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Fractal Yagi-Uda antenna for WLAN applications

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Abstract

This paper describes the development of a Fractal printed Yagi-Uda antenna for wireless local area network (WLAN) applications operating at 2.4 GHz frequency. In miniaturizing the dimensions of an antenna, fractal method is applied where the first iteration and second iteration is implemented. The Computer Simulation Technology (CST) software is used as the platform to design and simulate the antenna. The substrate material used is the FR-4 board which has a dielectric constant of 5.4, the thickness of 1.6 mm and tangent loss of 0.019. The antenna performance interm of the reflection coefficient, radiation pattern and gain are compared and analyzed. For the first iteration, 22.81% of reduction size has been achieved and 30.81% reduction of the antenna size for second iteration has been achieved.

***Keywords**: fractal antenna, Koch curve, WLAN, Yagi-Uda antenna*

1. Introduction

Lately, wireless local area network (WLAN) technologies are extremely popular for wireless communication because of their advantage such as high data rate transfer with limitless internet access. Previous research shows that for WLAN system that operates in 2.4 GHz frequency, ceramic chip and monopole antenna are widely used [1-5] plus numerous planar antennas presented in [6] for WLAN applications, but the flaws that comes with them are low gain and low power control capacity. However, by using a patch Yagi-Uda antenna, these limitations can be overcome. The Yagi-Uda antenna is one of the popular and most successful RF antenna designs for directive antenna applications. Originally, it was used in domestic application for receiving signals for televisions, but recently it is used for an extensive variety of applications where antenna design with high gain and directivity is required [7-11].

Yagi-Uda, which is also known as the Yagi antenna, is a directional antenna encompasses a driven element which is generally a dipole other parasitic element called the reflector and the directors [12]. The Yagi-Uda antenna is directional along the axis perpendicular to the dipole in the plane from the reflector towards the director's element. Figure 1 shows the diagram of the graphic configuration of a Yagi antenna.

Depending on specific design, typical spacing's for a Yagi-Uda antenna between elements vary from about 0.1 λ to 0.25 λ. According to the general design of a Yagi antenna, the director's length is smaller than the driven element, and the driven element are smaller than the reflector. Directional pattern with gain of the antenna are produced by the directors. The total gain is directly proportional to the dimension of the antenna array not by the number of directors used. The spacing of the directors range from 0.1 λ to 0.5 λ or more and will depend mostly up to the design specification [13, 14]. The reflector is the element that is positioned at the back of the driven element. The reflector length is generally 0.5 λ longer than the director's length with low resonant frequency and the director's length is approximately 0.5 λ shorter than the driven element. Its length will vary according to the other element spacing and diameter. The length of the reflector to the driven element is between 0.1 λ and 0.25 λ. Its length will depend upon the gain, bandwidth forward/backward ratio, and side lobe pattern requirements of the final antenna design [15, 16]. The Yagi antenna is known as a directional type antenna because power is

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radiated in one direction where it can transmit and receive signals with lower interference in that particular direction [17].

Designing a Planar Yagi antenna for wireless sensor network will produce a compact size antenna which is suitable for its application. Besides, a more miniaturize and compact size Yagi antenna can be acquired by using fractal technique. Fractal structure antennas have been proved to have unique appearance and features related to the geometry characteristics of fractal. In recent years, many antenna configurations have been developed and experimented on fractal geometries [18, 19]. These configurations have been specifically helpful in miniaturizing the size of the antenna [20].

Benoit Mandelbrot in 1975 originally defined fractals as a technique of classifying structures whose dimensions were not whole numbers [21]. The potential to improve input matching and reducing the size of antenna have been revealed by fractal antennas. Additionally, fractal structures antennas can be employed in a variety number of applications, specifically for limited space area. Besides fractal technique, Hilbert curve, Minkowski, Koch curve, and other structures are effectively to reduce antenna size. The potentialities of these configurations bring massive interest to antenna design since it can save cost in term of fabrication process and also space [22].

The benefit to a dipole antenna by using fractal method can reduce the total height of the antenna resonance. The geometry of Koch dipole is shown in Figure 2 [23]. By transforming the middle third of the straight part to curved or angled part of wire that spans the original third, a Koch curve is produced. Every iteration adds length to the total curve which produces in a total length that is 4/3 the original geometry [24], in other words, a straight line in a Koch curve is created by dividing it into three segments where the three segments lengths are identical [25, 26]:

$$L_{koch} = L_0.(\frac{2+cos\emptyset}{3}) \quad (1)$$

where
L_{Koch} = total length of Koch curve
L_0 = initiator length
Ø = flare angle degree

The proposed antenna is design at the resonating frequency of 2.4 GHz. In implementing fractal method to Yagi antenna, all elements are fractalize using the first iteration and second iteration. The performance between zeroth, first, and second iteration is compared in terms of its directivity, gain, radiation pattern, and return loss.

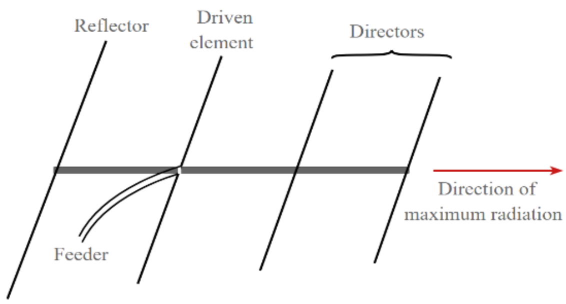


Figure 1. General configuration of Yagi antenna

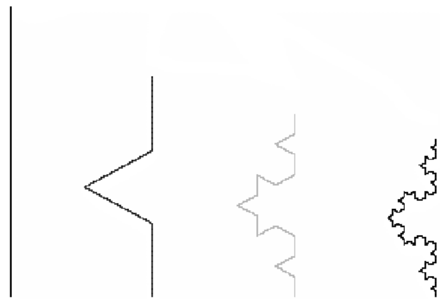


Figure 2. General of Koch dipole (from left, zeroth iteration, first iteration, second iteration, and third iteration [23]

2. Description of Antenna

The printed Yagi antenna is design with a reflector, driven elements, and 5 directors according to Table 1 parameters. The space between reflectors and driven element, the space between driven element and directors, and space between directors are also shown in Table 1. For the zeroth, first, and second iteration Yagi antenna, all of the spacing parameters are the same as the Yagi antenna dimensions in Table 1.

Table 1. Yagi Antenna Dimensions

Elements	Width (mm)	Length (mm)
Reflector	12	55
Driven element	2.5	40.6
Directors	1.78	31.25
Spacing between reflectors and driven element	-	11.75
Spacing between driven element and directors	-	12.11
Spacing between director	-	12.78

Figure 3 shows the antenna design, having dimension sides of 93.75×55 mm FR4 (Flame Resistant 4) with a dielectric constant 5.4 and thickness of 1.6 mm. After applying first iteration fractal, the printed Yagi antenna is more compact with a size of 87.66×45.41 mm and as for the second iteration, the size of the antenna reduces more to 83.2×42.88 mm as shown in Figure 4. The reflector and directors are also applied with the Koch curve.

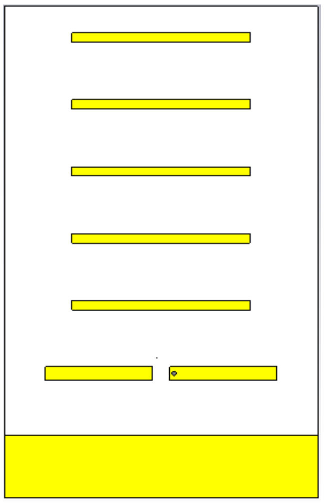


Figure 3. Standard design of Yagi antenna with dipole excitation (zeroth iteration)

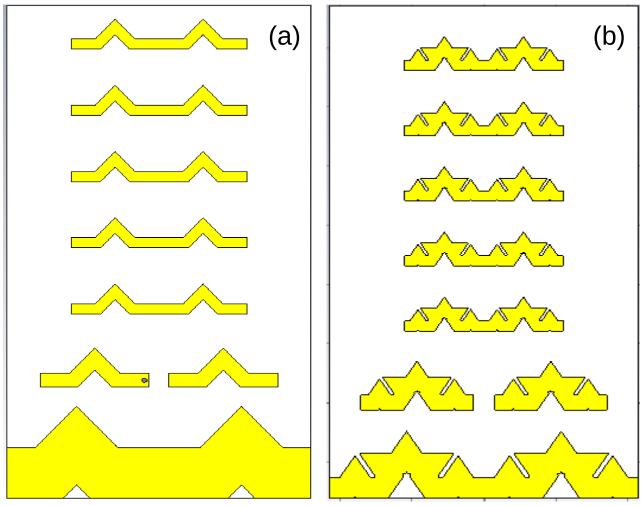


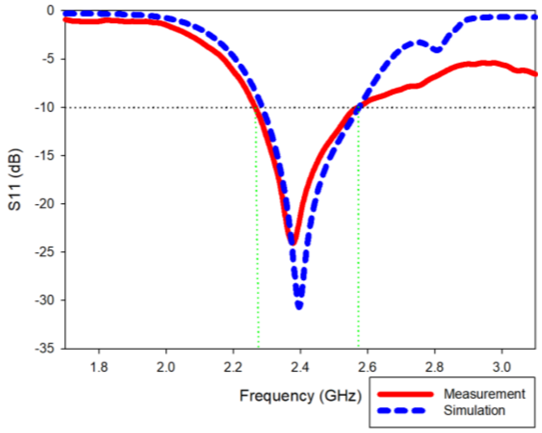
Figure 4. Yagi antenna with dipole excitation for (a) first iteration and (b) second iteration

3. Results and Analysis

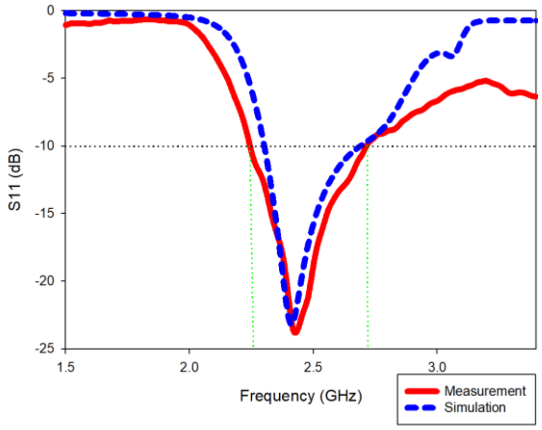
The proposed antenna was simulated using the Computer Simulation Technology (CST) software and fabrication was done also to compare measurement with simulation results. Various parameters such as reflection coefficient, bandwidth, radiation pattern, gain, directivity, and the size of the antenna are studied. Table 2 shows the dimensions of the Yagi antenna plus size reduction percentage after applying Koch curve for the zeroth iteration, first iteration, and second iteration. After applying fractal method for first and second iteration, there's a decrease in term of its directivity, and gain. The comparison of simulation and measurement for zeroth iteration Yagi antenna is shown in Figures 5 (a)-(c) for zeroth, first, and second iteration respectively. Figure 6 shows the H-Plane and E-Plane radiation pattern for the zeroth, first and second iteration. Table 3 depicts the performance between the three antenna.

Table 2. Performance Differences

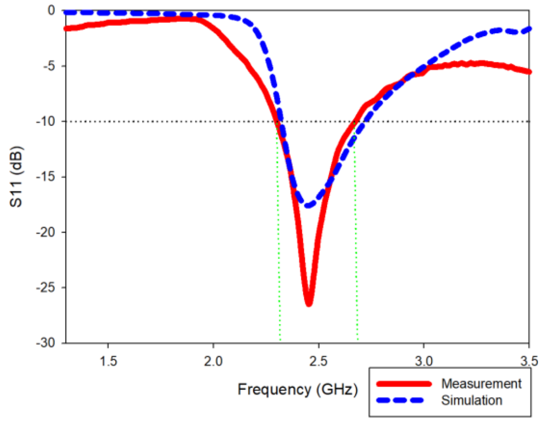
Description	Dimension (L × W × t) (mm)	Size of reduction from 0^{th} iteration (%)
0^{th} iteration	93.75×55×1.6	-
1^{st} iteration	87.66×45.41×1.6	22.8%
2^{nd} iteration	83.2×42.88×1.6	30.81%



(a)



(b)

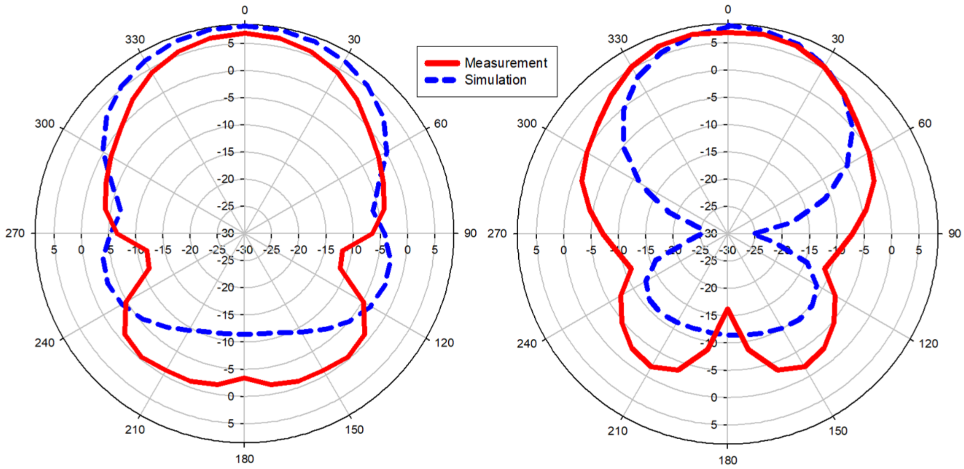


(c)

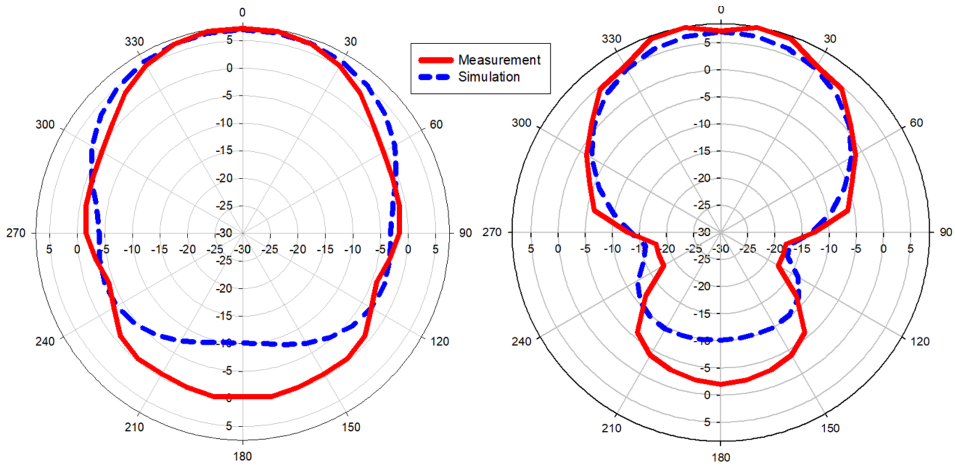
Figure 5. S_{11} Reflection coefficient for (a) zeroth iteration, (b) first iteration, and (c) second iteration

Table 3. Simulation Performance Differences between Zeroth Iteration, First Iteration, and Second Iteration

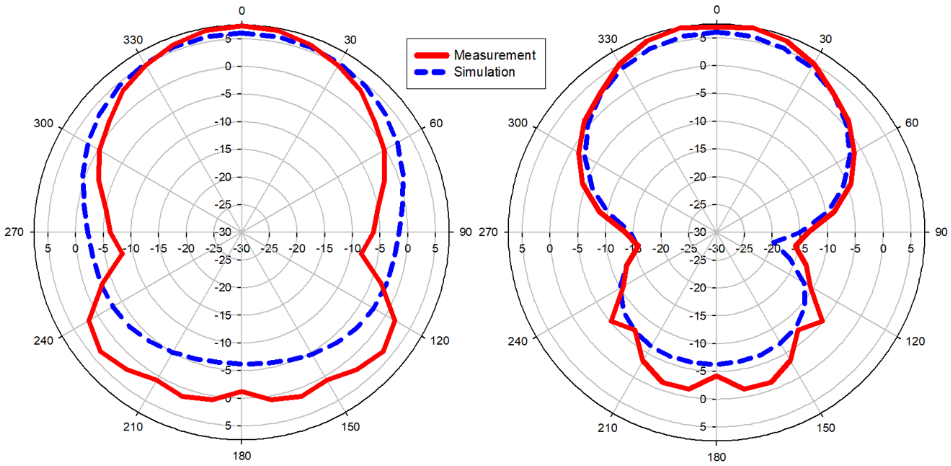
Antenna	Directivity (dBi)	Gain (dB)	Bandwidth (GHz)	Return loss (dB)
0th iteration	8.77	8.22	2.26-2.57	-30.23
1st iteration	7.57	7.07	2.3-2.6	-22.82
2nd iteration	6.67	6.17	2.32-2.7	-17.58



(a)



(b)



(c)

Figure 6. Radiation pattern H-Plane and E-Plane for (a) zeroth iteration, (b) first iteration, and (c) second iteration

4. Conclusion

The Planar Yagi antenna of zeroth, first, and second iteration has been designed for WLAN applications which operates at 2.4 GHz frequency. The size of the antenna reduce by

22.8% for the first iteration and 30.81% for the second iteration. Reducing the size of the antenna by applying fractal method also affects the antenna directivity and gain by 14% for the first iteration and 25% for the second iteration. But still, the gain is still high with a more compact size. Hence, due to its high gain and compact size, the antenna can be utilize in many application of ISM band and indoor plus WLAN applications.

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