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Design of Fractal Antenna with Modified Sierpinski Carpet for WiMAX Applications

D.Selvaraj, L.Chandrasekar
Dept. of Electronics and Communication Engineering,
Panimalar Engineering College, Chennai, India.

Su Sangeetha, G Sharmila, B Sowmiya, P Varshini
Dept. of Electronics and Communication Engineering,
Panimalar Engineering College, Chennai, India.

***Abstract*— A Fractal antenna with modified Sierpinski carpet is designed and simulated in this paper.This antenna operates efficiently at multiple frequency bands and has suppressed return loss of about 36.49dB at 8.7GHz.This modified Sierpinski carpet has notable enhancement in bandwidth and efficiency. Microstrip feeding is used for obtaining good impedance matching without the need for any additional matching elements. This antenna has been designed and simulated with ANSYS HFSS 15, an industry leading 3D Electromagnetic (EM) simulation tool.**

The modified carpet here, is a combination of rectangle and circle.The Antenna is designed using ROGER 5880 as substrate with the dimension of 70mm x 80mm which operates efficiently at 4.3GHz, 5.7GHz, 7.4GHz and 8.7GHz. This design is suitable for WiMAX, Radar, satellite communication and wireless computer networks (i.e) C band and X band applications.

Keywords*— *Fractal Antenna, Sierpinski Carpet, Microstrip Feeding, Impedance Matching.

I. INTODUCTION

In Wireless communication, antenna plays a major role for transmission and reception.Each antenna operates at single or dual frequency bands whereas for various applications antenna operating at multiple frequency bands is required.Fractal antenna is an antenna that operates at multiple frequency band [1]. In this developing world, wireless communication system with high data rate is required. So, an antenna with larger bandwidth is needed [2]. Fractal antenna is one among them. Fractal antenna has self-similar design and space-filling property with various iterations [3]. Due to this property the antenna has increased electrical length [4-5].Till now, many fractal antenna have been designed such as sierpinski carpet [6], and hexagonal fractal [7], circular fractal slot antenna [8] .The multiband behavior of Fractal antenna is due to the partial defected ground structure [9]. Microstrip patch antenna has the ability to operate in dual frequency and has wide bandwidth. This property made microstrip patch antenna to be used in microwave applications [10]. The proposed antenna has a good isolation and has been characterized by the electromagnetic simulation software ANSYS HFSS15 and validated experimentally.

II. DESIGN OF MODIFIED SIERPINSKI CARPET

Modified Sierpinski carpet is a combination of rectangular and circular patch. Initially, a ground, which is a perfect electric conductor of size 70mm x 80mm is designed.Then,

III. DESIGN SPECIFICATION

The following are the steps used to design the antenna and the formulas used is also given below.

Roger 5880 material having permeability of 2.2 is used as a substrate. The substrate has a thickness of 5.1mm.A patch of size 50mm x 50mm is made with circle and rectangle.A microstrip line feed of dimension 15mm x 5mm is provided. The flow diagram is given below (Fig. 1)

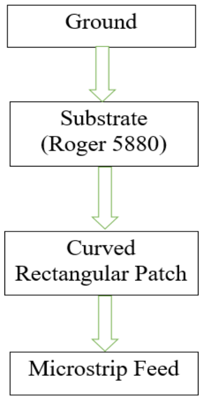

Fig. 1. Flow Diagram of Modified Sierpinski Carpet

This antenna consists of four iterations which are illustrated as follows (Fig.2).The figure shows the patch structure in all four iterations.

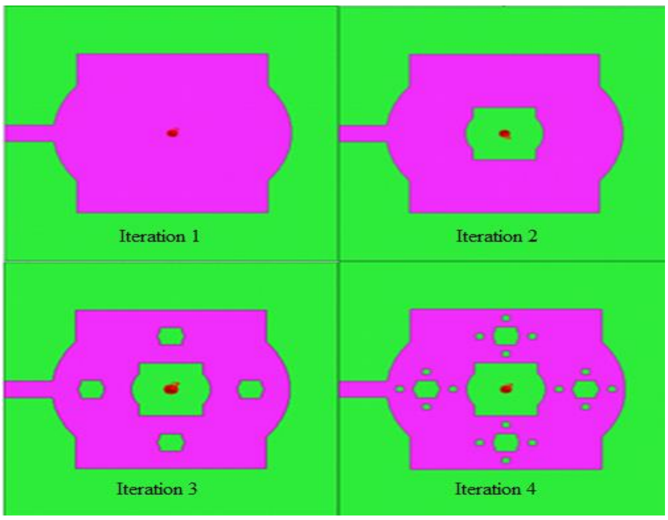

Fig.2 Iterations of Modified Sierrpinski Carpet

- The resonant frequency for which the antenna has to operate is decided.
- The material for the substrate is choosen.
- The Permeability of the selected material is noted.

The formulas below are considered to find the specifications of the antenna

A. Height of the substrate:

$$h = \frac{0.0606\lambda}{\sqrt{\varepsilon r}} \quad (1)$$

Here, f = 2.4GHz, C = 3*10^8 m/s

Therefore, h = (0.0606*0.125m)/1.483 = h = 5.1 mm

B. Width of the patch:

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon r+1}} \quad (2)$$

W = 49.41 mm

C. Effective Dielectric Constant:

$$\varepsilon reff = \frac{\varepsilon r+1}{2} + \frac{\frac{\varepsilon r-1}{2}}{\sqrt{\left(1+\frac{10h}{W}\right)}} \quad (3)$$

Ɛreff = 1.96

D. Effective Length:

$$Leff = \frac{c}{2f\sqrt{\varepsilon reff}} \quad (4)$$

Leff = 44.64 mm

$$\Delta L = \frac{h}{\sqrt{\varepsilon reff}} \quad (5)$$

ΔL = 3.64 mm

E. Length of the Patch:

$$L = Leff - 2\Delta L \quad (6)$$

L=44.64 – (2*3.64) =38.89 mm

F. Length and Width of the ground and substrate

$$L_{gs} = L + 6h \quad (7)$$

L_{gs} = 38.89 + (6*5.1) = 69.5 mm

$$W_{gs} = W + 6h \quad (8)$$

W_{gs} = 49.38 + (6*5.1) = 79.9 mm

G. Efficiency:

$$Efficiency = \frac{Gain}{Directivity} \quad (9)$$

The following table gives the specification of the designed antenna (Table. I)

TABLE I. DESIGN SPECIFICATIONS

Substrate material	Roger 5880
Thickness	5.1mm
Length, L	40mm
Width, W	50mm
Length of the Substrate,Ground	70mm
Width of the Substrate,Ground	80mm
Feed Length	15mm
Feed Width	5mm

IV. STEPS INVOLVED IN ANTENNA DESIGN

The antenna is designed and simulated in HFSS and the following are the steps used to design the antenna.

Start HFSS and create a new project using File > New Select the solution type form HFSS > solution type. Specify the solution type as Driven Modal. Specify the drawing units from Modeler > Units. In the set modal units Dialogue box, specify the units as mm.

1. Create the modal with Specified dimension using the drawing tab. find the coordinate fields at the bottom of the HFSS window, labeled Enter the Box position and specify the base corner of box as (0, 0, 0)

2. Press Tap to move to the X text to the box in the status bar and the procedure is as follows.

- Type 0 in the X box, and then press Tap to move to the Y box.
- Type 0 in the Y box, and then press Tap
- Type 0 in the Z box, and then press Enter
- Specify the length and width of the box
- Specify the length and width of the box by entering a point relative in distance to the base corner

3 .Specify the length and width of the box by enter a point relative in distance of the base corner: (-50, -45, -10) in the dX, dY, dZ boxes, and then press enter. Specify the height of the box by enter a point on the z-axis relative to the previously entered point.

4. The properties window with the commend tab selected, enables us to modify the dimension and position of the box. In the properties window the attributes tab selected enables us to assign name, assign material as Roger 5880 and Vacuum.

5. Similarly the entire modal is draw the material is types are defined

6. The substrates plane is designed using the Roger 5880.

7. A Microstrip feed is using the sierpinski carpet fractal antenna this feed is used to improve bandwidth of antenna. The feed is placed in the patch.

8. Right click the 3D modeler window and select Assign Excitation > Wave port. The wave port wizard appears. Type port 1 in the name text box and then click next.

9. An Air box is drawn such that it encloses the design of the antenna structure and it is assigned a 'Radiation Boundary (Fig. 3).

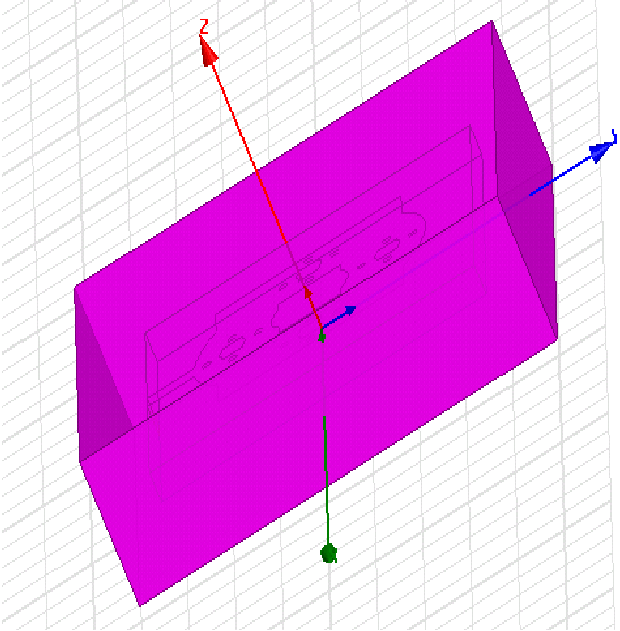

Fig 3 Air Box

10. To define the radiation setup, select the menu item HFSS > Radiation > Insert far field setup > Infinite Sphere. In the far field sphere setup dialog, select the infinite sphere tab. Assign a name to the infinite sphere as 2D cut and the range of phi as 0 start: 0 stop: 360. Specify the range of Theta as start: 0; stop: 180 step size: 0

11. To verify the boundary set up select HFSS > Boundary display.

12. A Validation check is performed on the antenna by clicking HFSS> validation check to check for the correctness of the design.

After completing all these procedures validity check have to be carried out.This will find out the missing step and denote it with a red mark.If the procedure is correctly done then it will denote it a green tick mark(Fig. 4)

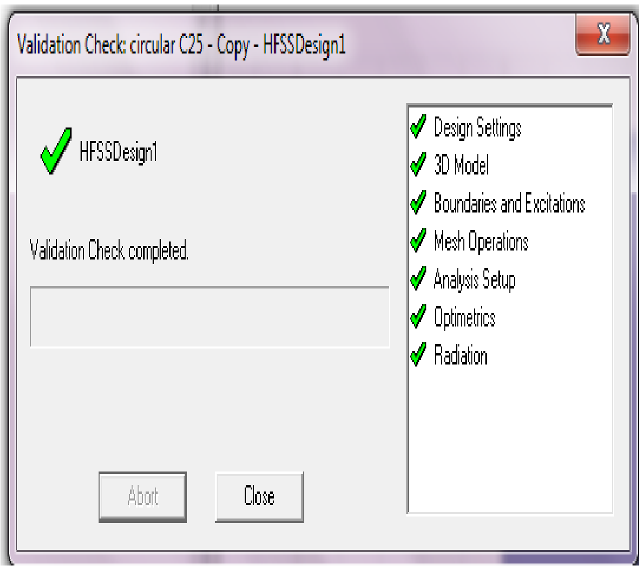

Fig 4 Validation Check

13. Add a solution set up to the design in click HFSS > analysis setup > add solution setup. In the solution set up, specify the solution frequency and do a port only by simulation to check if the mode of propagation within the port is quasi-TEM. (Fig. 5)

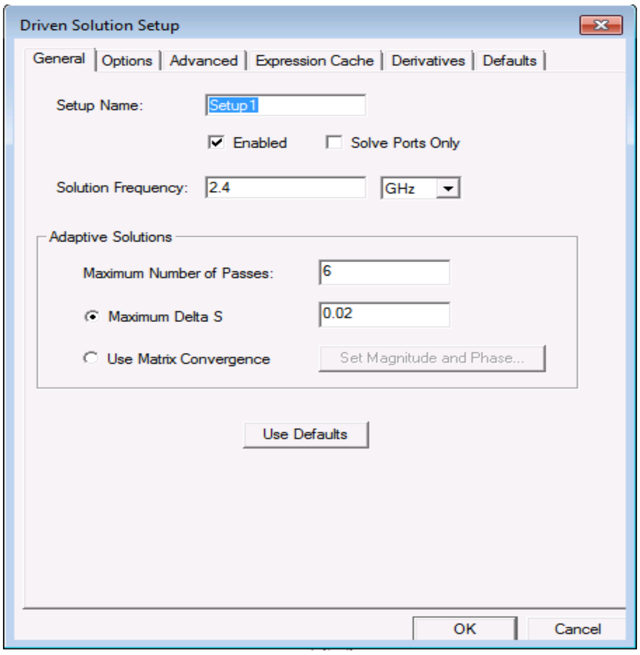

Fig 5 Solution setup box

14. Add a frequency sweep by HFSS > analysis setup > add frequency sweep. Specify the set up for which the frequency sweep has to be added. Specify the sweep type as fast and the frequency set up type as linear count. Specify the start and stop frequency and the step size. Click Ok (Fig. 6).

15. To save the project, select the menu item File > Save as. Specify the file name as reconfigure. HFSS

16. To start the solution process, select the menu item HFSS > analyze all.

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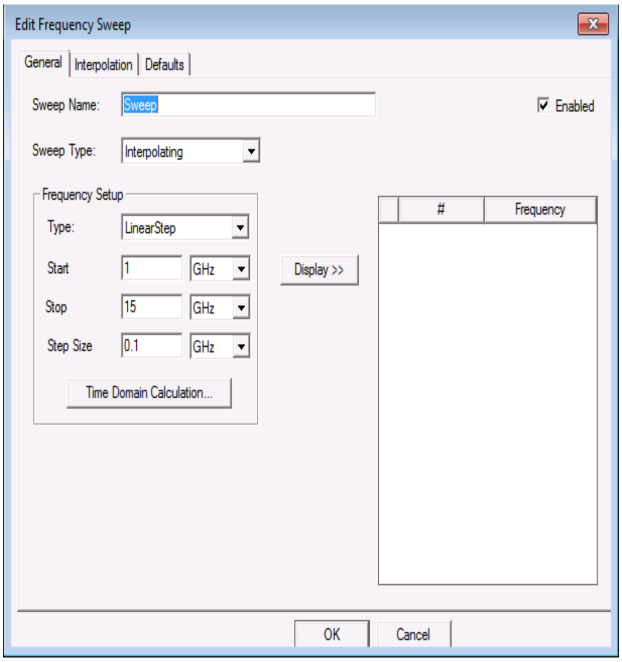

Fig 6 Sweep frequency Setup

17. To create S- parameter report, click HFSS> result> create modal solution data report >rectangular plot. Specify the category parameter and select the quantity as Specify the function as dBs

18. To create 2D polar far field plot, select the report type as far field, display type as radiation pattern. Click the ok button. In the traces window select the solution as set up 1. In the sweep tab select phi under the name and on the drop list selects theta. This changes the primary sweep to theat. Select the frequency as the solution frequency.

V. ITERATIONS OF THE ANTENNA

Since the Fractal antenna has space-filling property, it has to be designed using various iterations.

A. Zeroth Iteration:

The following figure gives the modified Sierpinski Carpet in Zeroth iteration (Fig.7).In this zeroth iteration we get a maximum efficiency of 97.67%.We get very low return loss of -27.81dB at 8.7GHz which is a X band and is used for various wireless applications.

Maximum bandwidth of 800MHz is obtained and the gain of 4.7264dB is obtained.

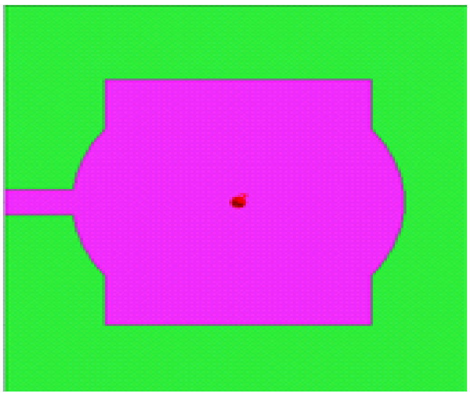

Fig 7 Patch of zeroth iteration

(Fig. 8) gives the diagram of zeroth iteration of the proposed antenna. The VSWR represented in dB is called Return loss. It is given in (Fig. 9).

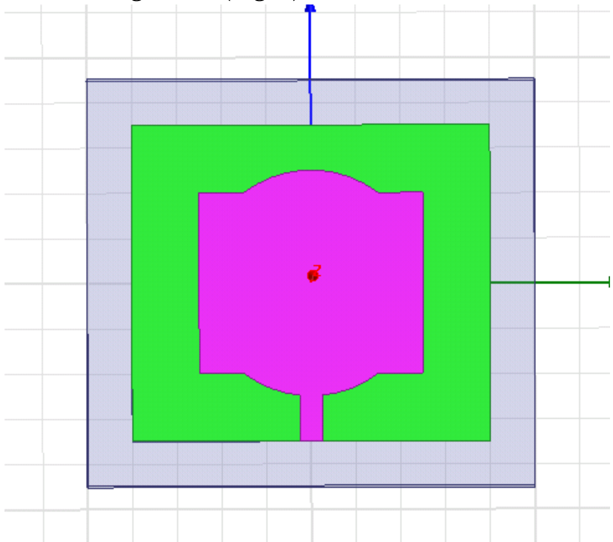

Fig 8 Zeroth Iteration of Modified Sierpinski Carpet

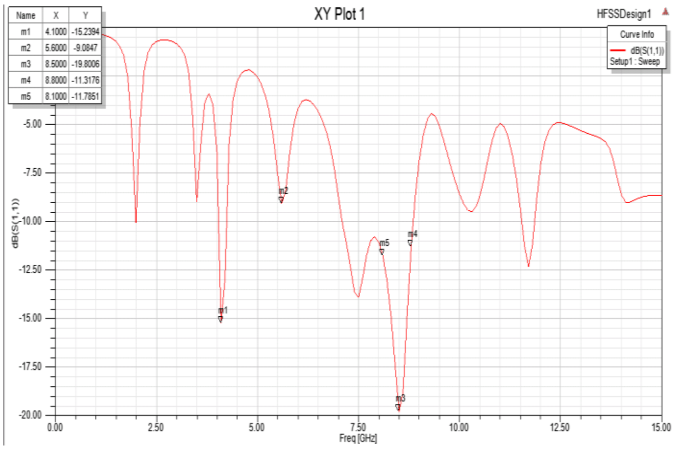

Fig 9 Return Loss plot for zeroth iteration

The ratio of input signal to the reflected signal is called VSWR. The VSWR of 1.08 at 8.7GHz is obtained (Fig.10).

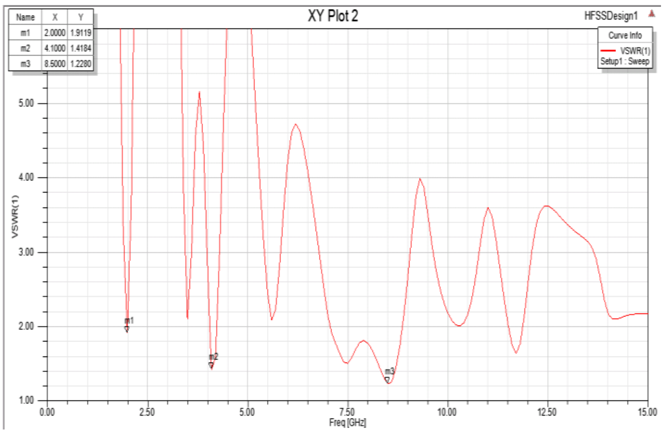

Fig 10 VSWR plot for zeroth iteration

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Efficiency is defined as the ratio of gain and directivity. They are represented in dB. The gain (dB) in 3D polar plot is given in (Fig. 11). The directivity (dB) in 3D polar plot is given in (Fig. 12).

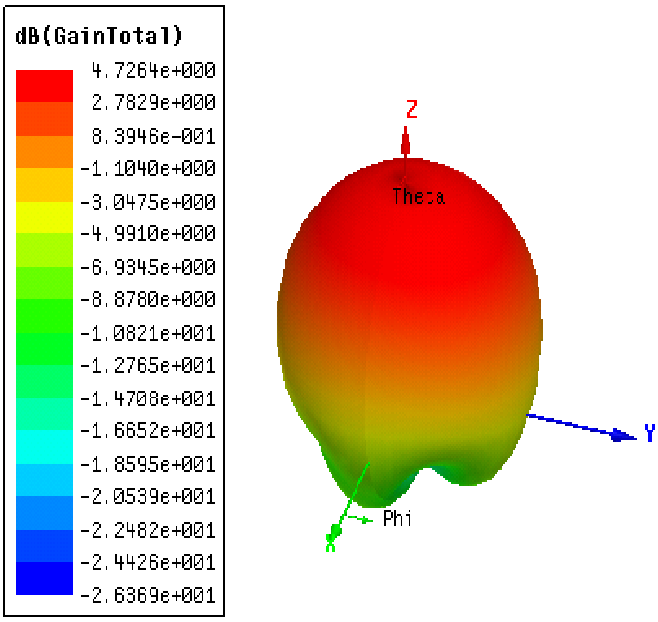

Fig 11 Zeroth Iteration Gain in dB (3D Polar plot)

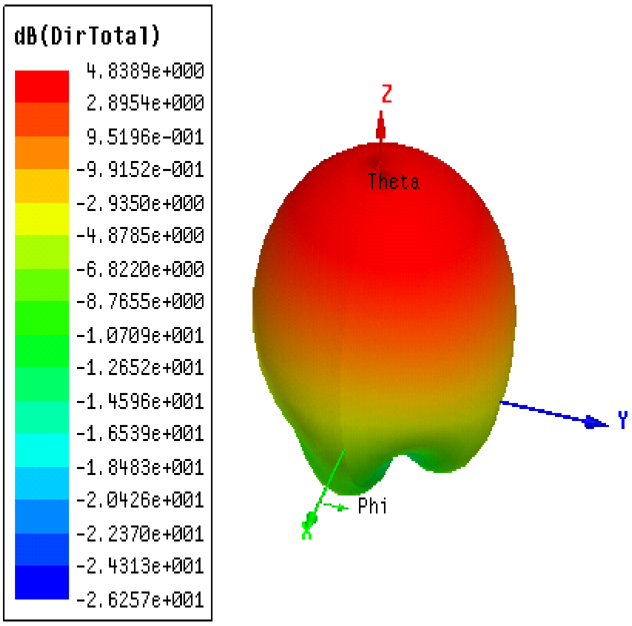

Fig 12 Zeroth iteration Directivity in dB(3D Polar plot)

Gain=4.7264dB, Directivity=4.8389dB, Efficiency=97.7%

B. First Iteration:

The following figure gives the modified Sierpinski Carpet in First iteration (Fig.7).In this zeroth iteration we get a efficiency of 95.7%. The structure of patch for first iteration is given in (Fig. 13).The antenna structure for first iteration is in (Fig. 14).The return loss plot is in (Fig. 15). The Voltage Standing Wave Ratio is given in (Fig. 16).The figures are as follows.

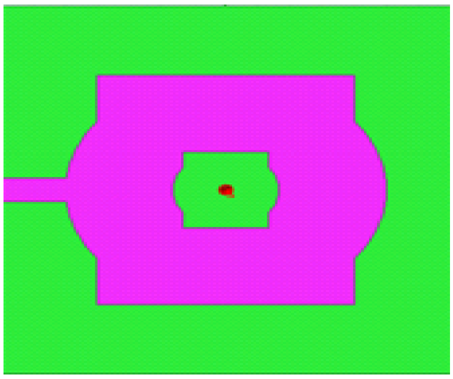

Fig 13 Patch for first iteration

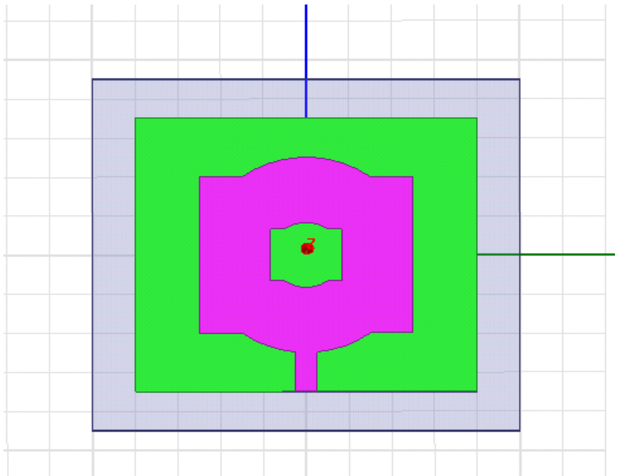

Fig 14 First Iteration of Modified Sierpinski Carpet

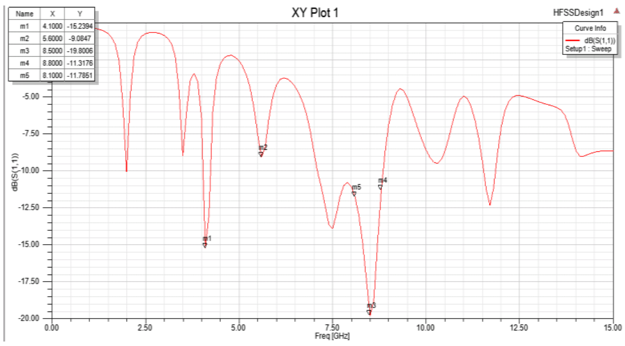

Fig 15 Return Loss plot for First iteration

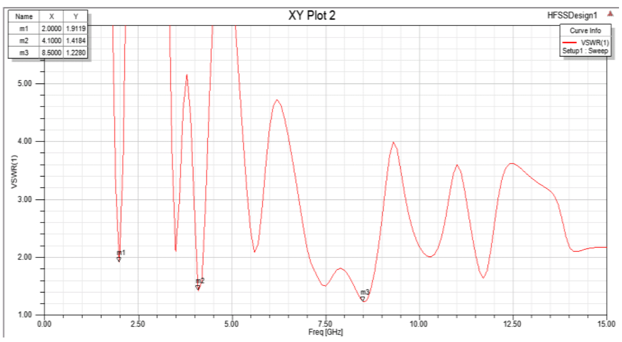

Fig 16 VSWR plot for First Iteration

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The gain and directivity are the important parameters of an antenna. Gain in dB (3D Polar plot) for first iteration is given in (Fig. 17). (Fig. 18) shows directivity in dB (3D Polar plot) for first iteration.

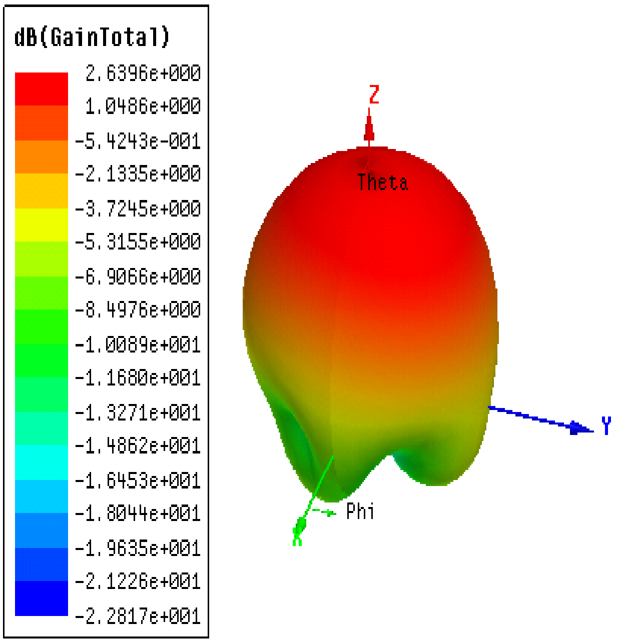

Fig 17 First iteration Gain (3D Polar plot)

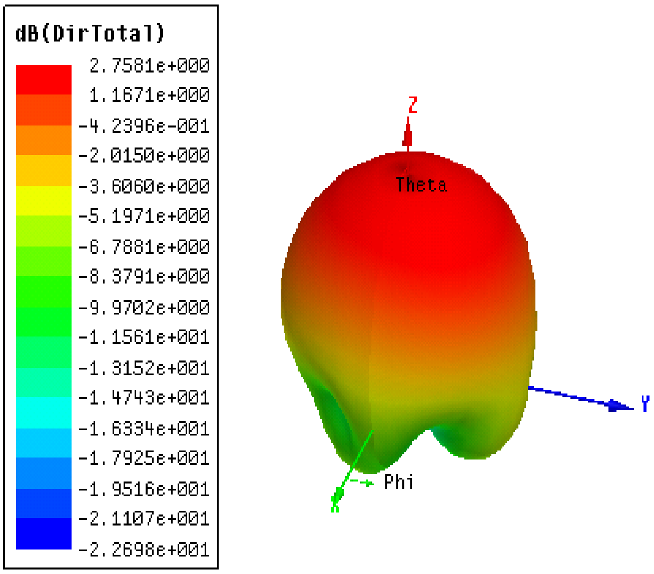

Fig 18 First iteration Directivity (3DPolar plot)

Gain=2.6396dB, Directivity=2.7581dB, Efficiency=95.7%

C. Second Iteration:

The patch structure for second iteration is given in (Fig. 19).

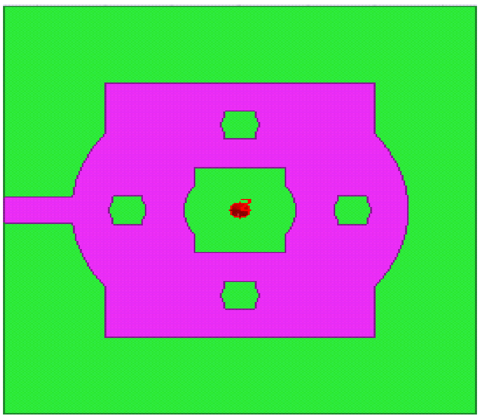

Fig 19 Patch for second iteration

The proposed antenna in second iteration is in (Fig. 20). (Fig. 21) shows the return loss plot for second iteration. VSWR plot is given in (Fig. 22).

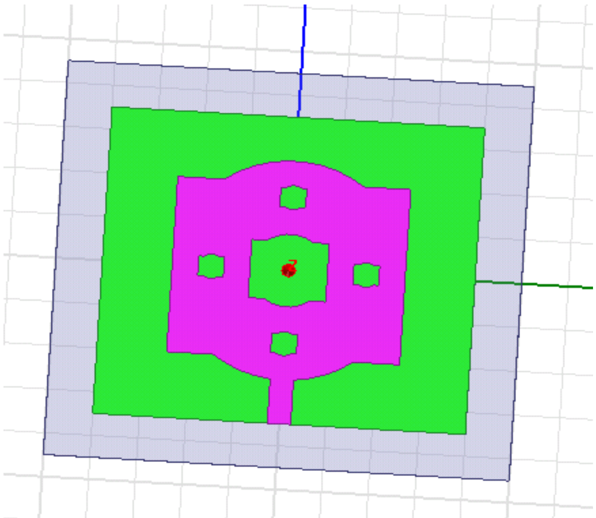

Fig 20 Second Iteration for Modified Sierpinski Carpet

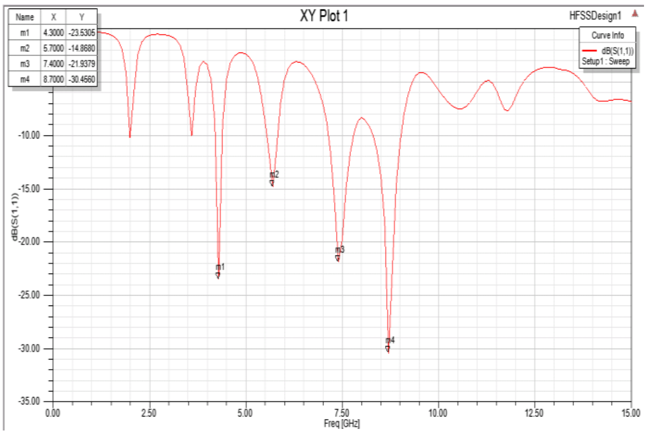

Fig 21 Return loss plot for Second iteration

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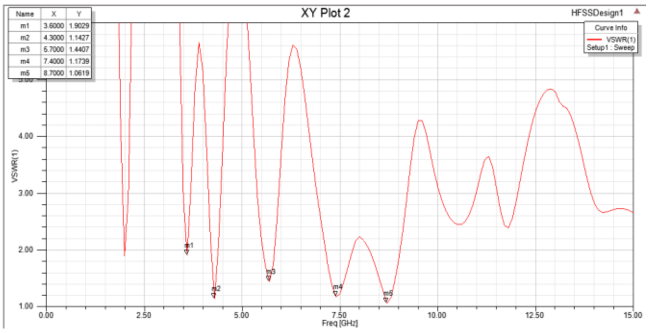

Fig 22 VSWR plot for Second iteration

Efficiency of an antenna is calculated by knowing gain and directivity. The gain and directivity is represented in dB. The gain (dB) in 3D Polar plot is given in (Fig.23). (Fig. 24) gives the directivity (dB) in 3D Polar plot.

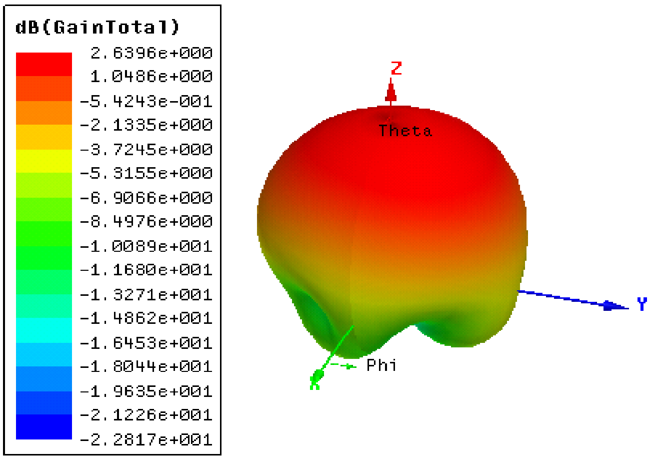

Fig 23 Second iteration Gain(3D Polar plot)

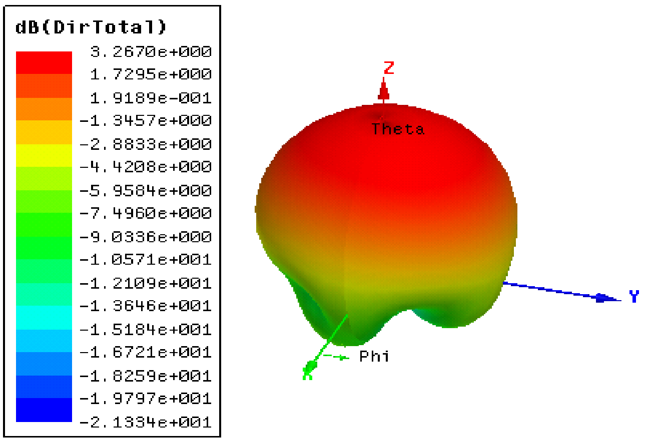

Fig 24 Second iteration Directivity (3D Polar plot)

Gain=3.1920dB, Directivity=3.2670dB, Efficiency=95.9%

D. Third Iteration:

The patch structure for third iteration is given in (Fig. 25).

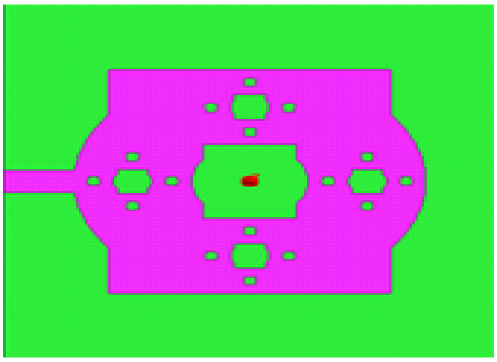

Fig 25 Patch for Third Iteration

The proposed antenna in thir iteration is in (Fig. 26). (Fig. 27) shows the return loss plot for second iteration. VSWR plot is given in (Fig. 28).

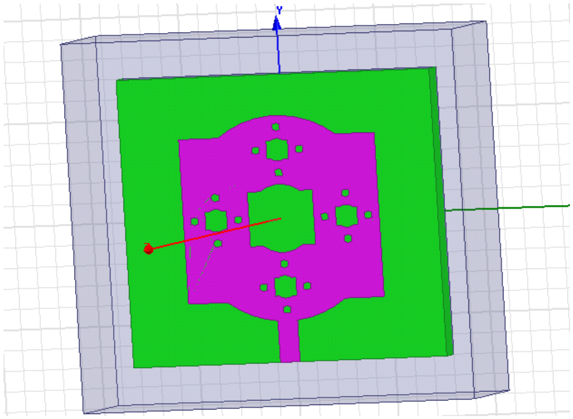

Fig 26 Third iteration for Modified Sierpinski Carpet

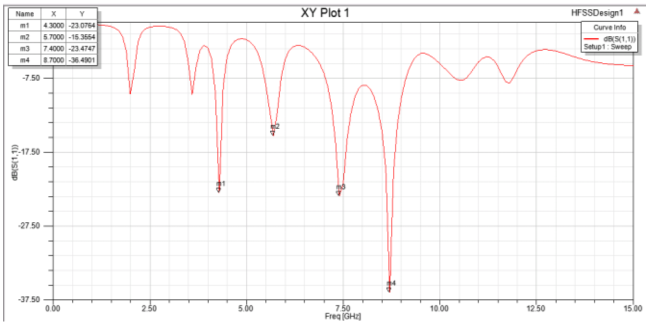

Fig 27 Return loss for Third iteration

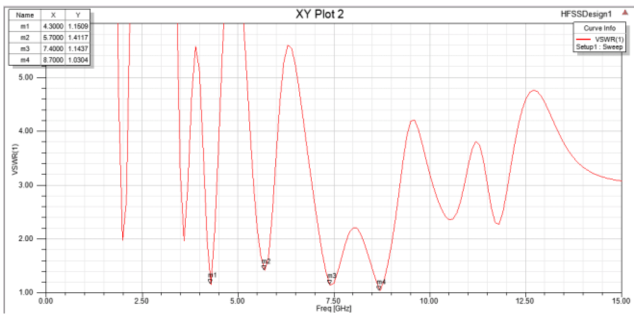

Fig 28 VSWR plot for Third iteration

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Efficiency of an antenna is calculated by knowing gain and directivity. The gain and directivity is represented in dB. The gain (dB) in 3D Polar plot is given in (Fig.29).

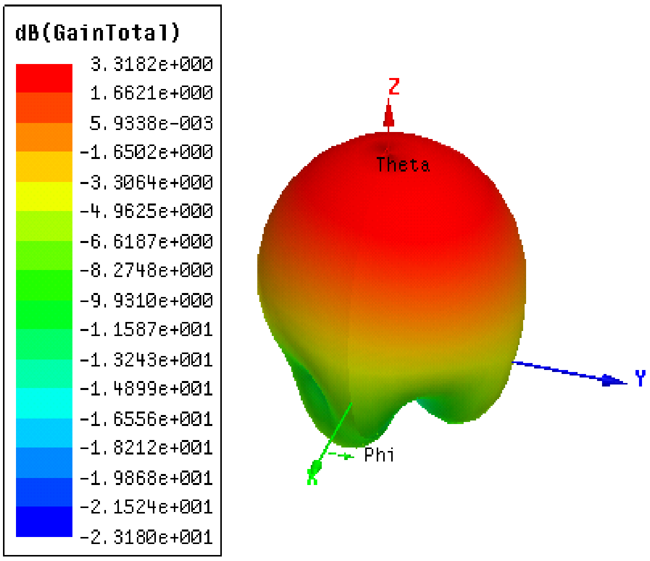

Fig 29 Third iteration Gain(3D Polar plot)

(Fig. 30) gives the directivity (dB) in 3D Polar plot. The plot is given as follows.

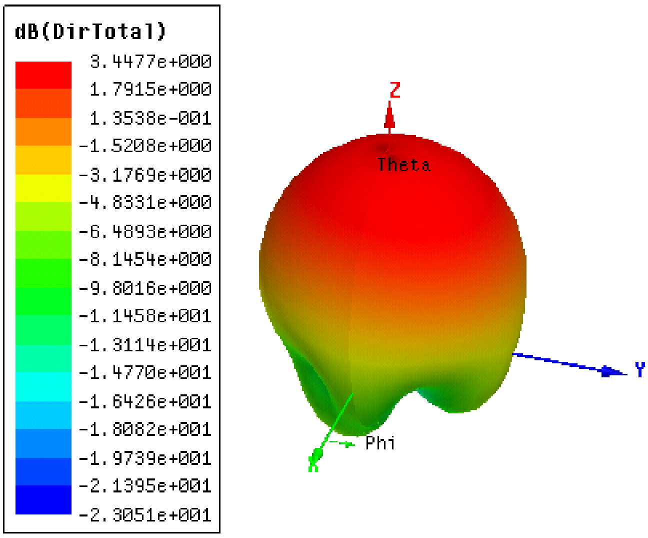

Fig 30 Third Iteration Directivity (3D Polar plot)

Gain=3.3182dB, Directivity=3.4477dB, Efficiency=96.2%

VI. COMPARISON OF ALL FOUR ITERATIONS

This table gives the relationship between return loss, VSWR, gain, directivity, efficiency and bandwidth for all the four iterations of modified Sierpinski Carpet (Table II).

TABLE II. COMPARISON OF PARAMETERS OF FOUR ITERATIONS

Parameter	Zeroth Iteration		First Iteration		Second Iteration		Third Iteration	
Return Loss(dB)	2.1GHz 4.3GHz 5.8GHz 8.7GHz	-14.77 -17.50 -20.00 -27.81	2.0GHz 4.1GHz 8.5GHz	-10.00 -15.23 -19.81	4.3GHz 5.7GHz 7.4GHz 8.7GHz	-23.53 -14.87 -21.94 -30.46	4.3GHz 5.7GHz 7.4GHz 8.7GHz	-23.08 -15.36 -23.47 -36.49
VSWR	2.1GHz 4.3GHz 5.8GHz 8.7GHz	1.44 1.31 1.22 1.08	2.0GHz 4.1GHz 8.5GHz	1.92 1.42 1.23	4.3GHz 5.7GHz 7.4GHz 8.7GHz	1.14 1.44 1.17 1.06	4.3GHz 5.7GHz 7.4GHz 8.7GHz	1.11 1.41 1.14 1.03
Bandwidth (MHz)	2.1GHz 4.3GHz 5.8GHz 8.7GHz	100 200 200 800	4.1GHz 8.5GHz	200 900	4.3GHz 5.7GHz 7.4GHz 8.7GHz	200 400 600 750	4.3GHz 5.7GHz 7.4GHz 8.7GHz	200 400 650 800
Gain(dB)	4.7264		2.6396		3.1320		3.3182	
Directivity (dB)	4.8389		2.7581		3.2670		3.4477	
Efficiency (%)	97.67		95.70		95.87		96.24	

From this table it is clear that we obtain multiple frequency which can be utilized for WiMAX applications.

VII. CONCLUSION

A Modified Sierpinski Carpet Fractal antenna has been proposed, designed, and simulated using Ansys HFSS15 with various iterations from zero to third. In all the four proposed iterations, the resonant frequency and bandwidth is better than Sierpinski Carpet. The return loss in third iteration is -36.49 which is higher than all other iterations. There is a notable improvement in efficiency. The VSWR plot in all four iterations shows that the Voltage Standing Wave Ratio is a desirable value (< 2). Here, we obtained multiple frequencies i.e.2.1GHz, 4.3GHZ, 5.8GHZ and 8.7GHz, whereas in sierpinski carpet only dual frequencies are obtained. This proposed antenna design can be accepted for various wireless applications especially for C and X band applications.

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