 at 2.1GHz and 0.37 at 3.7 GHz.

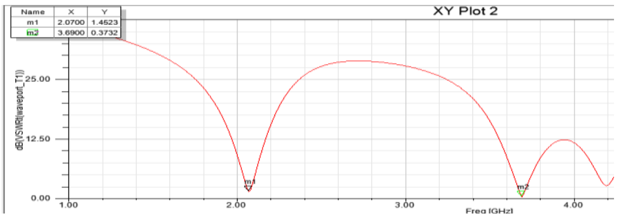

Fig. 15VSWR Plot of Sierpinski Carpet Iteration 2 Stage.

In order to be realized as a practical antenna, radiation pattern and efficiency should be excellent. The radiation pattern obtained for second iteration is given below.

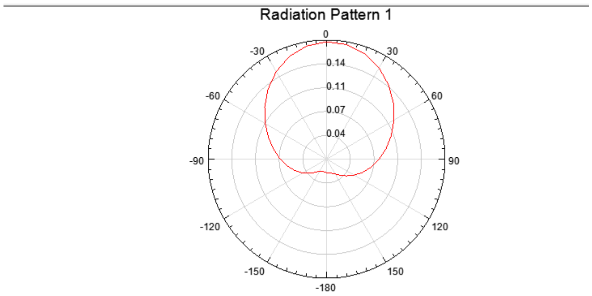

Fig. 16 Radiation Pattern of Sierpinski Carpet Iteration 2 Stage.

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The gain obtained for second iteration is 3.1229 dB

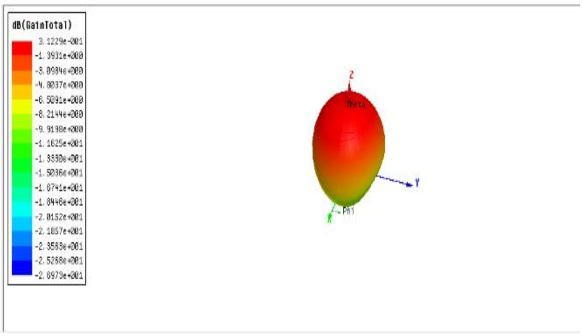

Fig. 173D Gain Plot of Sierpinski Carpet Iteration 2 Stage.

D. Third Iteration

In the third iteration of microstripSierpinski carpet fractal antenna, remaining square is divided into nine equal squares, and the center of each square is removed. The third iteration is done after the first and second iterations. An appropriate feed is given after the iteration. The feed location for the iteration is adjusted so as to connect to the metallic portion of the patch.

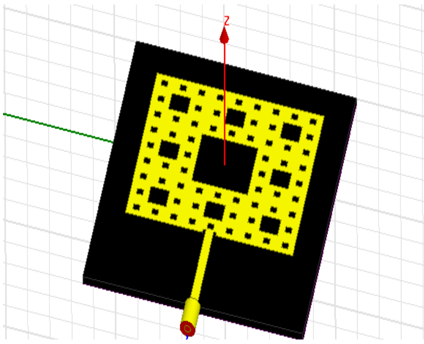

Fig. 18 Simulated Sierpinski Carpet Iteration 3 Stage.

The return loss obtained for third iteration of sierpinski carpet antenna are -21.6 dB and -33.4 dB at 2.1 GHz and 3.7 GHz respectively.

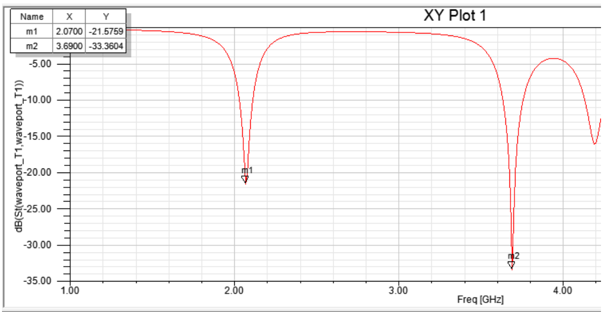

Fig. 19 Return Loss Plot of Sierpinski Carpet Iteration 3 Stage.

The VSWR obtained for second iteration of sierpinski carpet antenna are 1.45 and 0.37 at 2.1GHz and 3.7 GHz respectively.

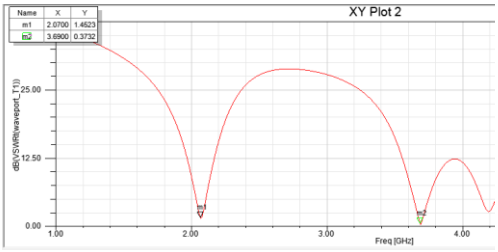

Fig. 20 VSWR Plot of Sierpinski Carpet Iteration 3 Stage

The radiation pattern obtained for third iteration of sierpinski carpet antenna is given below.

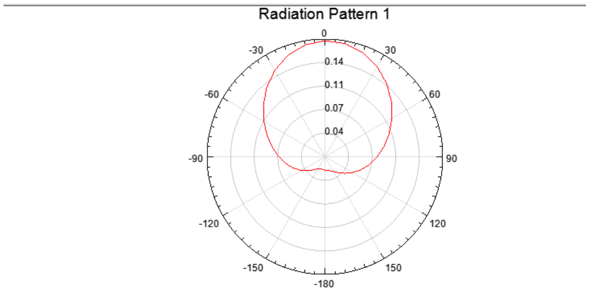

Fig. 21 Radiation Pattern of Sierpinski Carpet Iteration 3 Stage

The 3D gain plot for the third iteration of sierpinski carpet is given below.The gain obtained for the third iteration of sierpinski carpet antenna is 3.229 dB

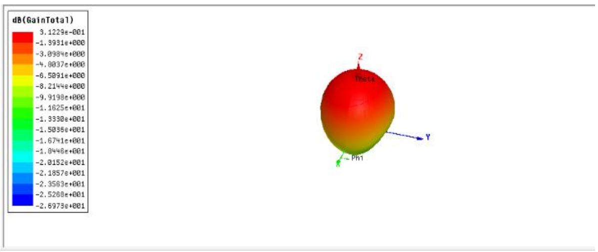

Fig. 223D Gain Plot of Sierpinski Carpet Iteration 3 Stage

V. CONCLUSION

The main goal of this paper is to design and develop sierpinskimicrostrip fractal antenna for wireless applications. The basics of microstrip fractal antenna are studied in detail and also all the design considerations of this antenna is been examined. Thus here size reduction along with the large bandwidth and high gain are the major considerations for designing the antenna. For designing a microstrip fractal antenna various designing steps corresponding to the antenna parameters are been examined. According to the designing parameters the relevant feeding techniques are selected. A single microstrip patch is designed and simulated using HFSS software. The sierpinski carpet antenna is designed in an operating frequency 2.4 GHz and simulated. The three

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iteration stages of sierpinski carpet antenna are studied and obtained the simulation results. The various design parameters such as return loss, VSWR, radiation pattern, axial ratio etc are obtained using simulation. It is observed that with increase in the number of iterations the bandwidth of the antenna increases & on second iterations the antenna starts showing the multiband behavior. As the no. of iterations increases the effective area of the antenna structure is reduced. Increase in multiple iterations also led to improvement in various performance parameters like VSWR, directivity, gain & return losses. The simulated results shows good band width enhancement.

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