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Multiple Input Multiple Output Antenna (MIMO) Ultra-Wideband Antenna With Dual Band Notched And Low Mutual Coupling Value

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***Abstract*— MIMO UWB antennas have become an attractive research subject in an effort to improve the performance of wireless networks. With its ability to transfer data at high speed in the ultra-wideband frequency spectrum, the MIMO UWB antenna promises to increase capacity, speed, and robustness against interference in wireless networks. This study presents the design, analysis, and fabrication of a MIMO UWB antenna developed for wireless network applications. Various optimization techniques are used in antenna design to improve radiation efficiency, reduce interference, and extend the coverage of the frequencies used. One of the benefits of UWB MIMO is interference rejection which can cancel the most dominant and unwanted wavefront impinging on the antenna. The most dominant interference in wireless communication standards are Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX). Therefore, designing a MIMO UWB antenna system that has low mutual coupling is a challenge especially coupled with the ability for WLAN and WiMAX band rejection. In this study, it was designed by modifying the MIMO UWB antenna using FR-4 substrate material with dielectric constant (εr) 4.4, loss tangent 0.035 and material thickness 1.6 mm. The results obtained are working frequencies of 2.8 - 12 GHz with dual band-notched 3.5 - 4.2 GHz and 5 - 5.9 GHz which can be used for Ultra Wideband (UWB) communications that have low mutual coupling.**

***Keywords*— Band-Notched, Multiple-Input-Multiple-Output (MIMO), Ultra-Wideband (UWB).**

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I. INTRODUCTION

In this modern era, technology has undergone many developments. This technology must provide better services, especially higher data rates so that the types of services offered are better and varied. With increasing consumer demand for network access performance in terms of higher capacity to faster services, even more secure wireless connections. So an antenna device that meets several communication standards is needed, one of which is wireless communication.

In wireless communication systems, signal propagation between transmitters and receivers passes through various different paths (Maddanaca, 2017). With the existence of different trajectories the signal traversed experiences multipath fading. To overcome this weakness, Multiple Input Multiple Output (MIMO) technology is present. MIMO is a system that uses multiple antennas on the transmitter and receiver sides (Sianipar, 2018). MIMO antennas are designed to meet the requirements of large data rates without additional transmit power and frequency spectrum in dense scattering areas with different separation techniques to improve isolation and polarization matching while minimizing channel noise and multipath fading (Liu, 2017).

MIMO antenna parameters are obtained from international standards such as the Federal Communications Commission (FCC) and the Institute of Electrical and Electronics Engineers (IEEE) which issue antenna-related standards for various applications, including IEEE 802.11 for wireless networking (Wi-Fi) technology but need to be customized based on the project. In its implementation, the band-notched MIMO antenna is designed for UWB technology. UWB technology has advantages such as low cost and high data rate. The frequency range spectrum of UWB antennas ranges from 3.1 - 10.6 GHz. UWB MIMO systems are designed for wireless communication spectra such as 3.3 - 3.8 GHz (WiMAX), INSAT operating between 4.5 - 4.8 GHz, WLAN systems (5.2 - 5.8 GHz), and 7.1 - 7.9 GHz (X band) which cause electromagnetic interference. To be immune from interference or other system noise, commercial UWB operates at very low spectral power levels. Therefore, the signal to noise ratio (SNR) at the receiver is very low and the performance of the UWB system will deteriorate. Research shows that the application of MIMO techniques can improve UWB system reliability and channel capacity.

Many isolation techniques are introduced in the literature to improve the isolation between the ports of two antenna elements and the notched band. Among them, open stubs are integrated into the patch to obtain band rejection at 4.9-6 GHz. Then H-pattern slots are added to the ground to lower the mutual coupling to <-20 dB at frequencies of 2.9-11.8 GHz. The MIMO antenna is designed using two square monopole antennas with a Ground slot to produce more than 30 dB isolation. U and L structured slots are used to achieve band elimination at frequencies of 3.3-3.8 GHz (Burhan A., 2018). In MIMO antennas with dual-notch bands are designed by arranging two circular patches orthogonally with two L-pattern slots embedded in them. Therefore in recent years, researchers have focused on introducing band-notched characteristics in UWB-MIMO antenna design (Shah, 2021). The use of slots, stubs or strips to achieve band-notched characteristics can produce effects on the isolation level.

In this research, an Ultra-Wideband (UWB) Multiple Input Multiple Output (MIMO) antenna with dual band notched and low mutual coupling is designed for high bandwidth data transmission over a very wide frequency range from 3.1 - 10.6 GHz with low noise, multiple transmitters and receivers can transfer more data simultaneously which is the result of the development of a journal entitled "Design of Ultra-Wideband MIMO Antenna with Dual Band Elimination Characteristics and Low Mutual Coupling". The form of development carried out is in the form of optimization and also changes in the shape of the stub which was originally an F stub to a T stub in order to get better parameter results. The antenna design and simulation were made using CST Studio Suite 2019.

II. METHOD

A. Page Layout

Antenna design aims to get the desired antenna design. With the design process, it can make it easier to get better design results. As for the design of the antenna design in the final project, the author uses CST Suite Studio 2019 software. The flowchart in the antenna design can be seen in Figure 1.

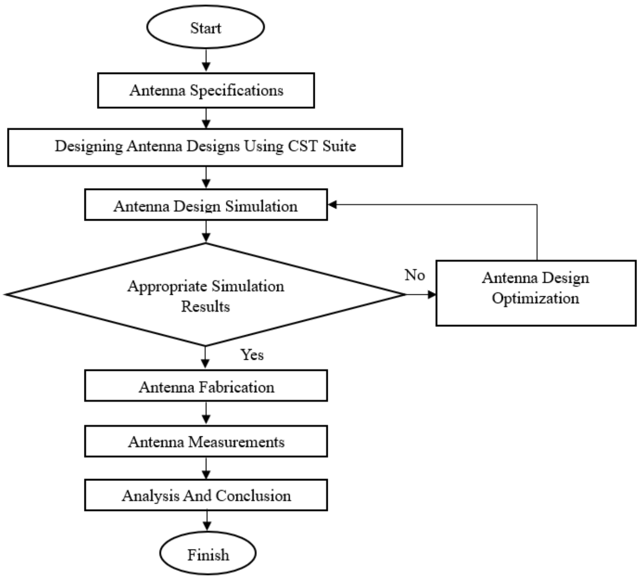


Fig. 1 Flowchart

The first stage is the literature study stage, at this stage a study of MIMO antennas is carried out along with the antenna parameters and the required literature obtained from final projects, journals, books, and article sources from the internet. The second stage is the stage of determining the size of the antenna dimensions, as well as MIMO antenna parameters obtained from literature studies on the internet. The third stage, namely planning to design a MIMO antenna, begins with determining the working frequency of the antenna, the length of the antenna elements, and the distance between the elements to the final stage in designing a MIMO antenna according to the literature study obtained. In the fourth stage of the simulation stage, at the simulation stage, if it meets the desired simulation result target, antenna manufacturing continues. Still, if the simulation results do not reach the target, an antenna design optimization is carried out. The fifth stage is the manufacturing stage, at this stage the antenna design and fabrication process of the CST Studio Suite software is carried out before manufacturing, the design results of the CST Studio Suite software, are moved first using Eagle software, in this process also obtained the expected parameter results using the software. The sixth stage of the measurement stage, the measurement stage is carried out after the design and fabrication process is complete. The measurement aims to determine the antenna parameters produced as a comparison between the manufactured antenna and antenna simulation in the CST Studio Suite software. The seventh stage of data analysis at this stage is the analysis of antenna measurement data obtained.

B. Antenna Dimensions

The size of the antenna obtained is the size of the journal (Revindra Bakale, 2022). The antenna dimensions used are 23 x 60 mm² using the type substrate FR-4 with having dielectric permittivity 4.4 and loss tangent 0.027. The proposed structure is designed with a monopole radiator having an impedance bandwidth of 2.65–11.65 GHz (138%) except for the notched band of WIMAX and WLAN. Mushroom-type EBG design structures are mounted close to the transmission feed line to achieve the rejection of bands at 3.60–4.20 GHz and 5.15–5.87 GHz frequencies. The two counter-faced F-pattern stubs are etched in the ground to maximize the isolation |S21| > 15 dB. The designed antenna with dimensions is depicted in Figure 2.

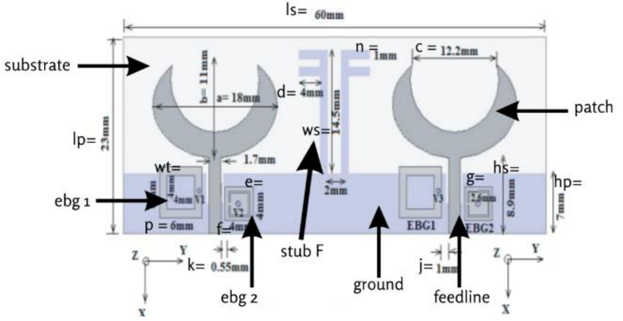


Fig. 2 Parameters of Reference Antenna.

Figure 2 is a display of antenna design based on references (journals) and the results of antenna design modifications. Details of the size of both antenna designs can be seen in

TABLE I.
PARAMETER VALUE

Parameter	a	b	c	d	e	f
Value	20	15	20	7	4	4.3
Parameter	g	hp	hs	hr	j	k
Value	4	7	8.9	1.6	1	0.5
Parameter	ls	lt	lp	ms	n	p
Value	30	2	1.7	2	0.5	6
Parameter	q	rt	t	u1	u2	v1
Value	4	3	0.035	18.2	10	16.5
Parameter	v2	p1	p2	p3	d1	g2
Value	15	2	0.5	0.5	2.2	0.5
Parameter	rv	y1	y2	zs	zt	wp
Value	0.5	1	2	13	25	35
Parameter	wt	ws	ls1	wp1	ghp	ws1
Value	4	14.5	60	25	1	30
Parameter	stub1	stub2	stub3	s44	R-pin	dpin
Value	5	1	28	4	0.39	0.37

This antenna uses a 50 Ω SMA port. Figure 3 shows the results of the antenna fabrication.

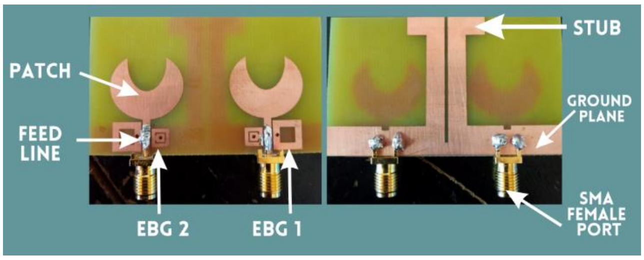


Fig. 3 Antenna Fabrication.

C. *Antenna Fabrication and Measurement*

After getting the optimization results on an antenna and by the expected specifications, then carry out the manufacturing process and take measurements.

III. RESULT AND DISCUSSION

A. *Effect of Antenna with Ground Full Elliptical Patch*

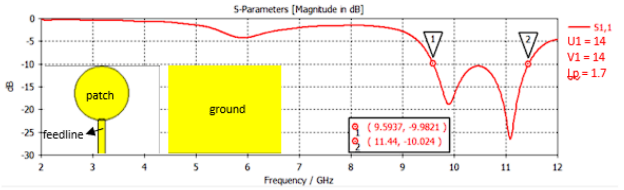


Fig. 4 Elliptical Patch Antenna with Full Ground.

In the picture above, there is a microstrip antenna design with an elliptical patch with a full ground. The S-parameter results obtained are with a working frequency of 9.5 - 11.4 GHz.

B. *Effect of Cutting on Ground*

Furthermore, the ground is cut in half to obtain omnidirectional polarization results. The S-parameter results can be seen in figure 5.

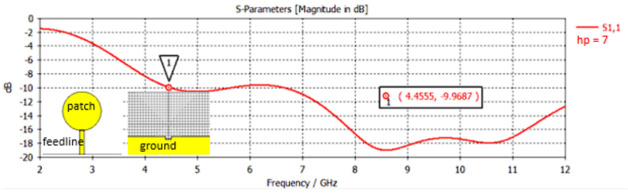


Figure 5 Ground Cutting.

Ground truncation results in a lower return loss at 4.4 GHz.

C. *Effect of Adding Elliptical and Trimmed Patches*

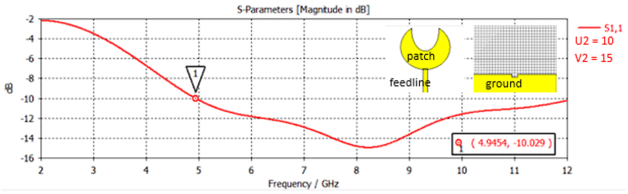


Fig. 6 Elliptical Patch Addition and Cut.

Cutting the ellipse so that the shape of the antenna patch is crescent-shaped, the S-parameter results are obtained with a return loss that starts to drop at a frequency of 4.9 GHz.

D. *Effect of EBG Addition Next to Feedline*

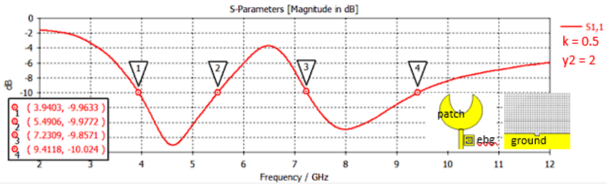


Fig. 7 Addition of EBG beside Feedline.

The addition of EBG affects the shape of the s parameter which results in one notched at frequencies of 3.9 - 5.4 Ghz. This notched addition is a form of WLAN rejection according to the reference antenna. Then added EBG 2 on the left side of the feedline which resulted in the S-parameter in Figure 8 below.

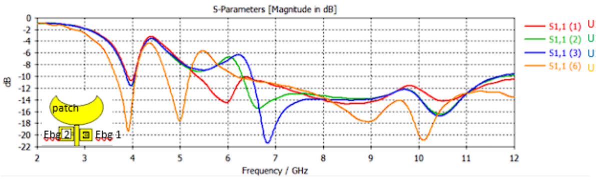


Fig. 8 Addition of two EBG.

In Figure 8 with 2 EBGs, one notched is obtained which is then optimized to achieve the dual notched target with parameter values y2 = 2, f = 5, u1 = 22, u2 = 17, v1 = 15, and v2 = 10 mm. S dual notched parameters are obtained but the shape of the patch size is very far from the shape of the reference antenna. Then, optimization is carried out for a better patch size but still getting the desired notched target. The results of the optimization can be seen in Figure 9 below.

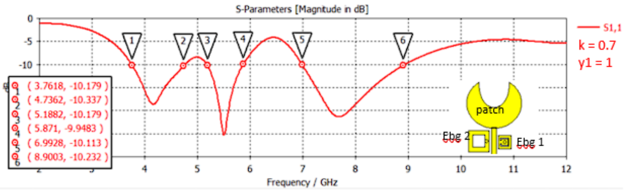


Fig. 9 Patch Size Modification.

In Figure 3.14, it can be seen that the addition of EBG beside the feedline produces two notched notches at frequencies of 4.7 - 5.1 GHz and 5.8 - 6.9 GHz. The working frequency obtained is from the range of 3.7 - 8.9 GHz.

E. *Effect of Adding One Antenna into a MIMO Antenna*

The results of adding a MIMO antenna can be seen in Figure 10 below.

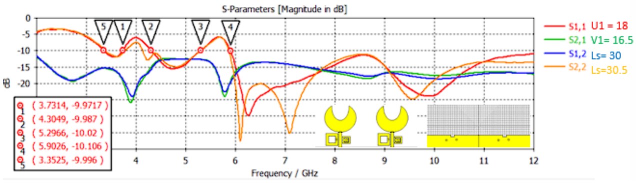


Fig. 10 Adding One Antenna into a MIMO Antenna.

The addition of the simulation design into a MIMO antenna with two EBGs and via on each EBG produces S parameters with working frequencies from 3.7 - 12 GHz with dual notched at frequencies of 3.7 - 4.3 GHz and 5.2 - 5.9 GHz. The isolation results obtained are still poor, the mutual coupling value obtained has not reached below -20 dB.

F. *Effect of Stub Addition*

Furthermore, optimization is carried out on the stub, which was originally an F-shaped stub, modifying the isolation method into a T-shape stub in order to get better frequency results in Figure 11 below.

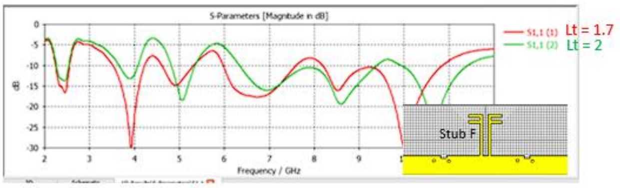


Fig. 11 Addition of Stub F Occurs Increase in Number of Notched.

In Figure 11, the results obtained are still not optimal, so the modification of the stub into a T-shape stub can be seen in Figure 12.

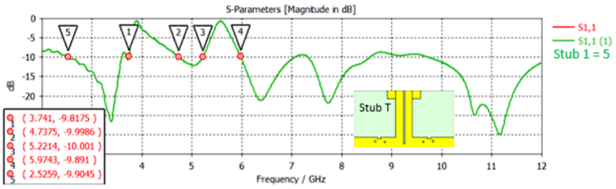


Fig. 12 Stub T-shape.

The results of the resulting stub modification are much better, namely there are dual notched at frequencies of 3.7 - 4.7 GHz and 5.2 - 5.9 GHz. The results of this modification are certainly much better than the previous F stub. The mutual coupling value obtained has reached <-20 dB as can be seen in Figure 13 below.

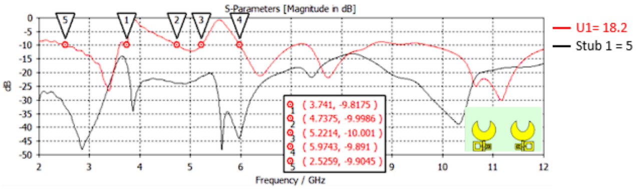


Fig. 13 Return Loss and Mutual Coupling.

The EBG position is also moved on the second antenna, because the corresponding EBG on the reference antenna produces more than two notched. So the EBG position is different from the reference antenna.

G. *Comparison of Simulated and Fabricated Return Loss*

To know that an antenna works at the specified frequency is by looking at the value of the return loss parameter. The minimum return loss value of a good antenna is ≤-10 dB. Comparison of return loss values between simulation and fabrication can be seen in Figure 14 below.

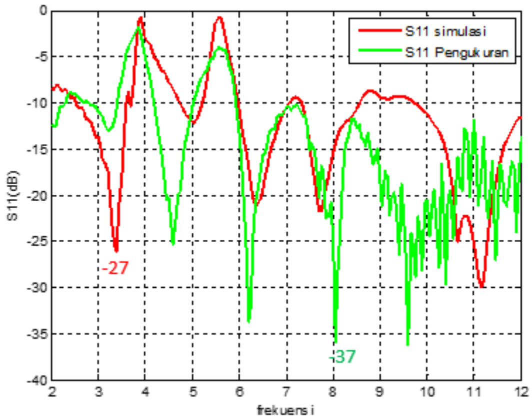


Fig. 14 Comparison of Simulated and Fabricated Antenna Return Loss.

In Figure 14 it can be seen that the comparison of the return loss of the fabricated antenna is deeper than the simulation, the lowest return loss value in the simulation is -27 dB at a frequency of 3.3 GHz, while in the fabricated antenna the lowest return loss is -37 dB at a frequency of 8.05 GHz. The measurement results are better than the simulation.

H. Comparison of VSWR of Simulated and Fabricated Antennas

Voltage Standing Wave Ratio (VSWR) is the ratio of maximum and minimum standing waves. Where an antenna has a good VSWR value if it is worth 1 - 2 dB. It can be seen in Figure 15 comparison of fabricated and simulated antenna values, the VSWR value of fabrication and simulation is already between the values of 1 - 2 dB, except at frequencies that are notched. VSWR results in simulation and fabrication have shown good results and are in accordance with the standard.

The VSWR comparison results of simulation and fabrication can be seen in Figure 15 below.

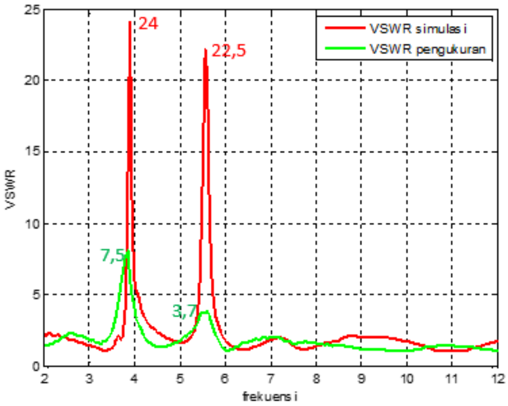


Fig. 15 Comparison of VSWR of Simulated and Fabricated Antennas.

I. Comparison of Fabricated and Simulated Antenna Insulation

The results of simulation and fabrication isolation comparison can be seen in Figure 16 below.

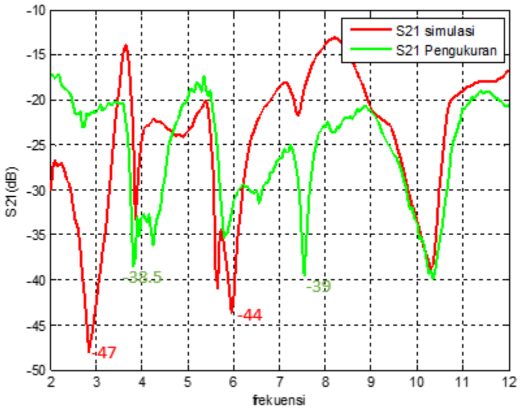


Fig. 16 Comparison of Fabricated and Simulated Antenna Insulation.

It can be seen in Figure 16 comparison of the isolation of fabricated and simulated antennas, the results of fabricated antenna isolation are better than simulation. Almost all graphs are below -20 dB. Isolation is used to see the quality of the mimo antenna, and to see the effect of mutual coupling which can cause changes in antenna parameters. The effect of mutual coupling is tried to be as minimal as possible because it affects the performance of the antenna.

J. Bandwidth Comparison of Fabricated and Simulated Antennas

From Figure 17, it can be seen that the bandwidth of the fabricated antenna is in the frequency range of 2.8-12 GHz while that of the simulated antenna is in the frequency range of 2.5-12 GHz. The bandwidth of the simulated antenna is wider than the fabricated antenna.

The results of the simulation and fabrication isolation comparison can be seen in Figure 17 below.

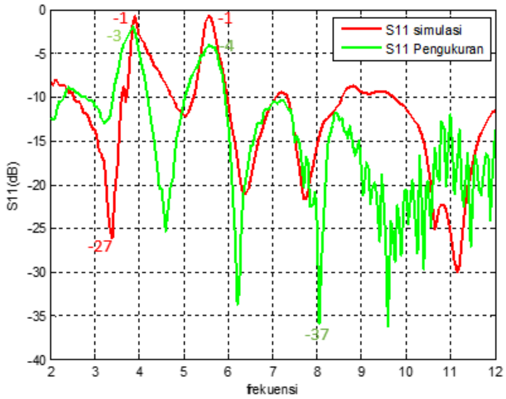


Fig. 17 Bandwidth Comparison of Fabricated and Simulated Antennas.

K. Correlation Coefficient Comparison

In addition to isolation, the MIMO parameter is the correlation coefficient or envelope correlation coefficient (ECC), which states the level of similarity between the signals received by each antenna. Where the value is 0 to 1 and the value must be <0.05 for better MIMO performance. In Figure 18, it can be seen that the ECC value on the reference and optimization antennas is below 0.02 except for the Notched band, which can be seen in Figure 18 below.

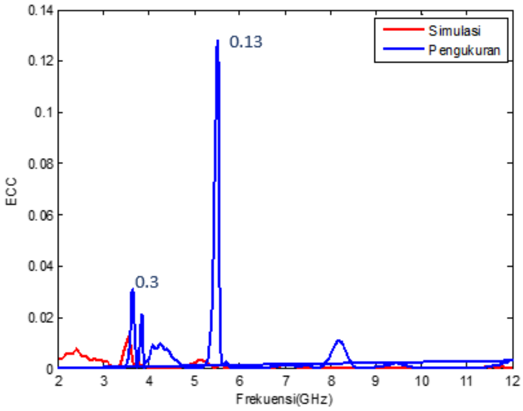


Fig. 18 Comparison of ECC Fabrication and Simulation.

L. Optimization Antenna Gain Results

The gain of the antenna is the ratio of the intensity of the power emitted by the antenna to the total power received. In Figure 19 below can be seen the graph of the optimization antenna gain results.

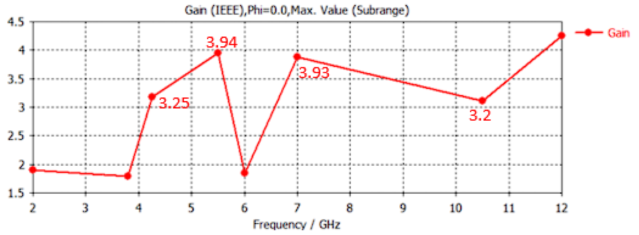


Fig. 19 Gain.

The amount of gain value targeted $\geq 2dB$, the greater the gain value the greater the antenna beam and vice versa. From the results of the antenna simulation above, it can be concluded that the best gain value is 3.94 dBi at a frequency of 5.5 GHz in this final project design antenna.

M. Comparison of Simulation and Measurement Radiation Patterns

Figure 20 is the radiation pattern of the design in this final project, which is in the form of omnidirectional. Where the omnidirectional radiation pattern emits signal intensity in all directions.

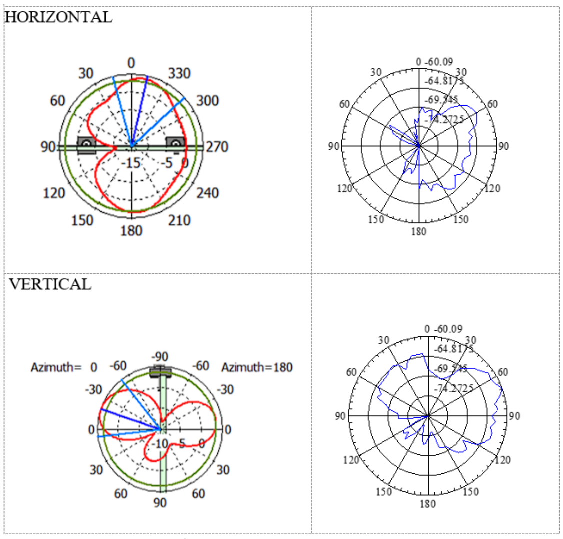
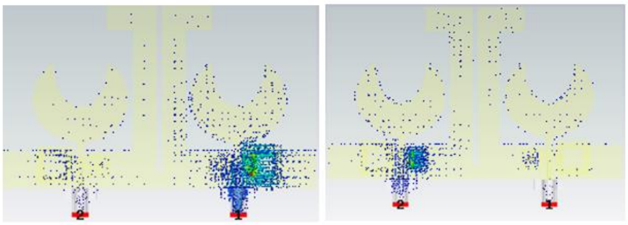


Fig. 20 Comparison of Simulated and Measured Antenna Radiation Patterns.

Simulation and measurement polaradiation results obtained almost the same results with an omnidirectional form that spreads in all directions. In the part of the signal that radiates slightly it is caused by the band notched antenna. Omnidirectional polarization is caused by cutting on the ground.

N. Current Distribution

Current distribution is also one of the parameters that can see isolation to reduce mutual coupling. Figure 21 below shows the current distribution on the modified antenna, it can be seen that the current is concentrated on one antenna without any current jamming on the other antennas.



(a) (b)

Fig. 21 Current Distribution (a) 3.8 GHz (b) 5.5 GHz.

In Figure 21 (a) it can be seen that at a frequency of 3.8 GHz the current density is concentrated at EBG 1 and at a frequency of 5.5 GHz the current is concentrated at EBG 2. The current is held at EBG because at that frequency there is a notched band so that no current is emitted to other parts of the antenna.

O. Comparison of Simulated Antenna Final Results with Fabricated Antenna

From all the MIMO antenna parameters that have been discussed, a comparison of the simulation results and measurement results on the fabricated antenna is obtained in table below.

TABLE II
Comparison Results of Simulated Antenna with Fabricated Antenna

No	Parameter	Simulation	Result Measurement Result
1	Frequency (GHz)	2.5 - 12	2.8 - 12
2	Return Loss (dB)	-27 dB	-37 dB
3	VSWR	≤ 2 2 - 3.7 4.8 - 5.2 5.8 - 12	≤ 2 2 - 3.5 4.2 - 5.2 5.6 - 12
4	Insulation	≤ -20 2.0 - 3.5 3.7 - 6.7 8.9 - 10.7	≤ -20 2.4 - 5.0 5.5 - 11.2
5	Gain (dBi)	3.94	-
6	Bandwidth (MHz)	2.5 - 12	2.8 - 12
7	ECC	< 0.02	< 0.02
8	Polaradiation	Omnidirectional	Omnidirectional
9	Band Notched (GHz)	3.7 - 4.7 5.2 - 5.9	.5 - 4.2 5.0 - 5.9

IV. CONCLUSION

After simulation and fabrication and analysis, the following conclusions can be drawn:
The MIMO UWB microstrip antenna was successfully modified and simulated using CST studio suite software with a fabrication size of 60 x 35 x 1.6 mm made of lossy FR-4 material and has a working frequency range of 2.8 - 12 GHz with dual band notched 3.5 - 4.2 GHz and 5 - 5.9 GHz. The MIMO UWB antenna parameters meet the specifications based on the Federal Communications Commission (FCC) and the Institute of Electrical and Electronics Engineers (IEEE) where the fabrication results obtained a better return loss value of -37 dB, a better VSWR value of 1 - 2 outside the resulting notched, ECC with a value of <0.02, the largest gain value obtained is 3.94 dBi, a better isolation value ≤-20 dB and almost perfect omnidirectional polarization throughout UWB. Several modifications were made to the simulated and fabricated antennas such as changing the shape of the stub connected to the ground, which was originally an F-stub to a T-shape stub to produce better isolation of ≤ -20 dB, then changing the location of EBG 1 and 2 on the second antenna in order to achieve the optimal value and match the desired dual band notched so that the MIMO antenna can work well at UWB frequencies.

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