Design of Hybrid Koch-Minkowski Fractal Dipole Antenna for Dual Band Wireless Applications

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Abstract — **In many wireless applications, antenna comes with variable sizes. The interest for small and compact antennas in wireless applications is increasing due to the mobility of the wireless devices. Internet of Things (IoT) defined as a network of small, low cost, low power, ubiquitous electronic devices. It is expected that WiFi proves to be one of the solutions for IoT technology. WiFi Alliance has introduced an unlicensed band of 900 MHz (HaLow) in 2017 to support IoT which requires low power, high data rate and long range. Hence, the demand for small antennas is substantial especially due to the booming industry in mobile communication. Generally, an antenna at low frequency exhibits large size of antenna. This paper presents the design of fractal dipole antennas for dual band wireless applications. The designs are based on hybrid Koch-Minkowski fractal method for the benefits of miniaturization. The antenna designs have been simulated using CST Microwave Studio and fabricated using Rogers 5880 substrate. Based on the results, it is observed that the fractal antennas are able to operate at dual frequencies, at 900 MHz and 2.6 GHz with return loss of 18dB and 16 dB respectively. The small size, thin and lightweight of antenna design (115 mm x 22.5 mm x 0.285 mm) makes it an attractive feature for compact wireless applications.**

Index Terms — Fractal Antenna, Koch, Minkowski, Dual Band

I. Introduction

The development of technology nowadays is growing rapidly, almost everything in the world and human life will be affected by the Internet. We are beginning to be involved in the era of the Internet of Things (IoT). The internet connectivity is all over, which has connection almost every area of the world and also transformed human life's in unpredictable manners [1, 2]. The examples of IoT devices are sensors, attenuators, transceivers and processors [1], where sending the information and communicating the data happen without the intervention of humans.

An antenna is known as a transducer. The attraction to the small antenna in this era increases due to fast-growth in an industry of mobile communications [3, 4]. The demand not only involved the small size of an antenna, but better performance and efficiency need to be considered. However, due to the limitations on fundamental of size and performance (Chu's limit), achieving the miniaturization antenna in better performance is challenging. The small size of an antenna can be defined as the antenna size should lower than its wavelength. It can be described in different wavelengths such as one-quarter wavelength (1/4), one-eight wavelength (1/8) or one-tenth wavelength (1/10).

For this research, a few of antenna designs at low frequency of 900 MHz are proposed according due to the new band introduced by WiFi Alliance [5] or known as WiFi HaLow. WiFi HaLow operates in frequency below 1 GHz which is 900MHz and offers a longer range. It also enabled at lower power connectivity and required lower frequency. The lower frequency is better in penetration and propagation which WiFi HaLow has the ability to go through walls and other obstacles. And IoT applications nowadays required low power and long-range connections.

The problem faced for low operating frequency is due to the large the size of antenna. It is due to the fact as the size of antenna is inversely proportional to operating frequency. Miniaturization is the most important key to overcome the large size of the antenna. Many miniaturization techniques have been discussed as in [6]. These includes meander-line techniques [7-9], fractals [10-11] and metamaterials [12]. For miniaturization technique, the fractal antenna has been chosen. Fractal shapes have revolutionized in the design for small size and multiband antenna [11]. Fractal shapes are generated by using recursive procedures which produce large surface area in limited space [13, 14]. Thus, geometries, dimensions, self-similarity and space filling of fractal structures are important deciding factors of the fractal antenna design [15].

This research presents the simulation and measurement results of the hybrid Koch-Minkowski. It was observed that the simulation and measurement results are in closer agreement with each other as compared with the article in [16] especially at 900 MHz. Moreover, the small size antenna designs exhibit dual band characteristics which are at 900 MHz and 2.6 GHz, suitable for wireless applications.

II. DESIGNS PARAMETERS CALCULATION

Koch's structure is from self-repetition fractals. The fractal antenna dimension can generate by Iterated Function System (IFS). IFS function by applied a series of affine transformations w to an elementary shape A over much iteration. The affine transformations in the plane, w comprised the rotation, scaling and translation [11].

$$\omega\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix} = A_x + t \qquad (1)$$

The matrix A is

$$A = \begin{pmatrix} \frac{1}{s}\cos\theta & -\frac{1}{s}\sin\theta \\ \frac{1}{s}\sin\theta & \frac{1}{s}\cos\theta \end{pmatrix} \qquad (2)$$

The scaling factor, $\frac{1}{s}$ which mean the factor of measure of self-function.

$$\frac{1}{s} = \frac{1}{2(1+cos\theta)} \qquad (3)$$

Resonant frequency of antenna is calculated using equation (4).

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{re}}} \qquad (4)$$

where l is the effective length, L is the resonate length, c is the speed of light, $\varepsilon_{re}$is the effective dielectric constant and f_r is the resonance frequency of the antenna.

The antenna designs are based on combination of Koch Fractal at second iteration and Minkowski's as referred in [16]. After getting the basic design, the alteration and addition on the design has been performed to achieve the goals of the resonant frequency, 900MHz.

III. METHODOLOGY

A. Antenna Design (Design 1)

Table 1 below shows the dimension of fractal antenna for design 1. The dimension is used to construct the proposed antenna at the 900MHz in Figure 1. The design and calculation are based on combination of Koch-Minkowski as referred in [16, 18].

Table 1. Dimensions of fractal antenna design 1

Antenna parameters	Value	Unit
Resonant frequency, f	900	MHz
Length of antenna, L	120.00	mm
Width of antenna, W	25.00	mm
Thickness of substrate, h	0.285	mm
Gap between arms, G	0.93	mm
Thickness of copper, t	0.035	mm
Dielectric Constant, εr	2.20	-

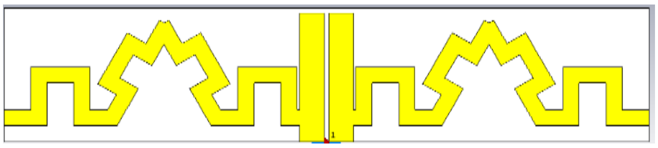

Figure 1. Fractal antenna for design 1.

B. Antenna Design (Design 2)

The dimensions of fractal antenna for design 2 are shown below in Table 2. The design has been adjusted in order to reduce the size of the antenna. Figure 2 displayed the top view of fractal antenna based on the dimension in the Table 2.

Table 2: Dimensions of fractal antenna design 2

Antenna parameters	Value	Unit
Resonant frequency, f	900	MHz
Length of antenna, L	115.00	mm
Width of antenna, W	22.50	mm
Thickness of substrate, h	0.285	mm
Gap between arms, G	1.50	mm
Thickness of copper, t	0.035	mm
Dielectric Constant, εr	2.20	-

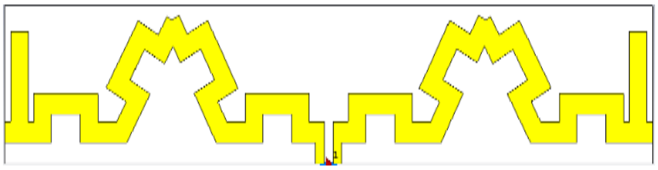

Figure 2: Top view of fractal antenna design 2.

C. Antenna Design (Design 3)

Table 3 below shows the parameters of fractal antenna for design 3. Figure 3 shows the fractal antenna design based on the dimension as stated in the table 3.

Table 3: Dimensions of fractal antenna design 3

Antenna parameters	Value	Unit
Resonant frequency, f	900	MHz
Length of antenna, L	108.00	mm
Width of antenna, W	24.00	mm
Thickness of substrate, h	0.285	mm
Gap between arms, G	1.50	mm
Thickness of copper, t	0.035	mm
Dielectric Constant, εr	2.20	-

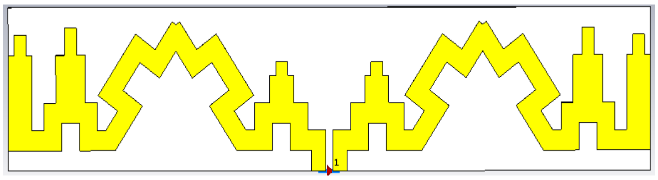

Figure 3: Top view of fractal antenna design 3.

IV. Antenna Fabrication

Figure 4 shows fabricated antenna with dimension of length is 12 cm and width is 2.5 cm. The size of antenna design 2 is 11.15 cm x 2.25 cm as shown in Figure 5. The fabricated antenna for design 3 is shown in Figure 6 below with dimension of the antenna is 10.8 cm x 2.4 cm.

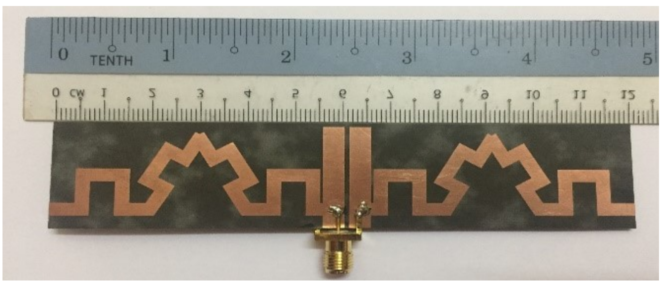

Figure 4: Fabricated of Antenna Design 1

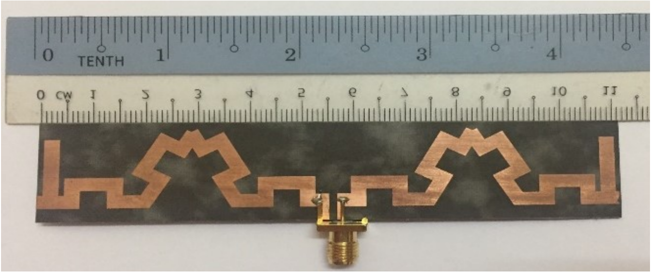
Figure 5: Fabricated of Antenna Design 2

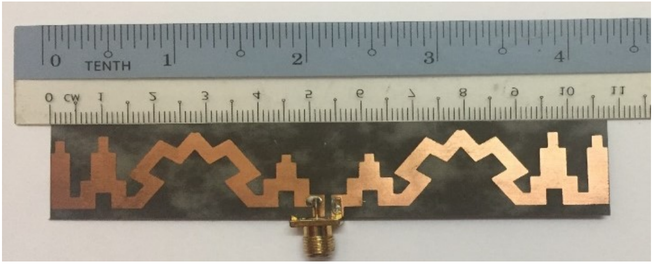
Figure 6: Fabricated of Antenna Design 3

V. Results and Analysis

A. S_{11} Parameters

Based on the simulation results for the fractal antenna designs, all antennas achieved specification at desired resonant frequency, which is at 900 MHz. Figure 7 compares the simulation results between design 1, 2 and 3 while table 4 summarizes the performance of each antenna designs. It is observed from the simulation results that another resonance appeared at high frequency, 2.6 GHz. This is due to the combination of Koch-Minkowski which lead to dual frequencies, 900 MHz and 2.6 GHz. Figure 8 shows comparison of measurement results between 3 designs. Fig. 9, 10 and 11 shows the comparison between simulation and measurement results respectively between design 1, 2 and 3. It is observed that the simulation and measurement results are in good agreement with each other.

In addition to that, it was observed that the resonance frequencies of the fabricated fractal antenna designs are shifted from 900 MHz to 872 MHz. The reason might be due to port assigned in simulation which is not equivalent to SMA connector that has been soldered to the antenna in practice. However, the difference between simulation and measurement results are small which still acceptable for antenna design at 900 Mhz. Moreover, an interesting finding has been observed which is the second resonance frequency existed at 2.6 GHz which makes the antenna designs (Design 1, 2 and 3) are dual-band antenna. This is largely due to the fact of combination of Koch and Minkowski fractal types of the antenna design. Thus, the antennas are able to operate not only at low frequency (875 MHz) but also at high frequency (2.6 GHz). In terms of small size, Design 2 has the smallest dimension in comparison to other designs. However, in terms of best S_{11} parameters at 900 MHz, Design 2 has the lowest S_{11} values compared to the other two designs.

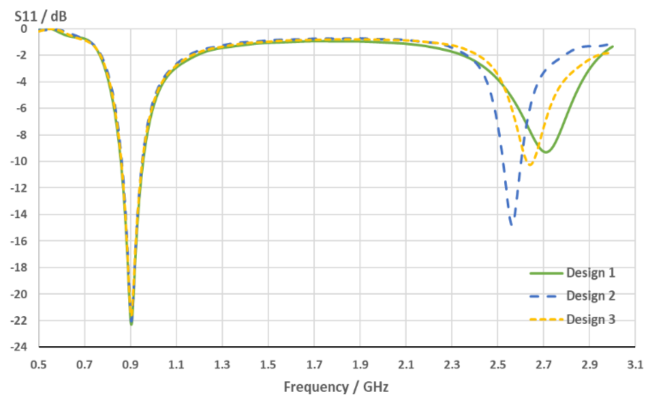

Figure 7 Comparison of S_{11} simulation results for antenna design 1, 2 and 3.

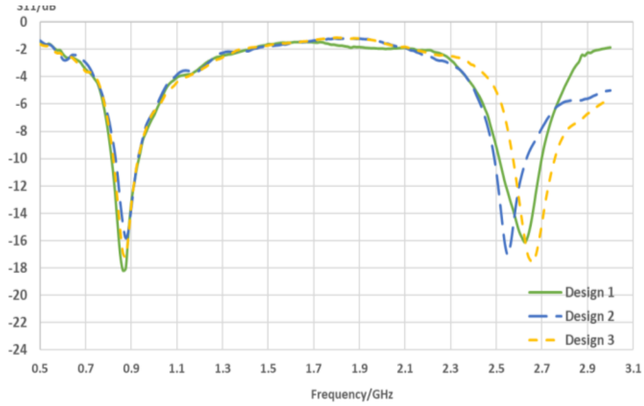

Figure 8 Comparison of S11 measurement results for antenna design 1,2 and 3.

The graph shown in Figure 9, 10 and 11 plotted the S11 simulation and measurement results for antenna design 1, 2 and 3 respectively. In Figure 9, the simulated result resonates at 900 MHz and 2.7 GHz with values of -22.3 dB and -9.8 dB respectively. The measurement result differs slightly with simulation results, which are at 875.77 MHz and 2.63 GHz with the S11 values of -18.0 dB and –16.1 dB respectively.

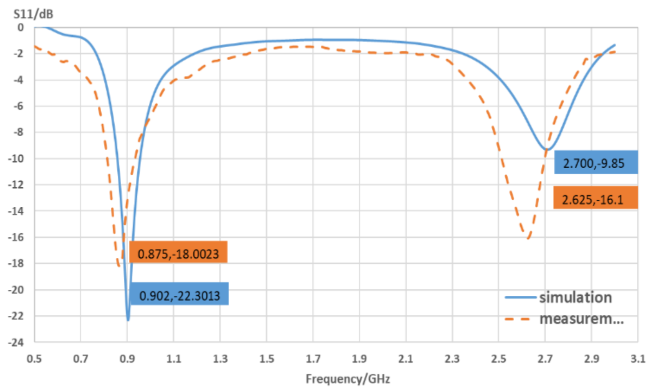

Figure 9 Comparison of S11 between simulation and measurement results for antenna design 1

Based on Figure 10 as shown below, S11 parameters for design 2 are displayed on the graph. The simulation result resonates at 900 MHz and 2.58 GHz with values of -22 dB and -14 dB respectively. The measurement result differs slightly with simulation results, which are at 875 MHz and

2.55 GHz with the S11 values of -15.8 dB and –17.1 dB respectively.

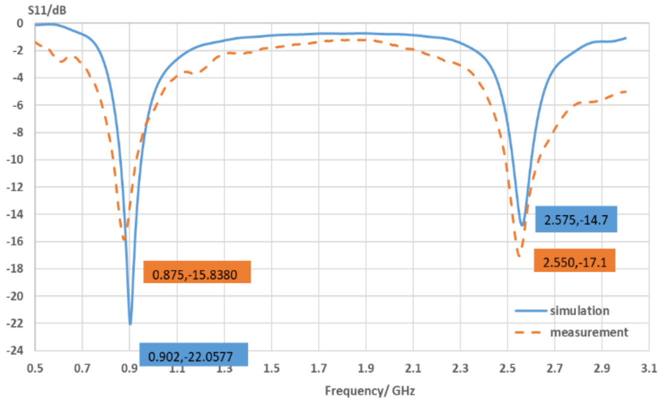

Figure 10 Comparison of S_{11} simulation and measurement results for antenna design 2.

According to Figure 11, the simulation result resonates at 900 MHz and 2.65 GHz with values of -21.7 dB and -10.2 dB respectively. The measurement result differs slightly with simulation results, which are at 875 MHz and 2.66 GHz with the S11 values of -17.2 dB and –17.6 dB respectively.

Based on the simulation results for the dipole antenna, printed patch antenna and fractal antenna, all antennas achieved specification at desired resonant frequency, which is 900 MHz. Table 4 below shows the comparison of fractal antenna design 1, 2 and 3 after simulation using CST software. While Table 5 shows the comparison of the measurement results between fabricated antenna 1, 2 and 3.

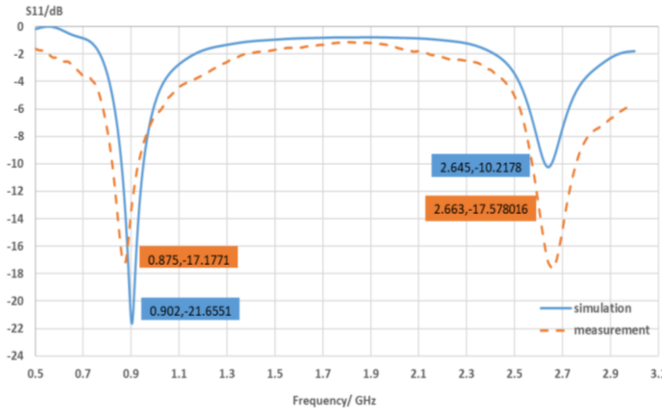

Figure 11 Comparison of S_{11} simulation and measurement results for antenna design 3.

Table 4: Comparison between simulation results.

Parameters	Design 1	Design 2	Design 3
Frequency	900 MHz	900 MHz	900 MHz
S_{11}	-19.291 dB	-19.799 dB	-19.261 dB
Bandwidth	0.0932 GHz	0.0873 GHz	0.0889 GHz

Bandwidth	10.35%	9.70%	9.88%.
Gain	2.090 dB	2.068 dB	2.069 dB
Radiation Pattern	Omni-directional	Omni-directional	Omni-directional
Dimension	120 mm x 25 mm x 0.285 mm	115 mm x 22.5 mm x 0.285 mm	10.8 mm x 24 mm x 0.285 mm

B. Radiation Pattern

The simulated radiation pattern for each antenna design are displayed in Figure 12 (a-c) at resonant frequency of 900 MHz. It was observed that they exhibit omnidirectional radiation pattern at 900 MHz.

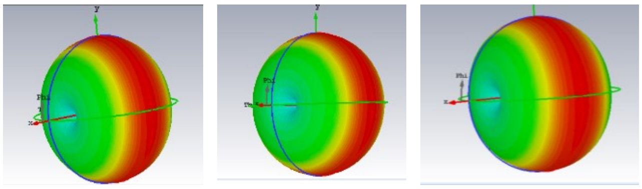

Figure 12. Radiation Pattern of Antenna a) Design 1, b) Design 2, c) Design 3 that exhibits omnidirectional at 900 MHz.

C. Comparison of the Antenna Designs

By comparing the size of the antennas, design 2 have the smallest size compared to design 1 and design 3. The total size of design 2 is 737.44 mm^3. However, Design 2 the lowest S_{11} measured parameters at 875.7 MHz. However, S_{11} parameter for simulation is lower compared to measurement result. This is due to the losses, tolerance and also error that occurred during fabrication process of antennas. Table 5 depicts the comparison of antenna design with respect to size, resonant frequencies and bandwidth.

VI. Conclusion

The simulation and measurement-based miniaturization antenna using fractal antenna has been performed. This research has been introduced to study how much antenna size can be reduced by using fractal at the same time able to resonate at required frequency. The simulation and measurement results display that the three proposed design are able to operate in desired frequency of 900 MHz and also at high frequency of 2.6 GHz. This antenna can be used as dual band antenna.

The fractal antennas have been fabricated to validate the antenna performances especially in terms of S11 parameter by conducting the measurement. The simulation and measurement results show that they are in good agreement with each other. A slight difference is due to the losses, tolerance as well as fabrication error when constructing the antenna. However, the antennas have good performance because S11 value is lower than -10 dB. Thus, fractal antenna can be used to reduce the size of the antenna.

Table 5: Comparison between measurement results.

Parameters	Ref [16]	Design 1		Design 2		Design 3	
Desired Frequency	900 MHz	900 MHz		900 MHz		900 MHz	
S_{11}	-19.9dB	-15.296 dB		-17.763 dB		-16.136 dB	
Resonant Frequency	859 MHz	875.7 MHz	2.63 GHz	875.7 MHz	2.55 GHz	875.7 MHz	2.66 GHz
S_{11}	-19.89dB	-18.8 dB	-16.1 dB	-15.8 dB	-17.1 dB	-17.2 dB	-17.6 dB
Bandwidth	856-892MHz (4.2%)	820-930MHz (12.5%)	2.52-2.7GHz (6.8%)	820-930MHz (12.5%)	2.49-2.63GHz (5.50%)	820-930MHz (12.5%)	2.57-2.77GHz (7.52%)
Dimension of antenna (L x W)	$0.32\lambda_0$ x $0.072\lambda_0$	$0.35\lambda_0$ x $0.073\lambda_0$		$0.34\lambda_0$ x $0.066\lambda_0$		$0.32\lambda_0$ x $0.07\lambda_0$	

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