Performance Analysis of an Extended Sierpinski Gasket Fractal Antenna for mmwave Femtocells Applications

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Abstract

A performance study on design and analysis of an extended sierpinski gasket fractal antenna for mm-wave femtocell applications were implemented. The initial analysis includes the design of different stages of basic sierpinski gasket fractal antenna and its performance characteristics like reflection coefficient, gain, and efficiency. The size of the basic equilateral triangle patch is around 5.193mm. The antenna is designed on Arlon Di-clad 880 mm substrate materials with the thickness 0.508mm and dielectric constant 2.2. The proposed antenna efficiently operates at frequencies from 24GHz to 61GHz with reflection coefficient values -10dB to -32dB. The simulated gains in dB values at resonant frequencies are from 02 to 16dB with almost 100% radiation efficiency. Later on, this design was extended and analyzed at different levels concerning various performance metrics. The designed extended sierpinski fractal antenna was radiated with the maximum electric field in a particular direction indicating directional antenna at various feed positions. The study shows that an extended Sierpinski fractal antenna had similar performance with three separately feeding positions. The proposed antenna can work with 5G femtocell applications where Femto base stations need miniaturized antennas for indoor communications.

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Key Points:

- Miniaturized antennas for 5G indoor communications are needed so Sierpinski fractal antenna is proposed and designed.
- Design of different stages of basic sierpinski gasket fractal antenna was performed and analyzed its performance characteristics.
- Later on basic sierpinski is extended for proposed antenna and analysis is done at different stages and measured simulated results.

Abstract

A performance study on design and analysis of an extended sierpinski gasket fractal antenna for mm-wave femtocell applications were implemented. The initial analysis includes the design of different stages of basic sierpinski gasket fractal antenna and its performance characteristics like reflection coefficient, gain, and efficiency. The size of the basic equilateral triangle patch is around 5.193mm.The antenna is designed on Arlon Di-clad 880 mm substrate materials with the thickness 0.508mm and dielectric constant 2.2. The proposed antenna efficiently operates at frequencies from 24GHz to 61GHz with reflection coefficient values -10dB to -32dB. The simulated gains in dB values at resonant frequencies are from 02 to 16dB with almost 100% radiation efficiency. Later on, this design was extended and analyzed at different levels with respect to various performance metrics. The designed extended sierpinski fractal antenna was radiated with the maximum electric field in a particular direction indicating directional antenna at various feed positions. The study shows that an extended sierpinski fractal antenna had similar performance with three separately feeding positions. The proposed antenna can work with 5G femtocell applications where femto base stations are in need of miniaturized antennas for indoor communications.

1 Introduction

Femtocells would be an essential component of 5G networks, because of its increased network capacity and coverage, especially indoors. This is because 5G requirements demand more capacity, maximum coverage which means more number of small cells can be deployed. More spectrums at higher frequencies and large bandwidth with low power shared spectrum can be achieved using miniaturized antennas at femtobase stations. Our wireless future completely depends on high definition applications where mobile data rates expand to multi gigabits per second range and usage of steerable antennas and mm wave spectrum came into existence. Miniaturized antennas play a major role in the implementation of femtobase stations, which leads to the design of mm-wave antennas. Performance of the femtocells depends on the efficient working of the antenna (Chandrasekhar et al., 2008), for which micro strip patch antennas are very reliable with good return loss and considerably high gain at 5G resonating frequencies. In the recent days, millimeter wave communications are attracted by industries and telecom operators because of their multiple features like high speed internet browsing and gigabit transmission rate (Rappaport et al.,2013). 5G networks are rapidly developing in extensive research and also with various field trials expected to deployed by the end 0f 2019. The maximum standardization of protocols and frequency band will also be done by 2020 (Abu-Rgheff et al.2019,). In 2019, TRAI (Telecom Regulatory Authority India) planned for 5G services. To realize the need for 5G, sufficient spectrums are made for auction in appropriate regularity bands. In addition to this, Asia-Pacific (APT) conference preparatory team, World broadcast Conference-2019 (WRC-19) made suitable studies on the corresponding frequencies of 24.25 to 27.5GHz, 31.8 to 33.4GHz and 37 to 40.5GHz bands for mm-wave communications (TRAI,2019) and (Harini et al.,2019*)* as shown in Fig.1.

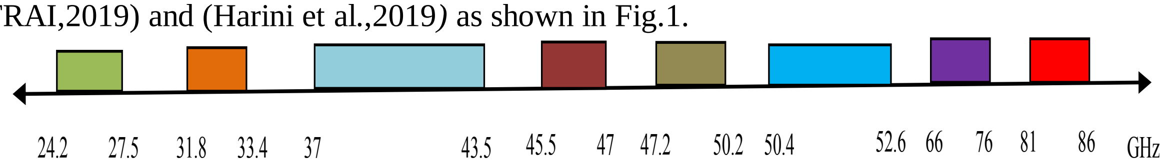


Fig.1. Millimeter wave frequency bands for 5G Communications

The return loss found at 38 GHz is -24.35 dB. The bandwidth corresponding to 10dB return loss at the center frequency is 1.021 GHz with gain of 1.26dB which is considerably low (Şeker et al., 2018). Analysis of microstrip patch array antenna at 28GHz has attained S_{11} (dB) as -15.35dB with gain of 6.92dB for single element antenna but it has followed a regular rectangular patch design (Imran et al.,2018). For Future 5G communications, the microstrip patch antenna is presented with resonating frequencies 38GHz and 54GHz and having bandwidth 1.94GHz and 2GHz respectively with a gain of 6.9dB and 7.4dB (Mashade et al.,2018). A dual-band single feed antenna operating at 28 GHz and 38 GHz is presented and attained gain of 2.7dB and 6dB with a corresponding return loss of -20dB and -15dB(Muhammad et al.,2019). Design of bow-tie printed antenna based on concepts of dipole using Method of Moments (MoM) simulations where the bandwidth is controlled by different flare angles and its self-similarity were controlled by the multiband feature without any modification on the radiation pattern(Kaur et al.,2011). Based on the change in location of the feeding points without using particular RF switches, the antennas have beam steering capability (Kang & Jung et al., 2015). A Right-angled Isosceles Triangular Microstrip Antenna is used as the basic structure of Sierpinski gasket fractal antenna with FR4 Substrate material having thickness 1.59mm, relative permittivity εr=4.4 and dielectric loss tangent of 0.025 which shows good bandwidth considerable gain and VSWR in wireless applications (Gupta et al.,2017). Based on above literature an extended sierpinski gasket antenna design is proposed and the design considerations are discussed in Section II. Section III presents the results and discussions of basic sierpinski gasket fractal antenna and an extended sierpinski fractal antenna at various stages considering diversified feed positions. Eventually the paper is concluded in Section IV.

2 Antenna Design

The terminal figure fractal, which implies divulged or asymmetrical fragments, comprised originally distinguishes a kind of composite figures that have a congenital self-similarity or self-affinity inwards their geometrical construction. The sierpinski gasket fractal is rendered by accomplishing these repetitive cognitive processes and thus sierpinski gasket is a exemplar from an self-similar fractal. From the antenna technology viewpoint, an important rendition comprises that the shaded triangular areas represent a copper conductor, whereas the white triangles interpret areas devoid of metals (Werner et al.,2017).The contemporaries of this geometry are explicated using Fig.2. Although the geometry acquainted hither dwells of equiangular triangle, the verbal description here agrees effective because of immoderate triangular geometry. One can explicate the genesis in two ways: Firstly, the multiple copy approach, or the decomposition approach. In the decomposition approach, one begins with an enceinte triangle comprehending the entire geometry. The centers from the sides are linked, and a cavernous space in the midst is acquired. This cognitive process disunites the master copy triangle to ternary armored down (half sorted) translations of the bigger triangle. The equivalent partitioning procedure can be constituted from each one of the replicates. After n such partitions, the geometry demonstrated in the figure was obtained. These involve scaling, rotation and translation. These translations can be extracted in the numerical chassis as:

$$K\begin{pmatrix} x \\ y \end{pmatrix} = \begin{bmatrix} r1\cos\theta & -s1\cos\phi \\ r1\sin\theta & s1\sin\phi \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}$$

In the above equation, r and s are scale factors, θ and φ correspond to rotation angles and x_0 and y_0 are translations involved in the transformation. If r and s are both diminutions (r1, s1 <1) or both exaggerations (r1, s1 >1), the transformation is self-affine. If r1 = s1 and θ = φ, the transformation is self-similar.

First the genesis of 'stringently self-similar' Sierpinski gasket is considered. Beginning with an equilateral triangle of unit length side the translations implied to acquire the next ingeminated geometry.

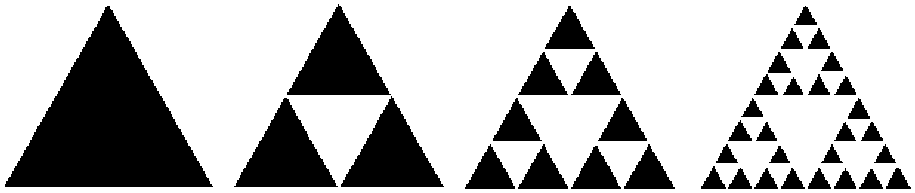


Fig.2. Decomposition approach of sierpinski gasket geometry

In evaluating the fractal dimension, the decomposition approach tool methods find an easier way. The similarity of fractal dimension for this geometry is:

$$\text{Dim} = \frac{\log(N)}{\log(1/f)} = \frac{\log 3}{\log 2} = 1.585$$

This expression make the best of the truth that there are three imitates of a triangle, each reduced to one-half of the size of the master copy, in each stage of fractal iteration. This expression demands the geometry to constitute purely self-similar. However, this is not an essential condition for geometry to be fractal (Vinoy et al., 2002).

The basic sierpinski gasket millimeter (mm) wave antenna patch size is 5.193mm. This triangle will work as stage 1 for sierpinski gasket fractal antenna. The antenna is designed on Arlon Di clad 880 substrate material with ε_r = 2.2 and a dielectric loss tangent of 0.0009. The thickness of the substrate h=0.508mm (Diclad series datasheet, 1998). The size of substrate is 6.5mm x 6mm and is extended for proposed sierpinski gasket fractal antenna with substrate size as13mmx12mm. A ground plane of width 6mm and length 6.5mm is considered at the bottom side and with the size of 13mmx12mm for the proposed fractal antenna. A coaxial feed is considered with outer diameter 1.85mm and inner diameter 0.3mm. To achieve this 1.85mm coaxial connector are used (1.85mm connector data sheet, 2016).

The fundamental design procedure of an equilateral triangular antenna is described as follows

The expression for lowest order resonance frequency

$$f_r = \frac{2c}{3a\sqrt{\varepsilon_r}} \quad (1)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{4}\left[1 + \frac{12h}{a}\right]^{-\frac{1}{2}} \quad (2)$$

$$a_{eff} = a + \frac{h}{\sqrt{\varepsilon_r}} \quad (3)$$

$$f_r = \frac{2c}{3a_{eff}\sqrt{\varepsilon_{reff}}} \quad (4)$$

where ε_{reff} is the effective permittivity, as is the triangle side, h is the height of substrate, c is the velocity of light and f_r is the effective resonant frequency.

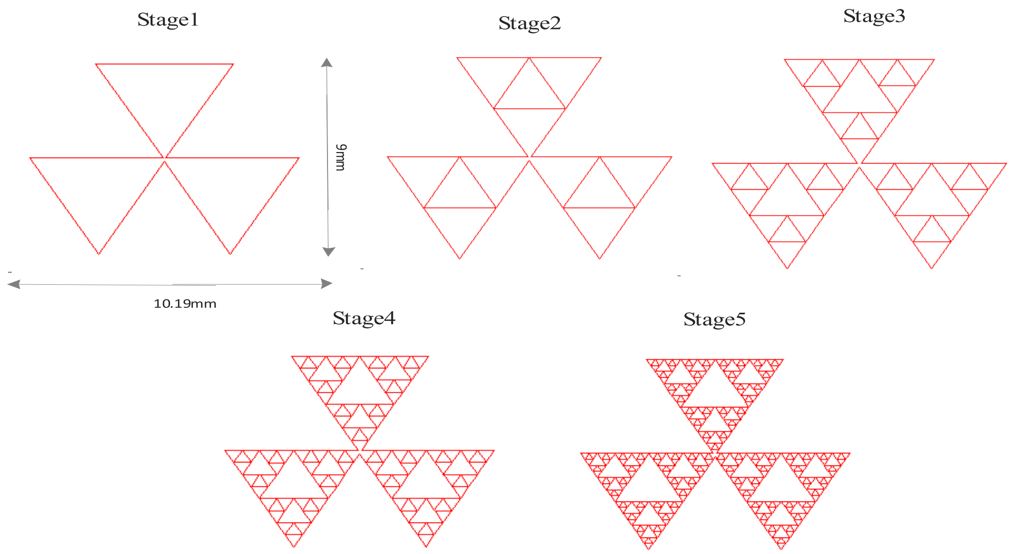


Fig.3.Various stages of extended sierpinski gasket mmwave fractal antenna

In the above equations from eq.1 to eq.4, ε_r is considered as 2.2 with the height of substrate h=0.508mm and resonating frequency 28GHz is considered for construction of triangular patch. The basic triangle construction is done by considering a rectangle with length 5.193mm and length 4.498mm with a right angle triangular polygon portion is cut at the bottom two edges of the rectangle. The sierpinski gasket antenna is generated through five iterations using the subtraction. Firstly, draw an equilateral triangle i.e., Stage1 (0th iteration). Secondly, generate an inner triangle by connecting the midpoints of the three sides of a triangle. Thirdly, subtract the inner triangle from the equilateral triangle. Then, the Stage1 structure is obtained. By repeating the same process with each of the remaining smaller triangles Stage2 to Stage5 structures are obtained. This proposed antenna is constructed for three times and joined together as shown in Fig.3.This internally includes the fractal geometry. With this shape, multiband frequencies can be obtained at various stages of fractal antenna. Whenever a combination of antennas is there, the position of the feed plays an important role. Analysis is performed on every position of feed and presented in the following Section III.

3 Results and Discussions

Designing fractal antennas includes the size of the seed antenna i.e., the stage1 and the number of bands, feed of the antenna. In this section, initial analysis is performed on basic sierpinski gasket fractal antenna by considering 5 stages. In all these cases, the position of feed of the antenna is fixed at (1.6, 3.8, 0) as shown in Fig.4. This position rests on the parametric analysis performed.

3.1 Basic Sierpinski fractal antenna

The basic sierpinski fractal geometry is demonstrated and results are discussed stage wise. All the simulations were performed on commercially available Ansoft HFSS version 16 tool. This HFSS is popular and high performance electric field simulator based on finite element method (FEM) for solving any 3D geometry usually at high frequency ranges.

3.1.1 STAGE 1

The return loss observed for Stage1 is -23.32dB at 24.21GHz with considerable gain of 4.55dB and high efficiency of 108.43% as shown in Fig.5 and Fig.6. Eventhough the antenna was designed for 28GHz, it was resonating at 24.21GHz due to type of the feed chosen. Here the coaxial feed was chosen and the position is finalized by optimization process by performing parametric analysis. The feed position is optimized to this location (1.6, 3.8, 0) expecting better resonating frequecies with good impedance matching at further stages. The Elevation and Azimuth cuts decribes the radiation pattern for a directional antenna since the maximum power is radiated only in one direction with maximum impedance bandwidth of 1.4GHz.

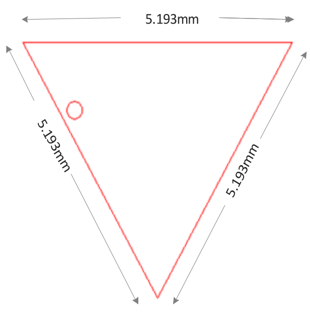


Fig. 4. Equilateral triangle shaped mmwave antenna for STAGE1

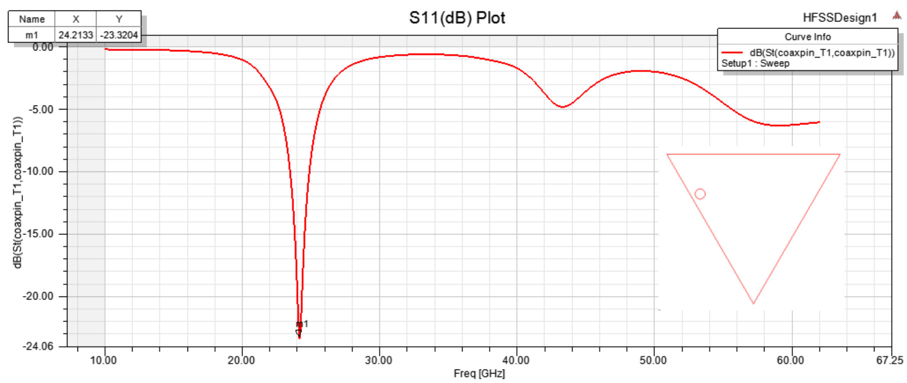


Fig.5. Reflection Coefficient of equilateral traingle shaped mmwave antenna for STAGE1

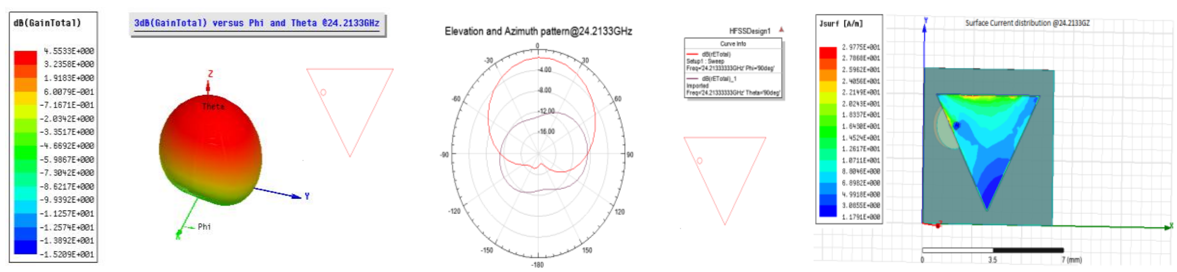
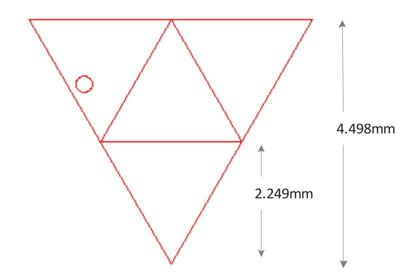


Fig. 6. (a)3dB Polar Plot @24.21GHz (b) Elevation and Azimuth Pattern @24.21GHz (c)Surface Current Distribution @24.21GHz

3.1.2 STAGE 2



In the second stage, exactly half the size of the triangle dimensions are considered by joining the mid points of the triangle and removed from the patch as shown in Fig.7. This is named as 1st iteration of Sierpinski gasket fractal antenna which defines the growth of the fractal antenna. To each and every growth a new resonant frequency band has to be obtained compared to the previous stages.

Fig.7. 1st Iteration of Sierpinski gasket fractal shaped mmwave antenna for STAGE2

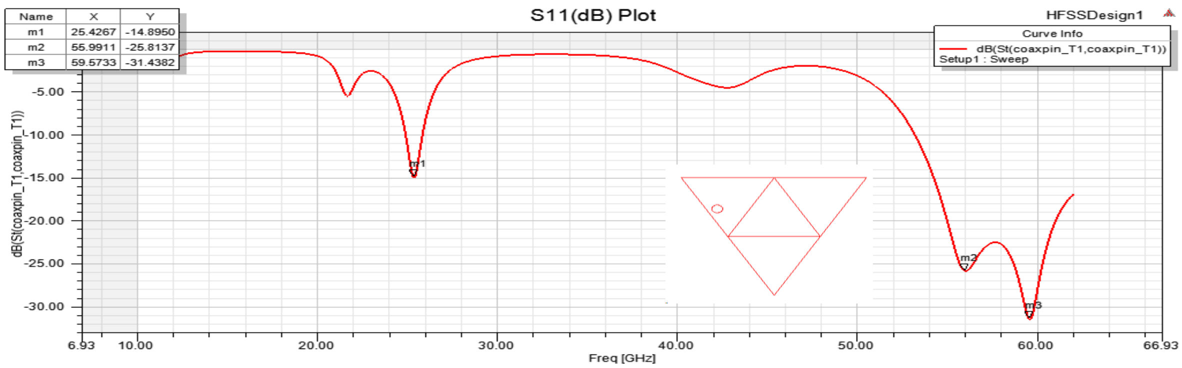


Fig.8. Reflection Coefficient of Sierpinski gasket fractal mmwave antenna for STAGE2

The reflection coefficient is calculated at three resonating frequencies like 25.42GHz, 55.9GHz and 59.57GHz with S_{11}(dB) values as -14.89dB,-25.81dB,-31.43dB with impedance bandwidths were 0.9GHz and 9.47GHz as shown in Fig.8.

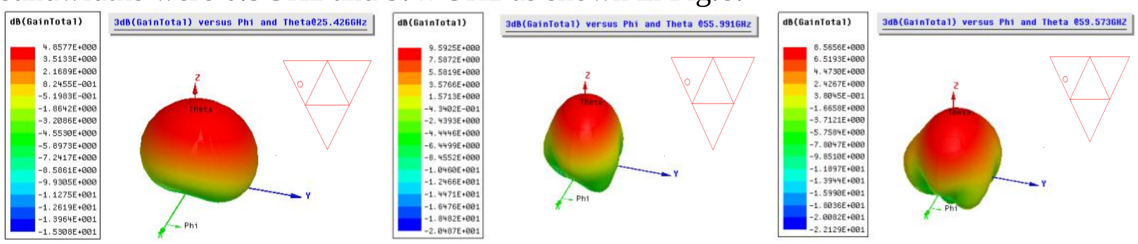


Fig.9. 3D Polar plots of Sierpinski gasket fractal mmwave antenna at various frequencies for STAGE2

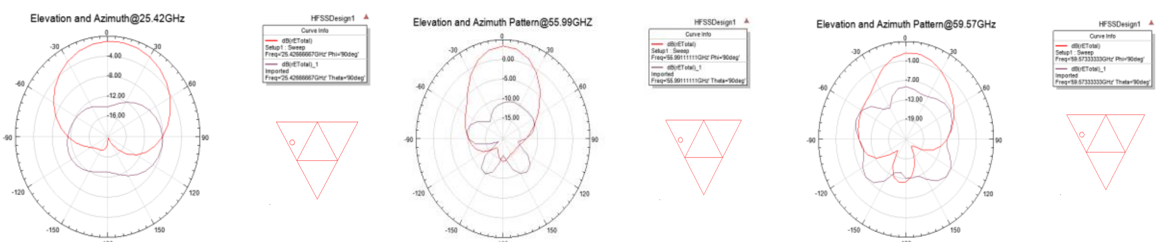


Fig.10. Elevation and Azimuth Pattern of Sierpinski gasket fractal mmwave antenna at various frequencies for STAGE2

The 3D gain plots at three frequencies indicate gains are increasing as the frequencies increases along with reflection coefficient values and these are summarized in Table.I. Elevation and Azimuth planes indicate the radiation is maximum only at one direction in the first two frequency bands and omnidirectional pattern at the third frequency band i.e., at 59.57GHz as shown in Fig.9. and Fig.10.

3.1.3 STAGE 3

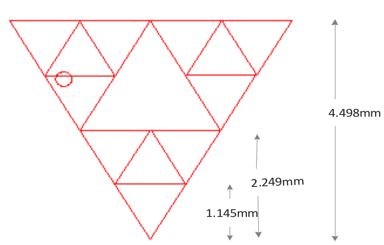


Fig.11.2nd Iteration of Sierpinski gasket fractal shaped mmwave antenna for STAGE3

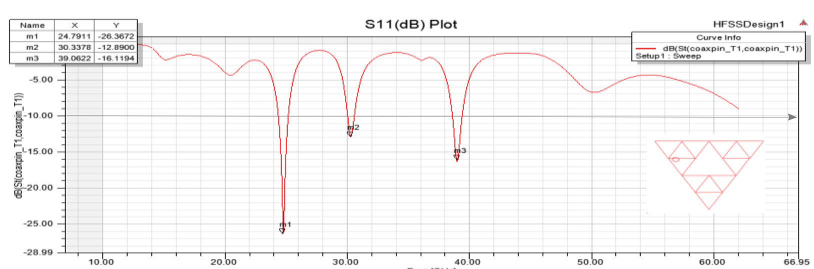


Fig.12. Reflection Coefficient of Sierpinski gasket fractal stage3

In the third stage, one-fourth size of the triangle is considered and removed from the triangle patch as shown in Fig.11.In this also antenna resonates at three different frequencies from 20 to 40 GHz whereas in previous stage antenna resonated at only one frequency band from 20 to 40GHz. The return loss is less when compared to the last stage as shown in Fig.12.

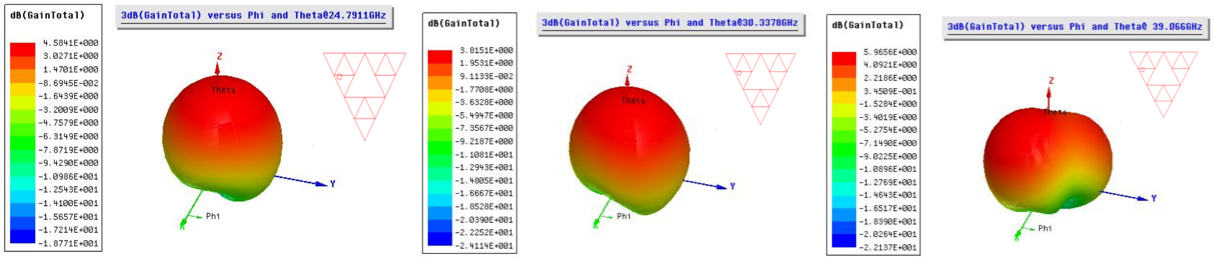


Fig. 13. 3D Polar plots of Sierpinski gasket fractal mmwave antenna at various frequencies for STAGE 3

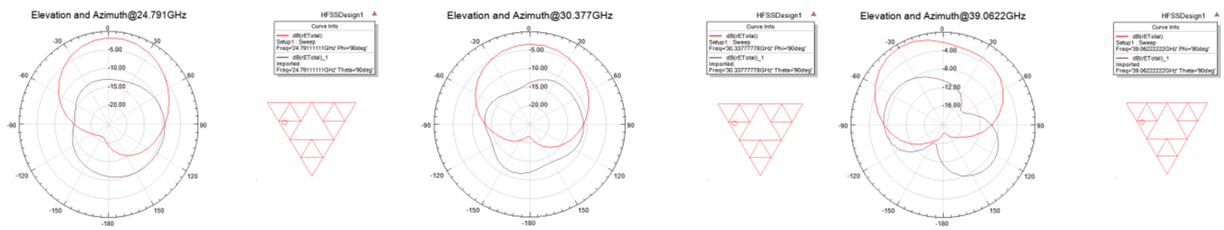
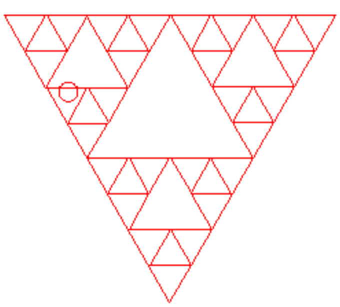


Fig.14. Elevation and Azimuth Pattern of Sierpinski gasket fractal mmwave antenna at various frequencies for STAGE 3

The 3D gain plots are shown in Fig.13. which indicates the gains are considerably high i.e., more than 2dB in all the cases and mostly followed directionality property where the maximum electric field is radiated in a single direction from all the radiation patterns, at all the three frequencies as shown in Fig.14.

3.1.4 STAGE 4



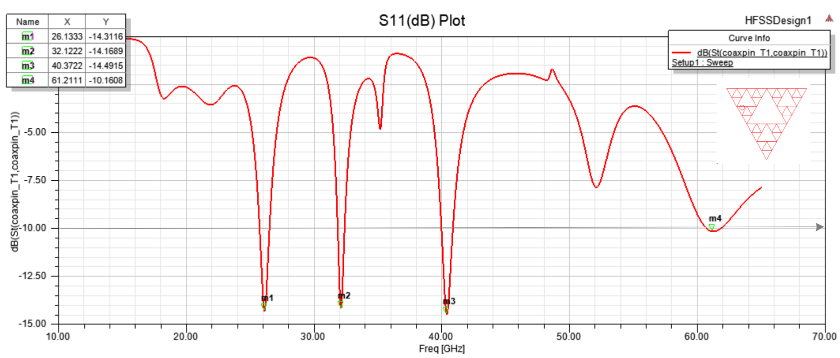


Fig.15. 3rd Iteration of Sierpinski gasket fractal shaped mmwave antenna for STAGE4

Fig.16. Reflection Coefficient of equilateral traingle shaped mmwave antenna for STAGE4

In Stage 4, the reflection coefficient is maintained almost constant for the first three frequency bands and it is reduced at 61GHz as shown in Fig.16. The bandwidths observed in the above simulations are 0.73GHz,0.48GHz,0.91GHz and 0.36GHz.

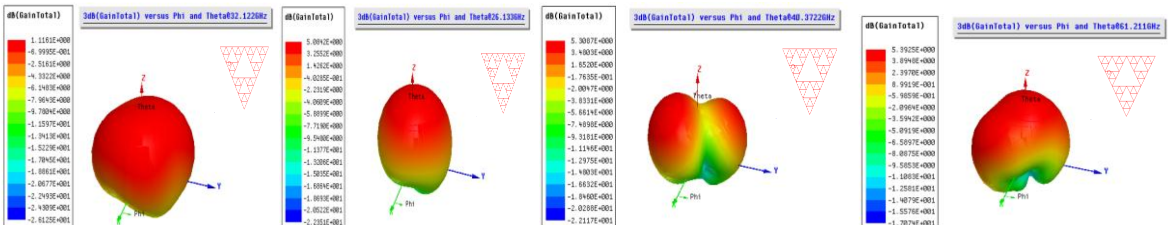


Fig. 17. 3D Polar plots of Sierpinski gasket fractal mmwave antenna at various frequencies for STAGE 4

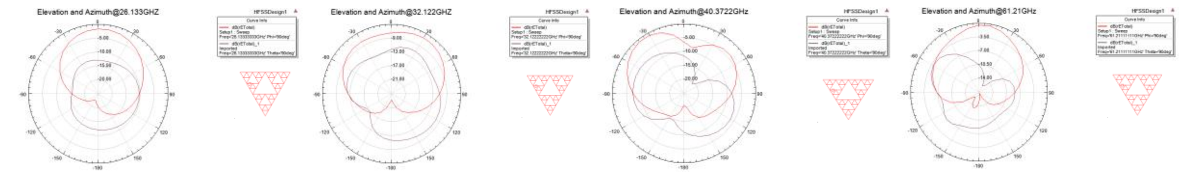
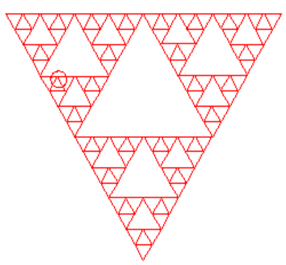


Fig.18.Elevation and Azimuth Pattern of Sierpinski gasket fractal mmwave antenna at various frequencies for STAGE 4

From the 3D gain plots, all the frequency bands are crossing the threshold value of 2dB but at 32GHz the gain attained was 1.11dB. So that particular frequency band is not considered for our application. From the elevation and azimuth patterns at two frequencies, the antenna is behaving is like a directional antenna and at other frequency bands like 40.3GHz and 61.2GHz, the antenna was acting like an omnidirectional antenna as shown in Fig.17 and Fig.18.

3.1.5 STAGE5



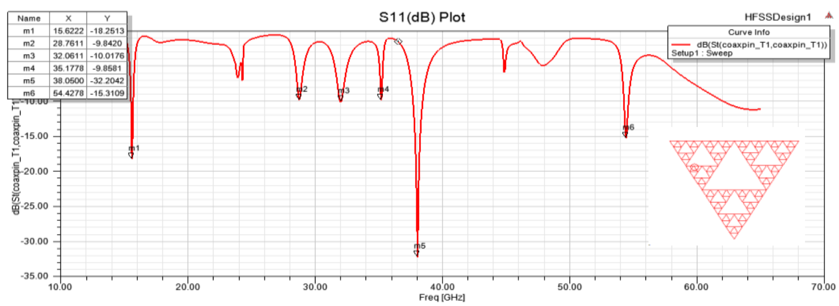


Fig.19.4th Iteration of Sierpinski gasket fractal shaped mmwave antenna for STAGE 5

Fig.20. Reflection Coefficient of equilateral traingle shaped mmwave antenna for STAGE 5

From the fifth stage onwards, the antenna is losing the property of resonating of multiband frequencies since the copper content in the antenna patch is almost reduced where the radiation of antenna becomes tough. Since the microstrip patch antenna works only with patch content made up of copper. As copper content is reducing, the radiation also reduces that is observed from the reflection coefficient plot. The negative value of the reflection coefficient deals with the return loss. The return loss is very low at the border concerning a threshold value of -10dB for the first three frequencies and is better for the next two frequency bands as shown in Fig.19 and Fig.20. Based on the literature that exists for dual-band this proposed antenna can also work as a dual-band antenna with this feeding position (Darimireddy, Rahayu, Puente et al., 1996,2018).

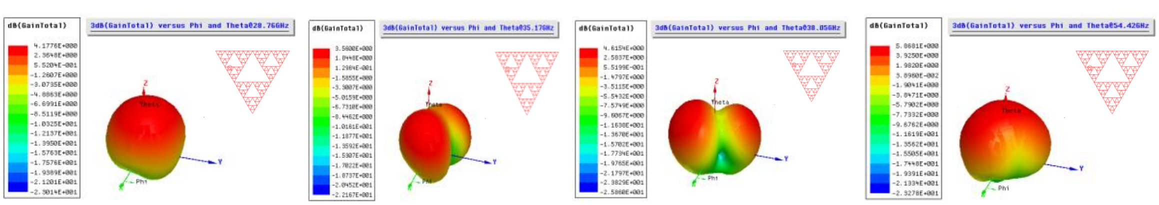


Fig. 21. 3D Polar plots of Sierpinski gasket fractal mmwave antenna at various frequencies for STAGE 5

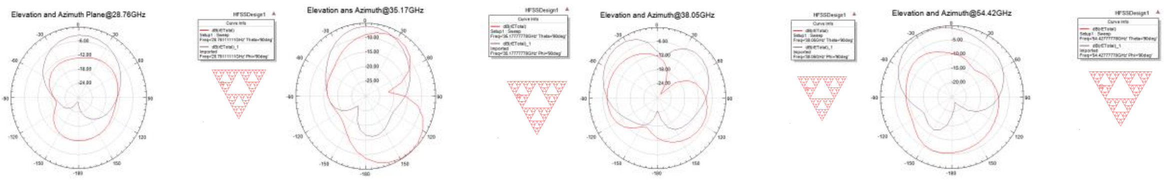


Fig.22. Elevation and Azimuth Pattern of Sierpinski gasket fractal mmwave antenna at various frequencies for STAGE 5

The 3D gain plots are shown in Fig.21. which indicates the gains are in the range of 3.5dB to 6dB in all the cases and mostly followed directionality property i.e, only in a single direction where the maximum electric field is radiated from all the radiation patterns at all the frequencies as shown in Fig.22.

A detailed analysis of the reflection coefficient(S11 in dB), Gain in dB and radiation efficiency at various frequencies for all stages are tabulated in Table I.

Table I Simulated Parameters of various stages of basic sierpinski gasket fractal antenna

		STAGE 1			
S. No	***Frequency (GHz)***	***S_{11}(dB)***	***Gain(dB)***	***Imp BW(GHz)***	***Efficiency (%)***
1.	24.21	-23.32	4.55	1.4	108.4
		STAGE 2			
S. No	***Frequency (GHz)***	***S_{11}(dB)***	***Gain(dB)***	***Imp BW(GHz)***	***Efficiency (%)***
1.	25.42	-14.89	4.85	0.91	104.96
2.	55.99	-25.81	9.59	9.47	110.37
3.	59.57	-31.43	8.56	9.47	108.95
		STAGE 3			
S. No	***Frequency (GHz)***	***S_{11}(dB)***	***Gain(dB)***	***Imp BW(GHz)***	***Efficiency (%)***
1.	24.79	-26.36	4.58	0.79	97.83
2.	30.33	-12.89	3.81	0.55	96.73
3.	39.06	-16.11	5.96	0.85	100.29
		STAGE 4			
S. No	***Frequency (GHz)***	***S_{11}(dB)***	***Gain(dB)***	***Imp BW(GHz)***	***Efficiency (%)***
1.	26.13	-14.31	5.08	0.73	95.82
2.	32.12	-14.16	1.11	0.48	95.67
3.	40.37	-14.49	5.30	0.91	99.57
4.	61.21	-10.16	5.39	0.36	92.94
		STAGE 5			
S. No	***Frequency (GHz)***	***S_{11}(dB)***	***Gain(dB)***	***Imp BW(GHz)***	***Efficiency (%)***
1.	28.76	-9.84	4.17	-	91.02
2.	35.17	-9.85	3.58	-	90.49
3.	38.05	-32.2	4.61	0.73	100.03
4.	54.42	-15.3	5.86	0.36	103.43

3.2 An Extended Sierpinski gasket fractal antenna results

As in the literature, a large number of Sierpinski gasket fractal antennas were designed for frequencies of less than 10GHz range. A proposal of an extended Sierpinski gasket fractal antenna was considered by joining three basic triangles which include fractal structures. A parametric analysis was done to choose the position of feed. Three best positions of feeds are considered for three triangles. Considering one by one all three feeds a detailed analysis of results was discussed in the following section. The results of an extended Sierpinski gasket fractal antenna are analyzed stage-wise considering feed position1. For the Stage1, the results are plotted below. The reflection coefficient (S_{11} in dB) plot shows that the antenna is resonating at one frequency i.e., 23.68GHz with S_{11}(dB) value as -11.97dB . It indicates that it is having very little return loss and it also follows a circular polarization as shown in Fig.23.

3.2.1 STAGE1

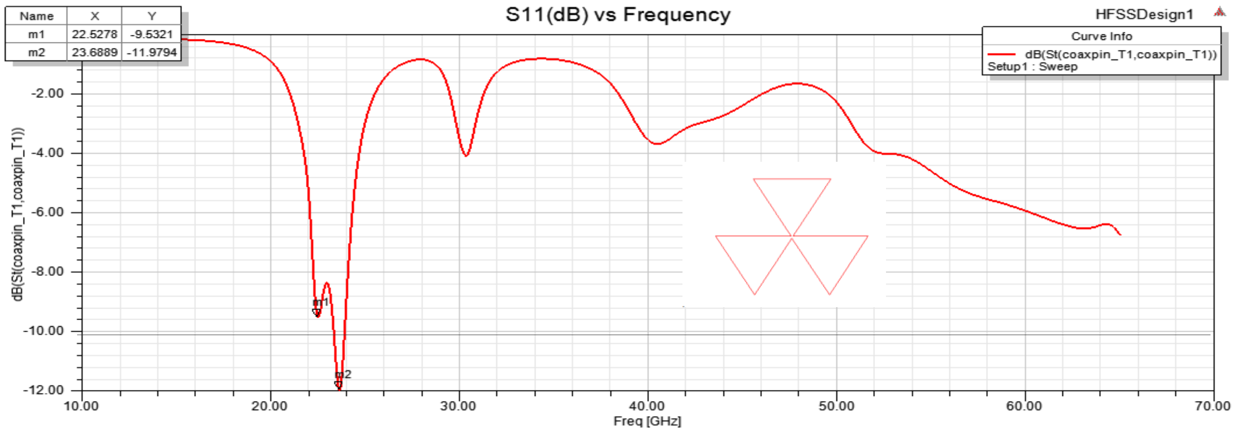


Fig.23. Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE 1

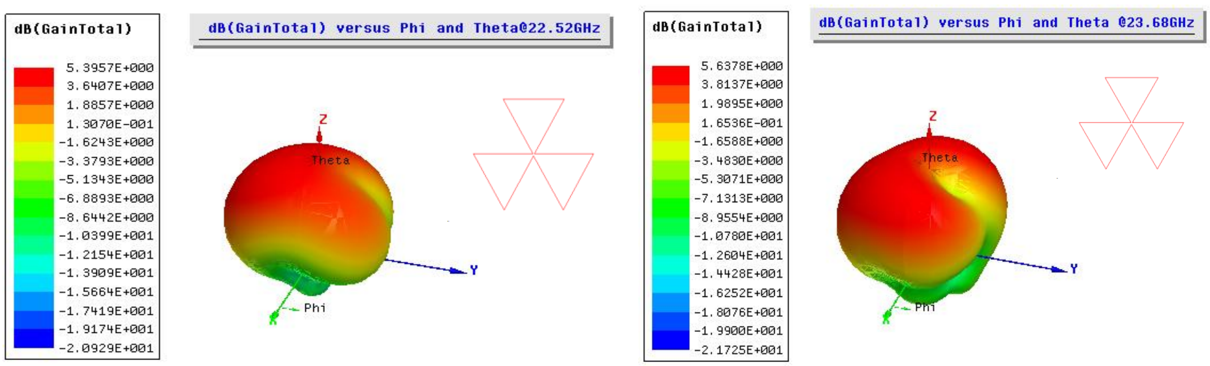


Fig.24.3D Polar plots of Extended Sierpinski gasket mmwave fractal antenna at twofrequencies for STAGE 1

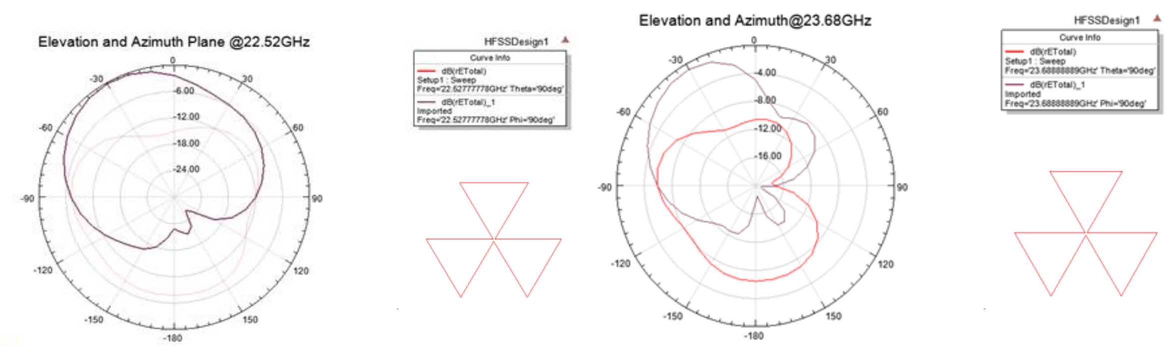


Fig.25.Elevation and Azimuth Pattern of Extended Sierpinski gasket fractal mmwave antenna at two frequencies for STAGE 1

The 3dB gain of the proposed extended Sierpinski gasket mmwave fractal antenna is radiating at two frequencies with considerable gains around 5.39dB and 5.69dB respectively. The horizontal and vertical cuts shown as azimuth and elevation describe that the radiation pattern where the maximum electrical field was radiating in a single direction indicating it as a directional antenna as shown in Fig.24 and Fig.25.

3.2.2 STAGE2

In the second stage, exactly half the size of the triangle dimensions is considered by joining the midpoints of the three individual triangles and removed from the patch as shown in Stage 2 of Fig.2. In this stage, antenna started to radiate at two wide-range frequencies like 22.16GHz with S11(dB) value as -24.42dB and gain of 3.8dB and 59.13GHz with S11(dB) value as -21.90dB with high gain of 11.76dB as shown in Fig.26 and Fig.27.

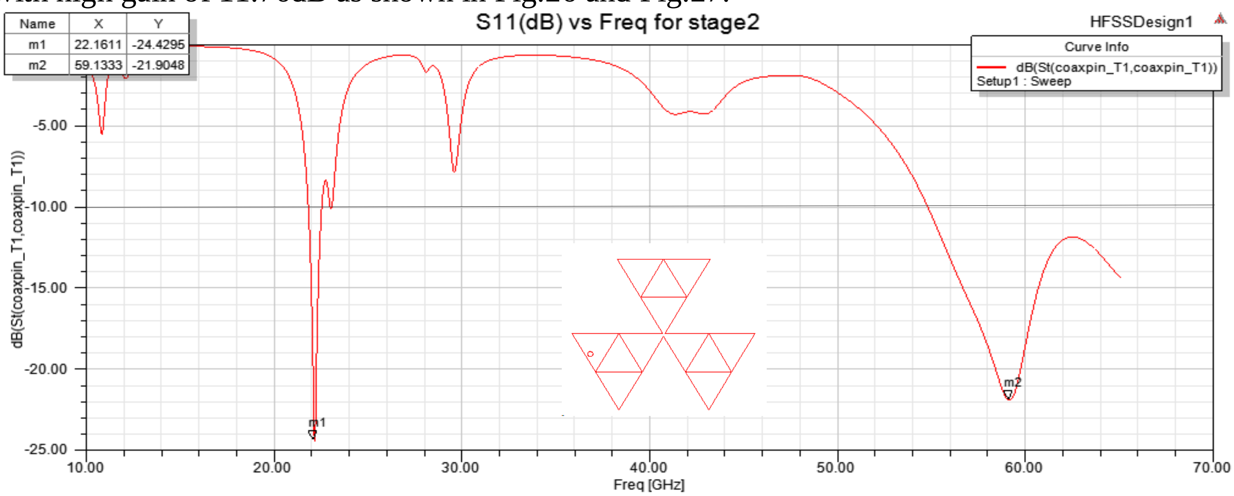


Fig.26. Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE2

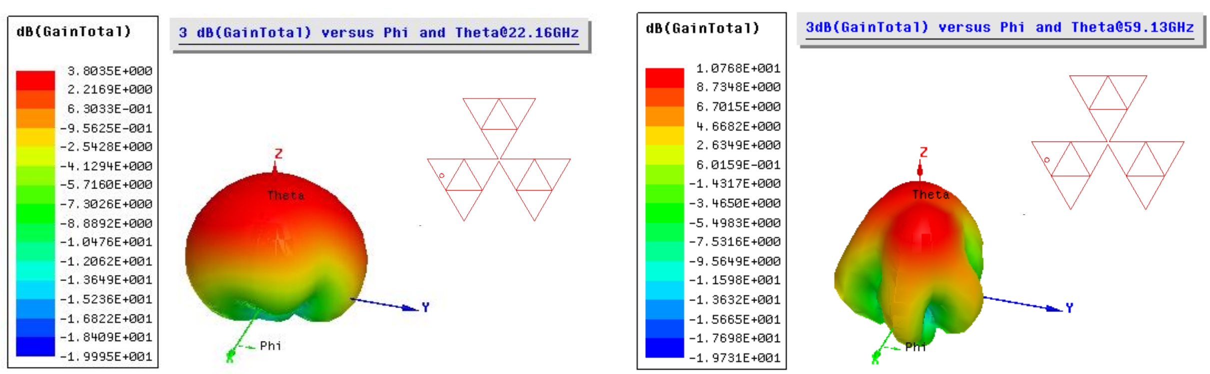


Fig.27. 3D Polar plots of Extended Sierpinski gasket mmwave fractal antenna at twofrequencies for STAGE 2

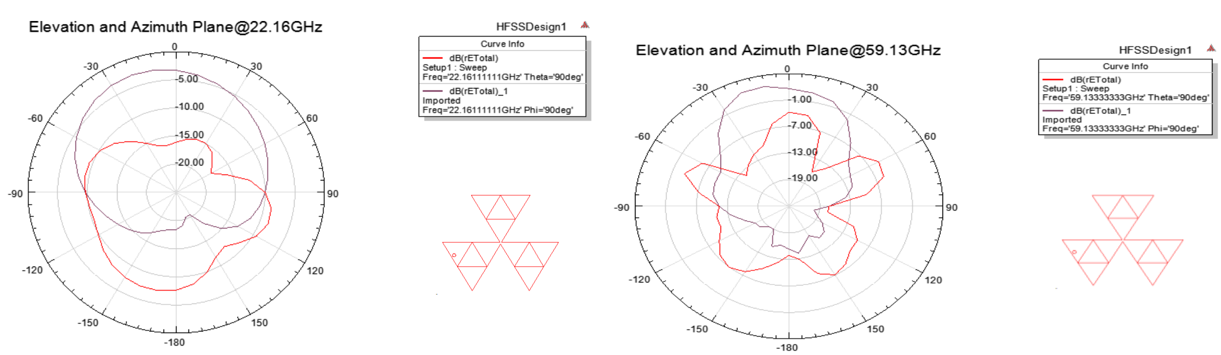


Fig.28. Elevation and Azimuth Pattern of Extended Sierpinski gasket fractal mmwave antenna at two frequencies for STAGE 2

The Elevation and Azimuth plane indicates the maximum electric field is radiated only in one direction narrating as a directional antenna at both the frequencies as shown in Fig.28.

3.2.3 STAGE3

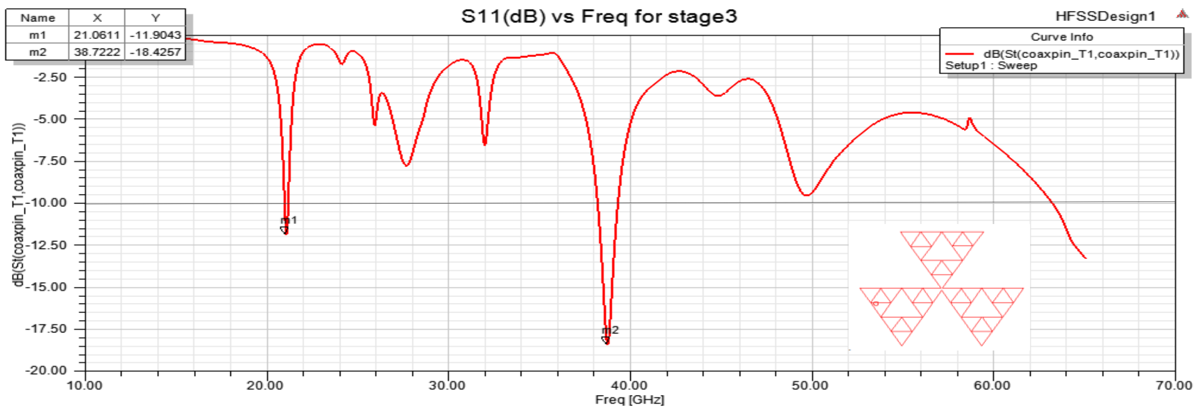


Fig.29. Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE3

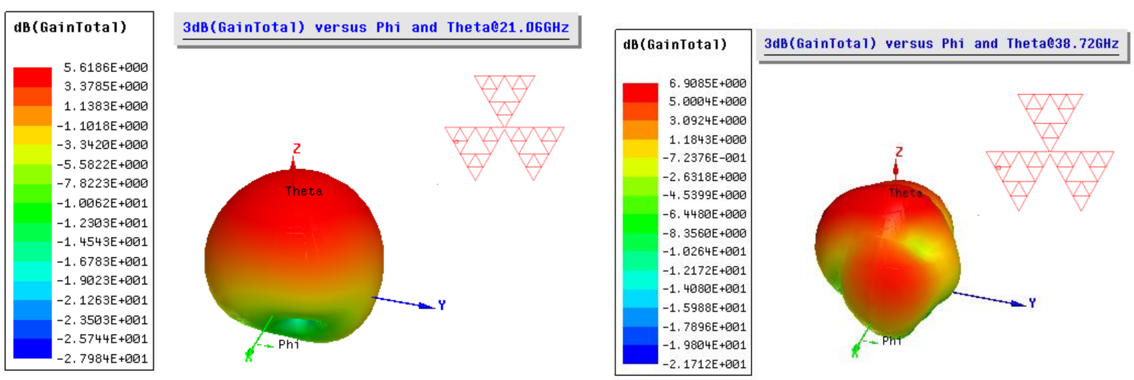


Fig.30.3D Gain plots of Extended Sierpinski gasket mmwave fractal antenna at twofrequencies for STAGE 3

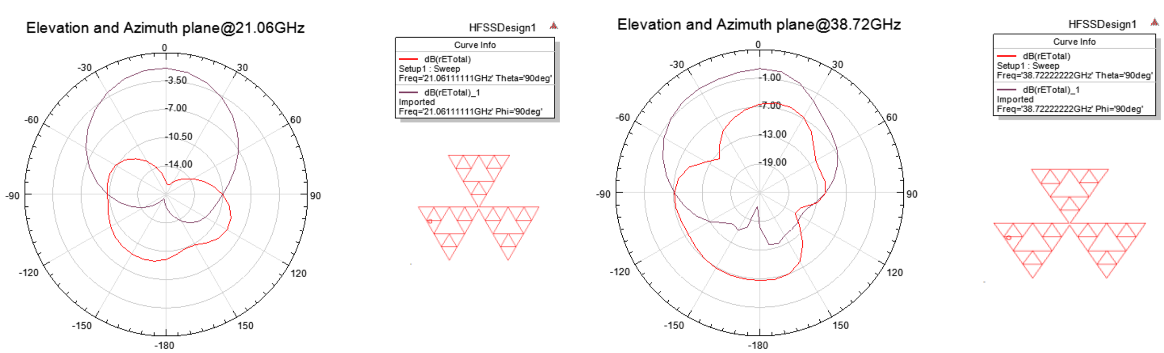


Fig.31.Elevation and Azimuth Pattern of Extended Sierpinski gasket fractal mmwave antenna at two frequencies for STAGE 3

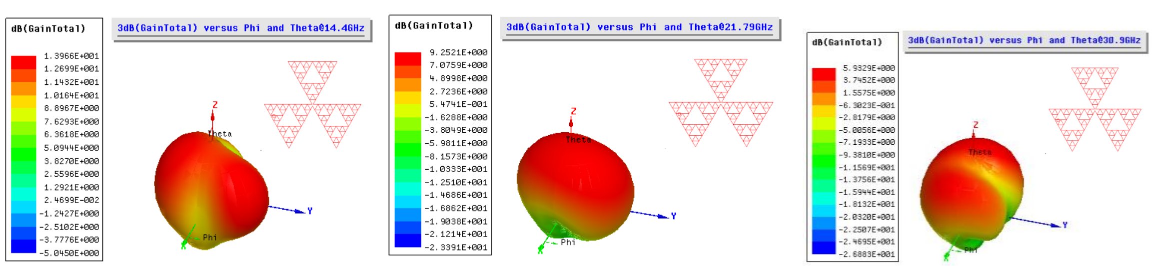
In this stage, even though there seem to be many spikes but all the spikes are not valid wrt reference value of S11(dB) as -10dB. So the valid bands considered here are 21.06GHz and 38.72GHz. There is huge reconfigurability that exists for radiating frequency bands when compared to Stage2. The gain is around 6dB at both frequencies and once again it follows directionality from radiation pattern as shown in Fig.29 to Fig.31.

3.2.4 STAGE4

In this stage, almost six working are bands observed, where the antenna can be used as a multiband antenna. This particular type of antenna stage is even preferred for fabrication. Multiband microstrip patch antenna has many applications where a single antenna can be used for multiple applications like wi-fi, wi-max, femtocell, etc.

Fig.32. Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE4

The reflection coefficient values are very good in comparison to the previous stages indicating less return loss. In this stage antenna started to radiate at six frequencies like 14.4GHz with S_{11}(dB) value as -20.5dB and gain of 13.9dB, 21.79GHz with S_{11}(dB) value as -19.90dB with high gain of 9.25dB, 30.9GHz with S_{11}(dB) value as -18.80dB with high gain of 5.93dB, 39.57GHz with S_{11}(dB) value as -21.60dB with high gain of 7.56dB, 48.07GHz with S_{11}(dB) value as -15.5dB with high gain of 8.35dB and 60.66GHz with S_{11}(dB) value as -11.50dB with high gain of 7.65dB as shown in Fig.32 and Fig.33. It is apparent from the results that the self-similarity property and elaborated electrical length due to fractal iterations allow the antenna wide impedance bandwidth.



In this particular stage, the gain in dB values is evaluated and analyzed such that all the values are ranging from 5.93dB to 13.9dB at various frequencies. The antenna was exhibiting directionality property from azimuth and elevation cuts as shown in Fig.34.

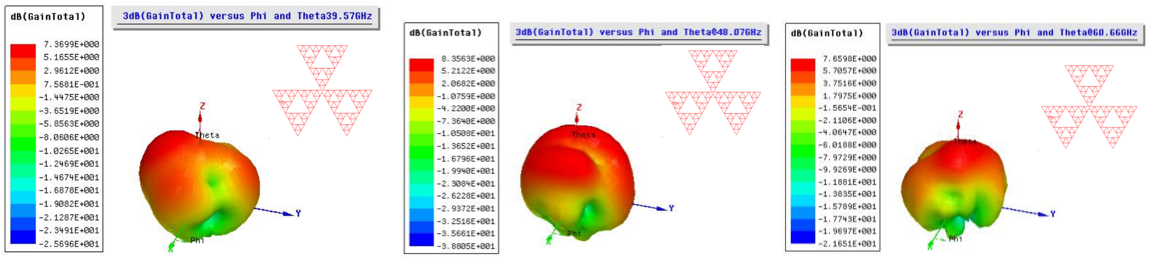


Fig.33.3D Gain plots of Extended Sierpinski gasket mmwave fractal antenna at twofrequencies for STAGE 4

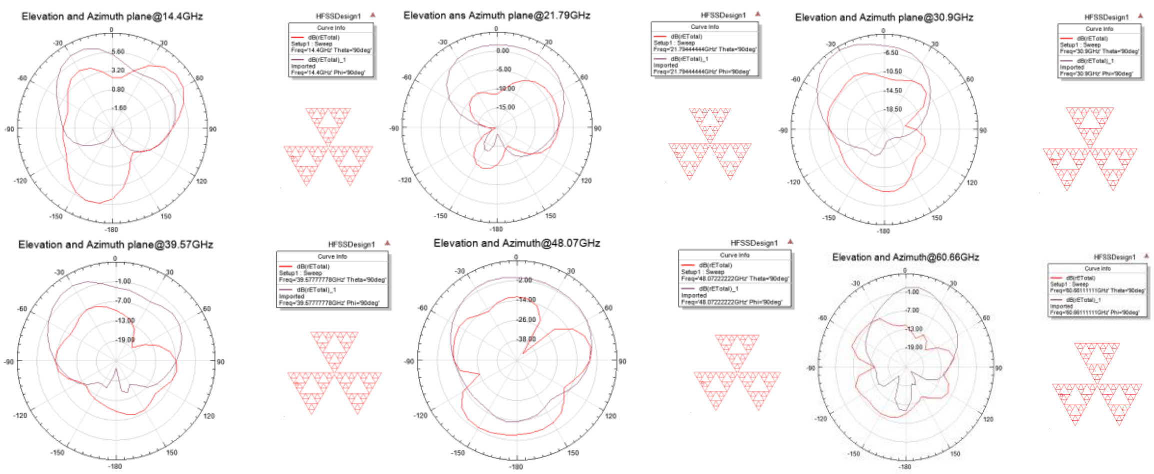


Fig.34. Elevation and Azimuth Pattern of Extended Sierpinski gasket fractal mmwave antenna at two frequencies for STAGE 4

3.2.5 STAGE5

In Stage5, the performance of the antenna is humiliating because the number of frequency bands is reduced and also there is a reduction in gain performance. But if one mm-wave application needs two particular frequencies like 26.5GHz and 38GHz this antenna can be perfectly preferable since it has considerable gain values around 5dB with perfect impedance matching.

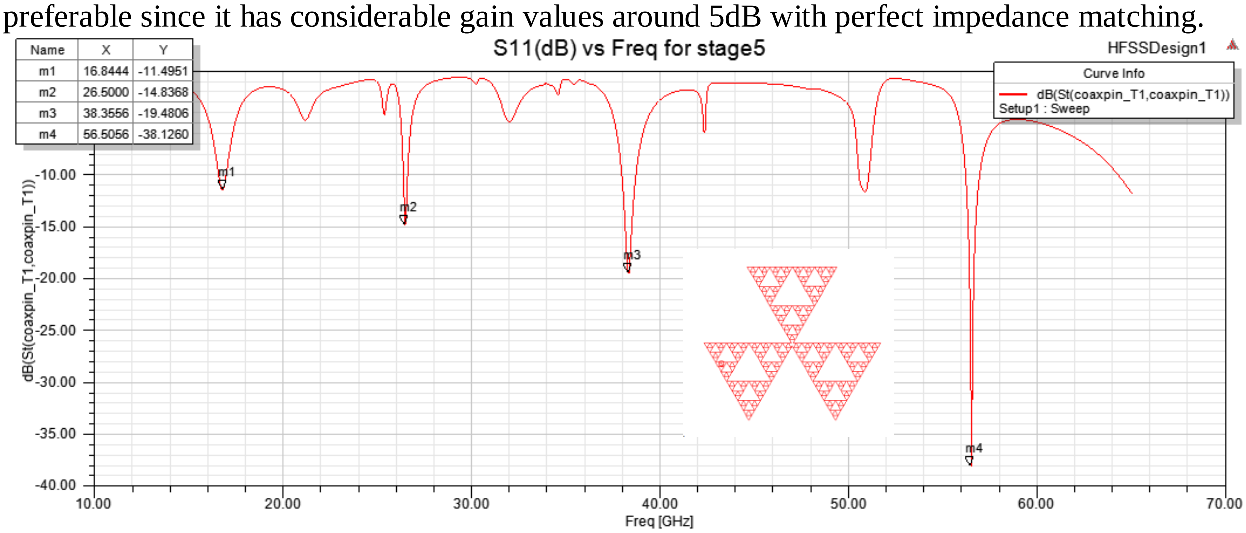


Fig.35. Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE 5

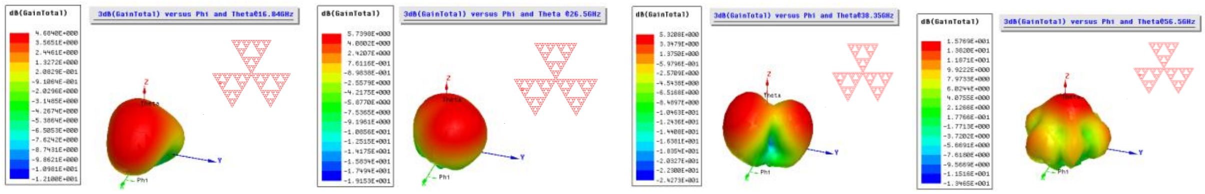


Fig.36. 3D Gain plots of Extended Sierpinski gasket mmwave fractal antenna at twofrequencies for STAGE 5

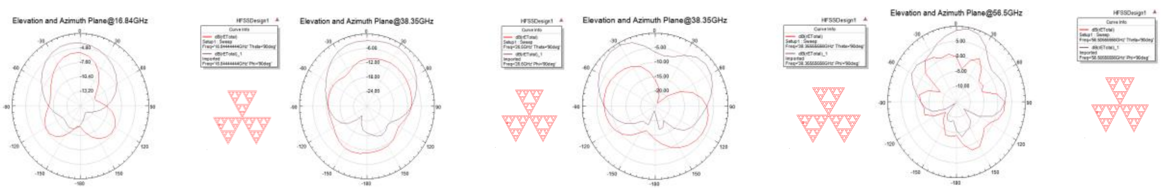


Fig.37. Elevation and Azimuth Pattern of Extended Sierpinski gasket fractal mmwave antenna at two frequencies for STAGE 5

In this stage, antenna started to radiate at four different frequencies like 16.84GHz with S_{11}(dB) value as -11.49dB and gain of 4.68dB, 26.5GHz with S_{11}(dB) value as -14.83dB with high gain of 5.73dB, 38.35GHz with S_{11}(dB) value as -19.48dB with high gain of 5.32dB, 56.5GHz with S_{11}(dB) value as -38.12dB with high gain of 15.76dB as shown in Fig.35 and Fig.36. From all the above stages the antenna is radiating maximum electric field in a particular direction defines directional antenna as shown in Fig.37.

Table II Simulated Parameters of various stages of extended sierpinski gasket fractal antenna @Feed Pos 1(1.6,3.8,0)

FeedPos1	Stage1		Stage2		Stage3	
Freq(GHz)	22.52	23.68	22.16	59.13	21.06	38.72
S_{11}(dB)	-9.53	-11.9	-24.42	-21.9	-11.9	-18.4
Gain(dB)	5.39	5.63	3.8	11.76	5.61	6.9
Imp BW(GHz)	0.30	0.55	0.67	7.51	0.18	1.03
	Stage4					
Freq(GHz)	14.4	21.79	30.9	39.57	48.07	60.66
S_{11}(dB)	-20.5	-19.9	-18.8	-21.6	-15.5	-11.5
Gain(dB)	13.9	9.25	5.93	7.56	8.35	7.65
Imp BW(GHz)	0.24	0.18	0.73	1.28	0.73	2.87

	Stage5			
Freq(GHz)	16.84	26.5	38.35	56.5
S_{11}(dB)	-11.49	-14.83	-19.48	-38.12
Gain(dB)	4.68	5.73	5.32	15.76
Imp BW(GHz)	0.42	0.24	0.73	0.73

The above table is summarized for all stages considering position @ FeedPos1 (1.6, 3.8, 0)

3.3 TRIPLE FEED ANTENNA

3.3.1 STAGE1

As described earlier, our proposed antenna can be excited by single feed, dual feed or triple feed. In the earlier section, a detailed analysis of stage-wise is described by considering a single feed. Now a triple feed is chosen. The feed positions are described below (1.6,3.8,0), (6.6,3.8,0) and (7.3,8.2,0). Generally, S_{11}(dB) refers to the reflection coefficient when excited from a single feed. But here it is referred to as the reflection coefficient when feed is excited from Pos1. Similarly, S_{22}(dB) and S_{33}(dB) refers to the reflection coefficients when excited from FeedPos2 and FeedPos3. In Stage1, the comparison of S_{11}(dB), S_{22}(dB) and S_{33}(dB) are shown in Fig.38.

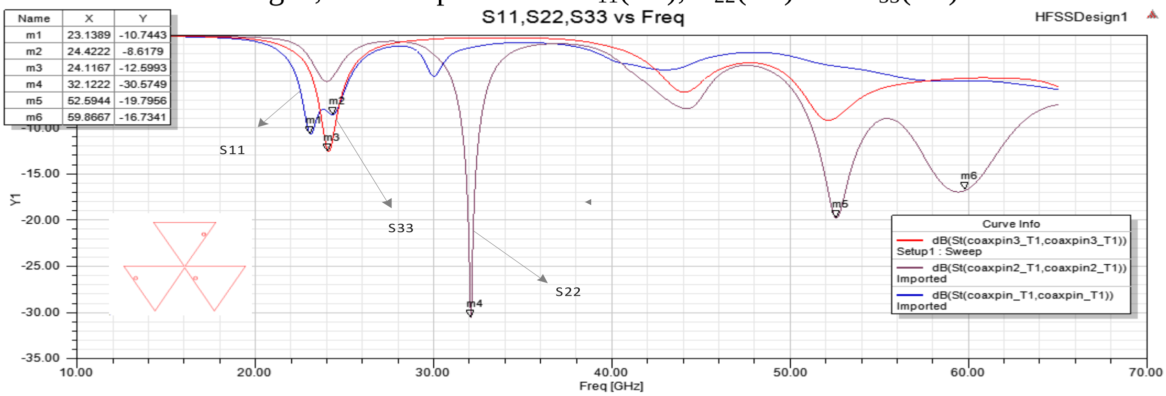


Fig.38. Comparison of Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE 1 at various feed positions.

It is clearly shown that the proposed antenna is excited for three frequency bands from feed pos2 i.e., 32,12GHz with S_{22}(dB) value as -30.57 dB, 52.59GHz with S_{22}(dB) value as-19.7dB and lastly at 59.86GHz with -16.7dB. And the remaining two feed positions excitations were confined to single frequency bands as 23.13GHz with S_{11}(dB) as -10.74dB and 24.11GHz with S_{33}(dB) as -12.59dB. Thus the feedpos2 is considered for multiband applications.

3.3.2 STAGE2

In Stage2, once again antenna is radiated at three frequency bands at feedpos2 and the frequency bands are 30.41GHz with S_{22}(dB) value as-11.57dB, 54.79GHz with S_{22}(dB) value as-23.18dB and 60.11GHz with S_{22}(dB) value as -38.66dB. The one advantage from Stage1 is at feed pos1, there are two frequency bands obtained whereas one band in stage1.The bands are 24.05GHz with S_{11}(dB) value as -25.54dB and 60.78GHz with S_{11}(dB) value as-19.57dB.And at the third feed position, there is a change in the frequency band from 24.1GHz to 23.01GHz but not with the number of frequency bands as shown in Fig.39.

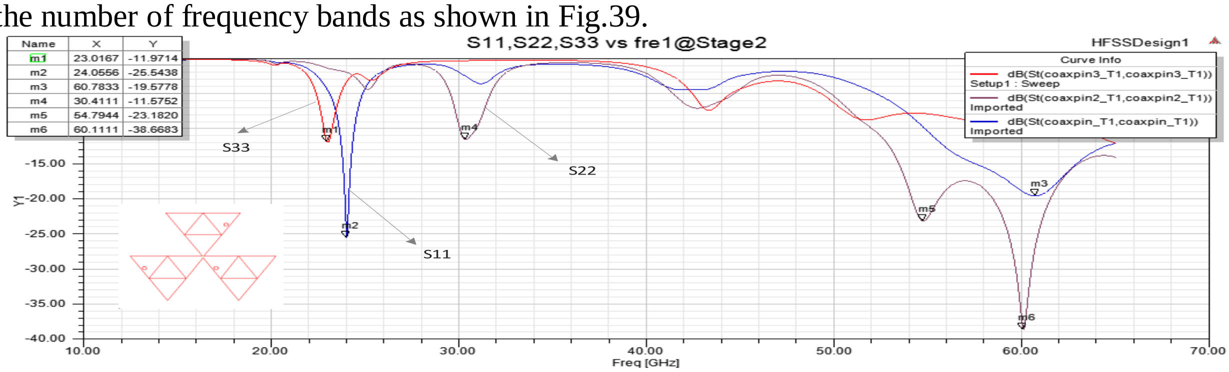


Fig.39. Comparison of Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE 2 at various feed positions.

3.3.3 STAGE3

In Stage3, there is a good improvement in several frequency bands at all the three feed positions. At feedpos1 the reflection coefficient values at frequencies 25.46GHz ,30.22GHz and 38.47GHz as -15.43dB, -14.98dB and -13.39dB with gains as 5.92dB, 6.39dB and 8.08dB.

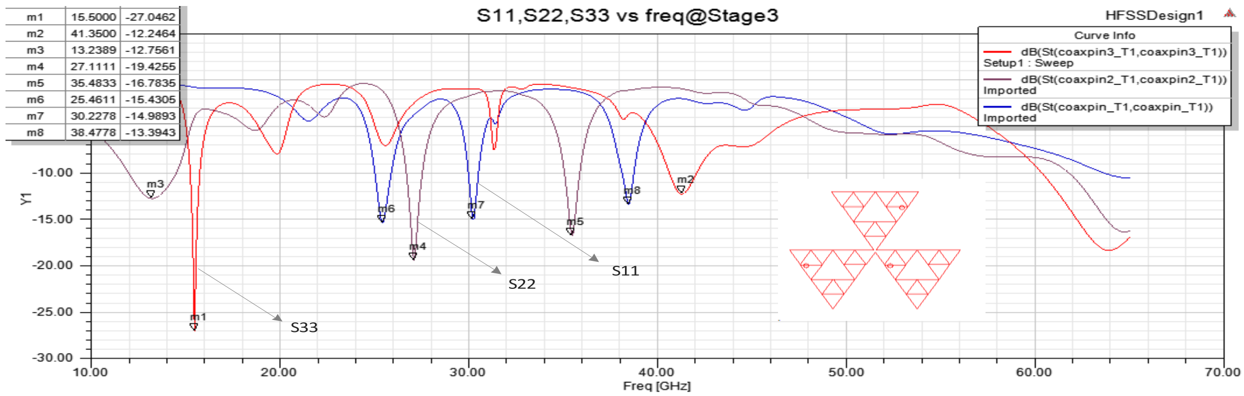


Fig.40.Comparison of Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE 3 at various feed positions.

At feedpos2 the reflection coefficient values at frequencies are 13.2GHz, 27.11GHz and 35.48GHz as -12.57dB,-19.42dB and -16.78dB with gains as 18.16dB, 6.76dB and 7.71dB. Similarly at feedpos3, the reflection coefficient values at frequencies 15.5GHz and 41.35GHz as -27.04dB and -12.24dB with gains as 15.58dB and 8.79dB as shown in Fig.40.

3.3.4 STAGE4

In Stage4, the number of frequency bands is increased from Stage3 at feed pos2 and there is the same number of frequency bands at feedpos1 and feedpos3. At feedpos1, the antenna radiated at three frequency bands like 22.58GHz, 35.3GHz and 49.4GHz with reflection coefficient values as -14.63dB -14.26dB and -17.64dB along with gains 11.4dB, 5dB and 8.93dB.

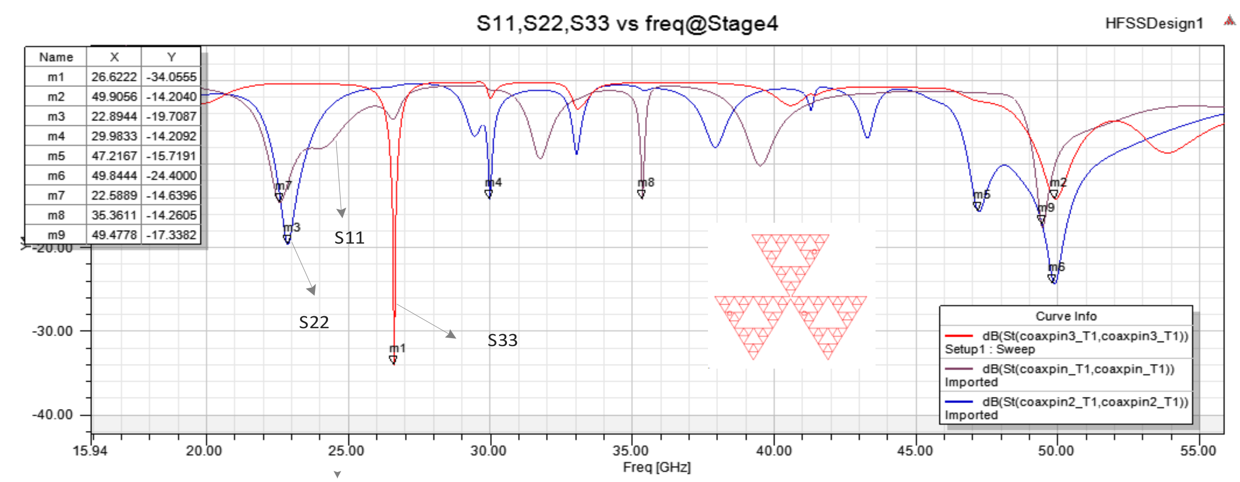


Fig.41.Comparison of Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE 4 at various feed positions.

At feedpos2, the antenna radiated at four frequency bands like 22.89GHz, 29.98GHz, 47.21GHz and 49.84GHz with reflection coefficient values as -19.7dB, -14.2dB,-15.71dB and -24.4dB along with gains as 11.4dB,6.51dB ,7.86dB and 9.97dB. Finally at feedpos3 the antenna is radiated at 26.62GHz , 49.9GHz frequencies with reflection coefficient value as -24.05dB and -14.2dB as shown in Fig.41.

3.3.5 STAGE5

In Stage5, the number of bands is increased at feedpos2 and feedpos3 when compared to previous stage. At feedpos2, the antenna radiated five frequency bands 15.13GHz, 26.74GHz, 39.74GHz, 45.2GHz and 48.43GHz with reflection coefficients as -17.39dB,-10.78dB, -11.21dB, -20.1dB and -26.69dB along with the gain in dB values are 10.77dB, 6.68dB, 5.99dB and 18.38dB. At feedpos1, the antenna started to radiate at five frequency bands namely 23.93GHz, 33.16GHz and 38.17GHz with reflection coefficients as -32.19dB, -18.65dB, and -18.75dB along with the gain values are 11.67dB, 3.51dB and 5.33dB.

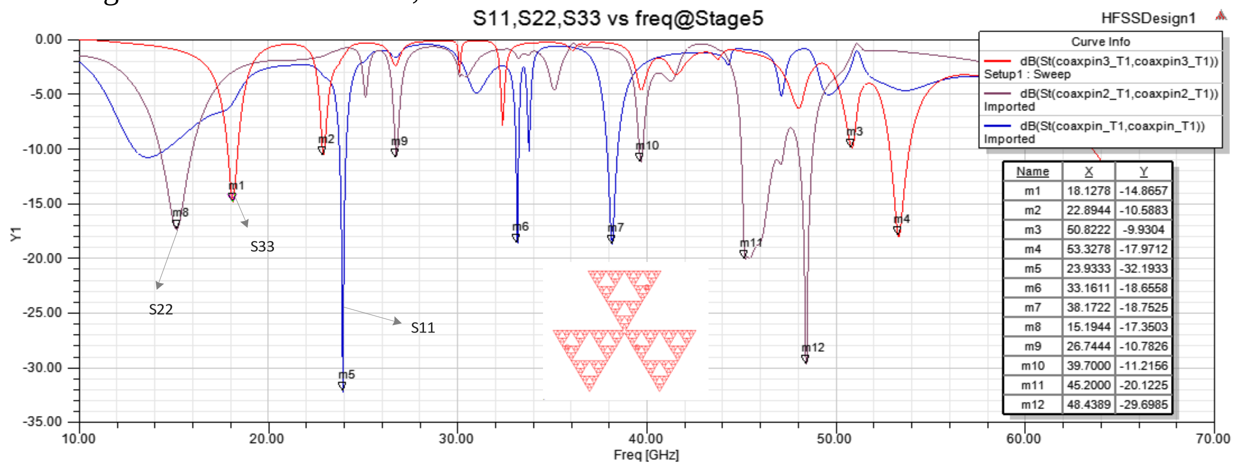


Fig.42. Comparison of Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna for STAGE 5 at various feed positions.

Finally at feedpos3, the antenna radiated at four different frequency bands 18.12GHz, 22.89GHz, 50.82GHz and 53.27GHz with reflection coefficients as -14.86dB, -10.58dB, -9.93dB, and -17.97dB along with the gain values are 8.44dB, 11.75dB, 26.7dB and 14.85dB as shown in Fig.42.

Table III. Simulated Parameters of various stages of extended sierpinski gasket fractal antenna @all three feed positions

Stage1/S.No	Freq(GHz)	S_{11}(dB)	Imp BW(GHz)	Gain(dB)
1	23.13	-10.74	0.36	5.67
S.No	Freq(GHz)	S_{22}(dB)	Imp BW(GHz)	Gain(dB)
1	32.12	-30.57	1.03	5.2
2	52.59	-19.79	3.30	8.61
3	59.56	-16.73	6.23	9.95
S.No	Freq(GHz)	S_{33}(dB)	Imp BW(GHz)	Gain(dB)
1	24.11	-12.59	0.67	6.67
Stage2/S.No	Freq(GHz)	S_{11}(dB)	Imp BW(GHz)	Gain(dB)
1	24.05	-25.54	0.85	6.19
2	60.78	-19.57	10.08	9.63
S.No	Freq(GHz)	S_{22}(dB)	Imp BW(GHz)	Gain(dB)
1	30.41	-11.57	0.91	10.15
2	54.79	-23.18	10.8	11.0
3	60.11	-38.66	10.8	9.86
S.No	Freq(GHz)	S_{33}(dB)	Imp BW(GHz)	Gain(dB)
1	23.016	-11.97	0.42	5.97
Stage3/S.No	Freq(GHz)	S_{11}(dB)	Imp BW(GHz)	Gain(dB)
1	25.46	-15.43	0.85	5.92
2	30.22	-14.98	0.55	6.39
3	38.47	-13.39	0.67	8.08

S.No	Freq(GHz)	S_{22}(dB)	Imp BW(GHz)	Gain(dB)
1	13.2	-12.57	2.56	18.16
2	27.11	-19.42	0.79	6.76
3	35.48	-16.78	0.85	7.71
S.No	Freq(GHz)	S_{33}(dB)	Imp BW(GHz)	Gain(dB)
1	15.5	-27.04	0.55	15.58
2	41.35	-12.24	1.77	8.79
Stage4/S.No	Freq(GHz)	S_{11}(dB)	Imp BW(GHz)	Gain(dB)
1	22.58	-14.63	0.91	11.0
2	35.36	-14.26	0.12	5.0
3	49.41	-17.64	0.79	8.93
S.No	Freq(GHz)	S_{22}(dB)	Imp BW(GHz)	Gain(dB)
1	22.89	-19.7	1.03	11.4
2	29.98	-14.2	0.14	6.51
3	47.21	-15.71	4.52	7.86
4	49.84	-24.4	4.52	9.97
S.No	Freq(GHz)	S_{33}(dB)	Imp BW(GHz)	Gain(dB)
1	26.62	-34.05	0.24	7.2
2	49.9	-14.2	1.10	11
Stage5/S.No	Freq(GHz)	S_{11}(dB)	Imp BW(GHz)	Gain(dB)
1	23.93	-32.19	0.36	11.67
2	33.16	-18.65	0.12	3.51
3	38.17	-18.75	0.61	5.33
S.No	Freq(GHz)	S_{22}(dB)	Imp BW(GHz)	Gain(dB)
1	15.13	-17.39	1.71	10.77
2	26.74	-10.78	0.18	6.68
3	39.7	-11.21	0.24	5.99
4	45.2	-20.12	1.52	5.93
5	48.43	-26.69	0.42	18.38
S.No	Freq(GHz)	S_{33}(dB)	Imp BW(GHz)	Gain(dB)
1	18.12	-14.86	0.61	8.44
2	22.89	-10.58	0.18	11.75
3	50.82	-9.93	0.30	26.7
4	53.27	-17.97	1.03	14.85

All the simulated values are summarized which includes reflection coefficient values at individual feed positions along with their gains and impedance bandwidths are as shown in Table.III.

3.4 Feed @2nd Pos Antenna

In our proposed extended sierpinski gasket fractal antenna, analysis is done at feedpos2 and feedpos3 also. A comparative study is done on the reflection coefficient at various stages and plotted in Fig.43. When the comparison is performed for feedpos1 and feedpos2, the advantage is only with a number of frequency bands.

For Stage2, Stage3 and Stage 4 the number of frequency bands has been increased when compared to previous positions of feed. But at Stage5, there is a huge drop in several frequency bands at pos2. The complete analysis at various stages is tabulated in Table.IV.

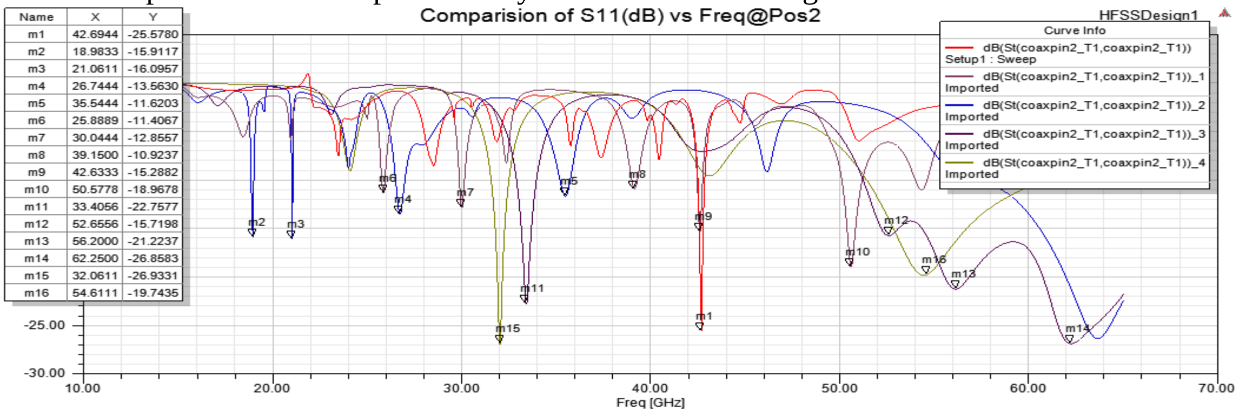


Fig.43.Comparison of Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna of various stages@Feedpos2 (6.6,3.8,0).

Table IV. Simulated Parameters of various stages of extended sierpinski gasket fractal antenna @2nd feed position

<table>
<tr><td>Feed Pos2</td><td colspan="2">Stage1</td><td colspan="4">Stage2</td></tr>
<tr><td>Freq(GHz)</td><td>32.06</td><td>54.5</td><td>33.4</td><td>52.65</td><td>56.2</td><td>62.12</td></tr>
<tr><td>S_{11}(dB)</td><td>-26.9</td><td>-19.7</td><td>-22.7</td><td>-15.7</td><td>-21.2</td><td>-26.8</td></tr>
<tr><td>Gain(dB)</td><td>9.48</td><td>11.04</td><td>8.86</td><td>11.17</td><td>11.56</td><td>8.82</td></tr>
<tr><td>Imp BW(GHz)</td><td>0.91</td><td>9.41</td><td>1.03</td><td>13.75</td><td>13.75</td><td>13.75</td></tr>
<tr><td></td><td colspan="6">Stage3</td></tr>
<tr><td>Freq(GHz)</td><td>18.98</td><td colspan="2">21.06</td><td colspan="2">26.74</td><td>35.54</td></tr>
<tr><td>S_{11}(dB)</td><td>-15.91</td><td colspan="2">-16.09</td><td colspan="2">-13.56</td><td>-11.62</td></tr>
<tr><td>Gain(dB)</td><td>2.68</td><td colspan="2">3.67</td><td colspan="2">7.22</td><td>8.27</td></tr>
<tr><td>Imp BW(GHz)</td><td>0.13</td><td colspan="2">0.05</td><td colspan="2">0.55</td><td>0.55</td></tr>
<tr><td></td><td colspan="6">Stage4</td></tr>
<tr><td>Freq(GHz)</td><td>25.88</td><td colspan="2">30.04</td><td>39.15</td><td>42.63</td><td>50.57</td></tr>
<tr><td>S_{11}(dB)</td><td>-11.4</td><td colspan="2">-12.85</td><td>-10.92</td><td>-15.28</td><td>-18.96</td></tr>
<tr><td>Gain(dB)</td><td>8.0</td><td colspan="2">5.37</td><td>6.79</td><td>8.7</td><td>8.73</td></tr>
<tr><td>Imp BW(GHz)</td><td>0.18</td><td colspan="2">0.3</td><td>0.3</td><td>0.27</td><td>1.1</td></tr>
<tr><td></td><td colspan="6">Stage5</td></tr>
<tr><td>Freq(GHz)</td><td colspan="6">42.69</td></tr>
<tr><td>S_{11}(dB)</td><td colspan="6">-25.57</td></tr>
<tr><td>Gain(dB)</td><td colspan="6">07.13</td></tr>
<tr><td>Imp BW(GHz)</td><td colspan="6">0.366</td></tr>
</table>

3.5 Feed @3rd Pos Antenna

Finally, the analysis is ended up with feed position3. When compared to feed pos1, the number of frequency bands has been reduced for stage2, stage4, and stage5. This particular feed position is not preferable when the antenna was used for multiband applications. The comparison of reflection coefficients of various stages at feed position 3 is as shown in Fig.44.

In the complete analysis of the reflection coefficient, the gain was evaluated at every frequency band for each stage and tabulated in Table V.

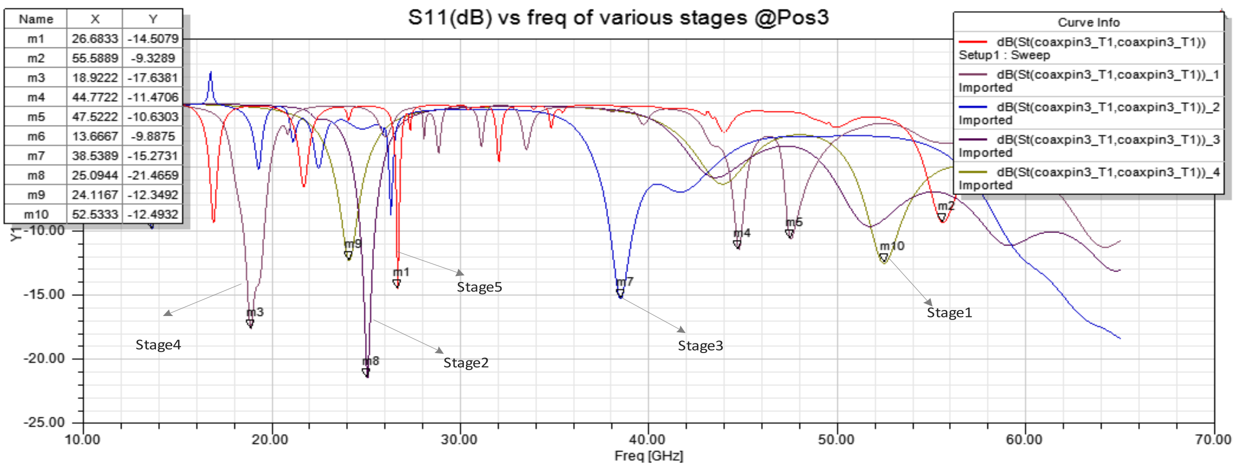


Fig.44.Comparison of Reflection Coefficient of Extended Sierpinski gasket mmwave fractal antenna of various stages@Feedpos3 (6.6,3.8,0).

Table V. Simulated Parameters of various stages of extended sierpinski gasket fractal antenna @3rd feed position

Feed Pos3	Stage1		Stage2	Stage3	
Freq(GHz)	24.11	52.47	25.09	13.66	38.47
S_{11}(dB)	-12.34	-12.5	-21.46	-9.88	-15.31
Gain(dB)	7.75	9.02	7.04	2.6	6.63
Imp BW(GHz)	0.61	1.4	0.79	-	1.22
	Stage4			Stage5	
Freq(GHz)	18.92	44.77	47.52	26.68	55.58
S_{11}(dB)	-17.63	-11.4	-10.6	-14.5	-9.32
Gain(dB)	8.16	8.08	9.08	7.76	11.41
Imp BW(GHz)	1.1	0.36	0.30	0.12	-

Table VI. Comparison of the proposed antenna with other existing antennas design

Design	Structure	Dimension (mm)	Resonant frequencies	Gain(dB)	Bandwidth(GHz)
[20]	Modified Sierpinski with meandered line	100 X 100 X 1.6	1.45-2GHz	5.49	0.94–2.25
[11]	Reconfigurable feed on Sierpinski structure	100 X 100 X 1.6	3 - 5.3GHz	3.2-5.19	0.1-0.6GHz
[12]	RITMA Sierpinski fractal antenna	90 X 60 X 1.59	3.4GHz 3.9GHZ	4.28 NA	-
[17]	Hexagonal-Triangular Fractal Antenna	25 X 30 X 0.8	3-25.2GHz	3-9.8	255.3%
[18]	Wideband Fractal Microstrip Antenna	60 X 60 X 1.524	10-50GHz	0-9	178.89%
[19]	Circular Hexagonal Fractal Antenna	31 X 45 X 1.575	2.18 - 44.5GHz	0-7	429.68%
[10]	Sierpinski with Defected Ground	4.2 X 3.9 X 1.6	28GHz 44.3GHz	1.25 -15.48	0.56 – 0.43GHz
Proposed	Extended Sierpinski gasket fractal antenna	10.19 X 9 X 0.508	24-60GHz	2-16	0.3-8GHz

4 Conclusion

This paper describes the detailed analysis and design of an extended Sierpinski gasket mm-wave fractal antenna along with a basic Sierpinski fractal antenna. All designed antenna was simulated using commercially available Ansoft HFSS version16 tool. The analysis is performed in various positions of feed using a coaxial feeding technique. Various resonating frequencies are attained based on the position of feed at various stages. The basic fractal antenna was resonating well with four number of frequency bands at stage4 and stage5. The proposed extended Sierpinski mm-wave fractal antenna is radiating the maximum electric field when it was excited with triple feed with the maximum number of frequency bands at various stages**.** But using single feed excitation the proposed antenna was resonating well with feed position1 with considerable gain and efficiency. The designed antenna is a miniaturized antenna with minimum dimensions that can be easily used for the Femto base station. The Elevation plane and Azimuth plane describes the directional pattern at a particular direction of the proposed antenna. Directionality helps us to reduce the interference between femtocell and macrocell and also between two femtocells. The frequency bands obtained 24GHz to 60GHz which are termed as frequency bands for 5G communications. Therefore the proposed extended Sierpinski gasket fractal mm-wave antenna has an application in 5G femtocells.

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