Design and Implementation of Disc Sector Slot on a 4x2 Microstrip Array Antenna Using the Truncated Corner Method for 2.4 GHz Frequency

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***Abstract*— One widely used antenna type is the microstrip antenna due to its small size, simple fabrication, compact structure, and low cost. However, microstrip antennas suffer from inherent limitations such as narrow bandwidth, low gain, and poor directivity. This research investigates the effect of adding a disc sector–shaped slot to improve antenna gain. The antenna is designed to meet specifications of VSWR less than 2, return loss below −10 dB, and gain greater than 3 dB. The objective is to enhance gain performance and demonstrate the effectiveness of slot addition within the 2401–2495 MHz frequency range for Wi-Fi applications. Simulation and measurement results show that the microstrip antenna with a disc sector slot achieves a gain of 12.55 dBi at 2448 MHz and operates effectively within the 2421–2467 MHz range. The antenna exhibits a return loss of −17.37 dB and a VSWR of 1.31. Furthermore, for Wi-Fi implementation at 2.4 GHz, the antenna achieves a received power level of −63 dBm at a distance of 20 meters, significantly improving reception compared to the built-in antenna with −88 dBm.**

Keyword— Array, Bandwidth, Disc Sector, Microstrip Antenna, Truncated Corner.

I. INTRODUCTION

Antenna is an important component in wireless communication. In general, an antenna functions to radiate and receive electromagnetic energy [1][2]. One common type of antenna used is the microstrip antenna. The microstrip antenna has several advantages, including its small size, ease of fabrication, simplicity, compactness, and relatively low cost [3]. However, the microstrip antenna has some disadvantages, such as narrow bandwidth, low gain, and poor directivity [4][5][6].

The array method is one approach to improving the performance of a microstrip antenna by enhancing its gain and bandwidth [7][8]. However, this method also has some drawbacks, such as increasing the return loss and axial ratio[9][10][11]. To address these issues, the truncated corner method can be used to achieve circular polarization, which aims to improve directivity by reducing polarization mismatch or cross-polarization [12][13]. Additionally, the antenna's performance can be enhanced by adding slots to the patch. Using different slot shapes can improve the antenna's efficiency compared to conventional microstrip patches and can also increase bandwidth, gain, and improve return loss and axial ratio [14][15].

Based on the above discussion, this research titled "Design and Implementation of Disc Sector Slot on 4x2 Microstrip Array Antenna with Truncated Corner Method for 2.4 GHz Frequency" will design a 4x2 microstrip array antenna using the truncated corner method, with a disc sector slot added to each patch. The substrate material used is FR-4 EPOXY with a dielectric constant of 4.43, and copper is used as the ground plane. This design is expected to provide innovation in microstrip antenna technology, enhancing antenna quality in terms of gain, return loss, bandwidth, and directivity, operating at a frequency of 2.4 GHz.

II. METHOD

The design that will be used in the research is the creation of stages of information search, tool manufacturing to testing, in a thesis that is prepared with the intention that the research is carried out in detail and planned through the stages that have design showed in Fig. 1.

A. Antenna Design

1) Element Patch Design

The planned truncated corner patch antenna resonates at around 2448 MHz with a slot in the truncated corner patch. The width of the rectangular patch is calculated using the Equation (1).

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

Information:

*Corresponding author

W_p = Wide Patch
f_r = Working Frequency (Hz)
ε_r = Dielectric Constant [1]

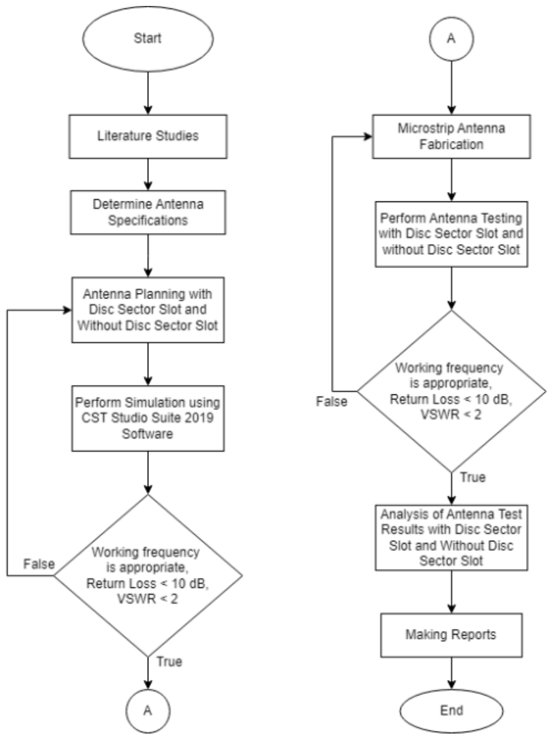

Figure 1. Research Flow Chart

The width of the rectangular antenna patch was 36.66 mm. Then, calculate the length of the corner cut of the antenna patch using the Equation (2) as follow:

$$\Delta L = \frac{1}{4} \times L \quad (2)$$

Information:
ΔL = Length of the corner cut of the antenna patch (mm).
L = Length of the patch (mm). [2]
The length of the rectangular patch antenna obtained is 9.15 mm.
From the results above, we obtained the side length of the square antenna and the length of the corner cut of the antenna patch. To calculate the radius of the disc sector slot, use the Equation (3).

$$\alpha = \frac{F}{\sqrt{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}}} \quad (3)$$

Information:
α = Circular radius (mm)
h = Substrate thickness (mm)
ε_r = Dielectric constant
F = Radiating element [2]

From the results above, the circular radius obtained is 13.03 mm. Then, to find the radius of the disc sector slot, the Equation (4) is needed [3].

$$\alpha_x = 30\% \times \alpha \quad (4)$$

Information:
α_x = Radius of the disc sector slot (mm)
α = Circular radius (mm)

From the calculations above, the obtained radius is 3.9 mm. Showed in Fig. 2.

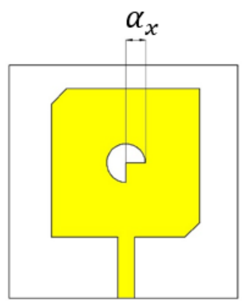

Figure 2. Truncated Corner Patch Antenna with Disc Sector Slot

2) Transmission Line Design

The specifications for the impedance and transmission line in the system are as follows: The supply impedance, referred to as Z_6, is recorded at 50 ohms, whereas the channel impedance, labeled as Z_{in}, is 115.11 ohms. These impedance values are crucial for ensuring optimal signal integrity and reducing reflection losses within the system.

In addition to the impedance, the widths of the transmission lines are meticulously defined to ensure optimal performance across different sections. Wf1 is 2.4 mm, creating a narrow pathway for accurate signal transmission. Wf2 is slightly wider at 4.8 mm, catering to various frequency requirements. Wf3 is considerably larger at 9.6 mm, likely intended for high-power transmission or wider bandwidths. Wf4 measures 16.53 mm, Wf5 is 19.2 mm, Wf6 is 10.8 mm, and Wf7 is 5.52 mm. Each width is specifically designed to address particular signal characteristics and system demands.

These dimensions are essential for attaining the desired electrical performance, reducing losses, and guaranteeing that the transmission line functions efficiently throughout its entire length.

3) Designing the length of the transmission line

The lengths of the transmission line components are specified as follows: The overall length of the transmission line, referred to as LT, measures 14.315 mm. The lengths of the individual sections are as follows: Lf1 is 3.5 mm, Lf2 is 48 mm, Lf3 is 18.3 mm, Lf4 is 143 mm, Lf5 is 18 mm, and Lf6 is 40 mm. These exact measurements are crucial for ensuring the proper functionality and performance of the transmission line, as illustrated in Fig. 3.

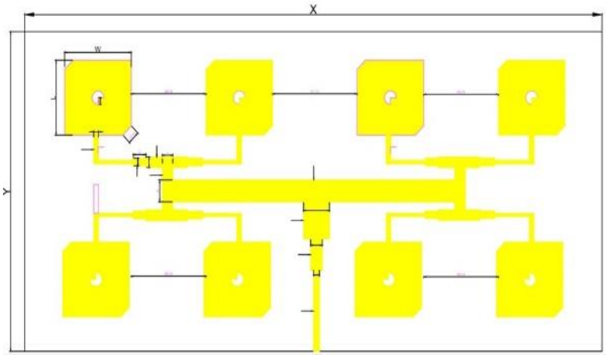

Figure 3. 4x2 Truncated Corner Patch Antenna with Disc Sector Slot

B. *Determination of Material Specifications*

The specifications of the materials used in this study are outlined as follows. The PCB, constructed from FR-4 material, consists of 2 layers (double-sided) and has a copper thickness of 0.035 mm. The substrate thickness measures 1.57 mm, while the overall dimensions of the PCB are 270 x 137 mm. These specifications guarantee durability and optimal performance for the intended application, as shown in Table I.

TABLE I
SPECIFICATION PCB FR-4

DETAILS	SPECIFICATION
Layer	2 (double)
Copper Thickness	0.035 mm
Substrate Thickness	1.57 mm
Size	x 160 mm

III. RESULTS AND DISCUSSION

A. *Fabrication Results*

The following is the result of fabricating a 4x2 truncated corner patch microstrip antenna with disc sector slot and without disc sector slot in Fig. 4 and Fig. 5.

Figure 4. Fabrication Results of Truncated Corner Patch Microstrip Antenna Array 4x2

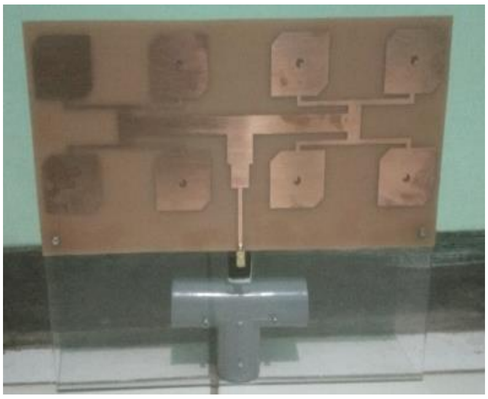

Figure 5. Fabrication Results of Truncated Corner Patch Microstrip Antenna Disc Sector Slot Array 4x2

B. *Return Loss Test Result (Simulation Result)*

Fig. 6 The simulation results of the return loss from the truncated corner patch antenna 4x2 without disc sector slot.

The simulation results using CST Studio 2019 show that the return loss occurs at a center frequency of 2448 MHz, which is the resonance frequency, with a return loss value of -36.77 dB. When compared to the minimum antenna design requirement, which sets the return loss at ≤ -10 dB, it can be concluded that the simulated antenna meets the established minimum requirements.

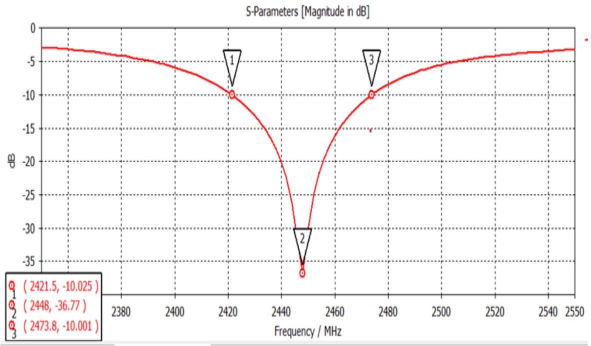

Figure 6. Return Loss Simulation of Truncated Corner Patch Antenna 4x2 Without Disc Sector-Slot

Figure 7 The simulation results of the return loss from the truncated corner patch antenna 4x2 with disc sector slot.

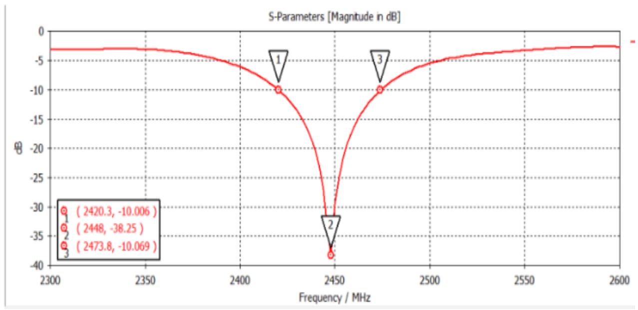

Figure 7. Return Loss Simulation of Truncated Corner Patch Antenna 4x2 With Disc Sector-Slot

The simulation return loss results are -10.006 dB at a frequency of 2420 MHz and -10.069 dB at a frequency of 2473 MHz. The frequency of 2448 has the lowest return loss, which is -38.25 dB.*VSWR Test Results (Simulation Results)*. From the simulated return loss values obtained, the simulated antenna has met the minimum standard for antenna operation, which is less than -10 dB.

Fig. 8 VSWR simulation results of a truncated corner patch 4x2 antenna without disc sector slot. The simulation was conducted using CST Studio Suite 2019, and the results are as follows.

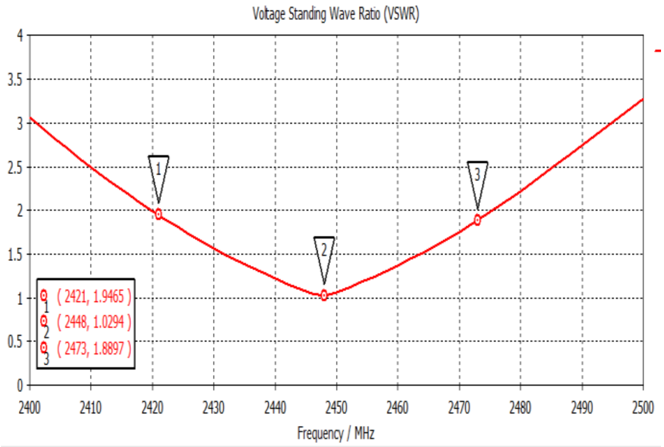

Figure 8. VSWR Simulation of Truncated Corner Patch Antenna 4x2 Without Disc Sector-Slot

The simulation VSWR results are 1.94 at a frequency of 2421 MHz and 1.88 at a frequency of 2448. The frequency of 2448 has a VSWR of 1.02.

Fig. 9 VSWR simulation results of a truncated corner patch 4x2 antenna with disc sector slot.

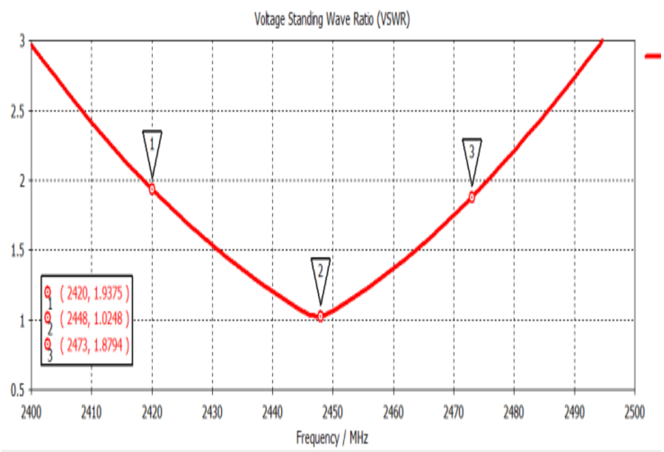

Figure 9. VSWR Simulation of Truncated Corner Patch Antenna 4x2 With Disc Sector-Slot

The simulation VSWR results are 1.93 at a frequency of 2420 MHz and 1.87 at a frequency of 2448. The frequency of 2448 has a VSWR of 1.02.

C. Bandwidth Test Results (Simulation Results)

Fig. 10 VSWR simulation results of a truncated corner patch 4x2 antenna without a sector-slot disc.

The bandwidth simulation results show that markers 1 and 2 represent the antenna's operating frequencies, located below the horizontal measurement line. The horizontal measurement line represents the antenna's standard return loss, which is ≤ -10 dB. It can be stated that the simulated antenna is capable of operating at a bandwidth of 52 MHz.

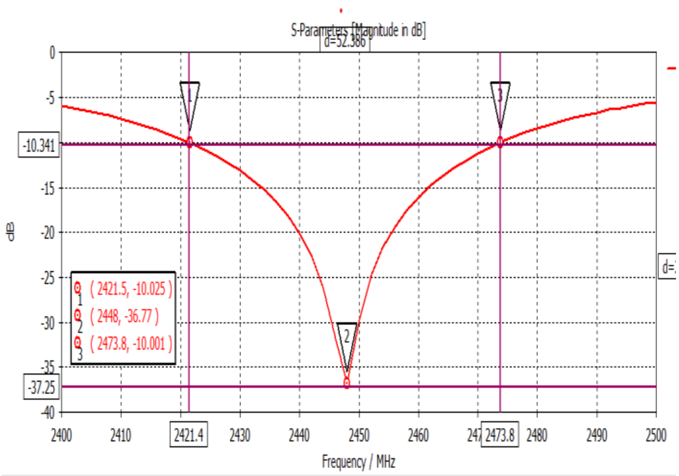

Figure 10. Truncated Corner Antenna Bandwidth Simulation Patch 4x2 Without Disc Sector-Slot

Fig.11 VSWR simulation results of a truncated corner patch 4x2 antenna without a sector-slot disc.

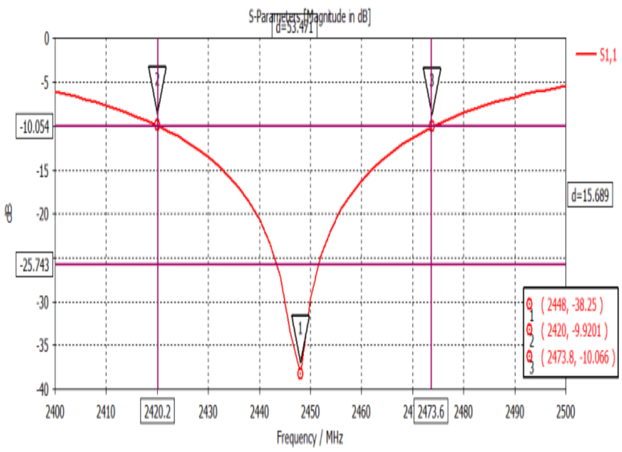

Figure 11. Truncated Corner Antenna Bandwidth Simulation Patch 4x2 With Disc Sector-Slot

The simulation results of the bandwidth using CST Studio 2019 show that markers 1 and 2 represent the working frequencies of the antenna, located below the horizontal measurement line. The horizontal measurement line represents the standard return loss of the antenna, which is ≤ -10 dB. Thus, it can be concluded that the simulated antenna is capable of operating at a bandwidth of 53 MHz.

D. Return Loss Test Results

Return loss test results of truncated corner patch 4x2 antenna without disc sector slot as shown at Fig. 12.

The test return loss results are -10.01 dB at a frequency of 2412 MHz and -10.02 dB at a frequency of 2457 MHz. The frequency of 2438 has the lowest return loss, which is -23.41 dB.

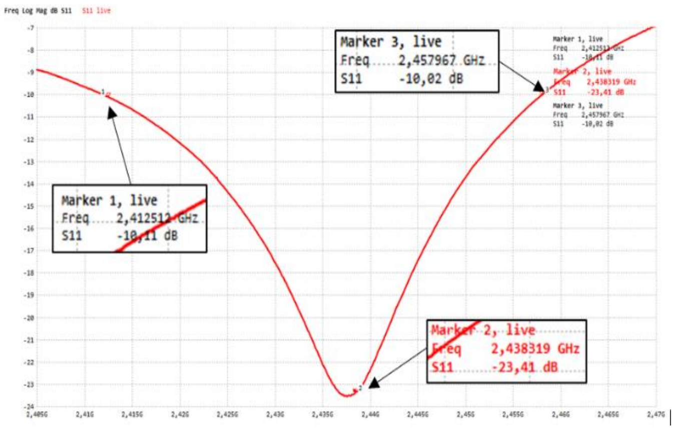

Figure 12. Return Loss Testing of 4x2 Truncated Corner Patch Antenna without Disc Sector Slot

Return loss test results of truncated corner patch 4x2 antenna with disc sector slot as shown at Fig. 13.

The test return loss results are -10.01 dB at a frequency of 2421 MHz and -10.02 dB at a frequency of 2467 MHz. The frequency of 2448 has the lowest return loss, which is -17.37 dB.

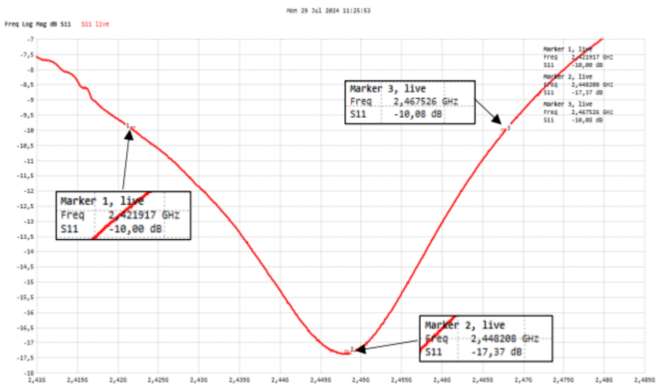

Figure 13. Return Loss Testing of 4x2 Truncated Corner Patch Antenna with Disc Sector Slot

E. VSWR Test Result

Fig. 14 VSWR test results of truncated corner patch antenna 4x2 without disc sector slot.

The VSWR test results are 1.968 at a frequency of 2412 MHz and 1.14 at a frequency of 2438. The frequency of 2457 has a VSWR of 1.92.

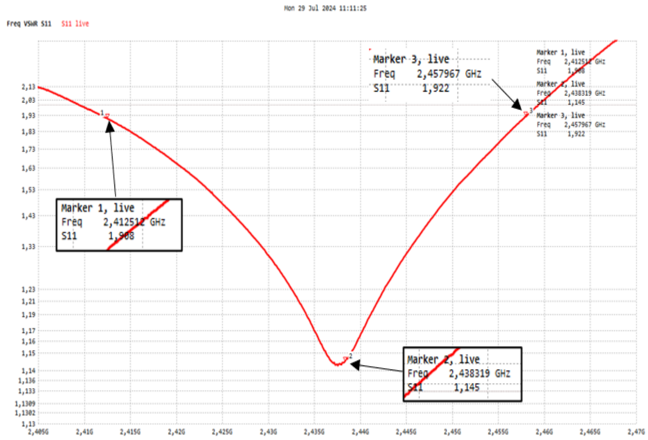

Figure 14. VSWR Testing of Truncated Corner Patch Antenna 4x2 Without Disc Sector Slot

Fig. 15 VSWR test results of truncated corner patch antenna 4x2 with disc sector slot

The VSWR test results are 1.924 at a frequency of 2421 MHz and 1.31 at a frequency of 2480. The frequency of 2467 has a VSWR of 1.912.

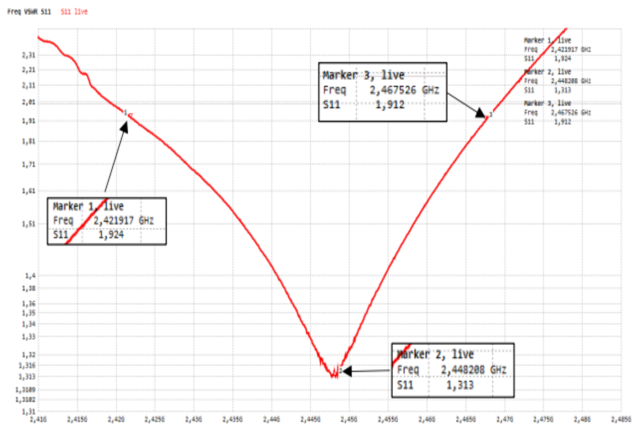

Figure 15. VSWR Testing of Truncated Corner Patch Antenna 4x2 With Disc Sector Slot

F. Gain Test Result

The antenna gain testing uses a 1/2 lambda dipole reference antenna because it has a simple radiation pattern and a gain of around 2.15 dBi, making it a standard for comparison in testing. The 1/2 lambda dipole has a symmetrical and predictable radiation pattern, allowing for clear analysis and relative gain calculation compared to an isotropic antenna.

Table 2 gain test results on truncated corner patch 4x2 antenna without disc sector slot.

TABLE II
GAIN TESTING WITHOUT SLOT

Frequency (MHz)	Level (dBm)		Gain (dBi)
	Antenna Reference	Antena Under Test	
2350	-67.3	-75.8	-6.35
2360	-70.2	-72.9	-0.55
2370	-68.2	-70.9	-0.55
2380	-74.2	-69.6	6.75
2390	-70.3	-69.7	2.75
2400	-66.3	-73.1	-4.65
2410	-69.7	-73.0	-1.15
2420	-73.2	-71.5	3.85
2430	-71.7	-66.7	7.15
2440	-73.5	-66.1	9.55
2450	-64.3	-66.1	0.35
2460	-64.9	-68.3	-1.25
2470	-62.8	-74.8	-9.85
2480	-63.1	-74.8	-9.55
2490	-63.4	-74.7	-9.15
2500	-71.7	-72.1	1.75
2510	-66.7	-74.8	-5.95
2520	-71.4	-74.6	-1.05

Fig. 16 shows the gain result of Truncated Corner Patch Antenna 4x2 Without Disc Sector-Slot.

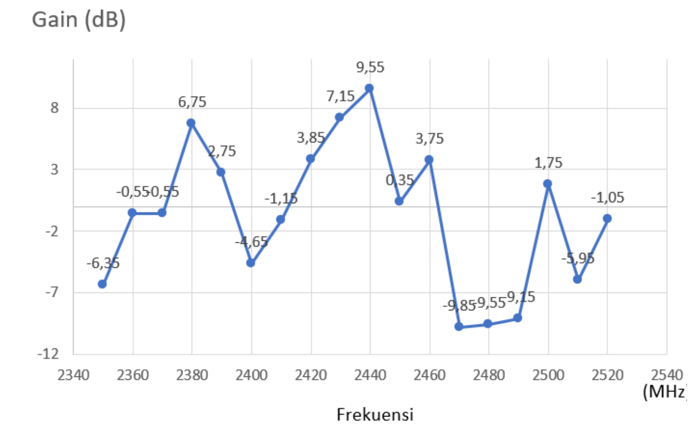

Figure 16. Graphic of Truncated Corner Patch Antenna Gain Results 4x2 Without Disc Sector Slot

From the gain results above, the gain result is 9.55 dBi at a frequency of 2440.

Table 3 gain test results on truncated corner patch 4x2 antenna with disc sector slot.

TABLE III
GAIN TESTING WITH DISC SECTOR SLOT

Frequency (MHz)	Level (dBm)		Gain (dBi)
	Antenna Reference	Antena Under Test	
2350	-67.3	-71.8	-2.35
2360	-70.2	-70.3	2.05
2370	-68.2	-70.0	0.35
2380	-74.2	-68.2	8.15
2390	-70.3	-68.0	4.45
2400	-66.3	-69.4	-0.95
2410	-69.7	-69.2	2.65
2420	-73.2	-68.6	6.75
	Level (dBm)		Gain (dBi)
Frequency (MHz)	Antenna Reference	Antena Under Test	
2430	-71.7	-64.1	9.75
2440	-73.5	-63.1	12.55
2450	-64.3	-67.0	-0.55
2460	-64.9	-69.5	-2.45
2470	-62.8	-67.1	-2.15
2480	-63.1	-66.3	-1.05
2490	-63.4	-70.2	3.65
2500	-71.7	-74.3	-5.45
2510	-66.7	-72.1	1.45
2520	-71.4	-74.6	-1.05

From the gain results above, the gain result is 12.55 dBi at a frequency of 2440.

G. *Radiation Pattern Test Results*

Table 4 Radiation pattern test results on a 4x2 truncated corner patch microstrip antenna with disc sector slot.

TABLE IV
RADIATON PATTERN TESTING

Frequency 2440		
Degree Coner	Power Level (dBm)	Normalization
0°	-63.1	0
10°	-63.6	-0.5
20°	-63.9	-1
30°	-64.1	-1
40°	-64.7	-1.6
50°	-66.1	-3
60°	-66.5	-3.4
70°	-66.2	-3.1
80°	-66.3	-3.2
90°	-71.1	-8
100°	-75.5	-12.4
110°	-69.8	-6.7
120°	-68.4	-5.3
130°	-73.1	-10
140°	-77.3	-14.2
150°	-75.0	-11.9
160°	-77.6	-14.5
170°	-77.4	-14.3
180°	-75.9	-12.8
190°	-74.9	-11.8
200°	-71.2	-8.1
210°	-70.5	-7.4
220°	-70.6	-7.5
230°	-71.9	-8.8
240°	-71.8	-8.7
250°	-71.3	-8.2
260°	-74.4	-11.3
270°	-73.3	-10.2
280°	-69.3	-6.2
290°	-64.5	-1.4
300°	-62.8	0.3
310°	-62.3	0.8
320°	-62.4	0.7
330°	-64.5	-1.4
340°	-64.1	-1
350°	-63.7	-0.6

From the results of the table above, the radiation pattern of a rectangular microstrip patch antenna with a disc sector slot is a directional radiation pattern, meaning it has a more effective radiation direction at a 0° angle compared to other angles. The results of the diagram are described in Fig. 17.

The HPBW value can be calculated by marking the normalized value of -3 dB. HP (left) angle 290° and HP (right) 50° so that it can be calculated using the following Equation (5):

$$HPBW = HP_{right} - HP_{left} \quad (5)$$
$$HPBW = (360° - 290°) + 50°$$
$$HPBW = 120°$$

The HPBW value can be calculated by marking the normalized value of -3 dB. HP (left) angle 290° and HP (right) 50° so that it can be calculated using the following Equation (6):

$$HPBW = HP_{right} - HP_{left} \quad (6)$$
$$HPBW = (360° - 290°) + 50°$$
$$HPBW = 120°$$

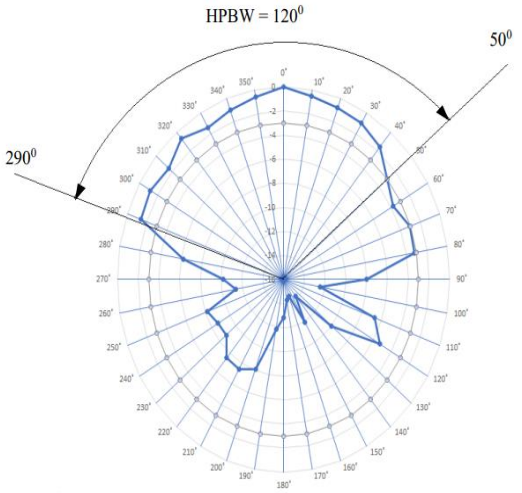

Figure 17. Graphic of the radiation pattern of Truncated Corner Patch Antenna 4x2 With Disc Sector-Slot

The HPBW value can be calculated by marking the normalized value of -3 dB. HP (left) angle 290° and HP (right) 50° so that it can be calculated using the following Equation (7):

$$HPBW = HP_{right} - HP_{left} \quad (7)$$
$$HPBW = (360° - 290°) + 50°$$
$$HPBW = 120°$$

H. Comparison of Simulation Results with Test Results

The results of the return loss simulation on the truncated corner patch 4x2 antenna with a disc sector-slot at a resonant frequency of 2448 with a result of -38.25 and a VSWR of 1.02. The results of the fabrication test obtained a return loss result at a resonant frequency of 2448 with a result of -23.41 and a VSWR of 1.31

This is not much different from the simulation results with the fabrication results. Where it has the same resonant frequency of 2448 MHz.

I. Results Implementation of Built-In Antenna With 4x2 Truncated Corner Patch Array Microstrip Patch Antenna With Disc Sector Slot and Without Disc Sector Slot

The implementation of the antenna for 802.11N wireless was conducted at Kos Capung 11, located at Candi Panggung St. No. 27, Mojolangu, Lowokwaru, Malang. Both built-in and external antennas were set up in an outdoor environment. The 802.11N wireless USB antenna was connected directly to a laptop through a USB port. Here is an image showing the setup of the 802.11N wireless USB adapter antenna.

Fig. 18, Fig. 19, and Fig. 20 show the test documentation for the implementation of a built-in antenna alongside a truncated corner patch with disc sector slot and without disc sector slot 4x2 array microstrip antenna. Figure 20, Figure 21 and Figure 22 display the RSSI results for both the built-in antenna and the truncated corner patch with disc sector slot anda without disc sector slot 4x2 array microstrip antenna using the Vistumber Software.

Figure 18. Picture of a Built-In Antenna Network

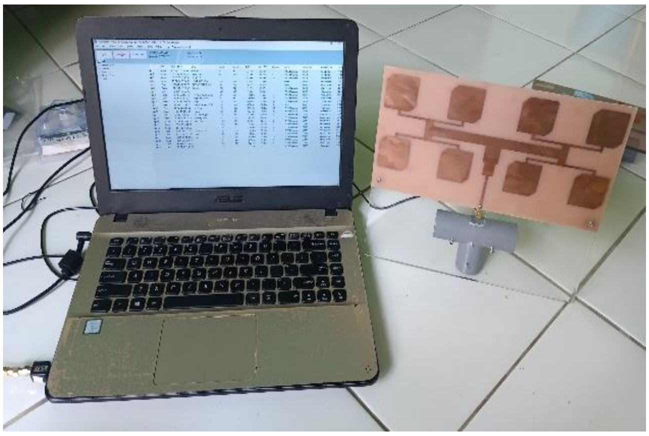

Figure 19. Truncated Corner Patch Without Disc Sector Slot 4x2 Array Microstrip Antenna for Signal Amplifier

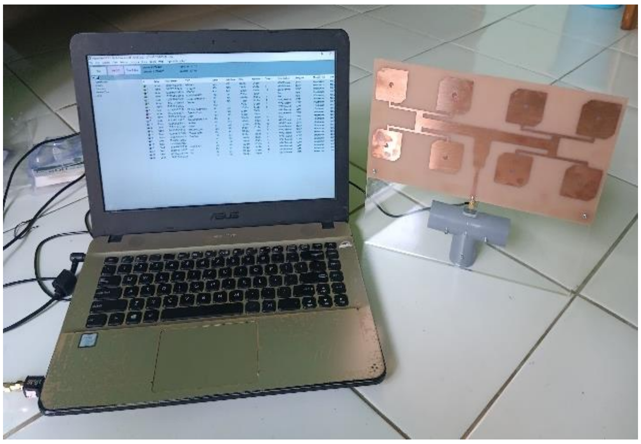

Figure 20. Truncated Corner Patch Without Disc Sector Slot 4x2 Array Microstrip Antenna for Signal Amplifier

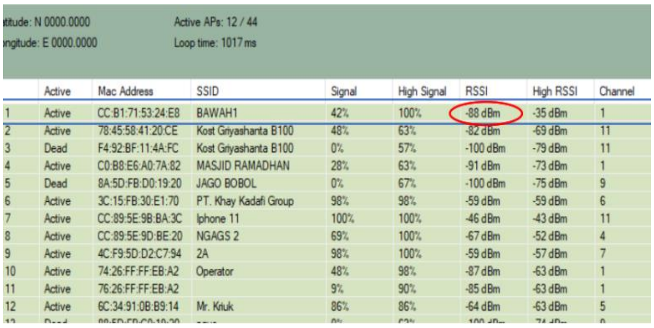

Figure 21. Results of the Implementation of the Built-In Antenna at a Distance of 20 Meters

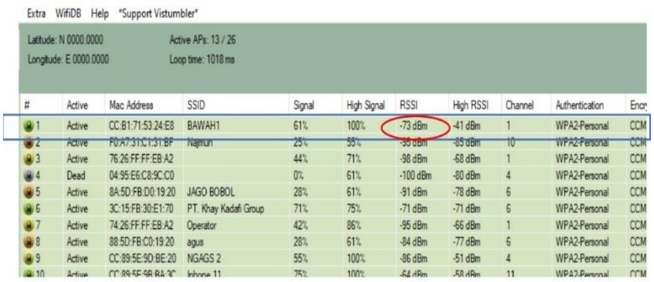

Figure 22. Results of the Implementation of a Truncated Corner Patch Without Disc Sector Slot 4x2 Array Microstrip Antenna at a Distance af 20 Meters

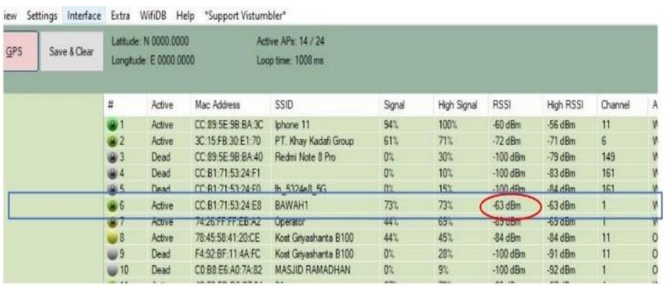

Figure 23. Results of the Implementation of a Truncated Corner Patch Without Disc Sector Slot 4x2 Array Microstrip Antenna at a Distance af 20 Meters

In Table 5 is the result of the implementation of a built-in antenna with a truncated corner patch with disc sector slot and without disc sector slot 4x2 array microstrip antenna.

TABLE V
RESULTS OF THE IMPLEMENTATION OF A BUILT-IN ANTENNA WITH A TRUNCATED CORNER PATCH WITH DISC SECTOR SLOT AND WITHOUT DISC SECTOR SLOT 4X2 ARRAY MICROSTRIP ANTENNA

Antenna	RSSI (dBm)
Built in Usb wireless 802.11N	-88
Antenna microstrip *patch truncated corner patch array* 4x2	-73
Antenna microstrip truncated corner patch with disc sector slot array 4x2	-63

Based on Table 5, there are RSSI values between the standard antenna and the truncated corner microstrip patch antenna with disc sector slot. Therefore, the power difference can be calculated using the following Equation (8):

$$\text{Power Difference} = RSSI_{microstrip} - RSSI_{built-in} \quad (8)$$
$$= -63\ dBm - (-88\ dBm)$$
$$= 25\ dBm$$

The power received from the 802.11n usb wireless when using a 4x2 truncated corner patch with disc sector slot array microstrip antenna is greater than that of a standard antenna with a difference value of 25 dBm.

J. Test Result Analysis

The overall test results of the antenna are shown in Table 6 as follows.

TABLE VI
SUMMARY OF ANTENNA TESTING

Parameter	Simulation		Fabrication	
	Antena Truncated Corner Patch 4x2	**Truncated Corner Patch 4x2 with Disc Sector Slot Antenna**	**Antenna Truncated Corner Patch 4x2**	**Antena Truncated Corner Patch 4x2 with Disc Sector Slot**
Return Loss	-36,77 dB	-38.25 dB	-23,41 dB	-17,37 dB
VSWR	1,0294	1,0248	1,145	1,313
Bandwidth	52 MHz	53 MHz	45 MHz	46 MHz
Frequency	2421-2473 MHz	2420-2473 MHz	2412-2457 MHz	2421-2467 MHz
Center Frequency	2448 MHz	2448 MHz	2438 MHz	2448 MHz
Gain	4,095 dBi	5,035 dBi	9,55 dBi	12,55 dBi
HPBW	$46{,}3^0$	$46{,}4^0$	120^0	120^0
RSSI	-	-	-73 dBm	-63 dBm

Truncated corner patch antenna with a disc sector slot demonstrates better performance compared to the 4x2 truncated corner patch antenna without a slot, both in simulation and fabrication stages. Although the return loss decreased after fabrication, the antenna with the disc sector slot successfully increased the gain to 12.55 dBi, significantly higher than the antenna without the slot, which only achieved 9.55 dBi.

Overall, despite a decline in some parameters, the antenna with the disc sector slot exhibits better overall performance compared to the antenna without the disc sector slot.

IV. CONCLUSION

Based on the research and testing conducted, several conclusions can be drawn. The truncated corner microstrip patch antenna with a 4x2 disc sector slot array was designed for 2.4 GHz using CST Studio Suite 2019 and printed on a double-layer FR-4 PCB. The results show a similarity in bandwidth and return loss between simulation and fabrication, but a significant difference in gain, with 5.05 dBi in the simulation and 12.55 dBi in the fabricated version. Additionally, the antenna demonstrated an RSSI of -39 dBm at a 5-meter distance, which outperformed other microstrip antennas (-41 dBm) and the built-in antenna (-44 dBm).

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