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Memo Slot Antenna Design (Multiple Input Multiple Output) With -22 Db Isolation Without Decoupling Structure For Application On Uwb (Ultra-wideband)

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Abstract--Technology that is always evolving requires us to always make the latest innovations, one of which is in the field of telecommunications. Currently, multiple input multiple outputs (MIMO) technologies are widely used in ultra-wideband (UWB) systems to overcome the effects of multipath fading. Multiple antennas are used to increase channel capacity. Two-element MIMO UWB systems have several techniques for obtaining good isolation between antenna elements. In this final project, the design and analysis of the change of a single UWB slot antenna into a 2-element MIMO UWB antenna is carried out by placing the antenna elements asymmetrically to get high antenna isolation. The proposed UWB MIMO antenna has a very compact size of 42×25 mm2. The fed slot microstrip antenna acts as a single UWB antenna element. Antenna design using CST Study Suite software. In the simulation results, a single UWB slot antenna that is modified into a UWB MIMO antenna has a return loss of -28 dB, a bandwidth of 7.2514 GHz, isolation below -20 dB, a VSWR of VSWR 2 in the frequency range of 3.7002 GHz to 9.6546 GHz, the gain reaches 3.2 dBi, and radiation pattern which is quasi omnidirectional.

Keywords: Multiple input multiple output (MIMO), antenna slot, ultra-wideband

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I. INTRODUCTION

Recently, multiple input multiple outputs (MIMO) technologies have been widely used in ultra-wideband (UWB) systems to overcome the effect of multipath fading. In addition, multiple antennas are used to increase the capacity of the channel. Some two- or four-element UWB MIMO systems are reported in the literature, where there are several techniques to obtain good isolation between antenna elements. One of the most popular techniques is to place a decoupling network such as a parasite stub or slot between the antenna lements to obtain good isolation. In addition, the orthogonal feed placement technique or antenna element also provides good isolation between the antenna elements. However, it will result in a negative impact on the efficiency of the antenna because the current also resonates near its decoupling structure. The placement of the antenna elements in the same polarization and to obtain high isolation without decoupling structure by maintaining compact dimensions.

The UWB MIMO slot antenna has been designed by (Chandrasekhar Rao, Venkateswara, et al. 2016), but the UWB MIMO slot antenna uses a decoupling structure that produces isolation below -15dB and is dual polarized. In addition, there is a single UWB slot antenna design from [1] that has omnidirectional polarization but has not been developed into a 2-element MIMO UWB slot antenna.

Based on the design of a single UWB slot antenna from [2] it was developed into a 2-element UWB MIMO antenna without a decoupling structure to produce high isolation, namely the mutual coupling below -22 dB for application in UWB (Ultra-Wideband).

III. METHOD

A. Antenna Design Flowchart

The flowchart for antenna design can be seen in Figure 1.

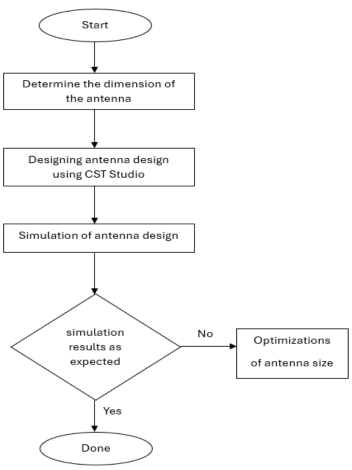


Figure 1. Antenna Design Flowchart

B. Antenna Dimensions

The antenna size obtained is a development of the design [3]. The dimension of the antenna used is mm2 with a substrate thickness of 1.6 mm. The type of substrate used is FR4 which has a dielectric constant of 4.4 and a tangent loss of 0.02. The design shape of the antenna can be seen in Figure .2.

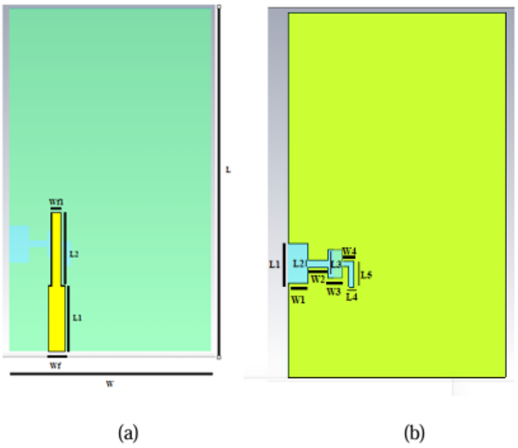


Figure 2. Single Antenna Design (a) Front View (b) Rear View

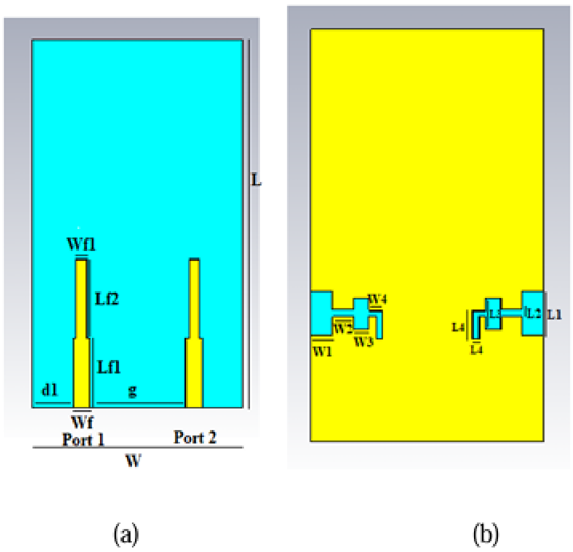


Figure 3. Two-element UWB MIMO Antenna Design (a) Front View (b) Rear View

In Figure 4 and Figure 5, you can see the design of a single UWB antenna based on the reference journal and the modified UWB MIMO antenna design. The details of the variable sizes in the antenna design above are L= 42 mm, W= 25 mm, Lf1= 8 mm, Lf2= 9 mm, Wf= 2 mm, Wf1= 1.2 mm, L1= 7.6 mm, W1= 4.3 mm, L2=0.8 mm, W2= 2.3 mm, L3= 3.2 mm, W3= 1.6 mm, L4= 0.6 mm, W4= 1.4 mm, L5= 3 mm, d1= 4.9 mm, g=11.2 mm.

III. RESULT AND DISCUSSION

A. Effect of Slots on UWB Antennas

Each element of the MIMO antenna is realized by gradually creating a slot antenna at a different resonant frequency than the UWB spectrum. The UWB antenna consists of slots fed by a 50-Ω microstrip path to gain wide bandwidth.

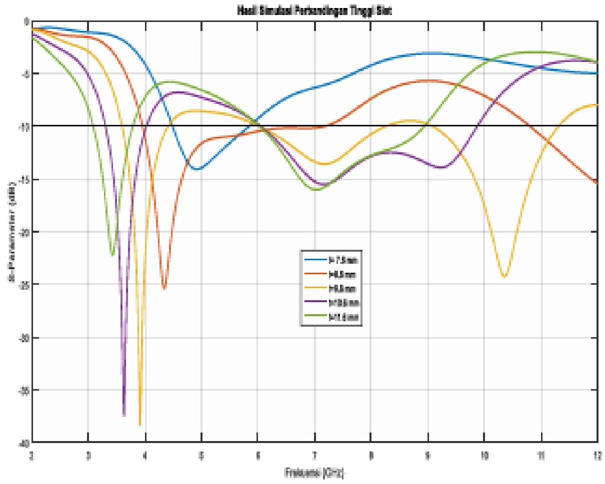


Figure 4. Slot High Comparison Simulation Results

Figure 4. shows how the high influence of slots on bandwidth and return loss. To see the influence of slot height, the author gradually increased the size of W1 by 1 mm. The initial size of W1 is 2.3 mm, resulting in a slot height of 7.6 mm obtained from the sum of W1+W2+W3+W4.

To increase the width of the bandwidth, the author increased the height of the slot to 9.6 mm. So that the bandwidth obtained is

$$BW = fu - fl$$
$$BW = 11.3\ GHz - 3.596\ GHz$$
$$BW = 7.704\ GHz$$

The increase in slot height by 2 mm makes the antenna bandwidth even larger. A bandwidth of 7,704 GHz is enough bandwidth for UWB. The frequency range obtained has also met the UWB working frequency.

However, the simulation results showed a rejection above -10dB. So the slot size must be optimized again. The next step that the author takes to optimize the size of the antenna slot is to increase the width of the antenna slot.
The simulation results of the antenna width comparison are shown in Figure 5.

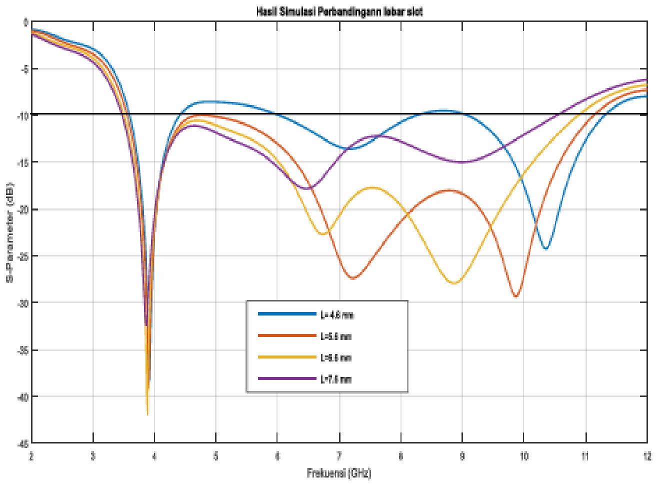


Figure 5. Slot Width Comparison Simulation Results

Figure 5. It shows a simulation of the comparison of slot widths, namely 4.6 mm, 5.6 mm, 6.6 mm, and 7.6 mm. The results show that the wider the slot, the less bandwidth the width, but the deeper the return loss.

The added slot width makes the bandwidth decrease, even though it is very thin. From the results of the s-parameter of the slot width comparison that the author can get, the most suitable slot width is 7.6 even though the resulting bandwidth width is less than 7.5 GHz, but the working frequency is in the UWB frequency range. The frequency range for UWB is 3.1 to 10.6 GHz so the bandwidth width is 7.5 GHz.

B. Comparison of Reference Antenna Parameters with Simulation Results

Table 1. Comparison of Reference Design Parameters with Design

Parameter	Reference Size	Design Size
L	42	42
In	25	25
L1	4.6	7.6
L2	0.8	0.8
L3	3.2	3.2
L4	0.6	0.6
L5	3	3
W1	2.3	4.3
W2	2.3	4.3
W3	1.6	3.6
W4	1.4	3.5
d1	4.8	5.9

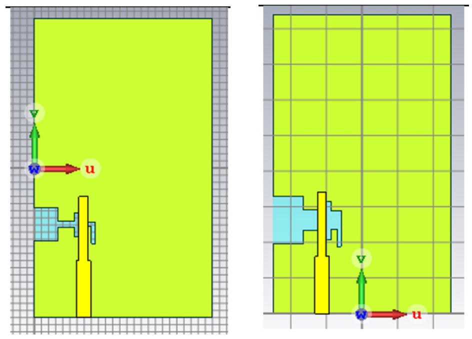


Figure 6. displays the design form of a single UWB slot antenna with the results of the antenna design simulation from the journal "Compact MIMO Slot Antenna for UWB Applications". Meanwhile, the results of the simulation that the author can see in figure 7. Comparison of S12 Insulation

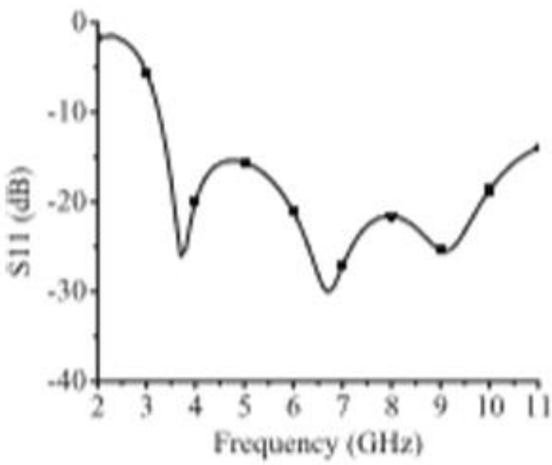


Figure 6. Simulation results of single reference UWB antenna

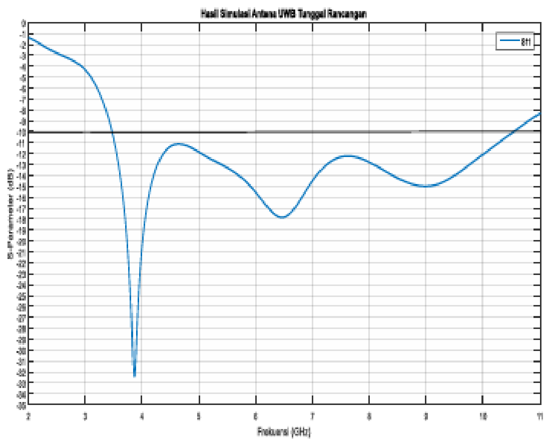


Figure 7. Simulation results of single UWB antenna design

Table 2. Comparison of Reference Antenna Parameters and Simulation Results

Parameter	Reference Antenna (Gunjan Srivasta.2016)	Antenna Design
Lower Frequency	3.1 GHz	3.4711 GHz

Upper Frequency	10.6 GHz	10.517 GHz
Bandwidth	7.5 GHz	7.0459GHz
Return Loss	-30 dB	-32.5 dB

C. Parametric Study of Antenna 1 and Antenna 2 Spacing

After obtaining the results of the simulation of a single UWB antenna that fits, the author developed a single antenna made by [4][5][6]into a 2-element MIMO UWB antenna. To obtain high isolation between antenna 1 and antenna 2 can be achieved with the help of the directional radiation properties of the antenna slots. This is affected by the distance between antenna 1 and antenna 2 (value "g"). The "g" values that will be varied are 9.2 mm, 11.2 mm, and 13.2 mm.

1).Comparison of S12 Insulation

High isolation between antenna 1 and antenna 2 can be achieved with the help of the directional radiation properties of the antenna slots. This is affected by the distance between antenna 1 and antenna 2 or by the value of "g" as shown in Figure 8

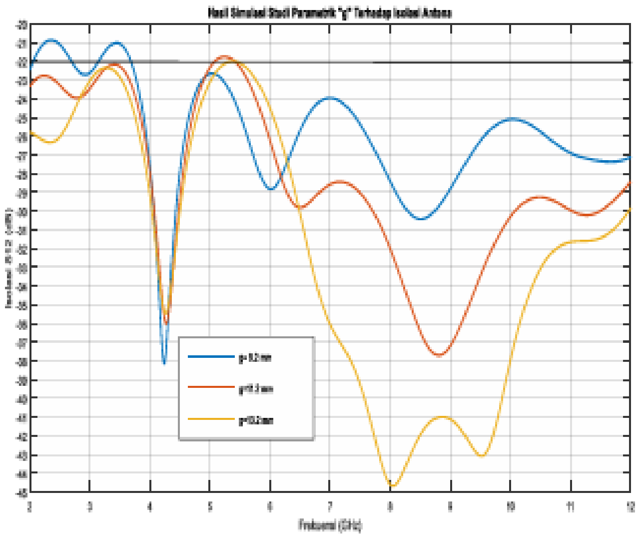


Figure 8. S12 Parametric "g" Study Against Antenna Isolation

An increase in the "g" value results in increased isolation at the expense of the overall size of the UWB MIMO antenna. Figure 4.10. proving that the farther the distance between the two antennas, the lower the mutual coupling of the antenna. This means good MIMO antenna isolation when the MIMO antenna mutual coupling is low[8][9]. The three variations in the "g" value result in fairly high isolation where the mutual coupling is below -22 dB. However, the best isolation is when the "g" value is 13.2 mm which can provide mutual coupling up to -45 dB.

2). Comparison of Return Loss and Bandwidth (S11)

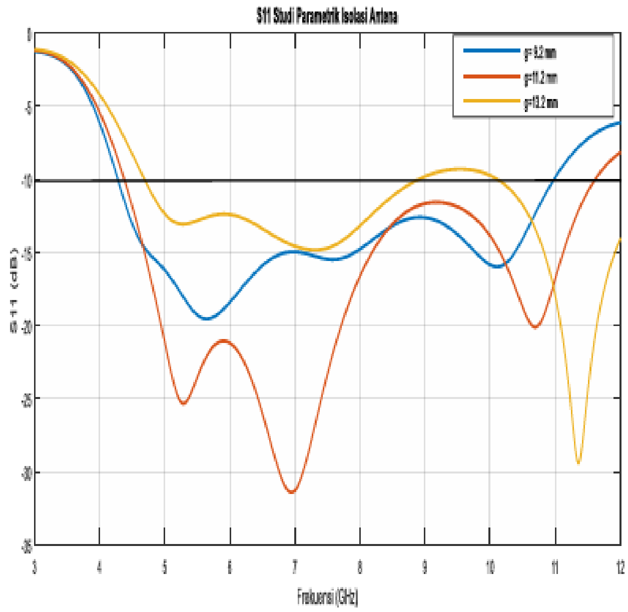


Figure 9. S11 Parametric Study "g" Against Antenna Isolation

Figure 9 shows the effect of increasing the "g" value makes the antenna bandwidth narrower and the resulting return loss deeper. This is because the size of the slot follows the location of the patch. If the patch is further down to the edge of the substrate then the slot size gets smaller, this makes the UWB spectrum of the antenna even narrower.

3). VSWR Comparison

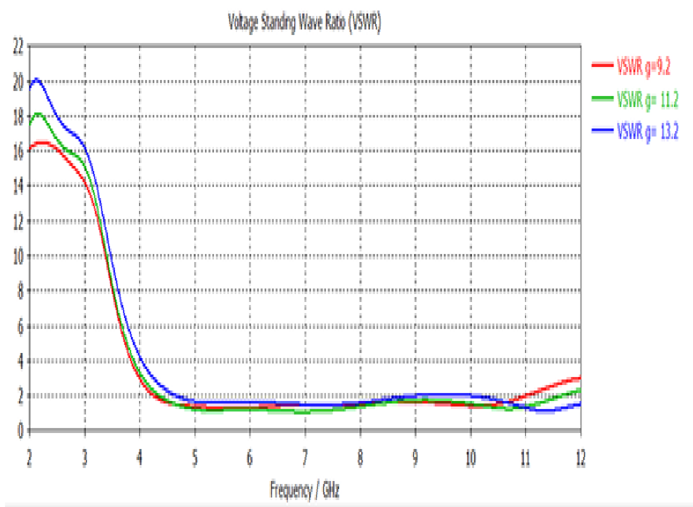
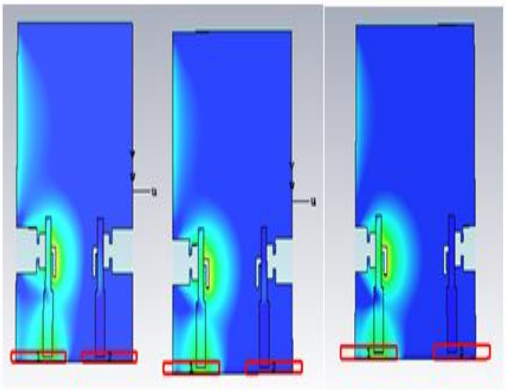


Figure 10. VSWR Comparison

Figure 14 shows that the increase in isolation did not affect the VSWR value of the antenna too much. The three variations of the value of "g" are equally good VSWR values, namely $1 \leq VSWR \leq 2$.

4). Comparison of Current Distribution



a) b) c)

Figure 11. Comparison of current distribution at 5 GHz (a) g= 9.2 mm (b) g= 11.2 mm (c) g=13.2 mm

The increased antenna isolation also improves the current distribution even slightly. If you look closely, the current spread at the time of excitation of antenna 1 is further away from antenna 2 if the "g" value is increased.

5). Gain Comparison

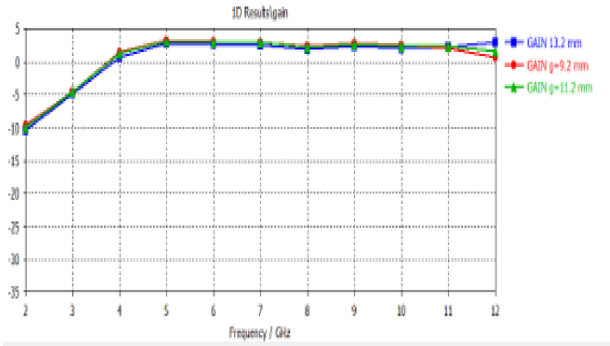
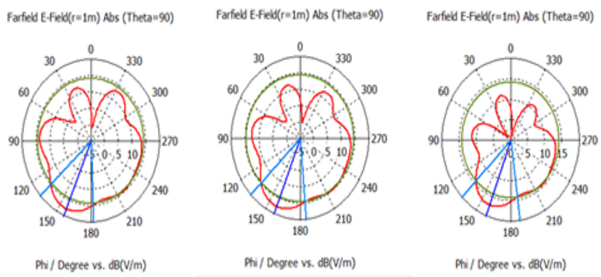


Figure 12. Gain Comparison

Figure 12 shows that the increase in antenna isolation did not affect the gain of a MIMO antenna.

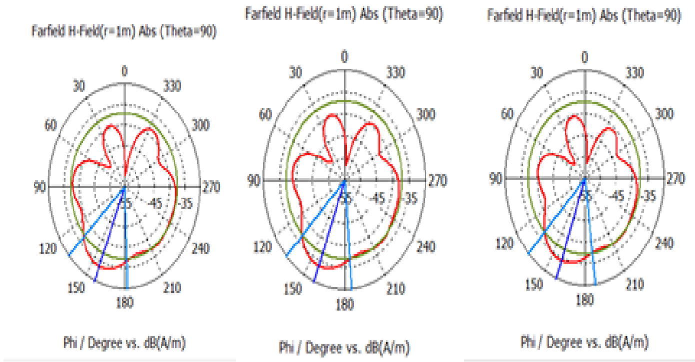
6). Comparison of Radiation Patterns



(a) (b) (c)

Figure 13 Vertical Radiation Pattern (a) g= 9.2 mm (b) g= 11.2 mm (c) g=13.2 mm

Figure 13 shows the results of the comparison of vertical radiation patterns of g= 9.2 mm, g= 11.2 mm, and g=13.2 mm. The third vertical radiation pattern is quasi-omnidirectional. Increased isolation does not affect the direction of the radiation pattern.



(a) (b) (c)

Figure 14 Horizontal Radiation Pattern (a) g= 9.2 mm (b) g= 11.2 mm (c) g=13.2 mm

Figure 14 shows the results of the comparison of horizontal radiation patterns of g= 9.2 mm, g= 11.2 mm, and g=13.2 mm. All three horizontal radiation patterns are quasi-omnidirectional. Similar to the vertical radiation pattern, the increase in isolation does not affect the direction of the horizontal radiation pattern. Based on the parametric studies that have been carried out, the most optimal "g" value is 11.4 mm or the design before it is carried out Parametric studies. because not only does it meet the basic isolation requirement of -20 dB across the UWB spectrum but the resulting bandwidth is also wider.

D. UWB MIMO 2 antenna

Element After obtaining the results of the parametric study, the best distance between antenna 1 and antenna 2, which is 11.2 mm, then the next step is to analyze the comparison of simulation results between a single UWB antenna and a UWB MIMO antenna.

1. Return Loss and Bandwidth

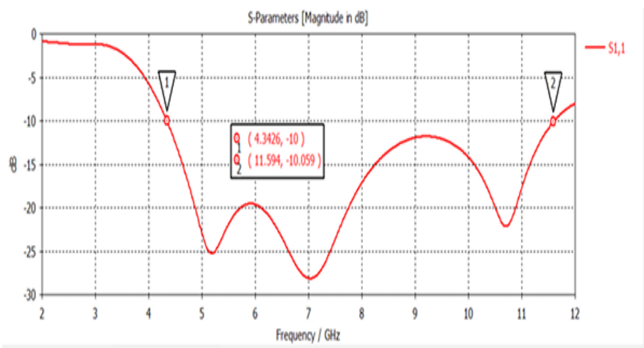


Figure 15. S11 UWB MIMO Antenna

Table 3. Comparison of S-Parameter Reference Antenna, Single UWB, and UWB MIMO Antenna

Parameter	Reference (Gunjan Srivastava, 2016)	Single UWB antenna	UWB MIMO 2 Antenna Element
Lower Frequency	3.1 GHz	3.4711 GHz	4.3426 GHz
Upper Frequency	10.6 GHz	10.864 GHz	11.594 GHz
Bandwidth	7.5 GHz	7.0459 GHz	7.2514 GHz
Return Loss	-30 dB	-32 dB	-28 dB

Figure 15 features an S11 element UWB MIMO 2 antenna. S11 is the return loss of antenna 1 which displays the frequency and bandwidth of antenna 1. In the S11 graph, it can be seen that the operating frequency range is from 4.3426 GHz to 11.594 GHz. So the bandwidth is as follows:

$$BW = fu - fl$$
$$BW = 11.594\ GHz - 4.3426\ GHz$$
$$BW = 7.2514\ GHz$$

The bandwidth generated by a 2-element UWB MIMO antenna is quite wide[9]. So that the antenna can work on a wider spectrum. Based on Table 4.6. The bandwidth generated by a UWB MIMO antenna is wider than the bandwidth on a single UWB antenna but smaller than that of a reference antenna. However, the working frequency range of the UWB MIMO antenna shifts to a higher frequency than the single UWB antenna and the reference UWB antenna.

The return loss value produced by the UWB MIMO antenna is quite good, reaching -28 dB. The return loss produced by a single UWB antenna is better compared to the UWB MIMO antenna and the reference UWB antenna. However, a return loss of -28 dB is good enough for MIMO antennas because it can provide a good distance for antenna isolation so that the return loss and antenna isolation do not intersect[10][11].

2. Antenna Isolation

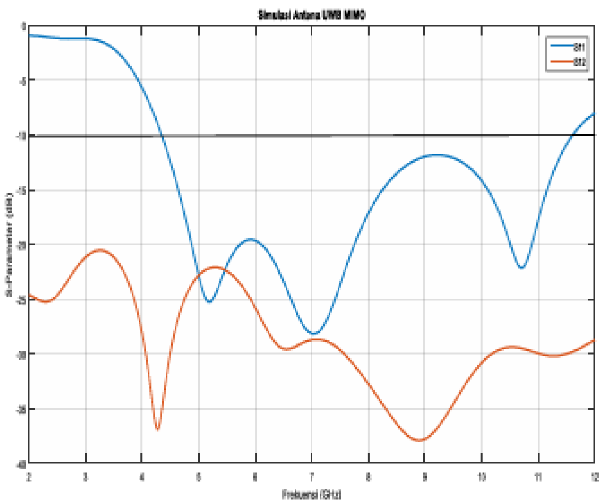


Figure 16. S-Parameter UWB MIMO Antenna

S12 chart in Figure 4.18. It is a mutual coupling between antenna 1 and antenna 2. The smaller the mutual coupling value, the better the antenna isolation. The better the isolation between the antennas, the better the MIMO antenna works. Antenna isolation in Figure 20 is very good because the S12 is below the S11 and does not interfere with the working frequency of the antenna. Although there is an S12 that intersects with the S11, it does not affect the work of antenna 1 too much because of the wide band or frequency of the UWB antenna. This is where the advantages of the UWB MIMO antenna can be seen, when there is a problem with the 5 GHz and 5.5 GHz operating frequencies, the antenna can still work on other frequencies.

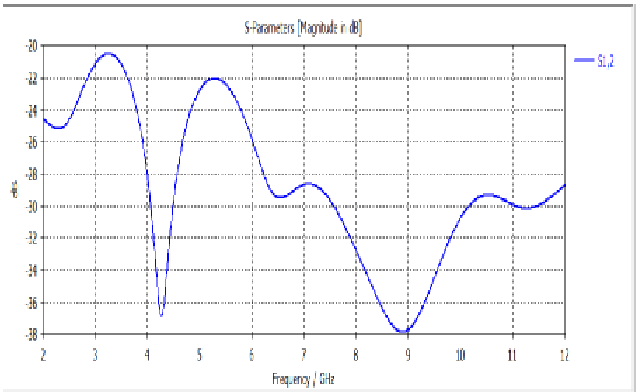


Figure 17. S12 UWB MIMO Antenna

Figure 17 shows that the isolation or mutual coupling of the antenna is below 20 dB, this means that it is under expectations. Good isolation is achieved in the absence of a decoupling structure. The placement of 2 asymmetrical antenna elements in the UWB MIMO design is proven to be able to produce low mutual coupling.

3. VSWR Antenna

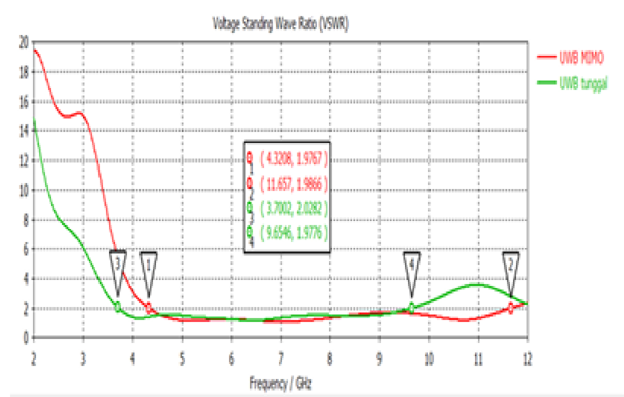
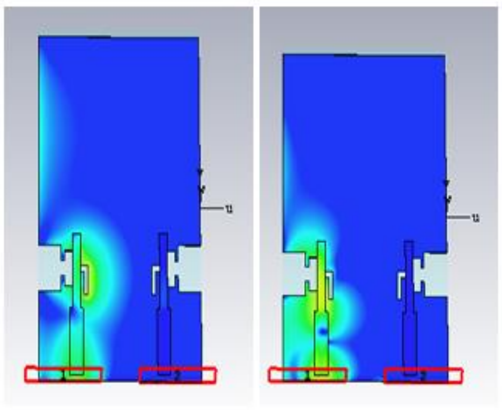


Figure 18. VSWR Comparison of Single UWB Antenna with UWB MIMO

A good VSWR is $1 \leq VSWR \leq 2$. Based on Figure 22 the VSWR value obtained by the UWB MIMO antenna is $1 \leq VSWR \leq 2$ in the frequency range of 4.3206 GHz to 11.57 GHz, while in a single UWB antenna in the frequency range of 3.7002 GHz to 9.6546 GHz. So the VSWR value generated by a UWB MIMO antenna is better than that of a single UWB antenna.

4. Antenna Current Distribution



(a) (b)

Figure 19. Antenna Current Distribution 1(a) 5GHz (b) 8GHz

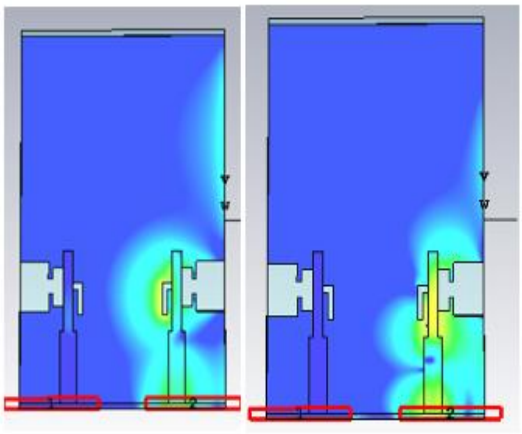


Figure 20. Antenna Current Distribution 2 (a) 5GHz (b) 8 GHz

Current distribution is a very important thing to pay attention to in MIMO antennas. The MIMO antenna works well if when one antenna 1 is excited, the amount of current in antenna 2 can be ignored, and vice versa, when antenna 2 is excited, the amount of current in antenna 1 can be ignored. Figure 20 displays the results of current distribution when antenna 1 is working on the 5 GHz and 8 GHz frequencies. Both frequencies have a good current distribution because when antenna 1 is excited by the number of

The current on the surface of antenna 1 is more, whereas the amount of current on antenna 2 is absent or ignored. This means that the MIMO antenna is working well.

5. Gain

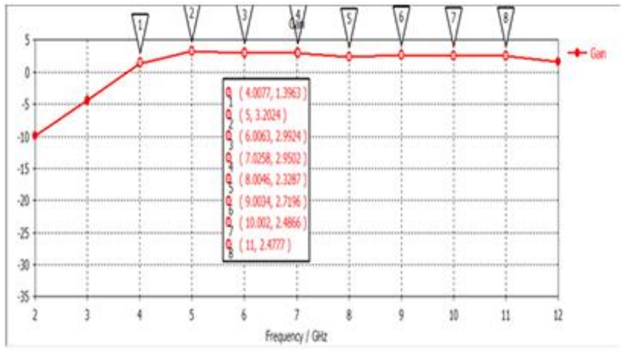


Figure 21. Gain UWB MIMO Antenna

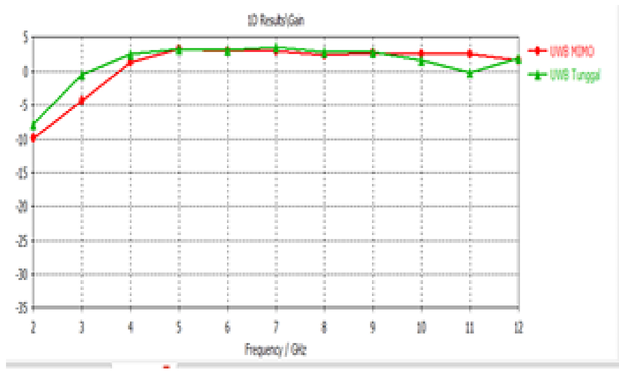
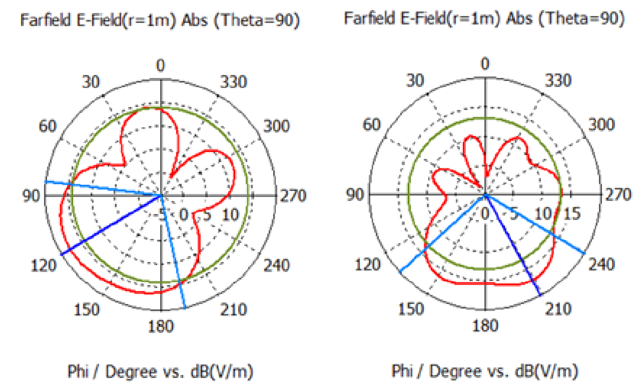


Figure 22. Gain Comparison of Single UWB Antenna with UWB MIMO

The gain of the UWB MIMO antenna obtained is about 1.3 dBi to 3.2 dBi as seen in Figure 4.23. Although a single UWB antenna is converted to a UWB MIMO antenna, the gain does not change as seen in Figure 22

6. Radiation Patterns



(a) (b)

Figure 23. Vertical Polarization at Frequency (a) 5 GHz (b) 8 GHz

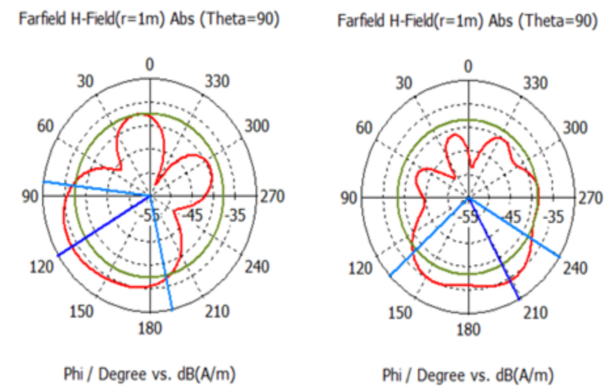
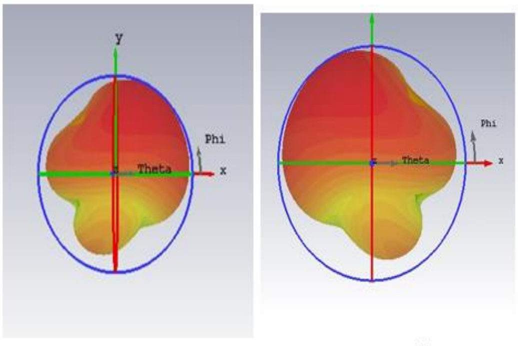


Figure 24. Horizontal Polaradiation at Frequency (a) 5 GHz (b) 8 GHz

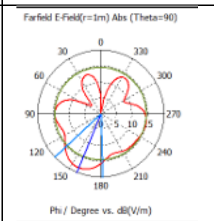
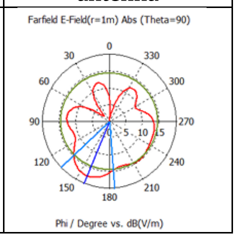
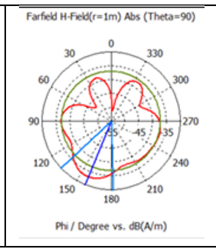
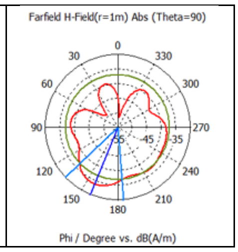


a) b)

Figure 25. 3D Polarization at 5 GHz Frequency (a) antenna 2 (b) antenna 1

Figure 24. and Figure 25. displays the results of vertical and horizontal radiation patterns on the UWB MIMO antenna. Both 5 GHz and 8 GHz frequencies have omnidirectional quasi-polarization. Due to the nature of UWB MIMO which has directional polarization. As in Figure 25. It shows that the asymmetrical placement of antenna seen 1 and antenna 2 elements forces the antenna to radiate in the opposite direction to negligible interaction between the two antennas. So the overlap of radiation patterns between the two antennas is negligible.

Table 4. Comparison of Polarization of UWB MIMO Antenna with Single UWB at 7 GHz Frequency

Polarization	Single UWB Antenna	UWB MIMO antenna
Vertical Radiation Pattern		
Horizontal Radiation Pattern		

Modifying a single UWB antenna to a MIMO UWB antenna does not affect the radiation pattern of the UWB antenna as seen in Table 4. This is very good because UWB MIMO antennas that have an omnidirectional radiation pattern are suitable for MIMO antenna systems that can act as transmitter and receiver antennas.

IV CONCLUSION

A. Conclusion

Conclusion Based on the results of the design and analysis of pliers that have been carried out in this final project, several conclusions can be drawn, namely:

1. Converting a single UWB antenna into a 2-element MIMO UWB antenna using the 2-element antenna placement technique asymmetrically can produce good antenna isolation, namely a mutual coupling value below 22 dB.
2. Converting a single UWB antenna to a 2-element MIMO UWB antenna makes the bandwidth increase to 7.2514GHz with a working frequency that also increases from 4.3426 GHz to 11.594 GHz but the return loss is reduced to -28dB. While the VSWR value remains at 1.5, as well as the gain remains at 3.2 dBi. For the horizontal and vertical radiation patterns produced by a single UWB antenna and UWB MIMO are equally omnidirectional.
3. The increase in the distance between antenna 1 and antenna 2 can provide low mutual coupling, high isolation, and better current distribution but causes the bandwidth to be narrow. Increased isolation does not affect the gain value, VSWR, and radiation pattern.

B. Suggestions

Based on the design and analysis of the data that has been carried out, the suggestions given by the author are as follows:

1. It is hoped that the manufacture of UWB MIMO antennas can further modify the antenna to work on an even wider frequency range.
2. For the manufacture of UWB MIMO, it is hoped that fabrication can be carried out to see how UWB MIMO antennas work in real life. 3. For the next design, it is expected to be able to design a UWB MIMO antenna with more than 2 elements.

REFERENCE

[1] Dirton, P. 2014. "Design and Build a Rectifier Antenna for Electromagnetic Energy Harvester at Gsm Frequency of 1800 Mhz". Thesis.Electrical Engineering, Faculty of

Engineering, University of Brewijaya.
[2] Faizal, WN. 2019. "Microstrip Massive MIMO Antenna Design for Base Transceiver Station (BTS) Applications 5th generation (5G)". Final Project. Electrical Engineering FTE ITSN.
[3] Gunjan, S. 2016. “Compact MIMO Slot Antenna for UWB Application”. IEEE Antennas and Wireless Propagation Letters, 16 (15): 1057-1060.
[4] Heri, R. 2009. "Design and Build an 8-Element Triangular Slot Microstrip Antenna with Indirect Feed Line Microstrip Enumeration for Wimax Cpe Applications". Thesis. Electrical Engineering FT UI.
[5] Nurfitriani. 2018. "Effect of Feeder Dimension on Square Patch Microstrip Antenna for DBS Ku-Band". SENIATI-National Institute of Malang, 18: 309-314.
[6] Rachmad N and Aini N.2011." Design and Build a Microstrip Antenna for Video Signal Receiver on Unmanned Aircraft". ICT Journal, 11 (6): 8-16.
[7] Yan Z dan Bingjian N.2014. “Compact Ultrawideband (UWB) Slot Antena with Wideband and High Isolation for MIMO Applications”. Program In Electromagnetics Research C, 14(54):9-16.
[8] Dwi, A.2017." Design and Build a 3-Element Linear Array Triangular Patch Microstrip Antenna as a Transmitter for Wireless CCTV (Closed Circuit Television) Camera Applications at 2.4 GHz Frequency". Thesis. Telecommunication Engineering, Department of Electrical Engineering, PNJ.
[9] Chandra, J. dkk. 2016.” Compact UWB MIMO Slot Antenna with Defected Ground Structure”. ARPN Journal of Engineering and Applied Sciences, 11(17):10487-10495.
[10] Yanjie, W. dkk. 2018.” Design of a Compact UWB MIMO Antenna without Decoupling Structure”. Hindawi International Journal of Antennas and Propagation, 18(18):1-7.
[11] Qureshi. dkk. 2011. “Performance Analysis of FR-4 Substrate for High-Frequency Microstrip Antennas”. ResearchGate, 11(8):1-4.