SIMULATION ANALYSIS OF MICROSTRIP ANTENNA MIMO 4X4 PATCH CIRCULAR 3.5 GHZ

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ABSTRACT
MIMO 4x4 circular patch array antena design for 5G Cellular Communication Technology using CST Studio Suite 2019 software to obtain an antena that can work at a frequency of 3.5 GHz. This antena has a circular patch shape with a proximity coupled supply method and uses a 4x4 MIMO system with tiered impedance arranged using the array method. The material used to design this antena is an FR-4 Epoxy substrate with a dielectric constant (εr) of 4.3 with a thickness (h) of 1.6 mm. The antena will be analyzed starting from a single patch, two patches, four patches and MIMO 4x4 array patch. The parameter specifications used are return loss with a value of ≤ -10 dB, VSWR ≤ 2 dB. The design results on the 4x4 MIMO antena that have obtained the return loss value of Port 1 -21.8202 dB, Port 2 is -21.8180 dB, Port 3 is -21.8172 dB, Port 4 is -21.8212 dB, VSWR values on ports 1, 2, 3 and 4 show the number 1.176 getting the same value, Gain Port 1 is 9.321 dB, Port 2 is 9.356 dB, Port 4 is 9.356 dB, and Port 4 is 9.321 dB, and the radiation pattern is directional. The antena design has a patch radius of 10.4 mm with a total antena dimension of 1080 x 101.76 x 3.305 $mm3$. The design results are in accordance with the initial specifications, so that the MIMO 4x4 circular patch antena can be realized at a frequency of 3.5 GHz.
Keywords: *CST Studio Suite Gain, MIMO, Return Loss VSWR, 3.5 GHz.*

INTRODUCTION

Communication technology is developing rapidly day by day, where the development of this communication technology is not only in terms of its devices but also in terms of the connecting network between communications, an example of a network is 4G which at that time in 2009 this network could cover internet speeds exceeding 3G, namely 500x faster and can even use VoLTE (Voice over LTE), but this technology has also developed along with the times and has given birth to the latest generation, namely 5G [1]. The Ministry of Communication and Digital (KOMDIGI) has stated that the 3.5 GHz frequency spectrum is ideal for the needs of 5G technology in Indonesia, and the International Telecommunication Union - Radiocommunication (ITU-R) has provided general 5G specification requirements, especially for bandwidth that can reach at least 100 MHz. With a high working frequency, it can produce large bandwidth. With this high frequency, a microstrip antenna is needed and with a Multiple Input Multiple Output (MIMO) system arrangement in order to provide wide transmission bandwidth. [2]

MIMO is a technology that uses more than one antenna on both the transmitter and receiver to coherently analyze more information than using a single 2 antennas [3].

Although it has many advantages, microstrip antennas also have several disadvantages, namely narrow bandwidth, small gain and directivity, and low efficiency [5]. There are many ways to overcome the disadvantages of this microstrip antenna. Starting from changing the dielectric constant of the substrate, changing the design and adding its field (patch) on the substrate so that it forms an array.

Therefore, this study was conducted with the title "SIMULATION ANALYSIS OF MICROSTRIP ANTENNA MIMO 4x4 PATCH CIRCULAR 3.5 GHz", to determine the parameter values that produce better Return Loss, Input Impedance, VSWR, and Gain values for use.

METHOD

In In this study, a 4x4 MIMO antenna with a circular patch consisting of 4 elements arranged in an array and utilizing the Proximity Coupling technique was designed. The initial stage of antenna design includes calculating the dimensions needed for the antenna design process. The frequency used in this study is 3.5 GHz.

RESULT AND DISCUSSION

Simulation Results of Single Patch Antenna Based on Calculations

In the first simulation, the single patch antenna is simulated using the dimensions obtained from the calculations. The design of this antenna can be seen in the image below.

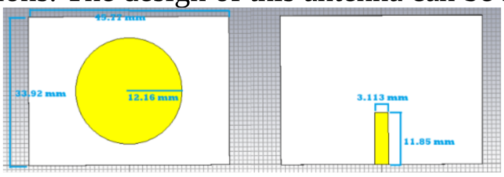

Figure 1. Single Patch Antenna (a) Front View (b) Rear View

Table 1. Circular Patch Antenna Dimensions

Parameter	Symbol	Initial Size (mm)	Parameter	Symbol	Initial Size (mm)
Ground Plane Width	wg	45.77	50 Ω Coupling Length	lf	11.85
Ground Plane Length	lg	33.92	Substrate Thickness	h	1.6
Patch Radius	a	12.16	Copper Thickness	t	0.035
50 Ω Coupling Width	wf	3.113			

The antenna with dimensions that have been calculated in advance in Table 3, then simulated using CST Studio Suite 2019 software. The value obtained in the initial simulation before optimization obtained a return loss value of -2.9695, so to get more appropriate results, optimization will be carried out on the size of the patch radius dimensions.

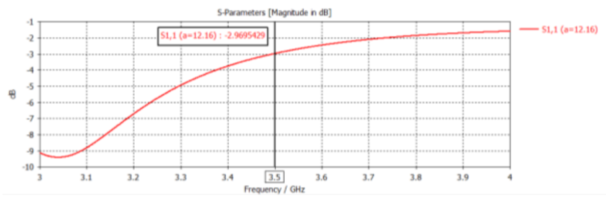

Figure 2. Frequency and Return Loss of Single Patch Based on Calculations

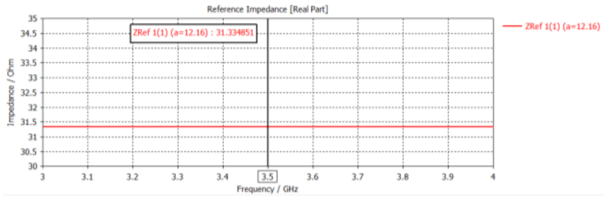

Figure 3. Input Impedance of Single Patch Based on Calculations

Figure 3 shows that the calculated channel impedance value is 31.3348 Ω. This value does not meet the antenna parameter requirement, which is expected to be 50 Ω.

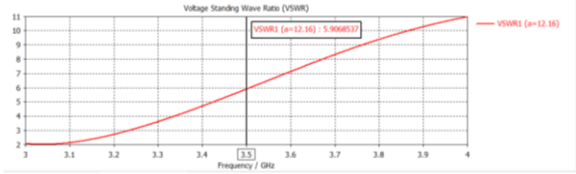

Figure 4. VSWR of Single Patch Based on Calculations

Figure 4 shows that the VSWR value for the single-element antenna based on calculations for a frequency of 3.5 GHz is 5.9068. This value meets the antenna parameter requirement of VSWR ≤ 2.

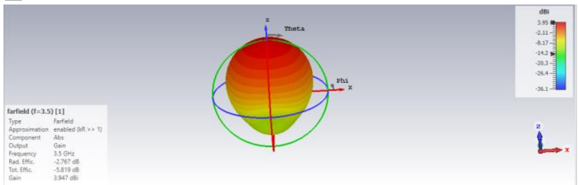

Figure 5. Gain Single Patch based on Calculation

The gain results for the single patch antenna based on simulation can be seen in Figure 5, with a value of 3.947 dBi. This result result has meet the antenna gain parameter, which is expected to be > 2 dBi.

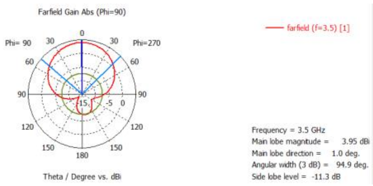

Figure 6. Radiation Pattern of Single Patch Based on Calculations

For this antenna, it can be observed that the values for frequency, input impedance, and gain do not meet the specified parameters, indicating a need for optimization.

Results of Single Patch Antenna Simulation Based on Optimization

Optimization is performed based on variations in the patch radius, including sizes of 12.16 mm, 13 mm, 11mm, 10mm, and 10.4mm, to determine the effect of the patch radius on frequency. Variants for the 50 Ω Width (wf) used are 3.113 mm, 3.55 mm, 2.65 mm, 2.2 mm, 1.75 mm, and 1.3 mm. Variants for the 50 Ω Length (lf) used are 11.85 mm, 11.82 mm, 12.82 mm, and 10.82 mm.

Table 2. Optimazation Dimensions of Single Patch Antenna

Parameter	Symbol	Value (mm)	Parameter	Symbol	Value (mm)
Ground Plane Width	wg	45.77	50 Ω Coupling Length	lf	10.82
Ground Plane Length	lg	33.92	Substrate Thickness	h	1.6
Patch Radius	a	10.4	Copper Thickness	t	0.035
50 Ω Coupling Width	wf	1.3			

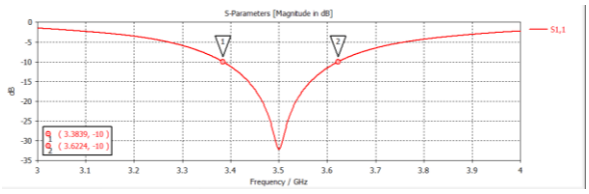

Figure 7. Return Loss Results of Single Patch After Optimization

$f_c = \frac{f_2+f_1}{2} = \frac{3.6224+3.3839}{2} = 3.503$ GHz

$BW = f_2 - f_1 = 3.6224 - 3.3839 = 0.2385$ GHz = 238.5 MHz

In Figure 11, it can be observed that the return loss result of the single patch antenna after optimization at a frequency of 3.5 GHz is -32.1898 dB. The frequency and return loss results meet the specifications of the antenna design, which are 3.5 GHz and ≤ -10 dB. The generated bandwidth is 238.5MHz.

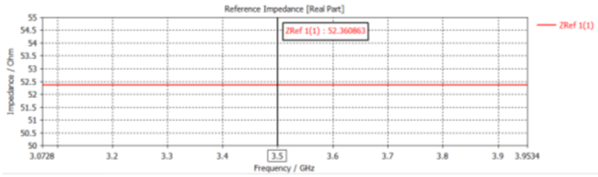

Figure 8. Input Impedance Results of Single Patch After Optimization

In Figure 8, the input impedance value of the single circular element antenna after optimization indicates a value of 52.3608 Ω. This input impedance result meets the parameter requirement of the antenna design, which is ≥50 Ω.

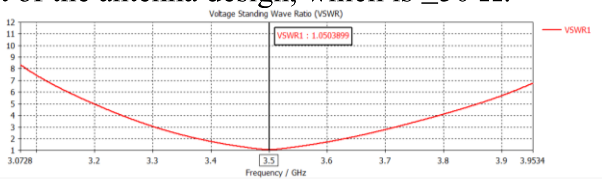

Figure 9. VSWR Results of Single Patch After Optimization

Figure 9 displays the VSWR value of the single circular element antenna after optimization, showing a value of 1.050. A VSWR value approaching 1 indicates better performance.

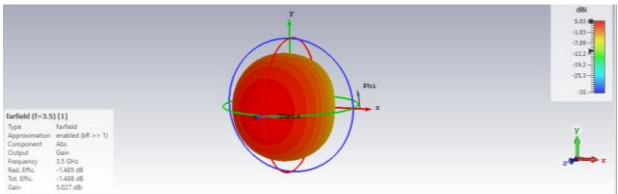

Figure 10. Gain Results of Single Patch After Optimization

The antenna gain results based on IEEE Gain from CST Studio Suite software for one circular element can be seen in Figure 4.17, with a value of 5.027 dBi. These results have met the antenna gain parameters, that is >2 dBi.

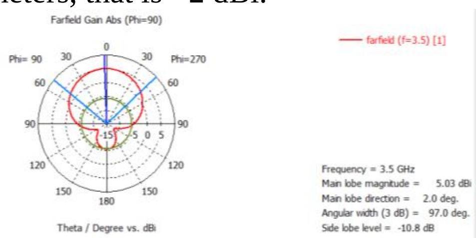

Figure 11. Radiation Pattern Results After Optimization

The simulation results in Figure 15 for the single patch show an Angular width of 97.0 degrees and a side lobe level of -10.8 dB. The radiation pattern of the optimized single-element circular microstrip antenna indicates an omnidirectional pattern in elevation.

Table 3. Comparison Results of Single Patch Antenna Between Calculation and Optimization

	Frequency (MHz)	Return Loss(dB)	Input Impedance	VSWR	Gain(dBi)	Bandwidth
Calculation	3500	-2.9695	31.3348	5.9068	3.947	-
Optimization	3500	-32.1898	52.3608	1.050	5.027	238.5 MHz

Simulation of 2-Patch Antenna

In this two-patch antenna simulation, a single patch antenna is enhance with an array method on the power divider channel, where the function of adding an array method to this antenna can increase the gain value because the number of patches increases in receiving and emitting electromagnetic power and by considering the distance between patches because it can affect the patch that radiates electromagnetic waves. This 2-patch antenna simulation has also implemented the proximity coupled supply method because the use of this supply can increase the bandwidth width on an antenna.

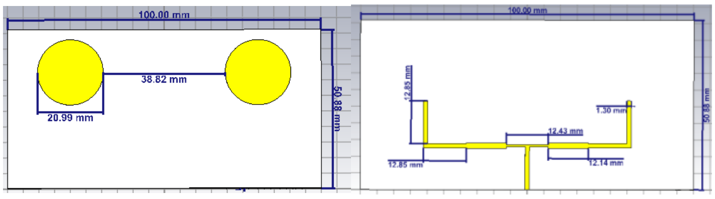

Figure 12. Two Patch Antenna (a) Front View (b) Rear View

After optimizing the single circular patch antenna, a two-element antenna can be designed. A T-junction is used with impedances of 50 Ω, 70 Ω, and 100 Ω. The T-junction is employed to support impedance matching on the transmission line. The following table shows the parameters of the two-patch antenna for simulation.

Table 4. Two-Patch Antenna Parameters

Description	Symbol	Initial Value (mm)	Optimized Value (mm)	Description	Symbol	Initial Value (mm)	Optimized Value (mm)
Grounplane width	wg	45.77	100	Length 50 Ω	lf50	11.85	12.85
Groundplane length	lg	33.92	50.88	Length 70 Ω	lf70	12.14	12.14
Patch radius	a	10.4	10.495	Length 100 Ω	lf100	12.43	12.43
Width 50 Ω	wf50	1.3	1.3	Substrate thickness	h	1.6	1.6
Width 70 Ω	wf70	1.632	1.632	Cooper thickness	t	0.035	0.035
Width 100 Ω	wf100	0.64	0.64				

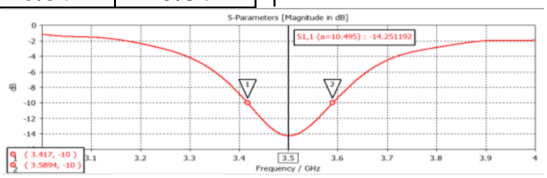

Figure 13. Return Loss Results of Two-Patch Antenna

$f_c = \frac{f_2+f_1}{2} = \frac{3.5894+3.417}{2} = 3.5002$ GHz
$BW = f_2 - f_1 = 3.5894 - 3.417 = 0.1724$ GHz = 172.4 MHz

Figure 13 shows that the return loss results for the two-patch antenna after simulation meet the antenna parameter requirements, with a frequency of 3.5 GHz and a value less than -10 dB, measuring -14.2511. The bandwidth produced is 172.4 MHz.

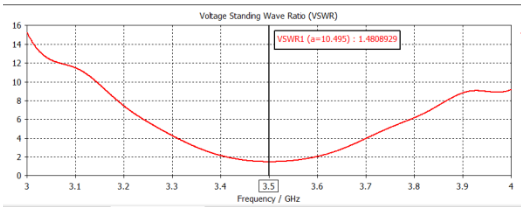

Figure 14. VSWR Results of Two-Patch Antenna

Figure 14 illustrates the VSWR values for the two-element circular antenna after optimization, measuring 1.4808, in accordance with the desired specifications.

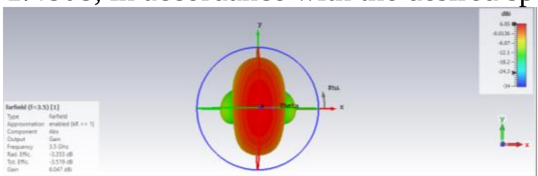

Figure 15. Gain Results of Two-Patch Antenna

In Figure 15, the gain results for the two-patch antenna, based on IEEE Gain from CST Studio Suite software, are shown with a value of 6.047 dBi. It can be observed that the gain experiences a significant increase due to the addition of patch elements.

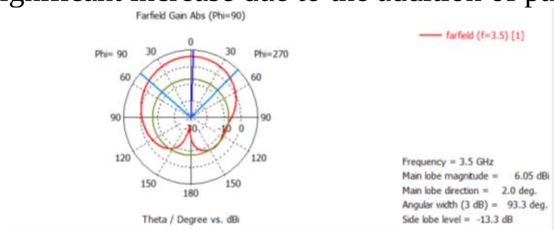

Figure 16. Radiation Paattern of Two-Patch Antenna

Figure 16 displays the radiation pattern of the optimized two-patch circular microstrip antenna, revealing an angular width of 93.3 degrees and a side lobe level of -13.3 dB. The radiation pattern remains directional in elevation.

Table 5. Parameter Results of Two-Patch Circular Microstrip Antenna

Parameter	Results	Parameter	Results
Return Loss (dB)	-14.511	Frequency (GHz)	3.5
Saluran Impedansi (Ω)	52.3382	Bandwidth (MHz)	172.4
VSWR	1.4808	Radiation Pattern	Directional
Gain (IEEE) (dBi)	6.047		

The array method has demonstrated significantly improved results, and the use of graded impedance in this array method facilitates obtaining and adjusting the desired values. This ensures that the transmission line in the designed antenna experiences matched conditions and maximizes the power obtained from the source to the load.

Four-Patch Antenna Simulation

The four-patch array antenna is directly simulated using the optimized calculations from the previous two-patch array antenna. The design is illustrated in Figure 21 below.

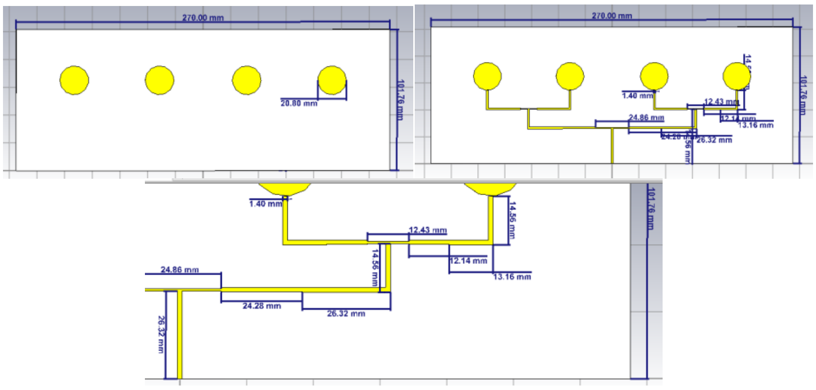

Figure 17. Four Patches (a) Front View (b) Rear View (c) A large view inside

Table 6. Antenna Parameter of Four-Patch Antenna

Description	Symbol	Initial Value (mm)	Optimized Value (mm)	Description	Symbol	Initial Value (mm)	Optimized Value (mm)
Grounplane width	wg	100	270	Length 50 Ω	lf50	12.85	13.16
Groundplane length	lg	50.88	101.76	Length 70 Ω	lf70	12.14	12.14
Patch radius	a	10.495	10.4	Length 100 Ω	lf100	12.43	12.43
Width 50 Ω	wf50	1.3	1.4	Substrate thickness	h	1.6	1.6
Widht70 Ω	wf70	1.632	1.2	Cooper thickness	t	0.035	0.035
Width 100 Ω	wf100	0.64	0.64				

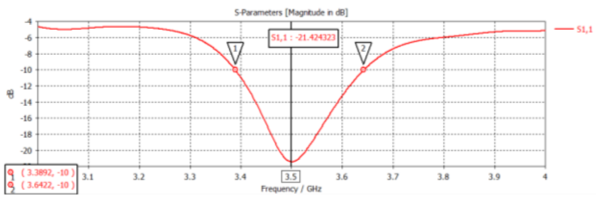

Figure 18. Frequency and Return Loss Results for Four Patches

$f_c = \frac{f_2+f_1}{2} = \frac{3.6422+3.3892}{2} = 3.515$ GHz

$BW = f_2 - f_1 = 3.6422 - 3.3892 = 0.253$ GHz = 253 MHz

Figure 18 shows that the return loss of the four-patch antenna after simulation is -21.4243 dB. The bandwidth generated is 253 MHz.

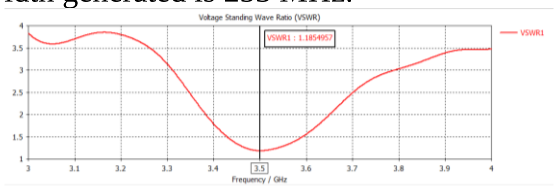

Figure 19. VSWR Results for Four Patches

Figure 19 shows that the VSWR value for the four-element circular antenna after optimization is 1.1854.

This VSWR result meets the design parameter requirement of < 2.

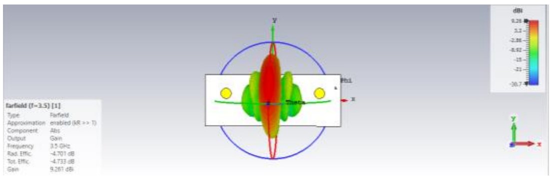

Figure 20. Gain Results for Four Patches

In Figure 20, the gain value is 9.261 dBi. The gain value has increased due to changes in the amplitude width of the wave and the center frequency shift to match the set frequency of 3500 MHz. This change is influenced by the optimized gain value, resulting in a gain increase of 3.214 dB compared to the two-patch antenna.

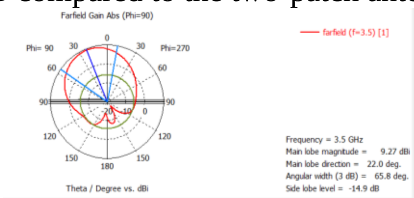

Figure 21. Radiation Pattern Results for Four Patches

In the polarization of the 4 patch array antenna, it produces an omnidirectional polarization form with an angular width value of 65.8 deg, and a side lobe level value of -14.9 dB. that the radiation pattern produced by elevation is directional, where the beam is focused in one direction, which is at an angle of 30 degrees.

Table 7. Four-Patch Antenna Parameter Results

Parameter	Results
Return Loss (dB)	-21.4243
Impedance (Ω)	50.4194
VSWR	1.1854
Gain (IEEE) (dBi)	9.261
Frequency (GHz)	3.4
Bandwidth (MHz)	253
Radiation Pattern	Directional

In this stage, the simulation of the MIMO 2x2 array patch antenna will be performed. This antenna is designed by duplicating, in parallel, the optimized 4-patch array antenna. The duplication of this MIMO antenna does not need to be optimized as it already meets the specifications due to the assistance of the array method in power distribution among each patch.

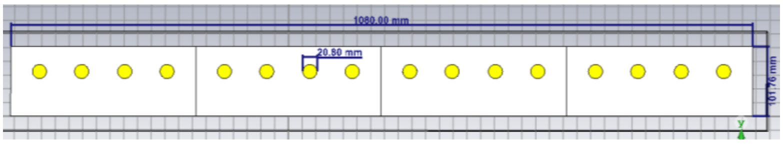

Figure 22. MIMO 4x4 Front View

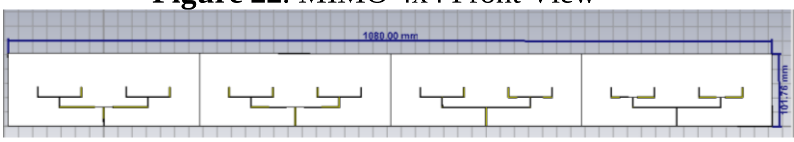

Figure 23. MIMO 4x4 Rear View

Figures 22 and 23 represent the design of the MIMO 4x4 antenna that will be simulated. Then, Figures 28, 29, 30, and 31 below show the simulation results for antenna parameters, specifically the return loss.

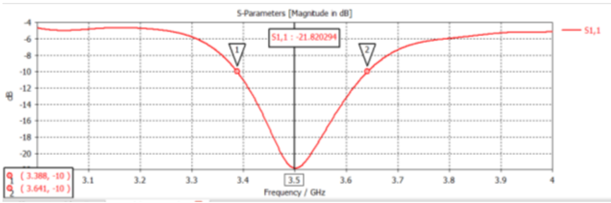

Figure 24. Frequency and Return Loss Results of MIMO 4x4 Array Patch Antenna for Port 1

$f_c = \frac{f_2+f_1}{2} = \frac{3.641+3.388}{2} = 3.514$ GHz

$BW = f_2 - f_1 = 3.641 - 3.388 = 0.253\ GHz = 253\ MHz$

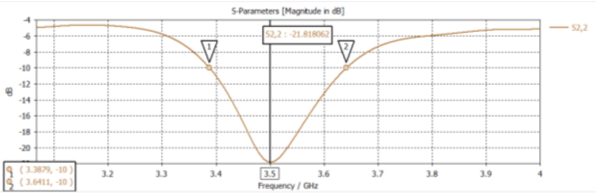

Figure 25. Frequency and Return Loss Results of MIMO 4x4 Array Patch Antenna for Port 2

$f_c = \frac{f_2+f_1}{2} = \frac{3.6411+3.3879}{2} = 3.514$ GHz

$BW = f_2 - f_1 = 3.6411 - 3.3879 = 0.253$ GHz = 253 MHz

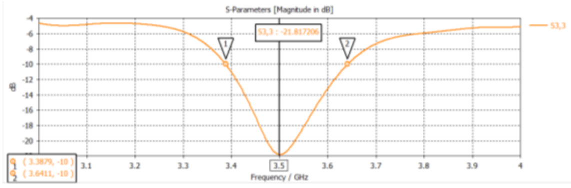

Figure 26. Frequency and Return Loss Results of MIMO 4x4 Array Patch Antenna for Port 3

$f_c = \frac{f_2+f_1}{2} = \frac{3.6411+3.3879}{2} = 3.514$ GHz

$BW = f_2 - f_1 = 3.6411 - 3.3879 = 0.253$ GHz = 253 MHz

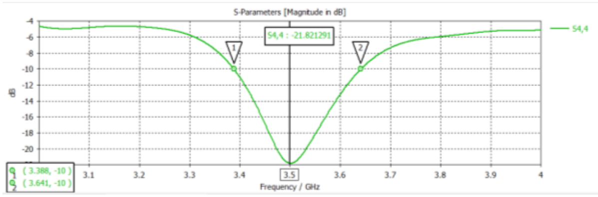

Figure 27. Frequency and Return Loss Results of MIMO 4x4 Array Patch Antenna for Port 4

$f_c = \frac{f_2+f_1}{2} = \frac{3.641+3.388}{2} = 3.514$ GHz

$BW = f_2 - f_1 = 3.641 - 3.388 = 0.253$ GHz = 253 MHz

Figures 28, 29, 30, and 31 shows that the return loss results of the 4x4 MIMO antenna after simulation. The frequency and return loss results are in accordance with the antenna parameter requirements, namely 3.5 GHz less than -10 dB with a Port 1 value of -21.8202 dB, Port 2 of -21.8180 dB, Port 3 of -21.8172 dB, Port 4 of -21.8212 dB. The resulting bandwidth is 253 MHz.

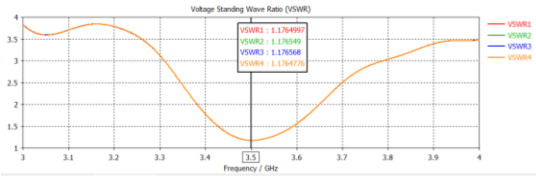

Figure 28. VSWR Results of MIMO 4x4 Array Patch Antenna for Ports 1, 2, 3, and 4

Figure 32 the VSWR value of the MIMO 4x4 array patch antenna on ports 1, 2, 3 and 4 shows a figure of 1.176. The VSWR results have met the requirements of the antenna design parameters, namely <2.

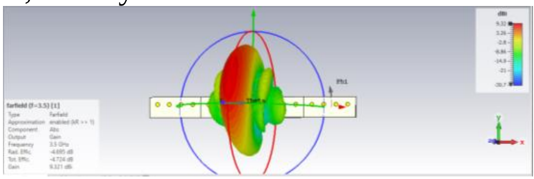

Figure 29. Gain Results of MIMO 4x4 Array Patch Antenna for Port 1

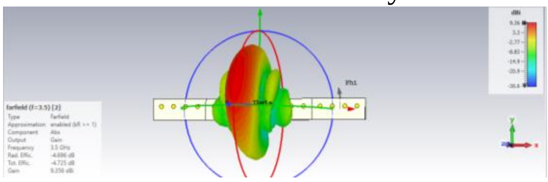

Figure 30. Gain Results of MIMO 4x4 Array Patch Antenna for Port 2

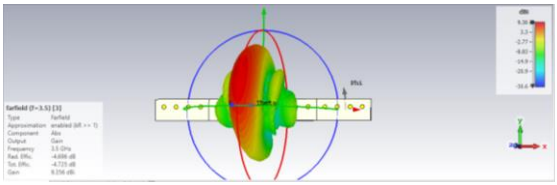

Figure 31. Gain Results of MIMO 4x4 Array Patch Antenna for Port 3

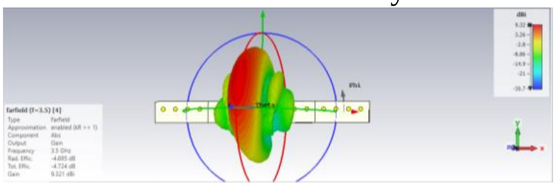

Figure 32. Gain Results of MIMO 4x4 Array Patch Antenna for Port 4

Figures 33, 34, 35, and 36 shows the gain value on the antenna for port 1 shows the same value, namely 9.321 dB, port 2 is 9.356 dB, port 3 is 9.356 dB, port 4 is 9.321 dB. This gain value is greatly influenced by the addition of a fairly optimal number of patches and power dividers, so that there is no overlap or uneven power distribution and can reach the appropriate position when performing the optimization analysis.

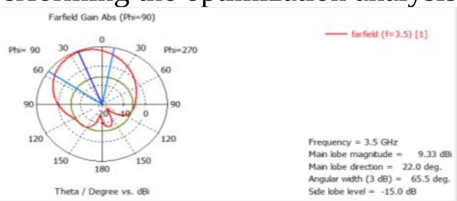

Figure 35. Radiation Pattern Results of MIMO 4x4 Array Patch Antenna

In this MIMO 4x4 patch array antenna polarization produces a unidirectional polarization form with an angular width value of 65.5 deg, a side lobe level value of -15.0 dB.

Table 8. MIMO 2x2 Patch Antenna Parameter Results

Parameter	Result			
	Port 1	Port 2	Port 3	Port 4
Return Loss (dB)	-21.8202	-21.8180	-21.8172	-21.8212
Impedance Input (Ω)	50.4036	50.4036	50.4036	50.4036
VSWR	1.1764	1.1765	1.1765	1.1764
Gain (IEEE) (dBi)	9.321	9.356	9.356	9.321
Frequency (GHz)	3.5	3.5	3.5	3.5
Bandwidth (MHz)	253	253	253	253
Radiation Pattern	*Directional*	*Directional*	*Directional*	*Directional*

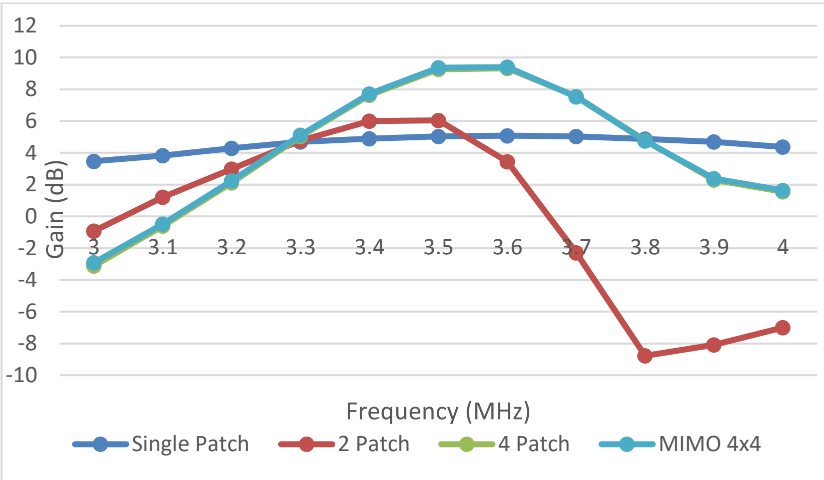

Figure 36. Gain Comparison Chart of Single Patch, 2 Patch, 4 Patch and MIMO 4x4

Table 9. Comparison Parameter Results of Gain against Patch Antenna

Antenna	Frequency Bandwidth	Gain (3.5 GHz)
Single Patch	3 – 4 GHz	5.027 dB
2 Patch	3 – 4 GHz	6.047 dB
4 Patch	3 – 4 GHz	9.261 dB
MIMO 4x4	3 – 4 GHz	9.356 dB

From Figure 38 and Table 11 shows the results of the most optimal design comparison in each configuration, can be seen from the Gain on the Single Patch, 2 Patch, 4 Patch and MIMO 4x4 antennas. This shows that the antenna performance is getting better as the number of Patches increases.

CONCLUSION

Simulation of a 3.5 GHz circular MIMO 4x4 patch microstrip antenna arranged in an array with proximity coupled feeding technique for 5G cellular communication was designed and simulated using CST Studio Suite 2019 software. The obtained values met the specifications and were successful.

Based on the results of the optimization design on the antenna with a frequency of 3.5 GHz which has a return loss value = Port 1 of -21.8202 dB, Port 2 of -21.8180 dB, Port 3 of -21.8172 dB, Port 4 of -21.8212 dB, VSWR values on ports 1, 2, 3 and 4 show the number 1.176 getting the same value, Gain Port 1 of 9.321 dB, Port 2 of 9.356 dB, Port 3 of 9.356 dB, and Port 4 of 9.321 dB, and the radiation pattern is in the form of Directional. The increase in gain value is caused by the addition of the number of patches on each antenna designed, then changes in the dimensions of the patch affect significant changes in the desired frequency value, and the use of the array method with tiered impedance makes it easier to optimize quickly to get the desired parameters.

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