RECTANGULAR MICROSTRIP 2×2 ARRAY ANTENNA 10 GHZ FOR X-BAND FMCW RADAR AS LUNGS DETECTOR

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Abstract

The lungs are vital organs in the respiratory system that help carry oxygen into the body and transmit carbon dioxide. Based on data from the World Health Organization (WHO) in 2020, stated that lung disease, especially lung cancer is the third most common disease in the world, so it is necessary to check the condition of the lungs so it's possible for early mitigation if there is a problem with the lungs. Radar-based on Frequency Modulated Continuous Wave (FMCW) technology is a radar that emits low-power electromagnetic radio waves, so it can detect the lungs to make it easier for doctors to analyze patient lung abnormalities. The FMCW radar requires a type of antenna that can produce variations in the direction of the main radiation lobe by adjusting the current-feeding phase difference of each element when emitting electromagnetic waves. Based on this case, the Final Project made a rectangular microstrip antenna for a radar-based on FMCW technology.The antenna design in this Final Project is done using software that was simulated and analyzed to get the antenna's parameters and specifications. Based on the simulation in this final project, the simulation results of a 2×2 rectangular antenna array are VSWR values of 1.187 at 10 GHz, the value of bandwidth is 231 MHz, the value of gain is 11.39 dBi, and the radiation pattern obtained is elliptical.

Keywords*: Antenna array, rectangular microstrip, FMCW radar, lung detector.*

I. INTRODUCTION

The lungs are one of the vital organs in the respiratory system, one of which is to help carry oxygen into the body (inhalation) and transmit carbon dioxide (called respiration, or ex halation)[1]. The lungs are also susceptible to airborne infections and injuries. Based on data from the Forum of International Respiratory Societies, respiratory diseases are the main cause of death and disability in the world. Approximately 65 million people suffer from Chronic Obstructive Pulmonary Disease (COPD) and 3 million die each year, making it the third leading cause of death world wide[7]. Several diseases can infect the lungs, such as tuberculosis, bronchitis, and emphysema to lung disorders caused by the Severe Acute Respiratory Syndrome Coronavirus-2 (SARSCoV-2) [1]. it is necessary to check the condition of the lungs so that early mitigation can be carried out if there is a disturbance in the lungs.

One of the early detection tools that can be an alternative so that early mitigation can be carried out is a lung detection radar based on FMCW (Frequency Modulated Continuous Wave) technology. This radar requires a type of antenna that can produce variations in the direction of the lobe main radiation by adjusting each element's current-feeding phase difference. Based on this, in this study antenna will be made microstrip rectangular on a tool developed for Radar that can detect lungs based on FMCW (Frequency Modulated Continuous Wave) technology.

II. BACKGROUND

A. Lungs

Lungs are components in the respiratory system that are very important in human life. There are five layers to reach the lungs namely skin, fat, muscle, ribs, pleura and lungs[4]. The dielectric properties of the lung and other layers that increased for the average frequency range from 2 to 14 GHz can be seen in table 1[5] [6].

Table 1. Differences in the value of the dielectric constant and conductivity.

No	Part	Network Dielectric Constant (F/m)	Conductivity (S/m)	Thickness (mm)
1	Skin	33,036	6,273	2
2	Muscles	45,467	8,235	10
3	Pleura	35,441	6,707	0,2 - 0,4
4	Lungs	17,320	3,284	10

B. Antenna

Antenna is a device element in a radio communication system that functions to radiate or receive electromagnetic signals from or to free space[7]. In radio communication, a signal is transmitted from one point to another. The antenna is a device thatas an intermediary between the transmission line and the air, so the antenna must have the appropriate properties (matchacts) with the supply line.

C. Antenna Parameters

In designing an antenna with the desired specifications, related parameters must be used to determine the performance of the antenna.

- Return Loss

Return loss states the ratio between the reflected power and the input power [8].

- Voltage Standing Wave Ratio (VSWR)

Voltage Standing Wave Ratio (VSWR) is the ratio of the voltage amplitude of the standing wave, the voltage standing wave ratio of the maximum amplitude $Vmax$(||), and the minimum standing wave voltage amplitude $Vmin$(||)[7].

- Radiation

Pattern The radiation pattern is a graphical representation of the radiation characteristics of an antenna, it seems like in the figure 1 [7].

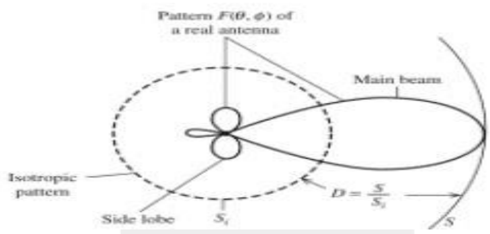

Figure 1. Antenna Radiation Pattern

- Bandwidth

Bandwidth is a frequency range where the performance of a device is still acceptable [7]. In an antenna, the bandwidth is the frequency range where the VSWR and return loss do not exceed the maximum value for the antenna.

- Axial Ratio

(Axial ratioAxial ratio) is always used as a measure of the quality of an antenna when the desired antenna polarization is circular polarization. The direction of propagation and the direction of rotation of the polarization can be seen in Figure 2[7].

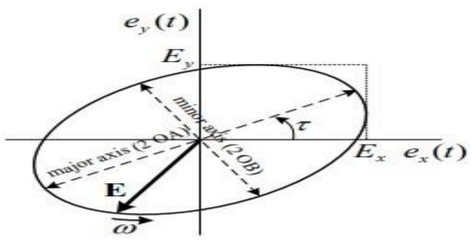

Figure 2. The Propagation Direction of Elliptical Polarization

The formula of axial ratio can be seen in the following equation [9].

$$\mathrm{AR_{dB}} = 20\log\frac{\text{Major Axis}}{\text{Minor Axis}}\ , AR<0<\infty$$

Table 2. Typespolarization based on the magnitude of axial ratio

Polarization	Axial Ratio	angle Large
polarization Linear	| AR | 40 dB	= 0°
Poalrisasi Circular	0 dB < | AR | < 3 dB	= 90°
Polarization Elliptical	3 dB |AR| <40 dB	0 ° <φ <90 °

- Gain

Gain is the ratio of the power density per unit antenna to the reference antenna power density in the same direction and power.

$$G(\theta,\phi) = \frac{4\pi\ U(\theta,\phi)}{Pm}$$

With variable information U(θ,ϕ) is the radiated power per angle unit (steradian), and Pm is the received power from the antenna[10].

- Beamwidth

Beamwidth is the measuring angle of the main lobe to values in the form of a value of 0 or a value of half power (equivalent to -3 dB). There are three parts of the radiation pattern, namely the Main lobe consisting of HPBW and Beamwidth Between First Null (BWFN), Side lobe is a radiation area that has a lower intensity than the main lobe, and back lobe is the radiation area that has a direction opposite to the main lobe, HPBW is the angle where the radiation intensity is half (-3dB) of the highest intensity. BWFN is the angle at which the radiation intensity becomes 0[7].

D. Antennas Microstrip word Microstrip is an abbreviation consisting of two words, namely micro, which means small, and strip so thewhich means microstrip chipshapedantenna is small-sized pieces. This antenna is in the form of a thin board and is able to work at very high frequencies[7].

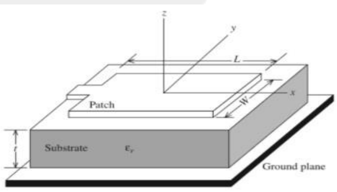

Figure 3. antenna structure Microstrip

A patch which is a microstrip antenna element made of a conductor located at the top of the microstrip antenna that radiates electromagnetic signals. Conductor materials that are often used include copper and gold. Patches have several types based on the shape, including triangle, square, circular, ring, pentagonal, ellipse[11].

E. Antenna Rectangular Patch

Patch rectangular patch (patch rectangular) has a simple shape, which allows reading theoretical analysis so that the configuration is the most widely used[10].

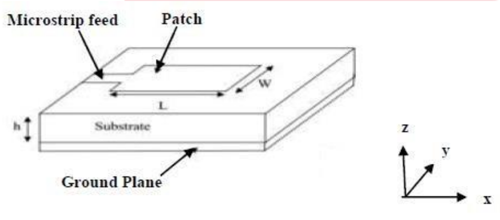

Figure 4. Rectangular patch

antennas are Rectangular patch also often modeled astransmission lines microstrip which have length (L), width (W), and substrate thickness (h). The equations used to find the length and width of theantenna microstrip are as follows[10]:

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}}.$$

To determine the length of the patch (L) we need the parameter L which is the increase in length from L due to the fringing effect. The length also required patch effective (Leff) is is formulated as which follows [10]:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon re}}.$$

So that thelength patch (L) can be found using the following equation[10]:

$$L = Leff - 2\Delta L.$$

For the formula for increasing the length of L (ΔL) it can be formulated as follows[10]:

$$\frac{\Delta L}{h} = \frac{0{,}412\ (\varepsilon re + 0{,}3)\ (\frac{w}{h} + 0{,}264)}{(\varepsilon re - 0{,}258)\left(\frac{W}{h}+0{,}8\right)}.$$

Where h is the thickness of the substrate, and$_r$ e is the effective dielectric constant which can be formulated as follows[10]:

$$\varepsilon_{reff} = \left(\frac{\varepsilon_r+1}{2}\right)\left(\frac{\varepsilon_r-1}{2}\right)\left(1+12\frac{h}{w}\right)^{-\frac{1}{2}}.$$

F. Antenna Feeding

Feeding is the channel used to provide power supply from the source to the antenna. There are several methods or types of channels that can be used to feed microstrip antennas, Coaxial probe feeding techniques which are done by perforating the patch so that it can be connected to the feed element. highest efficiency values because they are directly connected to the source. Therefore, in this final project, the coaxial probe feeding technique is used[10].

G. Array Planar Antennna antennas microstrip can be designed composition by arranging several similar antennas with a particular arrangement. Similar antennas are antennas that have the same field and phase direction diagrams with the same orientation. Array antenna is an antenna that consists of a number of radiating elements combined with the aim of getting gain a higherand a narrower radiation pattern or HPBW [10][14][15].

H. Inset-fed method Antenna with method inset-fed has advantages because it has the simplest form to implement and it is easy to study the basic behavior of patch antennas, where antenna properties can be easily controlled by inset gap and inset length[16]. By adjusting the size of the inset gap and inset length, it can reduce the value of the return loss antenna[17].

I. Radar Frequency Modulated Continuous Wave (FMCW)

The FMCW radar has radio wave energy with a stable and continuous frequency which is modulated with a triangular signal, as a result there will be frequency variations, then the reflection signal from a received target will be combined with the transmitted signal to get a beat signal[18]. Various variations of modulation are possible, but sawtooth modulation is chosen for FMCW radar applications because it is to obtain the distance and velocity of the object. The following is an illustration of the FMCW radar system[19].

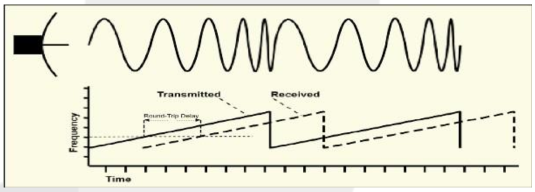

Figure 5. FMCW Radar Working System

III. SYSTEM DESIGN

Radar for electromedical devices that emit wave images so that they can detect the lungs. The radar is placed directly on the front with a distance of ± 1.5 meters and transmits electromagnetic radio waves with low power to the chest of the patient, then receives it and processes the data into a reflection level display. A picture of the lungs will appear along with plotting levels that will state the level of wetness of the lungs so that abnormalities in the lungs can be analyzed. This radar requires a type of antenna that can produce variations in the direction of the main radiation lobe by adjusting the current feeding phase of each element is emitting electromagnetic waves. The antenna used to detect the lungs is a rectangular antenna assisted by the SiversIMA RS3400X radar. The working devices used include PC/Laptop devices as radar controllers. PC/laptop is also a place to get data to be used from the antenna after the signal emitted will be reflected by the antenna. Here is the design of the FMCW Radar system for detecting:

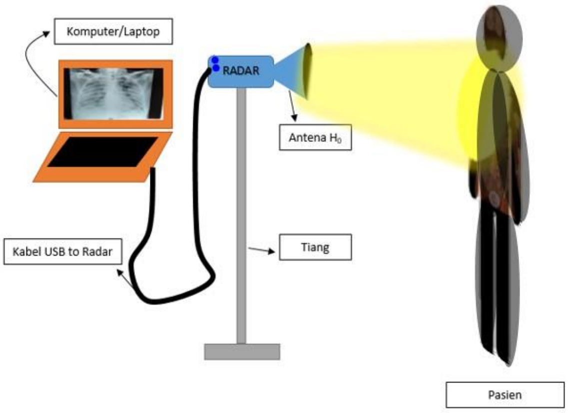

Figure 6. Illustration of Detecting Human Lungs with Radar

No	Component	Description	Dimention (mm)
1	W_p	Width Patch	9,94
2	L_p	lenght Patch	7,64
3	W_g	Width Ground Plane	14,82
4	L_g	Length Ground Plane	12,52
5	W_f	Width Feedline 50	1,81
6	L_f	Length Feedline 50	4,46
7	W_{in}	Inset-fed Width-fed	1
8	L_{in}	InsetLengthfed	2
9	H	Subsrat thickness	0,81
10	T	thickness Ground Plane	0,3
11	ε_r	Permittivity Substrates	3,55

Based on Figure 6, it can be seen that there are transmit and receive sections on the antenna which are the focus of this study. In this section, a rectangular microstrip array antenna will be arranged which can work to transmit and receive electromagnetic wave target data.

In this design, it is expected that the antenna from the design has specifications as shown below: **Table 3. Specifications of Rectangular Patch Array Antenna**

No.	Spesifikasi	Deskripsi
1.	Frequency of Operation	10GHz
2.	Gain	≥ 10 dBi
3.	VSWR	≤ 1,5
4.	Radiation Pattern	Unidireksional
5.	Polarization	Linear
6.	Input Impedance	50 Ω
7.	Bandwidth	≥ 50 MHz
8.	Return loss	> -10 dBi

In the process of designing an antenna, materials can affect a calculation, the material for making the antenna has a lot of advantages

Tabel 4. Antenna Material Characteristics

Material Characteristics	Jenis Bahan	
	Cooper	Roger 4003C
Material thickness	0,035 mm	0,813 mm
Dielectric Constant (ε_r)	1	3,55

A. Results Of Manual Calculations and Dimensional Determination

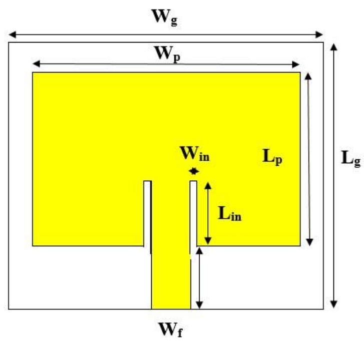

Figure 7. Initial Antenna Design

Simulation is needed before realizing the antenna in order to get the appropriate specifications and find out the optimal dimensions.

Table 5. Parameters of Initial Calculation Results

B. Simulation

- Single Patch

based on the design and calculations obtained previously, the results have not been maximized, so optimization is carried out and an inset-fed is also added so that the design becomes as shown in figure 8.

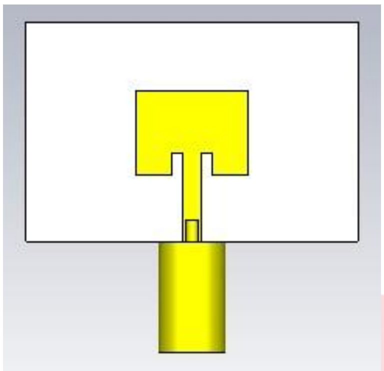

Figure 8. Antenna Design Single Patch

- Antenna Design Model Array 1×2

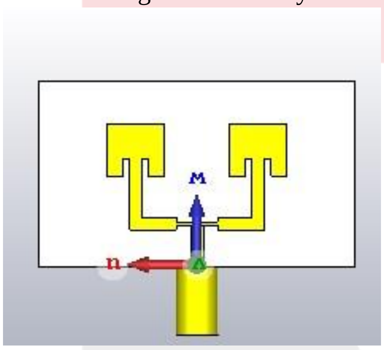

Figure 9. Antenna Design 2 Element Array

- Antenna Design Model Array 2×2

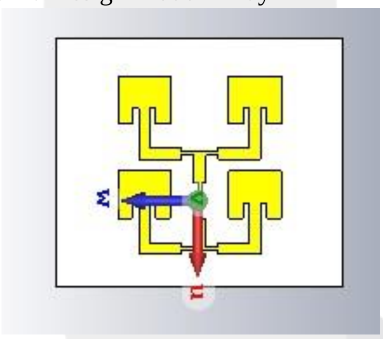

Figure 10. Antenna Design 4 Elements Arrangement

following is the simulation result of its parameters:

Table 6. Parameters of 2×2 Antenna Optimization Results

No	Component	Description	Dimensions Before Optimization (mm)	Dimensions After Optimization (mm)
1	W_p	Width Patch	8.30	8.55
2	L_p	Length Patch	7.70	7.70
3	W_g	Width Ground Plane	46.1	46.85
4	L_g	Length Ground Plane	27	40.40
5	W_f	Width Feedline 50	1.8	1.8
6	W_{f2}	Width Feedline 70.71	0.5	0.5
7	L_f	Length Feedline 50	6	6
8	L_{f2}	Length Feedline 70, 71	6	6
9	W_{in}	width Inset-fed	1	1
10	L_{in}	length Inset-fed	2.5	2.5
11	Sub L	Substrate Distance	17	17
12	h	Substrate Thickness	0.81	0.81
13	t	Thickness Ground Plane	0, 3	0.3
14	ε_r	substrate permittivity	3.55	3.55

From the optimized parameters, the simulation results are obtained as follows.

1) Return loss, VSWR, and Bandwidth

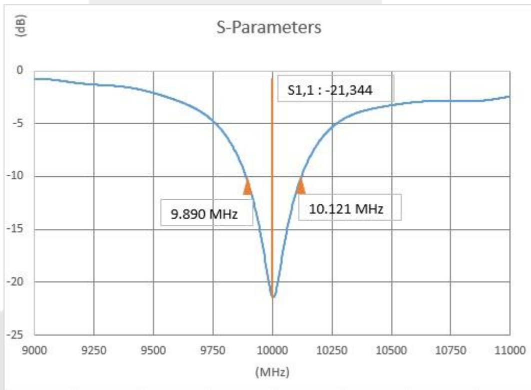

Figure 11. Value Return Loss Antenna Antenna array 2×2

In Figure 11 shows the working frequency of the microstrip antenna at 10 GHz has a value that return loss has met the criteria of -10 dB, which was obtained -21.34 dB, so the VSWR obtained was 1.187 (meets criteria). In addition, the bandwidth obtained is 231 MHz, it meets the requirements, namely 50 MHz

2) Polarization

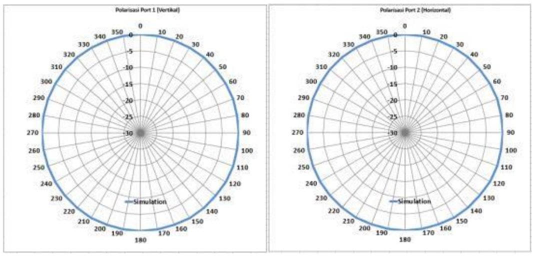

Figure 12. The value of the polarization of the antenna array is 1×2

Figure 12 shows that the AR value = 40, so it can be concluded that it has fulfilled the initial design, which has linear polarization.

3) Radiation Pattern

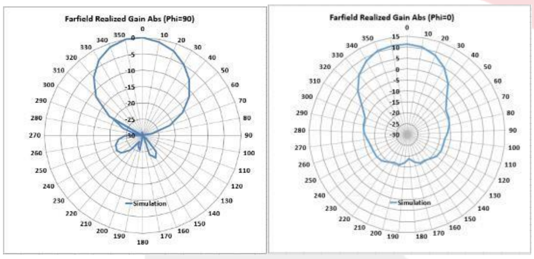

Figure 13. Value of antenna radiation pattern array 2×2

Based on Figure 13, the radiation pattern generated by the antenna in this design is a unidirectional pattern radiation pattern, according to the desired specifications.

4) Gain

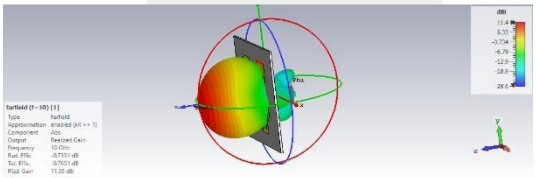

Figure 14. Radiation Pattern and Gain Antenna array 1×2

Based on Figure 14 the value gain generated by the designed antenna is 11.39 dBi, so it is by the expected antenna specifications, namely at 10 dBi.

C. Comparison of Simulation Results Simulation

This final project has shown that simulated more patch radiating the gain produced higher and beam produced by the smaller so that with the simulation experiments carried out to increase the gain, it is necessary to increase the number of Arrays.

Table 7. Comparison of Simulation Results

Parameters	Simulation 1	Simulation 2	Simulation 3
range Frequencyat Return loss -10 dB	9.909 GHz-10.106 GHz	9.890 GHz-10.164 GHz	9.890 GHz-10.121 GHz
Input impedance	50 Ω	50 Ω	50 Ω
Return loss at 10 GHz (-10 dB)	-12.7 dB	-20.32	-21.34 dB
Gain (>10 dBi)	6.89dBi	8.264dBi	11.39 dBi
radiation pattern	Unidirectional	Unidirectional	Unidirectional
Polarization (Linear)	Linear	Linear	Linear

IV. MEASUREMENT AND ANALYSIS

A. Antenna Realization

Based on the most optimal simulation results in chapter III, the next step is antenna fabrication. The materials used in the fabrication are copper for the ground plane and patch with a thickness of 0.035 mm and material Rogers 4003C for the substrate with a thickness of 0.813 mm. After being fabricated, the antenna will then be measured based on the parameters reviewed in this Final Project. The parameters reviewed are return loss, bandwidth, input impedance (Z_0), radiation pattern, polarization, and gain. The following is an antenna measuring 40.40mm × 46.85 mm which has been fabricated based on the simulation results.

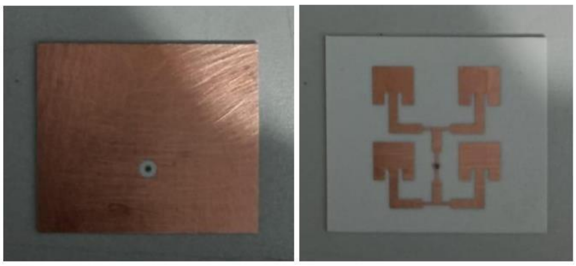

Figure 15. Antenna Realization

B. Antenna Measurements measurements in this final project were carried out at Radar Telekomunikasi Indonesia (RTI). Measurements are carried out in two stages, namely, measurements indoor (near field) which will produce values return loss, bandwidth, and input impedance, and measurements outdoor (far-field)which will produce gain, polarization, and antenna radiation patterns.

- The Near Field Measurement measurements made to obtain the return loss, VSWR, and input impedance values were carried out indoors (indoor) and only involved one antenna to be measured (port single). This measurement uses Network Analyzer E5063A with a frequency range of 300 KHz to 20 GHz.

A) return loss

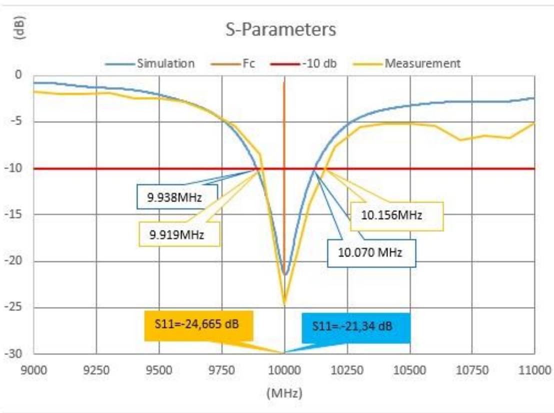

Figure 16. Value Return Loss

Figure 16 shows that the return loss at a frequency of 10 GHz amounted to -24.663 dB. This value already meets the initial antenna specifications, which is -10 dB, this value is different from that estimated in the simulation, which is -21.34 dB.

B) VSWR

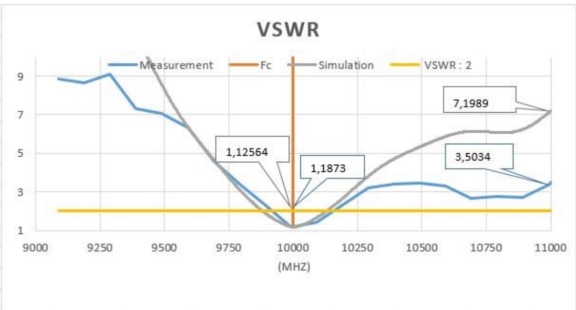

Figure 17. Comparison of VSWR Values in Measurement and Simulation

From Figure 17, it shows that the VSWR value at a frequency of 10 GHz is 1.187. This value already meets the initial antenna specifications, which is 2, this value is not much different from that estimated in the simulation, which is 1.125.

C) Bandwidth

Based on Figure 16, the limit value is -10 dB, bandwidth is obtained from the difference between the upper and lower frequencies:

$$\text{Bandwidth} = \text{Marking } 3 - \text{Marking } 2 = 10{,}156 - 9.919$$
$$= 237 \text{ MHz}$$

This value is almost the same as that estimated in the simulation, which is 231 MHz. In measuring the value, theira pattern,bandwidth is only a slight difference from the simulation, which is 6 MHz.

D) Input Impedance measurement results

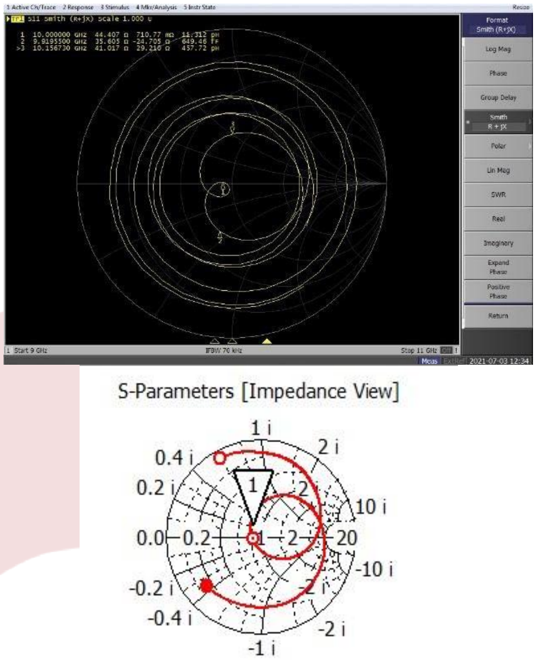

Figure 18. Value of Input impedance Realization and Design

Figure 17 shows that the antenna input impedance value is 44,407Ω + 710,77j mΩ, the value obtained is close to the specification, namely, the input impedance is 50.

- The Far Field Measurement In the process of measuring the far-field (outdoor), a reference antenna in the form of an antenna is used horn with the following specifications.

Center frequency	=	10 GHz
Gain	=	15.5 dB.
D	=	1 m

A) Antenna Radiation Pattern The antenna

The radiation pattern is the ratio of the power levels coming out of the antenna in various directions. The antenna radiation is measured in the far-field of the antenna and the antenna is not affected by objects around it. Polarization is measured by placing the antenna in a vertical or horizontal position.

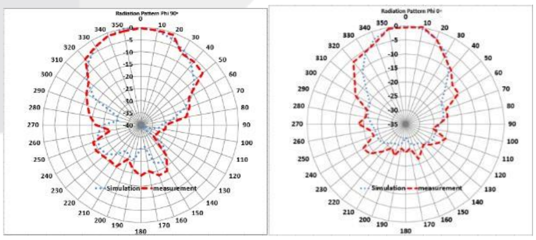

Figure 18. Comparison of Azimuth and Elevation on measurement and simulation.

From the measurement results, it can be seen that the radiation pattern is both azimuth and elevation. The results that occur are some are close to the specifications that have been previously determined. The radiation pattern obtained is close to apattern unidirectional.

B) Polarization

The antenna polarization measurement configuration is still the same as when measuring the antenna radiation pattern. However, in the polarization measurement, the position of the receiving antenna is rotated horizontally by 10°. After getting the data, to see the polarization obtained, then the data is processed using Microsoft Excel 2016.

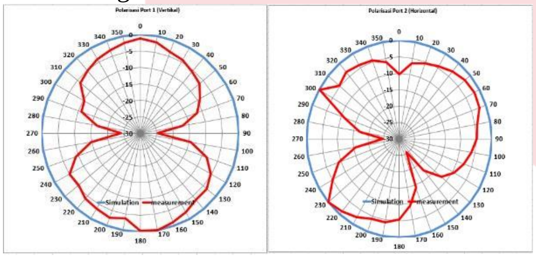

Figure 19. Comparison of Measurement and Simulation Polarization Values.

The simulation results obtained have met the desired specifications, namely AR is at a value of 40 dB (Linear). While the measurement of the fabrication results obtained results based on the calculation of the ratio of the electric field strength with the equation At port 1:

Maximum receiving power (mayor axis) = 0dBm

$$= 1 \times 10^{-3} \text{ Watt}$$

Minimum receiving power (minor axis)

$$= -24{,}66\text{dBm}$$

$$= 3{,}42 \times 10^{-6}\text{Watt}$$

$$= \frac{\sqrt{\text{Pwatt sb.mayor} \times 377}}{\sqrt{\text{Pwatt sb.minor} \times 377}} = \frac{0{,}614}{0{,}035} = 17{,}5$$

Electric field strength ratio (numeric)
On port 2:

Maximum receiving power (mayor axis) = 0dBm

$$= 1 \times 10^{-3} \text{ Watt}$$

Minimum receiving power (minor axis)

$$= -25{,}48\text{dBm}$$

$$= 2{,}83 \times 10^{-6}\text{Watt}$$

Electric field strength ratio (numeric)=

$$\frac{\sqrt{\text{Pwatt sb.mayor} \times 377}}{\sqrt{\text{Pwatt sb.minor} \times 377}} = \frac{0{,}614}{0{,}032} = 19{,}18$$

Then converted into dB = 10 log (19.18) = 12.8 dB.

The calculation of the electric field ratio from port 1 and port 2 shows that the antenna is elliptically polarized because its AR is 3 dB AR 40 dB. To get circular polarization the value must be at the value of 0 dB AR 3 dB, while for linear polarization it is 40 dB.

C) Gain

The process of measuring gain is done by placing a reference antenna (antenna horn) and the antennas are measured alternately as transmitters and receivers, respectively. This data collection was carried out as many as 10 samples to get precise results. The measurement results are in table 6.

Table 8. Results Value Gain Measurement

Measurement Gain10 GHz		
Sample Measurement	Receive Power (dBm)	Receive Power (mW)
1	-48.75 1,33352E-05	
2	-49.6 1,09648E-05	
3	-48.45 1,42889E -05	
4	-48.81 1.31522E-05	
5	-49.9 1.02329E-05	
6	-49.1 1.23027E-05	
7	-48.87 1.29718E-05	
8	-49.78 1.05196E -05 9 -49.2 1.20226E-05	
10	-49.78	1.05196E-05
Average	-49.19696554	1.2031E-05

Based on Table 6, the gain value is obtained with theequation link budget

$$\text{Pr (Power Receive)} = \text{Pt (dB)} - \text{LSt (dB)} - \text{FSL(d) (dB)} + \text{GAr (dB)} + \text{GAt (dB)} - \text{LSr (dB)}$$

With the formula:

$$\text{FSL (d) (dB)} = 32.45 + 20\text{Log10F(MHz)} + 20\text{Log10D(km)}$$

With a value of:

Pt (Power Transmiter) =	0	dB
Pr (Power Receiver) =	-49.19696554	dB
LSt (Loss Cable) =	-1	dB
GAt (Gain Antenna Transmiter) =	15.5	dB
FSL (D) =	-52.45	dB
LSr (Loss Cable) =	-1	dB

So that the GAr (Gain Antenna Receiver) value is 10.246 dBi. Although the estimates differ in the simulation, which is 11.39 dBi, the results obtained still meet the desired specifications, namely >10 dBi.

C. Measurement Analysis

Based on a series of processes, the following is a comparison table between the simulation results of a 2×2 microstrip array antenna using 3D simulation software and measurements based on the fabrication results.

Table 9. Comparison of Simulation and Measurement Results

No	Parameter	Simulation	Measurement
1.	Range frequency at return loss -10 dB	9.890 GHz 10.121 GHz	10.156 GHz 9.919
2.	GHz-inputimpedance of	50 Ω	44,407Ω + 710,77j mΩ
3.	Return loss at 10 GHz (-10 dB)	-21.34 Db	- 24,663 dB
4.	Gain (>10 dBi)	11.39 dBi	10,246 dBi
5.	Radiation pattern	Unidirectional	Unidirectional
6.	Polarization (Linear)	Linear	Elliptical

The results obtained based on Table 7, can be concluded that the simulation and measurement results are not much different, there are some differences in values that are not too significant big. What is different is the shape of the polarization.

V. CONCLUSIONS

From the research process, the final project titled "Antenna Structure 2 × 2 Microstrip The 10 GHz Rectangular For FMCW X-Band RADAR as a Lung Detector is as follows.

1. Using the method inset-fed makes optimization easier, but in this Final Project, although the gain increases after adding the inset-fed, it can be seen in simulation 1 and simulation 2 from 3.63 dBi to 6.89 dBi, but the return loss is reduced from -25.33 dB. to -12.7.
2. The more the patch radiating the gain produced higher and beam generated smaller, so the simulation experiments were conducted to increase the gain, so it is necessary to increase the number of Array.
3. The 2×2 Rectangular Microstrip Array Antenna is designed to work in the range frequencyof 9.919 GHz -10.156 GHz with a return loss of -24.663 dB at 10 GHz and a gain of 10.246 dBi. Thus,
4. this antenna design has fulfilled the need range for the desired working frequencyat 10 GHz with return loss 10 dB, bandwidth 50 MHz and gain 10 dBi. However, the polarization obtained when the measurement is an ellipse does not match the desired specification, which is linear.

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