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Microstrip Antenna Design Circular and Disc Sector Using Multilayer Parasitic Method for Gain Enhancement at 2.4 GHz Frequency

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Abstract— **WiFi has become a very important wireless communication technology device in everyday life, so that the increasing number of devices that require a stable WiFi connection. WiFi antennas also have gain limitations that cause suboptimal signal range, and decreased signal quality, especially in environments with many obstacles. Conventional antennas also have uneven radiation patterns and bandwidth limitations that can limit performance, especially in dense traffic environments. Therefore, a microstrip antenna is needed to increase the gain so that the range can be further, the radiation pattern is focused on one direction and sufficient bandwidth. Microstrip antennas have the advantages of being small, cheap and light. This study discusses increasing gain using the multilayer parasitic method as many as 4 layers with a patch circular shaped and disc sector. Implementation of the working frequency used by the microstrip antenna (2401-2495) MHz for WiFi (Wireless Fidelity) networks. The fabricated multilayer microstrip antenna works at a frequency of 2447 MHz with a return loss value of -13.91 dB, VSWR 1,505 and is in the frequency range (2411 - 2507) MHz. At a frequency of 2420, a gain value of 14.95 dBi was obtained with a bandwidth of 88 MHz, while at a frequency of 2440 MHz the gain obtained was 10.5 dBi. This antenna is directional because it has effective radiation in a certain direction.**

Keywords*— *Circular, Disc Sector, Gain, Microstrip Antenna, Multi layer Parasitic.

I. INTRODUCTION

Microstrip antenna is a thin board antenna consisting of 3 layers of structure [1][2]. Microstrip antenna is a type of wireless communication antenna. Microstrip antenna is widely recommended for radio communication systems because this type of antenna has many advantages including small, compact and simple shape [2][3]. However, microstrip antenna has several disadvantages such as narrow bandwidth [4] only around <5 %[5] and low gain [6]. There are several methods to increase gain , namely the array method and the multilayer parasitic method [3][7]. The weakness of the array method is that it has a large dimension and difficulty in designing its power supply. This is because the more elements are arranged to increase the gain , the more difficult the calculations are in designing the supply technique [3].

Related research on parasitic multilayer antennas was conducted by Galuh Indah Agus Pratiwi entitled "Design and Construction of Harvesting Microstrip Patch Antennas". Circular and Rectangular Using the Multilayer Parasitic Method at 2.4 GHz WiFi Frequency" discussed in [8]. This study designs a microstrip antenna at a frequency of 2.4 GHz using the multilayer parasitic method. which consists of 3 layers. The first and second layers are 4 patches rectangular and the third layer is a patch circular with feed line and ground. The substrate material used is FR-4 E-Proxy with a dielectric constant of 4.6 and the type of ground used is 2 copper. The fabrication results show a shift in the resonance frequency which should be at 2448 MHz shifted to a frequency of 2431. Where the resonant return loss value is at a frequency of 2431 is -14.92 dB. This is influenced by the screen printing or etching process which is less precise. The best gain results are at a frequency of 2480 MHz of 9.65 dBi. The multilayer antenna has a bandwidth of 84 MHz in the frequency range of 2400-2484 MHz. Meanwhile, the bandwidth obtained by the single microstrip antenna tends to be smaller with a value of 48 MHz in the frequency range of 2453-2405 MHz.

This research is entitled " Design of Microstrip Antennas " Circular and Disc sector Using Multilayer Parasitic Method for Gain Enhancement at 2.4 GHz Frequency "An antenna will be designed using 4 layers. Where patch the first to third layers are disc shaped sectoral and the fourth layer is patch circular , substrate and ground. The substrate material used is FR-4 FR-4 E-Proxy with a dielectric constant of 4.58 and the type of ground used is copper. Using the λ/4 method for impedance matching.

II. METHOD

A. *Types of research*

This research uses the Research method and Development (R&D). This research produces a parasitic multilayer microstrip antenna that works at a frequency of 2.4 GHz and is applied to WiFi. This research uses the parasitic multilayer method to increase gain. The parasitic multilayer method is one

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method to increase gain by adding one to several layers. parasitic in front of main layer.

B. Research Stages

In designing an antenna, there are stages that need to be carried out to help the design process so that the results obtained can be as optimal as possible. The flow diagram in this antenna research is divided into 2 stages, namely the design in the CST 2019 application and real tool testing. Systematically, the research stages in the form of flow chart shown in Figure 1.

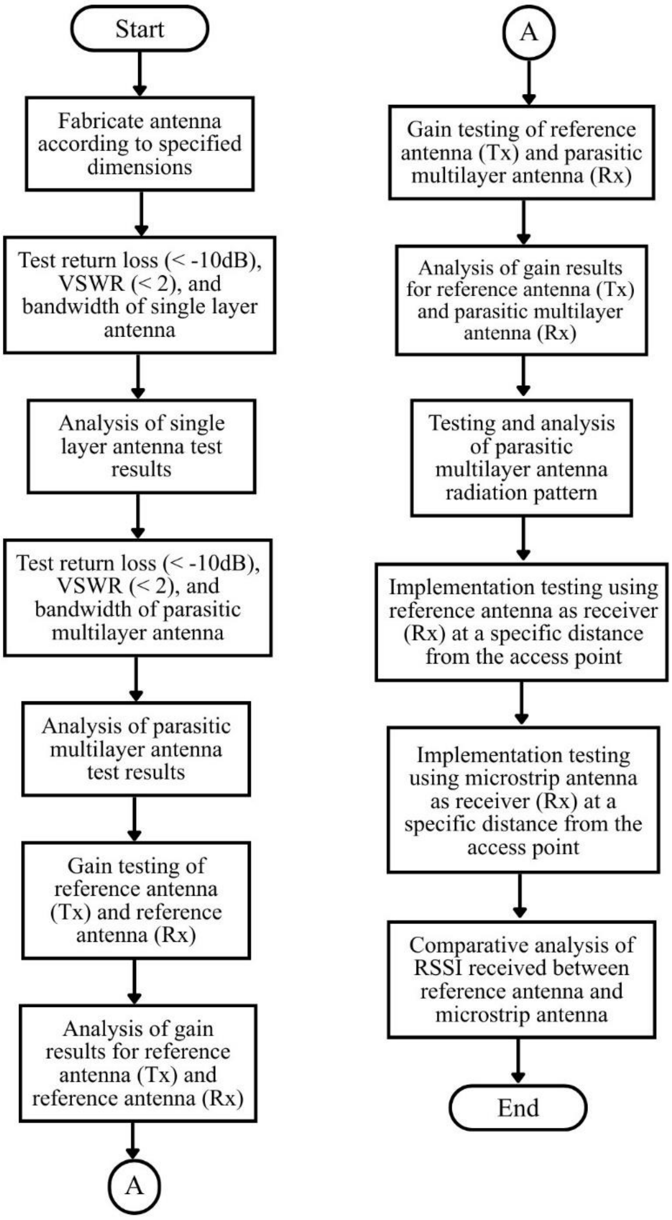

Figure 1. Testing Phase Flowchart

C. Determining Antenna Specifications

Before designing an antenna, you must first determine the specifications as in Table I.

TABLE I
PARASITIC MULTILAYER MICROSTRIP ANTENNA SPECIFICATIONS

No.	Parameter	Specification
1.	Working Frequency	2401-2495 MHz
2.	Center Frequency	2448 MHz
3.	Return loss	< -10 dB
4.	VSWR	< 2
5.	Impedance	50Ω
6.	Feeding Methods	Feed line
7.	Matching Methods	λ/4 Impedance Transformer
8.	Patch Layer 1 Form	Circular
9.	Patch Layer 2-4 Form	Disc sectors

Based on Table 1, the antenna is designed to work on WiFi frequencies of 2401-2495 MHz with a resonant frequency of 2448 MHz. The resonant frequency of an antenna is the working frequency of the antenna where at that frequency all power is transmitted maximally [9][10]. VSWR <2 because the requirement for a good antenna VSWR is ≤ 2 and a good return loss value is ≤ -9.54 dB [10]. The impedance used is 50Ω. The impedance characteristics that are often used are 50Ω and 75Ω [5]. The main patch is circular and the patch layers 1-4 are disc -shaped sector. In this study using Feeding Methods namely the feedline and using the λ/4 Impedance method Transformer as an impedance matching method.

D. Antenna Planning

Figure 2 shows circular planning patch based on calculation. Impedance The matching used in Figure 2 uses Quarter-Wave Transformer (λ/4 Transformer). This technique is a common technique used in transmission line design to ensure good impedance between source and load, thus maximizing power transfer, reducing signal reflections, and achieving optimal return loss and VSWR values.

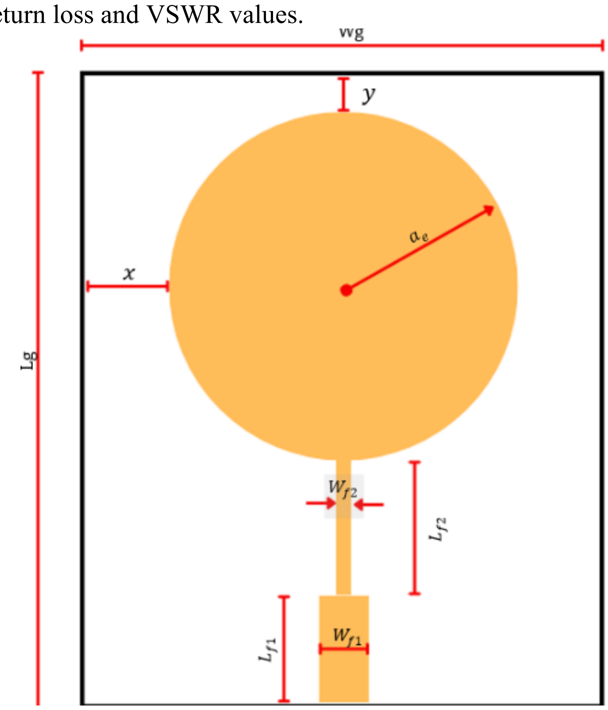

Figure 2. Circular Patch Planning

Antenna planning can affect the working frequency to be designed. Therefore, the variables to be used can be determined as shown in Table II.

TABLE II
CALCULATION COMPONENTS

No.	Variables	Mark
1.	c(Speed of light)	3 x 10^8m/s
2.	ε_r(Dielectric constant)	4.58
3.	h(PCB Thickness)	1.57 mm
4.	T (Cooper Thickness)	0.003 mm
5.	Z_0(Impedance)	50Ω

1. Counting fingers patch circular (a_e)
   circular radius can be calculated using the following formula [11][12] :

$$a=\frac{F}{\sqrt{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1{,}7726\right]}} \quad (1)$$

   Next, calculate the effective radiation value using the following formula [11]:

$$a_e = a \times \sqrt{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1{,}7726\right]} \quad (2)$$

   Fis a radiation element. To calculate the radiation element , use the formula [11]:

$$F=\frac{8{,}791\times10^9}{f_r\sqrt{\varepsilon_r}} \quad (3)$$

   So that the fingers are obtained circular a_e= 16.78 mm.

2. To calculate the width and length of the channel, first know the input impedance. circular patch R_{in} using formula [13] :

$$R_{in} = 60\frac{\lambda_d}{W} = 102{,}377\Omega \quad (4)$$

   After calculating R_{in}, then calculate the impedance matching using the formula [11]:

$$Z_1 = \sqrt{Z_0 \times R_{in}} = 71{,}54\ \Omega \quad (5)$$

3. Calculating the width $W_g$and length of the groundplane L_g using formula [8] :

$$W_g = 6h + \frac{\pi}{2}a_e \quad (6)$$

$$L_g = 6h + 2a_e \quad (7)$$

4. Supply line using line feed with the λ/4 transformer method. For the width of supply channels 1 and 2, you can use formulas [7] and [14]:

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} \quad (8)$$

$$W_{f1} = \frac{2h}{\pi}\left\{B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right]\right\} \quad (9)$$

The length of the transformer line λ/4 uses the formula [13]:

$$L_{f2} = \frac{\lambda_d}{4} \quad (10)$$

Based on the simulation results from the calculation, the results obtained are less in accordance with the specifications so that optimization is carried out. Optimization is carried out by changing the values of the calculation results (width and length of the channel, distance between elements, length and width of the substrate and ground) to obtain antenna parameters according to the expected specifications [15][9]. From several simulation optimizations carried out, the right dimensions for layer 1 are obtained as shown in Table III below.

TABLE III
LAYER 1 OPTIMIZATION

Antenna Dimensions (Layer 1)	Planning Size (mm)	Size after optimization (mm)
aeff	16.78	16.78
h	1.57	1.57
L_{f1}	14.31	11.8
L_{f2}	5	4
L_g	56.96	56.96
t	0.003	0.003
W_{f1}	2.91	2.3
W_{f2}	1.48	1.2
W_g	35.7	35.7

E. *Multilayer Planning*

Figure 3 shows the patch planning. Disc sector for layer 2 - layer 4 from the simulation results. The sizes of a1, a2 andϕ_1 will be changed where the most optimal results are the ones that will be used.

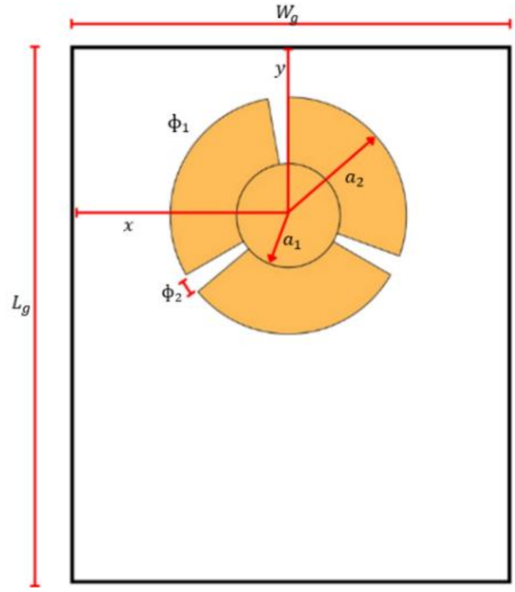

Figure 3. Disc Sector Planning

Disc design are as follows: sector as shown in Table IV.

TABLE IV
2-LAYER SECTOR DISC DIMENSIONS 4

Parameter	Director 1 (Layer 2)	Director 2 (Layer 3)	Director 3 (Layer 4)
a1	7mm	5mm	4mm
a2	13.7mm	12.7mm	11.7mm
Angle size (ϕ_1)	110˚	110˚	110˚
Lg	56.96 mm	56.96 mm	56.96 mm
Wg	35.7 mm	35.7 mm	35.7 mm
Air Gap (h)	25mm	35mm	30mm

After optimization, the antenna dimensions shown in Figure 4 were obtained.

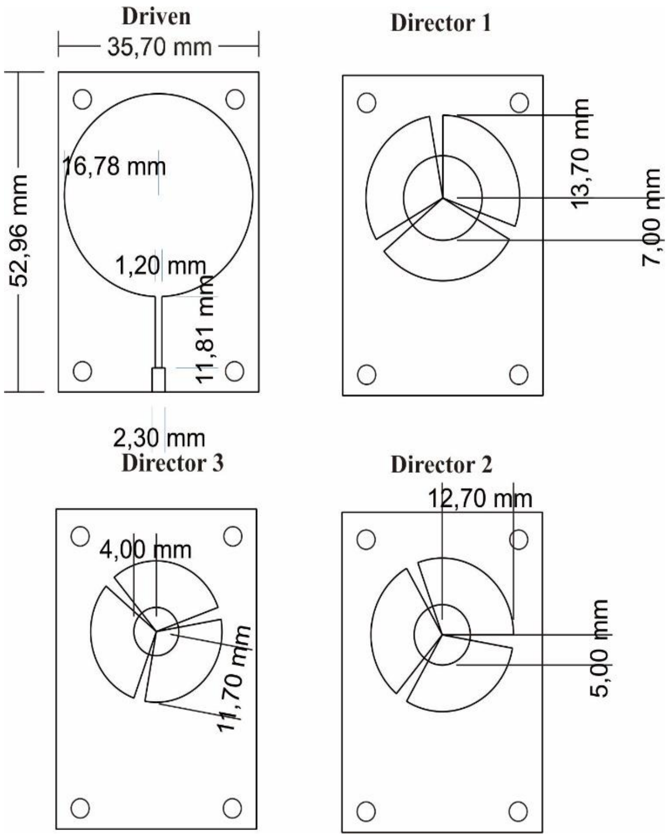

Figure 4. Layer 1 – Layer 4 Antenna Dimensions After Optimization

Distance h (Air Gap) between driven (layer 1) and Directors 1 (layer 2) is 25 mm (0.2 λ), the distance h (Air Gap) between the Directors 1 (layer 2) with Directors 2 (layer 3) is 35 mm (0.28 λ), and the distance h (Air Gap) between the Directors 2 (layer 3) with Directors 3 (layer 4) is 30 mm (0.24 λ) Determination of h (Air Gap) is done through simulation to find the optimal distance.

III. RESULTS AND DISCUSSION

A. Multilayer Simulation

Figure 5 shows the results of the multilayer simulation return loss of -23.10 with a resonant frequency of 2448 MHz. The simulation bandwidth is obtained at 104.29 MHz where the working frequency range is from 2397 MHz - 2502 MHz.

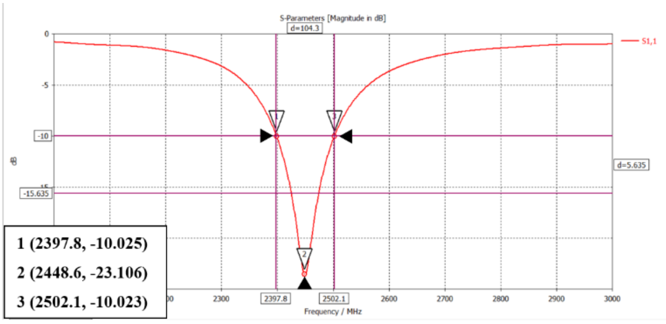

Figure 5. Return Loss and Bandwidth Multilayer Simulation

Figure 6 shows the results of the multilayer simulation VSWR of 1.05 at a frequency of 2448 MHz. This result is in accordance with the requirements for a good VSWR of <2.

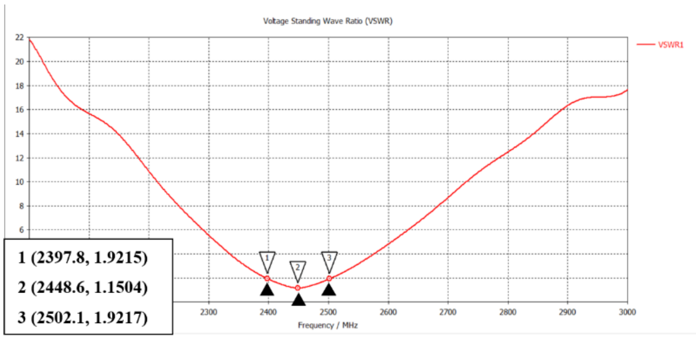

Figure 6. Simulated Multilayer VSWR

Based on Figure 7 with the addition of 3 layers as directors , the gain obtained at a frequency of 2448 MHz increases by 2,973 dB, which is 5,664 dB. With the addition of this layer , it proves that using the multilayer parasitic method can increase the gain. With the addition of up to 4 layers, it has met the specifications of the designed antenna, which is to have a gain of > 5 dB. The radiation pattern obtained in the simulation is directional where the antenna radiates its maximum energy in one direction only.

B. Antenna Fabrication

Antenna fabrication is the process of printing an antenna based on simulation results in the CST Studio Suite 2018 software. The material used for fabrication is FR-4 with a thickness of 1.57 mm with a dielectric constant of 4.58. The fabrication results are shown in Figure 7.

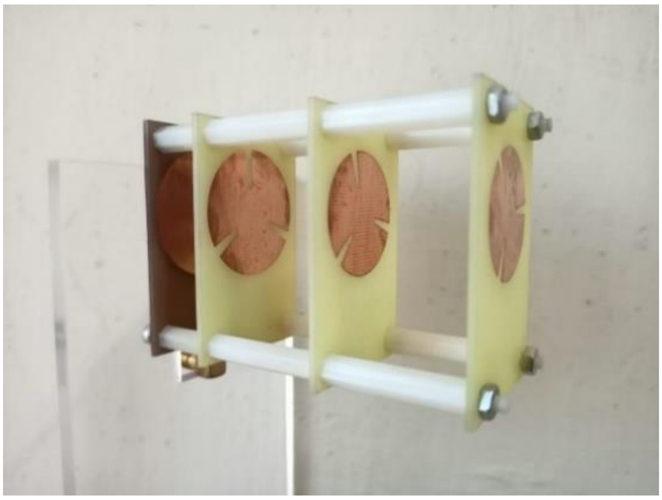

Figure 7. Fabrication Antenna

C. *Multilayer Testing Fabrication*

Figure 8 shows simulation return loss results of -13.91 with frequency resonant at a frequency of 2447 MHz. Simulation bandwidth got of 96 MHz where range Work frequency from 2411 MHz – 2507 MHz.

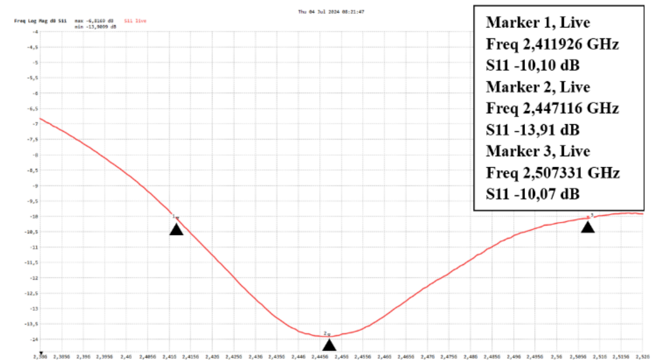

Figure 8. Return Loss and Bandwidth Multilayer Fabrication

Figure 9 shows the simulated VSWR result of 1.50 at a frequency of 2448 MHz. This result is in accordance with the requirement of a good VSWR which is <2.

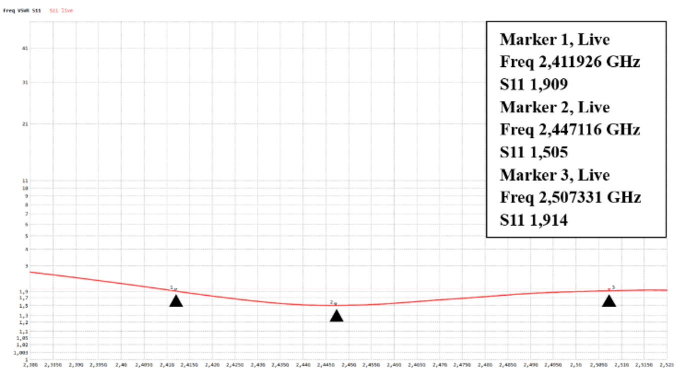

Figure 9. Multilayer VSWR Fabrication

D. *Radiation Pattern Testing*

Radiation pattern of microstrip antennas compared to strip antennas dipole ½ λ. Based on Figure 10, it forms a directional radiation pattern where an antenna radiates energy in one direction effectively. At an angle of 0º is the most effective radiation direction compared to other angles.

Half Power Beamwidth (HPBW) value is obtained by determining the angle that has a normalization of -3 dB.

$$HPBW = HP_{right} - HP_{left}$$
$$HPBW = (360^\circ - 312^\circ) + 40^\circ$$
$$HPBW = 88^\circ$$

Side lobe level attenuation (SLLA) and Front Back Ratio (FBR) is obtained from radiation pattern parameters whose level values are known.

$$SLLA = \frac{\text{1st side lobe}}{\text{Main lobe}}$$
$$SLLA = \frac{-62{,}7}{-60{,}9}$$
$$SLLA = 1.029$$

Front Back Ratio (FBR) is the ratio between the power of the radiation in the front direction and the back direction of an antenna. As for calculating the Front Back The ratio uses the following equation.

$$FBR = \frac{\text{Main lobe}}{\text{Back lobe}}$$
$$FBR = \frac{-60.9}{-66.5}$$
$$FBR = 0.915$$

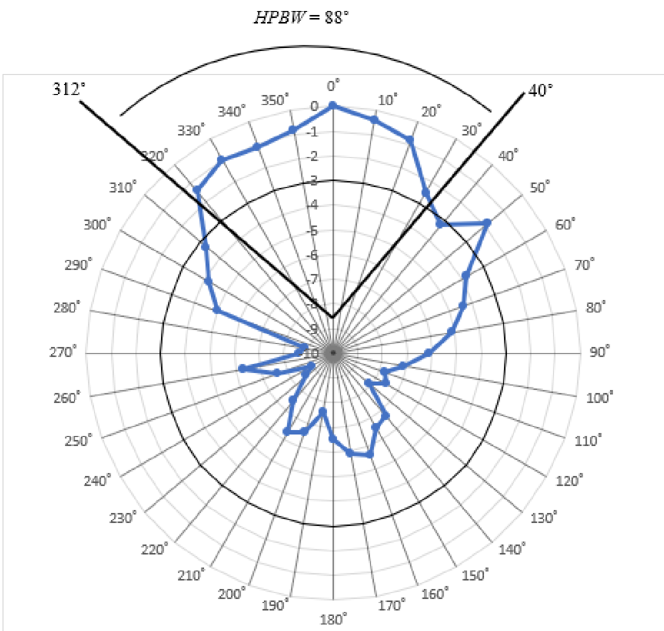

Figure 10. Directional Radiation Pattern of Multilayer Microstrip Antenna

E. Gain Testing

Gain testing is done by comparing the microstrip antenna with a reference antenna, namely a ½ λ dipole antenna. Positive gain indicates the antenna's ability to increase signal strength. The test data for the gain of the multilayer microstrip antenna are shown in Table 5. Positive gain indicates the antenna's ability to increase signal strength. The microstrip antenna can work optimally at a frequency of 2420 MHz. Table V shows the table of test results for the test antenna and reference antenna levels to obtain the gain of the test antenna.

TABLE V
GAIN TEST RESULTS

Frequency (MHz)	Level (dBm)		Gain (dBi)
	Reference Antenna	Under Antenna Test	
2400	-66.3	-69.8	2400
2410	-69.7	-63.0	2410
2420	-73.2	-60.4	2420
2430	-71.7	-62.4	2430
2440	-73.5	-65.5	2440
2450	-64.3	-65.5	2450
2460	-69.9	-62.7	2460
2470	-62.8	-71.1	2470
2480	-63.1	-69.5	2480
2490	-63.4	-73.1	2490
2500	-71.7	-77.6	2500
Average (dBi)			3

Microstrip Antenna Gain graph based on the data from Table V is shown in Figure 11.

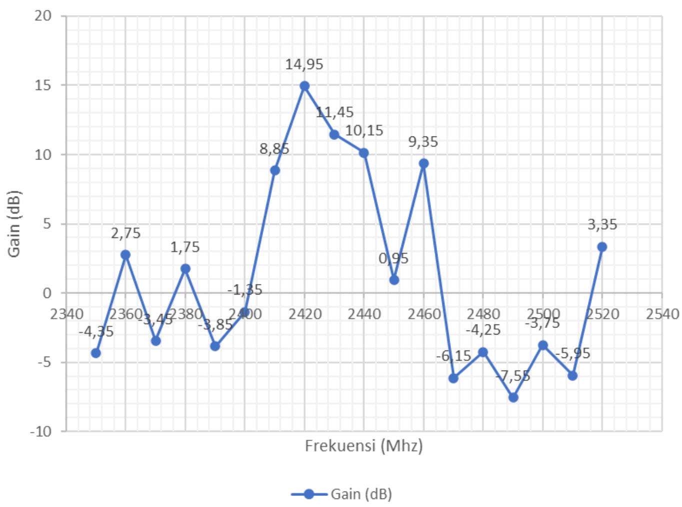

Figure 11. Graph Gains Microstrip Antenna

F. Comparison of Antenna Dimension Design Before Optimization and After Optimization on Layer 1

Based on Table VI, there is a comparison between the antenna design dimensions before and after optimization. The working frequency range shifts from 2384-2474 MHz to 2402-2494 MHz, indicating an increase in frequency range of about 18 MHz on the lower side and 20 MHz on the upper side. In addition, the antenna resonance frequency also shifts from 2429 MHz before optimization to 2448 MHz after optimization, which means there is an increase of about 19 MHz.

TABLE VI
COMPARISON BEFORE AND AFTER LAYER 1 OPTIMIZATION

Antenna Dimensions (Layer 1)	Planning Size (mm)	Size after optimization (mm)
Frequency Range	2384-2474 MHz	2402-2494 MHz
Resonant Frequency	2429 MHz	2448 MHz

G. Comparison Between Simulation and Fabrication Results on Return Loss and Voltage Standing Wave Ratio (VSWR) of Single Layer and Multilayer Microstrip Antennas

Based on Table VII, at a frequency of 2447 MHz there is a significant difference between the simulation and fabrication results. The simulation shows a very low return loss of -32.73 dB and a VSWR of 1.04, while the fabrication results also show a low return loss of -31.39 dB and a VSWR of 1.055.

TABLE VII
COMPARISON OF RETURN LOSS AND VSWR SINGLE LAYER

Frequency (MHz)	Simulation			Fabrication		
	RL (dB)	VSWR	Γ	RL (dB)	VSWR	Γ
2415	-12.86	1.58	0.22	-10.03	1,920	0.31
2447	-32.73	1.04	0.02	-31.39	1,055	0.02
2487	-11.41	1.73	0.26	-10.09	1,911	0.31

Based on Table VIII, at a frequency of 2447 MHz, there is a more significant difference. The simulation shows a return loss of -22.44 dB and a VSWR of 1.16, while the fabrication results show a return loss of -13.91 dB and a VSWR of 1.505.

TABLE VIII
COMPARISON OF RETURN LOSS AND VSWR MULTILAYER

Frequency (MHz)	Simulation			Fabrication		
	RL (dB)	VSWR	Γ	RL (dB)	VSWR	Γ
2411	-12.61	1.61	0.23	-10.10	1,920	0.31
2447	-22.44	1.16	0.07	-13.91	1,505	0.20
2507	-9.19	2.06	0.34	-10.07	1,911	0.31

H. Comparison of the Effect of Adding Layers on Gain and Radiation Pattern

Based on Table IX shows the results of the gain simulation single layer obtained a gain value of 2,691 dB at a frequency of 2448 MHz. The parasitic multilayer antenna simulation has a gain of 5,664 dBi with a directional radiation pattern at a resonant frequency of 2448 MHz while the multilayer fabrication results have a higher gain reaching up to 14.95 dBi at a frequency of 2420 MHz.

TABLE IX
THE EFFECT OF ADDING LAYERS ON SIMULATION

Parameter	Single Layer	Multilayer	Multilayer Fabrication
Gains	2,691	5,673	14.95
Frequency	2448 MHz	2448 MHz	2420 Mhz
Radiation Pattern	Directional	Directional	Directional
HPBW	88.3	68.0	88

I. Comparison Between Simulation and Fabrication Results on Bandwidth of Single Layer and Multilayer Microstrip Antennas

Based on Table X, the microstrip antenna was tested and compared with the built- in USB wireless antenna. 802.11N. From the test results, it was found that the microstrip antenna is superior to the built- in antenna. almost the entire distance.

TABLE X
ANTENNA IMPLEMENTATION RESULTS

Distance	Antenna		Power Difference
	Built- in USB wireless 802.11N	Parasitic Multilayer Microstrip	$RSSI_{mikrostrip}$- $RSSI_{buit\ in}$
5 m	-49 dBm	-45 dBm	4 dBm
10 m	-55 dBm	-55 dBm	0 dBm
20 m	-66 dBm	-61 dBm	5 dBm
30 m	-77 dBm	-71 dBm	6 dBm

IV. CONCLUSION

Based on the simulations and tests that have been carried out, it was found that the results before optimization showed a working frequency range of 2384-2471 MHz with a resonance frequency of 2429 MHz. The results of the resonant Single Layer fabrication at a frequency of 2447 MHz with a return loss of -31.39 dB, VSWR 1.05 and a bandwidth of 72 MHz while the multilayer is at a frequency of 2447 MHz with a return loss of -13.91 dB, VSWR 1.50 and a bandwidth of 96 MHz. Parasitic multilayer microstrip antenna produces a gain of up to 14.95 dBi at a frequency of 2420 MHz with a directional radiation pattern. This result is in accordance with the design specifications.

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