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A High Gain Double-Octagon Fractal Microstrip Yagi Antenna

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Abstract—A Double-Octagon Fractal Microstrip Yagi Antenna (D-OFMYA) which is aimed to cover unlicensed frequency of 5.8 GH is presented in this paper. The primary purpose of this experiment is to enhance gain of conventional microstrip antenna. The proposed antenna built on Arlon CuClad 217 substrate with thickness of 0.787 mm and dielectric permittivity of 2.2. A 3D full-wave EM simulator was used to design and to simulate the antenna. A computerized simulation model of the proposed antenna showed that the antenna is able to generate a maximum gain of 14.49 dB with S_{11} of −24.2 dB in a surface size of 80 mm × 120 mm. By contrast, results of an experiment indicated the fabricated D-OFMYA can reach a gain as high as 14 dB with the value of S_{11} is −19.8 dB. It can be concluded that a nominal gain of the D-OFMYA comes in higher than other microstrip Yagi array antennas and size reduction can be achieved through this design.

1. INTRODUCTION

Basically, frequency bands are allocated into two categories in which wireless technologies can operate, unlicensed bands and licensed bands. The available frequency bands which is designed for anyone who wants to use is called unlicensed bands since users can access without a license [1]. These unlicensed bands allocations are generally used by radar, sensor and other low rate applications [2]. The most commonly used is 5.8 GHz in which it covers a range from 5.725 GHz to 5.875 GHz [2, 3].

WiMAX which stands for Worldwide Interoperability for Microwave Access is one of wireless systems which uses the 5.8 GHz unlicensed frequency. This technology has capability to provide coverage over large areas [4]. The number of applications and users of unlicensed frequency have grown rapidly in recent years thanks to the absence of license payments.

It leads to an increase in demands for a huge amount of microwave devices and antenna is one of them. Antennas play a critical role in wireless systems because they are capable of transmitting and receiving electromagnetic waves [5]. In 2010, parasitic antennas in wireless networks have been exploited by F. Viani et al. [6]. Of all the types of antennas, microstrip Yagi antennas have gained positive attention for their performance, simplicity and ease of manufacture. They consist of reflector, driven and director elements, for which they have ability to enhance gain of a conventional microstrip patch antenna [7].

The first microstrip Yagi antenna was introduced by Huang and Densmore [7]. In 2003, Padhi and Bialkowski [8] proposed a combination between microstrip Yagi antenna and EBG structure on the ground plane in order to increase the gain without increasing the antenna size. The gain of 10.8 dB could be achieved through this antenna.

Dejean et al. [9] introduced two new microstrip Yagi antenna arrays in which one of them was called bi-Yagi. The measurement results showed that bi-Yagi has capability to produce a maximum gain of 13.3 dB with the antenna size of 115.8 mm × 137.1 mm. Two new microstrip Yagi array antennas in

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which each element has an opened edge and three shorted edges were reported by Liu and Xue in [10]. According to the final results, the microstrip Yagi with four elements can yield a gain of 10 dB in a surface size of 110 mm × 120 mm, whereas the microstrip Yagi using twelve elements generates 12.2 dB gain with the overall size of 100 mm × 200 mm.

A new structure of microstrip Yagi array antenna in this research work was realized on Arlon CuClad 217 substrate. The antenna is called Double-Octagon Fractal Microstrip Yagi Antenna (D-OFMYA). The basic structure of D-OFMYA is derived from the Octagon Fractal Microstrip Antenna in [11]. This research paper is structured as follows. Section 2. provides a short description of the proposed antenna configuration. All simulation and measurement results are given in Section 3. Afterwards, a summary of all results obtained is provided in Section 4.

2. ANTENNA CONFIGURATION

Fractal geometry is applied in the D-OFMYA since this structure has ability to reduce the size of the antennas and to enhance bandwidth of the antennas [12]. The basic idea of the D-OFMYA mirrors a derivative of Octagon Fractal Microstrip Yagi Antenna (OFMYA) concept in [11] and [13]. Fig. 1 illustrates the OFMYA configuration in [11]. The driven element is a modified rectangular patch. The values of director length and width were calculated using standard equation of square patch. Meanwhile, director elements were modified by adopting Octagonal-Shaped in [13] and first iteration of Cross Snow fractal concept in [14]. Further details on Octagon-Shaped patch and Cross Snow fractal calculations can be found in [13] and [14], respectively.

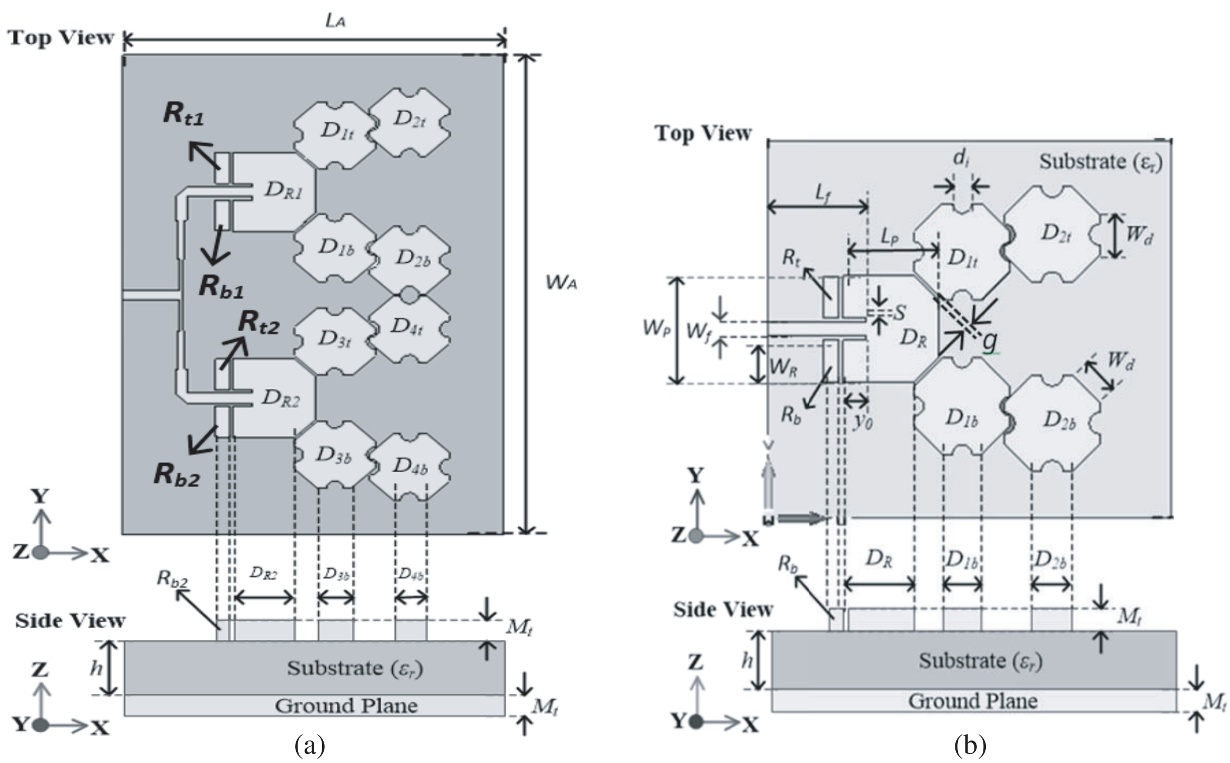


Figure 1. Schematic view of (a) the proposed D-OFMYA structure and (b) the original OFMYA in [11].

Additionally, 2×1 array concept is used in the D-OFMYA since array configuration can be employed to improve antenna performance [15] in terms of gain. The original OFMYA and the D-OFMYA structures are displayed in Fig. 1. It can be seen that there are four reflector elements (R_{t1}, R_{t2}, R_{b1} & R_{b2}), two driven elements (D_{R1} & D_{R1}), and eight director elements (D_{1t}, D_{1b}, D_{2t}, D_{2b}, D_{3t}, D_{3b}, D_{4t}, & D_{4b}). The length and the width of the D-OFMYA are denoted by L_A and W_A.

As can be seen in Fig. 1 above that the director elements are placed in front of the driven element, whereas the reflector elements are added behind the driven. The driven element is a modified rectangular patch. The values of director length and width were calculated using standard equation of square patch. Each director element was modified into octagonal-shaped. More details can be found in [13].

There is a gap between parasitic element which is symbolized by g. The value of g should be equal to or less than the dielectric substrate (ε_r) thickness as explained by Huang and Densmore in [7]. Moreover, Dejean and Tentzeris [16] found that the g must be less than $0.005\lambda_{\mathit{eff}}$ in order to increase the value of gap capacitance. The effective wavelength (λ_{eff}) can be calculated using (1) [16]:

$$\lambda_{\mathit{eff}} = \frac{c}{f_r\sqrt{\varepsilon_{\mathit{eff}}}} \tag{1}$$

where c is 3×10^8 m/s, and f_r is the resonant frequency. Meanwhile, the effective dielectric constant (λ_{eff}) in range of $1<\varepsilon_{\mathit{eff}} < \varepsilon_r$.

By this mean, there is a limit on the value of g. The closer parasitic elements are placed to each other will give influence in frequency shifting. Therefore, they must be placed within a range based on the coupling strength.

In order to match the proposed antenna to line, microstrip feed-line method was chosen since this method is simple to match by controlling the length of inset (y_o) and its position (S) [17]. According to Fig. 1, the proposed antenna consists of two branches of OFMYA. Parallel feeding network was used to combine two elements of single OFMYA. The final optimized parameter values of the proposed antenna are tabulated in Table 1.

Table 1. Optimized parameters for the proposed antenna.

Parameters	Value	Unity
Substrate Thickness (h)	0.787	mm
Total width of the proposed antenna (W_A)	110	mm
Total length of the proposed antenna (L_A)	80	mm
Width of patch (W_p)	16.9	mm
Length of patch (L_p)	20	mm
Side Length of Octagon-Shaped (W_d)	7	mm
Diameter of first iteration (d_i)	3.8	mm
Thickness of copper (M_t)	0.035	mm
Width of 50 Ω transmission line (W_f)	2.4	mm
Length of 50 Ω transmission line (L_f)	12	mm
Width of 70 Ω transmission line (W_{70})	1.35	mm
Length of 70 Ω transmission line (L_{70})	9.65	mm
Width of 100 Ω transmission line (W_{100})	0.66	mm
Length of 100 Ω transmission line (L_{100})	9.84	mm
Width of 100 Ω transmission line (W_{100})	0.66	mm
Length of 100 Ω transmission line (L_{100})	9.84	mm

3. FABRICATION AND EXPERIMENT RESULTS

This section is designed to provide details of the simulated and experimental results, hence it is classified into two subsections.

3.1. Simulated Results

The proposed antenna was simulated using a full-wave electromagnetic simulator. Based on the simulated results, it demonstrates that the designed D-OFMYA operates within a range from 5.69 GHz to 5.89 GHz meaning that it provides a bandwidth of 200 MHz. The bandwidth (BW) of an antenna can be expressed in percentage (%) by using (2):

$$BW(\%) = \frac{f_u - f_l}{f_c} \times 100\% \tag{2}$$

where center, upper and lower frequencies are symbolized by f_c, f_u and f_l, respectively. Therefore, the percentage of the simulated bandwidth for the proposed antenna is 3.44% at center frequency of 5.8 GHz. Fig. 2 depicts the simulated 3-Dimensional (3-D) far-field radiation pattern. It also shows that the proposed D-OFMYA is able to generate a gain of 14.49 dB.

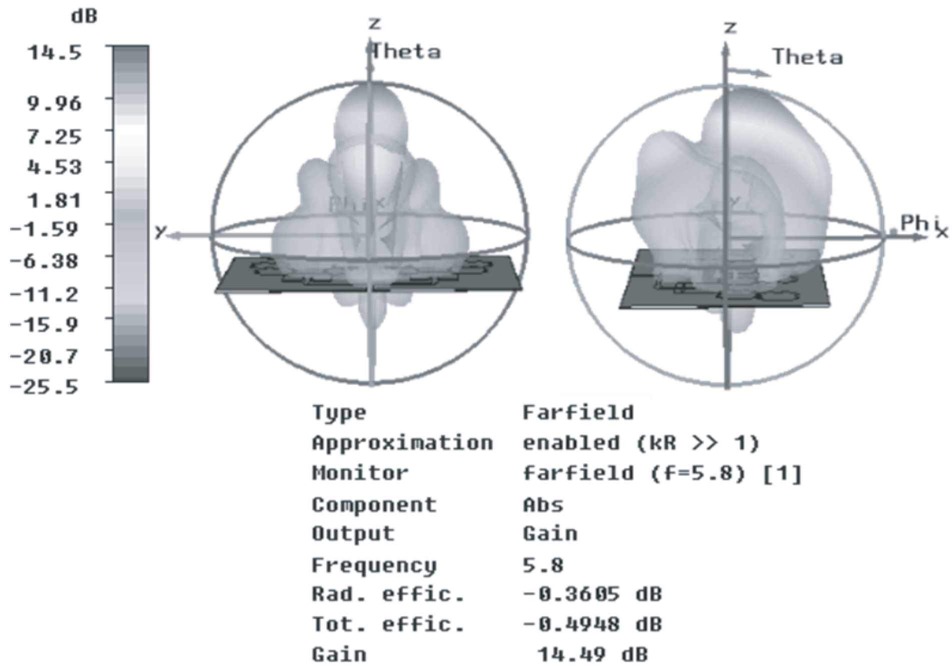


Figure 2. The simulated far field of D-OFMYA in 3-dimensional.

3.2. Fabrication and Measured Results

Figure 3 shows the fabricated D-OFMYA. It is clearly seen that a SubMiniature version A (SMA) connector is soldered to the edge of the 50 Ω feedline. This connector is used to connect measurement hardware coaxial cable to the D-OFMYA.

In order to validate the simulated results, the D-OFMYA was tested at UTHM EMC Center. A Vector Network Analyzer (VNA) of Rohde & Schwarz ZVB14 was used to measure S_{11} of the fabricated D-OFMYA, whereas the radiation patterns and gain measured using Rohde & Schwarz vector signal generator and Advantest R3267 spectrum analyzer in anechoic chamber to avoid reflections from surrounding objects and walls as shown in Fig. 4.

Figure 5 illustrates the computed S_{11} of the D-OFMYA in comparison with the measured S_{11} result over frequency range from 4.4 GHz to 7 GHz. Black solid line corresponds to the measured S_{11}, whereas the simulated S_{11} is represented by black dotted line. It is noted that the measured S_{11} demonstrates that the fabricated antenna has ability to cover frequency from 5.39 GHz to 6.00 GHz, thus the bandwidth is 610 MHz or 10.51%. In contrast to the simulation result, the proposed antenna has a bandwidth of 3.44%.

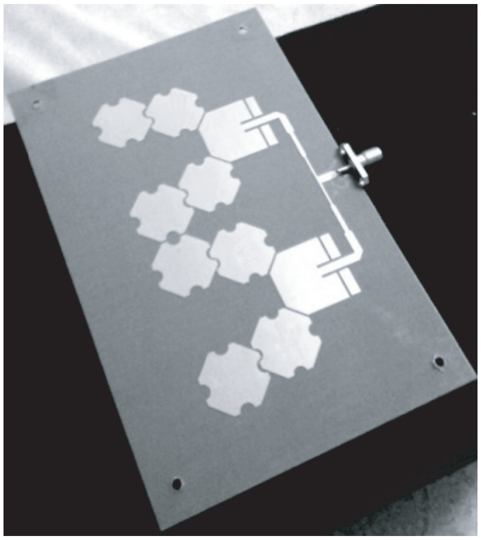


Figure 3. Photograph of the fabricated antenna.

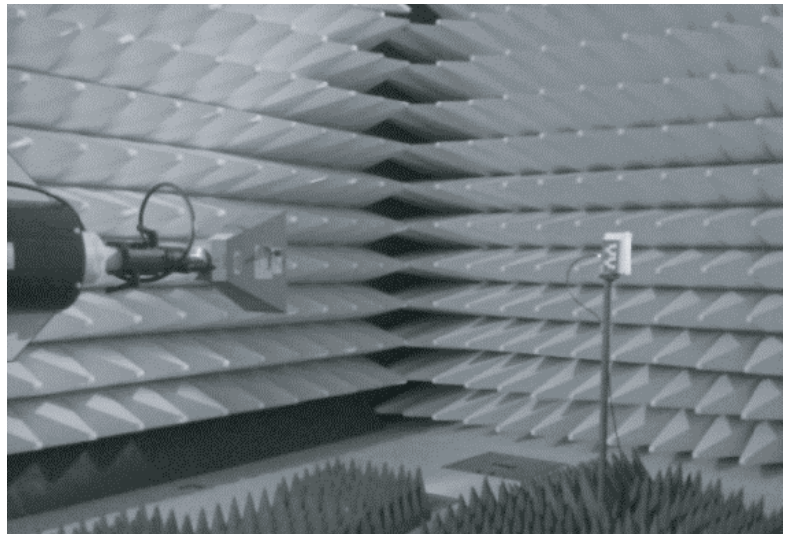


Figure 4. Radiation pattern and gain measurement setup for the D-OFMYA.

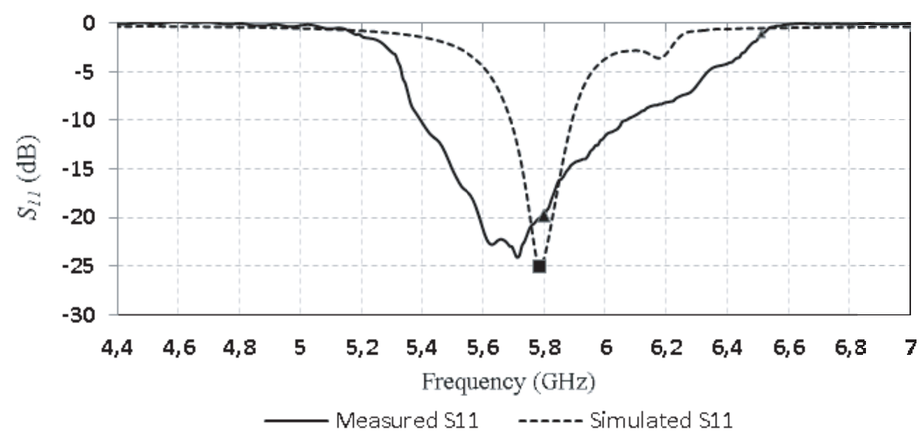


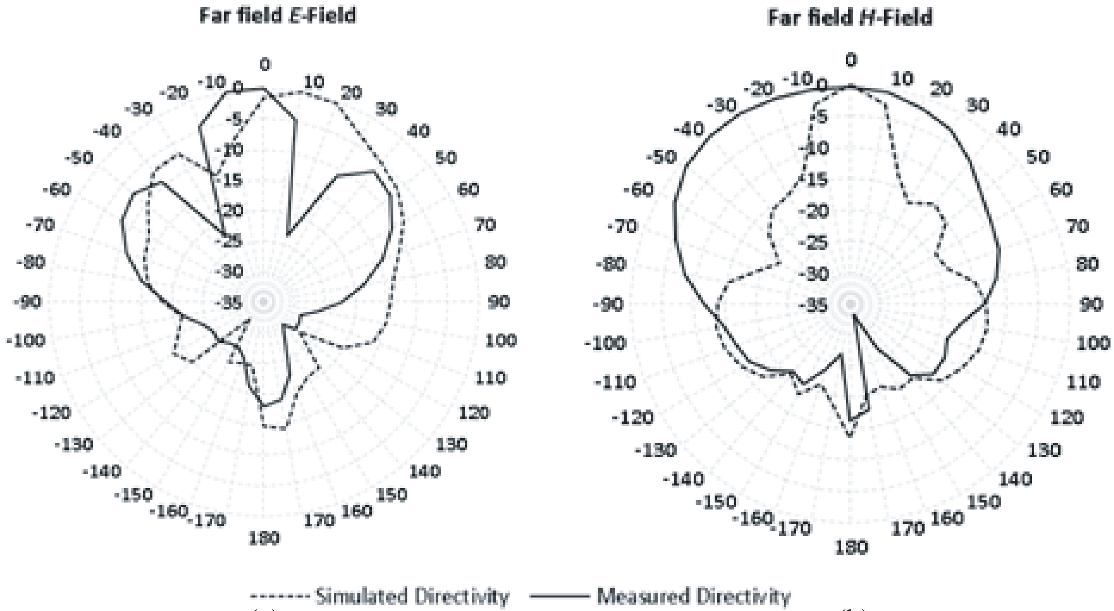
Figure 5. Comparison of S_{11} between the simulated and measured results.

There is a discrepancy of 330 MHz occurs at the upper frequency and 110 MHz at lower frequency. This shift might be caused by fabrication accuracy, the environmental factors such as noise and temperature of the room during measurement. Overall, the measured bandwidth of the D-OFMYA is wider than the simulated bandwidth.

The measurement result showed that the D-OFMYA has capability to provide a gain of 14 dB. It implies that there is a good agreement between the computed and measured gain for this antenna, although it is about 0.49 dB lower than the simulated gain.

E-field (*x*-*z* plane) and *H*-field (*y*-*z* plane) radiation patterns of the proposed antenna are plotted in Fig. 6. From these plots, it is obviously seen that *E*-field and *H*-field patterns are generally exhibit broadside direction. Black solid line and black dotted line represent the measured and simulated radiation patterns, respectively. The simulated *E*-plane of the proposed D-OFMYA has maximum radiation at an angle of 10° from broadside direction meaning that there is a small shift between the computed and the experimental results which might be caused by fabrication imperfections, for instance, inaccuracy in placing the fabricated D-OFMYA, etching process and connector soldering.

For comparison purposes, the computerized and experimental results of the D-OFMYA and previous



(a) (b)

Figure 6. Far-field directivity, (a) E-field and (b) H-field.

works are summarized in Table 2. It is interesting to note that the D-OFMYA in this research work has better performance in term of gain surface area size compared to the other [8–10]. Table 2 shows that the D-OFMYA exhibits 84.72%, 44.57%, 33.33% and 56% size reductions compared to [8], [9] and [10], respectively.

Table 2. Comparison results.

Parameters	Gain (dB)	Surface Area (mm^2)	Size Reduction Compared to The D-OFMYA (%)
The fabricated D-OFMYA	14	80×110	-
A microstrip Yagi antenna using EBG structure [6]	11.2	$\sim 240 \times 240$	84.72
Bi-Yagi antenna [7]	13.3	115.8×137.1	44.57
Microstrip Yagi Antenna with four dipole elements [8]	10	110×120	33.33
Microstrip Yagi Antenna with twelve dipole elements [8]	12.2	100×200	56

4. CONCLUSION

A prototype of the D-OFMYA was computerized, fabricated and tested. Based on the computer simulation results, a gain of 14.49 dB can be obtained through the D-OFMYA structure, whereas the measured gain is 14 dB. There is a shift in upper frequency and lower frequency, meaning that the measured bandwidth of the D-OFMYA is wider than the simulated design. However, the proposed antenna still covers the desired frequency range from 5.725 GHz to 5.875 GHz. In summary, the D-OFMYA can provide higher gain in comparison to previous works in [8–10]. Additionally, reduction in size can be achieved through this design.

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