

# Four-Port Multiple Input Multiple Output Antenna Using Stub and Defected Ground Structure Methods for Ultra-Wideband Applications

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**Abstract**— Multiple Input Multiple Output (MIMO) antennas using the Defected Ground Structure technique are able to produce wide bandwidth to meet Ultra-Wideband (UWB) frequencies. UWB MIMO antennas have the advantages of reducing interference, improving isolation, and optimizing multipaths, thereby expanding coverage and improving signal quality. The challenge in designing MIMO-UWB antennas is to produce low mutual coupling with small antenna dimensions so that they can be used in portable devices. In this final project, the aim is to design a 4x4 UWB MIMO antenna using FR-4 substrate material with a dielectric constant ( $\epsilon_r$ ) of 4.3, a loss tangent of 0.035 and a material thickness of 1.6 mm. With dimensions of 45 x 45 x 1.6 mm<sup>3</sup>. which has an Ultra-Wideband working frequency with a frequency range of 3.1 – 10.6 GHz. The results of the antenna simulation and measurement showed good performance with a simulated antenna operating frequency of 3.1–10.23 GHz, a minimum return loss of -49.85 dB, an isolation of  $\leq -20$  dB, and a maximum peak gain of 3.3 dBi at the frequency of 10.6 GHz with an omnidirectional radiation pattern. The measurement results show a working frequency of 3.2-10.64 GHz, a minimum return loss of -21.24 dB, and an Isolation of  $\leq -20$  dB. The designed four-port MIMO antenna parameters result in a simulated ECC and measurement of  $< 0.02$  and a diversity gain of over 9.989, and a TARC of  $\leq -10$  dB. The measurement and simulation results show a good fit and are within the permissible limits, indicating good performance for UWB communication.

**Keywords**— Multiple-Input-Multiple-Output (MIMO), Defected Ground Structure (DGS) Technique, Ultra-Wideband (UWB)

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## I. INTRODUCTION

Since the Federal Communications Commission (FCC) released the 3.1 – 10.6 GHz spectrum for commercial applications, the Ultra-Wideband (UWB) technique has attracted a lot of attention because it has advantages such as wider bandwidth, high data rates, and low cost. UWB antennas, as one of the key components of UWB wireless communication systems that have been extensively researched. Although UWB communication systems use large bandwidths, the spectral density of the power allowed from the UWB signal is limited enough to avoid interference with other systems. The Multiple Input Multiple Output (MIMO) technique allows data transmission over multiple channels, and thus increases channel capacity without the need for additional power. In addition, MIMO antennas can be used to achieve diversity performance

and reduce the effects of multipath fading (Addepalli and Anitha 2020).

Some antennas on transmitters and receivers are used in MIMO technology. In the characteristics of multipath fading can significantly increase spectrum utilization. To integrate multiple antenna elements on a small substrate, appropriate decoupling is introduced between the antenna elements to improve isolation (Wu et al. 2022).

The use of multi-element antennas can effectively increase the channel capacity and improve the reliability of UWB wireless communication. However, strong mutual coupling caused between antenna elements will degrade the performance of the UWB MIMO system (Addepalli and Anitha 2020). Therefore, Wireless communication is currently experiencing a significant increase in demand for better transmission quality and high data rates. Multiple Input Multiple Output (MIMO)

transmission can meet these needs effectively and comprehensively, thereby improving the overall performance of the wireless communication system.

The main challenge and also the attraction in doing the MIMO-UWB final task is to produce a small antenna size, low mutual coupling value and also produce a notched band in the UWB frequency.

Against this background, the author would like to raise the title about "Multiple Input Multiple Output Antenna Four Ports Using Stub and Defected Ground Structure Method for Ultra Wide-Band Applications". The antenna design and simulation were conducted using CST Studio Suite 2019 software. So that better antenna parameters are obtained for Ultra Wide-Band applications.

II. MATERIALS AND METHODS

The reference design is adapted from (Wu et al. 2022). The proposed MIMO antenna has four ports using the stub and defected ground structure method for ultra wide-band applications. In order to integrate multiple antenna elements on a small substrate, a suitable decoupling is introduced between the antenna elements to improve isolation with a target working frequency of 3.1-10.6 GHz.

The design process was carried out using CST Studio Suite 2019, a 3D electromagnetic simulation software. The antenna structure consisted of a rectangular microstrip patch with square-ring slots etched on the radiating element. The patch was mounted on an FR-4 substrate with a relative permittivity of 4.3 and a thickness of 1.6 mm. The antenna was fed using microstrip transmission lines and terminated with 50-ohm ports.

The geometry was optimized by varying the dimensions of the slots, feedline position, and element spacing. A parametric study was also performed to investigate the effect of substrate size and slot width on antenna performance.

A. Antenna Design and Dimensions

The antenna is a 4x4 MIMO antenna with dimensions of 45 x 45 x 1.6 mm<sup>3</sup> working frequency 3.1-10.6 GHz.

TABLE I  
ANTENNA OPTIMISATION PARAMETERS

Parameters	Value (mm)	Parameters	Value (mm)
W	45	Lg4	3.5
L	45	W1	9.5
H	1.6	a2	0.5
Wg	19	s1	0.2
Wg1	2	TC	0.035
Wg2	0.5	W2	1.4
Wg3	2.8	W3	4.8
b1	13	Lf	12
R	8.2	Lf1	4
Lsub	60	Wf1	2
Ws2	1	Wf2	1.3
Wg4	14.4	a1	0.20
Lg	10.3	b2	12
Lg1	7	Stub1	30
Lg2	22.2	Wsub	20
Lg3	2.5		

The design of the antenna is shown in Figure 2.

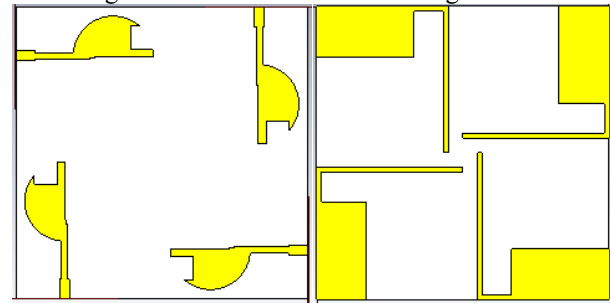


Fig. 2 Antenna Design

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

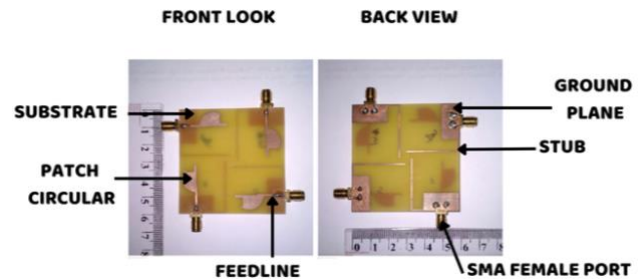


Fig 3. Antenna Parameter Measurement

B. 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. RESULTS AND DISCUSSION

A. Effect of Adding Antennas on Patches, Feedlines and Ground Planes

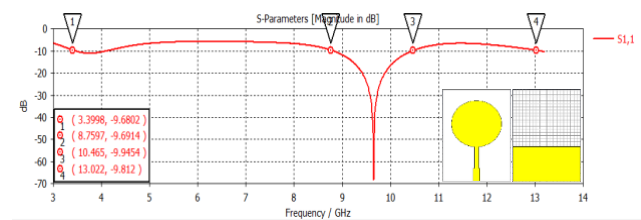


Fig 4. Antennas on Patches, Feedlines and Ground Planes

In the figure 4 above, there is a microstrip antenna design with patches in the form of circular patches, feedlines, ground. The results of the S-parameters obtained are with a working frequency of 8.7 with a value of -9.6914 dB to a working frequency of 10.4 GHz with a value of -9.9454 dB. The bandwidth obtained has not met the desired working frequency specifications.

B. Effect of Adding Two Patches and Cutting

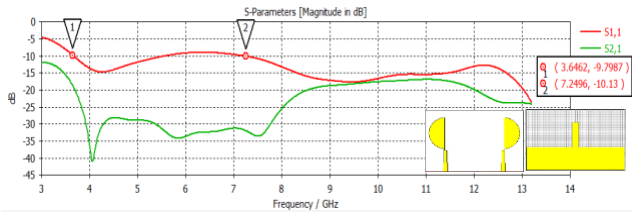


Fig. 5 Addition of Two Patches and Cut

In figure 5 above, there is a design of the monopole antenna cut into two parts to obtain two semicircular radiation elements. With the addition of the patch, two notches appear on the S11. Cutting can cause the S11 to be flatter and wider in the UWB frequency (3–10 GHz), which is in the middle of the graph, where the S11 value is quite low by a wide margin. The results of the S-parameter S11 obtained are with a working frequency of 3.6 – 7.2 GHz.

C. Effect of Adding Four Antennas to a UWB MIMO Antenna

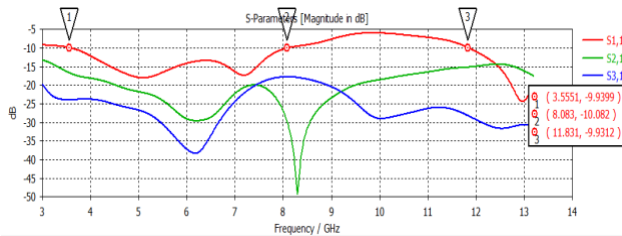


Fig 6. Addition of Four Antennas to Become UWB MIMO Antennas

In Figure 6 above, there is the addition of four semicircular antennas to the UWB MIMO antenna. This antenna aims to improve the isolation between elements and maintain the value of return loss and isolation. The S11 S-parameter results obtained are with a working frequency of 3.5 – 8.08 GHz which is acceptable, slightly above the standard threshold, while from the frequency of 8.08 – 11.8 GHz it is acceptable but not optimal. Therefore, it is necessary to carry out further design processes in the form of optimizing the dimensions of substrates, patches, feedlines, ground, and modification of the shape of patches and soils using the DGS technique.

D. Effect of Adding Stubs with Patch Cutting

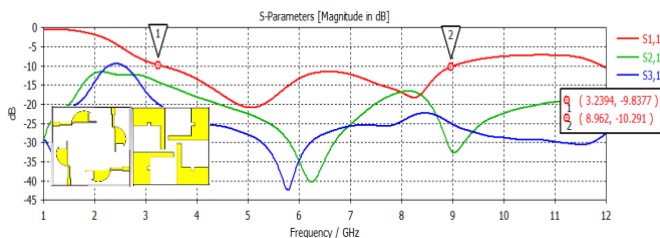


Fig 7. Stub Addition with Patch Cutting

In Figure 7 above, the effect of adding a stub lowers the value of S11 at high frequencies to produce an optimal second resonance. By cutting the patch, it can improve performance at low frequencies which produces an initial resonance around 3.2 GHz. The results of the S-parameter S11 are still not optimal, which is obtained with a working frequency of 3.2 – 8.9 GHz.

Therefore, it is necessary to carry out further design processes in the form of optimization on the feedline, ground and stub.

E. Effect of Adding L Stubs to Ground Plane Cutting

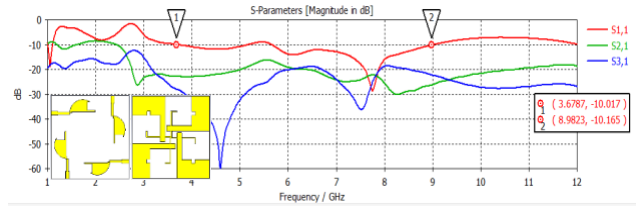


Fig 8. Addition of L Stub with Ground Plane Cutting

In Figure 8 above, the effect of the addition of the L stub can improve the matching performance at high frequencies by producing additional resonance. Ground plane cutting can help lower the S11 value at low frequencies and improve the overall performance of the antenna. The results of the S-parameter S11 obtained are with a working frequency of 3.6 – 8.9 GHz.

F. Four-Port Antenna Design with Addition of Stub L

Furthermore, optimization was carried out on the design of the four-port antenna with an L-shaped stub. Where the L stub affected the insulation at higher frequencies, the isolation method was modified by changing the length of the L stub in order to get better frequency results in Figures 6.

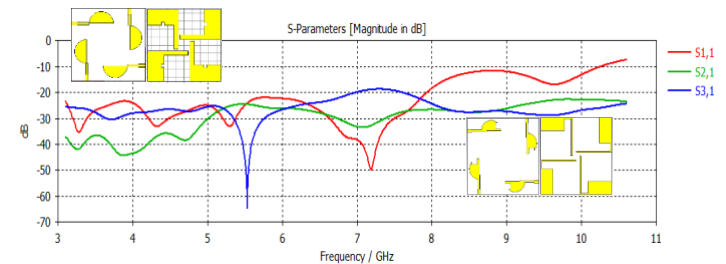


Fig 9. Four-Port Antenna Design with Addition of Stub L

In Figures 9 above, there is a four-port antenna design with the addition of an L stub for fabrication. The S-parameter results obtained have met the UWB frequency, namely with a working frequency of 3.1 – 10.6 GHz.

G. Comparison of Simulated and Measurement Return Losses

To know if an antenna is working at a specified frequency is to look at the value in the return loss parameter. The minimum return loss value of a good antenna is  $\leq -10$  dB. The comparison of the return loss values between the simulation and the measurement using the vector network analyzer can be seen in Figure 10.

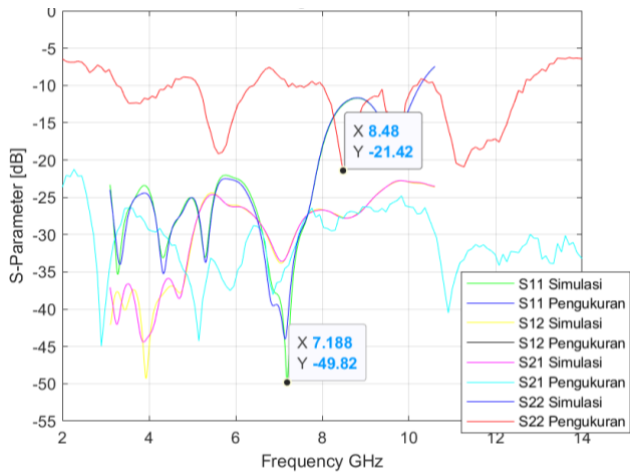


Fig 10. Antenna Return Loss Value Simulation and Measurement Results

Figure 10 shows the simulation and measurement results of S-Parameters S11, S12, S21, S22. From S-Parameters S11 and S22 show values lower than -10 dB in some frequency ranges, which indicates that the antenna performs quite well at those frequencies. However, there are discrepancies between the simulation and measurement results which may be caused by imperfections in noise during measurement. The lowest return loss value in the simulation was -49.85 dB at a frequency of 7.1 GHz, while the lowest return loss measurement antenna was -21.42 dB at a frequency of 8.4 GHz. The results of the simulation obtained better results than the measurements.

H. Comparison of VSWR Antenna Simulation and Measurement Results

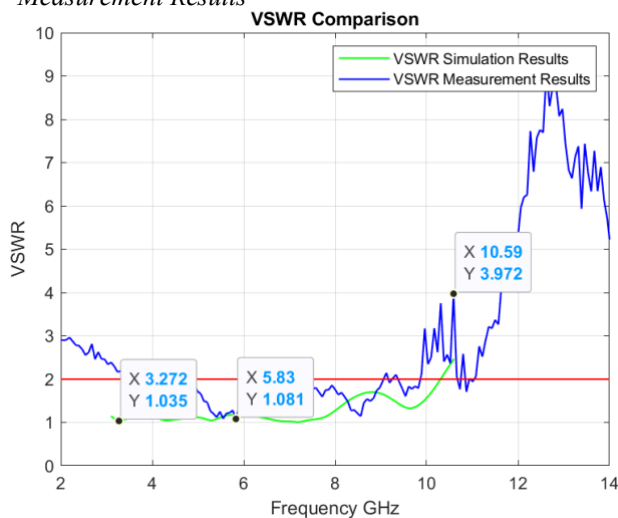


Fig 11. VSWR Antenna Value Simulation and Measurement Results

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 valued at 1 – 2 dB. It can be seen in Figure 4.2. The comparison of VSWR values on port 2 of the simulation is between the value of 1.04 dB at the frequency of 3.2 GHz. The VSWR results in the measurement are already between the value of 1.081 dB at the frequency of 5.8 GHz, showing good results and in accordance with the standard.

I. Comparison of Antenna Isolation Simulation and Measurement Results

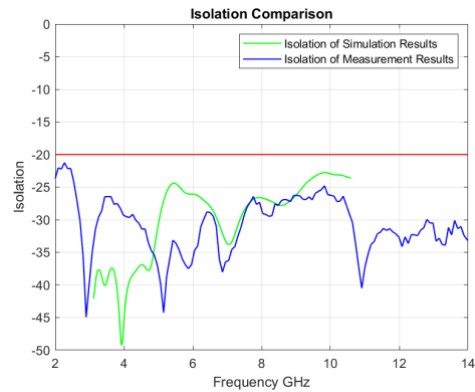


Fig 12. Antenna Isolation Value Simulation and Measurement Results

It can be seen in Figure 12 that the isolation of the simulation antenna and the measurement at port 2 can be seen that the isolation of the simulated antenna is better than the measurement. All charts are below -20 dB. Isolation is used to see the quality of the MIMO antenna, and to see the effects of mutual coupling that can cause changes in antenna parameters. The mutual coupling effect is tried to be as minimal as possible because it affects the performance of the antenna.

J. Comparison of Antenna Bandwidth Simulation and Measurement Results

The results of MIMO antenna measurements in Figure 10 were obtained that bandwidth was used to determine the performance of the antenna that could operate properly. The amount of targeted bandwidth value as issued by the FCC, the UWB signal must have a bandwidth greater than 500 MHz. Where the highest and lowest cutoff frequencies are at the point -10 dB of the UWB pulse spectrum.

K. Comparison of Correlation Coefficients

In addition to the isolation of the MIMO parameter is the envelope correlation coefficient (ECC), which states the degree 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 4.4 the ECC value on the simulation antenna can be seen and the measurement below 0.02 can be seen in the following figure 13.

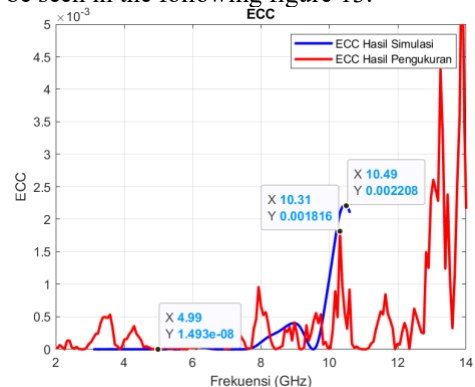


Fig 13. ECC Value of Antenna Simulation and Measurement Results

L. Diversity Gain Comparison

The Diversity gain values on the simulation and measurement antennas have met specifications close to 10 at most working frequencies can be seen in the following Figure 14.

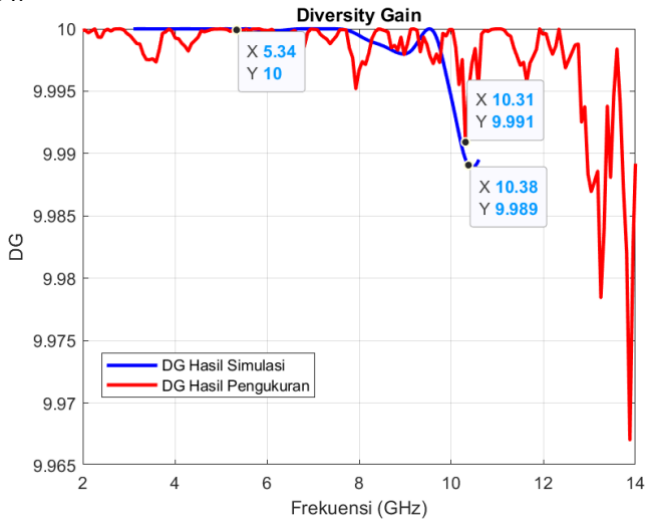


Fig 14. Antenna Gain Diversity Value Simulation and Measurement Results

It can be seen that the diversity gain result of the simulated antenna, which is  $> 9.989$ , is better than the measurement antenna with a diversity gain value of  $> 9.991$ . However, measurement antennas are still categorized in good diversity gain parameters.

M. Comparison of Total Active Reflection Coefficient (TARC)

TARC graph in Figure 15 shows that in all working frequency ranges of the simulated antenna, obtaining a TARC below  $-10$  dB according to the specification means that it has a minimum reflection power with the lowest TARC value of  $-61.03$  dB at a frequency of  $4.72$  GHz. Meanwhile, the measurement antenna has a TARC below  $-10$  dB with the lowest TARC value of  $-32.02$  dB at a frequency of  $6.81$  GHz. The measurement results that are close to the simulation antenna with better performance are the simulation antenna.

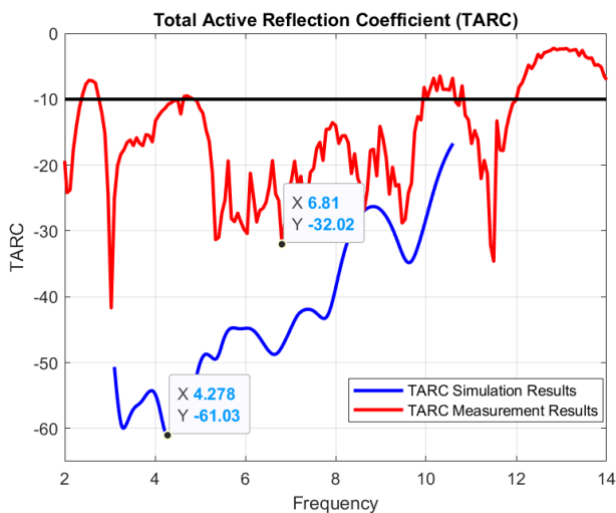


Fig 15. TARC Value of Antenna Simulation and Measurement Results

N. Simulated Antenna Gain Results

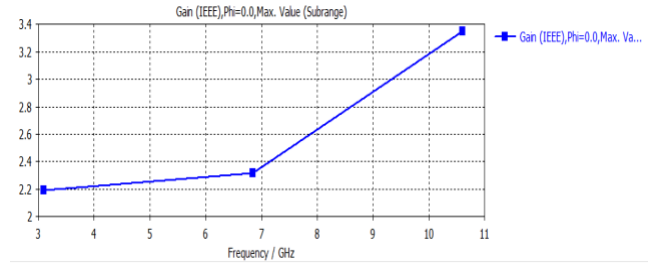


Fig 16. Gain Simulation

From the results of the antenna simulation in figure 16, it can be concluded that the gain value at the  $3.1$  GHz frequency is  $2.1$  dB, while the  $6.8$  GHz frequency gain is  $2.3$  dB. At the frequency of  $10.6$  GHz, the gain obtained is  $3.3$  dB. So the best gain value is obtained at  $3.3$  dBi at a frequency of  $10.6$  GHz on the antenna of this final project design.

O. Simulated Radiation Pattern Results

In Figure 14 is the design radiation pattern in this final project, which is in omnidirectional form. Where the omnidirectional radiation pattern emits the intensity of the signal in all directions. This means that the radiation pattern obtained meets the specifications of the UWB antenna. The results of radiation patterns at multiple working frequencies of  $3.1$  GHz,  $6.58$  GHz, and  $10.6$  GHz can be seen in the following Figure 17.

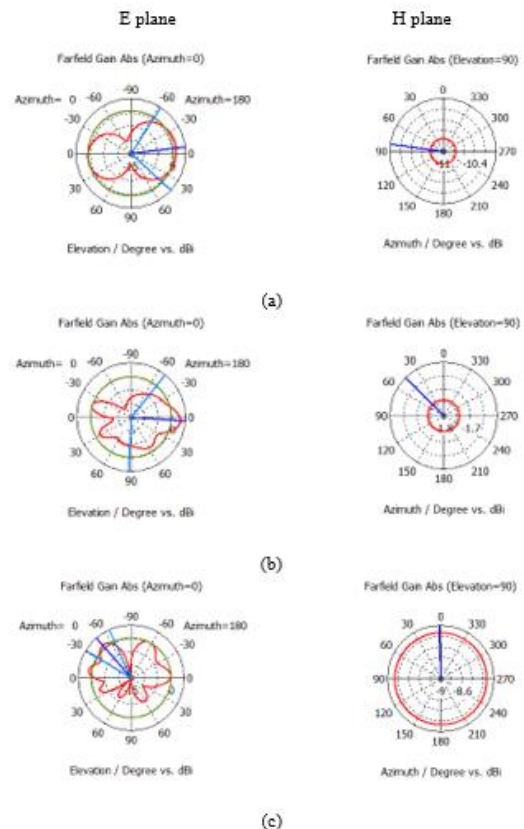


Fig 17. Antenna Radiation Patterns Multiple Frequencies (a)  $3.1$  GHz, (b)  $6.58$  GHz, (c)  $10.6$  GHz

### P. Comparison of Simulation Antenna Finishes with Measurement Antennas

From all the parameters of the MIMO antenna that have been discussed, a comparison of the simulation results and measurement results on the fabrication antenna is obtained in the following Table II.

TABLE II  
COMPARISON RESULTS OF SIMULATION ANTENNA WITH MEASUREMENT ANTENNA

No.	Parameter	Simulation Results	Measurement Results
1.	Working Frequency (GHz)	3,1 – 10,23 GHz	3,2 – 10,64 GHz
2.	Return Loss (dB)	-49,85 dB	-21,24 dB
3.	VSWR (dB)	1,04	1,081
4.	Isolasi	$\leq -20$	$\leq -20$
5.	Gain (dBi)	3,3 dBi	-
6.	Bandwidth (MHz)	7,130 MHz	1,260 MHz 1,170 MHz 2,070 MHz
7.	ECC	$< 0,02$	$< 0,02$
8.	Diversity Gain (dBi)	$>9,989$	$>9,991$
9.	TARC	$< -10$ dB	$< -10$ dB
10.	Polarization	<i>Omnidirectional</i>	-

Based on the data that has been obtained on the comparison parameters between the simulation results and the measurement of the MIMO UWB antenna, it is known that at the frequency of 3.1-10.23 GHz, it is lower than the measurement results of 3.2-10.64 GHz. The best return loss value is in the simulation results with a minimum return loss of -49.85 dB which shows a very small reflection. The measurement results show better results.

The simulation results have a very low VSWR of 1.04 indicating excellent antenna impedance suitability. In contrast, the measurement results show a higher VSWR, but remain within the Acceptable Limit  $< 2$ . In the bandwidth parameters, the resulting antenna simulation and measurement meet the requirements of UWB, which is greater than 500 MHz. Based on calculations, the simulated antenna has a bandwidth of 7,130 MHz. While the measurement results have a bandwidth of 2,070 MHz.

In terms of isolation, the simulation results show better than measurements. All charts are below  $\leq -20$  dB. ECC in simulation and measurement results below  $< 0.02$  indicates excellent MIMO performance.

The diversity gain from the simulation and measurement results was very high  $>9.991$ , indicating excellent performance in overcoming multipaths. The TARC of the simulation results showed a lower value of  $< -10$  dB compared to the measurements which meant less energy was reflected back.

Overall, it can be seen that the value of the measurement parameters obtained is slightly different from the measurement

results of the measurement antenna. The difference in the resulting parameters can be affected by the measurement antenna, namely, the design replication process on the substrate, the soldering of the SMA Female Port connector used, the dielectric constant value of the antenna PCB, and surrounding factors at the time of measurement such as poor calibration results, and indentations in the VNA cable.

### IV. CONCLUSION

After designing, simulating, optimizing, and fabricating a Four-Port MIMO Antenna with FR-4 Substrate for Ultra-Wideband applications, the results show successful operation across the 3.1–10.6 GHz frequency range with high isolation ( $\leq -20$  dB). While simulation and measurement results demonstrate good performance meeting specifications, a discrepancy in bandwidth is observed: 7.13 GHz in simulation versus 2.07 GHz in measurements. This difference is attributed to environmental factors, including measurement calibration and fabrication tolerances.

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