Rectangular Microstrip Antenna Design On Frequency Range 1 to 5 GHz and Working Frequency 2.4 GHz

Wendra Satria Utama[a]

Telecommunication Engineering, Politeknik Negeri Padang, Padang, West Sumatera, 20362, Indonesia

Corresponding author: wendra251@gmail.com

***Abstract*— This research aims to design a rectangular antenna obtained after optimizing the antenna in the frequency range of 1 to 5 GHz and the working frequency of 2.4 GHz. The substrate material used is FR-4 (lossy) which to get the basic antenna design needs to be calculated on each antenna parameter, so that it can perform simulations in CST studio. Based on the research that has been done, the results of the antenna design with the formula have a size of 38 mm × 28.92 mm for the size of the ground antenna and the size of the antenna substarte 47.64 mm × 39.04 mm and the results of the formula antenna simulation at a frequency of 2.4 GHz.After optimizing the antenna, the results are different from those obtained by the formula antenna, which has the size of the antenna patch and ground antenna different from the CST simulation due to the fabrication or dissolution process.**

***Keywords*— Antenna, Wireless, Rctangular, Parameters.**

Manuscript received 24 Dec. 2024; revised 06 Nov. 2025; accepted 26 Jan. 2026. Date of publication 30 Apr. 2026.

I. INTRODUCTION

Telecommunication is very important at this time, the era of information technology now demands fast, realtime communication, anywhere and anytime. Wireless communication system is a communication system with transmission media in the form of electromagnetic wave propagation without having to be connected to a cable.

The antenna functions as a device used to transmit and receive radio waves or electromagnetic waves that are radiated in a free medium to be emitted. Microstrip antenna is a metal conductor (patch) attached above the ground plane between which there is a dielectric material. Through decades of research, it is known that the ability to operate microstrip antennas is governed by their shape. Microstrip antennas are one of the most popular antennas today, this is because microstrip antennas are very suitable for telecommunications devices that are now concerned with shape and size, besides that microstrip antennas are easy to make, easy to install, low cost, but microstrip antennas also have disadvantages including narrow bandwidth. This can be overcome because the bandwidth of the antenna can be increased by various methods such as increasing the thickness of the substrate with a low dielectric constant value, by probe feeding cutting the slot, and by trying antennas with different shapes.

In this antenna task there are several types of microstrip antennas that can be designed to meet the needs of information transmission technology, this design uses a rectangular shape and looks for microstrip antenna formulas working at a frequency of 2.4 GHz applied to as a simulation.

Antennas function as transmitters or receivers of electromagnetic waves in communication systems. In its transmission from a transmitter to a receiver that is far away causes electromagnetic waves to experience a reduction in energy, so that when received by the receiver, the signal strength has decreased. To be well received by the receiver, an antenna is needed that has a radiation pattern factor, polarization, high gain gain and wide directivity.

II. THE MATERIALS AND METHOD

There are several stages in the design of the RECTTANGULAR 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_20_2)
File	PCB Layer Transfer Paper
Permanent Marker / Drawing Pen	Tin

B. Antenna Design

The design of the RECTANGULAR antenna design with a Frequency range of 1 - 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 2 as follows:

TABLE 2
ANTENNA SPECIFICATIONS

Working Frequency	**1 – 5 *GHz***
Return Loss (S_11)	≤ - 10 dB
Mutual Coupling (S_21)	≤ - 15 dB
Bandwidth	≥ 500 MHz
Notched Band	≤ 1 GHz
Radiation Pattern	Directional

The final design size of the antenna in the reference is 38 x 28,92 mm² as shown in Figure 1 below:

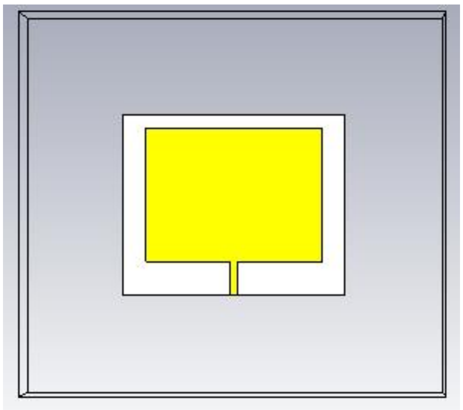

Fig. 1 Antenna Final Design Size According to Reference

At this stage, the design is carried out based on the values obtained from the microstrip antenna design formula so as to produce one basic antenna, for example, patch length, patch width, slot length, slot width, microstrip line length, microstrip line width, substrate length and width are parameters obtained from calculating using the microstrip antenna design formula.

Figure 1 is the final design size of the antenna on the patch and ground plane. The values can be seen in table 3 above.

TABLE 3
DESIGN PARAMETERS OF THE FINAL PROJECT

Parameter	Wsub	Lsub	hsub	Wg	Lg	Wp	Lp
Value(mm)	47.6	39	1.6	47.6	39	38	28.9

III. Results and Discussion

The results of the design and fabrication of the modified RECTANGULAR antenna are compared with existing reference antennas. The antenna performance evaluation aims to ensure that the results obtained meet the expected specifications.

Fig. 2 Fabricated Antenna Results

Fig. 3 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.

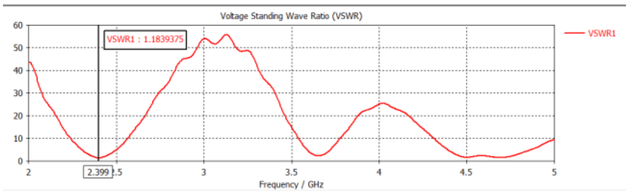

Fig. 4 Comparison of S-Parameter Values

From the picture above, the VSWR value of 1.18 from a frequency of 2.39 GHz has met the specifications because the VSWR value used is < 2.

TABLE 4
COMPARISON OF THE REFERENCE ANTENNA WITH THE MODIFIED ANTENNA.

	Antenna Reference [5]		Final Project Antenna	
	Simulation	Measurement	Simulation	Measurement
Working Frequency(GHz)	2 – 2.5	2.5 – 3.5	3.5 – 4	4 – 5
VSWR	1.18	8.	2.	1.2

A. *Comparison of Return Loss*

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 in the RECTANGULAR frequency range of 2.4 GHz.

In Figure 4 above, the results of the comparison between the final project antenna simulation and its measurements are presented. In Figure 4 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 RECTANGULAR range is at 2.4 GHz, with a return loss of -21.49 dB.

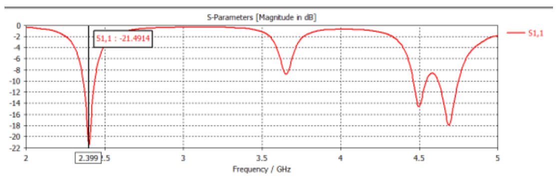

Fig. 4 S-Parameter Simulation of the Final Project Antenna

From the picture above at a frequency of 2.39 GHz, the retrun loss value of -21.4 dB is obtained, which meets the specification value of the antenna which is < -10dB.

B. *Radiation Pattern of Antenna*

in the simulation of the rectangular antenna at its best frequency of 2.4 GHz, the radiation pattern can be seen in this figure.

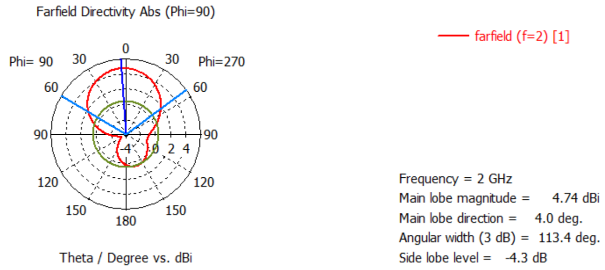

Fig.5 Bandwidth and Band Notched Reference Antenna

This figure shows the farfield directivity radiation pattern for an antenna at a frequency of 2 GHz. The radiation pattern is plotted in polar coordinates for theta angles (Θ) from 0° to 360° with directivity values in dBi. The red line indicates the radiation pattern at that frequency. The main parameters of this antenna include an operating frequency of 2 GHz, a main lobe magnitude of 4.74 dBi, and a main lobe direction of radiation at an angle of 4.0°. The angular width at a level 3 dB below the peak is 113.4°, indicating a fairly wide spread of radiation around the main direction. In addition, the radiation level at the side lobe is -4.3 dB, which is relatively lower than the main lobe, indicating that the antenna has fairly good directional characteristics.

Overall, this radiation pattern illustrates the antenna's performance in radiating electromagnetic energy. With a main direction of radiation at an angle of 4°, a maximum gain of 4.74 dBi, and a low side lobe, this antenna has directional properties suitable for wireless communication or radar applications. Analysis of such radiation patterns is important for evaluating the efficiency and quality of antennas in communication systems.

C. *Gain Antenna*

in this simulation shows the antenna gain from 2 GHz to 5 GHz.

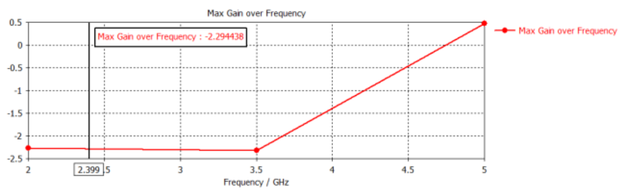

Fig. 6 Gain Antenna

This figure shows the Max Gain over Frequency graph, which is the relationship between the maximum gain of an antenna and the frequency in the range of 2 GHz to 5 GHz. The graph has a horizontal axis showing the frequency (in GHz) and a vertical axis showing the maximum gain (in dB).

From the graph, it can be seen that the maximum gain of the antenna at a frequency of about 2.399 GHz is -2.294 dB, corresponding to the markers on the graph. As the frequency increases, the maximum gain value increases gradually. In the initial range of frequencies, the gain tends to be at a negative value, which indicates that the antenna has a low gain or even experiences energy losses in that frequency. However, at higher frequencies close to 5 GHz, the maximum gain reaches positive values, reflecting that the antenna becomes more efficient at transmitting signals at that frequency.

In conclusion, this graph shows that the performance of the antenna in terms of gain varies with frequency. The antenna has lower efficiency at low frequencies and better performance at high frequencies. This information is important for understanding the characteristics of antennas and ensuring their use according to the needs of a particular communication application.

D. VSWR

in this simulation shows VSWR with the results of the VSWR value of 1.18 from a frequency of 2.4 GHz already meets the specifications because the VSWR value used is < 2.

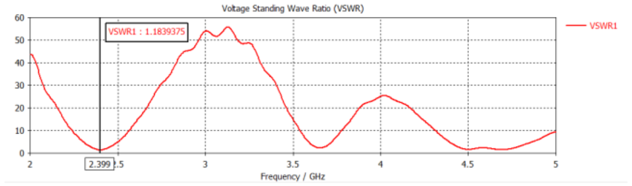

Fig. 7 VSWR Antenna

This figure shows a graph of Voltage Standing Wave Ratio (VSWR) against frequency in the range of 2 GHz to 5 GHz. The horizontal axis shows the frequency in GHz, while the vertical axis shows the VSWR value. This graph is used to evaluate the level of impedance matching of the antenna to the transmission system at various frequencies.

From the graph, the VSWR value is around 1.189 at a frequency of 2.4 GHz, which indicates that the antenna has excellent impedance matching at that frequency. In general, a VSWR close to 1 indicates optimal impedance matching, where almost all the transmitted power is received by the antenna without significant reflection. However, beyond a certain frequency, the VSWR value increases significantly, especially at certain peaks, indicating poor impedance matching and more power being reflected back to the source.

In conclusion, the antenna performs best in terms of impedance matching at frequencies around 2.4 GHz. VSWR is important to ensure that the antenna works efficiently at a given frequency and to identify frequency areas where the antenna performance degrades due to sub-optimal impedance matching.

IV. CONCLUSION

The conclusion on this antenna design project must be done carefully, at the beginning of the design carried out in CST Studio software as a simulation of antenna design to get good parameter results, you must use the size of the antenna and substrate properly because it can cause different measurement results - different even if only a few millimeters difference in the patch and ground as well as in the field. The size parameters I use on the substrate are 4.7 x 3.9 cm while on the patch 3.8 x 2.8 cm in CST Studio and the S-Parameter obtained is -21.4 dB and already exceeds the standard limits set, at VSWR -1.18 dB and that is at a working frequency of 2.4 GHz range of 1 to 5 GHz. However, when fabricating the antenna there are some differences in the size of the patch, ground, substrate because when dissolving FR-4 which has been paired with an antenna circuit that has been designed in CST Studio, after pairing the ports and connectors to take measurements of the antenna that's where the difference in simulation measurement results using CST Studio with Fabrication using Spetrum Analizer when using a spectrum Analizer gets S-Parameter results of -6 dB at a frequency of 2.4 GHz but at a frequency of 3.5 GHz it is - 23 dB and VSWR -2.8 at a frequency of 2.4 GHz. From this it can be concluded that the difference in measurement results in CST Studio and Fabrication is caused during the fabrication process due to differences in size when dissolving FR-4 and can also be due to the installation of ports using solder.

REFERENCES

[1] Balanis, C. A. (2016). *Antenna Theory: Analysis and Design* (4th ed.). Wiley.

[2] Pozar, D. M. (1992). *Microstrip Antennas*. Proceedings of the IEEE, 80(1), 79–91.

[3] James, J. R., & Hall, P. S. (1989). *Handbook of Microstrip Antennas*. Peter Peregrinus Ltd.

[4] Garg, R., Bhartia, P., Bahl, I., & Ittipiboon, A. (2001). *Microstrip Antenna Design Handbook*. Artech House.

[5] Kumar, G., & Ray, K. P. (2003). *Broadband Microstrip Antennas*. Artech House.

[6] Wong, K. L. (2002). *Compact and Broadband Microstrip Antennas*. Wiley.

[7] Waterhouse, R. B. (2003). *Microstrip Patch Antennas: A Designer's Guide*. Kluwer Academic.

[8] Munson, R. E. (1974). Microstrip Antennas: A New Low-Cost Antenna Technology. *IEEE Transactions on Antennas and Propagation*, 21(1), 74–78.

[9] Lo, Y. T., & Lee, S. W. (1988). *Antenna Handbook: Theory, Applications, and Design*. Van Nostrand Reinhold.

[10] Deschamps, G. A. (1953). Microstrip Microwave Antennas. *Proceedings of the Third USAF Symposium on Antennas*.

[11] Zhang, L., & Feng, Y. (2005). Design and Optimization of Rectangular Microstrip Antennas. *International Journal of Electronics and Communication Engineering*, 52(4), 267–272.

[12] Oloumi, N. A., & Dadgarpour, A. (2011). Analysis of Rectangular Microstrip Patch Antenna Using Transmission Line Model. *Journal of Applied Electromagnetics and Mechanics*, 16(3), 187–195.

[13] Abdelaziz, A. A. (2006). Bandwidth Enhancement of Rectangular Microstrip Antenna. *Progress in Electromagnetics Research (PIER)*, 63, 311–317.

[14] Ge, Y., Esselle, K. P., & Bird, T. S. (2004). Compact Microstrip Antenna Design for Multiband Applications. *IEEE Transactions on Antennas and Propagation*, 52(5), 1189–1196.

[15] Amin, M., et al. (2018). "Design of Compact Microstrip Antenna for Wi-Fi Applications." *IEEE Access*, 6, 78565–78571.

[16] Saini, P. K., & Dwari, S. (2014). "A Broadband Rectangular Microstrip Patch Antenna for Wi-Fi Applications." *Progress in Electromagnetics Research C*, 47, 29–36.

[17] Prakash, S., & Kumar, R. (2015). "High Gain Microstrip Patch Antenna at 2.4 GHz." *International Journal of Electronics and Communication Engineering*, 2(4), 123–127.

[18] Rao, Q., et al. (2007). "Compact Microstrip Antenna Design for WLAN Applications." *Microwave and Optical Technology Letters*, 49(4), 837–841.

[19] Alfares, A. M., et al. (2020). "Miniaturized Microstrip Antenna for IoT Applications." *International Journal of RF and Microwave Computer-Aided Engineering*, 30(6), e22112.

[20] Yulindon dan Firdaus. 2007. *Teori Dan Perancangan Antena.* Politeknik Negeri Padang, Padang.

[21] Constantine A. Balanis. 2016. *Teori Analysis And Design.* 4th edtion, E-book. John Wiley & Sons, Inc.

[22] R. Garg. 2001. *Microstrip Antena Design Handbook.* Artech House Antennas and Propagation Library.

[23] Alfares, A. M., et al. (2020). "Miniaturized Microstrip Antenna for IoT Applications." *International Journal of RF and Microwave Computer-Aided Engineering*, 30(6), e22112.

[24] Ibrahim, A. A., et al. (2019). "Design of Compact Rectangular Patch Antenna for IoT Applications at 2.4 GHz." *Journal of Communications Technology and Electronics*, 64(12), 1391–1396.