Hexagonal Patch Array Microstrip Antenna For WiFi Application Frequency 2.4 GHZ

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***Abstract* — The rapid expansion of internet networks in various sectors, such as education and e-commerce, relies heavily on Wireless Local Area Networks (WLAN). WLAN utilizes radio waves for data transmission, typically operating at the 2.4 GHz frequency. To enhance wireless communication efficiency, microstrip antennas offer a compact, lightweight, and cost-effective solution. This study focuses on the design and fabrication of a microstrip antenna featuring hexagonal patches arranged in a 4x4 array, specifically aimed at widening bandwidth for Wi-Fi applications. The research resulted in an external antenna device capable of increasing data transfer capacity while operating effectively at the 2.4 GHz frequency. Testing parameters demonstrated a return loss of -14.52 dB and a Voltage Standing Wave Ratio (VSWR) of 1.5, indicating efficient performance. Furthermore, the proposed 4x4 hexagonal array antenna achieved a bandwidth of 162 MHz. Implementation tests revealed a significant improvement in signal reception, with a power level of -37 dBm. This represents a substantial 12 dBm enhancement compared to the standard built-in antenna, which recorded a power level of -49 dBm. These results confirm that the design successfully provides superior signal quality for Wi-Fi networks.**

Keywords* — *Bandwidth, Hexagonal Patch, Internet, Microstrip Antenna, Wi-Fi

I. INTRODUCTION

WLAN is a computer network that uses radio waves as a data transmission medium. The implementation form of WLAN is Wi-Fi (Wireless fidelity). The development of Wi-Fi usage is currently very much needed by people in everyday life both at home and in the office. According to the Indonesian Internet Service Providers Association (APJII), the number of internet users in Indonesia in 2024 will reach 221,563,479 people from a total population of 278,696,200 Indonesians in 2023. In terms of age, the majority of people surfing the internet are Gen Z (born 1997-2012) at 34.40%. Then, the millennial generation is 30.62%. Then next, Gen X (born 1965-1980) as much as 18.98%, Post Gen Z (born less than 2023) as much as 9.17%, baby boomers (born 1946-1964) as much as 6.58% and pre boomers (born 1945 as much as 0.24%. Meanwhile, the level of internet user penetration based on region, APJII found that urban areas are still the largest with a contribution of 69.5% and rural areas contribute 30.5% [1]. Wi-Fi generally works at frequencies of 2.4 GHz and 5.8 GHz [2].

The antenna functions as a transmitter (transmitting antenna signals) and a receiver of radio wave antenna signals. Wi-Fi technology requires a transmitter antenna with a bandwidth wide enough to support the capacity requirements of Wi-Fi technology services. The use of Wi-Fi has time, distance and number of user usage that affect bandwidth [3]. Many users experience problems with inadequate Wi-Fi network speeds, especially when used for applications that require high bandwidth, such as online games, 4K video streaming, or video conferencing [4].

This study uses a microstrip antenna that has the advantages of being thin, small, lightweight, easy to make, easy to integrate with other electronic devices and relatively cheap. Microstrip antennas basically have several disadvantages such as low gain and narrow bandwidth. To increase the bandwidth and signal strength of technology [5]. The Array method is a method of duplicating elements on an antenna that can overcome the problems of narrow bandwidth and low gain [6], so this final assignment was designed and implemented a microstrip antenna with a patch in the form of a 4x4 hexagonal array for Wi-Fi applications with a frequency of 2.4 GHz.

II. METHOD

The method used in this study uses the Array method. Antenna array consists of an arrangement of several identical antennas. The signal from the antenna is combined or processed to improve the performance of an antenna. The purpose of making an antenna in an array is to increase antenna gain, increase antenna directivity, direct the transmit power to the desired sector, determine the direction of signal arrival [7]. Fig. 1 illustrates the research design.

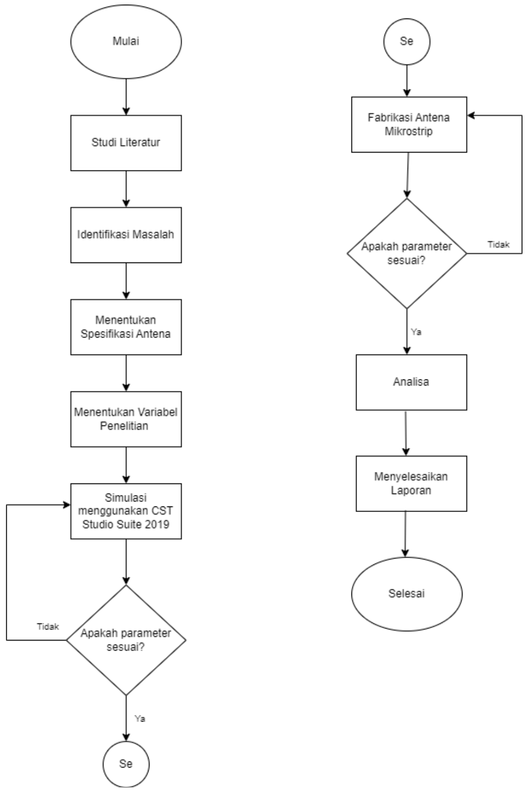

Figure 1. Research Design

The research variables include basic antenna parameters as a basis for determining the physical form of the antenna. Some parameters that will be discussed are *Return Loss*, VSWR, Gain, *Bandwidth* and Radiation Pattern.

A. Return Loss

Return loss is the ratio between the amplitude of the reflected wave to the amplitude of the transmitted wave [8]. *Return loss* is used to determine how much power is lost in the load and does not return as a reflection. RL is a parameter like VSWR that determines *the matching* between the receiving antenna and the transmitting antenna. Same as VSWR but by calculating the working power Where the value of RL ≤ -10 dB. For perfect *matching* of the transmitting antenna and the receiving antenna, the value of Γ = 0 and RL = ∞ which means no power is reflected, conversely if Γ = 1 and RL = 0 dB then all power will be reflected. The *Return loss value* can be calculated using the following Equation (1) [9].

$$RL\ (dB) = 20 log \Gamma \qquad (1)$$

Information:
RL = antenna (dB)*return loss*
Γ = reflection coefficient

B. VSWR (Voltage Standing Wave Ratio)

VSWR is the ratio of the maximum voltage to the minimum voltage on a transmission line. The greater the voltage value, the worse the performance of the antenna or the greater the interference waves, given in Equation (2) [10].

$$\text{VSWR} \quad \frac{V_{\max}}{V_{\min}} = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad (2)$$

Information :
Γ = reflection coefficient

C. Gain

The gain of an antenna is defined as the ratio of the intensity in a particular direction to the radiation intensity that would be obtained if the power received by the antenna were radiated isotropically. The radiation intensity is related to the power radiated isotropically equal to the power received by the antenna (Pin) divided by 4 π . This gain can be calculated using the following Equation (3) [5].

$$G = \frac{4\pi U(\theta, \Phi)}{Pin(lossless)} \qquad (3)$$

D. Bandwidth

Bandwidth is the frequency range where the antenna performance is continuous with some predetermined characteristics. The *bandwidth value* can be known if the lower frequency and upper frequency values of an antenna are known. The lower frequency is the initial frequency value of the antenna's working frequency, while the upper frequency is the final frequency value of the antenna's working frequency. *Bandwidth* can be calculated using the following Equation (4) [11].

$$BW = \frac{f_2 - f_1}{f_c} \times 100\% \qquad (4)$$

where to calculate the frequency or fc using the following Equation (5).

$$f_c = \frac{f_2 + f_1}{2} \qquad (5)$$

Information:
BW: *Bandwidth* (GHz or %)
f_2: Highest frequency (GHz)
f_1: Lowest frequency (GHz)
f_c: Center frequency (GHz)

E. Radiation Pattern

Radiation pattern is a graphical representation of the radiation properties of an antenna as a function of spatial coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization. The radiation pattern also depicts how strong the radiation from an antenna is as a function of direction [5].

There are several important parts in the antenna radiation pattern, namely:

1) The radiation lobe is the peak of the highest radiation intensity around the area of the lowest radiation intensity.

2) The Main Lobe is the radiation ear in the direction of maximum radiation.
3) Minor Lobe is another radiation ear from the main ear.
4) Side Lobe is a radiation ear in a direction other than the direction of the focused radiation.
5) The Back Lobe is the opposite of the radiation ear to the main ear.
6) Half Power Beamwidth (HPBW) is the width of the half power point of the antenna.
7) First Null Beamwidth (FNBW) is the angular width between the first null (empty) section on the other side of the main beam [12].

F. Microstrip Antenna

Microstrip antenna can be defined as one type of antenna that has a shape like a strip or piece that has a very thin and small size [13]. Microstrip antennas have been widely used in recent years because of their good characteristics, electrically thin, lightweight, low cost, aligned and so on. However, the electrical performance of basic microstrip antennas or arrays has a number of serious drawbacks, including very narrow bandwidth, high feed network losses, and low power handling capacity. With advances in theory and technology, some of these drawbacks have been overcome, or at least overcome to some extent. The market is growing rapidly, especially in personal communication systems, mobile satellite communications, direct broadcasting and wireless local area networks (WLAN) [14]. This study uses a hexagonal patch shown in Fig. 2.

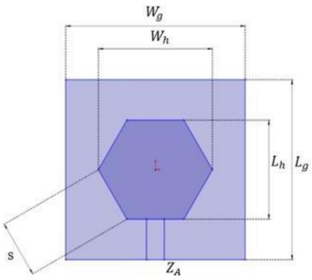

Figure 2

Patch side (S) and patch width can be calculated using the following Equations (6) and (7) [14].

$$s = \frac{c}{3{,}1033\ x\ F_r\sqrt{\varepsilon_r}} \tag{6}$$

$$W_h = \frac{c}{2\ x\ F_r\ x\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{7}$$

The length of the hexagonal patch (*Lh*) can be calculated using the following Equation (8) and (9) [5].

Information

s = side length (mm)
c = the speed of light in free space ($3\ x\ 10^8$)(m/s)
εr = dielectric constant (F/m)
Fr = resonant frequency (Hz)
Wh = *patch* width (mm)
h = substrate thickness (mm)
Lh = *patch* length (mm)
ΔL = length difference (mm)
$\varepsilon reff$ = effective dielectric constant (F/m)

There are several types of powering techniques for microstrip antennas, including the following:
a. microstrip direct coupling line feed
b. coaxial probe
c. aperture coupling
d. proximity coupled (electromagnetic coupling)

Each feeding technique has its advantages and disadvantages. In the feeding technique, the most important thing is the occurrence of impedance matching. In this study, the feeding technique used was microstrip feed line. The feeding technique was carried out by connecting the feeding line with the patch antenna [15]. The specifications of the FR-4 Epoxy PCB material are shown in Table 1 as follows:

TABLE 1
FR-4 EPOXY SPECIFICATIONS

Detail	Specification
Layer	2 (double)
Copper Thickness	0.015 mm
Substrate thickness	1.57mm
Size	215 x 220 mm
Made in	Shenzhen, China

The expected values in this study are shown in Table 2 below:

TABLE 2
EXPECTED ANTENNA VALUES

Parameter	Specification
Center Frequency	2448 MHz
Working Frequency	2401-2495 MHz
Return loss	≤-10 dB
VSWR	≤ 2
Gains	≥ 5 dBi
Bandwidth	≥ 100 MHz
Feeding Methods	Microstrip Line

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12x\frac{h}{Wh}}}\right) \quad (8)$$

$$\Delta L = 0{,}412 \frac{\left((\varepsilon_{\text{reff}} + 0{,}3) + \frac{W}{h} + 0{,}264\right)}{(\varepsilon_{\text{reff}} - 1{,}258)\left(\frac{W}{h} + 0{,}8\right)} \quad (9)$$

$$L_h = \frac{c}{2fr\sqrt{\varepsilon_{\text{reff}}}} - 2\Delta L$$

III. RESULTS AND DISCUSSION

A. *Hexagonal 4x4 Microstrip Patch Antenna Design Results*

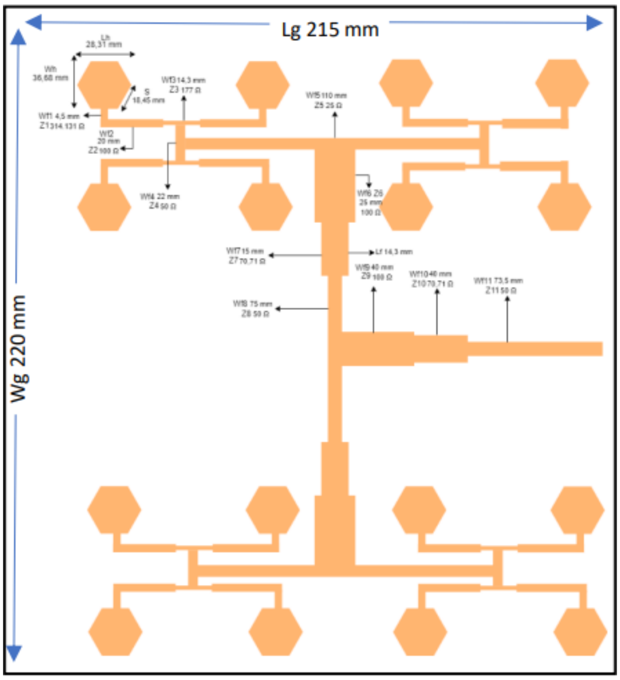

Figure 3. Antenna Design

B. *Return Loss (RL) Simulation Results, Voltage Standing Wave Ratio (VSWR), Bandwidth*

Fig. 4 shows the results of the Return Loss (RL) simulation of a 4x4 hexagonal microstrip patch antenna in the CST Studio Suite 2019 software .

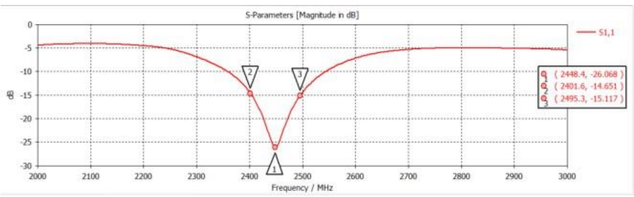

Figure 4. Return loss simulation results Marker

1 as the resonant frequency is at 2448 MHz with an RL level of -26.06 dB. *Marker* 2 as the upper frequency is at 2401 MHz. *Marker* 3 as the lower frequency is at 2495. *The return loss value* of less than - 10 dB indicates that the microstrip antenna matches the impedance of the load to be applied.

Fig. 5 shows the results of the Voltage Standing Wave Ratio (VSWR) simulation of a 4x4 hexagonal microstrip patch antenna in the CST Studio Suite 2019 software.

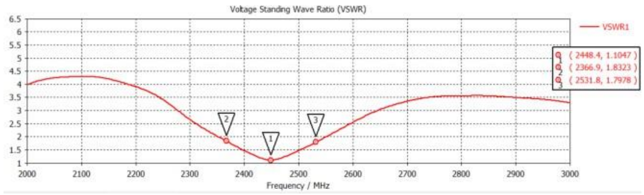

Figure 5. VSWR Simulation Results

Marker 1 as the resonant frequency is at 2448 MHz showing a result of 1.105. Marker 2 at 2401 MHz shows a result of 1.453. Marker 3 at 2495 MHz shows a result of

2.507. The VSWR value at a frequency of 2448 MHz is smaller and better than the frequencies of 2401 MHz and 2495 MHz, this is because 2448 MHz is the resonant frequency and working frequency.

Fig. 6 shows the simulation results of the 4x4 hexagonal microstrip patch antenna bandwidth in the CST Studio Suite 2019 software.

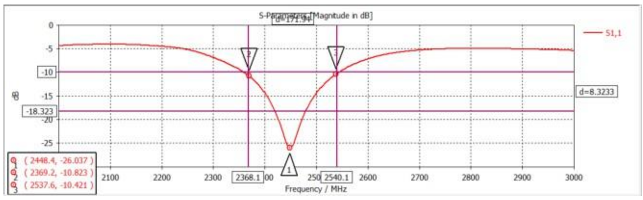

Figure 6 Bandwidth Simulation Results

Fig. 6 shows the simulation results of the bandwidth of a 4x4 hexagonal microstrip patch antenna designed at a resonance frequency of 2448 MHz, where the lower frequency is 2369.2 MHz and the upper frequency is 2537.6 MHz, resulting in a bandwidth of 168 MHz. The bandwidth can be determined by subtracting the upper and lower frequencies.

C. *Test Results Return Loss (RL), Voltage Standing Wave Ratio (VSWR), Bandwidth*

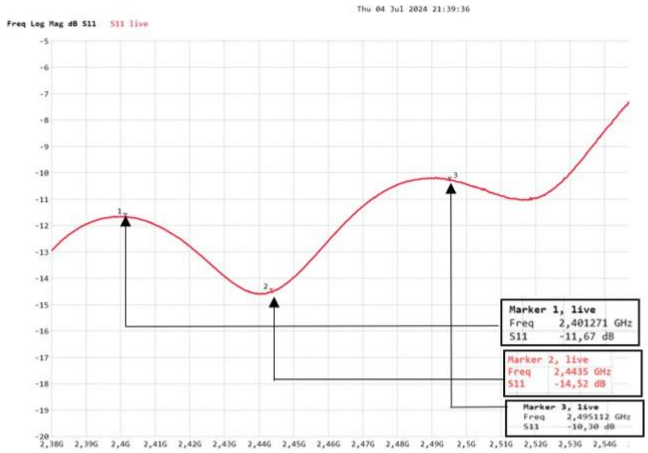

Figure 7. Return loss test results

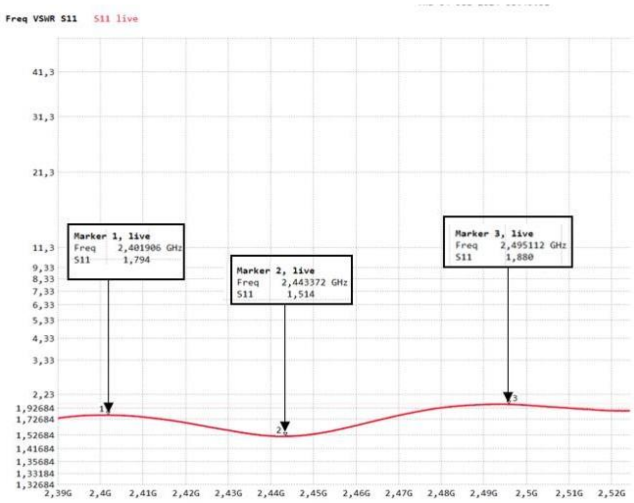

Figure 8. VSWR Test Results

Fig. 9 shows the results of testing *the bandwidth of a 4x4 hexagonal* microstrip patch antenna designed at a resonant frequency of 2448 MHz.

Figure 9. *Bandwidth* Test Results

Bandwidth Calculation: $f2 - f1$ = 2,563 − 2,401 = 162 MHz

D. Gain and Radiation Pattern Test Results

The results of the antenna gain test tested for the working frequency of the 16-element hexagonal microstrip antenna are shown in Table 3 and Fig. 10.

TABLE III
RESULTS OF THE ANTENNA GAIN TEST

Frequency (MHz)	Reference Antenna	Microstrip Antenna	Gain (dBi)
2400	-66.3	-72	-3.55
2410	-69.7	-68	3.85
2420	-73.2	-70	5.35

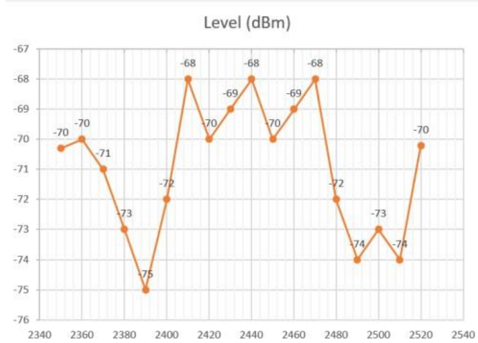

Figure 10. Gain Graph

Hexagonal microstrip antenna is a bidirectional radiation pattern, which means it has two effective radiation directions in two opposite directions. The results of the Radiation Pattern Test are shown in Fig. 11. The image was obtained from testing 0° to 360°.

The half power beamwidth (HPBW) value is obtained by knowing the angle that has a normalization of -3 dB, namely the angle 340º as HP (right) and 20º as HP (left). Therefore, HPBW can be calculated using the following equation:

$$\begin{gathered} HPBW = HPright - HPleft \\ HPBW = (360° - 340°) + 20° \\ HPBW = 40° \end{gathered} \tag{10}$$

Side lobe level attenuation (SLLA) and front back ratio (FBR) are obtained from the main lobe (main beam) at an angle of 0°, side lobe at an angle of 290°, back lobe at an angle of 180°. Therefore, SLLA can be calculated using the following Equation (11):

$$\begin{gathered} \text{SLLA} = \frac{\text{1st side lobe}}{\text{main lobe}} \qquad FBR = \frac{\text{main lobe}}{\text{back lobe}} \\ SLLA = \frac{-73{,}8}{-68{,}2} \qquad FBR = \frac{-68{,}2}{-76{,}7} \\ SLLA = 1{,}082 \qquad FBR = 0{,}88 \end{gathered} \tag{11}$$

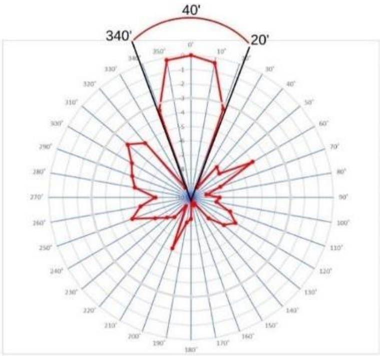

Figure 11. Radiation Pattern Test Results

E. *Hexagonal Microstrip Patch Antenna on 2.4 GHz Wi-Fi Frequency*

Receive signal strength indicator (RSSI) on the EchoLife EG8145V5 access point with built-in antenna gets a value of -49 dBm, where this value is below -70 so that the signal strength is classified as very good. Receive signal strength indicator (RSSI) on the EchoLife EG8145V5 access point with a 4x4 hexagonal microstrip patch antenna gets a value of -37 dBm where this value is below -70 so that the signal strength is classified as very good. The results of the implementation of the 4x4 hexagonal microstrip patch antenna for signal amplifiers on the EchoLife EG8145V5 access point can be seen in Table 4.

TABLE 4
COMPARISON OF RSSI OF BUILT-IN ANTENNA WITH MICROSTRIP ANTENNA

Antena	**Receive Signal Strength Indicator (RSSI)**
Built-in	-49 dBm
Hexagonal microstrip patch	-37 dBm

Built-in antenna and antenna implementation circuit The 4x4 Hexagonal Microstrip Patch at 2.4 GHz Wi-Fi frequency is shown in Fig. 12 and Fig. 13.


Figure 12. Built-in Antenna Implementation


Figure 13. Microstrip Antenna Implementation

The resonance frequency of the simulation, namely 2448 MHz, shifted to 2443 MHz during laboratory measurements. This frequency shift caused an increase in the Return Loss, VSWR and Gain values. . The increase in Return Loss value is 12.27 dB, VSWR with a value of 0.3, Gain -11.25 and bidirectional radiation pattern with HPBW value of 40°. The RSSI results when implementing the 4x4 hexagonal microstrip patch antenna get a value of -37 dBm. These results indicate a better increase in power level than the built-in antenna with a difference of 12 dBm.

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