The two-levels rectangular microstrip Yagi antenna for Wi-Fi application

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Abstract. An antenna is the most important part of a wireless communication system. Wi-Fi has an omnidirectional radiation pattern that results in a limited range of emissions. Therefore, it needs an external antenna with a higher gain than the internal antenna. This research designs rectangular Yagi microstrip antenna with two-levels of directors which can work at 2.4 GHz frequency (Wi-Fi Application). The selection of material permittivity value and dimension setting is committed carefully in order to gain > 5 dB. At the time of simulation, optimization is performed by changing the dimension of driven, director, reflector, and distance between levels. The realization of the antenna is committed by using dielectric material with relative permittivity of 4.3. The antenna test results show a bandwidth gain of 7.98 dB, S11 parameter of -16.223 dB with a bidirectional radiation pattern. By selecting the material permittivity value and prudence in managing the antenna dimensions, it is proven to produce an antenna with target gain although the antenna only uses 1 branch and 2-levels of directors.

1. Introduction
One of the devices to support wireless networks is Wi-Fi. In public, Wi-Fi access with a certain area is often referred to as a "hotspot" [1]. The Wi-Fi of access point devices has limited range and need to be improved. Thus, an external antenna with higher gain capacity is needed than an internal antenna [2]. An antenna is a component that is capable of converting energy or signals in open space to radiate and accept wave [3]. The microstrip antenna is an antenna that has a light and easy mass. Thus, it can be placed on most of all surface types. Furthermore, its size is smaller than other antennas [4].

Previous research of antenna microstrip with a frequency of Wi-Fi work by Karthick Murugan had been committed. It designed a single rectangular shaped microstrip antenna with a dielectric constant of 4.8 [5]. Zin Nyin Swe also did similar research by realizing a single hexagonal microstrip patch antenna with a dielectric constant of 4.4 [6]. Chosh, and Bhattacharjee in their studies stated that the single patch microstrip antenna has small weaknesses such as low range, low efficiency, low directivity, and narrow bandwidth. These weaknesses can be overcome by implementing many patch antennas with other methods [7]. One of the antenna forms is Yagi. Microstrip Yagi Antenna is an antenna consisting of driven elements and some parasitic elements, including reflector and director [8]. Syahrir Eka Putra et
al conducted a microstrip Yagi antenna using a microstrip feed line for Wi-Fi applications at a 2.4 GHz frequency by using FR-4 substrate material with a relative dielectric permittivity of 4.4 [9].

Various antenna parameters affect antenna performance. Delva Zuletmei, Delsina Faiza, and Khairi Budayawan, in their researches, concluded that there is dielectric permittivity towards gain, bandwidth, and beam width. If the permittivity is bigger, so the gain, bandwidth, and beam width are smaller [10].

In this current research, it is recommended to use microstrip Yagi antenna with a microstrip feed line for the Wi-Fi application of 2.4 GHz frequency supported by FR-4 substrate with relative dielectric permittivity of 4.3.

2. Method
The antenna is developed using the microstrip feed line in Yagi form. The microstrip yagi consists of driven and parasitic elements. The parasitic element consists of director and reflector elements. The antenna is designed with 2 levels of a director as presented in Figure 1.

The initial dimension of the antenna is obtained by calculating various parameter values, such as channel and patch dimensions. After the simulation to find the value of parameters that produce optimum performance, the antenna is realized by using wet-etching technique. The conductor is printed on the Printed Circuit Board (PCB) made of electric material. The material used as the substrate is FR-4 (lossy) with a relative permittivity of 4.3 with a thickness of 1.6 mm.

The measurement process is carried out after the realization process. The process of measuring parameters is done by both single and multiple port measurements. Single port measurement is done to measure return loss ($S_{11}$) and VSWR. Dual port measurements are done to measure radiation patterns and polarizations. Single and dual port measurement schemes are described in Figure 2 and Figure 3.

![Figure 1. The two-levels microstrip Yagi antenna.](image1)

![Figure 2. Single port measurement scheme.](image2)

![Figure 3. Scheme of Double port measurement.](image3)
3. Results and analysis
After the calculation regarding the initial dimension, the antenna is simulated with multiple variations of antenna dimensions to achieve optimum value. The optimization of the 2-levels microstrip Yagi antenna is carried out because it has not achieved a certain specification in the design based on manual calculation. The optimization carried out includes the settings of driven length, driven width, and microstrip feed line lengths.

3.1. Driven length optimization
The Driven length optimization of the antenna is performed to find the closest frequency to the antenna working frequency and keep the $S_{11}$ parameter as required. The results of driven length optimization and the effect on the frequency and $S_{11}$ parameter are shown in Figure 4. Based on Figure 4, it appears that the addition of the driven size causes the graph to shift to the left. The length of driven which produces the closest frequency to the frequency of 2.4 GHz is 27.55 mm.

3.2. Driven width optimization
As well as the driven length optimization, the driven width optimization on the microstrip Yagi antenna is performed to find the smallest return loss ($S_{11}$) value and the closest frequency to the antenna working frequency. The results of driven width optimization and the effect on the frequency and $S_{11}$ parameter are shown in Figure 5. Based on Figure 5, it appears that the addition of the driven width causes the graph to become steeper and deeper. Driven width which is closest to the 2.4 GHz antenna working frequency is at 45 mm with $S_{11}$ parameter of -28.715 dB.

3.3. Microstrip feedline length optimization
The optimization of microstrip feedline length is based on microstrip antenna transmission wavelength ($\lambda_g$). The results of the optimization of the microstrip feedline length are presented in Figure 6. Based on Figure 6, the Yagi microstrip antenna has a matching value at the 2.4 GHz frequency with $S_{11}$ of -50.119 dB when the feedline length is 15.457 mm. The final result of optimizing the microstrip Yagi antenna is presented in Table 1.

**Figure 4.** Influence of the microstrip Yagi antenna's driven length to the frequency and $S_{11}$ parameter.

**Figure 5.** Influence of the microstrip Yagi antenna's driven width to the frequency and $S_{11}$ parameter.
**Figure 6.** Influence of microstrip feedline length to the frequency and $S_{11}$ parameter.

**Table 1.** Dimensions of the 2 levels microstrip Yagi antenna.

| Parameter                              | Initial Value (mm) | After optimization (mm) |
|----------------------------------------|--------------------|-------------------------|
| Driven width ($W_d$)                   | 38.4               | 45                      |
| Driven length ($L_d$)                  | 30                 | 27.55                   |
| Microstrip feedline width ($W_f$)      | 2.89               | 2.89                    |
| Microstrip feedline length ($L_f$)     | 30.14              | 15.456                  |
| Patch Thickness ($T$)                  | 0.035              | 0.035                   |
| Substrate Thickness ($h$)              | 1.6                | 1.6                     |
| Director length ($L_{dir}$)            | 24.112             | 24.112                  |
| Width of 2nd level Director ($W_{dir2}$)| 45.21              | 45.21                   |
| Width of 1st level Director ($W_{dir1}$)| 42.196             | 42.196                  |
| Reflector width ($W_{ref}$)            | 24.112             | 24.112                  |
| Reflector length ($L_{ref}$)           | 9.042              | 9.042                   |
| Distance between the reflector and driven ($S_1$) | 0.6028          | 0.6028                  |
| Distance between 1st level director and Driven ($S_2$) | 0.6028          | 0.6028                  |
| Distance between 1st level director to 2nd level director ($S_3$) | 0.6028          | 0.6028                  |
| Distance between directors at the 1st level ($S_4$) | 0.9               | 0.9                     |
| Distance between directors at the 2nd level ($S_5$) | 27.126             | 27.126                  |

**Figure 7.** Gain and pattern radiation of the simulated microstrip yagi antenna.

**Figure 8.** Realization of the 2-level microstrip Yagi antenna.

Figure 7 shows the gain and the radiation pattern of the simulated microstrip antenna. The gain obtained in the simulation is 8.148 dB with a bidirectional radiation pattern.
3.4. Realization of microstrip Yagi antenna

The antenna is realized with the FR-4 (lossy) substrate with relative permittivity of 4.3 and a thickness of 1.6 mm. The two-levels Yagi Microstrip Antenna that is realized has dimensions of 130 X 110 mm. The conductor used as a material for the patch is copper with a thickness of 0.035 mm. The antenna that has been realized can be recognized in Figure 8.

The microstrip Yagi antenna uses an SMA connector which has a 50Ω impedance. This connector consists of an internal conductor, a dielectric layer, and an outer conductor. The feeding technique used is the stripline to slotline transition. The result of measuring $S_{11}$ of the microstrip Yagi antenna is described in Figure 9.

Based on Figure 9, the microstrip Yagi antenna meets the specifications of 2.4 GHz Wi-Fi frequency with $S_{11}$ of -16.223 dB. The VSWR value measurement of a microstrip antenna is described in Figure 10. Meanwhile, based on Figure 10, the microstrip Yagi antenna can already meet the specifications of the Wi-Fi frequency at 2.4 GHz with a VSWR of 1.365. Meanwhile, the radiation pattern measurement is aimed to describe areas covered by electromagnetic fields. The electromagnetic fields emitted in various directions around the antenna have different transmit power.

Figure 11 shows a radiation pattern of the proposed antenna. The radiation pattern formed is bidirectional to which the antenna can only direct one direction. The maximum main lobe file in the measurement of the radiation pattern of the 2-levels microstrip Yagi is obtained at the 40° angle with a value of -32.79 dB. Meanwhile, antenna polarization is presented in Figure 12. Based on Figure 12, the 2-levels microstrip Yagi antenna has a maximum magnitude at the 20° angle with a value of -32.60 dB and a minimum magnitude at the 90° angle with a value of -55.86 dB.

The gain of the proposed antenna has reached the target. Based on the measurement result, the gain is equal to the data presented in Table 2.
Figure 11. Radiation pattern of realized microstrip Yagi antenna.

Figure 12. Polarization of realized microstrip Yagi antenna.

Table 2. The measurement results of the microstrip Yagi antenna’s gain.

| Antenna as a transmitter (Tx) | Antenna as a receiver (Rx) | Gain of reference antenna (Pref) |
|-------------------------------|---------------------------|---------------------------------|
| -32.90 dB                    | -32.52 dB                 | 8.36 dB                         |

Based on Table 2, the two-levels microstrip Yagi antenna has Tx power = -32.90 dB, Rx power = -32.52 dB, and gain of reference antenna of 8.36 dB. Thus, the gain of the antenna is calculated by

\[
Gain = P(Rx) - P(Tx) + P_{ref}
\]

\[
Gain = -32.90 \text{ dB} - (-32.52) \text{ dB} + 8.36 \text{ dB} = 7.98 \text{ dB}.
\]

4. Conclusions
The proposed antenna has met the target. It can work at 2.4 GHz frequency with S11 of -16.223 dB. The gain of the microstrip Yagi antenna is 7.98 dB. Based on the test result, the radiation is bidirectional. Maximum main lobe file in the measurement of microstrip antenna radiation pattern is obtained at 40° angle with value -32.79 dB. By selecting the material permittivity value and prudence in managing the antenna dimensions, it is proven to produce an antenna with target gain although the antenna only uses 1 branch and 2-levels of directors.

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