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Modified Sierpinski Gasket Patch Antenna for UMTS and 2.4/5.2 WLAN

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Abstract

A modified Sierpinski Gasket fractal antenna for multiband application is proposed in this paper. The modified ground plane and the microstrip feed are used to obtain the wider bandwidth at the resonance frequency. The antenna is designed and printed on two layers FR-4 substrate (ϵr=4.4 and h=1.6 mm) to cover the UMTS and 2.4/5.2 WLAN. The radiation pattern of the proposed antenna is similar to an omnidirectional. The proposed antenna has maximum gain of 1.88, 1.6, 4.31 dB at 2, 2.4, 5.2 GHz, respectively The properties of the antenna such as return losses, radiation pattern, input resistance and gain are determined via numerical CST Microwave Studio 2010 software.

Keywords- Patch antenna ; fractal shapes; Sierpinski gasket

تعديل هوائي رقعة حشية سيربنسكي لاستخدامه في نظام UMTS والشبكة المحلية الاسلكية ذات التردد 2.4 / 5.2

الخلاصة

لغرض تصميم هوائي يعمل على عدة حزم، تم اقتراح هوائي حشية سيربنسكي بعد اجراء بعض التعديلات على الشكل الاساسي له. اذ باستخدام خط التغذية وبطول معين وتعديل طبقة الارضي، عمل الهوائي على حزمة UMTS وكذلك على حزمة 2.4و 5.2 . طبع الهوائي على لوحة الايبوكسي ذات الطبقتين و ثابت العزل لها 4.4 وارتفاعها 1.6 ملم . اظهرت النتائج ان نمط الاشعاع كان بجميع الاتجاهات عند الترددات المطلوبة. وكذلك لوحظ ان الكسب للهوائي كان 1.88، 1.6 ، 3،4 ديسبل. تم استخدام برنامج CST Microwave Studio 2010 في حساب خصائص الهوائي كنمط الاشعاع، فقد الارجاع، ممانعة الادخال وكسب الهوائي.

الكلمات الدالة: هوائي الرقعة، الاشكال الكسورية، حشية سيربنسكي

Introduction

Recently, the possibility of developing antenna design objective has been improved due to the use of fractal concept. The term of the fractal geometries was originally coined by Mandelbrot to describe a family of complex shapes that have self-similarity or self-affinity in their geometrical structures [1].

Also, Mandelbrot defined fractal as a rough or fragmented geometric shape that can be subdivided into parts, each of which is (at least approximately) a reduced-size copy of the whole.

There are five properties that most fractals have: [2]

1. Fractals have details on arbitrarily small scales

2. Fractals are usually defined by simple recursive processes
3. Fractals are too irregular to be described in traditional geometric language
4. Fractals have some sort of self-similarity
5. Fractals have fractal dimension.

While Euclidean geometries are limited to points, lines, sheets, and volumes, fractals include the geometries that fall between these distinctions. Therefore, a fractal can be a line that approaches a sheet. The line can meander in such a way as to effectively almost fill the entire sheet. These space-filling properties lead to curves that are electrically very long, but fit into a compact physical space.

Different from Euclidean geometries, fractal geometries have two common properties, space-filling and self-similarity. It has been shown that the space-filling property of fractals in [3] can be utilized to reduce antenna size, while the self-similarity property of fractal shapes in [4] can be successfully applied to the design of multi-band fractal antennas.

In conventional microstrip patch antennas, dual band or multi-frequency operation can be obtained by employing multiple radiating elements or tuning devices such as varactor diode. This method makes antennas more complicated [5]. In this project, the concept of a fractal has been applied to the geometry of a bowtie antenna to obtain multiband frequency operation.

Sierpinski Gasket Antennas

This is one of the most popular fractal structure used for multiband performance and can be constructed from a triangle. The self-similar current distribution on these antennas is expected to cause their multi-band characteristics [6].

The generation of Sierpinski gasket antenna is started with a large triangle encompassing the entire geometry. The midpoints of the sides are joined together, and a hollow space in the middle is created. This process divides the original triangle to three scaled down (half sized) versions of the larger triangle. The same division process can be done on each of the copies. After second divisions, the geometry shown in Figure-1 is obtained.

First the generation of ‘strictly self-similar’ Sierpinski gasket is considered. Starting with an equilateral triangle of unit length side the transformations involved to get the next iterated geometry are:

$$w_1\begin{pmatrix}x\\y\end{pmatrix}=\begin{pmatrix}0.5 & 0\\0 & 0.5\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}\ldots\ldots\ldots\ldots\ldots(1)$$

$$w_2\begin{pmatrix}x\\y\end{pmatrix}=\begin{pmatrix}0.5 & 0\\0 & 0.5\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}0.5\\0\end{pmatrix}\ldots\ldots(2)$$

$$w_3\begin{pmatrix}x\\y\end{pmatrix}=\begin{pmatrix}0.5 & 0\\0 & 0.5\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}0.25\\0.433\end{pmatrix}\ldots(3)$$

$$w(A)=w_1(A)\cup w_2(A)\cup w_3(A)\ldots\ldots(4)$$

It is assumed that the origin of the coordinate system is at the bottom left corner of the triangle, and the x-axis pass through the base side of the triangle.

Parametric Study of the Sierpinski Gasket Antenna

The schematic of a typical Sierpinski gasket monopole antenna is shown in Figure -2.

Several modeling studies are conducted to understand the role played by these geometries in the design of these antennas. These include the effects of changing the fractal iteration, apex angle and dielectric constant of the substrate. A similar study is also conducted for

similar geometries that do not have a strict geometrical self-similarity.
The resonant frequency of monopole Sierpinski gasket antenna can be calculated by [7]:

$$(f_r)_m = k \frac{v}{h_p} \cos\left(\frac{\alpha}{2}\right) (\delta)^m \ldots\ldots.\ldots (5)$$

where

v: speed of light in free space ,
h_p: height of monopole

α: apex angle,

δ: similarity factor=1/r_f

m: band number
k= 0.152 for FR-4 substrate

Effect of Fractal Iteration Numbers

The numerical study has been presented to investigate the effect of fractal iterations on the performance of the monopole antenna configuration. The substrate used was FR-4. This material has a dielectric constant of ε_r=4.3 and a thickness of 1.6 mm. In all cases, the total height of the geometry remained the same at 40 mm and apex angle at α=40^o. The geometry of 0th, 1st and 2nd iteration of monopole Sierpinski gasket antennas are shown in Figure-3.

The return loss characteristics for the different iterations of monopole Sierpinski gasket antennas are shown in Figure-4. It can be observed that the 0th iteration antenna operates at a single resonant frequency within the range (0-10 GHz) while the other antennas cover multiband frequencies.

Also, it can be noticed that the lower resonant frequency (1.1GHz) of the antennas remains unchanged by the increase in the iteration order but it has a poor match. This is consistent with the physics of the geometrical resonance of the antenna structure where the lowest resonance frequency corresponds to the largest triangle, which remains the same in all cases.

The antennas properties for the different iteration numbers of monopole Sierpinski gasket are given in Table (I).

The simulated current distribution for the different iterations of monopole Sierpinski gasket antennas are shown in Figure-5. The self-similarity of the current distribution can be observed at 1st and 2nd iterations. The change in the current distribution at 1st and 2nd iteration antennas compared with 0th iteration antenna make these antennas operating in multiband frequency.

Effect of Apex Angle

A similar approach is used to study the effect of changing the apex angle (α) on the antenna performance. In this study, all models are of the same height h_p=60 mm and only the second iteration geometries shown in Figure-6 for different apex angles of 30^o, 50^o, and 60^o.

The simulated return loss for different apex angles of Sierpinski gasket antenna are shown in Figure-7. These indicate a characteristic shift in resonance towards the lower side as the apex angle increased. The shift in the first resonant frequency at 50^o apex angle is about 7.2% whereas at 60^o is about 12.37%. Besides, the 50^o apex angle shifts the second resonant frequency about 20% whereas at 60^o the shift is about 24.6%.

From Figure-7, also it can be noticed that the antenna operates at dual bands at 30^o apex angle whereas at 50^o and 60^o covers triple bands within the range (0-10 GHz).

The antennas properties for the different apex angles are given in Table (II).

Effect of Similarity Factor

The effect of similarity factor (***δ***) on the performance of the monopole antenna configuration is presented. The FR-4 substrate is used with a dielectric constant of ε_r=4.3, and a thickness of 1.6 mm. In all cases, the total height of the geometry remained the same at 62 mm and apex angle α=48°.

The similarity factor will determine the height of each sub gasket and given by:

$$\delta = \frac{h_n}{h_{n+1}} = \frac{1}{r_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where h_n: subgasket height

Affine transformations (scaling, rotation and translation) of monopole Sierpinski gasket with similarity factor ***δ=3/2*** can be expressed mathematically as follows:

$$W_1\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} \frac{1}{2} & \frac{1}{4\sqrt{3}} \\ 0 & \frac{2}{3} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \quad \ldots\ldots\ldots.\ldots. (7)$$

$$W_2\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} \frac{1}{2} & \frac{-1}{4\sqrt{3}} \\ 0 & \frac{2}{3} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{1}{2} \\ 0 \end{pmatrix} \ldots\ldots. (8)$$

$$W_3\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} \frac{1}{3} & 0 \\ 0 & \frac{1}{3} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{1}{6} \\ \frac{2}{3} \end{pmatrix} \ldots\ldots\ldots. (9)$$

$$W(A) = W_1(A) \cup W_2(A) \cup W_3(A) \ldots\ldots (10)$$

The geometry of 2nd iteration monopole Sierpinski gasket antennas with similarity factor ***δ=2*** and ***δ=3/2*** are shown in Figure-8.

Figure -9 shows a comparison of return loss for different similarity factors of monopole Sierpinski gasket antennas.

It can be observed that the three log-periodic bands spaced with a log-period of 2 (***$f_{r3} / f_{r2} = f_{r4} / f_{r3} \approx 2$***) for antenna has similarity factor ***δ=2*** while the antenna which has similarity factor ***δ=1.5*** is spaced with log-periodic of 1.5 (***$f_{r3} / f_{r2} = f_{r4} / f_{r3} \approx 1.5$***), except the 1st band (0.75 GHz).

The antenna properties for the different similarity factors are tabulated in Table (III). It is clear that the lower resonant frequency (0.75GHz) remain unchanged when the similarity factor changed because it corresponds to the largest triangle which remains the same in all cases.

Modified Sierpinski Gasket Patch Antenna for UMTS and 2.4/5.2 WLAN

The geometry of the traditional Sierpinski gasket patch antenna (Antenna- 1) is shown in Figure-10(a). The gasket is a second iterations with 30 mm height (h_4), width =24 mm and similarity factor δ=2. After several attempts and optima processes, using the CST simulation tool, the apex angle is chosen to be 43.6°.

Antenna-2 is modified by using 50Ω microstrip feed line that is placed at the center of the patch to improve impedance bandwidth and shifted the resonant frequency towards the left side.

Antenna-2 shown in Figure-10(b) has (24×10) mm^2 ground plane with 3.5 mm ground feed gap (G_f). Other parameters are w=24 mm, h_4=30 mm, L=10 mm and F=3mm.

Simulated Return Loss and Input Impedance

Figure-11 shows the simulated results for the return loss behaviour of Antenna-1, compared to those simulated for Antenna-2. What can be noticed is that Antenna-1 has a single resonant frequency at 6.84 GHz with poor return loss (S11= -9dB) whereas Antenna-2 has multiband frequency; the first is at 2.11 GHz and the second is at 5.36 GHz

The enhancement in input impedance (real and imaginary) is clear in Figure-

12, and the simulated input impedances of antennas are tabulated in Table (IV).

Simulated Radiation Pattern

The far field radiation pattern for each frequency band of Antenna-2 is shown in Figure-13.

Note that the field patterns are omnidirectional and the antenna has maximum gain of 1.88, 1.6, 4.31 dB at 2, 2.4, 5.2 GHz, respectively. The azimuth cut (Phi=0) shows that antenna radiates in all directions.

Simulated Surface Current Distribution

The surface current distribution of Antenna-6 is obtained using CST microwave Studio 2010. Figure 4-21 shows the surface current distribution at 2 GHz, 2.4 GHz and 5.2 GHz. It is clear that these three frequencies have very similar surface current distributions. This characteristic agrees with the radiation patterns characteristics of these frequencies shown in Figure-14. Moreover, it has also been found that in this design the surface current on the feed line is strong and dominates the main radiation performance of the antenna. These results agree with the simulated radiation pattern results.

Conclusions

The presented Sierpinski gasket antenna covers the required operating frequency range for mobile applications which are UMTS and 2.4/5.2 WLAN. It is observed that the radiation pattern is Omni-directional, thus, this antenna is extremely suitable for applications in mobile communication devices. Its sensitivity to both the vertical and horizontal polarization is of immense practical importance in mobile cellular communication applications because the antenna orientation is not fixed. This satisfies the requirements in wireless communication.

References

1 C. Mahatthanajatuphat, S. Saleekaw, and P. Akkaraekthalin, "A Rhombic Patch Monopole Antenna with Modified Minkowski Fractal Geometry for UMTS, WLAN and WIMAX Application", Progress in Electromagnetics Research, PIER 89, pp. 57–74, 2009.

2 David A. Snchez-Hernndez, Multiband Integrated Antennas for 4G Terminals, Artech House, 2008

3 Ahmed M. A. Salama and Kaydar M. Quboa, "Fractal Dipoles as Meander Line Antenna for Passive UHF RFID Tags", 5th International Multi-Conference on Systems, Signals and Devices .2008 IEEE

4 S. R. Best, "On the Significance of Self-Similar Fractal Geometry in Determining the Multiband Behavior of the Sierpinski Gasket Antenna ", IEEE Antennas and Wireless Propagation Letters, Vol. 1, 2002

5 J. Huang, N. Li, J. She and Z. Feng, "A Novel Multiband Fractal Patch Antenna", Asia-Pacific Microwave Conference proceedings, Vol.4, 4-7 Dec. 2005 IEEE.

6 W. J. Krzysztofik, “Modified Sierpinski Fractal Monopole for ISM-Bands Handset Applications”, IEEE Transactions on Antennas and Propagation, Vol. 57, NO. 3, March 2009.

7 C. Puente, C. B. Borau, M. N. Rodero, and J. R. Robert, “An Iterative Model for Fractal Antennas Application to the Sierpinski Gasket Antenna”, IEEE Transactions on Antennas and Propagation, Vol. 48, No. 5, May 2000

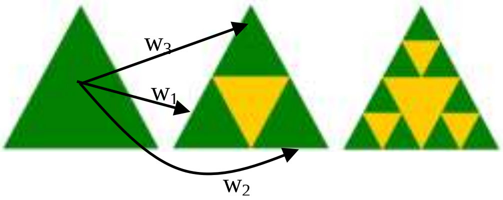


Figure-1: Generation of Sierpinski gasket geometry, (a)0thiteration (b) 1st iteration (c) 2nd iteration

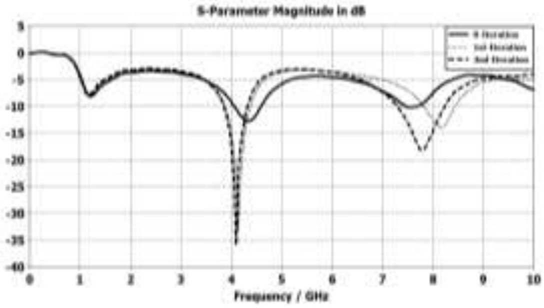


Figure-4: Simulated return loss characteristics for the different iterations of monopole Sierpinski gasket antennas

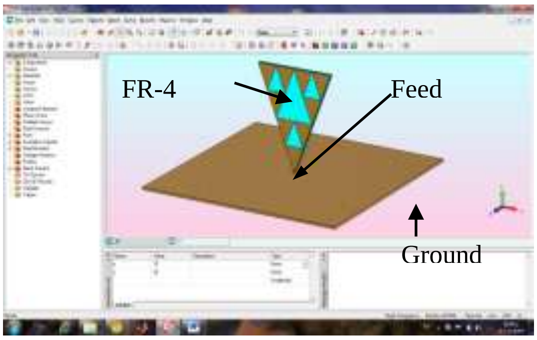


Figure-2:Monopole antenna configuration with 2nd iteration printed Sierpinski gasket antenna

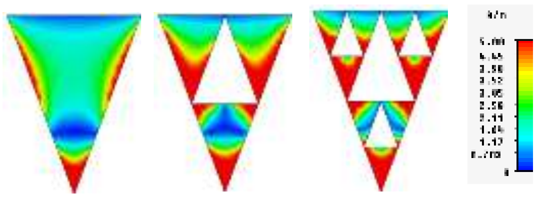


Figure-5: Simulated current distribution of 0th, 1st and 2nd iterations of monopole Sierpinski gasket antenna at 4.2 GHz

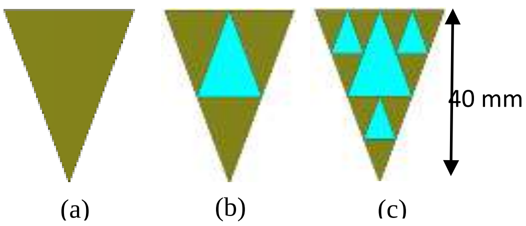


Figure-3: Monopole Sierpinski gasket antennas configurations (a) 0th iteration (b) 1st iteration (c) 2nd iteration

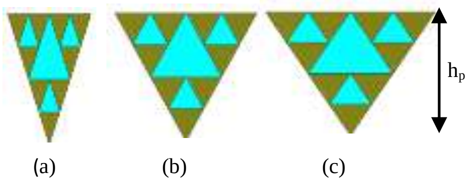


Figure-6: 2nd Iteration Sierpinski gasket antenna with different apex angles of (a) α=30^{o} (b) α=50^{o} (c) α=60^{o}

Tikrit Journal of Engineering Sciences/Vol.20/No.1/March 2013, (42-50)

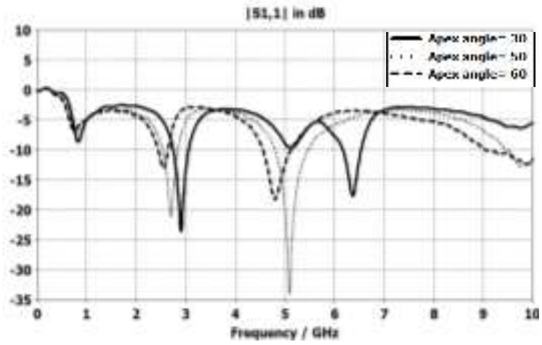
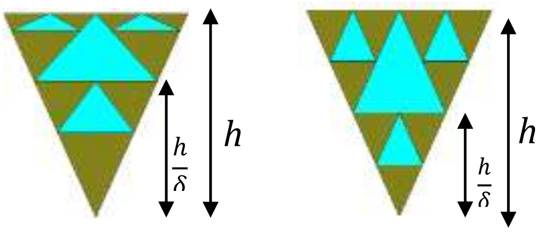


Figure 7: Simulated return loss (RL) for different apex angle of monopole Sierpinski gasket antenna



(a) (b)

Figure-8: Generalized Sierpinski gasket geometry with different similarity factor, (a) δ =3/2 (b) δ =2

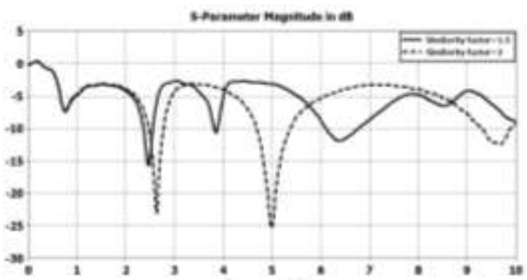
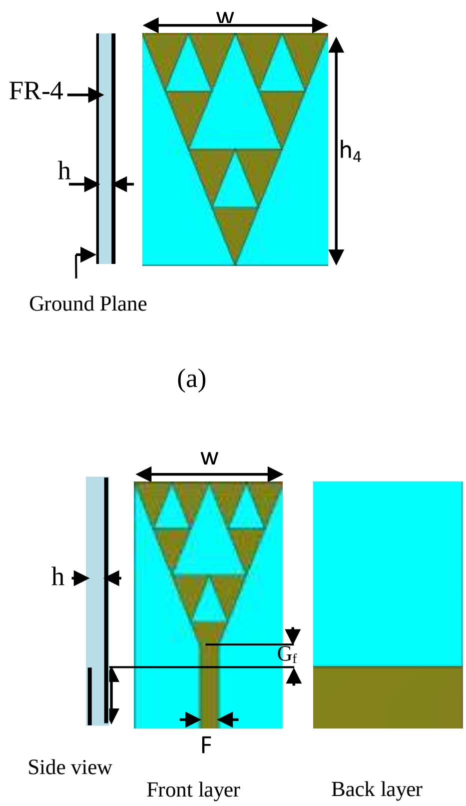


Figure-9: Simulated return loss of monopole Sierpinski gasket antennas for different similarity factors.



(a)

(b)

Figure-10: Sierpinski gasket antenna configurations (a) traditional Sierpinski gasket (Antenna-1) (b) modified Sierpinski gasket (Antenna-2)

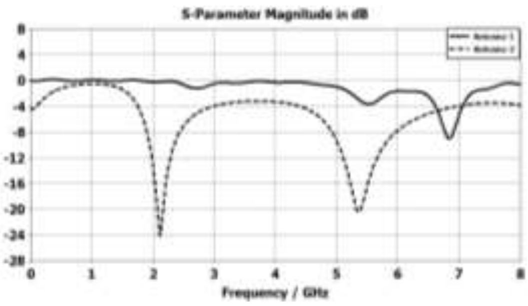


Figure-11: Simulated return loss of Antenna-1 and Antenna- 2.

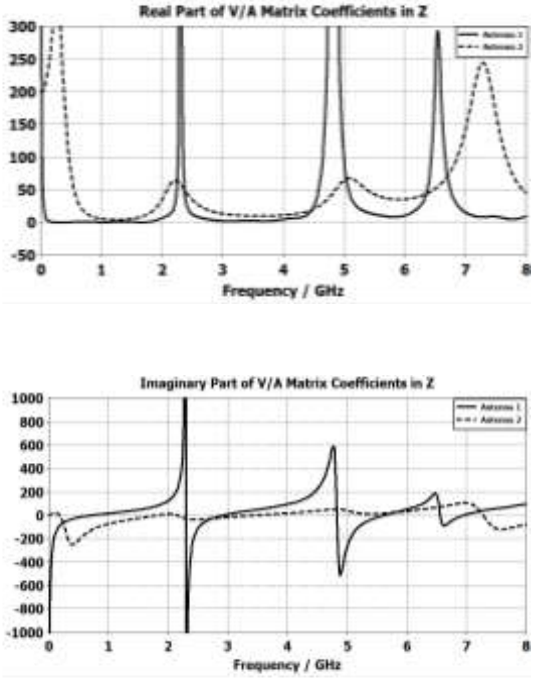
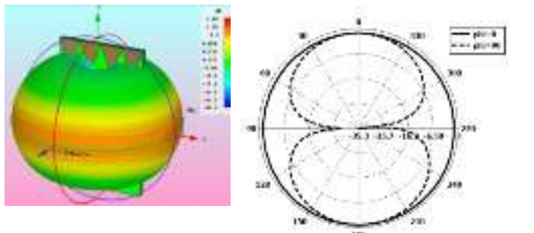
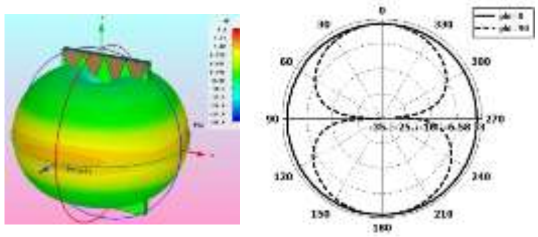


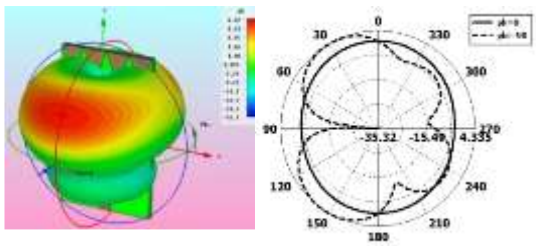
Figure-12: Simulated input impedance (real and imaginary) of Antenna-1 and Antenna-2



2 GHz



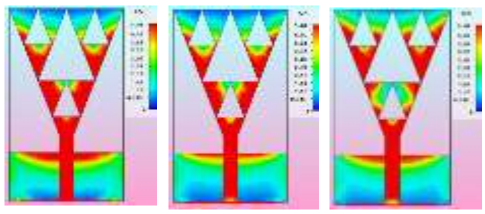
2.4 GHz



5.2 GHz

(a) (b)

Figure-13: Simulated radiation pattern of Antenna-2 at UMTS and WLAN bands (a) 3-Dimension (b) 2- Dimension



(a) (b) (c

Figure-14: Simulated surface current distribution of modified Sierpinski gasket Antenna-2 at different frequencies (a) 2 GHz (b) 2.4 GHz (c) 5.2 GHz

Table I: Summary of results of monopole Sierpinski gasket antennas for different iteration numbers

Iteration No.	Resonant Freq. /GHz	RL /dB	B.W
0	4.35	-12.7	12%
1	4.14	-32.9	12.46%
	8.17	-13.9	7.94%
2	4.1	-35.9	11.46%
	7.79	-18.18	12.02%

Table (2): Summary of the results of monopole Sierpinski gasket antenna for different apex angles

Apex angle	Resonant Freq. /GHz	RL /dB	B.W
30^o	2.91	-23.5	10.8 %
	6.37	-17.6	5.8 %
50^o	2.7	-21.1	11.5 %
	5.09	-34	13.2 %
	9.76	-12.6	5.21 %
60^o	2.55	-13	7.88 %
	4.8	-18.2	11.8 %
	9.9	-12.3	9.72%

Table (3): Summary of results of monopole Sierpinski gasket antenna for different similarity factor

Similarity factor	Resonant Freq./ GHz	RL /dB	B.W
2	f_{r1}= 2.63	-23	11.4 %
	f_{r2}= 4.99	-25.3	13.9 %
	f_{r3}= 9.69	-12.3	6.14 %
3/2	f_{r1}= 2.47	-15.7	8.42 %
	f_{r2}= 3.85	-11	1.89 %
	f_{r3}= 6.39	-12	9.01

Table (4): Simulated input impedances of Antenna-1 and Antenna-2

Frequency /GHz	2	2.4	5.2
Input impedance of Antenna-1	6.18 +j122.6	28.3 -j263.15	25.27 -j96.4
Input impedance of Antenna-2	35.2 +j10	46.03 -j37.7	63.24 +j15.7