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Design of Dual-Band Microstrip Linear Array MIMO Antenna With U Slot For 5G Communication System

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ABSTRACT

The development of 5G technology is expected to result in high data rate communication, low power consumption, and larger network capacity. Microstrip antenna is an antenna that can support 5G technology because it can work at high frequencies but has the disadvantage of producing a small gain and narrow bandwidth. The use of array and MIMO methods can increase the gain value. The addition of the U slot method aims to increase bandwidth and can produce multi-frequency. In this study, the antenna was designed using an epoxy substrate (FR-4) with a rectangular U-slot patch arranged in a 4×2 MIMO array and fabricated. From the simulation results, the return loss parameter (S11) is -12.49 dB, (S12) is -88.17 dB, the bandwidth is 610 MHz, the gain is 15.70 dB, the envelope correlation coefficient is 3.85 × 10-10. and diversity gain of 10 dB. From the fabrication results, two working frequencies are obtained, namely at a frequency of 3.2 GHz and 3.62 GHz with each return loss value (S11) of -25.96 dB and -29.22 dB, (S12) of -48.61 dB and -51.78 dB, a bandwidth of 50 MHz. The independence of each antenna is indicated by the envelope correlation coefficient of 6.48 × 10-6 and 1.5 × 10-6, and a diversity gain of 10 dB. This antenna can be recommended as a receiving antenna in 5G communication systems.

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1. INTRODUCTION

5G technology is the next phase of wireless network communication development [1]. One of the candidates for the radio frequency range for 5G trials in Indonesia is in the 3.3 – 4.2 GHz (3.5 GHz radio frequency band) [2]. The adaptation of the Multiple Input Multiple Output (MIMO) technique into 5G technology is used to produce high data rate communication and low power consumption compared to 4G technology and the radiation pattern can be in several directions. The MIMO technique can take advantage of multipath fading depending on the number of antennas it uses [3].

One type of antenna that can support 5G technology is the microstrip antenna because it has a small size, is easy to store, and can operate at high frequencies, but the microstrip antenna has drawbacks, namely small gain, poor directionality, and poor bandwidth efficiency resulting in poor quality and the signal reception level is not optimal. The gain value can be increased by the array method, namely by arranging several patch microstrip antennas that are connected to the supply line [4].

In Research [5], a 2×2 MIMO array microstrip antenna has been designed using the slot method at a frequency of 37 GHz for 5G with return loss ≤ 10 dB, VSWR ≤ 2, gain 18.7 dBi and bandwidth 2.12 GHz. However, in this study the frequency used was different from the radio frequency band for testing in the range of 3.3 – 4.2 GHz.

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In Research [6], the design of a 4x2 planar microstrip antenna array at a center frequency of 3.55 GHz with a return loss of -20.8 dB, VSWR 1.2, a bandwidth of 123.3 MHz, and gain of 10.4 dB was carried out. However, in this study, the antenna arrangement has not been arranged in MIMO. Furthermore, in research [7], a rectangular array microstrip MIMO antenna has been designed with a 2x2 u slot at a frequency of 3.5 GHz for 5G with a bandwidth value of 188 MHz, minimum return loss -23.65 dB, gain 8.528 dB and mutual coupling -63.16 dB. However, in this study, the working frequency of the antenna still operates at one working frequency.

In research [8], the design and realization of a dual-band microstrip antenna using a u-shaped slot has been carried out to produce frequencies of 2.4 GHz and 3.6 GHz, each having VSWR values of 1.56 and 1.33, a bandwidth of 124 MHz and 125 MHz with unidirectional radiation pattern. However, in this study, the antenna only had one patch and was not applied to 5G.

Based on previous research that has been carried out, this study uses a frequency of 3.5 GHz referring to [6, 7], adopting a linear MIMO array form in [5] and replacing the center load of the patch using a U slot like [7, 8], as well as developing research [7] become MIMO 4×2. The purpose of adding the U slot is to increase the reflection coefficient while the array method is used to increase the gain. Furthermore, the U-slot and array method also serves to generate double frequencies [8].

2. RESEARCH METHOD

In the antenna design process, starting from determining the desired antenna working frequency, which is 3.5 GHz, determining the substrate to be used, namely epoxy FR-4 with a dielectric constant value of 4.3, a thickness of 1.6 mm and a loss tangent of 0.0265, the selection FR-4 epoxy substrate material aims to improve antenna performance.

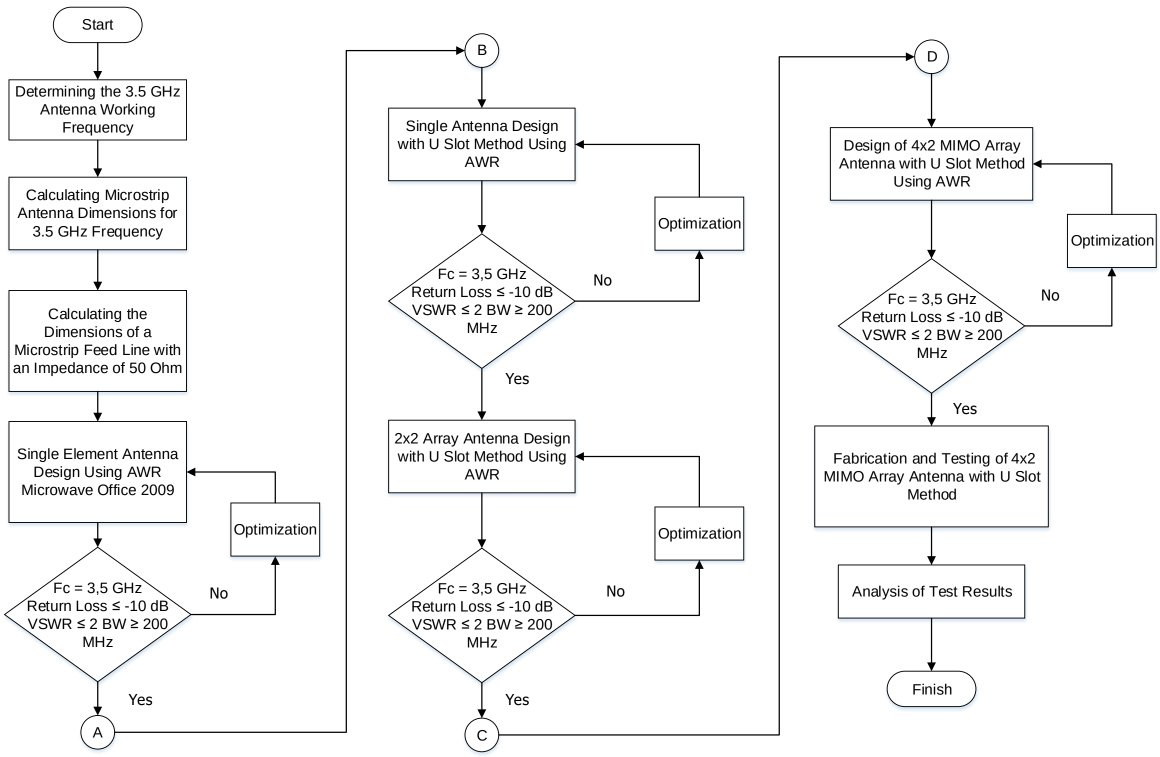


Figure 1. Design Flowchart

Figure 1 shows the antenna design process. Before the simulation process is carried out, first determine the dimensions of the antenna, namely patch dimensions, enclosure dimensions, and supply line dimensions. Next, perform a simulation of the antenna that has been designed using the software. In the simulation process it is possible to optimize several parameters by adjusting the dimensions of the antenna until it reaches the specified limit, namely return loss $\leq$ -10 dB, bandwidth $\geq$ 200 MHz, VSWR $\leq$ 2, gain $\geq$ 5 dB, directional radiation pattern, isolation loss $\leq$ -20 dB, envelope correlation coefficient $\leq$ 0.5 and diversity gain 10 [7]. From the simulation results that have been optimized, the antenna fabrication process can then be carried out. Fabrication is carried out to analyze whether the design is following the desired. After being fabricated, the antenna will be measured, analyzed, and compared with the simulation results. This analysis process is carried out to see the performance of the proposed antenna and its feasibility to be applied to 5G communication systems.

Antenna design begins with calculating the dimensions of a single-element antenna. Figure 2 shows the shape of the single-element design and the dimensions of the antenna can be calculated using equations (1) to (7) [9, 10].

$$W = \frac{c}{2f}\sqrt{\frac{\varepsilon_r + 1}{2}} \tag{1}$$

$$W/h > 1 \tag{2}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{w}\right)^{-\frac{1}{2}}$$

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}} \tag{3}$$

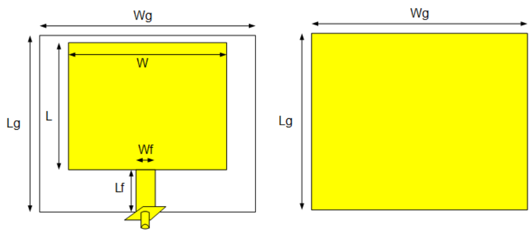
$$\Delta L = 0.412h\left(\frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} + 0.258}\right)\left(\frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.8}\right) \tag{4}$$

$$L = L_{eff} - 2\Delta L \tag{5}$$

$$Wg = 6h + W \tag{6}$$

$$Lg = 6h + L \tag{7}$$

W is antenna patch width in mm, *εreff* is effective dielectric constant, *Leff* is the effective length of patch antenna in mm, Δ*L* is patch length increase in mm, *h* is substrate thickness in mm, *f* is a frequency in Hz, *Wg* is enclosure width in mm, *Lg* is enclosure length mm, and *L* is antenna patch length in mm.



(a) (b)

Figure 2. Single Element Antenna Design; (a) Front View, (b) Back View

To get a higher bandwidth value, it is necessary to add a method to the antenna, namely the U slot method. Figure 3 shows the shape of the antenna design by adding a U-slot and the dimensions of the U-slot, it can be calculated using equations (8) to (13) [11, 12].

$$F = E = \frac{\lambda}{60} \tag{8}$$

$$C = 0.3 \times W \tag{9}$$

$$D = \frac{c}{f_{low}\sqrt{\varepsilon_{reff}}} - 2(L + \Delta L - F) \tag{10}$$

$$\varepsilon_{reff}(pp) = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{D - 2F}\right)^{-\frac{1}{2}} \tag{11}$$

$$2\boldsymbol{\Delta}_{L-E-H} = \frac{\left(\varepsilon_{reff}(pp) + 0{,}3\right)\left(\frac{D-2F}{h} + 0{,}264\right)}{\left(\varepsilon_{reff}(pp) - 0{,}258\right)\left(\frac{D-2F}{h} + 0{,}8\right)} \tag{12}$$

$$H \approx L - E + 2\boldsymbol{\Delta}_{L-E-H} - \frac{1}{\sqrt{\varepsilon_{reff}(pp)}}\left(\frac{C0}{fhigh} - (2C + D)\right) \tag{13}$$

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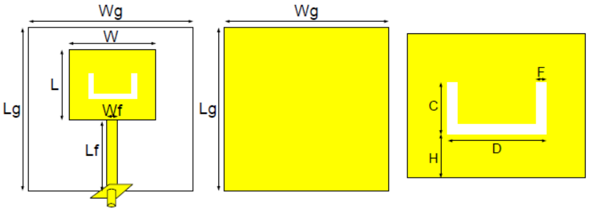
F/E is slot sleeve width in mm, *C* is vertical slot length in mm, *D* is horizontal slot length in mm, and *H* is slot distance from the base in mm.



(a) (b) (c)

Figure 3. Single Element Antenna Design with U Slot; (a) Front View, (b) Back View ; (c) U slots

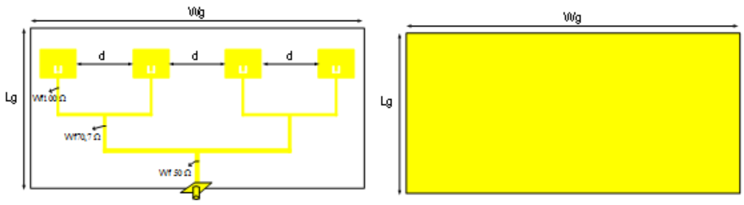
To increase the gain value, an antenna array technique can be used. The calculation of the array required calculations for the width of the feeder 50 Ω, 70,7 Ω, 100 Ω using equations (14) to (15) and the calculation of the distance between the radiating elements (patches) contained in equation (16) [4].

$$Wf = \frac{2h}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon r - 1}{2\varepsilon r}\left[\ln(B - 1) + 0{,}39 - \frac{0{,}61}{\varepsilon r}\right]\right\} \quad (14)$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon r}} \quad (15)$$

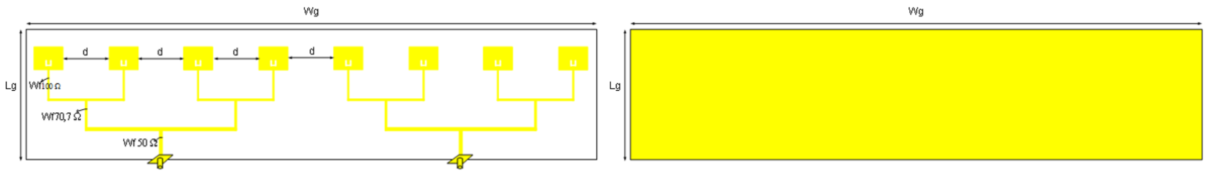
$$d = \frac{\lambda}{2} = \frac{c}{2f} \quad (16)$$

Wf is feed channel width in mm, *B* is microstrip feed line constant, *εr* is dielectric constant, and *d* is the distance between patch elements in mm.



(a) (b)

Figure 4. 2×2 U Slot Array Design; (a) Front View, (b) Back View



(a) (b)

Figure 5. Design of 4×2 U Slot MIMO Array Antenna; (a) Front View, (b) Back View

Based on the equations and the appropriate parameters the have been obtained, a 2×2 microstrip array antenna with the U slot method can be designed as shown in Figure 4, and to increase the bandwidth value and obtain a directional radiation pattern, the MIMO technique can be used. Figure 5 shows the design of the MIMO 4×2 Slot U, Array Antenna. Table 1 shows the dimensions of the designed antenna array and MIMO.

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Table 1. Dimensions of Array Antenna 2×2 U Slot

Parameter	Description	Dimension (mm)
W	Patch width	26
L	Patch length	20.5
Wg	Groundplane width	250
Lg	Groundplane length	120
Wf	Width of power supply line 50 Ω	2.1
Lf	Length of power supply line 50 Ω	28
D	Slot length	5.1
C	Slot width	4.8
E/F	Slot thickness	0.9
H	Slot distance from base	3.5
d	Distance between elements	43
$Wf_{70,7\Omega}$	Width of power supply line 70,7 Ω	1.1
$Lf_{70,7\Omega}$	Length of of power supply line 70,7 Ω	28
$Wf_{100\Omega}$	Width of power supply line 100 Ω	1
$Lf_{100\Omega}$	Length of of power supply line 100 Ω	28

3. RESULTS AND DISCUSSION

3.1. Simulation Results

The antenna design process is simulated using AWR Microwave Office 2009 software to see the results of the antenna parameters that have been designed. The comparison of return loss and bandwidth can be seen in Figure 6.

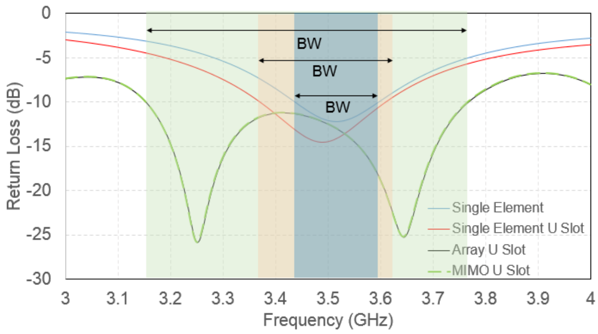

Figure 6. Comparison of Return Loss Simulation of Each Antenna

Figure 6 shows the comparison of the return loss and bandwidth of each antenna. It can be seen that the 4×2 slot U MIMO array antenna has a return loss value of -12.49 dB, a decrease compared to a single-element antenna. This decrease in return loss is due to the addition of patch elements, array methods, and MIMO so that power absorption is also better. For comparison of VSWR, results can be seen in Figure 7.

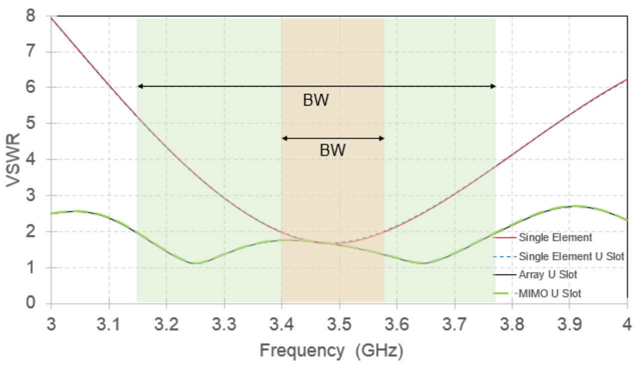

Figure 7. Comparison of the Overall Simulation VSWR of the Antenna

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Figure 7 shows the comparison of the VSWR values for each antenna. It can be seen that the MIMO 4×2 slot U antenna array has a VSWR value of 1.62, a decrease compared to a single-element antenna. The decrease in VSWR is due to the addition of patch elements, array methods, and MIMO so that power absorption is also better.

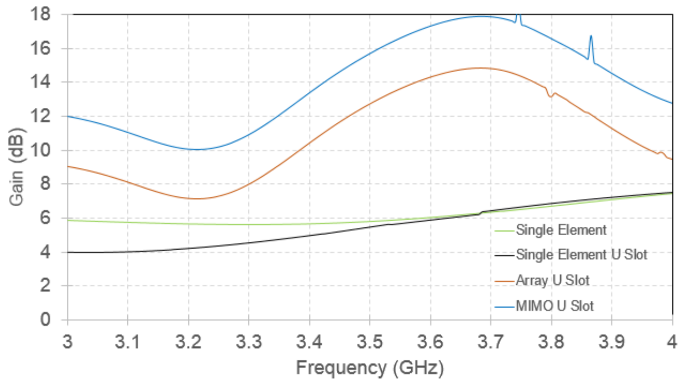


Figure 8. Comparison of Overall Antenna Simulation Gain

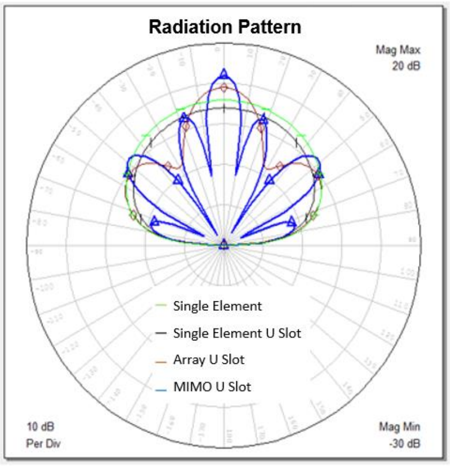
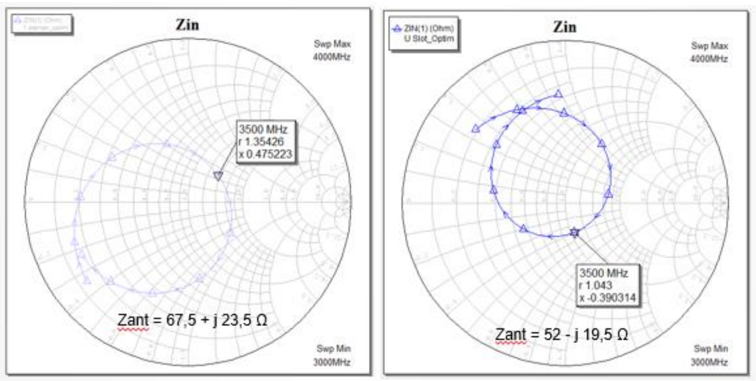


Figure 9. Comparison of Overall Antenna Simulation Radiation Patterns

Figure 8 shows the comparison of the overall gain value of the antenna. It can be seen that the overall gain value of the antenna increases and the MIMO 4×2 slot U antenna array has the highest gain value of 15.70 dB. Figure 9 shows the overall radiation pattern of the antenna. It can be seen that the antenna with a single element has a unidirectional radiation pattern and the addition of a patch using the array and MIMO method can produce a directional radiation pattern in which the beam becomes narrower. Figure 10 shows the overall impedance comparison of the antenna.



(a) (b)

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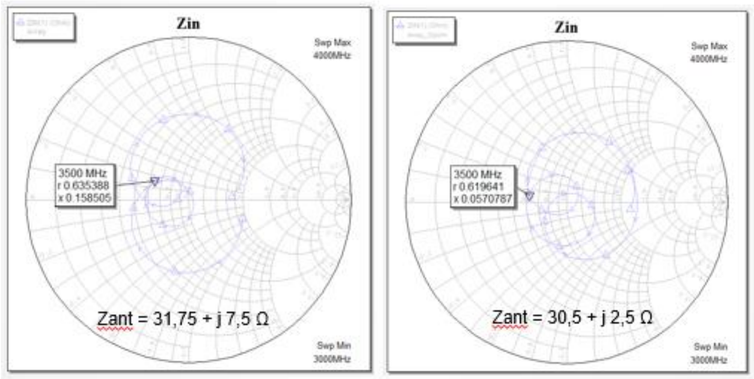

(c) (d)

Figure 10. Simulation Impedance Comparison of All Antennas; (a) Single Element Antenna, (b) Single Element U Slot Antenna, (c) 2×2 Array U Slot Antenna, (d) 4×2 MIMO Array U Slot Antenna

Figure 10 shows the overall impedance ratio of the antenna. The comparison value of the overall antenna parameters can be seen more clearly in Table 2.

Table 2. Comparison of Overall Antenna Simulation Parameters

Antenna	Parameter					
	Return loss (dB)	**Bandwidth (MHz)**	**VSWR**	**Gain (dB)**	**Impedance**	**Radiation Pattern**
Single Element	-12,15	155	1,65	5,82	67,5 + j 23,5 Ω	Unidirectional
Single Element U Slot	-14,48	235	1,68	5,48	52 - j 19,5 Ω	Unidirectional
2×2 Array U Slot	-12,50	3765 - 3155 = 610	1,62	12,75	31,75 + j 7,5 Ω	Directional
4×2 MIMO Array U Slot	-12,49	3765 - 3155 = 610	1,62	15,70	30,05 + j 2,5 Ω	Directional

From Table 2 it can be seen that the overall results of the antenna simulation parameters that have been designed have met the criteria, namely return loss ≤ -10 dB, bandwidth ≥ 200 MHz and VSWR ≤ 2.

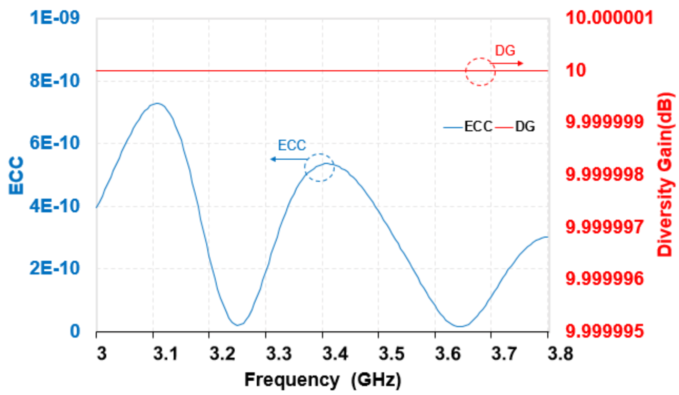

Figure 11. Envelope Correlation Coefficient (ECC) and Diversity Gain (DG) Simulation 4×2 MIMO Array U Slot *Antenna*

Figure 11 illustrates the value of the envelope correlation coefficient (ECC) and the diversity gain (DG) of the simulation results. It can be seen that the ECC value obtained is $3{,}85 \times 10^{-10}$ and the DG is 10 dB at a frequency of 3.5 GHz. From these two results, it can be stated that the antenna design has met the required ECC and DG limit values for MIMO antennas, namely the value of ECC < 0.5 and DG ≥ 10 dB.

After the results of the antenna simulation parameters match the desired criteria, the next step for the antenna can be the fabrication process.

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3.2. Antenna Fabrication Measurement Results

After obtaining the simulation and optimization results that match the criteria, then the fabrication process can be carried out and measurements of the antenna parameters of the fabricated results can be carried out. Fabrication is the process of realizing the simulation model into the original form of the antenna. The results of antenna fabrication will be measured using a Network Analyzer. In Figure 12, can be seen fabrication results of the 4×2 MIMO Array U Slot Antenna.

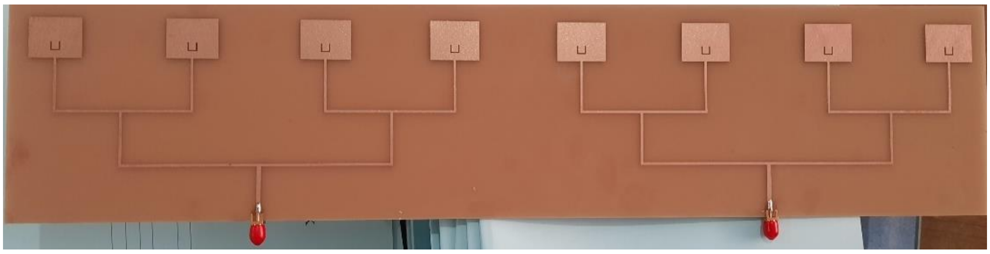
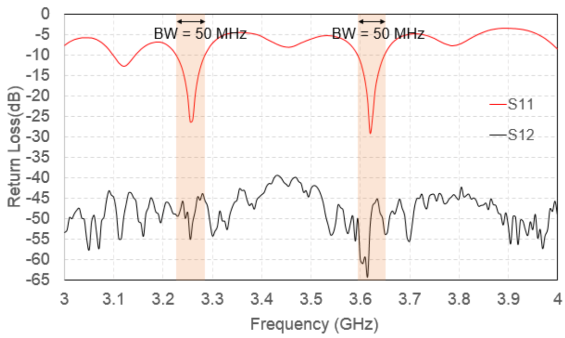
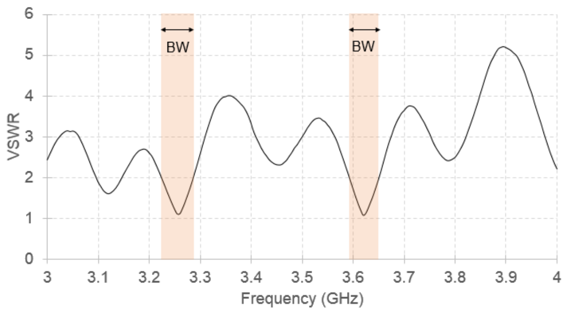


Figure 12. Fabrication Results of 4×2 MIMO Array U Slot Antenna

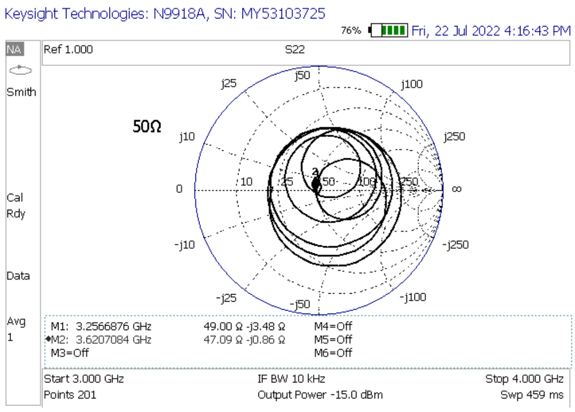
Measurement of the fabricated antenna obtained the parameters of return loss, bandwidth, VSWR, and impedance shown in Figure 13.



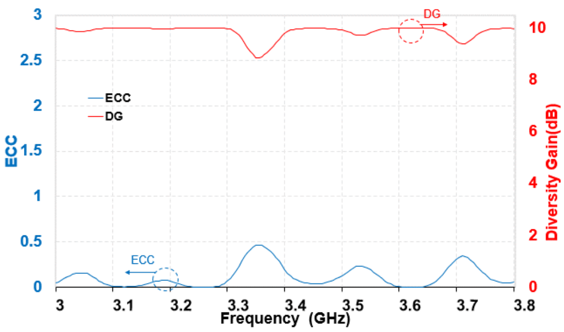
(a)



(b)



(c)



(d)

Figure 13. Parameters of 4×2 MIMO Array U Slot Antenna Fabrication; (a) Return loss, (b) VSWR, (c) Impedance, (d) Envelope Correlation Coefficient (ECC) and Diversity Gain (DG)

Figures 13 shows the results of measuring return loss, bandwidth, VSWR, impedance, envelope correlation coefficient (ECC), and diversity gain (DG) from 4×2 MIMO Array U Slot Antenna Fabrication. The results of the measurement of the return loss parameter (S11) of -6.03 dB, (S12) -42.78 dB, VSWR of 2.99, ECC of 0.12, and DG of 9.92 dB at a frequency of 3.5 GHz. Based on the measurement results of antenna fabrication, the parameters obtained at a frequency of 3.5 GHz do not match the desired criteria. This is caused by several factors including losses in connectors, soldering results, or poor dissolving of the antenna. However, it can be seen in Figures 12 to 15 that 2 valley points

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meet the desired antenna criteria, namely at a frequency of 3.26 GHz and 3.62 GHz. The results of the antenna parameters at the frequency of 3.26 GHz and 3.62 GHz will be described in Table 3.

Table 3. Measurement Results of 4×2 MIMO Array U Slot Antenna Fabrication at 3.26 GHz and 3.62 GHz

Parameter	Frequency	
	3,26 GHz	3,62 GHz
Return loss (S11)	-25,96 dB	-29,22 dB
Return loss (S12)	-50,90 dB	-51,78 dB
Bandwidth	50 MHz	50 MHz
VSWR	1,10	1,06
Impedance	49,00 – j0,48 Ω	47,09 – j0,86 Ω
ECC	$6{,}48 \times 10^{-6}$	$1{,}45 \times 10^{-6}$
DG	10 dB	10 dB

Table 3 shows the measurement of 4×2 MIMO Array U slot antenna fabrication at a frequency of 3.26 GHz and 3.62 GHz. It can be seen that 3.62 GHz frequency is the frequency that has the lowest value for return loss (S11) of -29.22 dB, (S12) -51.78 dB, VSWR of 1.06, an impedance of 47.09 - j 0.86 Ω, ECC of 1.45×10^{-6} and DG of 10 dB.

3.3. Analysis and Comparison of Antenna Parameters

Research [7] with a 2×2 MIMO array U slot antenna with a frequency of 3.5 GHz obtained the lowest return loss value (S11) -21.98 dB, (S12) -63.16 dB, Bandwidth 188 MHz, VSWR ≤ 2, ECC of 3.97 × 10-7 and a DG of 10 dB. Based on research simulation data using a 4×2 MIMO array U slot antenna, it shows an increase in the bandwidth value of 422 MHz and a return loss value of -25.01 dB when compared to the research results [7]. The increase in bandwidth and return loss is due to the addition of patch elements to the antenna so that power absorption is also better.

A Comparison of the results of simulation and fabrication studies of the 4×2 MIMO array U slot antenna shows slightly different results. The return loss value generated by the antenna fabrication is higher than the simulation results which causes the parameter value at a frequency of 3.5 GHz not to meet the antenna specifications. This is caused by several factors including losses in connectors, soldering results, or poor dissolving of the antenna. However, it can be seen at a frequency of 3.62 GHz that the antenna parameter values meet the criteria for return loss ≤ -10 dB, VSWR ≤ 2, gain ≥ 5 dB, directional radiation pattern, isolation loss ≤ -20 dB, envelope correlation coefficient ≤ 0.5 and diversity gain 10 dB.

A complete comparison of previous studies, simulation results, and fabrication studies of the 4×2 MIMO array U slot antenna is shown in Table 4.

Table 4. Comparison of Simulation Result Parameters and Antenna Fabrication

Parameter	2×2 MIMO Array Slot U [7]	Simulation	Fabrication	
Frequency	3.5 GHz	3.5 GHz	3.5 GHz	3.62 GHz
Return loss (S11)	-21.98 dB	-12.49 dB	-6.03 dB	-29.22 dB
Return loss (S12)	-63.16 dB	-88.17 dB	-42.78 dB	-51.78 dB
Bandwidth	188 MHz	610 MHz	-	50 MHz
VSWR	≤ 2	1.62	1,10	1.06
Impedance	-	31 + j 2.5 Ω	-	47,09 – j0,86 Ω
ECC	3.97×10^{-7}	3.85×10^{-10}	0.12	1.45×10^{-6}
DG	10 dB	10 dB	9.92 dB	10 dB

4. CONCLUSION

Based on the simulation, fabrication, and analysis results in this final project, it can be concluded that the design and simulation of the MIMO linear microstrip antenna array at a frequency of 3.5 GHz for 5G technology have successfully met the desired specifications for 5G technology with a return loss of -12.49 dB, a bandwidth of 610 MHz, VSWR of 1.62, a gain of 15.70 dB, an envelope correlation coefficient of 3.85×10^{-10} and diversity gain of 10 dB at a frequency of 3.5 GHz. Giving slots and increasing the number of patches has the effect of forming two resonant frequencies and forming a

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directional radiation pattern. From the results of the fabrication of the MIMO linear array antenna with a U slot at a frequency of 3.5 GHz, it has not met the desired specifications with a return loss of -6.03 dB and a VSWR of 2.99. However, two working frequencies meet the desired specifications for 5G technology, namely at frequencies of 3.2 GHz and 3.62 GHz with each return loss value (S11) of -25.96 dB and -29.22 dB, (S12) of -48.61 dB and -51.78 dB, a bandwidth of 50 MHz. The independence of each antenna is indicated by the envelope correlation coefficient of 6.48×10^{-6} and 1.5×10^{-6}, and a diversity gain of 10 dB.

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