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Design of Circular Patch Array Microstrip Antenna Using Slot for ISM Band

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Abstract – *This paper presents a Microstrip Antenna Analysis for the ISM Band with a circular patch design with a radius of 17 mm at a frequency of 2,400 – 2.484 GHz. The fabricated array antenna has a very compact width and length of 9.5 x 7.5 cm each. Therefore, an increase in bandwidth on the monopole antenna can be applied to the array arrangement. So to get the best antenna design, two optimizations of antenna size changes are carried out during the simulation: optimization of patch radius and slot length. The radius variation is used to shift the frequency range and slot length for impedance matching, as seen from the S11 value of less than -10 dB. From each change, the best results are taken. Experiments get the best antenna simulation results and are then fabricated. From the measurement results on the fabricated antenna, the lowest S11 value is -19.602 dB, and the gain is 3.52 dBi. The slot technique's optimization process has successfully shifted the frequency to approximately 100 MHz and increased the bandwidth by about 5% or 40 MHz.*

***Keywords**: ISM Band;2.4 GHz;Microstrip Antenna; Circular Array; Slot*

I. Introduction

The development of technology today is so fast. One of the technologies is in the telecommunications sector. The telecommunications system that is often used today is a wireless communication system [1], [2]. Wireless communication can be done without having to be connected to cables. Wireless communication has been widely utilized, especially in the ISM Band frequency, which is 2,400 – 2.484 GHz. One application at this frequency is WiFi technology. A WiFi can connect devices such as personal computers, smartphones, or digital audio players within range of a wireless network to the internet [3], [4]. In a communication system that uses radio waves, such as WiFi, the most important part to optimize its performance is the antenna [5], [6].

The antenna is a vital component in the communication system. With the development of wireless communication [7], [8], the need for antennas is increasing. The equipment used is even more practical and lightweight, so it requires an antenna that supports it with a physical form that is easy to fabricate and has a quality that is capable of being applied to the appropriate telecommunications equipment. One of the antennas that can be applied is the microstrip antenna. Microstrip antennas have the most straightforward configuration, consisting of a patch on one side of the dielectric substrate and a ground plane on the other. Microstrip antennas are easy to form, simple in construction, and low in cost [9], [10]. The antenna is to be designed as a specific frequency range which shows that the antenna can work according to the desired working frequency.

In the following design, a circular patch array microstrip antenna will be made with the addition of a slot at the bottom of the patch. It is known that the array technique can increase the bandwidth while the slot technique can make it easier for the antenna to get a suitable impedance. This antenna will be made with FR-4 material with a dielectric constant of 4.3 substrates, while copper as a patch and ground material.

II. Method

II.1. Microstrip Antenna

In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost,

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performance, ease of installation, and aerodynamic profile are constraints, low-profile antennas may be required [11], [12]. Many other governments and commercial applications, such as mobile radio and wireless communications, have similar specifications. The requirements have to get. Microstrip antennas can be used. As shown in Figure 1, microstrip antennas consist of a skinny metallic strip (patch) placed a small fraction of a wavelength above a ground plane. Often microstrip antennas are also referred to as patch antennas. The radiating elements and the feed lines are usually photoetched on the dielectric substrate. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. Figure 1 also shows the feeding method used is feed line. The microstrip-line feed is easy to fabricate, simple to match by controlling the inset position, and simple to model [13], [14].

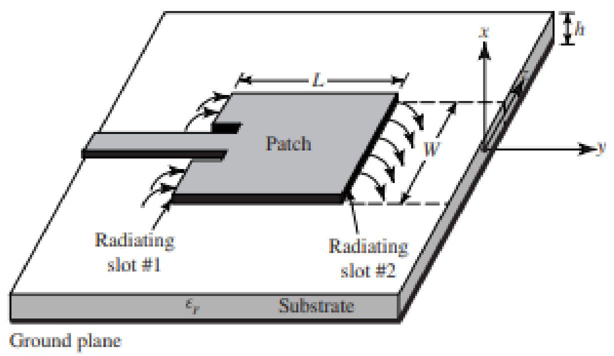

Fig. 1. Microstrip antenna

II.2. *Flowchart*

In the process of designing an antenna, several steps need to be done. It can be shown in Figure 2. First, determine the desired antenna performance specifications, including frequency range, S11, and radiation pattern. The second step calculates the dimensions of the antenna according to the existing formula. From the calculations, it is designed to be the initial design of the monopole antenna, which is then simulated to CST. The simulation process is complete if the results are to the performance specifications. Usually, the performance results from the initial design obtained from calculations do not match, so optimization needs to be done until the results are close to the performance specifications.

II.3. Specification

Antenna specifications are an important part of the design process. The antenna to be made is a narrowband microstrip antenna using a slot at the bottom edge of the circle with the following specifications:

- Frequency range: 2,400 - 2.484 GHz
- S11: -10 dB
- VSWR: 2
- Gain: ≥ 2 dBi
- Radiation pattern: directional.

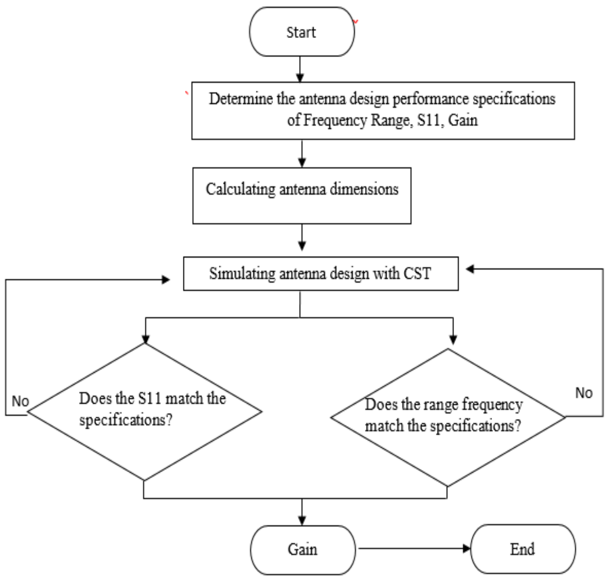

Fig. 2. Flowchart

The circular patch radiation configuration only consists of the patch radius parameter. Calculation of the patch radius using equation (1) [15]:

$$a = \frac{F}{\{1+\frac{2h}{\pi a \varepsilon_r}(In\frac{\pi F}{2h}+1.7726)\}^{0.5}} \quad (1)$$

The value of a is obtained by using equation (2) [15]:

$$F = \frac{8.791 \; x \; 10^9}{fr\sqrt{\varepsilon_r}} \quad (2)$$

The formula for calculating the width of the microstrip feedline is given by equations (3) and (4).

$$B = \frac{377\,\pi}{2Zo\sqrt{\varepsilon_r}} \quad (3)$$

$$w_f = w = \frac{2d}{\pi}\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}[\ln(B - 1) + 0{,}39 - \frac{0{,}61}{\varepsilon_r}\} \quad (4)$$

The arrangement of the circular array microstrip antenna can be seen in Figure 3.

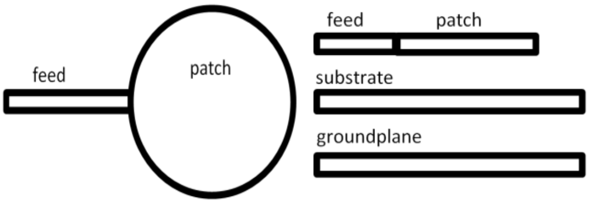

Fig. 3. Circular array microstrip antenna

II.4. Initial Design

The initial design in Figure 4 results from calculations using the formula (1) – (4). The dimensions of the antenna are shown in Table I. The feeding technique used is a line feed technique with an array arrangement. The result of S11 can be seen in Figure 5.

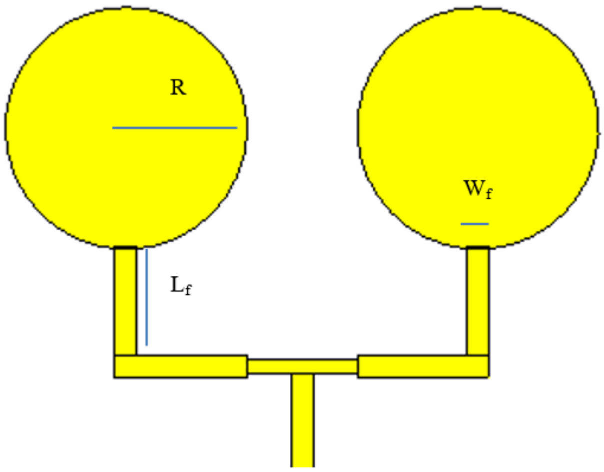

Fig. 4. Initial design

III. Result and Discussion

Based on the simulation results on CST, the S11 value of the antenna can be seen on the S-Parameter graph. Figure 5 shows the results of S11 of -9.23 dB at a frequency of 2.8804 GHz.

TABLE I
SIZE OF DIMENSION INITIAL DESIGN OF ANTENNA

No.	Variabel	Size (mm)	Description
1.	R	13,5	Radius of Patch
2.	Lf	15	Length of feedline
3.	Wf	3	Width of feedline
4.	Wg	70	Width of the ground plane
5.	Lg	80	Length of the ground plane

The graph shows that the antenna design made according to the calculation has not yet produced resonance and the parameter value S11 -10dB at a frequency of 2.400 – 2.484 GHz, so it does not meet the desired antenna planning requirements. Therefore, it is necessary to conduct parametric studies to obtain relevant results. Parametric studies are carried out by changing the patch radius and adding slots and sizes.

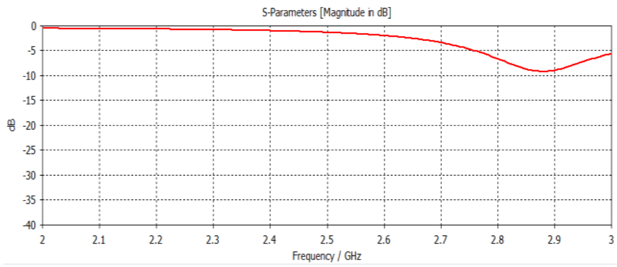

Fig. 5. S11 result of initial design

III.1. Parametric Study 1

The first parametric study step is to change the radius of the patch length (Lp) on the performance of the S11. Patch length variations are carried out from 13.5 – 16.5 mm with four samples, see Figure 6. Based on Figure 6, it can be seen that the patch length on the antenna affects the resonant frequency. Red color chart for 13.5 mm, green for 14.5 mm, blue for 15.5 mm, and other for 16.5 mm.

As seen in Figure 6, to shift the frequency from large to trim is to increase the dimensions of the patch antenna because the antenna dimensions are inversely proportional to the frequency. Therefore, there is a frequency shift, but it has not shown S11 -10 dB at a frequency of 2.400 - 2.484 GHz. Therefore, it is necessary to study the parametric dimensions of the antenna by adding slots.

III.2. Parametric Study 2

The following parametric study adds a slot at the bottom of the circular patch close to the transmission line or feed line. In the parametric study of the slot length, as shown in Figure 7 shows a design, and Figure 8 shows a graph of the S11 values with a length of 2 mm to 12 mm. Sequential graph from left to right of 2, 4, 6, 8, 10, and 12 mm. The S11 value is best shown when the slot has a length of 11.5 mm, which is -29.96 dB. However, the frequency is at 2.493 GHz; this is different from the design specifications. Therefore, it is necessary to redo the parametric study of the patch radius to shift the working frequency on the graph.

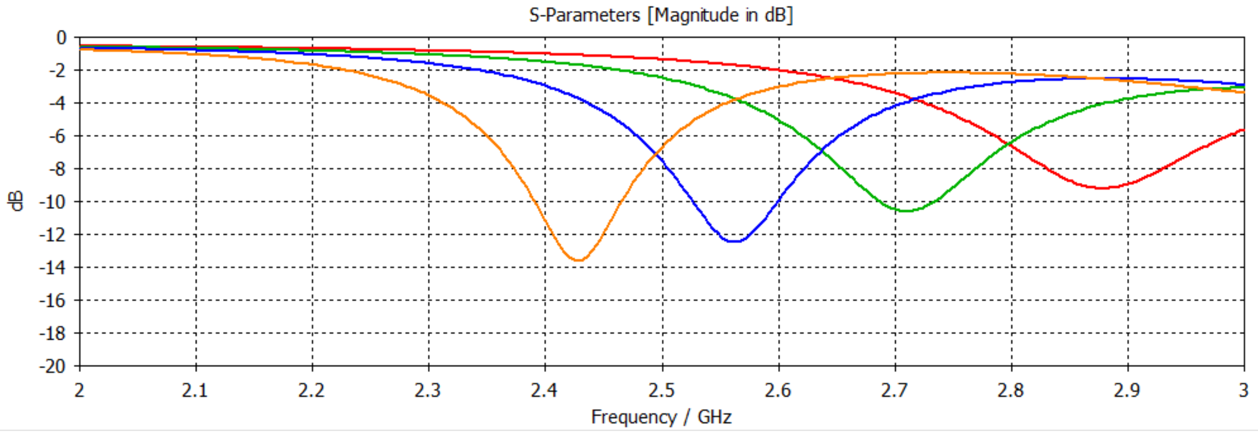

Fig. 6. S11 result of parametric study 1

III.3. Parametric Study 3

A parametric study of the patch radius is conducted again to find the desired frequency. Based on Figure 9, the most suitable patch radius is 17.35 mm at a frequency of 2.443 GHz. These indicate a slight shift in the frequency range to the design specifications.

III.4. Final Design

The final antenna design has resulted in the specifications from the parametric study of dimensions in patch radius and using slots at the bottom of a patch. Figure 10 illustrates the shape of the final antenna design, and Table II shows the dimensions of the final antenna.

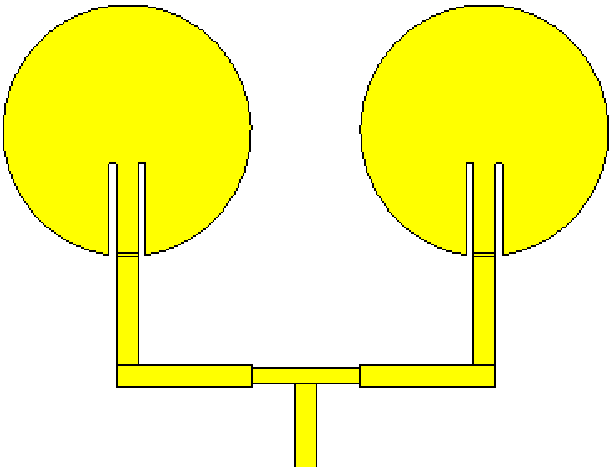

Fig. 7. Design using slot

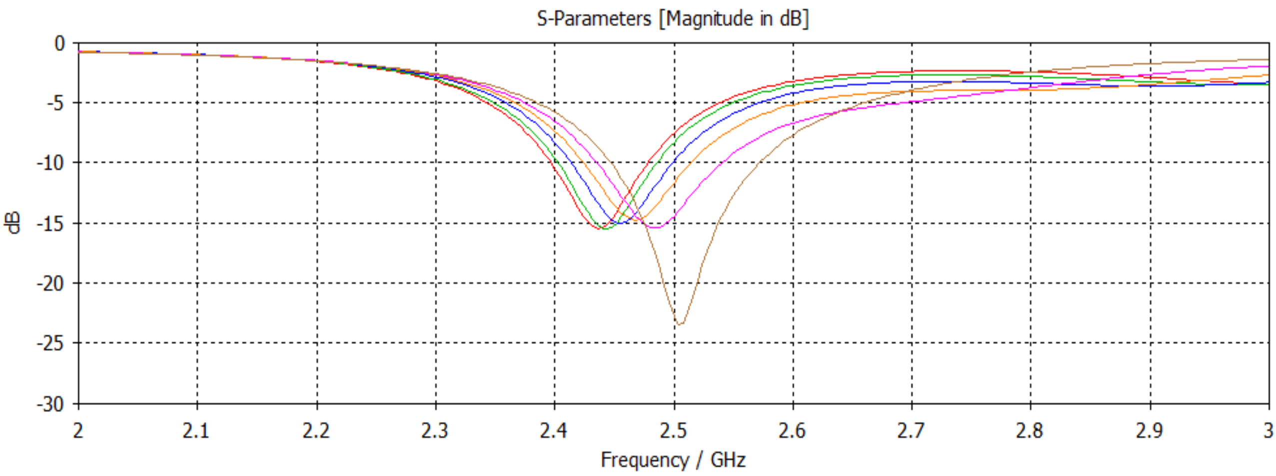

Fig. 8. S11 result of parametric study 2

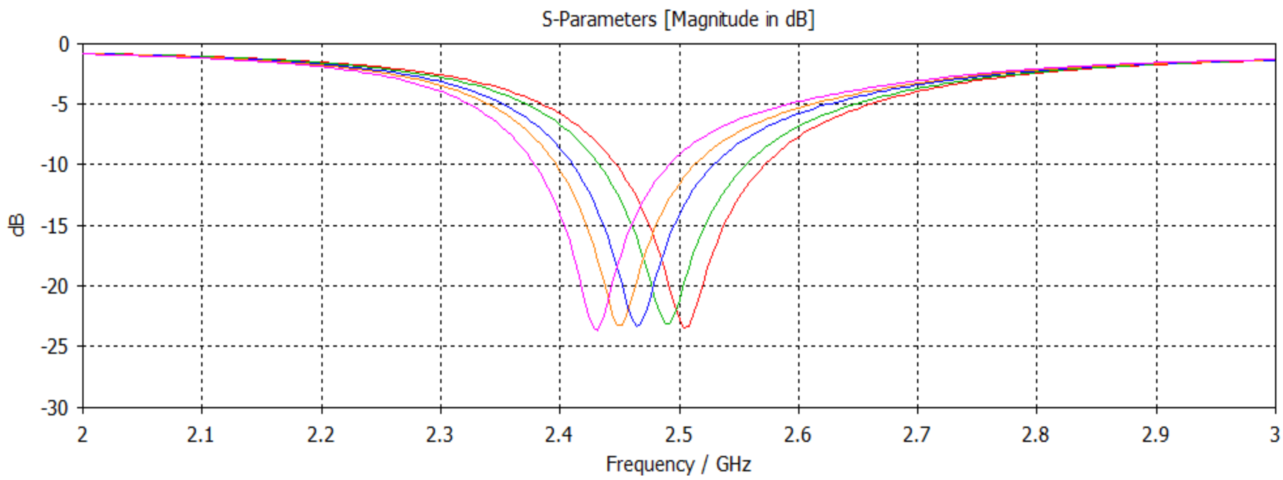

Fig. 9. S11 result of parametric study 3

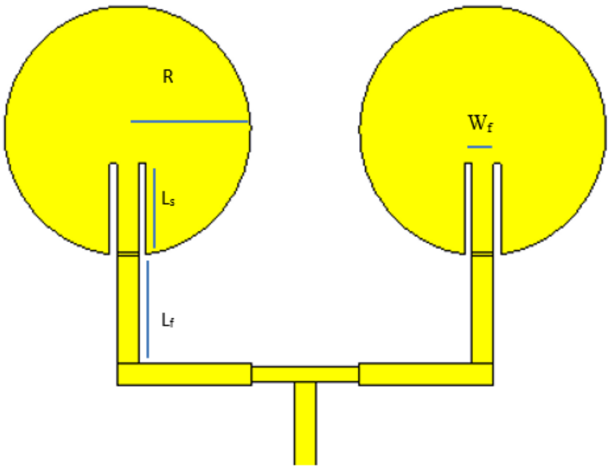

Fig. 10. Final Antenna Design

TABLE II
SIZE OF DIMENSION FINAL DESIGN OF ANTENNA

No.	Variabel	Size (mm)	Description
1.	R	17,5	Radius of Patch
2.	Ls	12	Length of Slot
3.	Ws	1	Width of Slot
4.	Lf	15	Length of feedline
5.	Wf	3	Width of feedline
6.	Wg	70	Width of ground plane
7.	Lg	80	Length of ground plane

III.5. S11 Simulation Result

Figure 11 shows the results of S11 of -23.66 dB at a frequency of 2.432 GHz. The graph shows that the value of S11 has met the specified specifications, namely -10 dB, and the obtained frequency range is appropriate at 2,400 – 2,486 GHz.

III.6. Gain and Radiation Pattern

The gain of the designed antenna based on the simulation of the final antenna design is shown in Figure 12. Figure 12 shows that the antenna has a gain value of 4.492 dBi, and it can be seen that it has a directional radiation pattern because it only points in one direction. Therefore, the resulting gain value is by the specified specifications.

III.7. S11 Measurement

The antenna performance parameters tested are S11, VSWR, and gain parameters. The measurement results will then be compared with the simulation results. Figure 13 is the shape of the antenna that has been fabricated.

Based on the simulation results using CST Microwave Studio 2019 and S11 measurements using the Nano Vector Network Analyzer, an image is obtained in the form of a graph in decibels (dB) from the simulation results and measurements, as shown in Figure 14. The horizontal axis shows the frequency range in GHz. The vertical axis shows the value of S11 in dB.

Figure 14 and Table III compare the S11 values in the simulation and measurement results. S11, in the simulation results, is 23.565 dB at a frequency of 2.443 GHz. The measurement has a -19.602 dB at a frequency of 2.45 GHz. The S11 value from the simulation results is slightly different from the measurement results but has met the specifications.

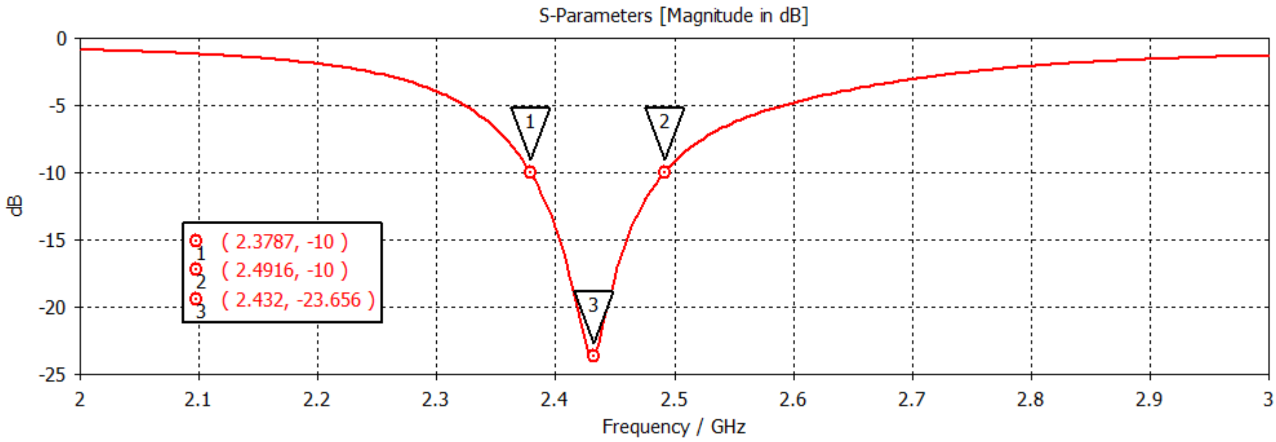

Fig. 11. S11 Result of Final Antenna Design

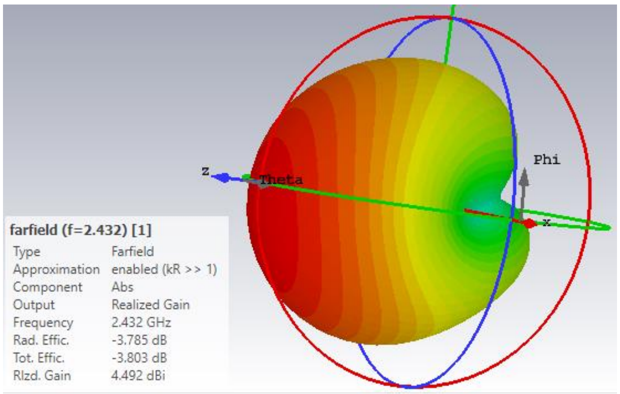

Fig. 12. Gain and radiation pattern simulation

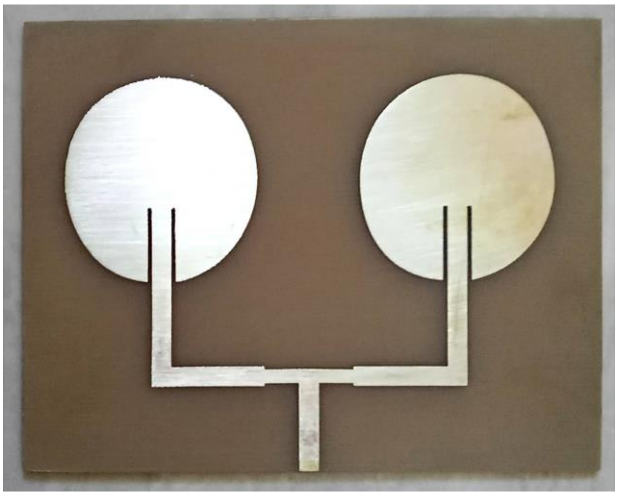

Fig. 13. Fabrication Antenna

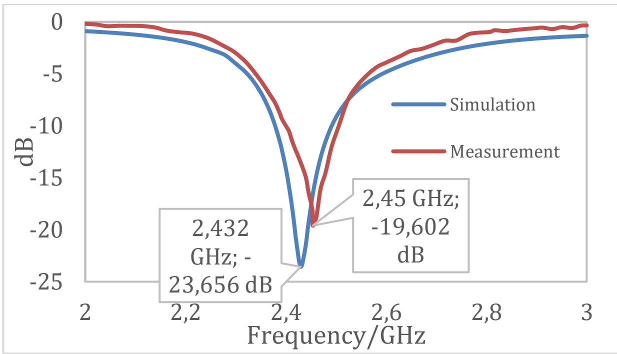

Fig. 14. Simulation and measurement comparison results of S11

TABLE III
SIMULATION AND MEASUREMENT COMPARISON RESULTS OF S11

Antenna	S_{11} (dB)	Frequency (GHz)	S_{11} at 2,45 GHz (dB)
Simulation	-23.656	2,442	-22,34
Measurement	-19,602	2,45	-21,13

III.8. VSWR Measurement

Table IV shows a VSWR comparison between the simulation results and measurements. The VSWR result in the simulation is 1.10 at a frequency of 2.432 GHz, while the antenna measurement has a VSWR value of 1.19 at a resonant frequency of 2.45 GHz. Therefore, it can be seen that the comparison of the simulation results with the measurements shows that the VSWR value is close to 1:1 with different resonant frequency ranges. Therefore, the microstrip antenna has a performance that still meets the desired VSWR specifications.

TABLE IV
SIMULATION AND MEASUREMENT COMPARISON RESULTS OF VSWR

Antenna	VSWR	Frequency (GHz)	VSWR at 2,45 GHz
Simulation	1:1,10	2,432	1 : 1,16
Measurement	1:1,19	2,45	1 : 1,19

III.9. Gain Measurement

Gain measurement is done in a free room. Table V shows the gain value from the simulation and measurement of the microstrip antenna.

TABLE V
SIMULATION AND MEASUREMENT COMPARISON RESULTS OF GAIN

Antenna	*Gain* simulation (dBi)	*Gain* measurement (dBi)
Microstrip	4,492	3,54

The results of the simulation gain values and measurements of the microstrip antenna are shown in Table V. The measurement results have a gain value of 4,492 dBi. The measurement results have a gain value of 3,54 dBi. The measurement results show a gain value close to the simulation results.

III.10. Antenna Performance Evaluation

Antenna performance evaluation aims to compare the simulation results and measurement results with the required antenna specifications for microstrip antennas. It can be seen in Table 6.

A comparison of measurement and simulation results is shown in Table 7. The difference lies in the simulation results with measurements. First, caused by imperfect antenna fabrication factors, such as untidy soldering techniques, cause an increase in the length of the conductor. As a result, a slight difference in the material's conductivity and resistance values does not match the simulation values. Another cause is the length of the patch and slot radii when fabricating, which is not by the simulation. Still, the working frequency, S11, VSWR, gain, and radiation pattern on the fabricated antenna meet the specifications.

TABLE VI
SIMULATION AND MEASUREMENT COMPARISON RESULTS OF ANTENNA

Parameter	Spesification	Simulation	Measurement
S_{11}	≤ -10 dB	-23,656 dB	-19,602 dB
VSWR	≤ 2	1,10	1,19
Gain	≥ 2 dBi	4,492 dBi	3,54 dBi

IV. Conclusion

Microstrip Antenna for ISM Band is designed and built, and its performance is measured by measurements using a Nano Vector Network Analyzer. The optimization process using the slot technique is proven successful in changing the frequency range by about 100 MHz and increasing the bandwidth by about 5% or 40 MHz. Slots at the bottom of the patch and the transmission line channel influence the S11 result. A slot length of 12 mm and width of 1 mm can increase the impedance in the frequency range with S11 values lower than -10dB. The fabricated antenna has the lowest S11 value of -19.602 dB at a frequency of 2.432 GHz and a gain of 3.54 dBi. The final result shows that the performance of the fabricated antenna meets the specifications.

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