

DESIGN OF SIERPINSKI GASKET FRACTAL ANTENNA WITH SLITS FOR MULTIBAND APPLICATION

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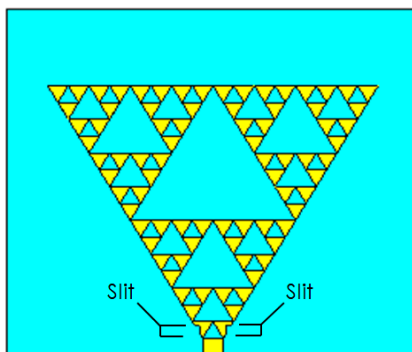
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Graphical abstract



Abstract

There is highly demand of antenna with these characteristics: compact size, low profile and multiband or broadband but at the same time have to maintain antenna parameters. This paper focuses on design of Sierpinski Gasket Fractal Antenna (SGFA) with slits for multiband application. Two methods are applied to this antenna to improve its performance. The first method is by adding two slits on the fractal antenna. The second method is by increasing the number of iterations of the fractal antenna. These methods can improve the return loss and gain of the antenna. The simulation of the designed antenna is carried out by using Computer Simulation Technology (CST) software. The simulated return loss of SGFA with slit is about -20.1 dB and -11.64 dB compare with SGFA without slit -19.25 dB and -12.27 dB at 2.4 GHz and 5 GHz. While, the gain also increase when slit is added to SGFA. The simulated and measured of antenna parameter is well compared.

Keywords: Sierpinski gasket fractal antenna, slits, return loss, gain,

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1.0 INTRODUCTION

In today world of wireless communications, there has been an increasing need for more compact and portable communications systems. Just as the size of circuitry has evolved to transceivers on a single chip, there is also a need to evolve antenna design to minimize the design. In the study of antennas, fractal antenna theory is a new area in antenna design technology. A fractal antenna is created using fractal geometry, a self-similar pattern built from the

repetition of a simple shape [1]. The inherent qualities of fractals enable the production of high performance antennas that are typically 50 to 75 percent smaller than traditional antennas [1-2].

Several fractal antennas have been proposed to obtain multi-band frequency operation. A dual band wireless device PCB fractal monopole antenna which can operate on WLAN or Bluetooth applications. The modified Sierpinski gasket is an efficient radiator with the ability to handle both the 2.4 and 5.2 GHz ISM bands without a matching network. The size of

antenna is reduced by controlling the space factor between the first two resonances [3]. Then, in [4] a modified Sierpinski fractal patch antenna with small triangles is drawn outside on three sides of each equilateral triangle to increase the radiating area. While, in [5] the SGFA has been designed and fabricated with defected ground structure (DGS) with center frequency at 5.8 GHz. A slot was used as a DGS. DGS was introduced in the design to increase the bandwidth as well as to further miniaturize the size of the antenna. The SGFA with slit has been reported in [6] about a design of dual band triangular fractal antenna with slits for wireless applications. The slits are made at the three corners of the triangular patch. Ground plane is located on the bottom side of the substrate. Port is to be placed in the antenna in order to achieve the circular polarization.

In this paper, a design of Sierpinski Gasket Fractal Antenna (SGFA) with slits for multiband application has been proposed. The slits are placed near to the feed line to have better return loss. The number of iteration is increased up to fourth iterations to lower the resonance frequency. The designed antenna can operate on WLAN (IEEE 802.11a) and Bluetooth (IEEE 802.15.1) applications.

2.0 ANTENNA DESIGN

Table 1 shows the substrate specification of proposed antenna. The proposed antenna is a broadband operation. The return loss of the antenna must be below -10dB to make sure the proposed antenna can achieve at least 90% matching efficiency [5]. The antenna is designed by using a FR4 epoxy dielectric substrate with dielectric constant, $\epsilon_r = 4.4$, tangent loss, $\tan \delta = 0.019$ and the thickness, $h = 1.6\text{mm}$. While, Table 2 shows the dimension of the SGFA with/out slit. The front view of SGFA with no slit is shown in Figure 1. The yellow region represents the copper layer of antenna while the blue region represents the substrate of the antenna. Then, Figure 2 shows the front view of SGFA with slit. Next, Figure 3 and 4 shows the bottom and side view of the antenna.

Table 1 Substrate specification

Substrate	FR4
Relative permittivity, ϵ_r	4.4
Tangent loss, δ	0.019
Substrate thickness, h	1.6mm
Copper thickness, t	0.035mm

Table 2 The dimension of the SGFA with/out slit (calculated and optimized)

Symbol	Description	Value (mm)
T_H	Triangle height	62.355
T_S	Triangle side length for 0 iteration	72
T_{S1}	Triangle side length for 1 iteration	36
T_{S2}	Triangle side length for 2 iteration	18
T_{S3}	Triangle side length for 3 iteration	9
T_{S4}	Triangle side length for 4 iteration	4.5
L_g	Substrate length	85
W_g	Substrate width	89.6
h	Substrate thickness	1.6
W_f	Feed line width	4.5
L_f	Feed line length	3.89
SL	Slit length	2.5
SW	Slit width	1
$L1$	Length between triangle patch and substrate	4.8
$W1$	Width between triangle patch and substrate	4.8
t	Copper thickness	0.035

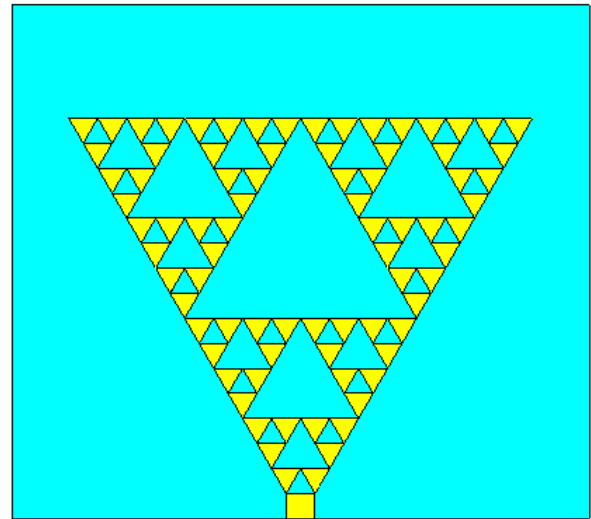


Figure 1 The front view of SGFA structure with no slit

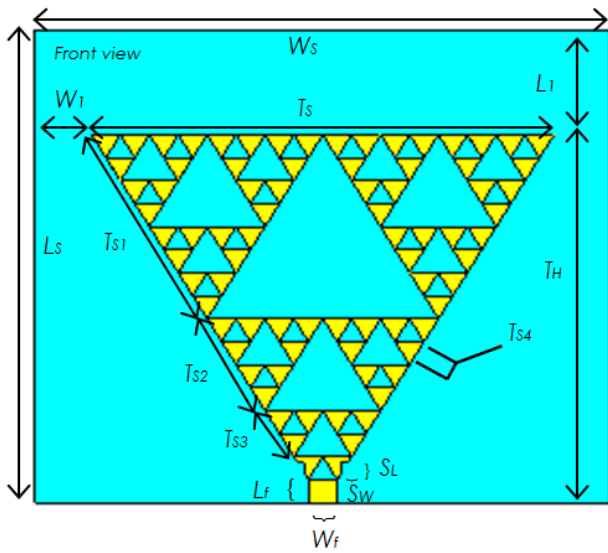


Figure 2 The front view of SGFA structure with slit

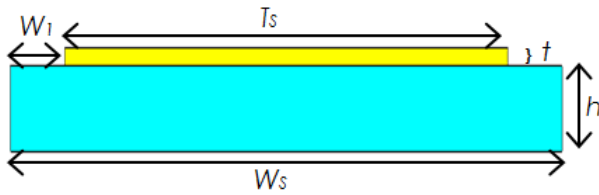


Figure 3 The bottom view of SGFA structure with slit

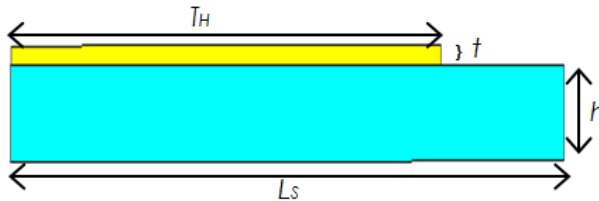


Figure 4 The side view of SGFA structure with slit

The antenna design process starts with calculation of side length of triangle [4], [7], [8]. The side length of the triangle, T_s is calculated by using equation (1).

$$T_s = \frac{1}{\sqrt{3}}(0.3069 + 0.68\rho x) \frac{c}{f_r} \left(\xi^{-1} \right)^n - \frac{1}{\varepsilon_r} \text{ for } n = 0 \quad (1)$$

$$\frac{0.52}{\sqrt{3}} \frac{c}{f_r} \delta^n - \frac{1}{\varepsilon_r} \text{ for } n > 0$$

where

$\xi = \frac{h_{k+1}}{h_k}$ is the ratio of height of gasket in the (k+1)th iteration to that in the kth iteration.

$\delta = \frac{1}{\xi}$ is the scale factor

n is the band number

$\rho = \xi - 0.230735$

$x = 0, k = 0$

$x = 1, k > 0$

t is the thickness of substrate

ε_r is the relative permittivity of substrate
 f_r is the resonant frequency
 c is the speed of light in vacuum

The triangle side length for 1st iteration, 2nd iteration, 3rd iteration, and 4th iteration is calculated by using equation (2).

$$T_{si} = \frac{T_s}{2^i} \text{ where } i = 1, 2, 3, 4 \quad (2)$$

The next resonant frequency can be calculated by using equation (3) [4], [7], [8].

$$f_r \cong \begin{cases} (0.15345 + 0.3\rho x) \frac{c}{h_e} \left(\xi^{-1} \right)^n & \text{for } n = 0 \\ 0.26 \frac{c}{h_e} \delta^n & \text{for } n > 0 \end{cases} \quad (3)$$

where

$S_e = S + t(\varepsilon_r)^{-0.5}$ is the effective side length of the largest gasket

$h_e = \frac{\sqrt{3S_e}}{2}$ is the effective height of the largest gasket

The substrate length and width are calculated by using equation (4) and equation (5) [9].

$$L_g = T_H + 6h \quad (4)$$

$$W_g = T_s + 6h \quad (5)$$

$$W_g = T_s + 6h \quad (4)$$

$$W_g = T_s + 6h \quad (5)$$

The slit length is obtained through parametric study while the slit width is assumed to be 1mm [10], [11].

The feed line width is calculated by using transmission line modal in equation (6) [13].

$$\frac{W_f}{h} = \begin{cases} \frac{8e^A}{e^{2A}-2} \text{ for } \frac{W_f}{h} < 2 \\ \frac{2}{\pi} \left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r} \left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r} \right] \right] \text{ for } \frac{W_f}{h} > 2 \end{cases} \quad (6)$$

where

$$A = \frac{Z_\tau}{60} \sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left(0.23 + \frac{0.11}{\varepsilon_r} \right)$$

$$B = \frac{377\pi}{2Z_\tau\sqrt{\varepsilon_r}}$$

The feed line length is calculated by using quarter wave transformer technique in equation (7) [12].

$$Z_{\tau} = \sqrt{Z_o Z_{in}} \tag{7}$$

where

Z_{in} is the reference impedance simulated from CST
 Z_o is the characteristic impedance

3.0 RESULT AND DISCUSSION

These sections show the several performance of the Sierpinski gasket fractal antenna (SGFA) with slit. Parametric study on the slit length is conducted in order to get the optimum result for the return loss. The variation of slit length has been selected from 1.2 mm until 2.4 mm. Although there is no significant changes, but 1.8mm of slit length give optimize return loss for this antenna. The return loss at 2.41GHz is -20.1dB while the return loss at 5GHz is -11.6dB.

Figure 5 shows the simulated return loss for SGFA with/out slit. While, Table 3 shows the comparison of antenna parameter between SGFA with/out slit. There are no significant differences by adding slit to the fractal antenna. There are certain parameter like bandwidth has become narrow after adding slit. Only the return loss and gain at 2.4GHz is improved. The designed antenna has 2.49dB of gain at 2.4GHz and 3.75dB of gain at 5GHz respectively.

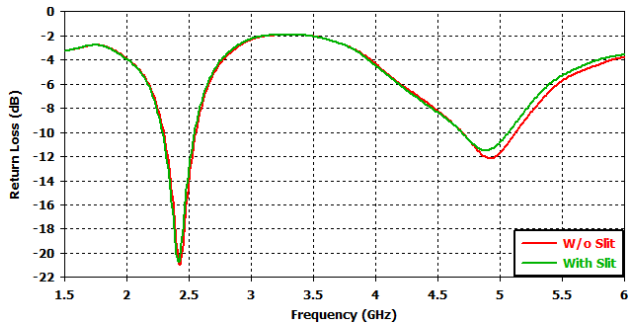


Figure 5 Simulated return loss for SGFA with/out slit

Table 3 Comparison of antenna parameter between SGFA with/out slit.

Parameters	With slit		Without slit	
	2.28-2.54	4.68-5.07	2.29-2.56	4.69-5.13
Frequency range (GHz)	2.28-2.54	4.68-5.07	2.29-2.56	4.69-5.13
Bandwidth (GHz)	0.26	0.39	0.27	0.44
Return loss (dB)	-20.1	-11.64	-19.25	-12.27
Gain (dB)	2.49	3.74	2.27	3.52
Efficiency (dB)	-2.25	-1.87	-2.21	-1.84

Figure 6 shows the comparison of return loss between simulation and measurement. While, Table 4 shows the comparison of antenna parameters

simulation and measurement of SGFA. The measured return loss at 2.4GHz and 5GHz are -11.466dB and -8.3543dB respectively. The measured return loss and gain is decrease and not shows a good response compare the simulation result. The measured return loss at 5GHz does not less than -10dB. This might be due to human error during the antenna fabrication process.

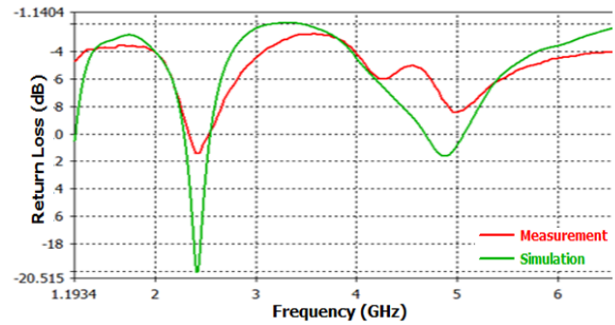


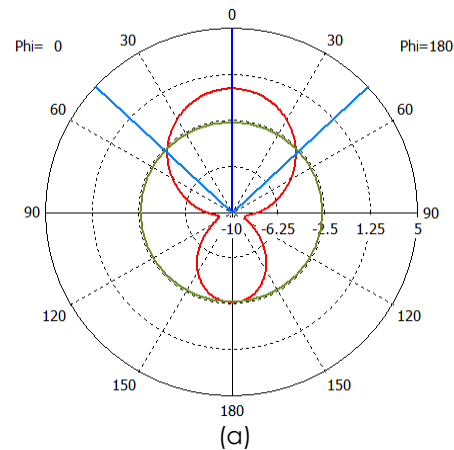
Figure 6 Comparison return loss between simulation and measurement

Table 4 Comparison of antenna parameter between simulation and measurement

Parameters	Simulation		Measurement	
	2.4GHz	5GHz	2.4GHz	5GHz
Frequency	2.4GHz	5GHz	2.4GHz	5GHz
Return loss (dB)	-20.1	-11.64	-11.466	-8.3543
Gain (dB)	2.49	3.74	1.87	2.29

Figure 7 and 9 shows the 2D radiation pattern for SGFA with slit for $\phi=0^\circ$ and $\phi=90^\circ$ at 2.4 GHz and 5 GHz. The radiation pattern at 5 GHz has bigger main lobe compare to 2.4 GHz for $\phi=0^\circ$. Both of these also have back lobes. While, the radiation pattern at 2.4GHz is nearly omnidirectional pattern. The radiation pattern at 5GHz has two main lobes and a side lobe.

Figure 8 and 10 show the 3D radiation pattern for SGFA with slit at 2.4 GHz and 5 GHz. It's show that radiation mostly concentrates in front of the SGFA area.



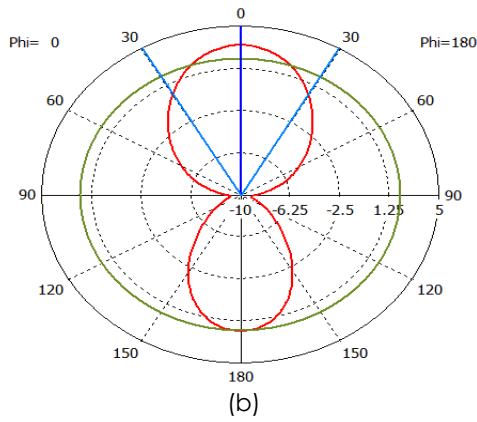


Figure 7 2D radiation pattern for SGFA with slit for phi=0°; (a) 2.4GHz and (b) 5GHz

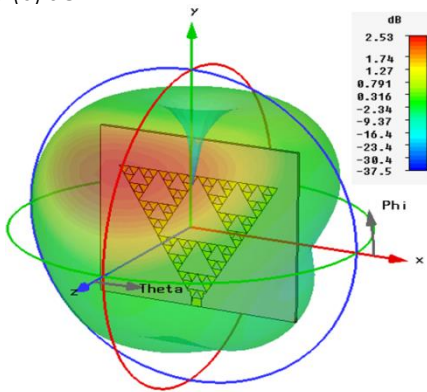


Figure 8 3D radiation pattern for SGFA with slit at 2.4 GHz

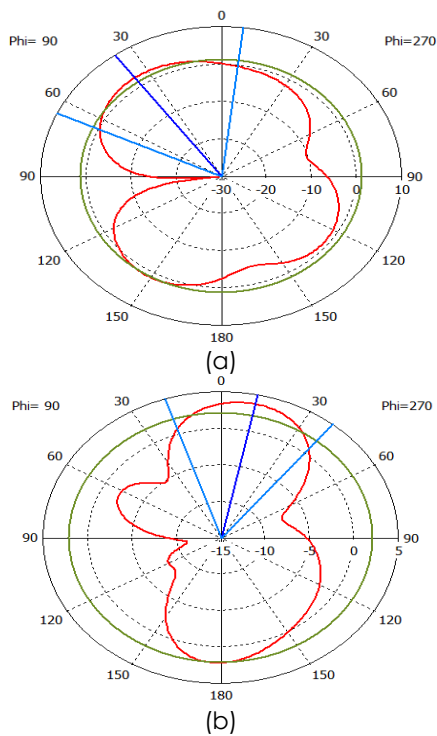


Figure 9 2D radiation pattern for SGFA with slit for phi=90°; (a) 2.4GHz and (b) 5GHz

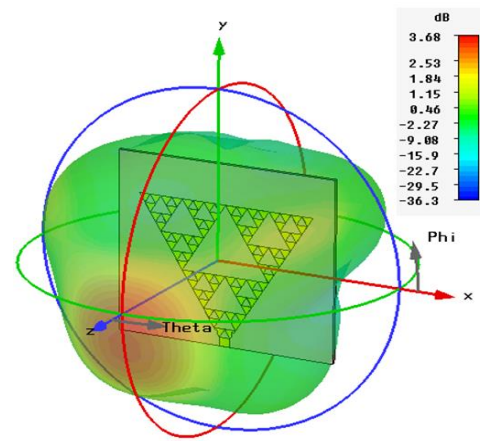


Figure 10 3D radiation pattern for SGFA with slit at 5 GHz

Figure 11 and 12 show the surface current distribution of SGFA with slit at resonant frequency of 2.4 GHz and 5 GHz. The red arrow show the significant high surface current distribution compare with the green arrow. While Figure 13 shows the fabricated antenna of SGFA with slits.

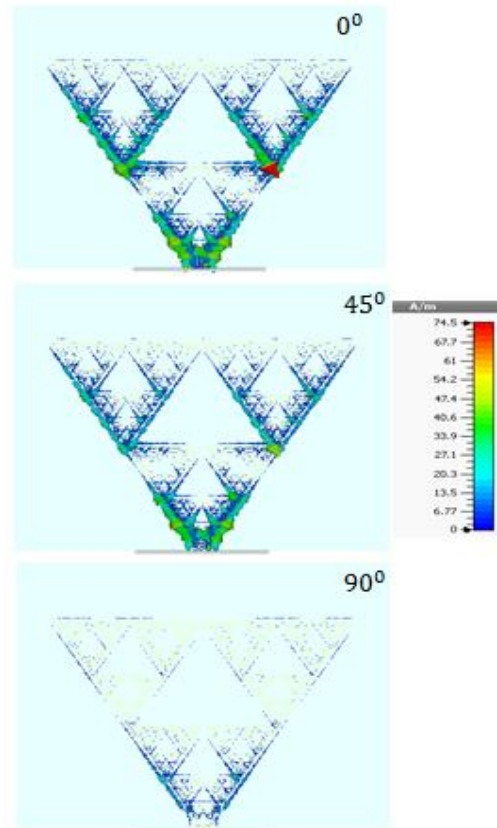


Figure 11 Surface current distribution of SGFA with slit at 2.4 GHz.

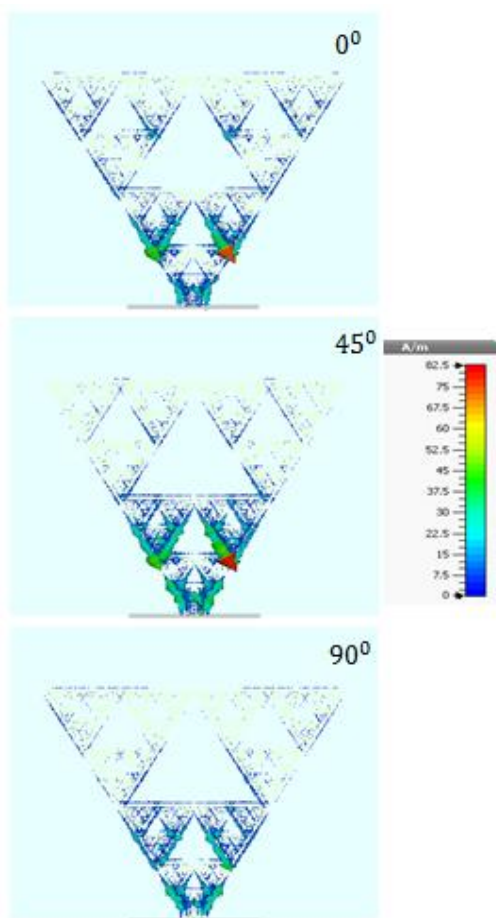


Figure 12 Surface current distribution of SGFA with slits at 5 GHz.

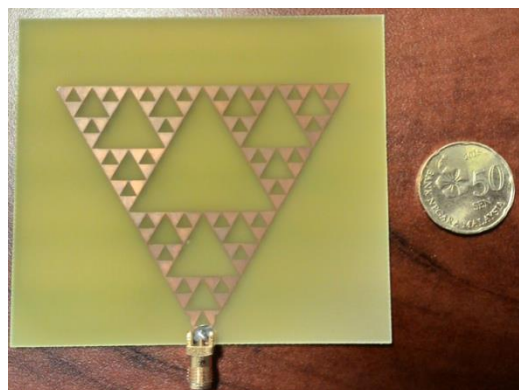


Figure 13 Fabricated antenna of SGFA with slits

4.0 CONCLUSIONS

As a conclusion, the Sierpinski Gasket fractal antenna with slits for multiband applications has been designed and fabricated. The simulation results showed that the designed antenna covered the frequencies from 2.28GHz to 2.54GHz and 4.68GHz to 5.07GHz. Hence, the designed antenna can be used for multiband applications. The measured antenna gain does not achieve as desired. Others substrate like Roger 5880 can be used to reduce the antenna loss because FR4 has higher loss compared to others substrate.

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