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Investigation on OMYA with single superstrate layer

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ABSTRACT

The need for wireless communication technology is increasing rapidly. Many people are already using internet data services offered by providers or using wireless fidelity (Wi-Fi) services. One of the things that must be considered in Wi-Fi technology is that it requires antenna characteristics that have a relatively small shape and light mass. This paper aimed to improve gain and to analyze the performance of octagon microstrip Yagi antenna (OMYA) with a single superstrate layer. The antenna was designed, simulated, and measured. The experimental result presents that this concept is capable to produce a gain of 11.80 dB, a return loss of -23.24 dB, and the bandwidth is up to 800 MHz with total dimensions of 70×75 mm.

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1. INTRODUCTION

At this time, the need for wireless communication technology is increasing rapidly. Many people are already using internet data services offered by providers or using wireless fidelity (Wi-Fi) services. One of the things that must be considered in Wi-Fi technology is that it requires antenna characteristics that have a relatively small shape and light mass. The microstrip antenna has one of those characteristics. Microstrip antennas also have the advantage, namely that they do not cost a lot of money in the manufacturing process. The 802.11x standard is a standard established by the Institute for Electrical and Electronic Engineers (IEEE) to underlie Wi-Fi technology. The Wi-Fi standards 802.11n and 802.11ac are standards that work at the 2.4 GHz and 5.8 GHz frequencies. Referring to research by Gocen *et al.* [1] who designed an antenna with a working frequency of 5.8 GHz for Wi-Fi and internet of things (IoT) applications.

Dejean and Tentzeris [2] demonstrated a high gain microstrip Yagi antenna by using new structure Yagi to improve the gain of the the first microstrip Yagi. Their antenna has capability to produce a gain of 10.7 dB and the antenna is 112×112 mm^2. However, their proposed antenna is still large. Quzwain *et al.* [3] introduced an octagon microstip Yagi antenna (OMYA) by applying four octagonal patches as director elements in order to improve the gain and bandwidth in compact size. Their antenna is able to provide 11 dB gain with the surface size around 70×75 mm. Several studies in [4], [5] have successfully conducted research in ordet to improve the gain by adding a superstrate layer on the top of a patch antenna. Shen *et al* [6] proposed a biplanar quasi-Yagi antenna in compact size but the gain is still low. Therefore, this paper proposes a concept to enhance the gain of microstrip Yagi antenna by combining OMYA concept and single superstrate layer concept. Once the simulation is done, the proposed antenna is fabricated and measured to analyze the performance the antenna in terms of gain, return loss and bandwidth. This paper is structured as follows, chapter 1 contains research background. In chapter 2 explains the theories related to this research. chapter 3 explains the research methodology for designing OMYA and OMYA antennas using a single superstrate layer. All simulation and measurement results is presented in chapter 4 and summary of the findings is explained in chapter 5.

2. THE COMPREHENSIVE THEORETICAL BASIS

2.1. Microstrip antenna

Antenna is a transition medium between free space and transmission channels which are used to support wireless communication systems because antennas can transmit and receive electromagnetic waves which contain information signals [7], [8]. Therefore, antenna is a crucial part in wireless communication systems due to it has the function of converting electrical signals into electromagnetic waves and then transmitting them into free space [9], [10]. Apart from that, the antenna can also act as a signal receiver by receiving electromagnetic wave signals and then converting them into electrical signals [11], [12]. Based on its shape, antennas have several types, including microstrip, Yagi, Vee, Horn, Helix, Parabolic, and Loop.

The concept of microstrip antennas was first introduced by Georges A. Deschamps in 1953. Then, in the 1970s, the development of microstrip antennas was very rapid with a lot of research and development on microstrip antennas [13]. Until now, microstrip antennas are still a very interesting topic in microwave applications, both in academic, industrial and research fields, especially in the field of telecommunications. This is because the characteristics of microstrip antennas have several advantages compared to other types of antennas [13]. Some of the advantages include has small dimensions, has a light mass, and fabrication costs are quite cheap. In general, the microstrip antenna structure consists of a patch antenna, substrate, and ground plane. The location of the patch is at the top of the substrate, while the position of the ground plane is at the very bottom as illustrated in Figure 1 [14].

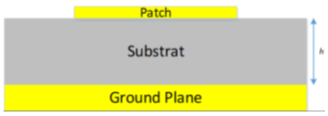

Figure 1. Microstrip antenna structure

2.2. OMYA

In this research, the proposed OMYA arrangement was inspired by the research of Dejean and Tentzeris in [2] in which the antenna configuration shown in Figure 2. Based on the image above, there are a total of seven patch elements consisting of one driven element, two upper and lower director elements, and two reflector elements. The reflector element is added behind the driven element. On the other hand, the director element is placed in front of the driven. The width and width of the reflector element are respectively signified by W_r and L_r.

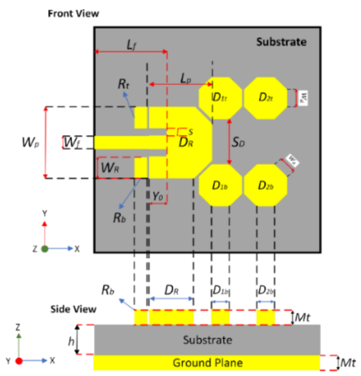

Figure 2. OMYA structure

The octagon-shaped structure was used as a director element which aims to produce small dimensions for the proposed OMYA. Additionally, a rectangular patch is chosen as the driven element. Then, trimming is carried out at the two corners of the driven element with the aim of reducing surface waves and increasing the reciprocal relationship between the driven element and the director element.

2.3. Superstrate layer

Microstrip antenna has some drawbacks, such as low gain [15]-[18]. Superstrate concept can be used to increase the gain [19]-[21]. The superstrate layer is a material placed on top of a microstrip antenna which has been designed with the aim of directing the radiated waves in the right direction [22], [23]. The materials used are grouped into 4 types based on their permittivity and permeability values, namely, double-negative materials, double-positive materials, epsilon-negative materials, and mu-negative materials. DPS material, also known as a dielectric substrate, can be used as a superstrate layer to obtain high antenna gain by adding this material on top of the microstrip antenna [24], [25]. In several studies, double-positive substances (DPS) material has been applied in microstrip antenna structures which function to increase gain. Sugio, *et al.* [4] have studied increasing the resonant gain of an antenna coated by a dielectric substrate with a ground plane in 1981. They explained that a high dielectric substrate can be used to increase the gain of antenna.

Then in 1995, Shen, *et al.* [5] has studied a method of increasing gain for a microstrip antenna where a superstrate layer having a dielectric permittivity (ε_{r2}) of 10.5 is placed on top of the microstrip antenna at a distance of h_1. They have researched that high gain can be obtained by placing a substrate that has a high dielectric permittivity and by adjusting the distance or thickness of the air gap (h_1). The thickness of the superstrate layer (t) also has an influence on the gain. Based on their research, high gain is obtained when the thickness of the superstrate layer, $t = \frac{\lambda}{4\sqrt{\varepsilon_{r2}}}$.

3. ANTENNA CONFIGURATION

In this section contains an explanation of the proposed antenna configuration. The proposed antenna has a configuration of an OMYA and a single superstrate layer in which added on top of the OMYA. The first stage is to determine the parameter specifications of the proposed antenna according to its application as shown in Table 1.

Table 1. Antenna parameters

Antenna parameters	Values
Centre frequency	5.8 GHz
Return loss	≤-10 dB
Gain	≥10 dB
Bandwidth	>520 MHz

In designing the antenna, the materials used are Rogers 5880 and Arlon AD1000. Rogers 5880 material was used because it has a fairly small thickness, has a low dielectric constant so it can have a good effect on antenna performance and the substrate material is easy to obtain. However, this substrate has a weakness, namely that it is quite expensive. Meanwhile, the Arlon AD1000 material was used because a material with a high dielectric constant is needed to make the superstrate layer to obtain a higher gain.

The antenna proposed in this paper consists of a DPS layer that acts as a superstrate layer of the OMYA. Figure 3 shows the configuration of the OMYA which was first introduced by Quzwain *et al* in [3]. The antenna was designed using the concept of conventional Yagi Uda microstrip antenna which consists of several reflector elements, a driven element and several director elements. In this research, Rogers 5880 was chosen as the substrate material with the thickness (h) of 1.6 mm.

Then the OMYA design was carried out using the method of adding a single superstrate layer. The addition of superstrate is a substrate material with high dielectric permittivity which is added on the top of the OMYA. Arlon AD1000 material with a dielectric constant (ε_r) of 10.2 and a thickness of 2.54 mm was chosen as the superstrate layer material. It is placed on the top of the OMYA and separated by the air gap (h_1) and installed using 4 plastic spacers at the 4 corners of the OMYA with plastic nuts. To find the thickness of the superstrate air gap, it can be calculated using (1) [20].

$$h_1 = \frac{\lambda}{2} \quad (1)$$

Where h_1 symbolizes the thickness of the superstrate air gap and λ is the wavelength.

Figure 4 shows the geometric structure of OMYA with a single superstrate layer. Several optimizations was done varying the thickness of the superstrate air gap (h_1) in order to obtain the best result. The simulated gain results was observed analyzes the relationship between the air gaps (h_1) and the gain.

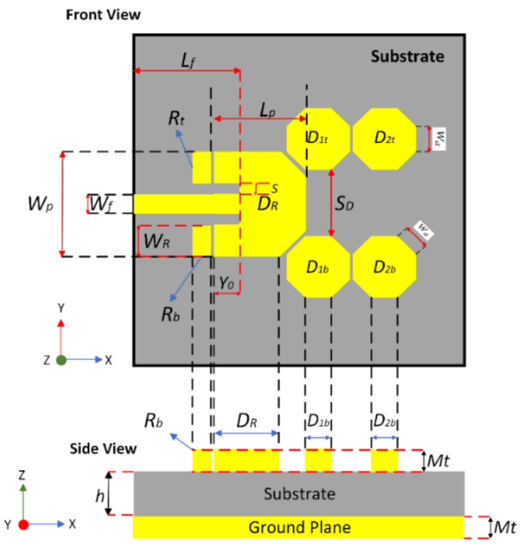

Figure 3. Geometric structure of OMYA

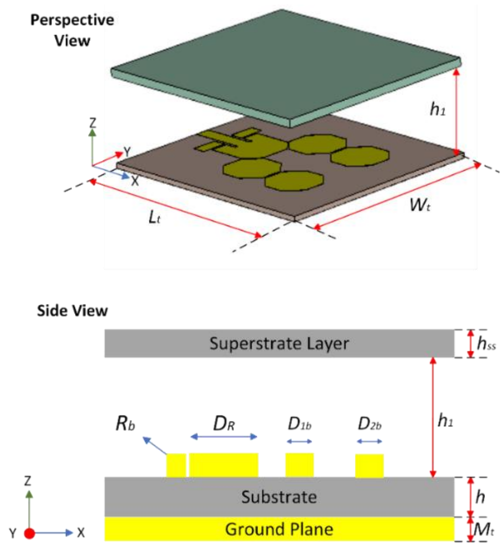

Figure 4. The structure of OMYA with single superstrate layer

4. RESULTS AND DISCUSSION

Quzwain *et al.* [3] calculated and simulated the OMYA in order to obtained a high gain and a wide bandwidth. They explain that the gain and bandwidth of OMYA can be influenced by the dimensions of the octagon side length (W_d) and the distance between parasitic elements (g). Then at this stage, the method of adding a single superstrate layer above the OMYA was carried out to determine the effect of the thickness of the superstrate air gap on the gain results. Figure 5 shows a comparison of the gain obtained by varying the thickness of the air gap superstrate. The graph depicts that the gain continues to increase between h_1 of 26 mm and 31 mm and then decreases slightly. The simulation results show that an increase of 1.1 dB can be obtained by placing a single superstrate above the OMYA. For this reason, it is proven that by adding a single superstrate layer above the OMYA can increase the gain results. In addition, the detailed results regarding the OMYA simulation results by varying the air gap can be seen in Table 2.

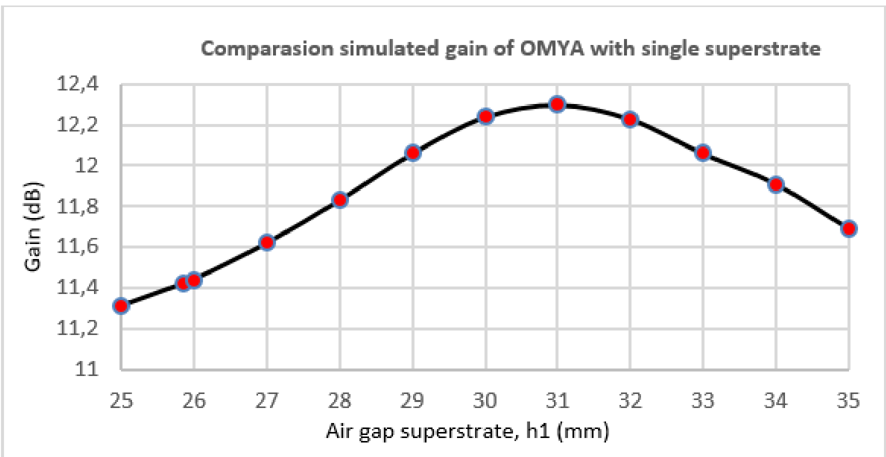

Figure 5. Comparison of the simulated gain obtained by varying the thickness of air gap (h_1)

Table 2. Comparison of parameter results by varying the thickness of air gap (h_1)

Air gap thickness superstrate/h_1 (mm)	Return loss/S_{11} (dB)	Gain (dB)
25	-11.298	11.31
25.85	-12.504	11.42
26	-12.732	11.44
27	-14.404	11.62
28	-16.618	11.83
29	-19.581	12.06
30	-26.047	12.24
31	-29.587	12.30
32	-41.37	12.23
33	-39.532	12.06
34	-34.545	11.91
35	-32.331	11.69

Figure 6 shows the results of the simulated S_{11} from OMYA with a superstrate layer that has an air gap thickness (h_1) of 31 mm. The plot image shows that OMYA with a superstrate layer works at a frequency of 5.64 GHz to 6.33 GHz so that the bandwidth obtained is 690 MHz and thus it has a fractional bandwidth of around 11.9%. Even though the bandwidth value is smaller compared to the results in OMYA, objectively in the simulation results the gain has been proven to have increased by 1.1 dB.

Figure 7 shows the simulation results of the radiation pattern from OMYA with a single superstrate layer at a frequency of 5.8 GHz. It shows that the antenna has capabillity to produce the gain up to 12.3 dB and the main lobe direction occurring in the E-plane of 19°. It can also be seen that the gain of OMYA with a single superstrate layer is 1.1 dB higher than OMYA without a superstrate layer. Therefore, it provides evidence that a single superstrate layer can be used to increase the gain of microstrip antenna and this concept is reported by Said *et al* [25] as well. In addition, the use of a single superstrate layer structure with OMYA is able to focus the emitted electromagnetic energy. Then Table 3 shows the final dimensional parameters of OMYA with single superstrate layer.

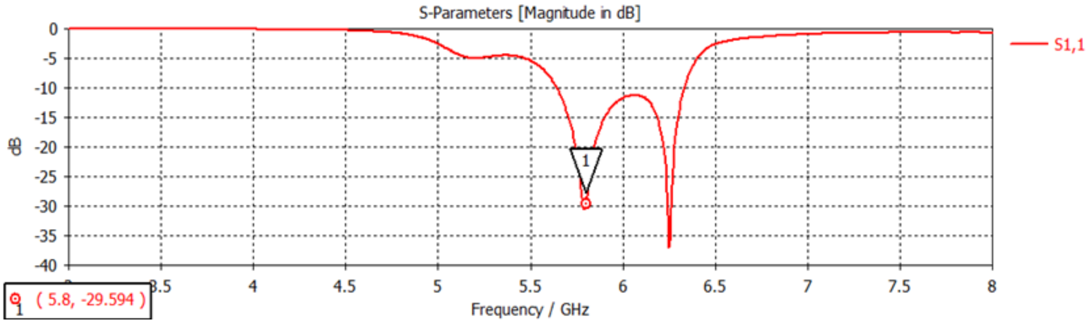

Figure 6. Simulated S_{11} of OMYA with single superstrate layer

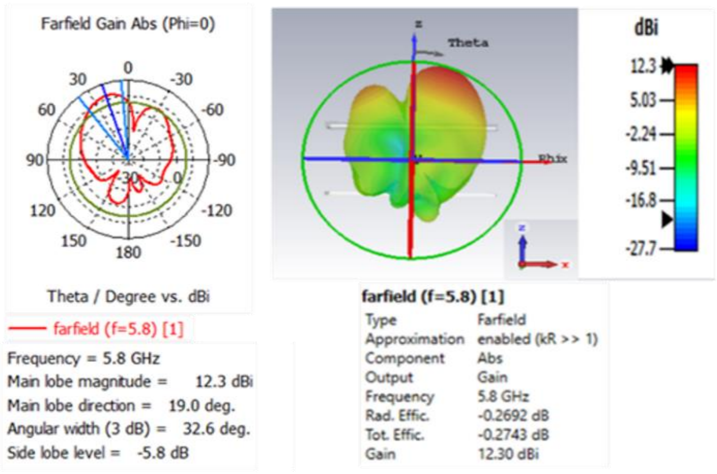

Figure 7. Simulated radiation pattern of OMYA with single superstrate layer

Table 3. Final dimensions of OMYA with single superstrate layer

Parameter	Dimension (mm)
Substrate thickness (h)	1.6
Total width of the proposed antenna (W_t)	70
Total length of the proposed antenna (L_t)	75
Thickness of copper (M_t)	0.035
Spacing between the element (g)	0.7
Length of Patch / driven (L_p)	17.4
Width of Patch /driven (W_p)	18
Side length of octagon-shaped (W_d)	7
Length of reflector element (L_r)	6.5
Width of reflector element (W_r)	9
Width of 50 Ω transmission line (W_f)	4.9
Length of 50 Ω transmission line (L_f)	15
Length of the inset (Y_0)	3.5
Spacing of the inset (S)	0.9
Superstrate thickness (h_{ss})	2.54
Air gap thickness (h_1)	31

Figure 8 shows the prototype of the OMYA with a single superstrate layer. The fabricated antennas was measured at UTHM EMC Center-Batu Pahat in order to validate the simulation results. The gain and radiation pattern was measured in anechoic chamber and S_{11} was measured using Anritsu 37347D vector network analyzer (VNA).

Figure 9 shows the comparison results of S_{11} between OMYA with and without single superstrate layer. The simulated results is symbolized by the solid yellow line and the dashed black line symbolizes the measurement results with a frequency range of 4 GHz to 7 GHz. It can be seen that the measured results S_{11} for the OMYA with single superstrate layer is -23.24 dB and the bandwidth is up to 800 MHz. Therefore, it has a fractional bandwidth of around 13.8%.

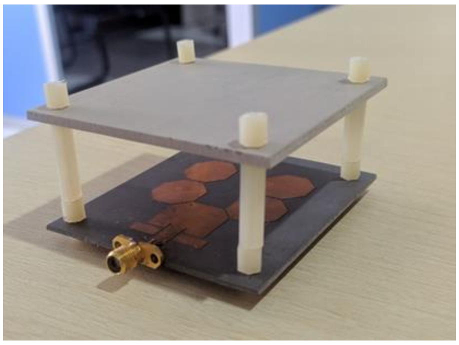

Figure 8. The prototype of the OMYA with single superstrate layer

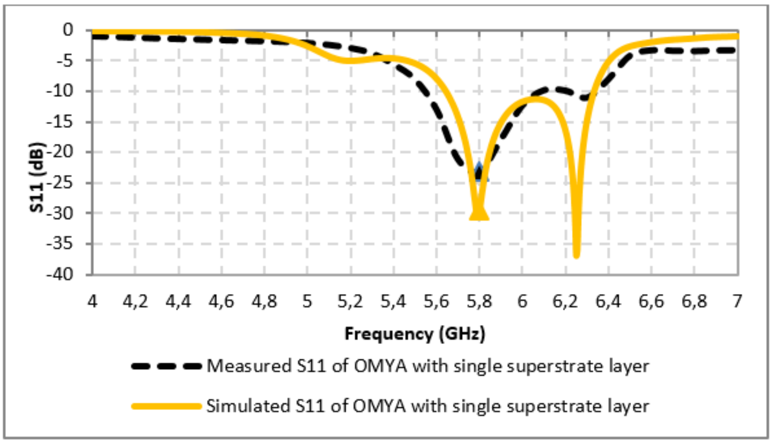

Figure 9. The simulated and measured results of S_{11}

Figure 10 shows a comparison of the radiation patterns between the simulated result of the OMYA with a single superstrate layer, symbolized by the solid yellow line, and the measured result from OMYA with a single superstrate layer, symbolized by the black dotted line. It can be seen that the maximum radiation angle measurement results are at 10°. The antenna has a gain of 11.80 dB based on the measurement results, thus it depicts that there is a good agreement between the simulated and measured results of the antenna gain. It can be seen that the gain can be improved by placing single superstrate layer with a proper choice of air gap thicknesses. The difference in results between the simulated result and measured result of the OMYA with a single superstrate layer can be caused by inaccuracies in installing the antenna on the tripod during measurement, imperfections in the fabrication process, for example inaccuracies in placing the superstrate layer, imperfections during the antenna printing process or during the process of soldering connector. All the simulation and measurement results of the proposed antenna and several microstrip Yagi antenna research results are summarized in Table 4. It is interesting to take note that the the proposed antenna in this paper has the best performances in terms of gain and surface area size in comparison to the other.

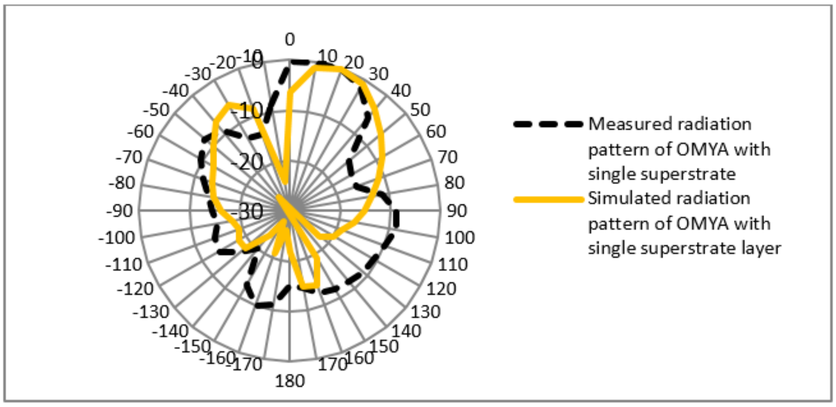

Figure 10. The simulated and measured results of radiation pattern

Table 4. Comparison of performance results between the proposed antenna and several microstrip Yagi antenna research

Antenna parameters	Center frequency (GHz)	Gain (dB)	S_{11} (dB)	Bandwidth (MHz)	Total dimensions of antenna (mm^2)
Simulated OMYA with single superstrate layer	5.8 GHz	12.30	-29.587	690	70×75
Fabricated OMYA with single superstrate layer		11.80	-23.24	800	70×75
A compact biplanar quasi-Yagi antenna with beam tilt via a bending strip and a rectangular patch director [11]		4.5	-	700	42×38
Design of reconfigurable planar Yagi-uda antenna for dual frequency wireless communication [12]		9.53	-26.15	-	75×150

5. CONCLUSION

The proposed antenna, OMYA using the single superstrate layer method has been simulated, fabricated and measured to find out the effect of adding a single superstrate layer to OMYA on antenna performance. Based on the simulation and measurement results, it shows that the OMYA with single superstrate layer is able to enhance the gain of OMYA. The simulated result of the OMYA shows that OMYA with a single superstrate layer can increase the gain by 1.1 dB compared to OMYA without a single superstrate layer. Therefore, it can be concluded that the OMYA gain can be enhanced by adding single superstrate layer on top of the OMYA. Apart from that, the proposed antenna has a more compact size compared to research on other microstrip Yagi antennas.

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