

## MIMO Microstrip Antenna with Multiple Inputs at 2.4 GHz Frequency for Long Term Evolution (LTE)

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### ABSTRACT

LTE (Long Term Evolution) is a fourth-generation wireless communication technology that is currently under development, necessitating the use of efficient antennas. This research focuses on the design and realization of a Multiple Input Multiple Output (MIMO) microstrip antenna operating at a frequency of 2.4 GHz, which is essential for LTE applications. The MIMO technique employs multiple antennas on both the transmitter and receiver sides, aiming for a correlation coefficient below 0.2 to enhance communication quality and channel capacity without requiring additional bandwidth. The antenna design was simulated using CST Studio Suite 2019 software, followed by fabrication. The simulation results indicated a return loss of -25.411 dB, a Voltage Standing Wave Ratio (VSWR) of 1.113, a gain of 6.464 dBi, an omnidirectional radiation pattern, and a bandwidth of 20 MHz. Upon fabrication, the measured return loss was -18.071 dB, with a VSWR of 1.285 and an increased bandwidth of 50 MHz. The results demonstrate that the designed antenna meets the necessary specifications for LTE applications, confirming its suitability for practical use in modern wireless communication systems.

### INTRODUCTION

Long Term Evolution has become a dominant standard in modern wireless communication, offering high data rates and low latency. To meet the ever-increasing demand for greater bandwidth, Multiple Input Multiple Output techniques have become essential (Donelli, 2021). MIMO systems utilize multiple antennas at both the transmitter and receiver to increase channel capacity and communication quality without requiring additional bandwidth (Liu et al., 2018).

Microstrip antennas are a popular choice in MIMO applications due to their compact size, low manufacturing cost, and ease of integration with other electronic devices (Sharawi et al., 2012). At 2.4 GHz, a frequency commonly used for applications like Wi-Fi and Bluetooth, the design of MIMO microstrip antennas requires careful attention to minimize mutual coupling between antenna elements and achieve good isolation (Bhatia & Sharma, 2021). Mutual coupling can degrade MIMO system performance by reducing antenna diversity and increasing error rates. A novel H-shaped parasitic element can be added to the ground plane to mitigate the mutual coupling (Liu et al., 2018).

The development of efficient MIMO microstrip antennas for LTE applications at 2.4 GHz requires optimization of various design parameters, including antenna geometry, element spacing, and decoupling techniques. This research aims to design, simulate, and test a MIMO microstrip antenna operating at 2.4 GHz for LTE applications, focusing on enhancing isolation, reducing mutual coupling, and achieving optimal performance.

### LITERATURE REVIEW

#### MIMO Microstrip Antennas at 2.4 GHz for LTE

The increasing demand for high data rates and reliable connectivity in modern wireless communication systems has driven significant research in Multiple-Input Multiple-Output antenna technology. MIMO systems offer enhanced channel capacity and spectral efficiency without requiring additional bandwidth, making them crucial for Long Term Evolution and other advanced wireless standards (Donelli, 2021); (Malathi & Thiripurasundari, 2017). Microstrip patch antennas are particularly attractive for MIMO applications due to their low profile, ease of fabrication, and compatibility with modern wireless devices (Sharawi et al., 2012). However, designing effective MIMO microstrip antennas, especially at the 2.4 GHz frequency band, presents several challenges related to bandwidth, isolation, and mutual coupling (Bhatia & Sharma, 2021).



### Challenges in MIMO Microstrip Antenna Design

- **Mutual Coupling:** A primary challenge in MIMO antenna design is minimizing mutual coupling between antenna elements. Close proximity of antenna elements, necessary for compact devices, leads to unwanted coupling, which degrades antenna performance by reducing diversity gain and increasing signal correlation (Raj et al., 2023). Various decoupling techniques have been explored to mitigate this issue.
- **Isolation:** Achieving high isolation between antenna elements is critical to ensure that each antenna operates independently, maximizing the benefits of MIMO technology (Raj et al., 2023). Isolation can be improved through various methods, including defected ground structures, parasitic elements, and optimized antenna spacing.
- **Bandwidth:** LTE systems require sufficient bandwidth to support high data rates. Designing microstrip antennas with wide bandwidths while maintaining compact size and good radiation characteristics is a significant challenge.
- **Compactness:** Modern wireless devices demand compact antenna designs. Miniaturizing MIMO antenna systems while preserving performance characteristics requires innovative design approaches (Yang et al., 2015).

### Techniques for Performance Enhancement

Researchers have explored various techniques to address the challenges associated with MIMO microstrip antenna design for LTE applications at 2.4 GHz:

- **Decoupling Structures:** Introducing decoupling structures, such as electromagnetic bandgap structures or metamaterials, between antenna elements can effectively reduce mutual coupling and improve isolation (Khajeh-Khalili et al., 2020).
- **Parasitic Elements:** The use of parasitic elements strategically placed near the radiating patches can help to improve isolation and bandwidth (Liu et al., 2018). For example, a novel H-shaped parasitic element can be added to the ground plane to mitigate the mutual coupling (Liu et al., 2018).
- **Defected Ground Structures:** Etching slots or patterns in the ground plane can modify the current distribution and reduce surface wave propagation, leading to improved isolation (Malathi & Thiripurasundari, 2017).
- **Optimization of Antenna Geometry:** Careful selection and optimization of antenna element geometry, including patch shape and feed network, can significantly impact antenna performance (Bhatia & Sharma, 2021).
- **\*\* использования МИМО и 5G:\*\*** Multiple input multiple output is an indispensable technology for sub-6 GHz and millimeter wave future generation mobile terminal applications (Ishteyaq & Muzaffar, 2022).
- Recent Advances and Research Directions
- Recent research focuses on developing novel antenna designs and decoupling techniques to meet the stringent requirements of modern LTE and 5G systems (Raj et al., 2023); (Tiwari et al., 2023). For example, a compact four-element MIMO antenna system for LTE/ISM operations achieves high isolation with close element spacing (Yang et al., 2015). Other studies explore the use of metamaterials to enhance gain and reduce mutual coupling in millimeter-wave MIMO antennas (Khajeh-Khalili et al., 2020). The design of multiband MIMO antennas for mobile applications is also an active area of research (Bhatia & Sharma, 2021).

## METHOD

### Design And Manufacturing

#### Planning

This chapter will explain how to design and make a circular MIMO microstrip antenna. This antenna is designed to work at the 2.4 GHz frequency. Microstrip antenna design simulation using the CST Studio Suite 2019 application. Before carrying out the simulation, calculate the dimensions needed to design a MIMO antenna with circular patches, such as the radius of the circle (a), feeder width (Wf) and so on.

#### Tools and materials

In this final project the tools and materials used are:

- 1) Pencil and ruler
- 2) Double layer PCB board with FR-4 dielectric substrate as antenna substrate
- 3) Antenna Heat Thermal PCB Heat Transfer Paper
- 4) Soap
- 5) Iron
- 6) Receptacle
- 7) Gloves



- 8) HCL, H2O, H2O2 solutions
- 9) Solder and Tin
- 32
- 10) SMA Female Jack RF Adapter PCB Connector

### Design Flow

In designing this final project, several stages were carried out which are depicted in the flow diagram in Figure 1 below.

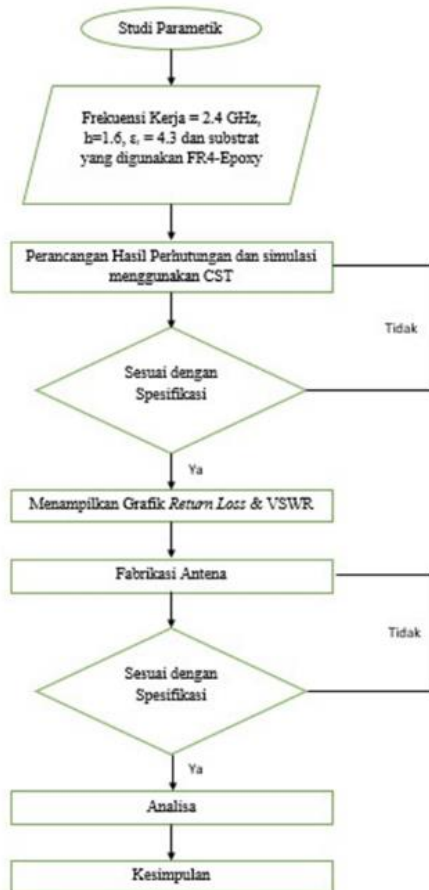


Figure 1. Flowchart

### Antenna design with formula calculations

The first step before designing an antenna is to determine the specifications of the antenna to be designed, such as working frequency, Return Loss, VSWR, and impedance, which can be known as follows:

<b>a. Frequency of work</b>	: 2.35 GHz
<b>b. Return Loss</b>	: $\leq -10$ dB
<b>c. VSWR</b>	: $1 \leq \text{VSWR} \leq 2$
<b>d. Impedance</b>	: $50 \Omega$

Then the substrate used is FR-4 Epoxy which has a dielectric constant ( $\epsilon_r = 4.3$ ) and a substrate thickness (h) of 1.6 mm. To start designing an antenna, start by calculating the antenna in theory so that it can be simulated using CST Studio Suite 2019 software. Figure 2 below shows the results of the antenna design using formula calculations.

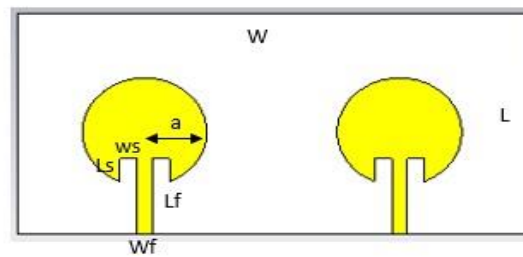


Figure 2. Antenna Design According to Calculations

Table 1. Dimensions of Calculation Results

No.	Dimensi	Nilai (mm)	Keterangan
1.	W	82.34	Lebar Substrat
2.	L	82.34	Panjang Substrat
3.	a	20.17	Jari-jari Patch
4.	Ts	1.6	Tebal Substrat
5.	Tg	0.035	Tebal Konduktor
6.	Wf	4.925	Lebar Feedline
7.	Lf	21	Panjang Feedline
8.	Ws	1	Lebar E-Shape
9.	ls	10	Panjang E-Shape

### Antenna Design Using CST Studio Suite 2019 Software

To design a circular MIMO microstrip antenna using the CST STUDIO SUITE 2019 application, do the following steps – following steps:

1. First, make sure the CST Studio Suite 2019 software is installed on the PC that will be used to design and simulate the antenna design.
2. Open the installed CST application. Then click "New Template" in the image below.
3. Click "Microwaves & RF/Optical".
4. After selecting "Antennas", continue by selecting "Planar (Patch, Slot, etc)" then press next.
5. Select "Time Domain" then press next
6. Then press Next because usually the parameters are as desired.
7. Next, enter the minimum and maximum frequency values according to those previously determined as well as the monitors or parameters you want to display and define or frequency range to be analyzed.
8. Give a name to the antenna file you want to design, then press Finish.
9. Then the initial screen will appear for create an antenna design, enter the antenna dimension values according to the results obtained previously

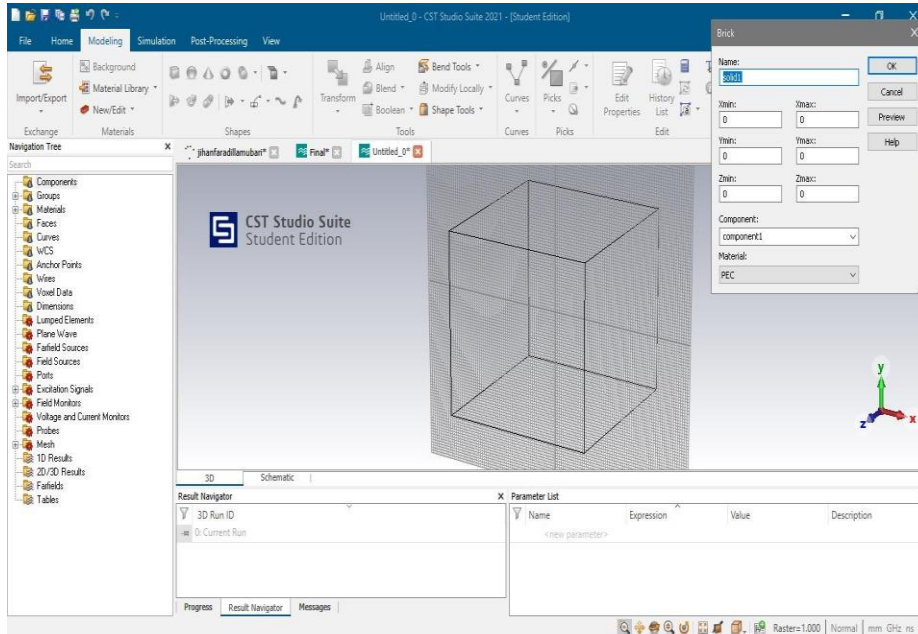


Figure 3. New Worksheet Display

10. After the antenna design is complete, before carrying out the simulation, the port must be given first by clicking "Home >> macros >> solver >> ports >> calculate port extension coefficient. Then enter the dielectric constant value according to the antenna being designed then select calculate.
11. After the design and assignment of ports to the antenna is complete. So then carry out the simulation by clicking "start simulation".
12. After the simulation process is complete, the parameter results that we want to achieve can be seen by clicking "1D result >> S – Parameters >> S1.1".

### Parametric Studies

The process carried out to obtain antenna parameters in accordance with the specifications required by the antenna is through parametric studies. This stage is carried out by changing the values of the antenna parameters to obtain optimal results, namely by changing the patch size, substrate and other parameters. In figure 11 below, is a display of the optimization carried out to obtain parameters that comply with the specifications required by the antenna.

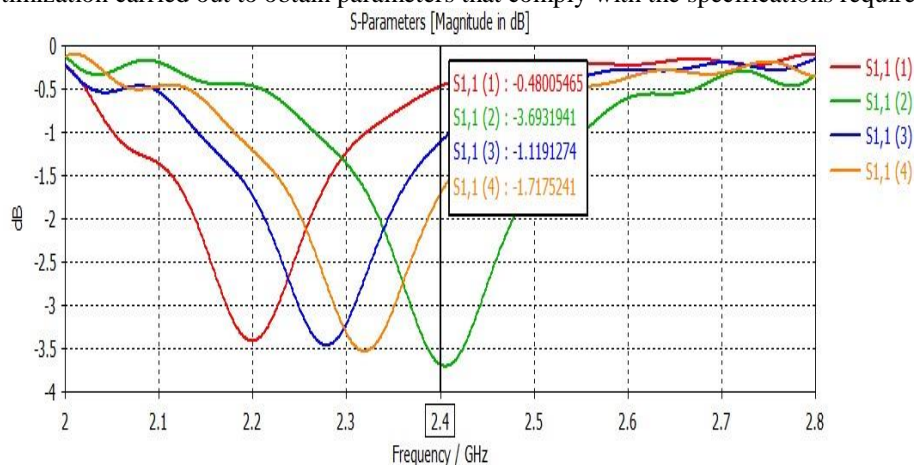


Figure 4. Changes in patch dimensions

From Figure 4 above, it can be seen that the changes that occur when changes are made to the patch size, which was initially valued at 20.17, were reduced to 18.5. From this figure it can be seen that the smaller the patch size, the graph will shift closer to the frequency used.

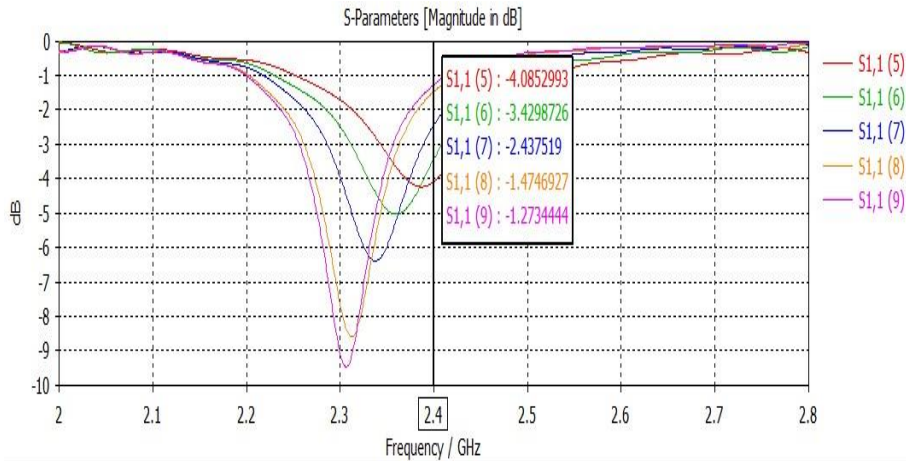


Figure 5. Effect of changing the size of the Feedline Width and Length

In figure 5 above is the return loss value by changing the feedline width and height values. By reducing the size of the feedline, it can be seen that the resulting return loss value will be deeper.

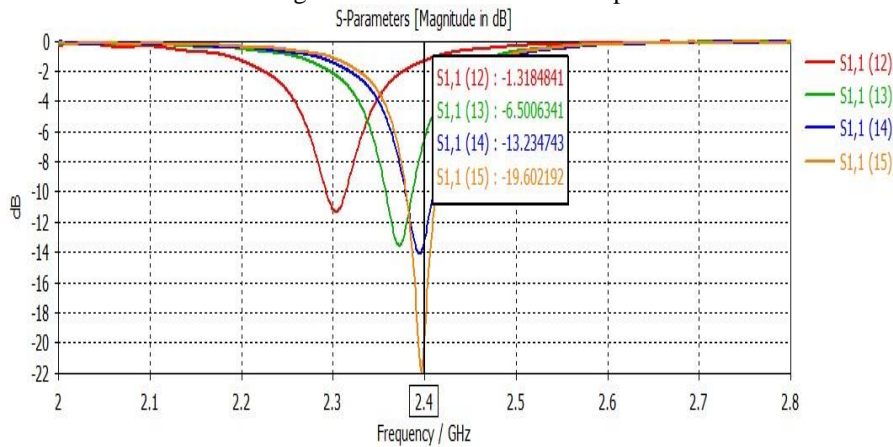


Figure 6. Effect of changing the size of the E-Shape

From figure 6 above, it is shown that the return loss falls at the required working frequency with a return loss of  $\leq -10$  dB. The changes made are by increasing the width of the E-shape from 1 to 5.7 and reducing the length of the E-shape from 12.55 to 11. So it can be seen in the picture above that the resulting return loss value is optimal or in accordance with the desired antenna standard.

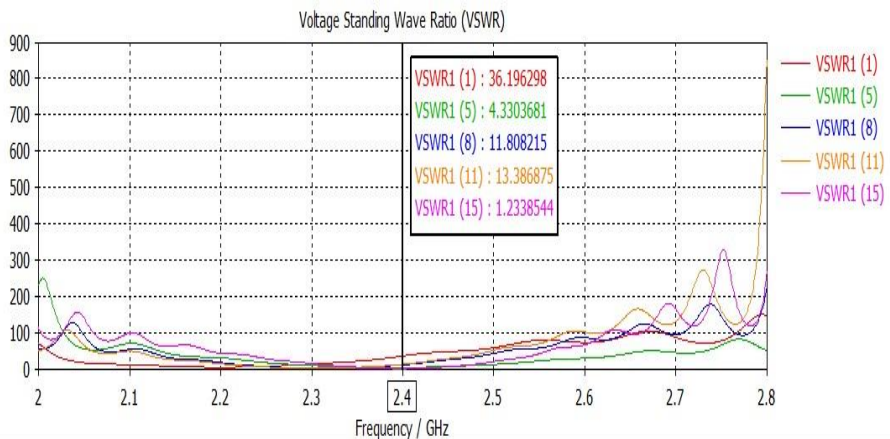


Figure 7. Effect on VSWR

In Figure 7, you can see the VSWR value that is in accordance with the required antenna standard, namely below 2, shown in the 15th experiment where a value of 1,233 was obtained. It can be concluded that if the return loss value does not match the desired antenna specifications, then the VSWR value will not match the antenna specifications.

### MIMO Microstrip Antenna Design and modification or optimization

After optimizing Figure 2 above, an optimal design is obtained which has results in accordance with the required antenna specifications.

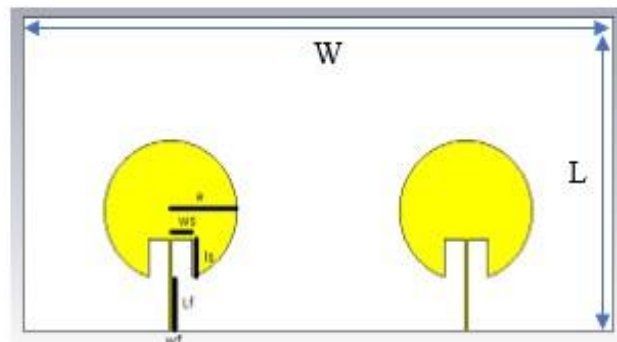


Figure 8. Optimized Antenna Design Results

In figure 8 below are the names and values of the parameters used to design the antenna as in figure 3.33 above:

Table 2. Optimized Antenna Parameters

Name	Expression	Value	Description
W	= 82.34	82.34	Lebar Substrat
L	= 82.34	82.34	Panjang Substrat
tc	= 0.035	0.035	Tebal Konduktor
ts	= 1.6	1.6	Tebal Substrat
Wf	= 0.75	0.75	Lebar Feedline
Lf	= 13	13	Panjang Feedline
a	= 18.5	18.5	Jari-jari Patch
ws	= 5.7	5.7	Lebar E-Shape
ls	= 11	11	Panjang E-shape

Where the parameters above are optimal values to produce antenna parameters that comply with the required antenna specifications by carrying out parametric or optimization studies by changing the parameter values such as increasing the width and length of the feedline, which originally had a feedline width 4,925 reduced to 0.75 mm. The feedline length, which was originally 21, was reduced to 13 mm. Then change the size of the patch radius, which is all from 20.17 reduced to 18.5 mm. Likewise by changing other parameters to get optimal results.

### Antenna Fabrication

After optimizing the antenna and getting optimal results and in accordance with the required antenna specifications, the antenna fabrication process is then carried out. Following are the steps for fabrication:

1. Prepare the tools and materials needed for fabrication, such as: Double Layer FR4 PCB, antenna layout transferred to PCB transfer paper, container, solvent solution (H3, HCL, H2O2), coir, iron, sandpaper, solder, tin, and female connector SMA 50 Ohm.
2. Next, wash the PCB that has been cut to the size of the substrate during the simulation using soap, then dry it.
3. Next, attach the transfer paper to the PCB by ironing the paper until the design from the transfer paper moves to the PCB.
4. After that, the PCB to which the design has been attached is dissolved, but the ground must be taped or covered so that it does not dissolve during the dissolution process.
5. After the PCB has dissolved, move the PCB to clean water then clean the cooper part of the PCB or the patch using thinner.

6. After the PCB is clean, the next process is to connect the PCB with the SMA female connector to the port, the part that is soldered is only the part that is exposed to the patch.
7. After all the antenna fabrication processes are complete, the next step is to carry out measurements in the lab using a Keysight measuring instrument. This measurement aims to see the results of the antenna parameters that have been fabricated.

### RESULT AND DISCUSSION

This chapter explains how the results and discussion of the modified antenna from the previous reference that was designed were simulated again using CST, which obtained quite good results in accordance with the objectives and antenna specifications required for this MIMO antenna. After the results of the antenna design have obtained results that are in accordance with the required antenna standards, the author compares the design results with the fabrication work that has been carried out. By comparing the simulation results with the fabrication results, it can be seen which has better parametric values from design using software or fabrication results which obtain good values. Figure 9 below is a view of the fabricated antenna.

From the results of the optimized modified MIMO antenna design, parameters such as Return Loss, VSWR, gain, radiation pattern, and Bandwidth as in the pictures below:

#### Simulation Parameter Results

Antenna optimization results are obtained when the antenna has been designed and optimized to obtain better results. The parameters obtained from the antenna optimization results are return loss, bandwidth, radiation pattern, gain, and VSWR. The following are the results of the optimization that has been carried out. Figure 9 below shows the antenna design after optimization.

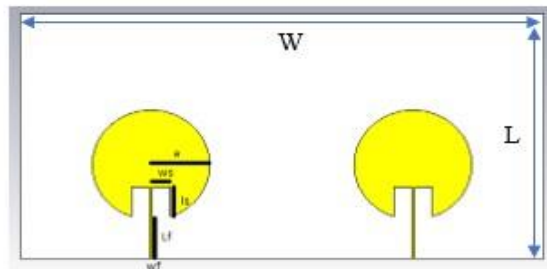


Figure 9. Antenna Design After Optimization

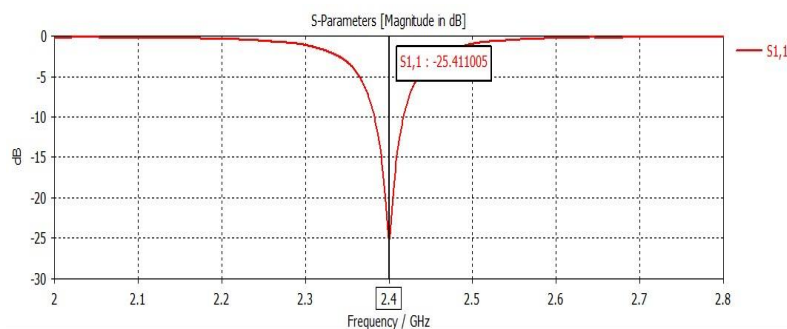


Figure 10. Return Loss Value

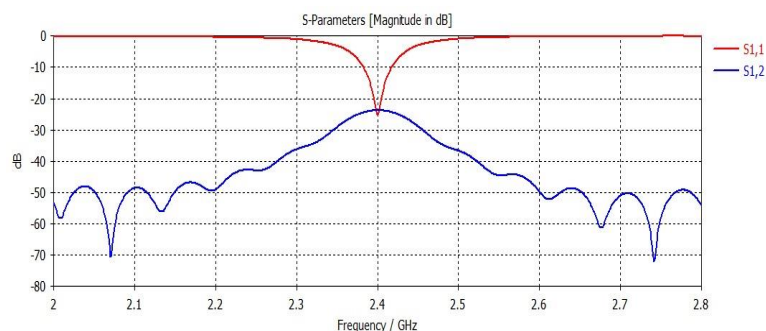


Figure 11. Insulation Value

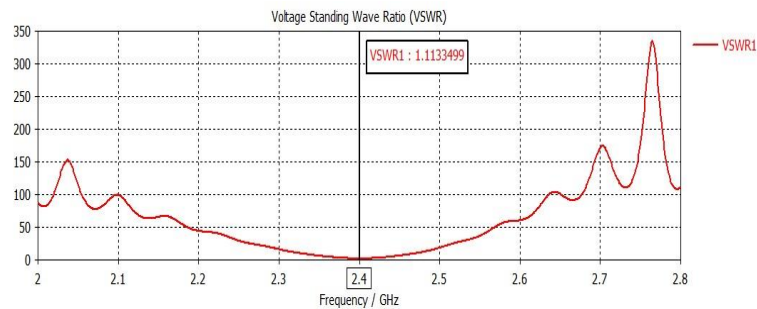


Figure 12. VSWR value

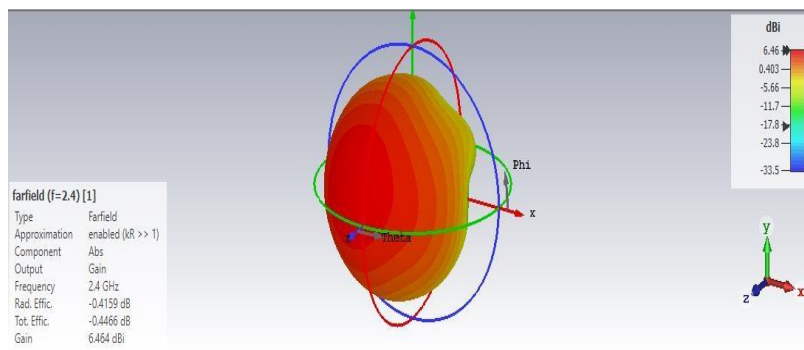


Figure 13. Gain Value

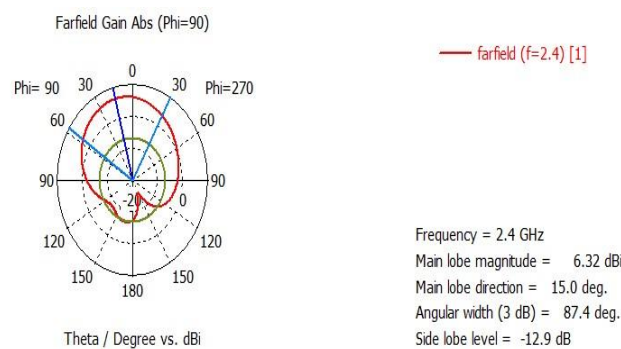


Figure 14. Radiation Pattern

The results obtained from this design are quite good and the aim of the MIMO antenna has been achieved, namely to obtain a reflective radiation pattern as desired, namely omnidirectional. And the resulting VSWR value is good, namely 1,113, where a good VSWR value is less than 2 and the return loss is -25,411 dB at the 2.4 GHz frequency. The value obtained by the return loss will affect the VSWR value, in determining the performance value it is directly proportional to the VSWR, that is, the smaller the return loss value, the better the performance of the antenna. It can be concluded that the less power lost in transmitting an antenna, the better the antenna.

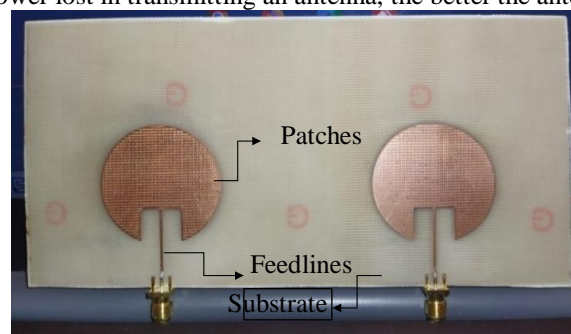


Figure 15. Fabricated Antenna

Figure 15 above is a picture of the fabricated antenna. After fabricating the antenna, the fabricated antenna is then measured using a keysight measuring instrument, where this measuring instrument can only measure the return loss value and VSWR value. The author will compare the results of the return loss and VSWR parameters of the modified antenna with the fabrication results as shown in the image below.

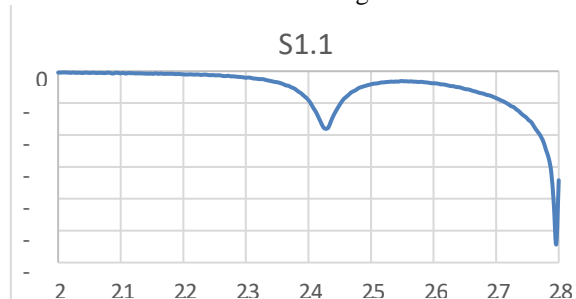


Figure 16. Return Loss Value of fabricated antenna

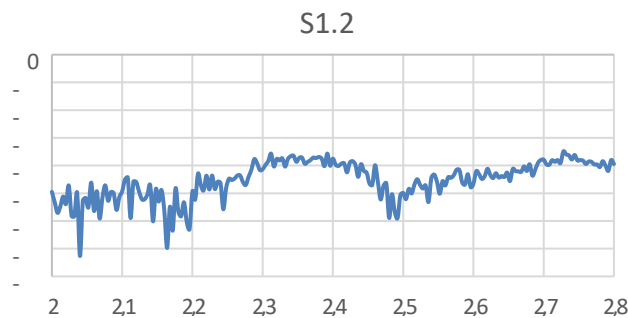


Figure 17. Value of S1.2

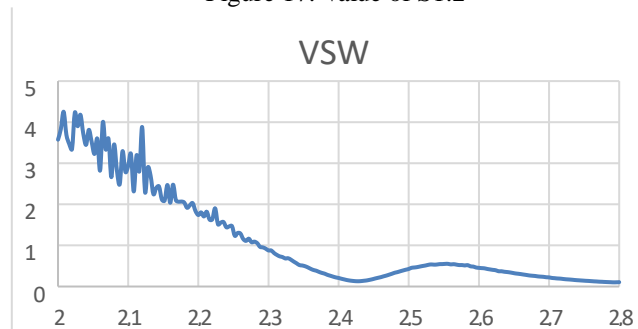


Figure 18. VSWR Value of Fabricated Antenna

### Antenna Parameter Analysis

Next, an analysis of the antenna parameters obtained is carried out to see which results and during which process obtain better quality, such as return loss, VSWR, gain, radiation pattern and bandwidth.

#### 1. Return Loss

Return Loss is a comparison of the amplitude of the reflected wave to the amplitude of the transmitted wave. The terms or conditions for a good return loss value for an antenna are below -10 dB, where 90 of the signal is absorbed and 10% of the signal is reflected back so that the value of the reflected wave is not that large compared to the wave sent or can be said to be matching (Balanis, 2006). As seen in Figure 4.46, the return loss simulation measurement results are -25,411. The results obtained are in accordance with good antenna specifications. Meanwhile, in the fabrication in Figure 4.45, the measurement result is -18.071, the value obtained is in accordance with the return loss specifications required for the antenna.

#### 2. Isolation

Isolation is the weakening that arises between one antenna and another antenna. Isolation can be seen in the s-parameter, namely the distance between the S11 and S12 values. Figure 16 shows that the isolation of the simulated antenna is less good than the isolation of the fabricated antenna as in Figure 17. The mutual coupling value obtained

between the simulated and fabricated antennas is also smaller, namely the mutual coupling value for the simulated antenna is -23.81 dB and the fabricated antenna is -38.423dB.

Another parameter that can look at isolation to reduce mutual coupling is current distribution. Figure 18 below shows the current distribution on a modified antenna. It can be seen that the current is concentrated on one antenna without any current transmitting to other antennas.

### 3. VSWR

VSWR is the comparison between maximum voltage and minimum voltage. A good VSWR value is  $\leq 2$ , meaning that all the power radiated by the transmitting antenna is received by the receiving antenna (match) which is in the picture 4.40 above, the simulation result is 1,113 and in figure 4.48 the fabrication result is 1,285. So you get a good VSWR value. If the VSWR value is greater, the reflected power will be greater and it will not match.

### 4. Gains(dB)

Gains is a reinforcement or can also be interpreted as the character of an antenna which has the ability to concentrate signal radiation produced by the antenna itself, or receive signals from a certain direction. So from the data seen in Figure 4.41, the antenna gain value is 6,464. The gain value of an antenna greatly influences the amount of transmit power. The higher the gain value obtained, the better the antenna's transmit power will be.

### 5. Radiation pattern

When an antenna radiates, the radiation pattern is the form of radiation from an antenna in the form of spherical coordinates represented. It can be seen in Figure 4.42 that during the simulation the radiation pattern is omnidirectional, where this omnidirectional radiation pattern can be described as a donut shape where the antenna can transmit and receive signals from all directions. The radiation pattern required is in accordance with the radiation pattern required by LTE.

### 6. Bandwidth

Bandwidth is the difference between the lower frequency value and the upper frequency value within a certain time span or the resulting bandwidth width value. Bandwidth has a function as a size of the media or data transmission path owned by a network. So if the bandwidth value is greater, the bandwidth performance will be better. From the simulation results shown in Figure 4.43, the bandwidth value is 34 MHz. And during fabrication, the bandwidth value was obtained, namely 50 MHz, this illustrates that the fabricated antenna has a wider bandwidth than the simulated antenna.

From the antenna parameters that have been measured, then compared between the modified antenna and the fabricated antenna, where when fabricated the frequency was originally 2.4 GHz changed to 2.44 GHz, the return loss value changed from -25.41 to -8.413, the return loss results at the time of fabrication did not meet the requirements. antenna specifications. Meanwhile, the VSWR value goes from 1,113 to 1,854. The difference in results can be caused during the fabrication process which can be caused by the process of cutting and measuring the PCB incorrectly, transferring the layout to a PCB that is not optimal, the etching or coating process is not perfect, the soldering process is excessive or not good enough, as well as PCB ground elements that are often handled by hand will cause differences in design results and fabrication results.

## CONCLUSION

The process begins with design, simulation and fabrication as well as analysis carried out by the author in this final project, so the following conclusions can be drawn:

1. The MIMO microstrip antenna has been designed and modified by the author using CST Studio 2019 software with a working frequency of 2.4 GHz and fabrication has been carried out.
2. The parameter results of the simulated antenna obtained a return loss value of -25,411 dB, mutual coupling of -23.811013, VSWR 1,113, gain 6,464, omnidirectional radiation pattern and bandwidth 34 MHz. And the measurement results of the fabricated antennas have different values, but are still within a fairly good standard. The results of the fabricated antenna have a return loss shift from -24,411 dB to -18,071 dB or a change of 6.34 dB. The mutual coupling value is from -23,811 dB to -38,423, or has a change of -14,612. Meanwhile, VSWR went from 1,113 to 1.285 or a change of 0.741. And bandwidth from 34 MHz to 50 MHz, the bandwidth obtained during fabrication is wider than the bandwidth during simulation. The measurement results of each antenna parameter meet the classification of a good antenna.
3. This simulated MIMO microstrip antenna is suitable for application for LTE which has an omnidirectional radiation pattern, gain of 6,464, and a mutual coupling value of -23,811, the results of which are the parameters required for LTE where the radiation pattern is omnidirectional and the gain is greater than 2 dBi. And the MIMO parameter where the mutual coupling is small than -20 dB.
4. The bandwidth produced during the simulation is 34 Mhz, while during optimization the bandwidth value obtained is 50 Mhz. A wider bandwidth value is obtained when fabrication is carried out. The bandwidth

obtained is in accordance with the specifications of a good antenna, namely below 100 Mhz. However, the reference used cannot be compared whether it is getting wider or not, because the previous reference did not include the actual bandwidth value.

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