

Design and Realization of Compact Microstrip Antenna Using Fractal Sierpinski Carpet For Wireless Fidelity Application

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ABSTRACT

This paper proposed new design of compact microstrip antenna using fractal sierpinski carpet method for Wireless Fidelity application at working frequency of 2400 MHz. The proposed antenna using FR4 Epoxy with (ϵ_r) of 4.3, substrate thickness (h) of 1.6 mm and loss tangent ($\tan \delta$) of 0.0265. Antenna is designed using AWR Microwave Office software. The sierpinski carpet method is used in order to reduce the dimensions of the microstrip antenna to become more compact. From the measurement results obtained reflection coefficient value -26.077 dB, VSWR 1.104 at working frequency of 2400 MHz frequency with a bandwidth of 127 MHz (2338 MHz – 2465 MHz). Beside that, by using fractal sierpinski carpet method, microstrip antenna dimension was reduced until 47.80% compared to conventional rectangular microstrip antenna.

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1. INTRODUCTION

The development of information technology is now growing rapidly, especially in wireless telecommunications. Data transfer speeds become an important requirement to make the telecom provider optimize the network in order to meet customer needs. The user side needs a receiver that can work for some diversified telecommunications systems, such as DCS at frequency band (1710 MHz -1885 MHz), PCS (1907 MHz -1912.5MHz), UMTS (1920 MHz – 2170 MHz), WLAN 2.4 GHz and LTE 2.3 GHz [1]. According to the Regulation of the Minister of Transportation of the Republic of Indonesia Number KM. 2 / PER / MENHUB / 2010 stated that the band frequency of 2400 MHz - 2483 MHz is used for data and internet communication system such as Wireless Fidelity[2].

Microstrip antenna is one of many type of antennas that can be used for wireless communications, because this antenna has an advantages such as small size, compact and easy to be fabricated. Many techniques have been reported to reduce the size of microstrip antennas for fixed operating frequency. The inverseproportionality of the relative permittivity can be exploited to reduce the physical antenna length at a fixed operating frequency. A higher permittivity substrate can significantly reduce the antenna size by as much as about 90% [3]. One way to get compact design of microstrip antenna is using fractal method and by using fractal method the dimensions of the antenna can be reduced and become more compact. There are several methods of fractal being developed based on its geometry, such as Hilbert [4], Sierpinski [5], Koch [6], and Minkowski [7].

In previous study done by [8], at the range frequency 2.3 GHz the dimension of microstrip antenna can reduced until 66 % using cohan sinkowski fractal. The research conducted by [9] showed that the fractal method can be reduced the antenna size until 58.7%. In another study done by [10] fractal method achieved 57.15 % miniaturization dimension of microstrip antenna at work frequency of 2.04 GHz.

From the above results of previous studies it can be concluded that the fractal method can reduce the dimension of the proposed antenna. Therefore this paper proposed a new design of compact fractal patch microstrip antenna using sierpenski carpet method to reduce dimension of antenna for Wireless Fidelity application purposes.

2. ANTENNA DESIGN

In this research, antenna designed using rectangular patch with dimension of width (W) and length (L). The proposed antenna is realized on single layer substrate with relative permittivity (ϵ_r) of 4.3, substrate thickness (h) of 1.6 mm and loss tangent ($\tan \delta$) of 0.0265 [11]. The dimensions of the rectangular patch antenna is given by [12] as follows.

$$W = \frac{C}{2f\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

$$L = L_{\text{eff}} - 2\Delta L \quad (2)$$

$$L_{\text{eff}} = \frac{C}{2f\sqrt{\epsilon_{\text{reff}}}} \quad (3)$$

$$\epsilon_{\text{reff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[1 + 12 \frac{h}{W}\right]^{-\frac{1}{2}} \quad (4)$$

$$\Delta L = 0,412h \frac{(\epsilon_{\text{reff}} + 0.3) \left(\frac{W}{h} + 0.264\right)}{(\epsilon_{\text{reff}} - 0.258) \left(\frac{W}{h} + 0.8\right)} \quad (5)$$

In this research, the fractal iteration is done in two stages. At the first stage the fractal antenna is done by giving a rectangular slot in the middle of the patch antenna. After that, the second-stage fractal is done by adding 8 rectangular slot around the first stage fractal. The use of fractal method gives the effect of shifting the value of the working frequency to be smaller than the frequency designed in conventional dimension. To increase the working frequency, an iteration of the antenna dimension should be done by minimizing the patch size. The dimension of fractal microstrip antenna is given by [13] can be seen at equation (6), (7) and (8). In this study, the type of fractal used to optimize the antenna is the sierpenski carpet.

$$N_n = 8^n \quad (6)$$

$$L_n = \frac{L}{3^n} \quad (7)$$

$$A_n = \frac{A}{9^n} \quad (8)$$

Figure 1(a), 1(b) and 1 (c) shown the two stages process of the fractal antenna and in Figure 2 shown the fractal antenna at the modified design with $n = 2$.

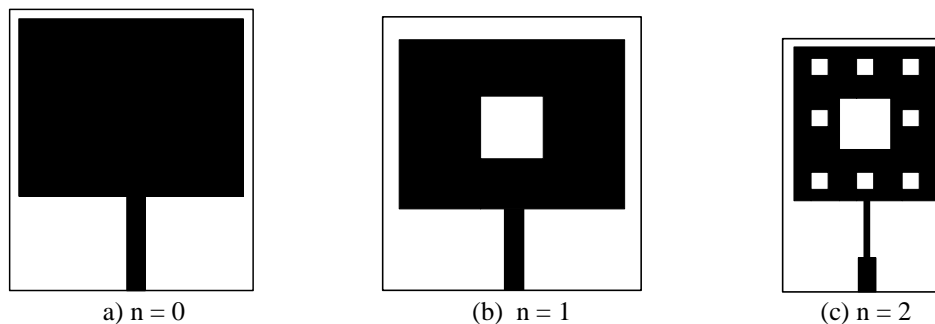


Figure 1. Sierpinski Carpet Fractal process on two stages

From Figure 1 above can be seen that the process to optimize the antenna by using fractal consists of 3 stages. The first stage is done by designing an antenna with a rectangular shape that works at 2400 MHz frequency. The second stage, to reduce the dimensions of the antenna is given a rectangular slot load load with dimensions of 10 mm x 10 mm. The impact of slot loading on the center of the initial design patch antenna will disrupt the current flow on the surface, forcing the current to winding, which then increases the electrical length of the patch. In the end, the operating frequency will drop, while the physical dimension of the patches remains. To some extent, the frequency value can be reduced by increasing the number of slot loads. In order to obtain a more optimum antenna dimensional reduction, in the third stage there are 7 slots with dimensions of 3 mm x 3 mm placed around the initial slot located in the center of patch microstrip antenna. Comparison of simulation values of the initial design antenna with the first and second stage can be seen in Figure 2 below. Comparison of simulation results from the initial design antenna with the second and third stage can be seen in Figure 2.

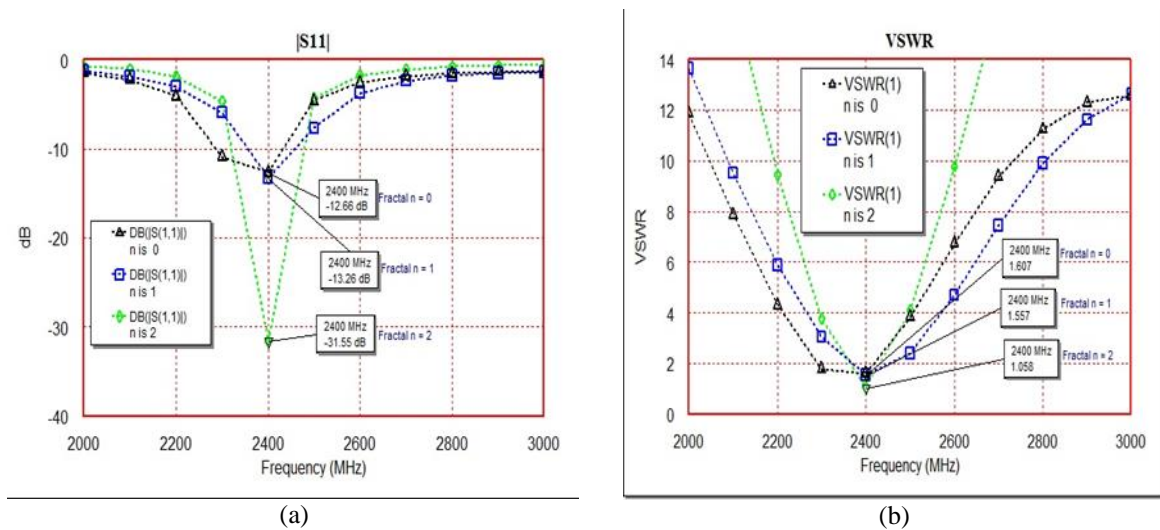


Figure 2. Comparison Simulation Result of Fractal Microstrip Antenna n=0, n=1, n=2
(a) Reflection coefficient (b) VSWR

From figure 2 (a) and (b) above it can be seen that the simulation of adding slot load at fractal stage of $n = 2$ obtains reflection coefficient of -31.55 dB and VSWR of 1.058 at 2400 MHz working frequency. The overall comparison of the fractal stage simulation process can be seen in table 1 below.

Table 1. Comparison Simulation Process of Fractal Stage

Patch Condition	Dimension of Antenna	Reflection coefficient	VSWR
n = 0	50 mm x 50 mm	-12.66 dB	1.607
n = 1	45 mm x 45 mm	-13.26 dB	1.557
n = 2	29 x 45 mm	-31.55 dB	1.058

From table 1 above it can be seen that the addition of slot load can reduce the dimension of the microstrip antenna. The size of the antenna dimension before adding the slot loading is 50 mm x 50 mm, after adding the center slot of the patch with a size of 10 mm x 10 mm, the dimensions of the antenna are reduced to 45 mm x 45 mm. Furthermore, the addition of loads of 7 slots with size of 3 mm x 3 mm placed around the slot in the middle can reduce the dimensions of the antenna reaches 29 mm x 45 mm. The design of second stage fractal microstrip antenna using sierpenski carpet can be seen in figure 3(a) and 3(b) while the dimension of fractal microstrip antenna can be seen in Table 2.

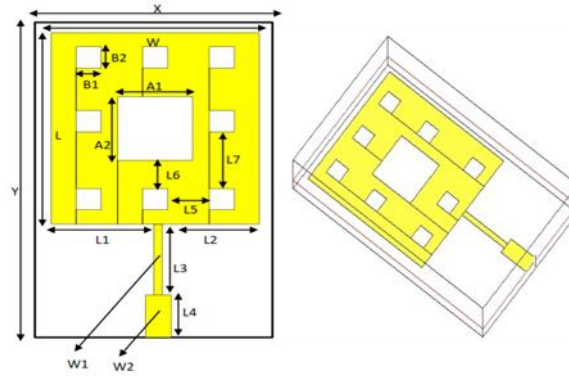


Figure 3. Sierpinski Carpet Fractal Microstrip Antenna (a) 1 Dimension (b) 3 Dimension

Table 2. Dimension of Fractal Microstrip Antenna

Parameters	Value
X	29 mm
Y	45 mm
W	25 mm
L	27 mm
L1	12.3 mm
L2	11.7 mm
L3	10 mm
L4	6 mm
L5	5 mm
L6	4 mm
L7	8 mm
A1	9 mm
A2	9 mm
B1	3 mm
B2	3 mm
W1	1 mm
W2	3.1 mm

This study uses two types of feeders with different impedance values, the first feeder (W1) has a 70.7 Ohm impedance value and a second feeder (W2) with an impedance value of 50 ohm. The first feeder is directly connected to the patch antenna while the second feeder connects directly to the connector with a 50 Ohm impedance. The use of two types of feeders is intended to reduce the reflection coefficient and VSWR value to be better. To calculate the dimension of the feeder dimension we can use the equation below [14], while the dimension of feeder length is obtained from the iteration result.

$$W = \frac{2h}{\pi} \left\{ B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left[\ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r} \right] \right\}. \quad (9)$$

$$B = \frac{60\pi^2}{Z_0 \sqrt{\epsilon_{eff}}}. \quad (10)$$

3. RESULTS AND DISCUSSION

To obtain the best simulation result, iteration process is done by changing the dimension of antenna parameter that has been designed. After having several iterations, the work frequency of antenna controlled by adjusting the dimension of the height L3 and L4. In addition, to generate the best reflected coefficient parameter values is done by controlling the slot dimensions of B1 and B2. The simulation results of reflection coefficient and VSWR from iteration process are shown in Figure 4 and Figure 5. In this research, simulation and design of microstrip antenna using AWR Microwave Office 2009.

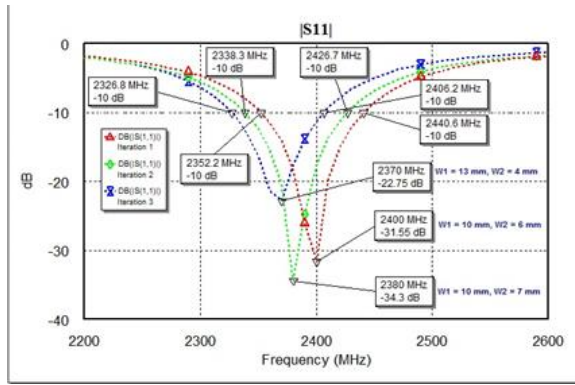


Figure 4. Simulation Result of reflection coefficient from iteration L3 and L4

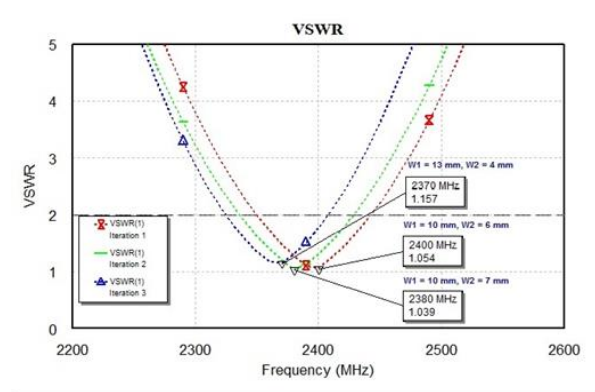


Figure 5. Simulation Result of VSWR from iteration L3 and L4

From Figure 4 and Figure 5 it can be seen that the iterations on the dimensions of L3 and L4 can adjust and control the working frequency values of the designed antenna.. The overall iterations can be summarized into Table 3 and Table 4 as follows.

Table 3. Iterations L3 and L4 of Fractal Antenna Dimension

Iterations	Parameters								
	W1	W2	L1	L2	L3	L4	L5	L6	L7
First	1 mm	3.1 mm	12.3 mm	11.7 mm	10 mm	6 mm	5 mm	4 mm	8 mm
Second	1 mm	3.1 mm	12.3 mm	11.7 mm	10 mm	7 mm	5 mm	4 mm	8 mm
Third	1 mm	3.1 mm	12.3 mm	11.7 mm	13 mm	4 mm	5 mm	4 mm	8 mm

Table 4. Simulation Result of Iteration Process L3 and L4

Iterations	Parameters			
	Reflection coefficient	VSWR	Bandwidth	Frequency
First	-31.55 dB	1.054	88 MHz	2400 MHz
Second	-34.30 dB	1.039	88 MHz	2370 MHz
Third	-22.75 dB	1.157	80 MHz	2380 MHz

From Table 3 and Table 4 it can be seen that the best simulation results are obtained at the first iteration where the values $W1 = 10$ mm and $W2 = 6$ mm. From the first iteration process obtained reflection coefficient of -31.55 dB and VSWR of 1.054 at working frequency of 2400 MHz. In the second and third iterations, the antenna's working frequency has shifted to 2380 MHz and 2370 MHz.

After that, the next stage is to optimize the antenna by doing iteration of slot size of B1 and B2. The purpose of controlling the slot dimension is to obtain the best reflected coefficient and VSWR values of the designed antenna. The overall result of the slot size iteration process of B1 and B2 can be seen in the figure 6(a) , 6(b) and table 5.

Table 5. Iterations B1 and B2 of Fractal Antenna Dimension

Iterations	Parameters			
	A1	A2	B1	B2
First	9 mm	9 mm	3 mm	3 mm
Second	9 mm	9 mm	4 mm	4 mm
Third	9 mm	9 mm	4.5 mm	4.5 mm

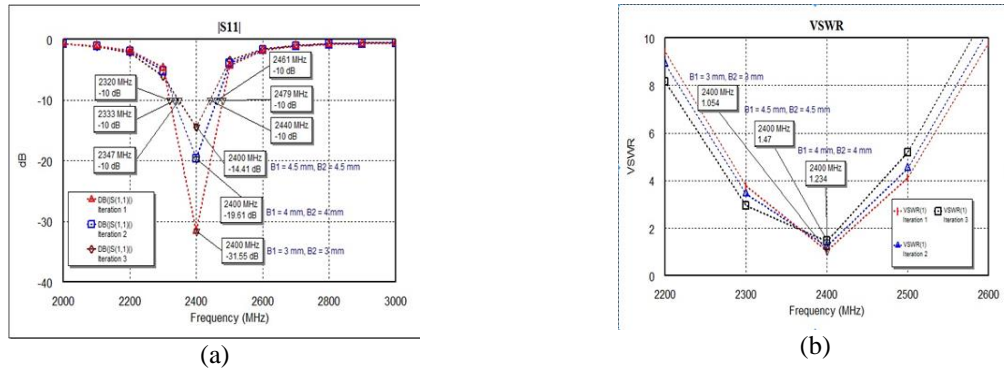


Figure 6. Comparison Simulation Result of Iteration B1 and B2
 (a) Reflection coefficient (b) VSWR

From Figure 6 (a) and 6 (b) above it can be seen that the simulation results of the reflected coefficient, VSWR and bandwidth of the designed antenna can be controlled by changing the size of the slots B1 and B2. In the second and third iteration obtained return loss value of -19.61 dB and -14.41 dB at working frequency of 2400 MHz. The best simulation values obtained at the first iteration with the size of B1 and B2 of 3 mm with a reflection coefficient value of -31.56 dB and VSWR of 1.054 at working frequency of 2400 MHz. The overall result of the iteration process from B1 and B2 can be seen in table 6 below.

Table 6. Simulation Result of Iteration Process B1 and B2

Iterations	Parameters			
	Reflection coefficient	VSWR	Bandwidth	Frequency
First	-31.55 dB	1.054	159 MHz	2400 MHz
Second	-19.61 dB	1.234	128 MHz	2400 MHz
Third	-14.41 dB	1.470	93 MHz	2400 MHz

From table 6 above it can be seen that the bandwidth of the design antenna can be increased by controlling the slot size of B1 and B2. In the first iteration obtained bandwidth of 159 MHz (2320 - 2479 MHz), the second iteration of 128 MHz (2333 - 2461 MHz) and the third iteration of 98 MHz (2347 - 2440 MHz). From the overall results obtained, it can be concluded that the best results were obtained during the first iteration with slot size of B1 and B2 of 3 mm.

After obtaining the best simulation results from the iteration process, the next stage is to fabricate the fractal microstrip antenna that has been designed. The type of substrate used for fabrication is FR4 Epoxy double layer type $\epsilon_r = 4.3$ and $h = 1.6$ mm with the antenna element at the top and ground on the bottom side of the substrate. The type of connector used for fractal microstrip antennas is Female SMA Connector with 50 Ohm impedance. The fabrication result of fractal microstrip antenna can be seen in figure 7 (a) and 7 (b) below.

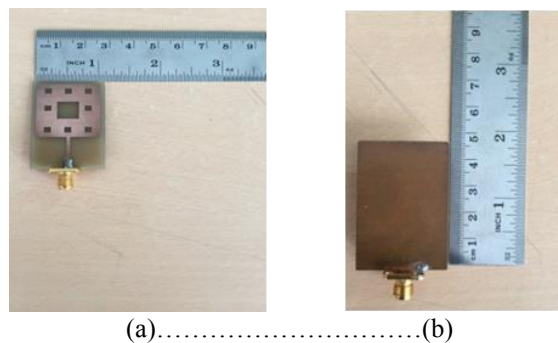


Figure 7. Fabrication Result of Fractal Microstrip Antenna (a) Top Layer (b) Bottom Layer

The next step is to measure the performance of the antenna that has been designed. The antenna parameters measured and observed are reflection coefficient and VSWR. The results of the measurement process will be compared with the results obtained from the simulation process with the software. Comparison of measurement results with simulation results of reflection coefficient and VSWR of antennas that have been designed can be seen in Figures 8 and 9. The measurement process is done by connecting the antenna with Vector Network Analyzer.

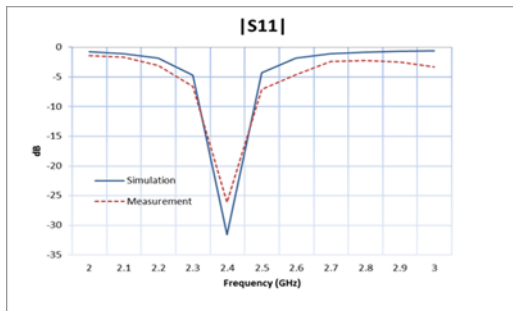


Figure 8. Comparison between Simulation and Measurement Result of Reflection coefficient

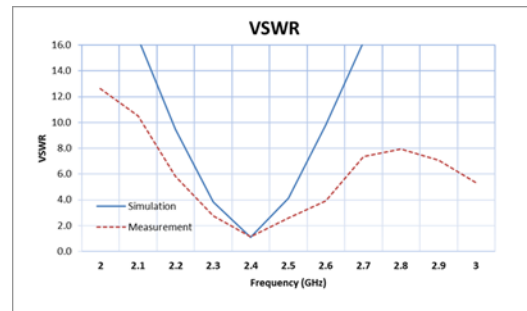


Figure 9. Comparison between Simulation and Measurement Result of VSWR

From the Figure 8 and Figure 9 can be seen that from the measurement results obtained the reflection coefficient of -26.10 dB and VSWR of 1.10 at 2400 MHz working frequency. The bandwidth obtained from the measurement result is 127 MHz with a frequency range of 2338 MHz - 2465 MHz. The overall comparison of simulation and measurement results can be seen in Table 7.

Table 7. Comparison between Simulation and Measurement Result

Condition	Parameters			
	Reflection coefficient	VSWR	Bandwidth	Frequency
Simulation	-31.55 dB	1.054	159 MHz	2400 MHz
Measurement	-26.10 dB	1.10	127 MHz	2400 MHz

From Table 7 it can be seen that the reflection coefficient, VSWR and bandwidth value of the measurement process decreased compared with the result of the simulation process. This is because the value of loss tangent ($\tan \delta$) of FR4 substrate used is still quite large around 0.0265, besides that the other factor is from the low level of accuracy of the fabrication process causing dimensional reduction of patch antenna that decreases the value of reflection coefficient, VSWR and bandwidth. Fractal method also succeeded in reducing dimension of microstrip antenna, comparison of microstrip antenna dimension before and after using fractal method can be seen in figure 10 (a), 10 (b) and table 8 below.

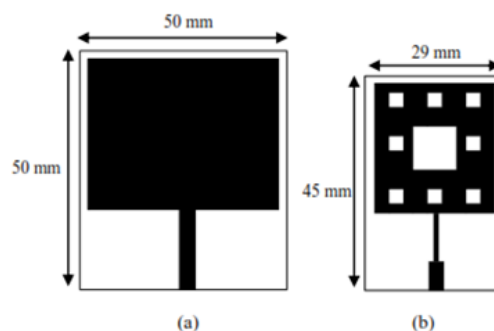


Figure 10. Comparison Dimension of Microstrip Antenna (a) Rectangular Patch (b) Fractal Patch

Table 8. Comparison Dimension of Antenna between Rectangular and Fractal

Patch of Microstrip Antenna	Dimension Patch Of Antenna
Rectangular	50 mm x 50 mm
Fractal	29 mm x 45 mm

From figure 10 and table 8 above it can be seen that the dimensions of the microstrip antenna after using the fractal method are reduced. The patch dimension of designed antenna was reduced up to 47.80% compared with rectangular patch of microstrip antenna. In figure 11 and 12 below can be seen the value of the gain and radiation pattern of the fractal antenna that has been in the design.

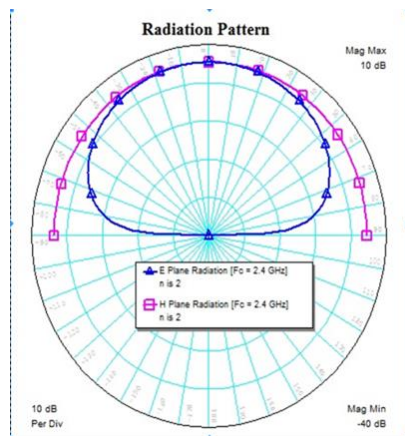


Figure 11. Radiation Pattern of Fractal Microstrip Antenna

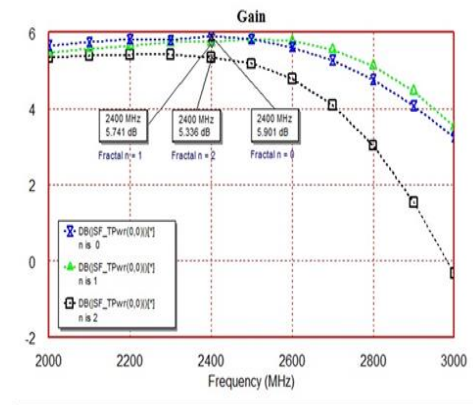


Figure 12. Gain of Fractal Microstrip Antenna

From Figure 11 above it can be seen that fractal antennas that have been designed to produce radiation patterns are broadside, whereas in Figure 12 it can be seen that fractal antenna produce gain of 5.336 dB at working frequency of 2400 MHz. The gain of the fractal antenna decreases due to the smaller size of the antenna so that the amount of electric current flowing on the patch antenna also decreases.

From the overall results obtained can be analyzed that to reduce the dimensions of microstrip antenna can be done by using fractal method. To control the working frequency of an antenna can be done by adjusting the dimensions of L3 and L4. In addition, to generate the best reflected coefficient parameter values is done by controlling the slot dimensions of B1 and B2. The dimensions of the microstrip antenna can be reduced up to 47.80% by not changing the predetermined working frequency of 2400 MHz. Beside that, fractal microstrip antenna produce gain of 5.34 dB and bandwidth of 127 MHz. From the overall results it can be seen that fractal method can produce small microstrip antenna and stable gain when compared with other method used to reduce antenna dimension. The results of this study also compared with the research that has been done by previous studied that can be seen in table 9 below.

Table 9. Comparison Dimension of Patch Antenna with the other studied for Wireless Fidelity Application at 2.4 GHz

Title	Reflection Coefficient	Frequency	Parameter Dimension	Percentage of Reduction	Gain
Proposed Antenna	-26.10 dB	2.4 GHz	29 mm x 45 mm	47.80 %	5.34 dB
[15]	-22.30 dB	2.4 GHz	59 x 52 mm	33.1 %	3.45 dB
[9]	-24.54 dB	2.4 GHz	30 mm x 38 mm	58.7 %	3.47 dB
[16]	-16.80 dB	2.4 GHz	14.45 mm x 19.22	73.5 %	2.20 dB

4. CONCLUSION

A new design of fractal microstrip antenna using sierpenski carpet is eventually well proposed. From the measurement results obtained reflection coefficient of -26.10 dB and VSWR of 1.10 at 2400 MHz. The working frequency and bandwidth of the antenna can be controlled by adjusting the length of L3, L4, B1 and B2. Designed antennas generate 127 MHz bandwidth with a frequency range of 2338 MHz - 2465 MHz and gain of 5.336 dB. The sierpenski fractal method succeeded in reducing the dimensions of the microstrip antenna up to 48.70% compared to the rectangular microstrip antenna without changing the working frequency of 2400 MHz for Wireless Fidelity Application.

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