Optimizing Rectangular Microstrip Patch Antennas for High-Frequency 5G Applications

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***Abstract*—The inset-feed rectangular patch microstrip antenna is proposed as an effective solution for 5G communication applications that require large bandwidth and high data transmission rates. This antenna is designed with commonly used FR-4 substrate material and is easy to mass-produce. In this design, rectangular slots are integrated to extend the bandwidth to 3 GHz, which is in line with the needs of modern communication applications. The antenna performance shows excellent results, with a return loss value of -37.45 dB, VSWR value of 1.02, and directivity of 13.57 dBi. Simulation and analysis were performed using CST Studio Suite software, which provided optimal results with antenna patch dimensions of 24 mm × 12 mm. The results indicate that this microstrip antenna is a good choice for 5G communication applications, especially in meeting the needs of wide bandwidth and high transmission efficiency. The implication of this research is further development of microstrip antenna design to support future communication technology.**

***Keywords*— Rectangular Microstrip Patch Antenna; Antena microstrip, bandwidth, CST Studio, inset-feed, return loss, 5G.**

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I. INTRODUCTION

Antennas are one of the important components of wireless communication systems. They function to convert electrical signals into electromagnetic signals, which are then radiated [1]. Furthermore, antennas can also receive electromagnetic signals and convert them back into electrical signals [2]. A widely developed type of antenna for wireless communication systems is the microstrip antenna. Microstrip antennas have become a popular choice in antenna design for 5G systems due to their advantages. They are lightweight, small in size, capable of operating at high frequencies, and easy to use.

Although microstrip antennas have these benefits, one of their main disadvantages is their narrow bandwidth, which limits their operational frequency range [3]. The compact size of microstrip antennas makes them ideal for use as receiving antennas, allowing for integration into portable devices. This makes them highly effective in various wireless communication applications, including mobile devices and communication systems that require efficient antenna design and optimal performance [4].

The development of wireless cellular technology has reached the fifth generation (5G), which offers high data transfer speeds and reliable connectivity. The fifth-generation communication system (5G) was introduced in 2018 and has advantages, including high data transfer speeds. And very wide bandwidth [5]. The fifth-generation cellular communication system is designed to meet the need for greater capacity, necessitating a wider bandwidth compared to current cellular technologies. One way to achieve a larger bandwidth is by using high frequencies in the range of 10-100 GHz [6]. Wireless communication is dominated by digital transmission, not only for human interaction but also for transmitting data that requires large amounts of information [7]. The 5G technology aims to enhance the efficiency and capacity of cellular networks, as well as improve data rates with broader coverage and lower power consumption [8].

Various methods and techniques have been applied to enhance the bandwidth of microstrip antennas, including increasing substrate thickness, adding an inset to the antenna feed, modifying the size of the antenna patch, adding slots, and changing the size of the antenna ground plane [9]. In previous studies, numerous improvements in bandwidth and return loss have been conducted. For example, the research proposed by [10] involved testing a U-Slot antenna at a frequency of 15 GHz, yielding a return loss of -20.9094 dB and a bandwidth of 1200 MHz. The study proposed by [11] designed a circular microstrip antenna with a U-slot, resulting in a return loss of -21.75 dB and a bandwidth of 719 MHz at a frequency of 26 GHz. Additionally, the research proposed by [12] conducted testing on the design of a square patch microstrip antenna using the inset feeding method at a frequency of 2.4 GHz, with an inset addition yielding a bandwidth of 112 MHz and a return loss of -14.77 dB. Furthermore, the research proposed by [13] designed a circular microstrip antenna using direct feeding and slots for 5G antennas, achieving a return loss of -36.781 dB and a bandwidth of 1.044 GHz at a frequency of 28 GHz.

However, despite these advancements, previous research still reveals shortcomings in bandwidth and coefficient values. This study proposes an increase in both bandwidth and return loss in the design of an Inset-Feed Rectangular Patch Microstrip Antenna using an FR-4 substrate for a frequency of 18.8 GHz in a 5G communication system.

II. METHOD

In this study, the microstrip antenna design uses a rectangular model with an FR-4 substrate that has a dielectric constant (εr) of 4.3 and a substrate thickness (h) of 1.6 mm. To determine the dimensions of the microstrip patch antenna in the rectangular model, it is necessary to calculate the length (Lp) and width (Wp) of the patch, as well as the length (Lg) and width (Wg) of the ground plane, the length (Lf) and width (Wf) of the feed line, and the insert feed position (Y0), which can be calculated using the following equations [14].

1) Pacth width (Wp) (1)

$$W_p = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

2) Pacth length (Lp) (2)

$$L_p = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L$$

Where ΔL and $\varepsilon reff$ can be found using the equation below

(3)

$$\Delta L = 0.412h\left[\frac{(\varepsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.8\right)}\right]$$

(4)

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

The calculation of the length and width dimensions of the ground or substrate can be found using the following equation

3) Ground Width (Wg) (5)

$$W_s = Wg = 6h + W$$

4) Ground Length (Lg) (6)

$$L_s = L_g = 6h + L + L_f$$

The insert feed unification technique can facilitate impedance adjustment between the feedline and the antenna lead by controlling the insert feed position point (Y0). This union provides a cut in the patch so that the feedline looks more indented into the patch. The dimensions of the feed insert can be found using the following equation

5) Feedline Width (Wf) (7)

$$\frac{W_f}{h} = \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left(\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right)\right]$$

Where, (8)

$$\beta = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

6) Feedline Length (Lf) (9)

$$L_f = \frac{1}{4}\frac{\lambda_0}{\sqrt{\varepsilon_{reff}}}$$

7) Insert Feed Position (*Yo*) (10)

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})}\left[\cos^2\left(\frac{\pi Y}{L} - Y_0\right)\right]$$

Where for; (11)

$$W \le \lambda_0 \quad \text{then} \quad G_1 = \frac{1}{90}\left(\frac{W}{\lambda_0}\right)^2$$

After the dimensions and design of the antenna have been determined, the next step is to perform the antenna design simulation. The simulation is conducted to illustrate the designed antenna on a device. The numerical simulation methods used are:

1. *Method of moments* (MoM)

This method analyzes a surface current that functions to design microstrip patches and volume polarization currents on a dielectric plate for designing in the dielectric domain.

2. *Finite Element Method* (FEM)
This method is used for three-dimensional configurations. The analyzed section is divided into several parts, or the number of elements depends on the value of the antenna being analyzed.
3. *Spectral Domain Technique* (SDT)
This method uses a two-dimensional Fourier transform that is perpendicular to the antenna patch.
4. *Finite Difference Time Domain* (FDTD) *Method*
This method is often used in microstrip antennas and printed circuit boards (PCBs) because it can design homogeneous structures. This method can achieve a wide bandwidth in microstrip antennas through simulation [15].

III. RESULTS AND DISCUSSION

Design of a Rectangular Microstrip Patch Antenna with Inset-feed Slot operating at a frequency of 18.8 GHz. The input impedance is 50Ω, and it uses an FR4 substrate with a dielectric constant of 4.6 and a thickness of 1.6 mm. The following are the antenna dimensions based on the calculations:

TABLE I
ANTENNA PARAMETER

VARIABLE	DESKRIPSI	UKURAN (mm)
WP	Patch width	**24**
Lp	Pacth length	**12**
Wf	Feedline Width	**1,9**
Lf	Feedline Length	**9,7**
Wg	Ground Width	**27,6**
Lg	Ground Length	**36,40**
G	Width notch	**1,65**
Y0	Insert Feed Position	**4,70**

From the calculated parameters (Table 1), the antenna design and simulation are subsequently carried out using CST Studio Suite software.

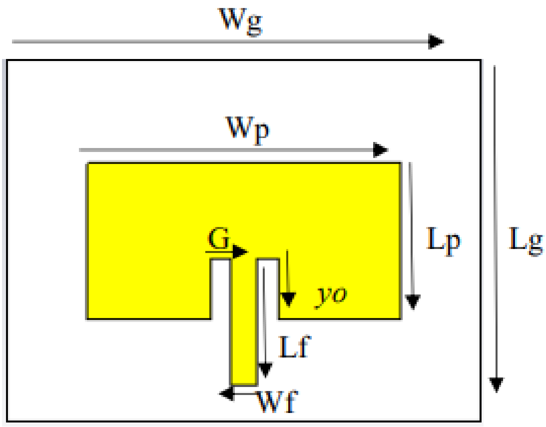

Fig. 1 Design of Rectangular Microstrip Antenna

The figure above shows the simulation of the designed rectangular microstrip patch antenna with a rectangular slot, which serves to widen the bandwidth, as microstrip antennas typically have narrow bandwidth.

A. *Simulation Results Using CST Studio Suite Software*

After designing the antenna by inputting the calculated results, this section discusses the simulation results using CST Studio Suite software. In this stage, the parameters tested include return loss, VSWR, gain, bandwidth, radiation pattern, and polarization.

a. *Results of Return Loss / S-Parameters*

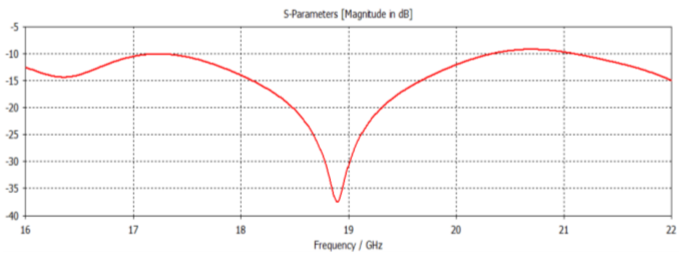

Fig. 2 Results of S-Parameters Simulation in CST Studio Suite 2019

Figure 2 shows the simulation results of the antenna design at an operating frequency of 18.8 GHz with a return loss value of -37.44 dB. It can be seen that the return loss value is lower than the specification requirement of ≤ -10 dB, thus the simulated antenna meets the fabrication specifications.

b. *Results of VSWR*

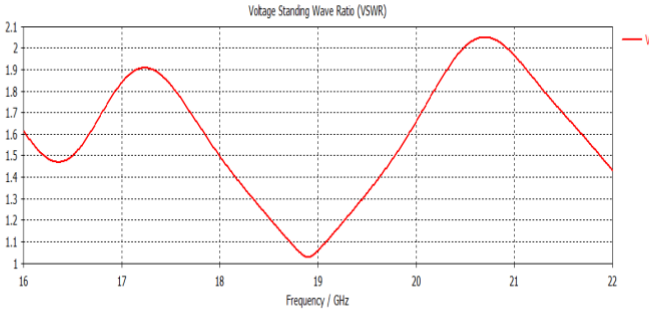

Fig. 3 Results of VSWR Simulation in CST Studio Suite 2019

Figure 3 shows the VSWR value at a frequency of 18.8 GHz, which is 1.027. The value obtained from the simulated antenna has met the VSWR specification. In general, a VSWR value of less than 2 is considered good for antennas, while a VSWR value between 2 and 3 is still acceptable for some applications [16].

c. Antenna Bandwidth

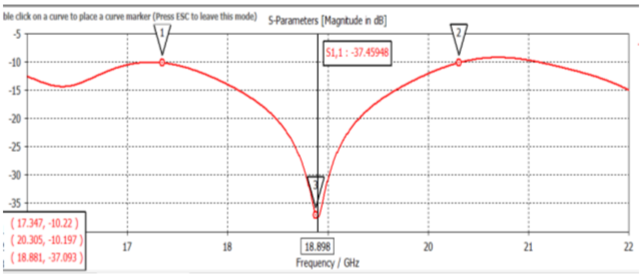

Fig. 4 Results *of Bandwidth Simulation* in CST Studio Suite 2019

The bandwidth width of the antenna from the measured results, observed from the reference limit at -10 dB, can be calculated using the formula:

$$Bw = f_2 - f_1$$

$$Bw = 20.305 - 17.347 = 3 \text{ GHz}$$

d. Antenna Radiation Pattern

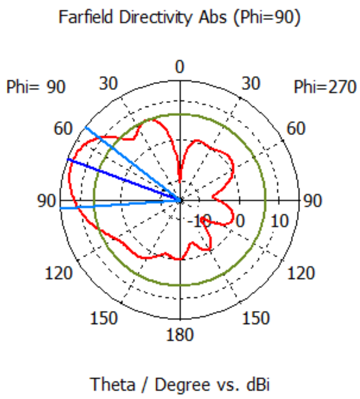

Fig. 5 Results *of Radiation Pattern Simulation* in CST Studio Suite 2019

e. Antenna Gain

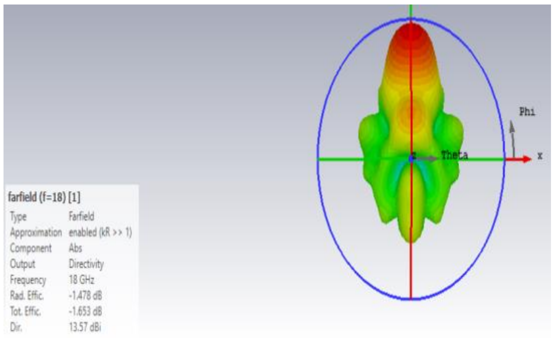

Fig. 6 Results *of Antenna Gain Simulation* in CST Studio Suite 2019

The antenna at a frequency of 18 GHz has a gain value of 13.57 dBi.

B. *Antenna Measurement Results*

Before measuring the antenna, it must be fabricated according to the dimensions designed in CST Studio Suite, and an SMA port must be attached to the antenna. This measurement uses a Vector Network Analyzer (VNA). The antenna to be measured is connected to one of the ports on the Vector Network Analyzer.

Fig. 7 Front View of the Fabrication Result

Fig. 8 Rear View of the Fabrication Results

The fabrication results of the inset-feed microstrip antenna using FR-4 substrate with dimensions of 36.40 mm x 27.40 mm.

a. *Measurement of Return Loss*

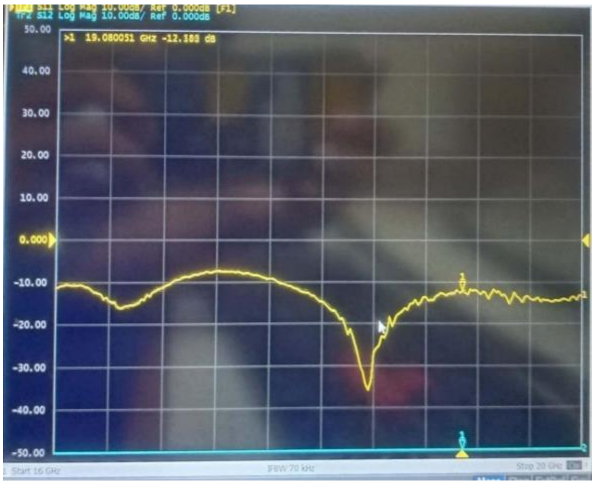

Fig. 9 Results of S-Parameter Measurements on a Vector Network Analyzer (VNA)

b. Measurement of VSWR

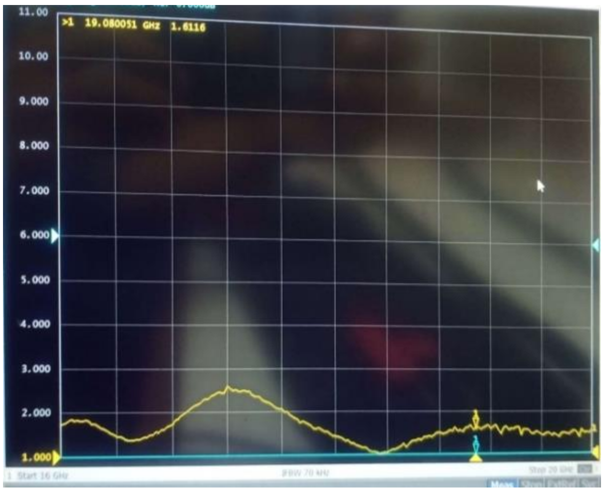

Fig. 10 Results of VSWR Measurement on a Vector Network Analyzer (VNA)

The results of the return loss measurement can be seen in Figure 8, and the VSWR (Voltage Standing Wave Ratio) values are displayed in Figure 9. The return loss shows a difference caused during fabrication. The return loss at the simulation frequency was -37.44 dB, while the measurement yielded -36.24 dB. The VSWR during the simulation was 1.027, compared to 1.047 during measurement. Although there are differences observed during fabrication, these differences are not significant, and the antenna performance still meets the expected specifications. This indicates that the fabricated microstrip antenna retains good characteristics, which is consistent with the simulation results.

IV. Conclusion

Based on the simulation results and performance measurements of the rectangular inset-feed microstrip patch antenna using FR-4 substrate for a frequency of 18.8 GHz in 5G communication systems, it can be concluded that this antenna meets the specifications required for 5G communication applications. The simulation results using CST Studio Suite software indicate that the antenna operates at a frequency of 18.8 GHz with a return loss of -37.44 dB and a VSWR value of 1.027, indicating high efficiency and nearly perfect matching conditions. The antenna's bandwidth is 3 GHz, and the gain is 13.57 dBi, demonstrating good signal amplification capability and wide frequency coverage.

The measurement results after fabrication, conducted using a Vector Network Analyzer (VNA), show a return loss of -36.24 dB and a VSWR value of 1.047. Although there is a slight difference compared to the simulation results, this difference is not significant, and the antenna's performance still meets the expected specifications.

Overall, the fabricated microstrip antenna shows characteristics consistent with the simulation results, with stable and efficient performance for 5G communication applications. The small differences that occur due to the fabrication process do not affect the overall performance of the antenna, making it suitable for use in 5G communication systems.

References

[1] D.-G. Fang, Antenna theory and microstrip antennas. CRC Press, 2017.

[2] M. Alaydrus, “Riset Antena –State of the Art,” J. Telekomun. dan Komput., vol. 6, no. 1, p. 1, 2017.

[3] W. Ibrahim, S. Alam, and I. Surjati. "Peningkatan Performansi Desain Antena Mikrostrip dengan Penambahan Slot M dan Inset untuk Komunikasi 5G," JTERA (Jurnal Teknologi Rekayasa), vol. 7, no. 1, pp. 157-162, 2022.

[4] R. C. Sianturi, “Rancang Bangun Antena Mikrostrip dengan penambahan Slot untuk Meningkatkan Bandwidth,” *Skripsi Univ. Negeri Jakarta*, 2018.

[5] M. Höyhtyä, O. Apilo, and M. Lasanen, “Review of latest advances in 3GPP standardization: D2D communication in 5G systems and its energy

consumption models," *Futur. Internet*, vol. 10, no. 1, 2018.

[6] K. Hiltunen, A. Simonsson, P. Ökvist, and B. Halvarsson, "5G Trial System Coverage Evaluation Utilizing Multi-Point Transmission in 15 GHz Frequency Band". European Conference on Network and Communications (EuCNC), hal. 1-5, 2017.

[7] T. Qiu, B. Chen, A.K. Sangaiah, J. Ma, R. Huang, "A Survey of Mobile Social Networks: Applications, Social Characteristics, and Challenges," IEEE Syst J, vol. 12, no. 4, pp. 3932–3947, Dec. 2018.

[8] R. N. Mitra, D. P. Agrawal, "5G mobile technology: A survey," ICT Express, vol. 1, no. 3, pp. 132–137, 2015.

[9] M. Marchellia, A. B. Simanjuntak, and H. Madiawati, "Desain Antena Mikrostrip Persegi Menggunakan Kombinasi U-Slot dan Elemen Parasitik pada Frekuensi 2.4 GHz," Prosiding The 12th Industrial Research Workshop and National Seminar, Bandung, Indonesia, pp. 724, 2021.

[10] Sinaga, K. J., Nur, L. O., & Syihabuddin, B, "Perancangan Antena Array 1×2 Rectangular Patch Dengan U-Slot Untuk Aplikasi 5G", 2017.

[11] Bloko Budi Rijadi, "Perancangan Antena Mikrostrip Circular Dengan U-Slot Untuk Aplikasi 5g Di Indonesia," Jurnal Teknik Majalah Ilmu Fakultas Teknik Unpak, vol. 21, no. 1, 2020.

[12] D. Pasaribu, A. H. Rambe, and K. Kunci, "Rancang Bangun Antena Mikrostrip Patch Segiempat Pada Frekuensi 2,4 Ghz Dengan Metode Pencatuan Inset," *Singuda ENSIKOM*, vol. 7, no. 1, pp. 30–35, 2014.

[13] Haidi, Junas. "Desain Atena Mikrostrip Bentuk Lingkaran Menggunakan Metode Pencatuan Langsung dan Slot Untuk Antena 5G." *Journal Scientific and Applied Informatics* 1.2, 35-40, 2020.

[14] Marchellia, A. B. Simanjuntak, and H. Madiawati, "Desain Antena Mikrostrip Persegi Menggunakan Kombinasi U-Slot dan Elemen Parasitik pada Frekuensi 2.4 GHz," in *Proc. The 12th Industrial Research Workshop and National Seminar*, Bandung, Indonesia, Aug. 4-5, 2021.

[15] Saidah, N, "Fabrikasi Dan Karakterisasi Antena Mikrostrip Patch Rectangular Dengan Slot Persegi Panjang & Slot T Pada Groundplane Untuk Frekuensi Wifi (2, 4 Ghz)". Jurnal Matematika Dan Sains, 1(2),133-14,. 2021.

[16] C. Bahhar, C. Baccouche, and H. Sakli, "A Novel 5G Rectenna for IoT applications," in, Proceedings - STA 2020: 2020 20th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering, 2020.