Design and Implementation of 2x4 Octagonal Array Patch Microstrip Antennas using T-Slots at 2.4 GHz Frequency for Wifi Applications

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***Abstract*—Wireless communication requires a useful device to transmit and receive electromagnetic waves. WiFi is a particular kind of wireless communication device used to send data over the internet network. The bandwidth and signal coverage of WiFi have significant limitations. As a result, an antenna is utilized to enhance signal reception in order to solve this issue. The research method used is to compare the design of the 2x4 octagonal microstrip array antenna using a T-slot and without the T-slot to see the results of simulation and testing in terms of return loss, VSWR, gain, and bandwidth. The results of bandwidth testing for octagonal microstrip antennas without a 2x4 T-slot array are 32 MHz, while for octagonal microstrip antennas using a 2x4 T-slot array of 40MHz. The octagonal microstrip antenna without a 2x4 T-Slot array has Return Loss of -18.2 dB and a VSWR of 1.280. The 2x4 octagonal T-Slot array microstrip antenna has Return Loss of -17.6 dB and a VSWR of 1.303. The test results 2x4 octagonal array microstrip antenna gain without using T-slot produces the largest gain of 9.55dBi, and the antenna using T-slot produces the largest gain of 12.55dBi.**

Keywords*— *Microstrip Antenna, Array, Octagonal Patch, T-Slot, Bandwidth, Wi-Fi.

I. INTRODUCTION

WiFi is a type of wireless communication tool that serves to transmit and receive electromagnetic waves [1]. WiFi network also has a weakness where bandwidth and signal coverage are very limited. Therefore, to overcome this problem, an antenna is used to improve the quality of signal reception. Antenna is a tool that is useful for emitting waves in a certain direction or vice versa receiving waves from a certain direction. One type of antenna that can be designed for a network amplifier that works at a WiFi frequency of 2.4 GHz is a microstrip antenna [2].

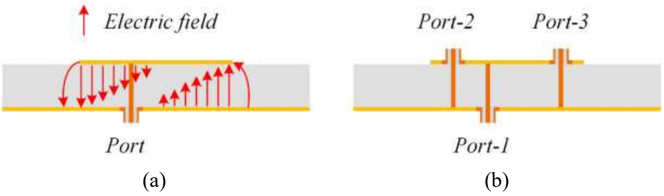
An access point is a network device that contains a transceiver and antenna for transmitting and receiving signals to and from remote clients [3]. However, the antenna at the access point has a disadvantage, namely the poor signal reception quality. This can be overcome by using a microstrip antenna. Microstrip patch antenna is more versatile features like compact in size, flexible in installation, best circular polarization and less return loss [4]. The microstrip antenna itself also has a weakness, namely the bandwidth and gain are small [5]. The small gain can be improved by adding an array to the microstrip antenna. While the small bandwidth can be widened in various ways, one of which is to add slots on the microstrip patch antenna and try the design of the microstrip patch antenna with different shapes.

Based on this background, it is proposed to design and realize a microstrip antenna with the aim of improving signal reception quality and an array with octagonal patch elements as many as eight elements is proposed to increase antenna gain in WiFi applications. In addition, antenna gain can be increased by adding slots [6]. This design uses the method of giving a T-shaped slot on the patch antenna which is often used to increase antenna gain and widen antenna bandwidth. To increase the bandwidth by 41%, a microstrip antenna with a hybrid strip-slot structure is proposed [7]. The antenna is designed to work on the Wi-Fi working frequency, namely 2.401–2.495 GHz, using the microstrip feedline technique where the feedline can facilitate the antenna fabrication process because the feed line and the radiation element are printed on the same substrate. Besides that, matching impedance in this feeding technique is also simpler than other feeding techniques. The antenna has a ground plane, substrate and patch arrangement in a single PCB made of FR4-Epoxy with an r value of 4.3 and a thickness of up to 1.6 mm to support Wi-Fi function.

In the design process, the CST Studio Suite 2018 software will be used. The application is used in the design and testing process based on simulations. The tests carried out will be based on the parameter values of return loss, VSWR (Voltage Standing Wave Ratio), bandwidth, gain and radiation pattern.

The microstrip antenna (MSA), also called the patch antenna [8]. In the early decades, it did not find many uses, but in recent years, wireless communication has made extensive use of them. A substrate, a dielectric material, is sandwiched between two plates of the conducting materials of a microstrip antenna. Microstrip antennas have the benefits of a simple design, small weight, and ease of integration, however its usual half power beamwidth (HPBW) is only between $70^\circ - 80^\circ$ [9].

A workable way to increase the beamwidth of a microstrip antenna is to modify the radiating patch's form so that its radiation equivalent magnetic current is different from the original pair rather than comparable to it [10][11]. Another technique for improving beamwidth performance involves adding the coplanar parasitic element to the microstrip antenna [12]. The third technique involves creating vertical currents, which can be done by enclosing the main radiating device in a metal chamber [13]-[15] or a number of metal pillars [16]-[18].



(a) (b)

Figure 1. An example of a common microstrip antenna schematic. (a) TM01 mode's electric field. (b) Microstrip-based power divider. [12]

II. METHOD

A. Design of patch antenna

The design of the microstrip antenna includes the selection of the antenna substrate, the shape of the patch antenna, and the determination of the shape and slot. The patch antenna is octagonal in shape with eight sides. The type of substrate used is FR4 with a thickness of 1.57 mm and dielectric constant = 4.58. This substrate was chosen because it is available in the local market, reduces the need for imports, and is relatively inexpensive.

1) Dimensions of octagonal patch: The patch antenna width is calculated using the following equation [19].

$$W = \frac{c}{2\,fr\sqrt{\frac{\varepsilon r+1}{2}}} \tag{1}$$

Information:
W = Width of rectangular patch (mm)
c = Speed of light in free space (3x108 m/s)
fr = Working frequency of antenna (GHz)
$\mathcal{E}r$ = Dielectric constant of the substrate (F/m)

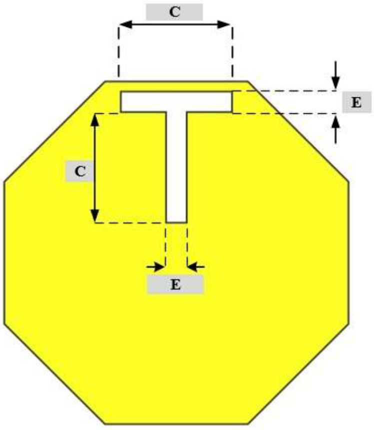


Figure 2. Microstrip antenna octagonal patch

The sides of the octagonal patch can be calculated by the following equation.

$$S = 2\,(Cos(\,\alpha\,)\;x\;R)) \tag{2}$$

Where R is the radius of the octagonal patch calculated using the approximation formula of the hexagonal side.

$$R = \frac{c}{3.1033\;x\;fr\;x\;\sqrt{\varepsilon_r}} \tag{3}$$

Calculation of the length of the octagonal patch as shown in the equation below:

$$L = Leff\text{-}\;2\Delta L \tag{4}$$

Where Leff and 2ΔL are obtained through the following equation [20].

$$Leff = \frac{c}{2fo\sqrt{\epsilon_{eff}}} \tag{5}$$

$$L = 0.412h\frac{(\epsilon_{eff}+0.3)\left(\frac{Wp}{h}+0.264\right)}{(\epsilon_{eff}-0.258)\left(\frac{Wp}{h}+0.8\right)} \tag{6}$$

Where h is the height of the substrate or commonly called the thickness of the substrate while is the effective dielectric constant which can be found from the following equation [19]:

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2}\frac{\epsilon_r+1}{2}\left[\frac{1}{\sqrt{1+12\frac{h}{W}}}\right] \tag{7}$$

Information:
h = Substrate thickness (mm)
ϵ_r = Dielectric constant k substrate (F/m)
W = Rectangular patch width (mm)

2) Method Slot: This study chose I-Slot because of its simple slot shape, for I-Slot on rectangular patch can be done in the following equation.

$$C = \frac{\lambda}{60} \tag{8}$$

$$\frac{E}{Wp} \geq 0{,}3 \tag{9}$$

Information:
C = Slot (mm)
E = Vertical length (mm)
Wp = Patch (mm)

The calculation of I-Slots on circular Patches can be done by following equation.

$$C = \frac{\lambda}{60} \tag{10}$$

$$\frac{E}{2a} \geq 0,3 \tag{11}$$

Information:

C = Slot (mm)
E = Vertical length (mm)
a = Dimensional radius circular (mm)

B. Design of antenna transmission line

In practice, the transmission line leads to the feeder, that is, between the lossless line and the antenna. To design the antenna feed, it is done by calculating the input impedance of each individual patch using the following formula.

$$Z_A = 60\frac{\lambda_d}{L} \tag{12}$$

Information:

Z_A = Impedance *octagonal patch* (Ω)
λ_d = Transmission wavelength (mm)
L = Octagonal patch length (mm)

The impedance value at one patch is used as a determinant of the initial value in the design calculations, so that the impedance value at the end of the line is 50. After knowing the impedance of one patch, the next step is to calculate the impedance and branch impedance of each channel. Impedance in each design can be determined by the following equation:

$$\frac{1}{Zp} = \frac{1}{Z_1} + \frac{1}{Z_2} \tag{13}$$

Information:

Z_p = parallel impedance (Ω)
Z_1 = Branch impedance 1 (Ω)
Z_2 = Branch impedance 2 (Ω)

By knowing the impedance of each channel, you can also find out the width of each impedance channel. The channel width can be determined by the following equation:

$$W_f = \frac{120\pi h}{Z_p\sqrt{\varepsilon_r}} \tag{14}$$

Information :

W_f = Channel width (mm)
Zp = line impedance(Ω)
h = Thick *substrate*(mm)
ε_r = Dielectric constant (F/m)

III. RESULTS AND DISCUSSION

A. Return Loss and VSWR Test Results

1) Results of the Return Loss and VSWR Octagonal Array Microstrip Antenna 2x4 without T-Slot: Based on testing the return loss and VSWR values of the octagonal microstrip antenna without slots, the AUT power level value can be seen in Fig. 3. while the reference level value can be seen in Fig. 4. The power level that has been obtained during testing is used to calculate the return loss value with the following equation.

$$RL = Level_{AUT} - Level_{referensi} - Att_{DC} \tag{15}$$

Description:

RL = *Return Loss*
$level_{AUT}$ level = antenna power level under test
Att_{DC} = attenuation of *directional coupler*

Marker 2 Return Loss can be known by the calculation:

$$RL = Level_{AUT} - Level_{referensi} - Att_{DC}$$
$$RL = -70.6 \text{ dBm} - (-32.4 \text{ dBm}) - (-20 \text{ dB})$$
$$RL = -18.2 \text{ dB}$$

After the Return Loss is known, it can be seen the value of the rebound coefficient used for calculations on VSWR.

$$RL = 20 \text{ Log } |\Gamma| \tag{16}$$
$$|\Gamma| = 10^{\frac{RL}{20}}$$
$$|\Gamma| = 10^{\frac{-18.2}{20}}$$
$$|\Gamma| = 0.123$$

VSWR can be known by the value of the coefficient of reflection as follows.

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{17}$$
$$VSWR = \frac{1+0.123}{1-0.123}$$
$$VSWR = 1.280$$

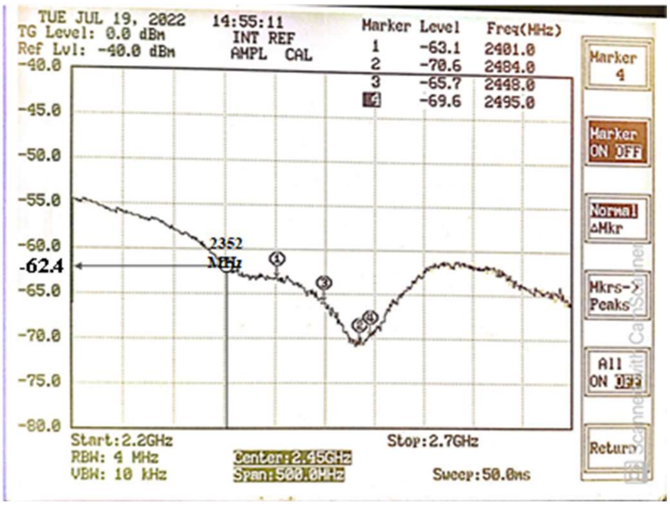


Figure 3. Return loss test result 2x4 octagonal array microstrip antenna without T-Slot.

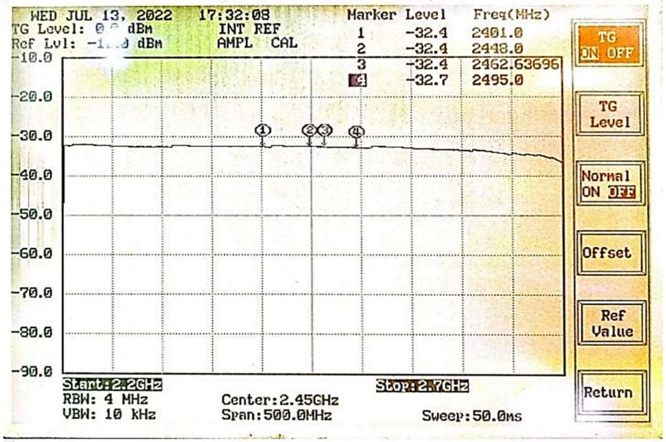


Figure 4. Reference Level Value

TABLE I
RESULT OF RETURN LOSS AND VSWR OCTAGONAL MICROSTRIP ANTENNA WITHOUT T-SLOT

Marker	Frequency	*Return Loss*	*VSWR*
1	2401MHz	-10.7 dB	1.820
2	2484 MHz	-18.2 dB	1.280
3	2448 MHz	-13.3 dB	1.551
4	2495 MHz	-16.9 dB	1.331
5	2352 MHz	-10 dB	1.923

2) The results for Return Loss and VSWR Octagonal Array Microstrip Antenna 2x4 with T-Slot: Marker 2 lies at the resonant frequency of 2518 Mhz. Return Loss can be determined by calculating.

$$RL = Level_{AUT} - Level_{referensi} - Att_{DC}$$
$$RL = -70\text{ dBm} - (-32.4\text{ dBm}) - (-20\text{ dB})$$
$$RL = -17.6\text{ dB}$$

After the Return Loss is known, it can be seen the value of the reflection coefficient used for calculation on VSWR.

$$RL = 20\text{ Log }|\Gamma|$$
$$|\Gamma| = 10^{\frac{RL}{20}}$$
$$|\Gamma| = 10^{\frac{-17.6}{20}}$$
$$|\Gamma| = 0.131$$

VSWR can be known by the value of the coefficient of reflection as follows:

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$
$$\text{VSWR} = \frac{1 + 0.131}{1 - 0.131}$$
$$\text{VSWR} = 1.301$$

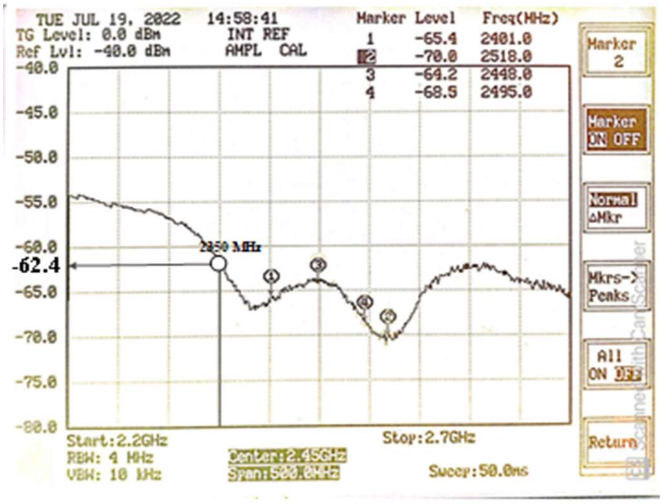


Figure 5. Return loss test results 2x4 octagonal array microstrip antenna with T-slot.

TABLE II
RESULT OF RETURN LOSS AND VSWR OCTAGONAL MICROSTRIP ANTENNA WITHOUT T-SLOT

Marker	Frequency	Return Loss	VSWR
1	2401 MHz	-13 dB	1.574
2	2518 MHz	-17.6 dB	1.301
3	2448 MHz	-11.8 dB	1.691
4	2495 MHz	-16.1 dB	1.369
5	2350 MHz	-10 dB	1.923

B. Gain Test Results

1) Test Results 2x4 Octagonal Array Microstrip Antenna Gain Without Using T-Slot: Based on the results of the antenna gain test results table without using a slot, a graph is made as shown in Fig. 6. which is shown in the graph 0 dBi is at a frequency of 2540 MHz where the frequency produces the largest gain of 9.55 dBi. Then it is shown that the graph of -3 dBi is at a frequency of 2550 MHz and 2518 MHz, where these frequencies will be used as a reference to determine bandwidth. The resulting bandwidth in the gain measurement for a microstrip antenna without using a T-Slot is 32 MHz.

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$$BW = f_2 - f_1 \tag{18}$$
$$BW = 2550\text{ MHz} - 2518\text{ MHz}$$
$$BW = 32\text{ MHz}$$

TABLE III
TEST RESULT OF 2X4 OCTAGONAL ARRAY MICROSTRIP ANTENNA GAIN WITHOUT USING T-SLOT

Frequency (MHz)	Level ref (dBm)	Level Test (dBm)	Gain (dB)	Normalization (dB)
2360	-61.6	-64.9	-1.15	-10.70
2380	-56.9	-67.2	-8.15	-17.70
2400	-60.3	-65.5	-3.05	-12.60
2420	-56.6	-66.7	-7.95	-17.50
2440	-53.4	-62.9	-7.35	-16.90
2460	-55.9	-60.5	-2.45	-12.00
2480	-58.6	-60.8	-0.05	-9.60

2500	-63.1	-65.7	-0.45	-10.00
2520	-69.9	-64.1	7.95	-1.60
2540	-70.9	-63.5	9.55	0.00
2580	-57.3	-62.8	-3.35	-12.90

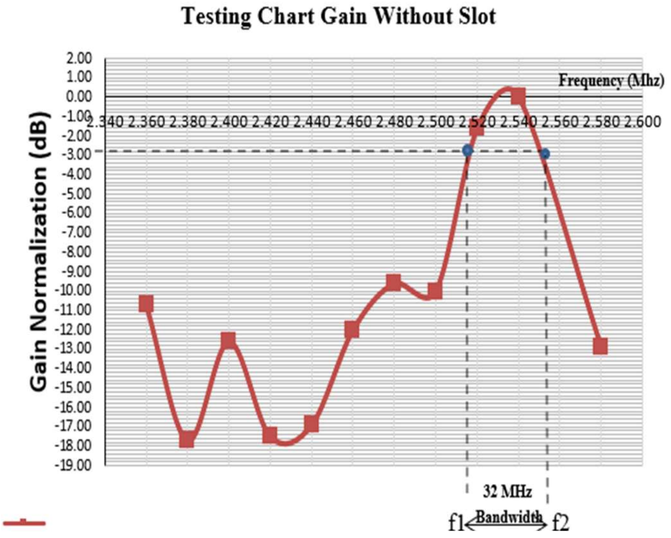

Figure 6. Graph of gain testing for 2x4 octagonal array microstrip antenna without using T-slot

2) Test Results 2x4 Octagonal Array Microstrip Antenna Gain Using T-Slot: Based on the results of table IV, a graph as shown in Fig. 7 is made, which is shown by the graph of 0 dBi at a frequency of 2520 MHz where the frequency produces the largest gain of 12.55 dBi. Then it is shown that the graph of -3 dBi is at a frequency of 2545 MHz and 2505 MHz, where these frequencies will be used as a reference to determine bandwidth. The resulting bandwidth in the gain measurement for microstrip antenna using T-Slot is 40 MHz. It can be concluded that there is a widening of the bandwidth of 8 MHz between the microtrip antenna without using T-Slot and using T-Slot.

$$BW = f_2 - f_1$$
$$BW = 2545\text{ MHz} - 2505\text{ MHz}$$
$$BW = 40\text{ MHz}$$

TABLE IV
TEST RESULT OF 2X4 OCTAGONAL ARRAY MICROSTRIP ANTENNA GAIN USING T-SLOT

Frequency (MHz)	Level ref (dBm)	Level test (dBm)	Gain (dB)	Normalization (dB)
2360	-61.6	-62.7	1.05	-11.50
2380	-56.9	-68.2	-9.15	-21.70
2400	-60.3	-62.4	0.05	-12.50
2420	-56.6	-57.5	1.25	-11.30
2440	-53.4	-56.8	-1.25	-13.80
2460	-55.9	-60.5	-2.45	-15.00
2480	-58.6	-57.4	3.35	-9.20
2500	-63.1	-57.1	8.15	-4.40
2520	-69.9	-59.5	12.55	0.00
2540	-70.9	-62.2	10.85	-1.70
2580	-57.3	-63.5	-4.05	-16.60

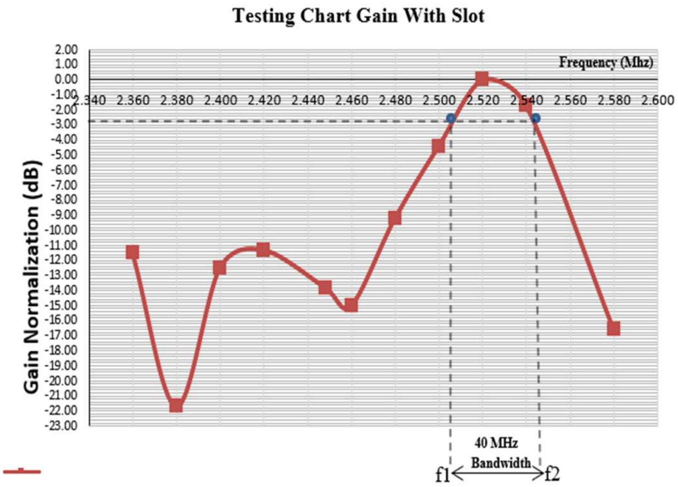

Figure 7. Graph of gain testing for 2x4 octagonal array microstrip antenna using T-slot.

C. Radiation Pattern Test Results

The results of the radiation pattern test can be concluded that the radiation pattern of the 2×4 element Octagonal T-Slot array microstrip antenna at a frequency of 2448 MHz is directional, meaning that the antenna has a more effective radiation direction at 354˚ and 24˚ angles.

The HPBW calculation can be known by marking the angle that has a normalized value of -3 dB, namely the HP (left) angle of 354˚ and HP (right) 24˚ so that it can be calculated using the formula:

$$HPBW = \text{HP (left)} + \text{HP (right)} \qquad (19)$$
$$HPBW = (360^\circ - 354^\circ) + 24^\circ$$
$$HPBW = 30^\circ$$

Based on the polar diagram representation in the test, the radiation pattern of the microstrip antenna octagonal array 2x4 using T-Slot which is directional.

TABLE V
RADIATION PATTERN TEST RESULTS

(°)	2448 MHz		(°)	2448 MHz	
	Power Level (dBm)	Normalization (dB)		Power Level (dBm)	Normalization (dB)
0	-56.6	0	190	-67.5	-10.9
10	-57.3	-0.7	200	-67.8	-11.2
20	-57.5	-0.9	210	-65.5	-8.9
30	-61.1	-4.5	220	-68.1	-11.5
40	-64.2	-7.6	230	-67.2	-10.6
50	-65.2	-8.6	240	-68	-11.4
60	-66	-9.4	250	-67.4	-10.8
70	-65.7	-9.1	260	-68.2	-11.6
80	-66.3	-9.7	270	-67.6	-11
90	-67.4	-10.8	280	-65.2	-8.6
100	-67.6	-11	290	-64.5	-7.9
110	-67.8	-11.2	300	-63.3	-6.7
120	-67.5	-10.9	310	-62.8	-6.2
130	-66.5	-9.9	320	-61.7	-5.1

140	-66.6	-10	330	-64.4	-7.8
150	-64.6	-8	340	-62.4	-5.8
160	-67.2	-10.6	350	-60.9	-4.3
170	-66.9	-10.3	360	-59.9	-3.3
180	-66.7	-10.1			

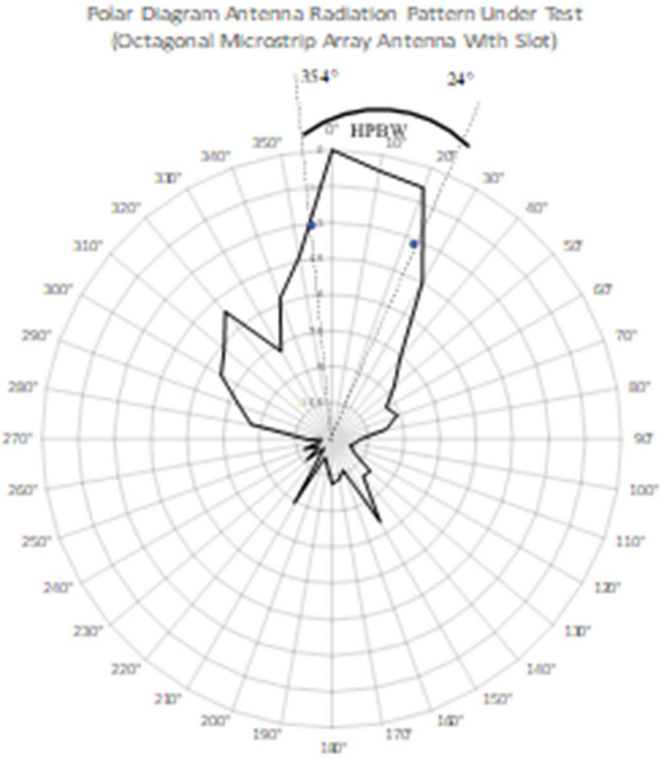

Figure 8. The directional radiation pattern of a 2x4 octagonal array microstrip antenna using a T-slot.

The results of the research should be written clearly and concisely. Discussions consider outlines the importance of research, not repeat it. Avoid excessive uses quotations and discussions about literature published.

D. Comparison of Simulation Values and Test Values

1) Comparison of Return Loss and VSWR Values: Table 5. can be seen that in the simulation the resonant frequency is located at 2448MHz. Comparison of the return loss at a frequency of 2448 MHz between the simulation and the test has a comparative value that is not that far away, which is around -11.8dB. Meanwhile, at the time of testing the resonant frequency is located at a frequency of 2518 MHz with a return loss of -17.6dB.

These results indicate that the simulated and fabricated antennas have shifted the resonant frequency. This happens because the antenna fabrication results are not so precise. Looking at the comparison of the resonant frequency between the simulation and the test, the dimensions of the fabrication result are smaller than the simulated design, therefore the resonant frequency of the test is higher than the simulation. Even though there is a shift in the resonant frequency, this is not a problem because in the working frequency range of 2401 MHz - 2495 MHz, the *return loss* is still in accordance with the minimum requirements for antenna manufacture, which is ≤10dB.

TABLE VI
COMPARISON OF RETURN LOSS AND VSWR VALUES

Frequency (MHz)	**Return Loss (dB)**		**Reflection Coefficient**		**VSWR**	
	Simulation	**Test**	**Simulation**	**Test**	**Simulation**	**Test**
2448	-19.456	-11.8	0.106	0.257	1.237	1.69
2518	-6.9159	-17.6	0.451	0.132	2.642	1.30

2) Comparison of Gain and Bandwidth Values: To compare gain between the simulation and the test, the simulation obtained a gain of 5.005dBi. In contrast to the test, the gain obtained increased by 12.55dB. This value meets the minimum requirements for making an antenna, which is ≥ 5dB. Comparison of the bandwidth between the simulation and the test, in the simulation the bandwidth 124.95 MHz and in the test the value is 40MHz.

TABLE VII
COMPARISON OF GAIN AND BANDWIDTH VALUES

Frequency (MHz)	**Simulation**	**Test**	
2401-2495	5.005 dB	12.55 dB	***Gain***
	124.95 Mhz	40 Mhz	***Bandwidth***

E. Wi-Fi Implementations

Measurements The implementation of the design antenna was carried out at the House, Grand Mahabharata Saxophone Housing Number B15, Malang City. The following is a picture of the signal reception quality test circuit: antenna shown in Fig. 9.

The measurement of the power level of the signal reception quality in the wifi analyzer is used as a reference for the input power received by the design antenna in implementation, it is known that the results of power measurements through the wifi analyzer are as follows:

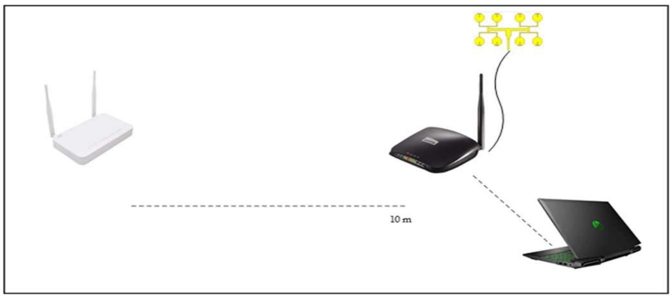

Figure 9. Implementation of AUT antenna on Wifi

The results of signal reception quality from the implementation using the build in wifi router Netis WF2210 antenna is -25 dB with a distance of 10 m between the access point and wifi router Netis WF2210These results will then be compared to replacing the build in wifi router antenna with a microstrip design antenna using a T-slot arrays 2x4.

The results of the quality of signal reception from the implementation using a microstrip antenna design using T-slot array which is -14 dB with the same 10 m distance between the access point and the wifi router Netis WF2210. These results can be concluded that the quality of signal reception from the microstrip design antenna is better than the build in wifi router antenna.

IV. CONCLUSION

In testing the octagonal microstrip antenna without a 2x4 T-Slot array, the resonant frequency shift was obtained at 2484 MHz with a Return Loss of -18.2 dB and a VSWR of 1.280. Although there is a shift in the resonant frequency, the center frequency, which is expected to still be operational, is because the frequency of 2401 – 2495 MHz is still below the minimum requirement for antenna design, which is -10dB.

In testing the 2x4 octagonal T-Slot array microstrip antenna, the resonant frequency shift was found at 2518 MHz with a Return Loss of -17.6 dB and a VSWR of 1.303. Although there is a shift in the resonant frequency, the center frequency, which is expected to still be operational, is because the frequency of 2401 – 2495 MHz is still below the minimum requirement for antenna design, which is -10dB. The largest gain value is located at a frequency of 2520 MHz of 12.55dBi. The radiation pattern produced is directional and the HPBW value is 30°.

The results of bandwidth testing for octagonal microstrip antennas without a 2x4 T-slot array are 32 MHz, while for octagonal microstrip antennas using a 2x4 T-slot array of 40MHz. The results of the comparison of the two antennas can be concluded that there is a bandwidth widening of 8 MHz between an octagonal microstrip antenna without a 2x4 T-slot array and an octagonal microstrip antenna using a 2x4 T-slot array.

On implementation octagonal microstrip antenna using a 2x4 T-slot array resulted in an average signal reception quality power value of -14dB. Compared to the built in antenna of the Netis WF2210 wifi router, it is -25dB. These results can be concluded that the power value of the average signal reception quality of the octagonal microstrip antenna design using a 2x4 T-slot array is better than the built-in antenna of the Netis WF2210 wifi router.

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