

Design and build multiple input multiple output (MIMO) wideband element microstrip antennas for WiFi access-point applications

Popy Maria^{1*}, Aprinal Adila Asril², Nasrul³, Sri Nita⁴, Afrizal Yuhanef⁵

^{1,2,3,4,5}Department of Electrical Engineering, Telecommunication Engineering Study Program, Padang State Polytechnic
¹april69@gmail.com



*Corresponding Author

Article History:

Submitted: 09-05-2024

Accepted: 12-05-2024

Published: 27-05-2024

Keywords:

Multiple Input Multiple Output (MIMO) Antenna; WIFI 2.4 GHZ, Bandwidth; Isolation; Return Loss; VSWR.

Brilliance: Research of Artificial Intelligence is licensed under a Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0).

ABSTRACT

Technology in the telecommunications sector continues to develop. One of them is the Multiple Input Multiple Output (MIMO) antenna used in WIFI access point application using MIMO technique in enhancement the need to transfer large amounts of data. In the design and manufacture of MIMO antennas for WIFI access applications point with dimensions of 110 mm x 112 mm using FR-4 substrate specifications with a thickness of 1.6 mm. The antenna consists of four ports and is at each corner The groundplane has four slots to achieve good isolation and produces good bandwidth. The antenna simulation produces a bandwidth of 1.0516 GHz with frequency 2.4 GHz, return loss -12.78 dB, isolation -16.08 dB, and VSWR 1.53 dB. Meanwhile, manufactured antennas produce a bandwidth of more than 100 MHz with frequency 2.4 GHz, return loss -13.5 dB, isolation -18.8 dB, and VSWR 1.29 dB. Antenna simulation using the CST Studio Suite 2019 software application. In the application of the antenna used for Wi-Fi as a transmitter By comparing distances, different results are obtained where the power value is Each distance is different because the farther the distance, the greater the power value produced or emitted will be smaller or less optimal network.

INTRODUCTION

The existence of antennas in wireless communication systems is something that is important important. This is based on the need to communicate and exchange data quickly and easily. One of them is an antenna on the world telecommunications which are starting to be widely implemented, especially in Indonesia is Wi-Fi wireless technology. The 802.11n standard is an established standard by the Institute for Electrical and Electronic Engineers (IEEE) to underlie that technology. Wi-Fi with the 802.11n standard is a working standard on the 2.4 GHz and 5 GHz frequencies and is supported by Multiple Input technology Multiple Output (MIMO)(A. Sri rahayu).

Multiple-Input Multiple-Output (MIMO) is a wireless technology that uses multiple transmitters and receivers to transfer more data simultaneously. This technology helps make 802.11n possible achieves higher speeds than without 802.11n. For To implement MIMO, a device in the form of an access point (AP) is really needed for optimal performance and signal coverage (I. Amara).

The use of MIMO antennas can effectively increase channel capacity and improve the reliability of wireless communications. However, the mutual coupling is strongncaused between the antenna elements will reduce the performance of the MIMO system. So that the antennas do not influence each other, each antenna must be spaced apart the mutual coupling value is small. In a MIMO system, the influence of mutual coupling effects kept to a minimum because it affects the performance of each antenna.

The farther the antenna distance, the smaller the mutual coupling, but the dimensions of the antenna overall it will be large and difficult to implement on the user's device (A. B. Adipurnama, H. Wijanto, and Y. Wahyu). Based on the research journal Alishir Moradi Kordalivand, Member, IEEE, Tharek A. Rahman, and Mohsen Khalily, Member, IEEE that for increasing high isolation on MIMO for WIFI using access point by moving the port on the perpendicular feed line to reduce mutual coupling by moving further apart and using a slot on the ground plane(A. MoradiKordalivand, T. A. Rahman, and M. Khalily). Based on research journals conducted by Jian Ren, Wei Hu, Members, IEEE, Yingzeng Yin, and Rong Fan that isolation between elements Low antenna is caused by the absence of a slot or lack of a slot. Because The use of shaped slots in rectangular patch microstrip antennas can be used improve MIMO antenna isolation(J. Ren, W. Hu, Y. Yin, and R. Fan). Based on several research journals conducted above, it can be drawn conclusion that adding a slot or no slot to the antenna has an effect on antenna isolation, where in theory it is found that high isolation will reducing the value of mutual coupling, namely the effect that causes it to occur decrease in the quality of parameters such as gain, return loss, antenna radiation polarization due to the presence of two or more antennas that are too close together and there are slots on the ground plane which will affect the mutual coupling value. Based on the research journal Alishir Moradi Kordalivand, Member, IEEE, Tharek A. Rahman, and Mohsen Khalily, Member, IEEE there is an isolation value low, which will cause a mutual coupling effect on the antenna. By Therefore,



the author is interested in conducting research similar to development in more detail, the author carried out an optimization for changing the slot size on the MIMO antenna for high isolation and increasing the gain of the utility antenna reduces the effect of mutual coupling on the antenna. To apply it on field, the author uses a 2.4 GHz Wi-Fi access point device with a larger signal area coverage, where the data is taken as research materials based on data simulated using CST software Studio Suites 2019.

LITERATURE REVIEW

Microstrip Antenna

One of the most popular antennas today is the microstrip antenna. Matter This is because microstrip antennas are very suitable for use in devices Current telecommunications pay great attention to shape and size. A microstrip antenna is a metal conductor attached to ground plane between which there is a dielectric material. Frequent microstrip antennas used in various applications wireless, satellite communications, communications cellular, radar, and more, as it has a number of advantages in terms of size, weight, cost, and radiation pattern adjustment capabilities, as indicated in figure 1.

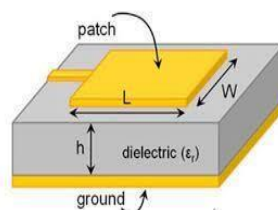


Figure 1. Microstrip Antenna Structure with Feeding (F.Abdurrahman)

The types of microstrip antennas are shown in Figure 2.

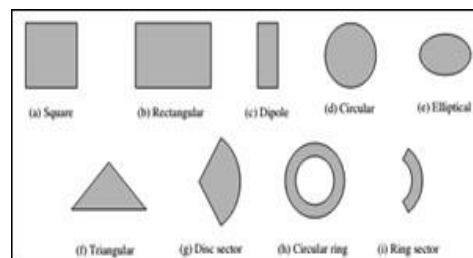


Figure 2. Types of Microstrip Antennas (F.Abdurrahman)

Microstrip Antenna Structure

A microstrip antenna is an antenna composed of 3 elements namely radiation elements (radiators), substrate elements (substrate), and elements defense (ground).

1. The radiation element (radiator) or commonly referred to as a patch, functions to radiates electromagnetic waves and is made of metal layers which has a certain thickness. Radiation elements (radiators) produce desired radiation pattern and overall antenna performance. Patches can be circular, rectangular, and triangular etc.
2. The substrate element functions as the dielectric material of the antenna microstrip that separates radiating elements from ground elements. This element has various types that can be classified based on the dielectric constant value (ϵ_r) and thickness (h). Both values This affects the working frequency, bandwidth, and also the efficiency of the device antenna to be made.
3. Defense element (ground), namely the layer located under the substrate and functions as a reflector for antenna radiation polarization. This defensive element generally have the same type of material as the radiating element. Form Conductors can vary but the ones commonly used are shaped rectangles and circles because they can be more easily analyzed. This element helps form radiation patterns and reflect energy radiation in the desired direction.

Figure 3 shows the basic structure of a microstrip antenna composed of patch, substrate and ground.

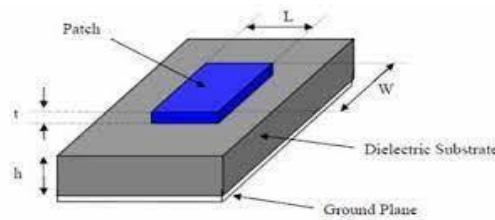


Figure 3. Microstrip Antenna Structure (A. H. Rambe)

Multiple Input Multiple Output (MIMO)

Multiple Input Multiple Output (MIMO) is a transmission system where the number of antennas, both transmitting and receiving, consists of several elements antenna. MIMO techniques aim to increase capacity, reliability, and transmission quality in wireless communication systems by utilizing effects multipath and reduces interference. MIMO is often used in technology wireless communication because it has significant capabilities in increase data access speed without additional bandwidth or transmit power (transmitter power). MIMO also has a diversity function, namely by using two or more antennas to improve quality and wireless link reliability.

In the system, MIMO does not only use one antenna but using two or more (plural) antennas at both the transmitter and to the recipient. By using multiple antennas this results in performance is better, this can be compared to the Single system

Input Single Output (SISO). For more details, we can see Multiple Input Multiple Output (MIMO) in figure 4.

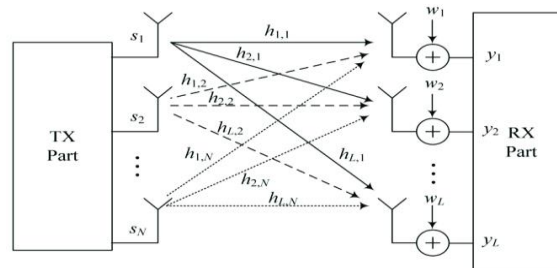


Figure 4. MIMO Antenna Systems(A. H. Rambe)

The picture above shows how we can shift the load performance through signal processing. Where from the picture it can be seen that an information signal is divided into 3 data streams (according to the number of antennas used) which is then encoded and then modulated and transmitted.

MIMO signal modeling is divided into two, namely the Spatial model Multiplexing and Diversity models.

1. Spatial Multiplexing

This technique is the first technique used in MIMO. On the sending side of the signal will be transmitted via several multipath paths then it will be received at the recipient's side. With this technique it is possible achieve large channel capacity.

2. Diversity

In the diversity model, data is transmitted on each transmitting antenna is the same. Then the transmitter selection diversity method can be used to choose just one transmitter with the best quality. Meanwhile on recipients used the combining method (EGC/MRC) to obtain diversity pure. The diversity model is used to reduce errors due to fading and noise with antenna diversity at the transmitter and receiver.

MIMO antennas also have characteristics. As for the characteristics of the antenna MIMO is as follows:

1. Mutual Coupling and Isolation

Mutual coupling is an effect that causes a decrease quality of antenna parameters. Mutual coupling occurs when two sources of radiation or energy receivers are close together, then the energy from one of the antennas affecting neighboring antennas. In other words, inter-change energy occurs. Factors that influence the level of mutual coupling are:

- Radiation characteristics of each antenna.
- Distance between antennas

Good mutual coupling makes the current distribution even better. The greater the mutual coupling, the current in the antenna will only be focused on only the antenna is excited, while the current in the other antennas can be ignored.

Mutual coupling can be measured by looking at the amount of isolation. Isolation is defined as the amount of transmission power between the two input ports on the multiport antenna being tested. In a MIMO system, the influence of mutual coupling effects is kept to a minimum perhaps because it affects the performance of each antenna.

2. Correlation Coefficient

The correlation coefficient is a coefficient that states the level of similarity between signals received by each antenna. The correlation coefficient has a value of 0 up to 1. System diversity requires a correlation coefficient close to zero, meaning The signal received by each antenna is not the same. Coefficient correlation should be as small as possible (A. H. Rambe).

Advantages of Multiple Input Multiple Output (MIMO)

The advantages of using Multiple Input Multiple Output (MIMO) include as follows :

- Reflected signal (multipath) as the main signal amplifier so don't thwart each other.
- Speeds up wireless connections and extends coverage distance.
- Saves bandwidth usage and increases capacity channel(A. H. Rambe).

Disadvantages of Multiple Input Multiple Output (MIMO)

Apart from having many advantages, MIMO also has weaknesses, namely There is a time interval which causes a slight delay in the antenna that is moving sends a signal even though sending the signal itself is faster. Time This interval occurs because the system process must divide the signal according to the amount There are more than one antennas owned by MIMO devices (A. H. Rambe)

CST Studio Suite 2019

CST Studio Suite 2019 is antenna simulation software for makes it easier for users to design various kinds of devices with easy to operate in various frequencies, one of which is in designing MIMO antenna. The function of CST Microwave Studio is to make things easier designing antennas and as a tool for solving field problems electromagnetic. That's why this software is used for designing patch antennas. The tools used in this CST application are easy to use understood and used like bricks used to enter values antenna parameters, WCS axes used to determine the inner point designing antennas, transformers used for mirroring and copying existing designs, etc. CST Studio Suite 2019 offers computing solutions accurate and efficient in designing and analyzing electromagnetic devices. The following is the logo and appearance of the 2019 CST studio suite simulation, in figure 5 below.



Figure 5. CST Studio Suite 2019 logos

METHODS

Antenna Design Flowchart

A flowchart or flow chart is a diagram that displays the steps steps and decisions to carry out a process before carrying out a process antenna design. Each step is depicted in diagram form and connected by a line or arrow direction, can be seen in Figure 6.

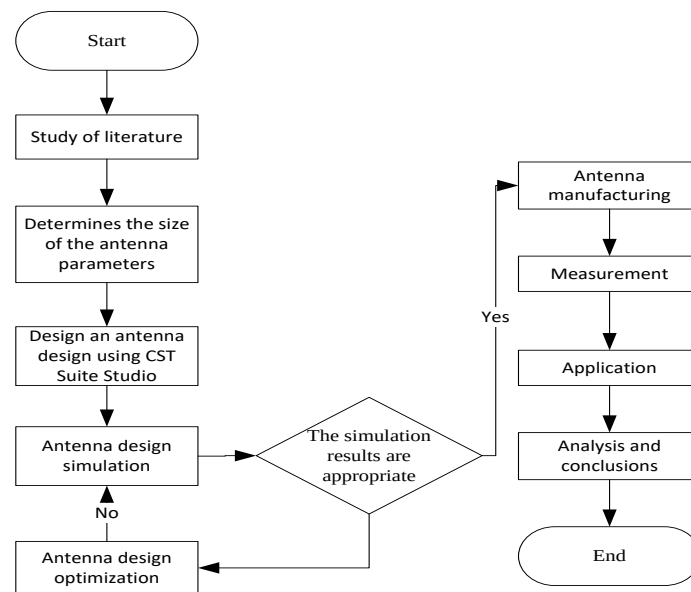


Figure 6. Antenna Design Flowchart

Antenna Dimensions

The antenna size obtained is the size from the journal entitled "Common Elements Wideband MIMO Antenna System For WIFI/LTE Access-Point". The dimensions of the antenna used are 112 x 110 mm² using type FR-4 substrate with a thickness of 1.6 mm which has a dielectric constant substrate 4.3 and loss tangent 0.025. The antenna design can be seen in the Figure 7.

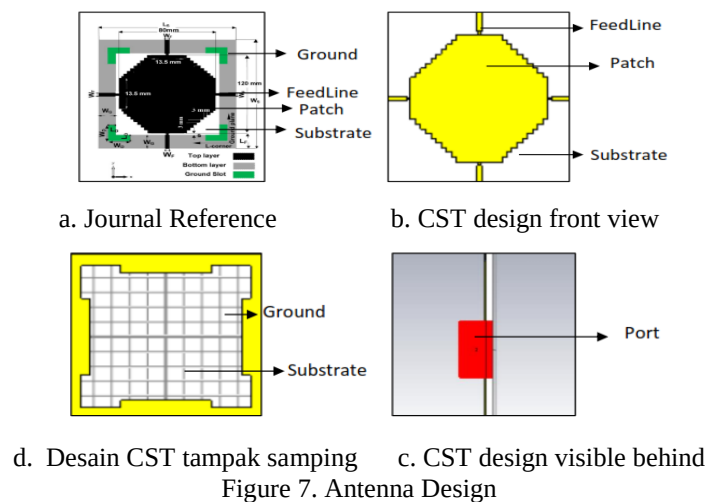


Figure 7. Antenna Design

In the picture above is a display of the antenna design based on references (journals) and results of modified antenna designs. As for the size details of The two antenna designs can be seen in tables 1 and 2 below.

Table.1 Antenna Parameter List

Parameter	Ws	Ls	Wf	Lf	Wd	Ld	h	Wj7
Mark	112	110	3	13	22	1.5	1.6	38
Parameter	Wg	t	Wt	s	Wp	Wp2	Lp2	Wj8
Mark	20	0.03	1.5	2	13.5	82	80	32
Parameter	Wj	Sj	Wj2	Wj3	Wj4	Wj5	Wj6	Wj9
Mark	74	3	68	62	56	50	44	26

Table.2 Comparison of Design Sizes between Reference and Modified Antennas

Substrate Size/Ground Plane	Slot Size	
Long: 110 mm	Referensi (<i>Paper</i>)	Modification
Wide: 112 mm	Long slot: 1.5 mm	long slot: 5 mm
Thickness: 1.6 mm (substrate)	Wide slot: 22 mm	Wide slot: 15 mm
Thickness: 0.035 (groundplane)		

Antenna Fabrication and Measurement

After getting the optimization results on an antenna and it is suitable with the expected specifications, then carry out the manufacturing process and carry out measurements at the Antenna Laboratories. The steps are as follows following:

1. Prepare the tools and materials needed such as PCB FR-4 Double Layer, the antenna design has been transferred to the PCB layer transfer paper, thinner, tin, solder paste, iron.
2. Measure the PCB with a size of 110 x 112 mm according to the antenna design, Use a roller and permanent marker to avoid excess or lack of size on the PCB which can be seen in figure 8.



Figure 8. PCB measurements

3. Cut and sand the PCB to a size of 110 x 112 mm and Clean the PCB with thinner after sanding, then dry it can be seen in figure 9.



a. PCB Cutting Process



b. The process of sanding the remaining remaining PCB size



c. Measuring PCB Length



d. Measuring PCB Width

Figure 9. PCB Cutting, Sanding and Measuring Process

4. Attach the PCB layer transfer paper to the clean PCB, and Iron the paper that is stuck to the PCB until the ink is on the transfer paper has been copied to the PCB. As seen in Figure 10 below this.



Figure 10. PCB Cutting, Sanding and Measuring Process

5. Prepare the solution and dissolve the design that has been transferred to PCBs. For the dissolution process, you can use H_2 and HCl H_2O_2 solutions seen in Figure 11 below.

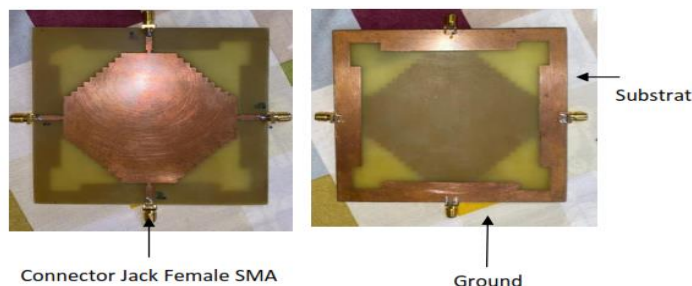


Figure 11. PCB Dissolution Process

6. Clean the copper part that still has ink on it using thinner and sand it using fine sandpaper.
7. Next, solder the PCB and the connector using tin. Between the PCB and the connector it must be attached well, because of this can affect the measurement of antenna parameters. The connector used for antennas, namely SMA Female Jack Connector, connector soldered on the feedline part of the patch and antenna ground. For 1 The antenna design requires 4 connectors, this is due to The antenna design consists of 4 feedlines. As can be seen in Figure 12 below.



Front View Antenna



Connector Jack Female SMA

Ground

Rear View Antenna

Figure 12. Connector Installation to Design

8. Next, measure the antenna at the Antenna Laboratories using a Visual measuring instrument Network Analyzer (VNA) and ensure the measuring instrument is properly calibrated, as seen in Figure 13 and save the measurement results.

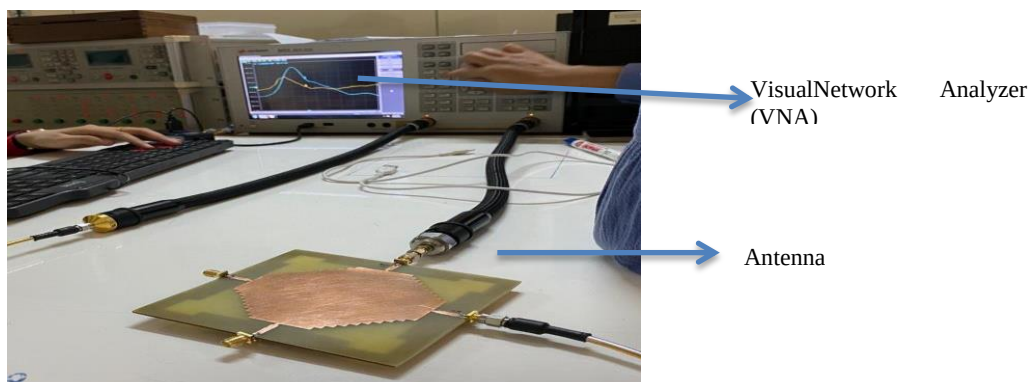


Figure 13. Antenna Measurement Process

RESULT

Parametric Study

Parametric studies are a process carried out to obtain appropriate antenna parameters. Parametric studies are carried out by adding or reduce the dimensions of the antenna. This is done to find out changes in antenna design to existing parameters. To see Changes in antenna design can be seen in Figure 14 and the simulation results of Changes in antenna design can be seen in figure 15 and 16.

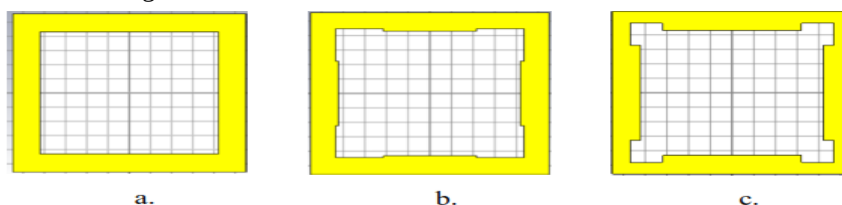


Figure 14 a. Slotless Antenna b. Reference Antenna Slot LD=1.5 WD=20 c. Antenna Slot LD=5 WD=15

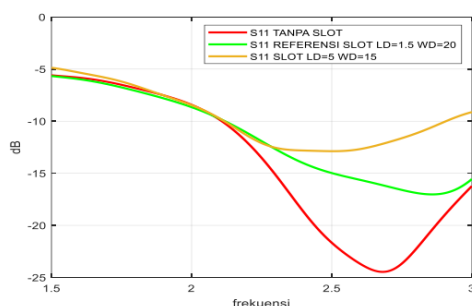


Figure 15. S11 Simulation Results

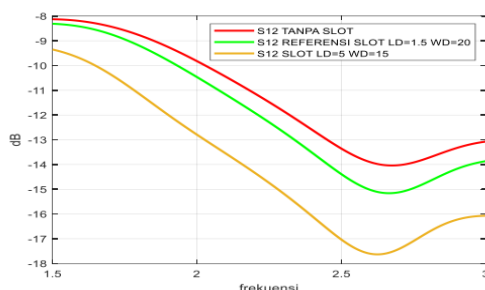


Figure 16. S12 Simulation Results

The image above shows changes in antenna design to obtain appropriate value. Where the slots are arranged into several shapes and sizes with the same frequency range, namely 2.4 GHz. On changing the slotless antenna, get a return loss value of -18.72 dB and get an isolation value of -12.61 dB, where in changing the slotless antenna design, the return loss value meets criteria because it still has a value of <-10 dB, but the isolation value changes in the design Antennas without slots do not meet the criteria because the good isolation value is <-15 dB. Next, make changes by

adding slots according to journal reference where the slot length is 1.5 mm and the slot width is 20 mm so obtained a return loss value of -13.57 dB and an isolation value of -13.53 dB, where in changing the antenna design the return loss value is obtained meets the criteria because it still has a value of <-10 dB, but the isolation value has not meets the criteria because of good isolation, namely <-15 dB. Next do changes in the size of the slot value in the antenna design, namely the slot length is 5 mm and the slot width is 15 mm, getting a return loss value of -12.81 dB and get an isolation value of -16.10 dB, where the return loss value is with adding the slot size gets a value that matches the criteria, namely <-10 dB and get the isolation value according to the criteria, namely <-15 dB. So that it can be concluded that in good antenna design, namely using slots in all four corners of the groundplane of the same size and the same frequency range. Where the greater the length of the slot, the greater the value the results will be better.

Antenna Optimization Results

After carrying out a parametric study, the design and results were obtained the most optimal simulation of the modified antenna. Next compare between the reference antenna and the modified antenna. The goal is to see that The modified antenna produces better results than the reference antenna. Following The optimized antenna design is shown in Figure 17 and the simulation results are shown in Figure 18 after carrying out parametric studies and parameter comparisons antenna is done.

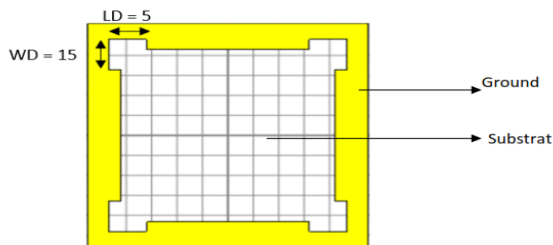


Figure 17. Antenna Optimization Results Design

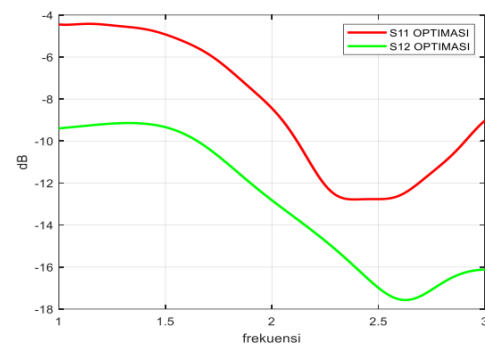


Figure 18. Antenna Simulation Results After Optimization

DISCUSSION

Simulation Comparative Analysis between the Reference Antenna and the Antenna Modification

After going through the simulation and optimization process, then you can analyze several comparisons contained in the reference antenna with modified antenna.

1 Return Loss Comparison

The return loss value is an important thing that must be considered in antenna design. Where the simulated return loss value is ≤ -10 dB which means 90% of the signal is absorbed and 10% of the signal is reflected back so that in this situation the antenna can be said to be matching or can be interpreted the reflected wave value is small compared to the wave value that is emitted. Comparison of return loss results between references and modifications can be seen in figure 19 and 20.

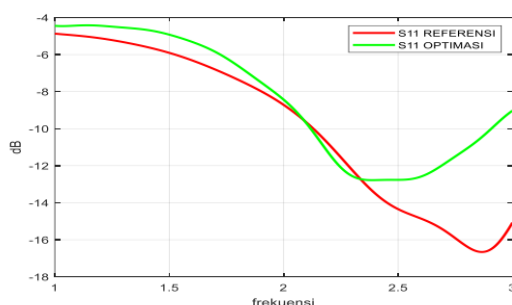


Figure 19. S11 Return Loss Comparison

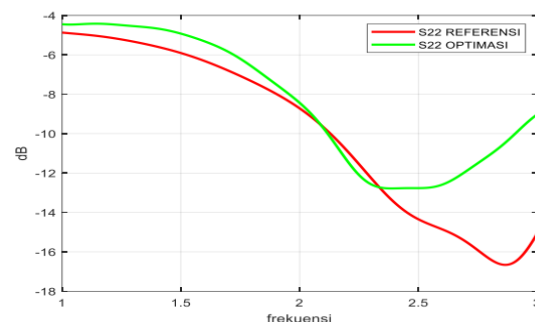


Figure 20. S22 Return Loss Comparison

Figure 19 S22 Return Loss Comparison In figure 4.6 is a comparison of return loss S11 which is port 1 on the antenna and in figure 20 is a comparison of S22 return loss which is port 2 on the antenna, you can see that the values are S11 and S22 almost the same value because the S-parameter is an input-output relationship between port, where port 1 is the power sent to port 2. In comparison return loss between reference and modification get different values however has the same frequency because it has a change in the slot size value different, so that the reference return loss value is -13.57 dB which has a depth greater than the return loss value when it is modification of -12.81 dB. Although

the return loss depth of the antenna deeper reference than a modified antenna, but a modified antenna still meets the good return loss criteria because it is still < -10 dB.

Comparison of Voltage Standing Wave Ratio (VSWR) Results

VSWR is one of the most important factors that must be considered in antenna design, because VSWR explains the comparison of values maximum and minimum voltage on non-matching lines. The antenna good is an antenna that has a value of $1 \leq \text{VSWR} < 2$. Comparison of VSWR between Reference with modifications can be seen in Figure 21.

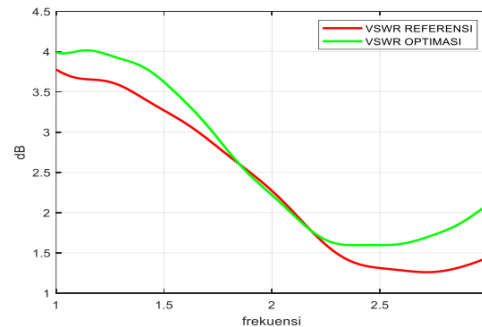


Figure 21. VSWR comparison

In Figure 21 you can see the VSWR comparison between reference antennas with the optimization antenna having the same frequency value. On the reference antenna produces a VSWR value of 1.36, while the antenna optimization produces a VSWR value of 1.52. It can be seen that the VSWR tolerance of The reference antenna is better than the optimization antenna, but the optimization antenna is still within good VSWR tolerance.

Insulation Comparison

Isolation is the weakening that occurs between one antenna and another other. Isolation can be seen in the S-parameters, namely in the distance between the S11 values with S12. Comparison of insulation can be seen in figure 22, 23 and 24.

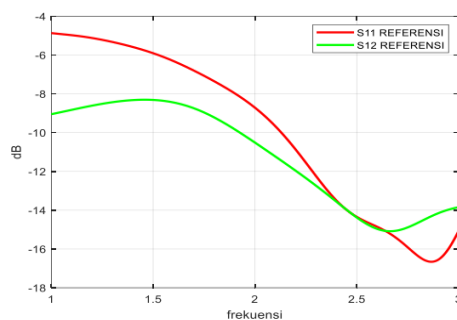


Figure 22. Reference Antenna Isolation Results

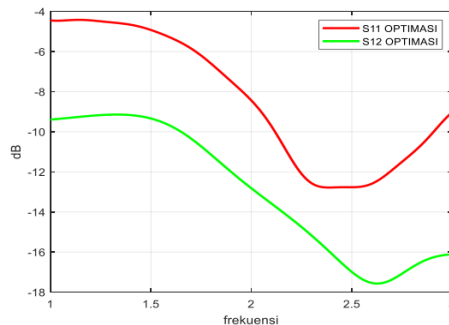


Figure 23. Antenna Isolation Optimization Results

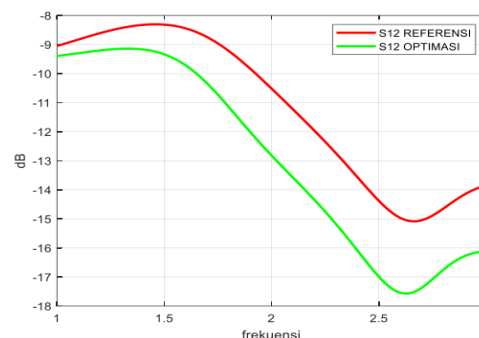


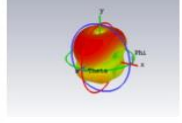
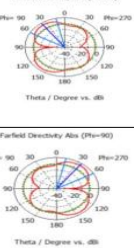
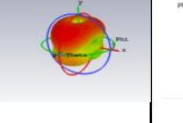
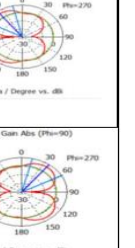
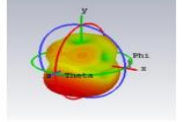
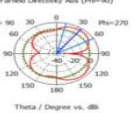
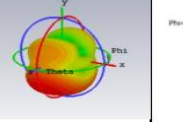
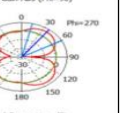
Figure 24. Results of Reference Antenna Isolation and Optimization

The ideal antenna is an antenna that is capable of transmitting all the power attributed to him. The power is then transmitted to the receiving antenna. It is hoped that each antenna does not affect each other. Mutual coupling value It is hoped that it will be as small as possible by increasing the isolation between elements. Mutual coupling can be associated with two reasons, the first is interaction electromagnetic and second, namely surface currents between elements. On comparison the results of isolating the reference antenna with the modified antenna, it can be seen that The isolation of the reference antenna is not good which will later affect the value antenna parameters. This is due to the intersection of the graph between S11 with S12, but the antenna value when modified has an isolation value or value mutual coupling < -15 dB at the 2.4 GHz frequency which does not occur the intersection of the graphs which will later influence the antenna parameters.

Comparison of Radiation Patterns

The radiation pattern shows the direction of transmission and reception of an antenna. On Table 3 shows the radiation pattern of the reference antenna and the modified antenna in 2D and 3D form. The radiation pattern of an antenna describes how the antenna works radiate energy into free space or how the antenna receives energy. It can be seen that the resulting radiation pattern is omnidirectional radiation pattern, which in this form of radiation polarization will emit signals in all directions. So this antenna is more intended for internal wireless communication links antenna room that is attached to the Wi-Fi router which functions as re-amplifier so that this antenna will work as a transceiver amplifier with a working frequency of 2.4 GHz for wireless LAN.

Table.3 Comparison of Radiation Patterns

Port	Antena Referensi (2.4 GHz)		Antena Modifikasi (2.4 GHz)	
	3D	Polar	3D	Polar
1				
2				

Comparison of Reference, Modified, and Antenna Design Results Manufacturing

Table.4 Comparison Tables

NO	Parameter	Reference Results	Simulation Results	Antenna Simulation Results	Results
		(paper)	Referensi	Modification	Measurement
1	Frequency of work (GHz)	2.4	2.4	2.4	2.4
2	Return Loss (dB)	≤ 10	≤ 10	≤ 10	≤ 10
3	VSWR	-	1,361	1,53	1,29
4	Isolasi (dB)	≤ 15	$\leq 13,58$	≤ 15	≤ 15
5	Gain (dBi)	5,8	6,134	6,142	-
6	Bandwidth (MHz)	1100	2002	1051	$>20-40$
7	Polaradiasi	Omnidirectional	Omnidirectional	Omnidirectional	-

From the comparison table.4 it can be seen that the results from references (journals) are has results that are not much different from the simulation results in CST. And value The best results are in the modified antenna simulation results, however there is a narrow bandwidth value, but it is still within the specification value, namely 20-40 MHz. Likewise, the measurement results only affect the value VSWR is better than the modification results.

CONCLUSION

After carrying out simulations, parametric studies, fabrication, and analysis, then can be concluded as follows.

1. Design and simulation of MIMO Microstrip Antenna for WIFI application for access point devices using CST Studio software Suite 2019 as well as antenna manufacturing.
2. Optimization results obtained from the MIMO Antenna design for the application WIFI access point device uses CST Studio Suite 2019 software namely by increasing the slot length by 5 mm and the slot width by 15 mm.
3. The parameter value obtained from the designed antenna is return loss of -12.78 dB, isolation value of -16.12 dB, VSWR of 1.5 dB, gain of 6.142 dBi, bandwidth width 1.0516 GHz in the 2.4 GHz frequency range, and has an omnidirectional radiation pattern. Meanwhile, the antenna parameter values manufacturing, namely return loss as deep as -13.5 dB, isolation value as deep as -18.8 dB, and a VSWR value of 1.29 dB.
4. In the application of the antenna used for Wi-Fi as a transmitter By comparing distances, different results are obtained where the power value is Each distance is different because the farther the distance, the greater the power value produced or emitted will be smaller or less optimal network.

REFERENCES

- A. MoradiKordalivand, T. A. Rahman, and M. Khalily, "Common Elements Wideband MIMO Antenna System for WiFi/LTE Access-Point Applications," *IEEE Antennas Wirel Propag Lett*, vol. 13, pp. 1601–1604, 2014, doi:10.1109/LAWP.2014.2347897
- A.B. Adipurnama, H. Wijanto, and Y. Wahyu, "Perancangan dan realisasi antena mimo 4x4 mikrostrip patch persegi panjang 5, 2 ghz untuk wifi 802.11 n," *eProceedings of Engineering*, vol. 3, no. 1, 2016.
- A. Srirahayu, Y. H. Pramono, and M. S. Muntini, "Antena Monopole sebagai Transceiver Wi-Fi Frekuensi 2, 4 GHz pada Saluran Transmisi Silinder (Pipa PDAM)," *Prosiding Pertemuan Ilmiah XXIX HFI Jateng & DIY*, vol. 25, 2015.
- A. H. Rambe, "Antena Mikrostrip: Konsep dan Aplikasinya," 2012
- F. Abdurrahman, "Desain Antena Mikrostrip Rectangular untuk WIFI pada Frekuensi 2,462 GHz dan 5, 52 GHz," 2018.
- I. Amara, "MINI TINJAUAN JARINGAN NIRKABEL," 2021.
- M. A. Habib and T. A. Denidni, "Design of a new wideband microstrip-fed circular slot antenna," *Microw Opt Technol Lett*, vol. 48, no. 5, pp. 919–923, 2006.
- J. Ren, W. Hu, Y. Yin, and R. Fan, "Compact printed MIMO antenna for UWB applications," *IEEE Antennas Wirel Propag Lett*, vol. 13, pp. 1517–1520, 2014.
- P. Radiasi, "Desain reflektor antena parabola untuk keperluan komunikasi data teresterial pada frekuensi 2, 4 GHz," 2005.
- T. Aswin, F. Imansyah, J. Marpaung, and R. R. Yacoub, "ANALISIS PENERAPAN ACCESS POINT DALAM RENTANG FREKUENSI 2400–2500 MHz DI BALMON KELAS II PONTIANAK," *Jurnal Teknik Elektro Universitas Tanjungpura*, vol. 2, no. 1, 2021.