Analysis of the Effect of Slot Size and Shape On Microstrip Antenna 5G Band N40 Application

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ABSTRACT

With the emergence of digital wireless communication technology, the fifth generation of LTE (Long Term Evolution) - 5G technology was developed to enhance faster data performance. For ensuring optimal execution of this technology, an antenna is required as a transmitter. Microstrip antenna is a low-cost and easy-to-manufacture antenna. Nevertheless, the drawback of microstrip antennas is their low gain.

In this study, a microstrip antenna was designed by adding a slot to the patch for use in the 5G band N40 network. The antenna's dimensions were determined, and it was designed, simulated using software, fabricated, and measured. The measurement results were analyzed in conjunction with the simulation results. The study involved the design and testing of a microstrip antenna operating at 2.35 GHz. The antenna exhibited a S1.1 value of -21.2 dB, a VSWR value of 1.19, a gain value of 3.69 dBi, and a bandwidth value of 90.6 MHz. Additionally, a rectangular slot antenna was designed and tested, yielding a S1.1 value of -19.884 dB, a VSWR value of 1.225, a gain value of 3.707 dBi, and a bandwidth value of 91.7 MHz. Meanwhile, the most optimal circular slot antenna has a return loss value of -19.55 decibels, a voltage standing wave ratio value of 1.235, a gain value of 3.71 decibels, and a bandwidth value of 91.8 megahertz.

The measurement results of the single patch microstrip antenna give a return loss S1.1 of -13.01 dB, VSWR of 1.48, gain of 4.3 dBi and bandwidth of 170 MHz. Then the best rectangular slot antenna has a return loss S1.1 of -16.22 dB, VSWR value of 1.37, gain value of 4.7 dBi and bandwidth value of 170 MHz. Meanwhile, the best circular slot antenna has a return loss S1.1 of -16.91 dB, a VSWR value of 1.34, a gain value of 6.7 dBi and a bandwidth value of 170 MHz.

Keywords: *Band N40, Microstrip Antenna, Slot, 5G.*

1. INTRODUCTION

Today, mobile communication is rapidly advancing as the number of internet users in Indonesia increases. According to the Central Statistics Agency's (BPS) data reported on September 7, 2022, 62.10 percent of Indonesians accessed the internet in 2021[1]. To meet the necessary demands of the internet, a communication system that provides unrestricted access to information and swift data transfer is imperative [2]. In modern communication systems, the speed of data transmission is a critical factor. The evolution of network technology has progressed through generations 1G, 2G, 3G, 3.5G, 4G, and currently, 5G. Each update is designed with existing demands in mind. The 5G system was engineered to meet performance goals and is capable of providing services that cater to diverse demands. In Indonesia, the N40 frequency band is being utilized to supplement 4G requirements and begin the implementation of 5G network technology. According to reports from the Ministry of Communication and Information, the ministry is currently reallocating and reorganizing the spectrum at different levels in 2021 to satisfy the demand for 5G frequencies in Indonesia. The N40 2.3 - 2.4 GHz band represents a promising spectrum band for 5G [3].

Antennas play a crucial role in the data transmission process, by transmitting and receiving radio or electromagnetic waves. Among these, the microstrip antenna is frequently used in communication due to its lightweight and cost-effectiveness, which makes it an ideal option for 5G communication devices. When compared to other types of antennas like parabolic antennas and yagi, microstrip antennas possess a lower gain value [4]. To increase the gain value of microstrip antennas, the array antenna method is widely employed. In this method, the antenna design involves connecting several identical antennas, which results in increased gain value [5]. Additionally, adding slots to the antenna patch also increases the gain value. Additionally, the parasitic element method can be utilized. A parasitic element is an element without its own feedline and instead relies on the feedline of another patch [6]. Of the three available methods, adding slots to the antenna patch is one of the most effective for increasing gain [7]. Therefore, experts add slots to the patch and modify its size and shape to produce optimal gain value.

Microstrip antenna researchers have commenced investigating the N40 frequency band, which was previously researched by Fannush Shofi. Technical term abbreviations will be explained when first used. The research involves utilizing a 4-element MIMO technique that concentrates on the mutual coupling and correlation of MIMO antennas. Based on the measurement results of the elements, the return loss is -11.24 dB, and the bandwidth is 80 MHz at the central frequency of 2.35 GHz. For the analysis of mutual coupling between elements, the MIMO 2x2 arrangement with non-uniform polarization and a value of < -20 dB for all elements yields the best results. The measurement results of the antenna show good agreement with the simulation results. These results are well-suited for MIMO applications requiring low values of mutual coupling and correlation between elements [27].

Additionally, they are relevant to a slot investigation conducted by Zaharah Tricahyani Ardian. The impact of circular slot size and position on the super wideband circular planar patch antenna (SWB) was analyzed in this study. Simulation results indicate that alterations to slot size and position influence multiple characteristics ofthe circular patch SWB planar antenna. The most optimal performance is achieved by adding a 6 mm diameter circular slot to the bottom of the antenna patch, resulting in a gain of 2.50 dBi and the lowest S11 of -23.94 dB at 50 GHz. For the desired operating frequency range of 3-50 GHz, it is possible to attain S11 values below -10 dB [26].

In addition, Jeffri Parragan conducted a study on slots. The research analyzed the impact of a combination of horizontal and vertical slots on a 2.4 GHz microstrip antenna simulation. Without altering the shape of the radiator patch from the antenna, the simulation was performed by generating a hybrid of horizontal and vertical slots on the ground plane and observing the influence on return loss parameters and other parameters. The simulation results indicate a more favorable return loss of -32.564 dB [28].

2. METHOD

This study starts by specifying the antenna requirements (Table 1) and then computing the proportions of the microstrip rectangular single patch antenna., and the outcomes of the calculations are simulated using relevant antenna design software. If the results of the single-element simulation do not meet the target specifications, the simulation process will optimize the antenna dimensions. If appropriate, a rectangular slot with a size of 1-30% of the patch size will be added, with the slot position in the middle of the patch. This will be followed by a rectangular slot with a size of 1-30% of the patch size, with the slot position at the top, and then moved to the bottom position. Technical terms will always be explained when first used. Then, a circular slot antenna should be simulated with a size ranging from 1 to 30% of the patch size. It should be placed in the centre of the patch, followed by another circular slot with the same size and position on top. The slot should then be moved to the lower position. After conducting the simulation, we analyze the antenna's performance using the slot that yielded the optimal parameter values. We then print the antenna design and obtain additional measurements of its performance parameters. Finally, we compare the measurement results with the simulation results.

2.1. *Element Antenna Specifications*

In this research, Table 1 shows the specifications of the microstrip antenna to be designed. The substrate material used will be FR4 with a dielectric constant value of $\varepsilon_r = 4.3$ and a thickness of $h = 1.6$ mm.

Table 1. Element Antenna Specifications

Antenna Specifications	Description
Patch Shape	*Rectangular*
Frequency	2,3 – 2,4 GHz (Fc = 2,35 GHz)
Return Loss	< -10 dB
VSWR	≤ 2
Impedance	± 50 Ω
Substrate Material	FR-4 *lossy*
Relative Dielectric Constant	4,3
Substrate Thickness	1,6 mm
Patch/Ground Material	*Copper*

2.2. *Element Antenna Dimension Calculation*

The design of the microstrip antenna in a rectangular shape is presented in Antenna dimensions that can be computed using the equations referenced in [18-19]. To determine the width of the patch (W), Equation (1) can be employed.

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

where c represents the speed of light (3×10^8 m/s), f_0 stands for the working frequency, and ε_r denotes the dielectric constant of the substrate material.

Then, to calculate the length of the patch (L), first determine the value of the effective dielectric constant (ε_{eff}) using Equation (2) below.

$$\varepsilon_{eff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{2}$$

Whereas h denotes the thickness of the substrate, Equations (3) and (4) can be utilized to calculate ΔL and L_{eff}, respectively.

$$\Delta L = 0{,}412\,h\,\frac{(\varepsilon_{eff}+0{,}3)+(\frac{W}{h}+0{,}264)}{(\varepsilon_{eff}+0{,}258)+(\frac{W}{h}+0{,}8)} \tag{3}$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \tag{4}$$

Thus, Equation (5) below can be used to obtain the length of the patch (L):

$$L = L_{eff} - 2\Delta L \tag{5}$$

Furthermore, to determine the width of the supply line (Ws) use Equation (6) as follows:

$$W_s = 2\times W \tag{6}$$

Next to determine the width of the supply channel (Ws) use Equation (6).

$$L_s = 2\times L \tag{7}$$

The antenna with specification of dimension is visible in Figure 1.

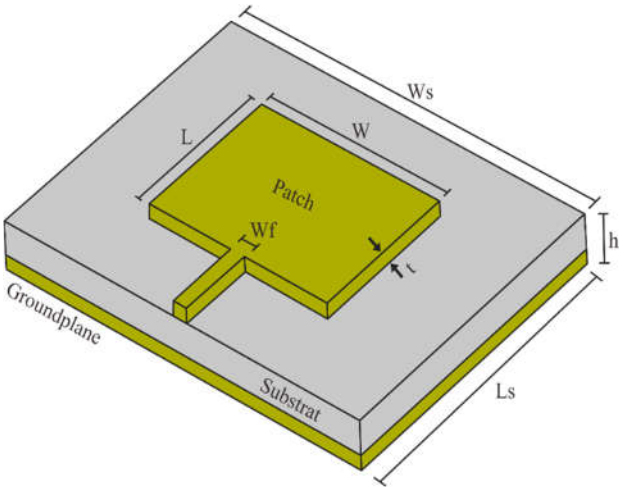


Figure 1 Rectangular Microstrip Antenna

2.3. Single Element Antenna Design

The dimensions of the microstrip antenna's square patch with inset-feeding, as calculated using Equations (1)-(7), are presented in Table 2. Subsequently, these villages were simulated via simulation software to analyze their return-loss performance, VSWR, Gain, Bandwidth and radiation pattern.

Table 2. Dimension Antenna Specifications

No.	Part	Symbol	Specification
1.	*Patch* Length	L	29,04 mm
2.	*Patch Width*	W	52,00 mm
3.	Supply Line Width	Wf	2,89 mm
4.	*Groundplane Length*	Ls	62,18 mm
5.	*Groundplane width*	Ws	78,4 mm

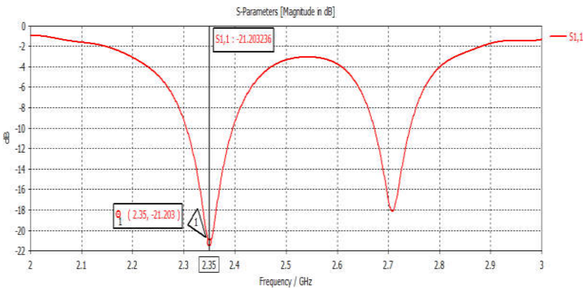


Figure 2 Single Patch Antenna Return Loss Simulation Results

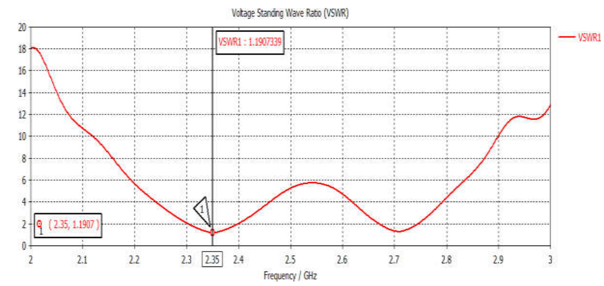


Figure 3 single patch antenna VSWR simulation results

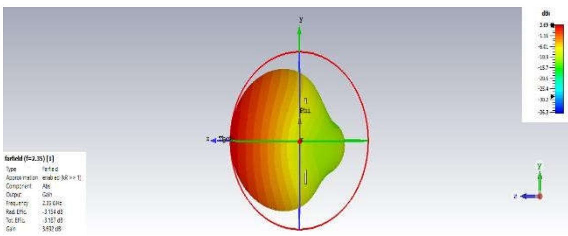


Figure 4 single patch antenna Gain simulation results

Figure 2 illustrates the simulation results for return loss at 2,35 GHz, with a measurement of -19,884 dB. In addition, this antenna also has a dual band function that works at 2.35 GHz and 2,708 GHz frequencies. The VSWR results in a value of single patch antenna is 1,19, as shown in Figure 3. The obtained bandwidth extends from 2.3052 GHz to 2.3958 GHz, with a range of 90,6 MHz. Simulation of radiation patterns is displayed in Figure 4, indicating a maximum gain of 3,69 dBi. From the results of this design, it can be concluded that the single element antenna design using a microstrip square patch with inset feeding unification is successful. The simulation results are in line with the target specifications and the antenna performs well at a frequency of 2.35 GHz. Therefore, this single element antenna is effective at 2.35 GHz. This antenna component will be mounted onto the slot of the patch structure.

2.4. Design of microstrip antenna with slot

In this antenna design, a microstrip rectangular patch antenna will be modified with rectangular and circular slots that range in size from 1-30%. The slots will be positioned at either the centre, top, or bottom of the antenna. Figure 5 displays the design drawing of the antenna with slots.

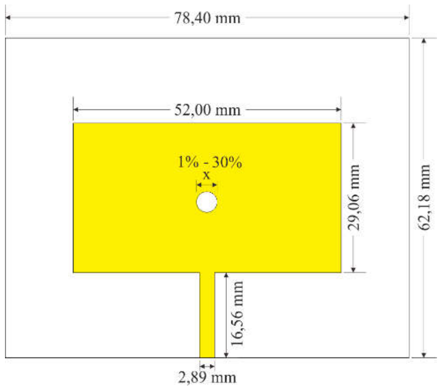


Figure 5 Design of microstrip antenna with slot

The design depicted in Figure 5 will also undergo simulation software. The figures (7)-(9) depict the simulation results for the return loss, VSWR, gain, and bandwidth. Furthermore, the process proceeds to analyzing the simulation results of the antenna in order to obtain optimal performance.

3. RESULT AND DISCUSSION

This section discusses the printed antenna's measurement results, specifically the return loss and mutual coupling between elements. A VNA device was utilized for the measurements. Following this, the design process involves the comparison and analysis of measurement and simulation results.

3.1. Antenna Simulation Results Analysis

After simulating 180 samples of rectangular patch antennas, the addition of slots resulted in changes to the values of the antenna parameters. In Figure 6, it is evident that incorporating a slot beneath the patch reduces the S11 value of the antenna as compared to the one without the slot. However, the S11 value increases with a slot size ranging from 19% to 30%. Remarkably, at a size of 10%, the rectangular slot produces a significant decrease in S11 value, with a difference to the S11 value of the antenna sans slot of 2.37 dB at the bottom rectangular slot, 3.184 dB at the top rectangular slot, and 3.293 dB at the center rectangular slot. The value of S11 in the circular slot at the center, ranging from 24% to 30%, and the upper circular slot between 28% and 30% is greater than -10 dB, indicating non-compliance with the antenna specifications.

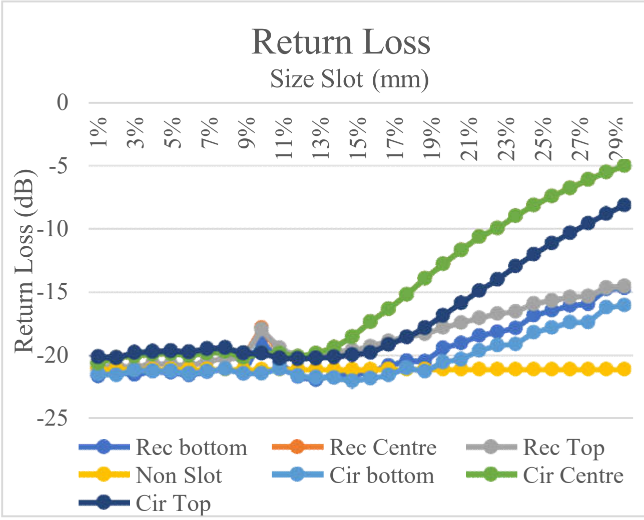


Figure 6 All Antenna Return Loss Simulation Results

In the figure 7, the VSWR values reveal that incorporating lower circular, upper circular, upper rectangular, and lower rectangular slots produces a variance compared to antennas without slots that is not significant and falls between 1 and 1.5. However, the rectangular slot positioned at 24-30% and the circular slot at 29-30% of both circular and rectangular shapes show a constant increase in VSWR value, violating predetermined antenna specifications with VSWR values exceeding 2. Antennas incorporating rectangular slots in the center demonstrate a more substantial decrease in VSWR values than those featuring circular slots.

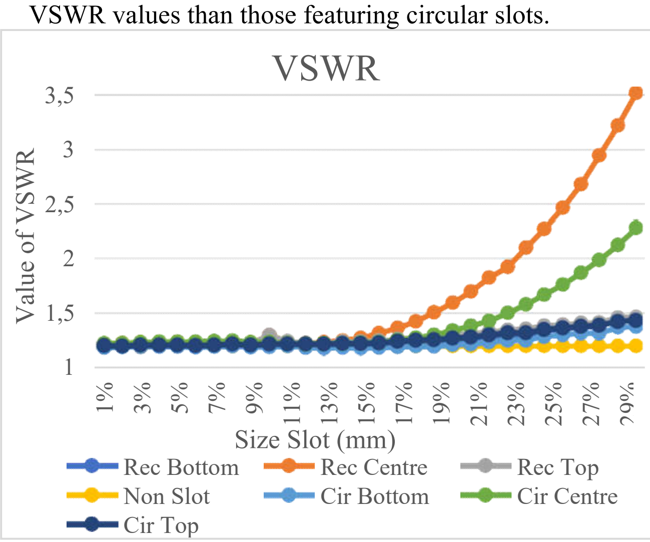


Figure 7 All Antenna VSWR Simulation Results

In figure 8, the simulation results of adding slots to the gain value are displayed. The gain value of the antenna with added slots shows a significant change in value. By examining the existing graph, it is apparent that the graphs coincide with the antenna graph without adding a slot. Nevertheless, the gain value of the upper rectangular and lower circular slots at 26-30% size decreases, but not less than 3.6 dBi. As for the slot situated in the center of the patch with sizes ranging from 1-13%, the gain value increases. However, for sizes between 14-30%, the gain value considerably decreases. The antenna with the center rectangular slot at a 30% slot size possesses the lowest gain value of 2.983 dBi. Antennas with rectangular slots in the center of the patch encounter a more substantial reduction in gain value than those with circular slots in the center of the patch.

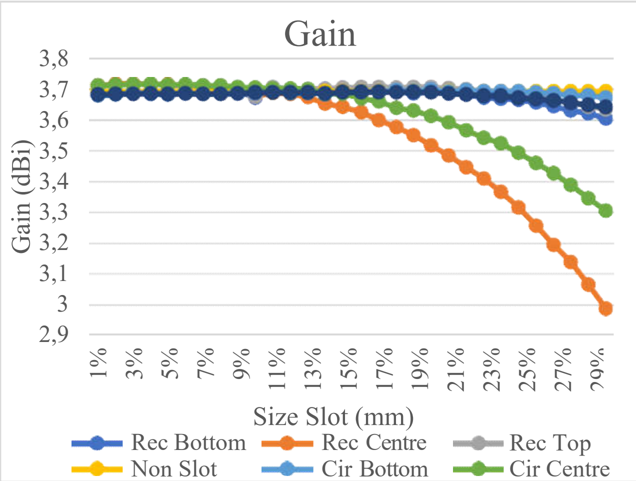


Figure 8 All Antenna Gain Simulation Results

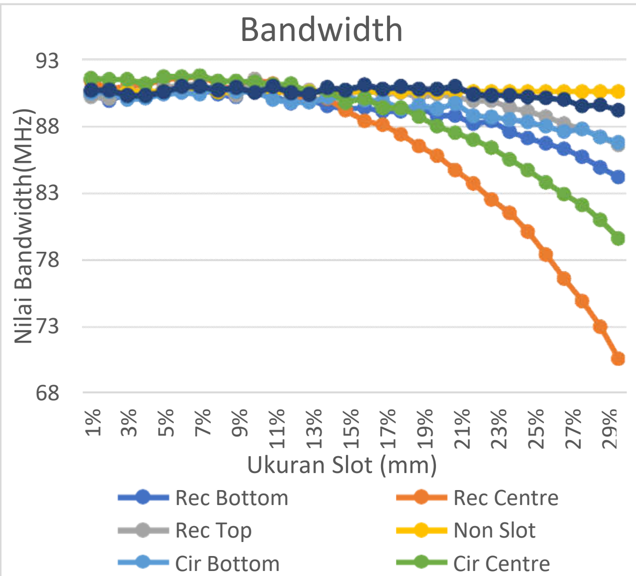


Figure 9 All Antenna Bandwidth Simulation Results

The figure 9 shows that the slot has an effect on the bandwidth value. In the center rectangular and center circular slots at sizes 1-13%, the bandwidth value increases compared to the bandwidth value of the antenna without the initial slot. For the slot antenna in the center of the patch, the larger the slot size, the smaller the bandwidth value, but the decrease in the center rectangular slot is more significant than in the center circular slot.

After analyzing the parameter values of the simulation results of 180 antennas, it is found that the rectangular antenna with the best rectangular slot is in the 7% slot size positioned in the center of the patch with a gain value of 3.707 dBi. Furthermore, the rectangular antenna with the best circular slot is in the 7% slot size positioned in the center of the patch with a gain value of 3.71 dBi. Then manufacture the two top antennas and perform measurements to compare the optimal antenna parameter values with those of antennas that do not have slots.

3.2. Antenna Measurement Results

This section discusses the measurement results of the printed antenna. Objective evaluations include return loss, VSWR, bandwidth, and gain, measured using a VNA device. Subsequently, an analysis comparing the measurement and simulation results in the design process follows.

3.2.1. Measurement Results of Single Patch Antenna

The microstrip rectangular patch antenna, connected with the microstrip feed-line as the input port via an SMA-to-PCB connector, is illustrated in Figure 10. The Figure 11 displays the return-loss (S11) measurement outcomes of the single-element antenna. The S value obtained at 2.35 GHz frequency is -13.01 dB, whereas the lowest S11 value is achieved at 2.41 GHz, which is -23.02 dB. The measurement results exhibit an 170 MHz bandwidth, beginning from 2.34 to 2.5 GHz.

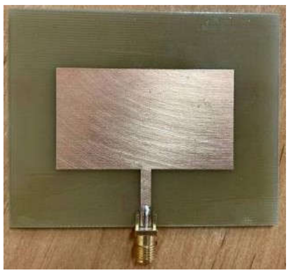
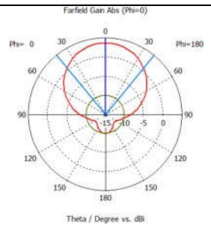
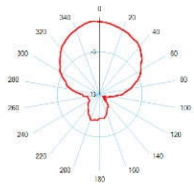


Figure 10 Single Non slot Patch Antenna Fabrication Results

Figure 11 single patch non slot antenna Return Loss measurement results

Table 3. Parameter Comparison of non slot Single Patch Antenna

Antenna Parameters	Non Slot Antenna Simulation Results	Non Slot Antenna Measurement Results	Deviation
Returnloss S1.1	-21,2 dB	-13,01 dB	-8,19 dB
Bandwidth	90,6 MHz	170 MHz	79,4 MHz
VSWR	1,19	1,48	0,29
Gain	3,69 dBi	4,3 dBi	0,61 dBi
Radiation Pattern			The radiation pattern is co-polar with vertical polarization.

A comparison between the simulation results and the measurement results is apparent that the S11 value in the measurement results is higher than the simulation results by 8.19 dB. Despite this difference, the S11 measurement results remain acceptable since the value is below the maximum limit of -10 dB. Moreover, the bandwidth derived from the measurement results is 79.4 MHz wider than that of the simulation results. The VSWR value of the measurement results is 0.29 higher than that of the simulation results. Similarly, the gain value of the measurement results is 0.61 dBi higher than the simulation results. Both sets of results have co-polarization with vertical polarization for the polar radiation parameters.

3.2.2. Measurement results for the best rectangular slot antenna

The best rectangular antenna slot analysis result is found on an antenna with a 7% slot size located in the center of the patch. After fabricating the best rectangular slot microstrip antenna, the antenna was measured. The microstrip antenna fabrication result with the best rectangular slot can be seen in figure 12.

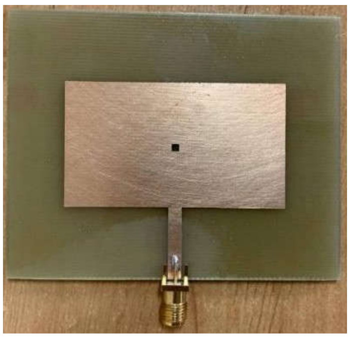


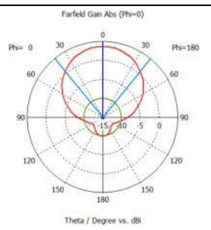
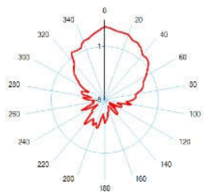
Figure 12 fabrication results for the best rectangular slot antenna

Figure 13 the best rectangular slot antenna Return Loss measurement results

The Figure 13 displays the S11 measurement outcomes of the best rectangular slot antenna. The S11 value obtained at 2.35 GHz frequency is -16.22 dB, whereas the lowest S11 value is achieved at 2.4 GHz, which is -21.62 dB. The measurement results exhibit an 170 MHz bandwidth, beginning from 2.3 to 2.47 GHz.

A comparison between the simulation results and the measurement results is apparent that the S11 value in the measurement results is higher than the simulation results by 3.664 dB. Despite this difference, the S11 measurement results remain acceptable since the value is below the maximum limit of -10 dB. Moreover, the bandwidth derived from the measurement results is 78.3 MHz wider than that of the simulation results. The VSWR value of the measurement results is 0.145 higher than that of the simulation results. Similarly, the gain value of the measurement results is 0.993 dBi higher than the simulation results. Both sets of results have co-polarization with vertical polarization for the polar radiation parameters.

Table 4. Parameter Comparison of Single Patch the best Rectangular Slot Antenna

Antenna Parameters	the best Rectangular Slot Antenna Simulation Results	the best Rectangular Slot Antenna Measurement Results	Deviation
Returnloss S1.1	-19,884 dB	-16,22 dB	-3,664 dB
Bandwidth	91,7 MHz	170 MHz	78,3 MHz
VSWR	1,225	1,37	0,145
Gain	3,707 dBi	4,7 dBi	0,993 dBi
Radiation Pattern			The radiation pattern is co-polar with vertical polarization .

3.2.3. Measurement results for the best circular slot antenna

The best circular antenna slot analysis result is found on an antenna with a 7% slot size located in the centre of the patch. After fabricating the best rectangular slot microstrip antenna, the antenna was measured. The microstrip antenna fabrication result with the best circular slot can be seen in figure 14.

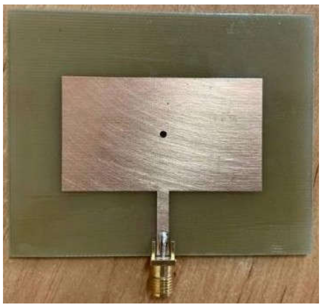


Figure 14 fabrication results for the best rectangular slot antenna

Table 5. Parameter Comparison of Single Patch the best Circular Slot Antenna

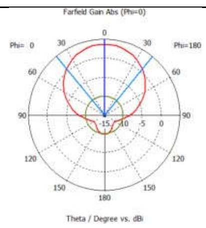
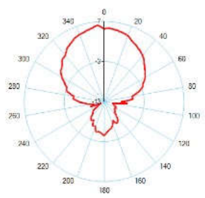
Antenna Parameters	the best Circular Slot Antenna Simulation Results	the best Circular Slot Antenna Measurement Results	Deviation
Returnloss S1.1	-19,55 dB	-16,91 dB	-2,64 dB
Bandwidth	91,8 MHz	170 MHz	78,2 MHz
VSWR	1,235	1,34	0,105
Gain	3,71 dBi	6,1 dBi	2,39 dBi
Radiation Pattern			The radiation pattern is co-polar with vertical polarization

Figure 15 the best circular slot antenna Return Loss measurement results

The Figure 15 displays the S11 measurement outcomes of the best rectangular slot antenna. The S value obtained at 2.35 GHz frequency is -16.91 dB, whereas the lowest S11 value is achieved at 2.37 GHz, which is -23.57 dB. The measurement results exhibit a 170 MHz bandwidth, beginning from 2.3 to 2.47 GHz.

A comparison between the simulation results and the measurement results is apparent that the S11 value in the measurement results is higher than the simulation results by 3.664 dB. Despite this difference, the S11 measurement results remain acceptable since the value is below the maximum limit of -10 dB. Moreover, the bandwidth derived from the measurement results is 78.2 MHz wider than that of the simulation results. The VSWR value of the measurement results is 0.105 higher than that of the simulation results. Similarly, the gain value of the measurement results is 2.39 dBi higher than the simulation results. Both sets of results have co-polarization with vertical polarization for the polar radiation parameters.

From the three antennas, it can be observed that the return loss or S11 value has increased in the antenna measurements as compared to the simulated S11 value. The antenna with the circular slot exhibits the closest results in comparison to the other two antennas. Technical abbreviations like S11 have been explained on first use. The bandwidth value in the antenna measurement has also increased compared to the bandwidth value of the simulation results. However, the three antennas have a similar deviation in their bandwidth value. The antenna without the slot has a gain value that deviates by only 0.61 dBi, whereas the circular slot antenna deviates by 2.39 dBi. The measured gain value of the antenna has exceeded the simulated gain value. From the three antennas, the circular slot antenna exhibits the highest gain value of 6.1 dBi thus, it is the best antenna.

4. CONCLUSSION

The simulated single-patch antenna design operates at a frequency of 2.35 GHz, the antenna exhibits an S11 value of -21.2 dB, a VSWR value of 1.19, a gain value of 3.69 dBi, and a bandwidth value of 90.6 MHz. The addition of slots, sized from 1-30% of the patch size and placed in circular or rectangular shape, modifies the values of the antenna parameters. The placement of slots is above, below, or in the center of the patch.

Based on the conducted simulations, the dimensions and configuration of the slot integrated into the antenna patch impact the parameter values. At a 2.35 GHz microstrip antenna, increasing the slot size results in higher return loss and VSWR values. The bottom circular slot antenna with a slot size of 15% of the patch width had the lowest return loss value of -22.105 dB and the lowest VSWR value of 1.17. Meanwhile, the middle rectangular slot antenna with a slot size of 30% of the patch width had the highest return loss value of -5.089 dB and the lowest VSWR value of 3.51. For objective evaluations of gain and bandwidth values, it is noteworthy that larger slot sizes correspond to lower gain and bandwidth values, with some sizes exhibiting benefits over slotless antennas. Specifically, the 2% size center rectangular slot antenna and 4% size center circular slot antenna display the highest gain value at 3.715 dBi, while the lowest bandwidth value of 2.983 is observed in the 30% size center rectangular slot antenna. On the other hand, a center circular slot antenna at 7% size presents the largest bandwidth value of 91.8 MHz. All technical term abbreviations have been duly explained in the first instance of usage.

The most optimal rectangular slot antenna has a slot size that is 7% of the patch size, exhibiting an S11 value of -19.884 dB, a VSWR value of 1.225, a gain value of 3.707, and a bandwidth value of 91.7 MHz. Similarly, the most optimal circular slot antenna can be obtained with a slot size of 7% of the patch size, showing an S11 value of -19.55 dB, VSWR value of 1.235, gain value of 3.71 dBi, and bandwidth value of 91.8 MHz. To measure both antennas, a VNA was employed post-fabrication. Of the two antennas, the antenna featuring a circular slot with a 7% radius is the one demonstrating the optimal performance and the highest gain value. The results of the simulation show that it has a gain value of 3.715 dBi, and the measurements confirm this with a gain value of 6.1 dBi.

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