Design And Realization of Dual-Band Linear Array Microstrip Antenna With 4x1 element For WiFi And 5G Communication System

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A B S T RACT

Nowadays, the need for long-distance communication with wireless communication technology is increasing. The popular wireless communication technology currently used is at a frequency of 2.4 GHz, namely Wi-Fi. In addition, to meet the needs of high data rates, low power consumption, and greater network capacity, the development of 5G technology is needed. However, antennas generally work only at one resonant frequency, so it is impossible to use them in other communication systems simultaneously. Therefore, this research proposes a dual-band microstrip antenna design using the slot method, and the gain is increased using the array method. The antenna design is proposed at dual frequencies operating at 2.4 GHz frequency for Wi-Fi communication and 3.5 GHz frequency for 5G communication using FR4-epoxy substrate with a dielectric constant price of 4.4 and a thickness of 1.6 mm. The slot method is applied to accommodate the dual-band frequency resonant mode and improve the impedance matching at the second resonant frequency so that the antenna is able to operate at the desired frequency, and the linear array method is applied to strive to increase the antenna gain. The main contribution of this research is to produce an antenna that can operate at two different frequencies with high gain. Antenna design and simulation will be carried out using software. After the design and simulation can operate according to parameters, it will then be tested technically. This research is targeted to produce an antenna with dual-band frequency and gain ≥ 5 dB. Based on the design and measurement results, the antenna that has been made has a resonant frequency at fr1 2.48 GHz and at fr2 3.61 GHz. The specifications at fr1 and fr2 are return loss values of -33.14 dB and -11.05, respectively; VSWR values of 1.04 and 1.88; and bandwidths of 110 MHz and 270 MHz. The antenna is capable of producing a gain of 8.18 dB at 2.4 GHz and 4.28 dB at 3.5 GHz.

1. Introduction

Wireless communication technology continues to evolve to meet the growing demand for long-distance data communication. Speed, allocation availability, and flexibility in accessing data are increasingly needed in this era, so Wi-Fi and 5G communication systems are some of the communication technologies that can be relied upon to meet these needs. Wi-Fi is a technology used in Wireless Local Area Network (WLAN). The 5th generation IEEE technology standard, IEEE 802.11ac, is capable of providing data rates of up to 7 Gbps in the 5 GHz frequency band (Usrah et al., 2022). Working frequencies in Wi-Fi applications have different frequency bands, from 2.4 GHz to 5.8 GHz. This frequency band is divided into three bands, namely 2.4 GHz, 5.2 GHz, and 5.8 GHz (Sandhiyadevi et al., 2021).

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In addition, the development of 5G technology is also required (Usrah et al., 2022). Compared to 4G, 5G technology is able to maximize wireless data transmission speeds that are 100 times faster up to 20 Gbps, lower latency, able to handle more devices per km^2 so that it can be relied upon to support various usage scenarios (Aston Dsouza, 2022; Dangi et al., 2022). In use, the working frequency of 5G technology is divided into 3 groups, namely low band spectrum at frequencies below 1 GHz, mid band spectrum between 1 and 6 GHz and high band (mmWave) frequencies above 24 GHz (Usrah et al., 2022). One of the candidate radio frequency ranges for 5G trials in Indonesia is in the range of 3.3 - 4.2 GHz (3.5 GHz radio frequency band) (Dhanyswari et al., 2023; Kementerian Komunikasi dan Informatika, 2022). 5G networks will enable new high speed and low latency for various wireless broadband applications such as internet and other innovations (Usrah et al., 2022).

The use of Wi-Fi and 5G are in frequency bands that are far enough apart that antennas are needed that can work at different frequencies to maximize their use. Dual-band microstrip antennas are an alternative that can be used in wireless communication systems that work in two frequency bands that have quite a difference (Andrieyani et al., 2020). But in general, single microstrip antennas have low gain and narrow bandwidth (Aulia, 2021). To solve this problem, a technique is needed to increase the gain and widen the bandwidth (Aulia, 2021). Techniques to increase the gain of microstrip antennas can use several techniques, a few of which are arrays of microstrip antennas (ALAM et al., 2021; Aulia, 2021; Dhanyswari et al., 2023). The target of this research is to produce an antenna with dual-band frequency and gain ≥ 5 dBi.

2. Literature review

Antennas are generally designed for single band frequencies. The development of microstrip antennas for WiFi communication systems has been carried out in research (Kirana, 2021) and the development of microstrip antennas for 5G communication systems has been carried out in (Muhammad Ammar Fadhlurrohman & Kristyawati, 2023) but the antennas designed from both researches (Kirana, 2021; Muhammad Ammar Fadhlurrohman & Kristyawati, 2023) only operates at one of the working frequencies and still has a low gain. In research (Kirana, 2021) designed an antenna that operates at a frequency of 2.4 GHz with a gain of 3.43 dBi while in research (Muhammad Ammar Fadhlurrohman & Kristyawati, 2023) designed an antenna that operates at a frequency of 3.5 GHz with a gain of 3.721 dBi. Furthermore, in research (Azka, 2019; Nathaniel et al., 2019) has successfully designed a dual-band frequency antenna using the twin slot method, for the first resonant frequency is at a frequency of 2.4 GHz but for the second resonant frequency is at a frequency of 5.8 GHz. In research (Pramdhan et al., 2023) has also successfully designed a dual-band antenna at a frequency of 2.4 GHz and 5.8 GHz band with a different method using a chip arrangement for the antenna patch. However, from the three studies (Azka, 2019; Nathaniel et al., 2019; Pramdhan et al., 2023) still produce low gain.

This research provides a solution to previous research (Azka, 2019; Nathaniel et al., 2019; Pramdhan et al., 2023) who have developed microstrip antennas that work at dual-band frequencies for Wi-Fi and 5G communication systems by applying twin slots but still have low gain by applying the array method as in research (Dhanyswari et al., 2023; Putranto et al., 2023) to produce an antenna at the specified resonant frequency with improved gain. This proposed research is expected that the antenna can produce resonant frequencies at 2.4 GHz and 3.5 GHz with enhanced gain.

3. Method

3.1. *Research Flow*

The research conducted includes several stages. These stages are depicted in the research flow chart in Figure 1.

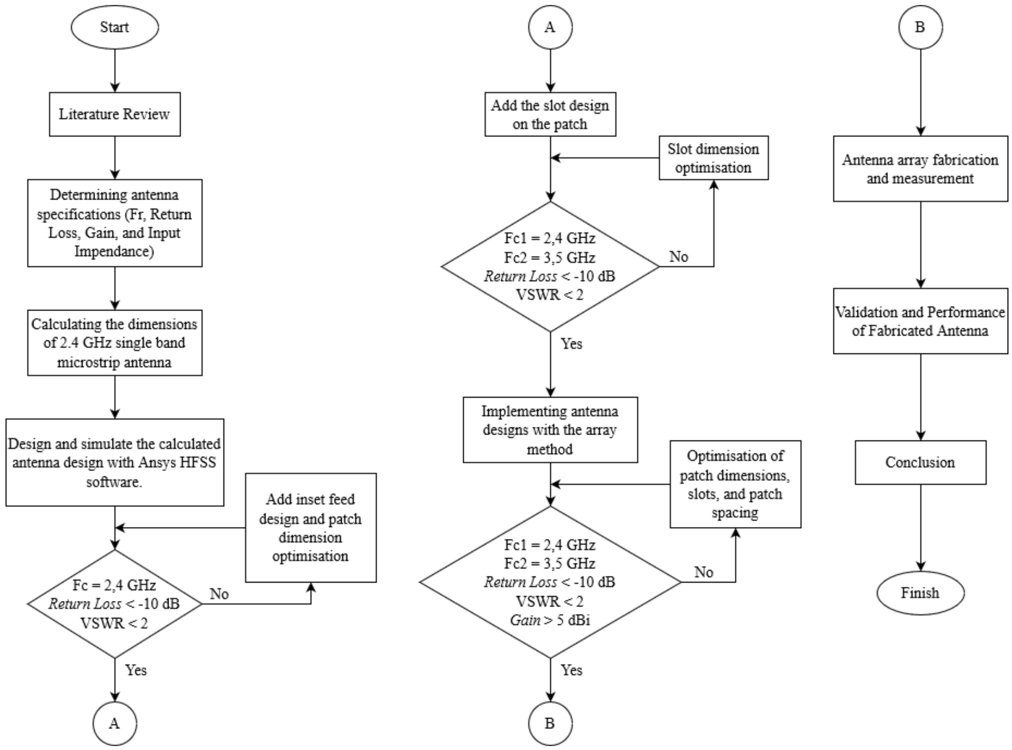

Figure 1. Research Flow

From Figure 1, a literature study was conducted to conduct a literature review and validated references to support this research.

Furthermore, mathematical calculations, design and simulation of software are carried out. The initial stage is to determine the specifications of the specified antenna. Then determine the type of substrate material, namely FR-4 with a dielectric constant (εr) 4.4 and a thickness of 1.6 mm. The next stage is to calculate and design the antenna at the specified fr. The design results are then simulated using Ansys HFSS software, during the simulation process it is possible to perform several iterations and optimizations until you get the expected results, such as the results of the return loss parameters ≤ -10 dB, VSWR ≤ 2, BW ≥ 100 MHz and gain ≥ 5 dBi.

The simulation results of the optimized antenna design will then be fabricated and measured to validate and analyze its performance. The antenna test results that have been analyzed will then draw a conclusion from the formulation of the specified problem.

3.2. *Antenna Development Model*

The research conducted includes several stages of antenna design development starting from single element antenna design, antenna design with inset feed and twin slots, 2x1 element array antenna design, 4x1 array antenna design. The proposed development model and stages are shown in Figure 2.

In this study, the first stage is to calculate and design a single-element rectangular patch antenna at the main working frequency at 2.4 GHz as shown in Figure 2(a). The second stage is to add inset feeds to improve the impedance matching at 2.4 GHz fr and add slots and iterate the slot dimensions to improve the impedance matching at 3.5 GHz fr so that the antenna can accommodate dual frequency resonant modes as shown in Figure 2(b). The third and fourth stages are to develop the antenna into a linear array to increase the gain as shown in Figure 2(c) and Figure 2(d).

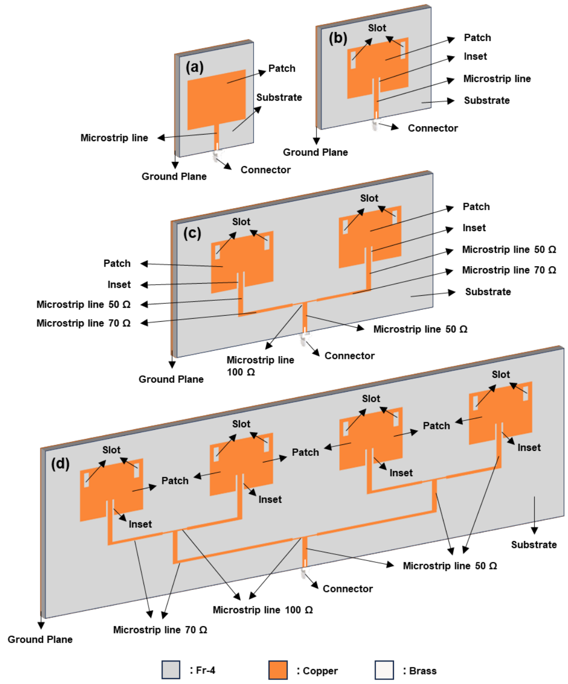

Figure 2. Proposed Antenna Development Model; (a) Single Element Rectangular Patch Antenna Design, (b) Rectangular Patch Antenna Design with Inset Feed and Twin Slots, (c) 2x1 Element Array Antenna Design, (d) 4x1 Element Array Antenna Design

3.3. *Single-element rectangular patch antenna design*

The initial stage is to calculate and design a single element antenna at the main working frequency at 2.4 GHz. The calculation of microstrip antenna dimensions used the following equations (1)-(4):

$$W = \frac{c}{2fr\sqrt{\frac{\varepsilon_r + 1}{2}}} \qquad \text{……1)}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12h}{W}}}\right) for\ (\frac{W}{h} > 1) \qquad \text{……2)}$$

$$\Delta L = 0{,}412h\frac{(\varepsilon_{reff} + 0{,}3)\left(\frac{W}{h} + 0{,}264\right)}{(\varepsilon_{reff} - 0{,}258)\left(\frac{W}{h} + 0{,}8\right)} \qquad \text{……3)}$$

$$L = \frac{c}{2fr\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad \text{……4)}$$

Where W is the width of the patch conductor, c is the speed of light in free space (3×10^8), fr is the resonant frequency of the 2.4 GHz antenna, h is the thickness of the substrate, ε_{reff} is the effective dielectric constant. To calculate the patch length (L) requires the parameter ΔL which is the increase in length L due to the fringing effect. Then to obtain the dimensions of the ground plane, equations (5) and (6) can be used.

$$W_g = 6h + W_{patch} \qquad \text{……5)}$$

$$L_g = 6h + L_{patch} \qquad \text{……6)}$$

Where W_g is the width of the ground plane and L_g is the length of the ground plane. To calculate the width of the supply channel (W_f) equations (7) and (8) are used.

$$B = \frac{60\pi}{Z_o\sqrt{\varepsilon_r}} \qquad \text{……7)}$$

$$W_f = \frac{2h}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left(\ln(B-1) + 0{,}39 - \frac{0{,}61}{\varepsilon_r}\right)\right] \qquad \left(\frac{W}{h} > 2\right) \quad \text{……8)}$$

To calculate the length of the supply line (L_f) is used equation (9) - (11)

$$\lambda_o = \frac{c}{f_r} \quad \text{……9)}$$

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{reff}}} \quad \text{……10)}$$

$$L_f = \frac{60{,}8}{4} \quad \text{……11)}$$

The dimensions of the Single element antenna from the calculation results can be seen in Table 1.

Table 1. Calculated Single Element Microstrip Antenna Dimensions

Parameters	Dimensions (mm)
Patch Width (W_p)	37
Patch Length (L_P)	29
Ground Width (W_g)	47
Ground Length (L_g)	39
Supply Channel Width (W_f)	3
Length of Supply Line (L_f)	15

The calculated single-element antenna design can be seen in Figure 3.

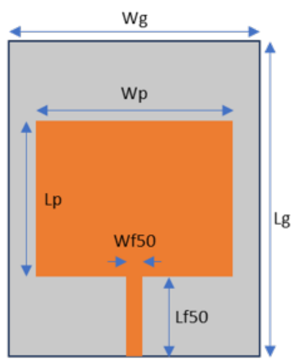

Figure 3. Single Element Rectangular Patch Antenna Design

To find out its characteristics, an experiment with simulation was carried out, the results of which can be observed in the graph in Figure 4.

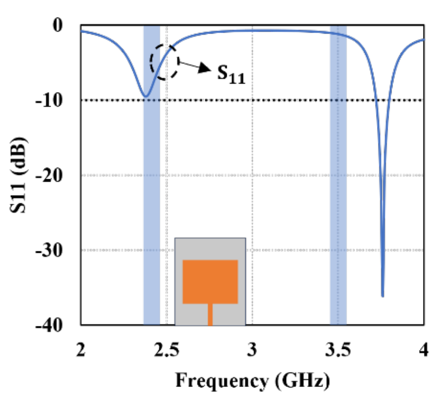

Figure 4. S11 Simulation Results of Single Element Rectangular Patch Antenna

Figure 4 shows that the peak return loss value for the first resonant frequency is not at 2.4 GHz and is not below -10 dB, so it is necessary to continue the development to the next stage.

3.4. *Design of single-element rectangular patch antenna with inset feeds*

This stage is to improve impedance matching at fr 2.4 GHz so as to reduce the return loss value to below -10 dB. The depth or length of an inset feed (L_{if}) is obtained using equation (12).

$$L_{if} = 10^{-4}\begin{pmatrix} 0{,}001699\varepsilon_r^{\,7} + 0{,}13761\varepsilon_r^{\,6} - 6{,}1783\varepsilon_r^{\,5} \\ +93{,}187\varepsilon_r^{\,4} - 682{,}69\varepsilon_r^{\,3} + 2561{,}9\varepsilon_r^{\,2} - 4043\varepsilon_r + 6697 \end{pmatrix}\frac{L}{2} \quad \text{....12)}$$

In this study, the length of the inset feed (L_{if}) obtained is 9 mm, the antenna design can be seen in Figure 5.

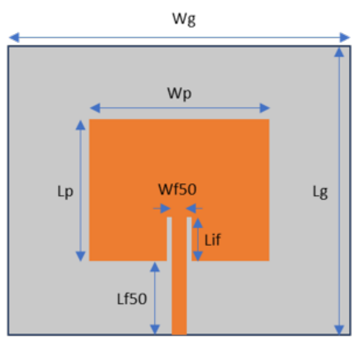

Figure 5. Single Element Rectangular Patch Antenna Design with Feed Inset

The simulation results of return loss (S11) with Wp sample iterations of the antenna design can be seen in Figure 6.

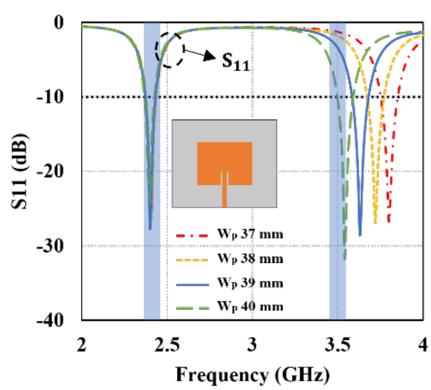

Figure 6. Return loss (S11) Simulation Results with Wp Sample Iterations of Single Element Rectangular Patch Antenna Design with Feed Inset

Figure 6 shows that the addition of inset feed (L_{if}) is able to reduce the return loss value to much lower than -10 dB. Furthermore, the enlargement of the patch width (W_p) from the range of 37 mm - 40 mm affects the shift of the second fr tends to the left. Sample W_p = 39 mm has the best return loss value at fr 2.4 GHz but is still relatively low at fr 3.5 GHz so further development is needed.

3.5. *Single-element rectangular antenna design with inset feed and slot*

The slot is used as an additional resonator element to accommodate the second fr at 3.5 GHz. The antenna design is shown in Figure 7.

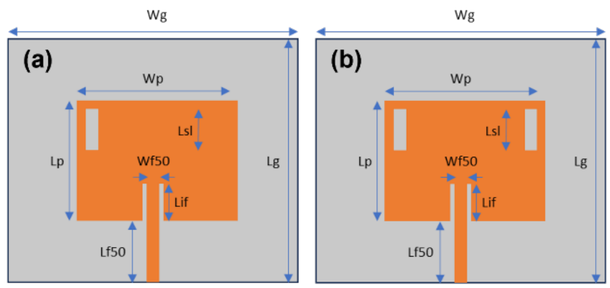

Figure 7. Single Element Rectangular Patch Antenna Design with Feed Inset and (a) 1 Slot, (b) 2 Slots

The simulation results of changing the slot length (L_{sl}) from the range of 6 mm - 10 mm can be observed in the graph of Figure 8 as follows.

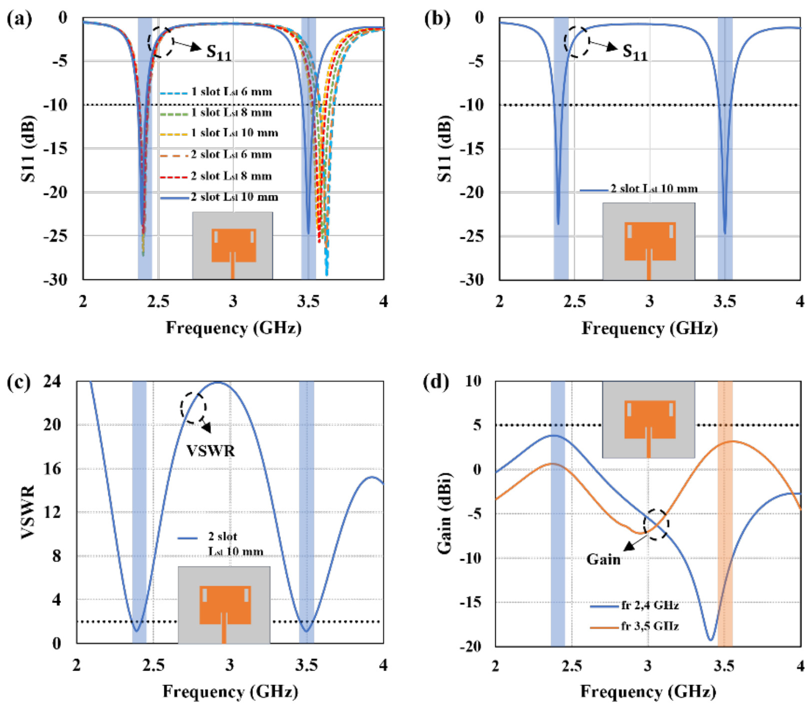

Figure 8. Simulation Results of Single Element Rectangular Patch Antenna Design with Feed and Slot Insets (a) Iteration Results of Sample Lsl, (b) S11 of Sample 2 Slots Lsl 10 mm, (c) VSWR of Sample 2 Slots Lsl 10 mm, (d) Gain of Sample 2 Slots Lsl 10 mm.

In Figure 8 (a), the change in slot length (L_{sl}) affects the shift of the second resonant frequency to the left where the best return loss simulation results are in the sample of L_{sl} = 10mm with 2 slots. The simulation results of these samples shown in Figure 8 (b), Figure 8 (c), and Figure 8 (d) show that at fr 2.4 GHz and fr 3.5 GHz, respectively, the return loss is -23.6 dB and -24.57 dB, VSWR values are 1.29 and 1.12. The simulation results show that the antenna design can operate at the specified frequency. However, the gain at 2.4 GHz and 3.5 GHz is only 3.82 dBi and 3.01 dBi respectively, while the bandwidth is only 40 MHz and 70 MHz respectively. The gain and bandwidth of the antenna are not optimal, so the antenna needs to be developed into an array.

3.6. *Design of 2x1 element array rectangular patch antenna*

The antenna needs to be developed into a linear array of 2 elements to increase gain and bandwidth. The design can be seen in Figure 9.

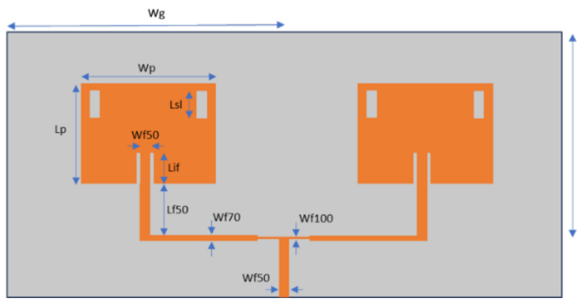

Figure 9. 2x1 element array rectangular patch antenna design with t-junction supply line

The simulation results of changing the slot length (L_{sl}) from the range of 6 mm - 10 mm are shown in the graph of Figure 10 as follows.

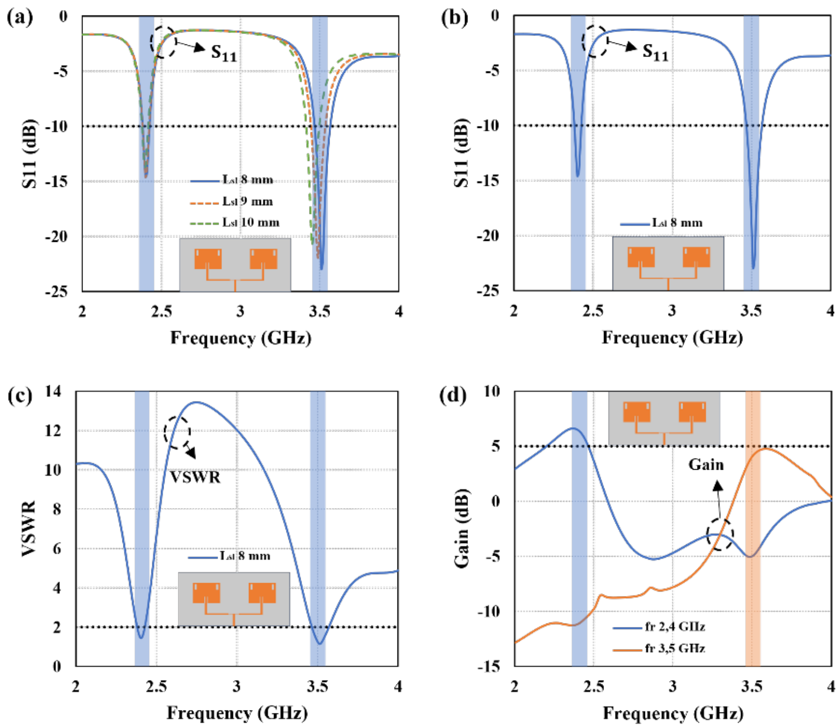

Figure 10. Simulation Results of Rectangular Patch Antenna Design Array 2x1 Elements (a) Iteration Results of Lsl Sample, (b) S11 of 8 mm Lsl Sample, (c) VSWR of 8 mm Lsl Sample, (d) Gain of 8 mm Lsl Sample

In Figure 10 (a), the change in slot length (L_{sl}) affects the shift of the second resonant frequency towards the left where the best return loss simulation results are at sample L_{sl} = 8 mm. The gain at fr 2.4 GHz is known to have increased from 3.82 dBi to 6.44 dBi, the gain at fr 3.5 GHz has also increased from 3.01 dB to 4.06 dB. However, the gain increase at fr 3.5 GHz is still slightly below 5 dB, besides that the bandwidth at fr 2.4 GHz and 3.5 GHz is still below 100 MHz so it needs to be developed into a 4-element array.

3.7. *Design of 4x1 element array rectangular patch antenna*

The antenna needs to be developed into a linear array of 4 elements to increase gain and bandwidth. The design of the antenna can be seen in Figure 11.

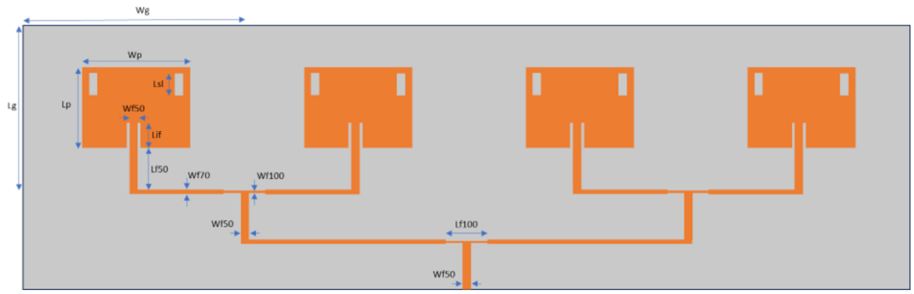

Figure 11. 4x1 element array rectangular patch antenna design with t-junction feed line

The simulation results of changing the length of the 100 Ω feed line (L_{f100}) from the range of 5 mm - 15 mm are shown in the graph of Figure 12 as follows.

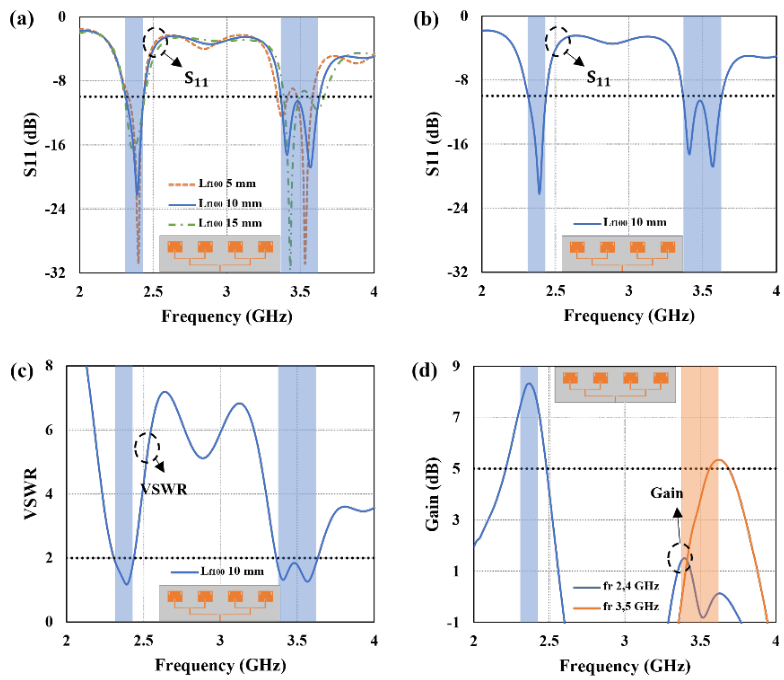

Figure 12. Simulation Results of Rectangular Patch Antenna Design Array 2x1 Elements (a) Iteration Results of Sample Lf100, (b) S11 of Sample Lf100 10 mm, (c) VSWR of Sample Lf100 10 mm, (d) Gain of Sample Lf100 10 mm

In Figure 12 (a), the change in slot length (L_{sl}) affects the shift of the second resonant frequency to the left where the best return loss simulation result is at sample L_{f100} = 10 mm. The simulation results of the sample L_{f100} = 10 mm displayed in Figure 12 (b), Figure 12 (c), and Figure 12 (d) show respectively at fr 2.4 GHz and fr 3.5 GHz have return loss *of* -20.22 dB and -11.03 dB, VSWR values of 1.21 and 1.78, gain of 8.01 dBi and 3.81 dBi, bandwidth of 110 MHz and 250 MHz. Except for the gain at fr 3.5 GHz still slightly below 5 dB, the overall performance of the antenna has improved significantly after being developed with a linear array of 4x1 elements. Therefore, the antenna can be fabricated for measurement and validation.

4. Result and Discussion

4.1. *Near Field Measurement and Validation*

The 4x1 Element Linear Array Antenna was fabricated using FR-4 substrate material with a dielectric constant range of 4.4 - 4.9, a dielectric tan loss of 0.0265, and a substrate thickness of 1.6 mm. The results of the antenna fabrication with a 50 Ω RP-SMA connector are shown in Figure 13(a).

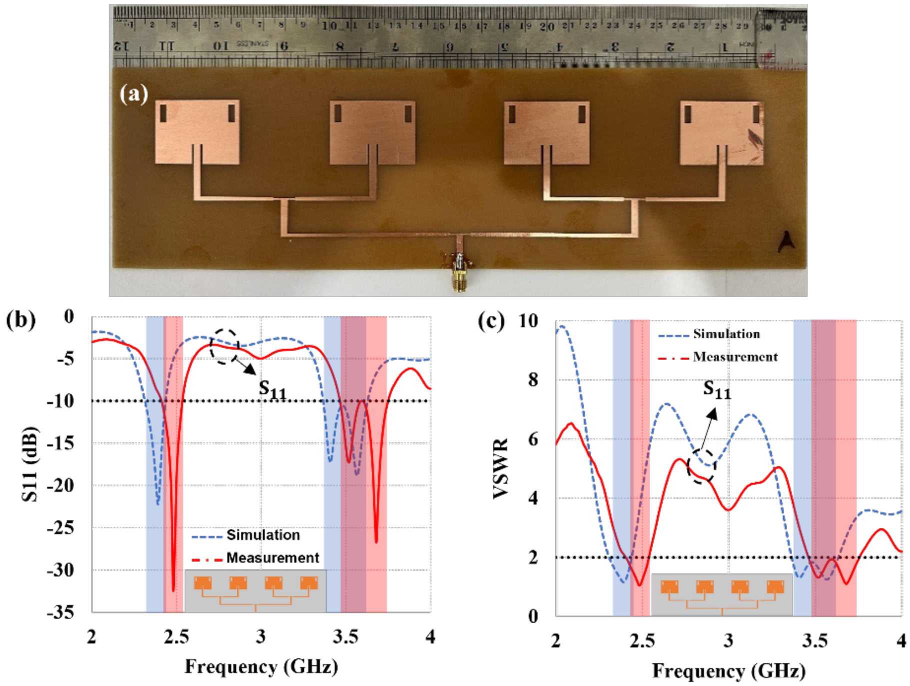

Figure 13. Comparison process of simulation and measurement results of array 4x1 element rectangular patch antenna: (a) Fabricated of array 4x1 element rectangular patch antenna, (b) Comparison of S11, (c) Comparison of VSWR

Figure 13 (b) shows the comparison results of return loss and Figure 13 (c) shows the comparison results of VSWR that have the same pattern characteristics, but there is still a shift in resonant frequency between the simulation and measurement results. The simulated return loss value (S_{11}) shows that the antenna is suitable to operate at fr 2.4 GHz and fr 3.5 GHz with values of S_{11} = -20.22 dB and -11.03 dB; while the measurement results show at fr 2.48 GHz and 3.61 GHz with values of S_{11} = -33.14 dB and -11.05 dB. This phenomenon shows a shift or error between simulation and measurement results of 3.33% at fr 2.4 GHz and 3.14% at fr 3.5 GHz. This is due to the range permittivity of FR4 between 4.4 – 4.6 (Dhanyswari et al., 2023; Putranto et al., 2023).

4.2. *Far Field Measurement and Validation*

Far field measurements were taken in an anechoic chamber using a spectrum analyzer to observe the Received Signal Level (RSL) value to analyze the gain value and radiation pattern of the antenna. Far-field antenna measurement is a technique used to characterize an antenna's performance parameters by analyzing its radiation pattern, gain, directivity, and other properties in the far-field region. The far-field region is the zone where the distance from the antenna under test (AUT) is sufficient for the electromagnetic waves to form a plane wavefront. The far-field region is typically defined as the region (R) where the distance can be determined using following equation (13):

$$R > \frac{2D^2}{\lambda} \quad \text{.........13)}$$

where D represented the largest physical dimension of the antenna and λ is wavelength of the transmitted signal.

4.2.1. *Gain Measurement*

In Figure 14 (a), the Antenna Under Test (AUT) in this case the 4-element linear array antenna as the Antenna Under Test (AUT) is connected to the rf generator and the 2-element linear array reference antenna is connected to the spectrum analyzer.

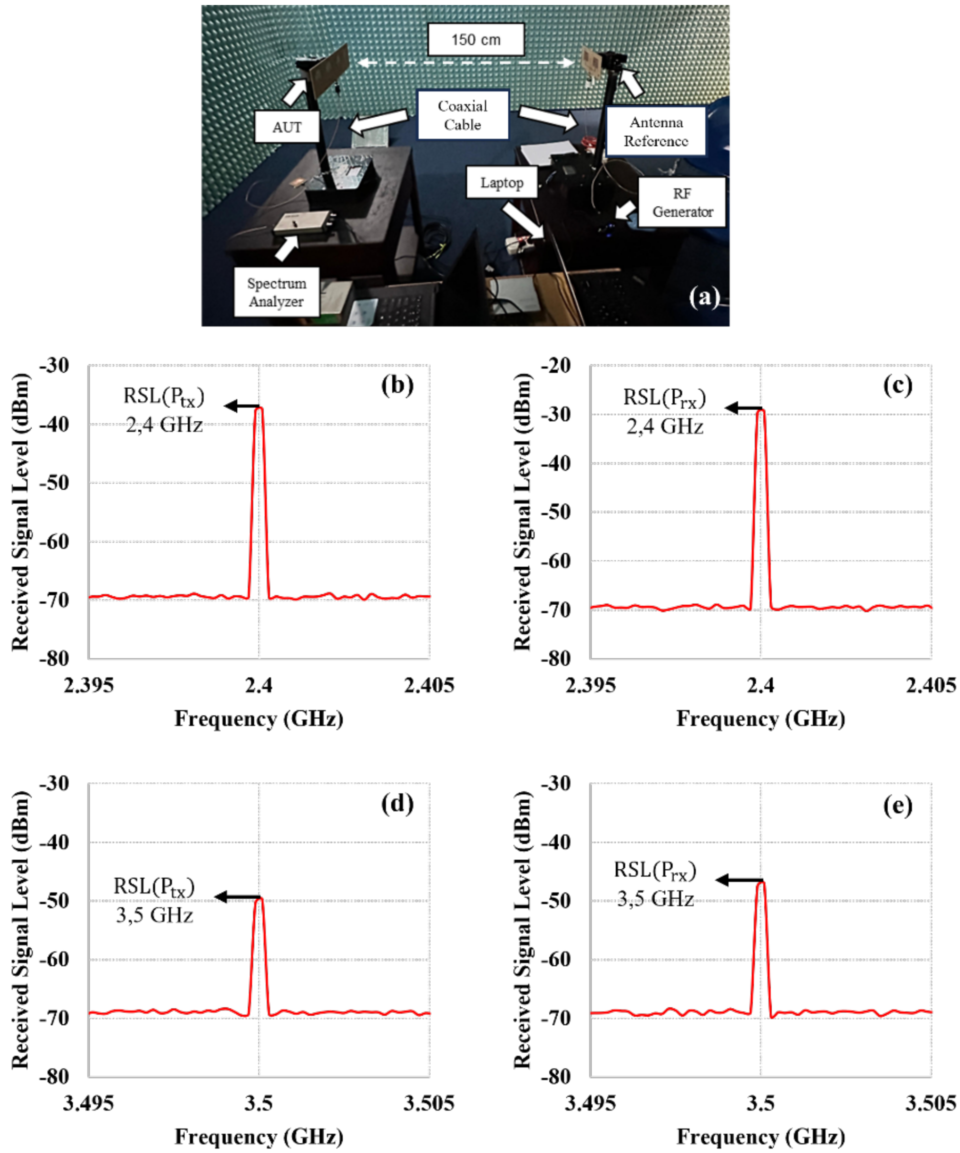

Figure 14. Measurement setup of proposed antenna: (a) measurement in anechoic chamber, (b) RSL of proposed antenna as Tx at 2.4 GHz, (c) RSL of proposed antenna as Rx at 2.4 GHz, (d) RSL of proposed antenna as Tx at 3.5 GHz, € (d) RSL of proposed antenna as Rx at 3.5 GHz

Figure 14 (b) to Figure 14 (e) shows the RSL measurement results. By using the measured RSL value and the simulated 2-element linear array reference antenna gain values of 6.44 dBi and 4.06 dBi, the gain value can be obtained using equation (14).

$$G = \frac{P_{tx}}{P_{tx}} \times G_{ref} \quad \text{.......................................14)}$$

Where G represented the gain of proposed antenna, P_{tx} represented transmitted power and P_{rx} represented received power of proposed antenna. In this measurement, the reference antenna used has a gain of 4 dBi. From equation 13, the gain values of the 4-element linear array antenna at 2.4 GHz and 3.5 GHz are 8.18 dBi and 4.29 dBi, respectively, while the simulation results are 8.01 dBi and 3.81 dBi. It is known that the gain performance of the fabricated antenna is slightly higher than the simulated one.

4.2.2. *Radiation Pattern Simulation*

The radiation pattern of the antenna is shown in Figure 15.

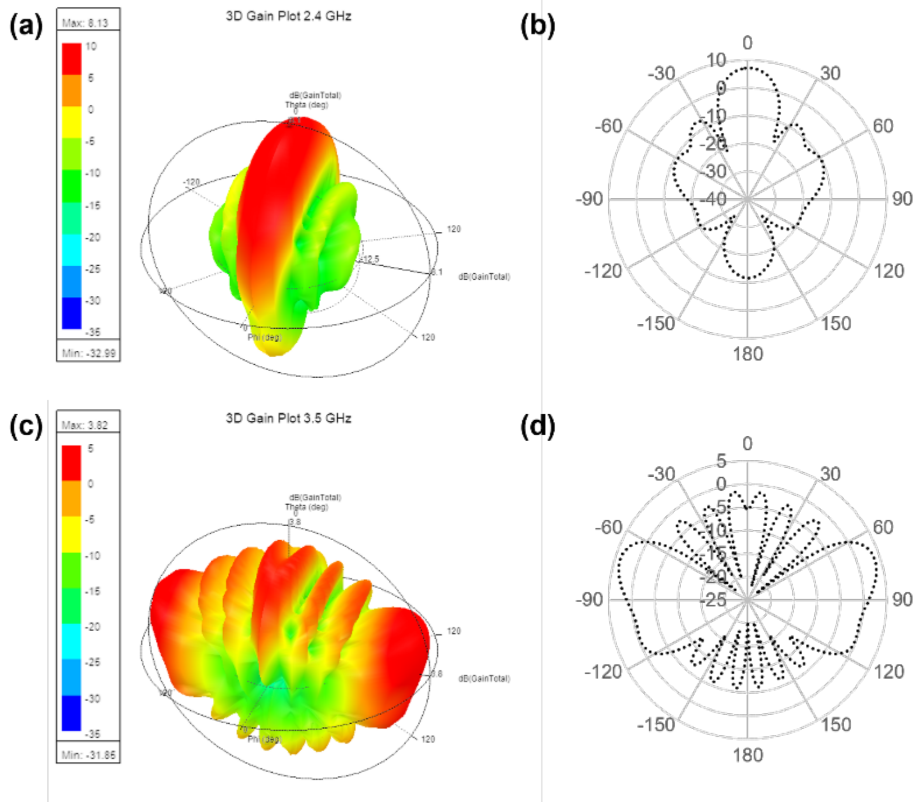

Figure 15. Radiation Patterns of the 4x1 Element Array Rectangular Patch Antenna (a) 3d Radiation Pattern 2.4 GHz, (b) 2d Radiation Pattern 2.4 GHz, (c) 3d Radiation Pattern 3.5 GHz, (d) 2d Radiation Pattern 3.5 GHz

Figure 15 (a) and Figure 15 (b) show that the radiation pattern of the antenna at 2.4 GHz has directional characteristics characterized by the main lobe pointing to an angle of 0°, while Figure 15 (c) and Figure 15 (d) show that the radiation pattern of the antenna at 3.5 GHz has bidirectional characteristics characterized by the emergence of 2 main lobes pointing to an angle of ±72°

5. Conlusion

A microstrip antenna with a linear array of 4x1 elements operating at 2.4 GHz and 3.5 GHz using the inset feed method and two twin slots has been successfully designed and realized. The specifications of the realized antenna at fr1 have met the specified specifications with the return loss (S_{11}) -33.14 dB and VSWR 1.04 and gain ≥ 5 dB of 8.18 dB. Meanwhile, at the resonant frequency of 3.5 GHz, it has met the specified specifications for return loss (S_{11}) -11.05 dB and VSWR 1.88 but does not meet the gain ≥ 5 dB specification of 4.29 dB. The bandwidth at both resonant frequencies has met the specifications, namely at fr 2.4 GHz of 110 MHz and fr 3.5 GHz of 270 MHz. The existence of several specifications that are not met is due to the error factor of the substrate material which has a different dielectric constant value, the fabrication process, and poor connector installation. In addition, the designed antenna has the capacity to work at resonant frequencies of 2.4 GHz and 3.5 GHz as shown by the RSL measurement results. At the resonant frequency of 2.4 GHz, the resulting transmitting power (P_{tx}) of -37.73 dBm and reception power (P_{rx}) of -29.67 dBm. At the resonant frequency of 3.5 GHz, the transmitting power (P_{tx}) of -49.77 dBm and reception power (P_{rx}) of -47.02 dBm.

6. Acknowledgements

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