

Design and Development of a Multiple Input Multiple Output (MIMO) Antenna with Parasitic Structure for Ultra Wideband Applications

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Abstract— MIMO UWB antenna is one of the leading technologies in wireless communication, which offers large capacity and high data transmission speed. This technology has various benefits, one of which is the ability to reject interference. This interference rejection serves to cancel the most dominant and unwanted wavefronts that can interfere with antenna performance, thereby improving the quality of the received signal. In this study, a MIMO UWB antenna was designed by modifying the antenna design using FR-4 substrate material, which has a dielectric constant (ϵ_r) of 4.4, loss tangent of 0.02, and material thickness of 1.6 mm. The antenna works in the frequency range of 2.9 to 10.3 GHz, which is suitable for use in Ultra Wideband (UWB) communications. In addition, the antenna is also equipped with three band notched features to avoid interference from unwanted frequencies. The simulation results of this final project show good agreement with the measurements on the fabricated antenna. The return loss obtained reached -17.7 dB, while the mutual coupling value was recorded at -24.73 dB; In addition, the resulting VSWR is 1.44, indicating effective antenna performance and compliance with expected UWB communication standards.

Keywords— Antenna, Wireless, Ultra Wideband, band notched.

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I. INTRODUCTION

The world of telecommunications is experiencing rapid development. The increasing customer need for fast and flexible data communication is the background for the emergence of wireless networks [1]. In wireless communication systems, signal propagation between transmitters and receivers passes through various different paths [2]. With the existence of different trajectories the signal traversed experiences multipath fading. Where this multipath fading can cause the signal received on the user's side to be weak, damaged, and there are different phase shifts, so interference occurs [3]. So it requires a technique to overcome the effects of multipath fading and improve system quality. To overcome these weaknesses, Multiple Input Multiple Output (MIMO) technology is present [4].

MIMO is a system that consists of a number of transmitting and receiving antennas. The use of MIMO techniques can increase data rates. Microstrip MIMO antenna consists of 2 radiating elements of the same size [4]. In its implementation, MIMO antennas have been combined with

Ultra Wideband (UWB) systems for wireless communications with twice the bandwidth requirements. In addition, the benefits of UWB and MIMO are interference rejection that can cancel the most dominant and unwanted waves on the receiving antenna.

In the previously made design, a band-notched MIMO 2x2 WiMAX antenna using FR4 material measuring 25 x 38 x 1.6 mm³ with a wide bandwidth of 8.6 GHz and has a band-notched for WiMAX applications with high isolation [5].

II. THE MATERIALS AND METHOD

There are several stages in the design of the MIMO UWB microstrip antenna, namely at the initial stage starting with making a design according to the reference, then modifying it to determine the effect of the antenna structure so as to get optimal results by simulating it using CST Studio Suite 2019 software.

A. Tools and Materials

In fabricating this antenna using several tools and materials as listed in table 1 below:

TABLE 1
TOOLS AND MATERIALS NEEDED

Tools	Material
Soldering	SMA Jack Female Connector
Tin Sucker	Double Layer PCB (FR-4)
Plastic Container	Thinner
Iron	Soldering Paste
Sandpaper	Solution (H ₃ and HCL H ₂ O ₂)
File	PCB Layer Transfer Paper
Permanent Marker /	Tin
Drawing Pen	

B. Antenna Design

The overall antenna design has several steps in antenna modification. The antenna is designed on FR-4 substrate with specifications as shown in table 2 below:

TABLE 2
FR-4 SUBSTRATE SPECIFICATIONS

Substrate Specification	Value
Dielectric Constant (ϵ_r)	4.4
Dielectric Loss Tangent ($\tan\delta$)	0.02
Substrate Thickness (mm)	1.6

The design of the MIMO UWB antenna design with a Frequency range of 3.7 - 9.5 GHz is not obtained using a formula but from references that will be modified and parametric studies are carried out to obtain optimal results in accordance with the specifications. The expected specifications can be seen in table 3 as follows:

TABLE 3
ANTENNA SPECIFICATIONS

Working Frequency	3,7 – 9,5 GHz
Return Loss (S ₁₁)	≤ - 10 dB
Mutual Coupling (S ₂₁)	≤ - 15 dB
Bandwidth	≥ 500 MHz
Notched Band	≤ 1 GHz
Radiation Pattern	Omnidirectional

The final design size of the antenna in the reference is 38 x 25 mm² as shown in Figure 1 below:

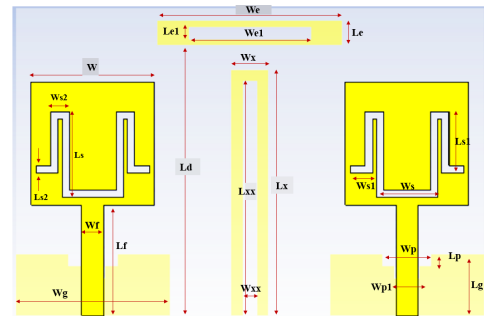


Fig. 1 Antenna Final Design Size According to Reference

TABLE 4
ANTENNA FINAL DESIGN PARAMETERS

Parameter	Ws _{ub}	Lsu _b	hsu _b	Wg	Lg	Wp	Lp	Ws1
Value(mm)	38	25	1.6	12.5	5	4	1	1.8
Parameter	Wf	Lf	W	Ls2	Ws	Ls	Ws2	Ls1
Value(mm)	1.8	9	10	0.6	5	7	1.5	5
Parameter	Wx	Lx	Wx _x	Lxx	We	Le	We1	Le1
Value(mm)	3	20	1.2	19.1	15	2	10	1

Figure 1 is the final design size of the antenna on the patch and ground plane. The values can be seen in table 4 above.

The final structure of the antenna obtained from the reference obtained results not according to the expected specifications where the optimal value of the different parameters is in table 5 below and for the antenna design image is in Figure 2 below:

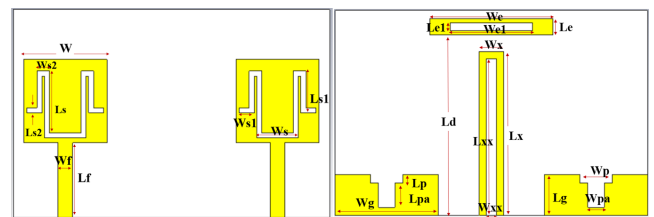


Fig. 2 Shape of the Final Project Antenna Design, left front view and right rear view

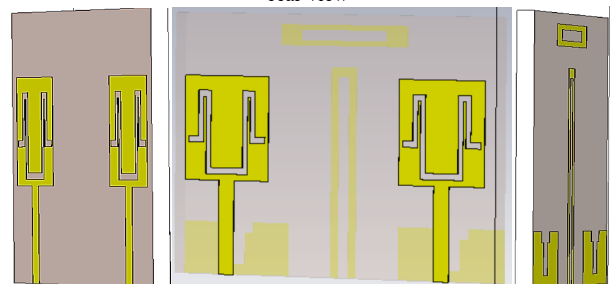


Fig. 3 Side View of the Design Shape of the Final Project Antenna Design

TABLE 5

DESIGN PARAMETERS OF THE FINAL PROJECT

Parameter	Wsu b	Ls ub	hsu b	Wg	Lg	Wp	Lp	Wp a	Lp a
Value(m)	38	25	1.6	12.5	5	4	1	2	4
Parameter	Wf	Lf	W	Ls2	Ws	Ls	Ws2	Ls1	Wsl
Value(m)	1.8	9	10	0.6	5	8	1.5	5	1.8
Parameter	Wx	Lx	Wxx	Lxx	We	Le	We1	Le1	Ld
Value(m)	3	20	1.2	19.1	15	2	10	1	22

Fig. 5 Comparison of S-Parameter Values

A comparison of the generated antenna parameters has been conducted, resulting in the values listed in Table 6 below.

TABLE 6
COMPARISON OF THE REFERENCE ANTENNA WITH THE MODIFIED ANTENNA.

	Antenna Reference [5]		Final Project Antenna	
	Simulation	Measurement	Simulation	Measurement
Working Frequency(GHz)	4.08 – 9.55	2.2 – 10.8	3.72 – 9.6	2.95 – 10.3
Return Loss (dB)	-18.18	-20.8	-23.48	-17.7
Mutual Coupling (dB)	-28.79	-36.7	-37.9	-24.73
Bandwidth (MHz)	360 (Band I)	1100 (Band I)	360 (Band I)	400 (Band I)
	2720 (Band II)	6700(Band II)	2620 (Band II)	1350 (Band II)
	190 (Band III)	730 (Band III)	730 (Band III)	1150 (Band III)
				900 (Band IV)
Notched Band (GHz)	4.44 – 5.94 8.66 – 9.36	3.3 – 3.8	4.08 – 5.84 8.46 – 8.87	3.35 – 4.4 5.75 – 6.55 7.7 – 9.4
VSWR	1.44	-	1.073	1.171
Radiation Pattern	Omnidirectional	Omnidirectional	Bidirectional	-

III. RESULTS AND DISCUSSION

The results of the design and fabrication of the modified MIMO UWB antenna are compared with existing reference antennas. The antenna performance evaluation aims to ensure that the results obtained meet the expected specifications. Figure 8 shows the appearance of the successfully fabricated antenna.

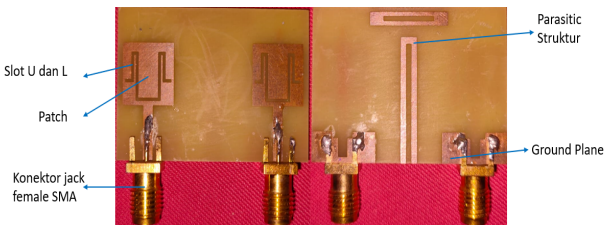
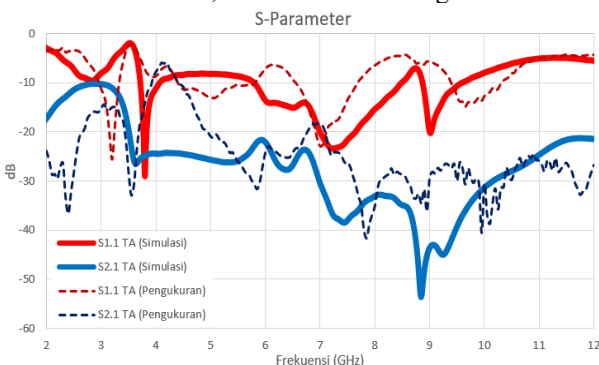


Fig. 4 Fabricated Antenna Results

Next, measurements were taken using the Keysight measuring instrument, which can only measure Return Loss and VSWR. The measurements were conducted until results close to the expected specifications were achieved.

After all the necessary parameters have been obtained, the next step is to compare the parameter results from the final project antenna simulation with the measurement results of the fabricated antenna, as shown in the image below.



A. Comparison of Return Loss and Mutual Coupling

Return loss is one of the parameters used as a comparison between the amplitude of the reflected wave and the amplitude that is transmitted. The main factor that serves as a benchmark for the quality of a designed antenna is that it should have a return loss value of ≤ -10 dB, which means that 90% of the signal can be absorbed and 10% is reflected back, indicating that the transmission line is well-matched. Or it can be said that the value of the reflected wave is not as significant compared to the wave that is transmitted.

In the simulation and measurement process that has been conducted, the fabricated antenna is compared with the designed antenna to determine the best return loss and mutual coupling in the UWB frequency range of 3.1 – 10.6 GHz.

In Figure 5 above, the results of the comparison between the final project antenna simulation and its measurements are presented. In Figure 4.3 below, the S-Parameter results from the final project antenna simulation conducted in CST software are shown. The simulation results indicate that the best operating frequency within the UWB range is at 7.24 GHz, with a return loss of -23.47 dB and mutual coupling of

-36.85 dB; From this simulation, the isolation achieved is very good because the mutual coupling does not interfere with the performance of the return loss parameter.

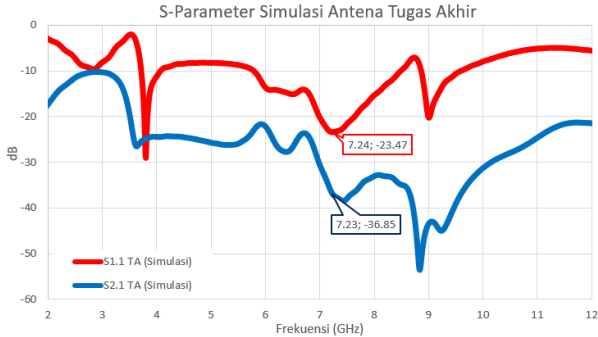


Fig. 6 S-Parameter Simulation of the Final Project Antenna

In Figure 7 below is the S-Parameter result from the final project antenna measurement. The results of return loss and mutual coupling were obtained at the same operating frequency as the simulation, which is at a frequency of 7.2-7.25 GHz. The return loss value obtained is -17.70 dB and the mutual coupling obtained is -24.73 dB; The measurement results show that the isolation is not as good as that of the simulation; here, the researcher analyses that the factors affecting the antenna are due to the antenna material not meeting the specifications.

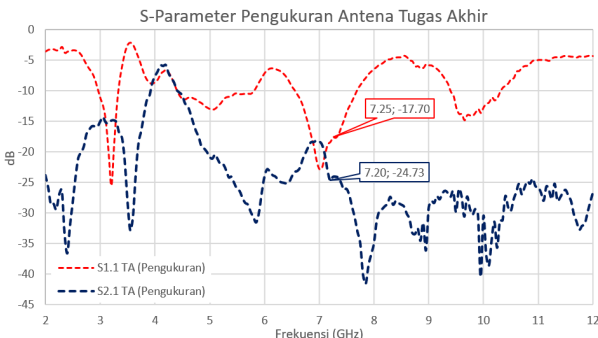


Figure 7 S-Parameter Measurement of the Final Project Antenna

B. Bandwidth and Band-Notched Comparison

Bandwidth is used to determine the performance of an antenna that can operate properly. In UWB communications, the antenna requirement must have a bandwidth greater than 500 MHz or have a fractional bandwidth (Bf) greater than 20% at all transmission times. Interference rejection or can be called a notched band in order to cancel the most dominant and unwanted waves of the receiving antenna [11].

In the simulation and measurement process that has been conducted, a graph of the operating frequency values of a MIMO antenna was obtained, ranging from 2 to 12 GHz. The frequency range of 2 to 12 GHz shows the differences in bandwidth and band notched characteristics of the final project antenna compared to the reference antenna.

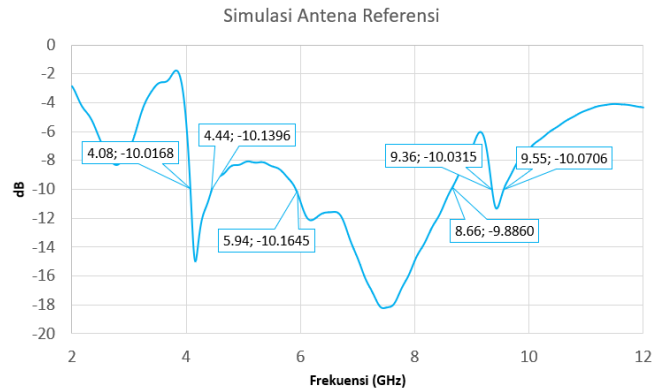


Fig.8 Bandwidth and Band Notched Reference Antenna

Figure 8 above is a simulation of the reference antenna operating from a frequency of 4.08 – 9.55 GHz with two notched bands. The first notched band is at a frequency of 4.44 – 5.94 GHz (1500 MHz) and the second notched band is at a frequency of 8.66 – 9.36 GHz (700 MHz). Due to these two notched bands, the operating frequencies of the antenna are divided into three working frequencies: the first operates at a frequency of 4.18 GHz with a bandwidth of 360 MHz (4.08 – 4.44 GHz), the second operates at 7.51 GHz with a bandwidth of 2720 MHz (5.94 – 8.66 GHz), and the last operates at a frequency of 9.46 GHz with a bandwidth of 190 MHz (9.36 – 9.55 GHz).

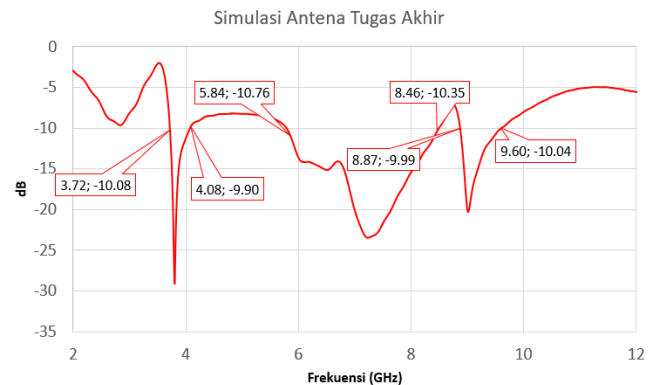


Fig. 9 Bandwidth and Notched Band of the Final Project Antenna

Figure 9 shows a simulation of the modified final project antenna, operating in the frequency range of 3.72 - 9.6 GHz, larger than the reference antenna. There are two notched bands: the first at 4.08 - 5.84 GHz (1760 MHz), slightly larger by 260 MHz than the reference antenna, and the second at 8.46 - 8.87 GHz (410 MHz), 290 MHz smaller than the reference antenna. The antenna's working frequency is divided into three: 3.8 GHz (360 MHz bandwidth), 7.23 GHz (2620 MHz bandwidth), and 9.01 GHz (730 MHz bandwidth).

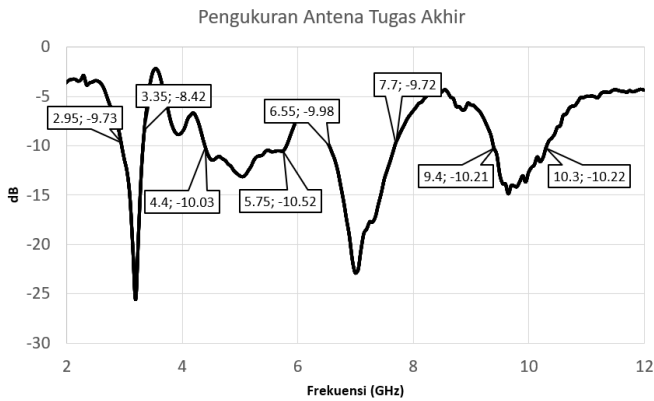


Fig. 10 Bandwidth and Notched Band of Final Project Antenna Measurement

Figure 10 represents the measurement results of the final project antenna in the antenna lab. The measurement results show that the antenna operates from a frequency range of 2.95 – 10.3 GHz, which significantly differs from the simulated antenna, which operates within a frequency range of 3.72 – 9.6 GHz. In the measurement results, the antenna has three notched bands: the first notch band is at 3.35 - 4.4 GHz (1,050 MHz), the second notch band is at 5.75 – 6.55 GHz (800 MHz), and the third notch band is at 7.7 – 9.4 GHz (1,700 MHz). Due to these notched bands, the operating frequency of the antenna is divided into four frequencies: first operating at 3.2 GHz with a bandwidth of 400 MHz (2.95 – 3.35 GHz), second at 5.05 GHz with a bandwidth of 1,350 MHz (4.4 – 5.75 GHz), third at 7 GHz with a bandwidth of 1,150 MHz (6.55 – 7.7 GHz), and fourth at 9.65 GHz with a bandwidth of 900 MHz (9.4 – 10.3 GHz). Based on the analysis of the comparison between bandwidth and notched bands, it can be concluded that the measured antenna performance is not as poor as the simulated antenna.

C. Comparison of VSWR

Voltage Standing Wave Ratio (VSWR) is the ratio between the maximum and minimum voltage occurring in a mismatched transmission line. An antenna is considered to have a good VSWR value if $1 \leq VSWR \leq 2$ dB;.

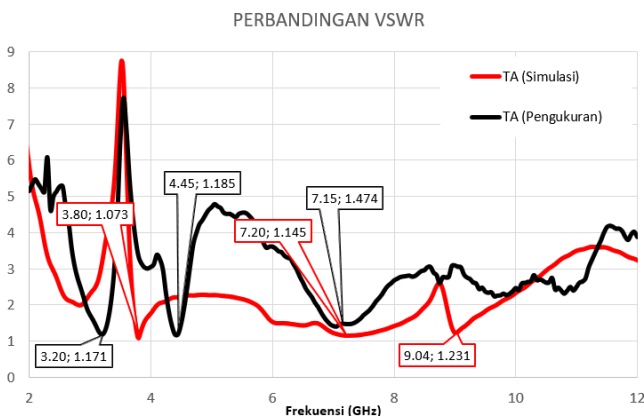


Fig. 11 Comparison of VSWR

As seen in Figure 11 below, it shows the comparison of the VSWR of the reference antenna that was simulated, the final project antenna simulation, and the measurements of the final project antenna. The average VSWR value is below 1.5 dB, with the best VSWR of the final project antenna being 1.073 dB at a frequency of 3.8 GHz. For the final project antenna measured using Keysight measuring equipment, the best value obtained was 1.171 dB at a frequency of 3.2 GHz.

Based on the results of the simulation and measurement of the antenna, it can be concluded that the VSWR value is considered good, as it meets the expected specifications.

D. Comparison of Radiation Patterns

In Figure 12 below is the radiation pattern of the reference antenna that has been simulated. When simulated, the radiation pattern is omnidirectional, although the radiation formed is not perfect.

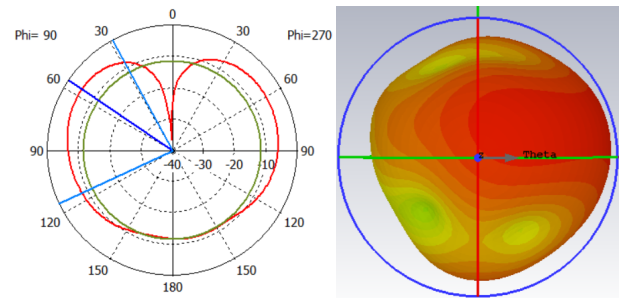


Fig. 12 2D and 3D Radiation Pattern Displays of Reference Antennas

In Figure 12, the radiation pattern of the final project antenna is displayed. It can be observed that the shape of the antenna radiation pattern is bidirectional, as the direction of the antenna's emission points towards both the front and back sides. However, the back radiation of the antenna is not perfect.

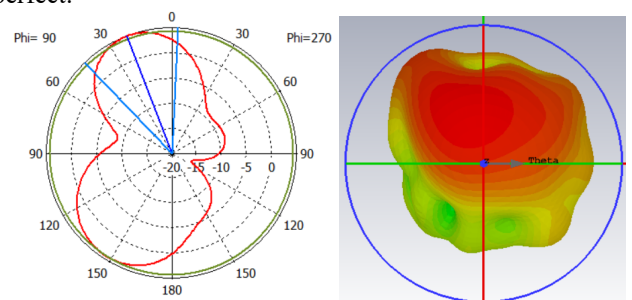


Fig. 13 2D and 3D Radiation Pattern Display of the Final Project Antenna

The difference in radiation patterns between the reference antenna and the modified antenna in the final project can be observed from the simulation results. The reference antenna has an omnidirectional radiation pattern, while the final project antenna exhibits a bidirectional radiation pattern. The measurement of the antenna radiation pattern for the final project could not be carried out due to the limitations of the measuring equipment that does not support such measurements.

IV. CONCLUSION

In this research, the design, simulation, fabrication, and measurement of a MIMO antenna with a parasitic structure for UWB applications using CST Studio Suite 2019 have been successfully carried out. The simulation results show that the antenna has a return loss of -23.48 dB and a mutual coupling of -37.9 dB at a frequency of 7.2 GHz, with a bidirectional radiation pattern. In the measurement, a return loss of -17.7 dB and mutual coupling of -24.73 dB were obtained; however, radiation pattern measurements could not be conducted due to equipment limitations.

Although there are differences between the simulation results and the measurements, such as a higher measurement operating frequency, lower return loss and mutual coupling, as well as a smaller notched band and bandwidth in the measurements, the fabricated antenna still operates within the UWB frequency range. Thus, the designed and produced MIMO antenna is considered quite suitable for application in UWB communication.

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