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Design of Rectangular Patch Array 2x4 Microstrip Antenna on C-Band for Weather Radar Applications

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Abstract

Weather radars are essential for detecting rainfall, calculating movement, and estimating the object type (rain, snow, or hail). For such applications, the C-Band frequency range of 3.7 GHz to 4.2 GHz is typically utilized. A key challenge lies in improving antenna gain for better system performance. This research aims to design a C-Band downlink microstrip antenna at a working frequency of 3.9 GHz. We used a 4 x 2 array to increase the gain. Before designing, we did calculations using the CST Studio Suite 2019 software. The results of our design are a return loss of -29,171 dB, a VSWR of 1.061, a bandwidth of 713 MHz, and a gain of 8.23 dB. This research contributes an improved gain and bandwidth contribution of this study is the better gain and bandwidth compared to similar studies.

I. INTRODUCTION

The need for information about weather conditions, both local and regional, is essential in Indonesia [1]-[4]. Accurate weather information for forecasting and mitigating weather, climate, and disasters are useful for transportation, agriculture, and industry [1], [3]. Indonesia employs several types of weather radars such as Gematronic Radar, Baron Radar, and Vaisala Radar, which operate on the C-Band frequency with specific antenna types, and EEC radar, which can function on both C-Band and X-Band frequencies [1].

The performance of radar largely depends on the design of its antenna. Studies have aimed at improving the performance of radar antennas. For example, [5] has introduced a Microstrip antenna with a 16 x 1 array to increase gain, while [6] [7] proposed a microstrip antenna design for the altimeter. Additionally, several researchers proposed the design of antennas at the C-Band frequency [8], [9].

In previous studies, the microstrip antenna design resulted in a gain of 5.6 dB [8] and 3.9 dB [7]. Meanwhile, the Vivaldi method resulted in gains ranging between 4.8 and 8.02 dB, where this research emphasizes on bandwidth capacities. While radar systems do not require need broad bandwidth, as the data transmitted is relatively small and to avoid interference with other communication [8], [9], [10], increasing the antenna gain remains an important goal to improve the performance of an antenna.

This research aims to design a radar antenna with superior gain. We have used a rectangular microstrip with a 2 x 4 array and feed line model [11], [12]. The novelty of our research is that the gain value is greater than the existing reference research.

II. BACKGROUND STUDY

A. *Microstrip Antenna*

Microstrip antennas are valued for their compact shape and size, making them highly suitable for applications where small size and portability are essential. Their design allows for easy integration with a range of electronic circuits (such as ICs), active circuits, and passive circuits) [7]. The versatility of these antennas makes them ideal for use in satellite and radar communications, military operations, and mobile applications [13].

B. *Antenna Design*

The calculation to determine the rectangular patch through Equation 1.

$$W = \frac{c}{2f\sqrt{\frac{\varepsilon r + 1}{2}}} \quad (1)$$

Where:
- W = Patch Weight
- c = speed of light ($3x10^8$ m/s)
- f = working frequency of the antenna (Hz)
- ε_r = Dielectric constant of the substrate.

Meanwhile, to determine the length of the rectangular patch, the parameter l is needed. How does the fringing effect contribute to the increase in length beyond *l*? The increase of *l* (Δl) is expressed through Equation 2.

$$\Delta L = 0{,}412\ h \left(\frac{(\varepsilon_{reff} + 0{,}3)\left(\frac{W}{h} + 0{,}262\right)}{(\varepsilon_{reff} - 0{,}258)\left(\frac{W}{h} + 0{,}813\right)} \right) \quad (2)$$

where *h* is the height of the substrate and ε_{reff} is the effective dielectric constant expressed through Equation 3.

$$\varepsilon_{reff} = \frac{\varepsilon r + 0{,}3}{2} + \frac{\varepsilon r - 1}{2} \left(\frac{1}{\sqrt{1 + 12\left(\frac{h}{W}\right)}} \right) \quad (3)$$

By getting the value of ε_{reff}, we can determine the length of the rectangular patch, which is expressed by Equation 4.

$$L = L_{eff} - 2\Delta L \quad (4)$$

The next step is to determine the distance between elements (*d*). This calculation is needed so that the neighbouring elements do not overlap with each other. The calculation to determine the distance between elements is expressed through Equation 5.

$$d = \frac{c}{2f_r} \quad (5)$$

First, we determine the patch and the distance between the elements, and the next step is to determine the wavelength λ_0 of the air on the antenna and the wavelength on the transmission line, using Equation 6.

$$d\lambda_0 = \frac{c}{f} \quad (6)$$

Next, the channel wavelength is calculated in advance to get the length and the width of the transmission line. The calculation of the channel wavelength (λ_d) is expressed through Equation 7.

$$\lambda_d = \frac{\lambda_0}{\sqrt{\varepsilon_r}} \quad (7)$$

The effective dielectric constant (λ_g) is calculated using Equation 8, and then the length of the transmission line (L_T) is calculated through Equation 9.

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon reff}} \quad (8)$$

$$L_T = \frac{\lambda_d}{4} \quad (9)$$

Furthermore, the width of the transmission line (W) is determined through Equation 10.

$$W = \frac{2h}{\pi}\left\{B - 1 - Ln(2B - 1) + \frac{\varepsilon_r - 1}{2\ \varepsilon_r}\left[\ln(B - 1) + 0{,}39 - \frac{0{,}61}{\varepsilon_r}\right]\right\} \quad (10)$$

where, the value of *B* is expressed by using Equation 11.

$$B = \frac{60\ \varepsilon_r^2}{Z_0\sqrt{\varepsilon_r}} \quad (11)$$

C. Antenna Characteristics

The Voltage Standing Wave Ratio (VSWR) is the maximum and minimum standing wave amplitudes ratio. It is a parameter that determines how well the antenna is matched with the transmitter, indicated by the ratio of incident to the reflected waves that form the standing wave.

Antenna Return Loss shows the power lost due to an impedance mismatch between the transmission line and the antenna's input impedance. It is closely related to VSWR as both are affected by the interaction between transmitted and reflected wave and are critical for determining the match between the transmitter and the antenna [14].

A bandwidth or *frequency band* of an antenna is defined as the width within which antenna performs effectively. This performance is related to several characteristics (such as input impedance, beamwidth, polarization, gain, efficiency, VSWR, and return loss) that meet standard specifications [14].

Gain is the ratio of the maximum radiation intensity of an antenna to the radiation intensity of a reference antenna with the same input power. Gain is an inverse comparison with beamwidth; if we increase the gain value, the beamwidth value will decrease [15].

The radiation pattern is defined as a mathematical function or a graphical representation of the spatial coordinate function of the radiation properties of the antenna. Radiation properties can include flux density, radiation intensity, field strength, or polarization. Usually, the most critical property of radiation is the three-dimensional or two-dimensional distribution of the radiated energy.

D. Weather Radar

A *weather radar* is a specialised meteorological tool designed specifically to monitor various atmospheric phenomena. It uses echoes from scanning multiple levels to detect clouds and their movement, rain distribution and intensity, wind and direction speeds, and thunderstorms [1]. Most weather radars integrate systems operating within the C-band frequency, and, in some areas, the X-band frequency. These radars are essential for providing detailed meteorological and climatological data, particularly adept at detecting precipitation, particularly from water particles in clouds.

Due to the high frequency of observations by radar, weather radar data generates quite large amounts of data, which vary depending on the type of radar product. This data is then transferred and backed up to the regional BMKG station or the central BMKG (Meteorology Climatology and Geophysics Council of Indonesia). In instances where data transfer is not immediately processed and data storage area at the radar location is completed, new incoming data will overwrite the existing stored data [1].

III. METHOD

In this design, we performed a simulation with CST software. Once the desired parameters were achieved, we manually produce the antennas based on our simulation. The initial parameters of the design are presented in Table 1.

Table 2 and Figure 1 present the results of our initial design with the CST Studio Suite 2019 software. This final design result was iteratively developed, starting from designing a single antenna without a patch. Since the gain value achieved with a single rectangular antenna did not meet our target, we expanded the design by increasing the number of arrays 1x2, 2x2, and 2x4. The desired gain was successfully achieved with the 2x4 array condition. In this optimization, the try-and-error method is used to reach the optimal value as expected. It is this 2x4 patch array antenna that we recommend for potential implementation in Indonesian weather radar systems.

Table 1
Antenna Specifications

Paramater	Value
Frequency of Work	3,9 GHz
Return Loss	<-10 dB
VSWR	<2
Bandwidth	500 MHz
Gain	>5 dB

Table 2
Rectangular Patch Antenna Dimensions Proposed Design

Parameter	Dimension (mm)
Weight Patch (W_p)	20.05
Long Patch (L_p)	9
Distance between element (*d*)	30
Weight Substrate (W_{sub})	135
Long Substrate (L_{sub})	60
Weight ground plane (W_g)	95
Long ground plane (L_g)	60
Weight Transmission (W_f)	2.8
Long Transmission (L_f)	11.5
Distance between element (W_{fd})	5
Weight Transmission 1 (W_{f1})	3
Long Transmission 1 (L_{f1})	7
Weight Transmission 2 (W_{f2})	4,8
Long Transmission 2 (L_{f2})	9
Hight ground dan patch (*t*)	0.1
high Substrate (*h*)	1.6
Weight Slot (W_{slot})	45.6
Long Slot (L_{slot})	17

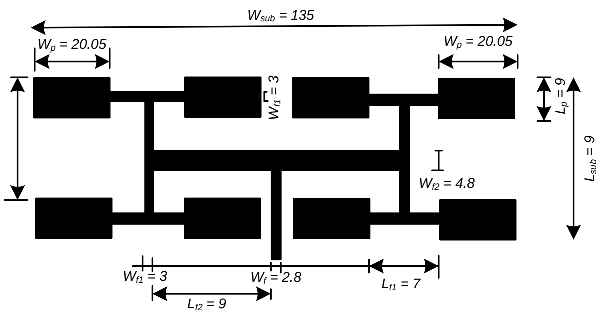

Figure 1. Design of Antenna patch rectangular

We performed several simulations to obtain the optimal return loss and bandwidth. Figure 2 shows the simulation results of some methods.

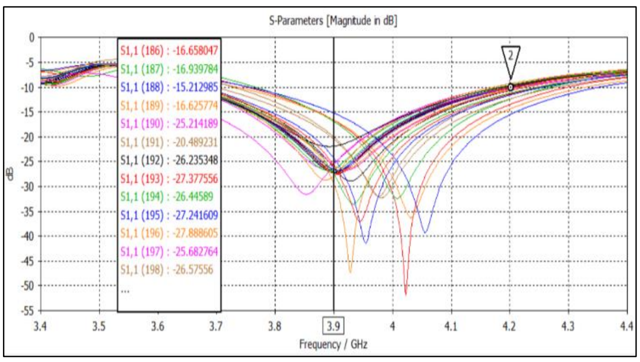

Figure 2. Return Loss and Bandwidth Simulation Results

The optimum result achieved was a return loss value of -27.07 dB at a frequency of 3.9 GHz, with a bandwidth of 540MHz. The marking position in Figure 2 is the limit bandwidth value, which meets the value of -10dB. While Figure 3 gives the VSWR values of our experimental results, with the optimal value at 1.09.

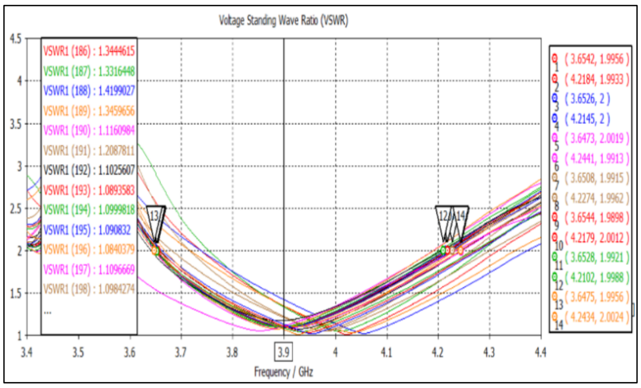

Figure 3. The VSWR simulation results

The maximum VSWR is 2 dB, the marking in Figure 3 indicates the lowest value for VSWR. Figure 4 shows the results from our experiment to obtain the impedance. The result is Maximum Impedance at 50.2Ω.

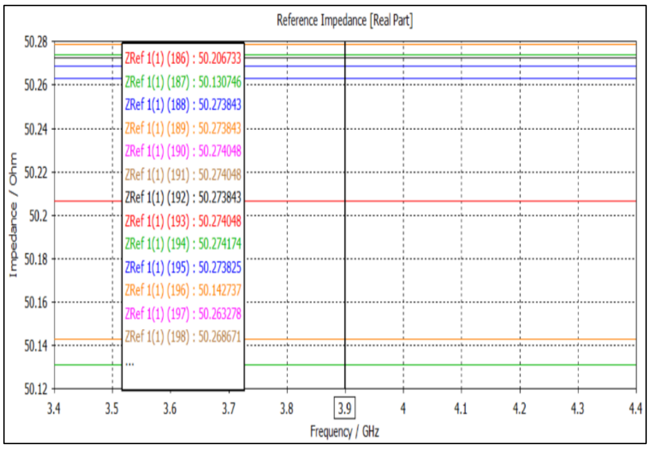

Figure 4. Experimental Results for Impedance

Figure 5 shows the antenna gain value at the desired working frequency of 5.827 dB. The results of the gain parameter values follow the expected specifications (> 5 dB).

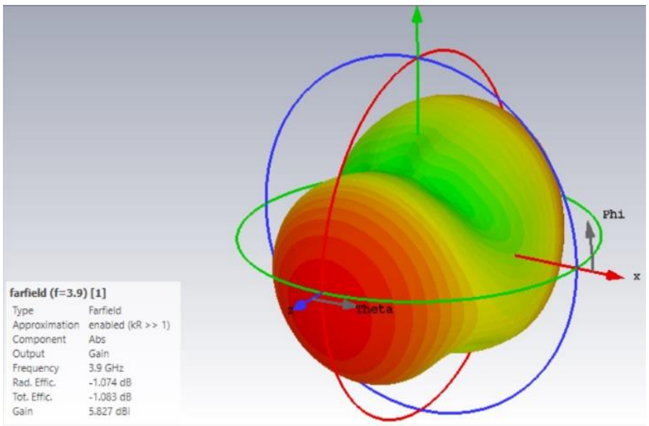

Figure 5. Radiation pattern Simulation Results

Figure 6. shows that the radiation pattern and beamwidth obtained at the 3.9 GHz frequency antenna is bidirectional with an HPBW of 73 degrees.

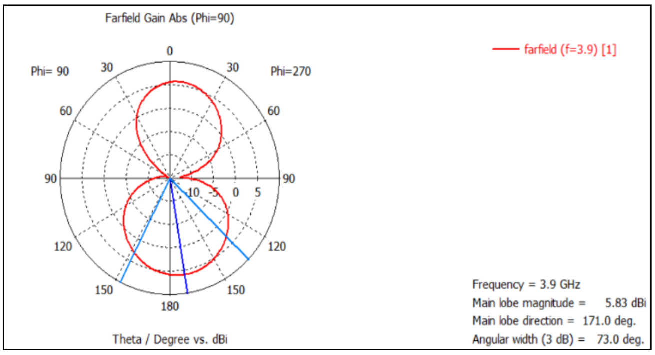

Figure 6. Beamwidth simulation Results

IV. RESULT AND DISCUSSION

In this section, we present the results of our antenna design. Figure 7 shows the photo of the designed antenna and the process of measuring the antenna.

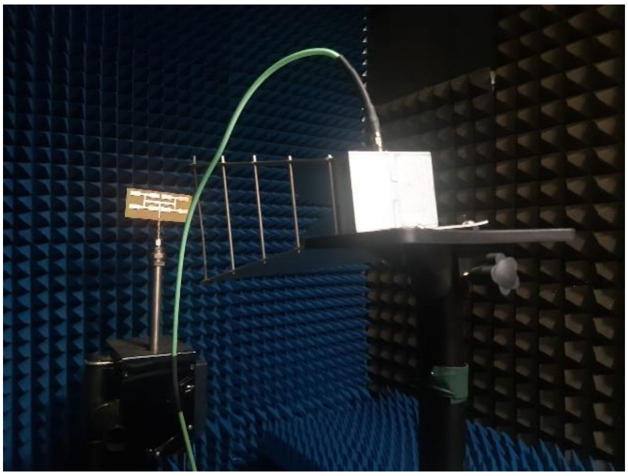

Figure 7. Antenna Measurements in the Chamber Room

Figure 8 shows the results of the antenna return loss of -29.171 dB and a bandwidth of 713 MHz. Furthermore, Figure 9 and Figure 10, show the VSWR measurement results, indicating a maximum antenna VSWR of 1.061 with an antenna gain of 8.32 dB.

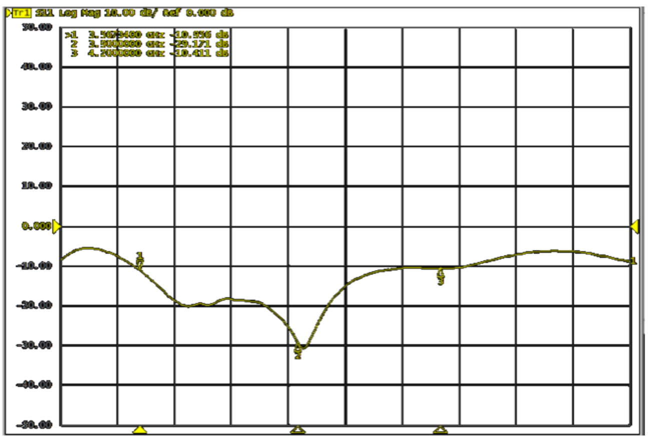

Figure 8. Antenna Return Loss Measurement Results

The radiation pattern results can be seen in Figure 10. The results of the antenna radiation pattern are bidirectional with a Half Power Bandwidth of 92° azimuth radiation pattern testing. This value is obtained with an intersection of -3db at corners 316^0 and 48^0.

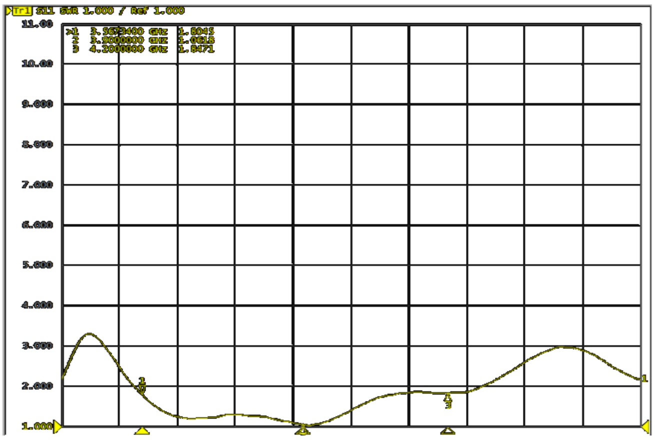

Figure 9. Antenna VSWR Measurement Results

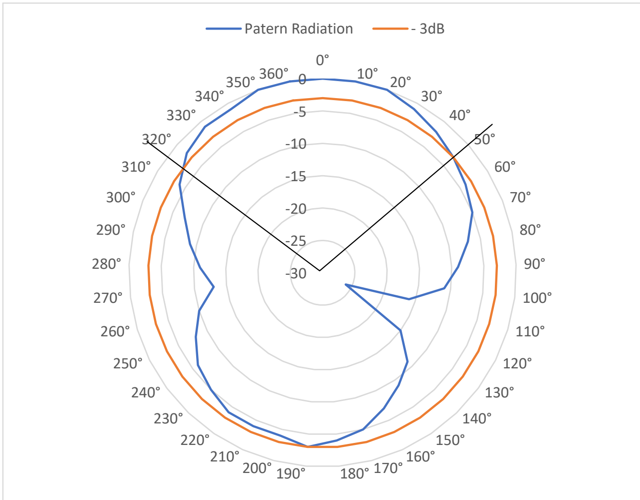

Figure 10. Beamwidth measurement Results

Table 3 is the result of our antenna design parameters. The table compares the results of the previous research antenna designs.

Table 3
Antenna design results table and antenna parameter comparison

Parameters	Simulation	Measurements	Ref. 1 [8]
Return Loss	-27,07 dB	-29,1 dB	-26.8dB
VSWR	1,092	1,061	1.09
Bandwidth	540 MHz	713 MHz	200 MHz
Impedance	47,63 Ω	47,06 Ω	50 Ω
Gain	5,827 dBi	8,32 dBi	5,6 dB

There is a slight difference between the simulation results and the actual manufactured antenna. This is because the simulated gain calculations assume ideal conditions, whereas the physical manufacturing process can introduce improvement. In addition, measurements taken in a less-than-ideal indoor condition can also contribute to variations. Manual handmade antenna production is susceptible to errors, particularly in the dimensions of the patch and the feeder lines, which are unstable and prone to size shifts. The condition of the reference antenna used in the measurement has experienced a shift in gain towards the antenna slot.

V. CONCLUSION

The results of our antenna designs yielded a return loss of -29.1 dB, with a bandwidth of 713 MHz and a VSWR of 1.061. The measured antenna impedance is 47.06Ω, and the antenna gain is 8.32 dB. The observed radiation patterns are bidirectional, which is sufficient to meet the expected antenna design. For optimal gain performance, we suggest producing a directional radiation pattern in future iterations.

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