Antenna design and implementation patch diamond array 2x4 elements with DGS shaped dumbbell square head at frequency 2.4 GHz

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Abstract*— Technological advances in the field of telecommunications without cables or wireless are growing rapidly by utilizing radio waves as transmission. This happens because people's mobility is currently quite high and requires practicality in the use of devices. The discussion in this paper is about the comparison of the design and fabrication performance of a diamond microstrip patch antenna composed of a 2x4 element array using DGS and without using DGS. The design was carried out using the CST 2018 simulator. The DGS was placed on a PCB ground plane with an epoxy fiberglass substrate having a dielectric constant of 4.58. This is measured by improving the value of VSWR, return loss, and bandwidth. The application of the working frequency used by the microstrip antenna is at (2401-2495) MHz for WIFI (Wireless Fidelity) networks. Microstrip antennas have a narrow bandwidth shortage, so they require bandwidth widening using the DGS (Defected Ground Structure) technique in the form of dumbbell square ahead. The resulting bandwidth is 15 MHz wider than a microstrip antenna without DGS. This research is in accordance with the antenna test parameters, which have a return loss value of -24.3dB, VSWR 1.12 and a bandwidth of 34 MHz.

Keywords*— diamond, DGS, micro strip antenna, WIFI.

I. INTRODUCTION

Technological advances in the field of wireless telecommunications are growing rapidly by utilizing radio waves as transmission. This happens because people's mobility is currently quite high and requires practicality in the use of devices. Wireless Fidelity or WIFI is a WLAN (Wireless Local Area Network) technology with the IEEE 802.11 protocol. This technology requires an antenna as a data transmission medium. In its application, WIFI requires a wide bandwidth so that the user's needs for data transfer speed are met.

The allocation of the working frequency of the WIFI used in the design of this antenna is at a frequency of 2.4 GHz (2400 MHz – 2483.5 MHz). The 2.4 GHz frequency is used by the IEEE 802.11b, 802.11g, and 802.11n protocol standards for Wireless Fidelity (Wi-Fi) [1]. In addition, based on the Regulation of the Minister of Communication and Information of the Republic of Indonesia Number 1 of 2019 concerning the Use of Radio Frequency Spectrum Based on the Class Permit of WLAN/Wi-Fi devices in article 4, it is explained that the radio frequency band can operate at a frequency of 2400 – 2483,5 MHz [2].

Antenna is an important device for optimizing performance in communication systems that use radio waves for WiFi. Antenna as a means of transmitting (transmitting antenna) and receiving (receiving antenna) radio waves [3] The implementation of this research uses a microstrip antenna. In this case, microstrip antennas have the advantages of being thin and small, light in weight, easy to fabricate, easy to integrate with other electronic devices and relatively cheap prices [4]. However, microstrip antennas have some disadvantages such as low gain, narrow bandwidth and low efficiency. [5]

Performance improvement on microstrip antenna is needed to get optimal signal quality and reception. A way to make it easier to adjust the impedance [6] between the feedline and the antenna feed by controlling the feed insert position point (y_0). This feed provides a cut in the patch so that the feedline looks more protruding into the patch [3]. One of the ways to improve bandwidth in microstrip antenna is by using the DGS (Defected Ground Structure) technique [7] [8]. DGS is implemented by deforming the ground plane of the microstrip antenna by etching [9]. The signal quality improvement is done by using the array method, which is how to arrange the microstrip antenna into several patches that are connected to the microstrip line [10].

This study is designed and realized a microstrip antenna with a 2x4 diamond-shaped patch (antenna array arrangement) with DGS (Defected Ground Structure) in the form of a dumbbell square head with a port impedance of 50 ohms. To realize this, the author uses an epoxy FR-4 substrate with a dielectric constant of 4.3 and a thickness of 1.6 mm. In the design process, the author will use the CST Studio Suite 2018 software [11]. The application is used in the design and testing process based on simulations. The tests carried out will be based on the parameter values of return loss, VSWR (Voltage Standing Wave Ratio), bandwidth, gain and radiation pattern.

II. METHOD

A. Design

Fig. 1. is a flow diagram of the research design that will be made

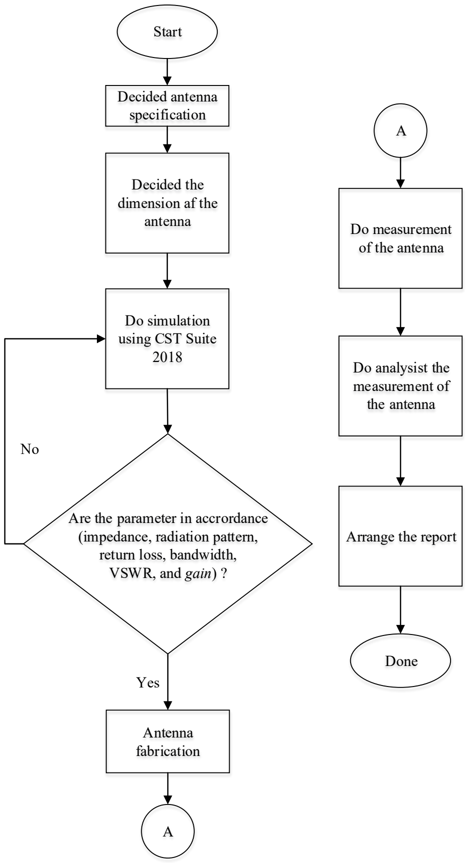

Figure 1. Research Flowchart

B. Design System

Design System design in system planning is shown in Fig 2 as follows.

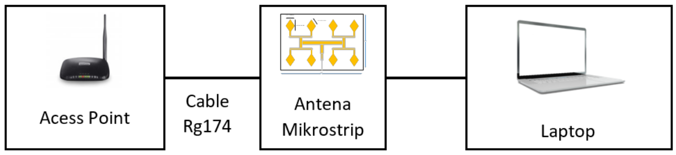

Figure 2. Block diagram of the system

C. Determination of Material Specifications

The following is a specification of the materials to be used.

TABLE I
PCB SPECIFICATIONS FR-4

Detail	Specification
Layer	2 (double)
Copper Thickness 0.035	mm
Substrate Thickness	1.57 mm
Size	330 x 200 mm
Made in	Shenzhen, China

D. Microstrip Patch Diamond Array 2x4 Elements

The design of a microstrip antenna with a 2x4 diamond patch element with a defected ground structure is as follows.

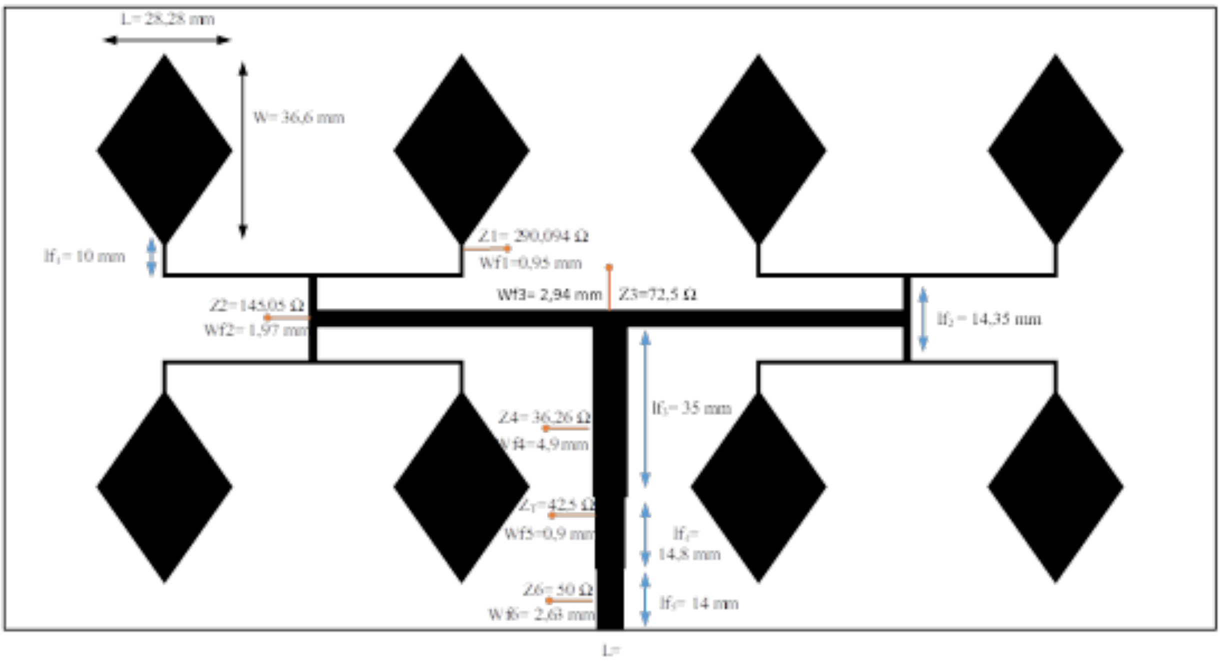

Figure 3. Antenna design patch diamond array 2x4 elements

E. Determination of Wavelength and Dimensions of Radiating Elements

1. Wavelength λ_0 = 120,54 mm
2. Calculation Patch Diamond
   - width Patch (W)=36.66 mm
   - ε_{reff} (effective dielectric constant) = 4.58
   - length Patch (L) = 27.324 mm
   - Side length (x)=2.933 mm
   - Diamond input impedance Z_3 = 290 Ω

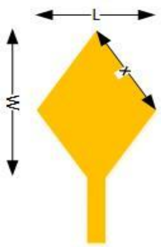

Figure 4. Diamond patch design

3. Supply Line Impedance Determination Supply
   - Line Impedance Z_6= 50 Ω.
4. Calculation of Transmission Line
   - Width Transmission Line Width 1 Wf_1 = 0.95 mm
   - Transmission Line Width 2 Wf_2 = 1.97 mm
   - Transmission Line Width 3 Wf_3 = 2.94 mm
   - Transmission Line Width 4 Wf_4 = 4.86 mm
   - Channel Width Transmission 5 Wf_5 = 0.87 mm
   - Transmission line width 6 Wf_6 = 2.63 mm
5. Transmission line length calculation
   - Transformer length L_T = 19.51 mm
   - Transmission line length (Lf_n)
     Lf_1 = 10 mm
     Lf_2 = 20 mm
     Lf_3 = 14,315 mm
     Lf_4 = 14,315 mm
6. Determination of Ground plane Length and Width Ground plane
   - Ground plane length Lg= 160 mm
   - Ground plane width Wg= 280 mm

F. Microstrip patch diamond array 2x4 elements using CST Studio Suite Software

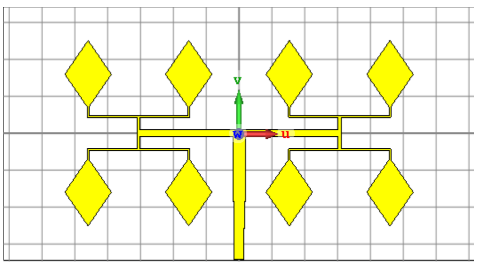

Figure 5. Design simulation of a microstrip patch diamond array 2x4 elements using CST 2018.

III. RESULTS AND DISCUSSION

A. Simulation Results Return Loss (RL)

Fig 6 is the result of a simulation of the return loss of a 2x4 diamond patch microstrip antenna using a defected ground structure.

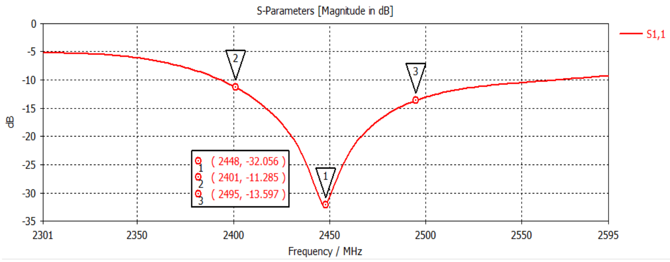

Figure 6. Return loss simulation antenna patch diamond 2x4 elements using Defected Ground Structure

- Marker 1 as the resonant frequency of 2448 MHz gets a return loss of -32.056 dB.
- Marker 2 as the lower frequency of Wi-Fi 2400 MHz which is 2401 MHz gets a return loss of -11,285 dB.
- Marker 3 as the top frequency of Wi-Fi 2400 MHz which is 2495 MHz gets a return loss of -13,597 dB.

The antenna has a fixed return loss value of -10 dB. The return loss value of a 2x4 element diamond microstrip patch antenna using a simulated Defected Ground Structure has met the requirements for the return loss value at a frequency of 2401 MHz – 2495 MHz, which is less than -10 dB.

B. Simulation Results Voltage Standing Wave Ratio (VSWR)

Fig. 7 is the results of a VSWR simulation of a 2x4 diamond patch microstrip antenna using a defected ground structure.

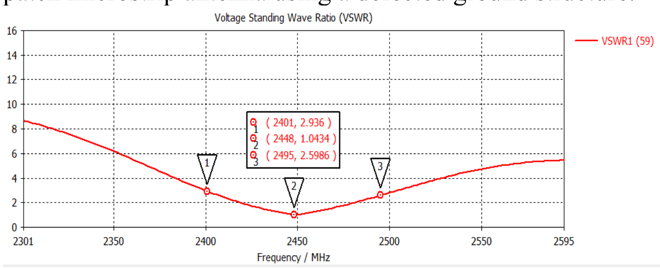

Figure 7. VSWR simulation microstrip antenna patch diamond 2x4 elements using Defected Ground Structure

- Marker 1 as the resonant frequency of 2448 MHz gets a VSWR of 1.0512.
- Marker 2 as the lower frequency of Wi-Fi 2400 MHz which is 2401 MHz gets a VSWR of 1.7505.
- Marker 3 as the top frequency of Wi-Fi 2400 MHz which is 2495 MHz gets a VSWR result of 1.5286.

The antenna has a VSWR value less than 2. Where the VSWR value of a 2x4 diamond microstrip patch antenna using a simulated Defected Ground Structure (DGS) has met the requirements for the VSWR value because it has a value less than 2.

C. Bandwidth Simulation Results

Fig 8 is the simulation result of bandwidth antenna patch diamond 2x4 elements using Defected Ground Structure.

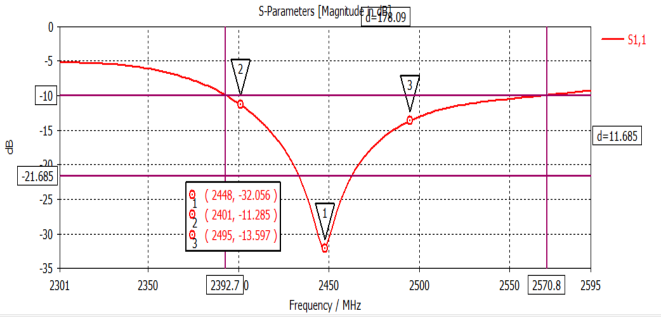

Figure 8. Bandwidth simulation of 2x4 diamond patch microstrip antenna using a defected ground structure

Bandwidth testing aims to determine the bandwidth (working frequency range) of the diamond 2x4 element microstrip patch antenna that has been designed [12]. Bandwidth can be determined by subtracting the upper and lower frequencies [13].

Fig. 8 is the result of a simulation of the bandwidth of a 2x4 diamond microstrip patch antenna using a Defected Ground Structure which is designed at a resonant frequency of 2448 MHz, where the lower frequency is 2392.1 MHz and the upper frequency is 2570.4 MHz so that a bandwidth of 177.3 MHz is obtained.

The bandwidth results obtained in the simulation are already more than the bandwidth of wireless fidelity (Wi-Fi), which is 94 MHz. Thus, the 2x4 element diamond microstrip patch antenna signal uses a Defected Ground Structure whose bandwidth already covers the wireless fidelity (Wi-Fi) frequency range, which is 2401 MHz – 2495 MHz.

D. Test results of Return Loss and Voltage Standing Wave Ratio (VSWR)

Fig. 9 is the result of measuring the return loss reference level of a 2x4 diamond patch antenna using a defected ground structure.

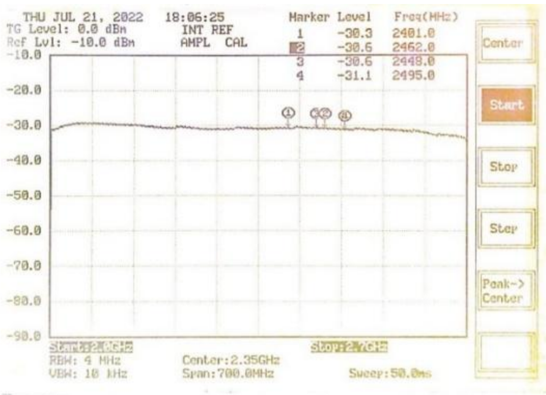

Figure 9. Measurement results of the return loss reference microstrip patch diamond 2x4 elements using Defected Ground Structure

Fig. 10 The return loss value is -24.3 dB with a VSWR value of 1.12 at a frequency of 2448 MHz, while the lowest return loss value is -25.6 with a VSWR value of 1.1 at a frequency of 2429 MHz.

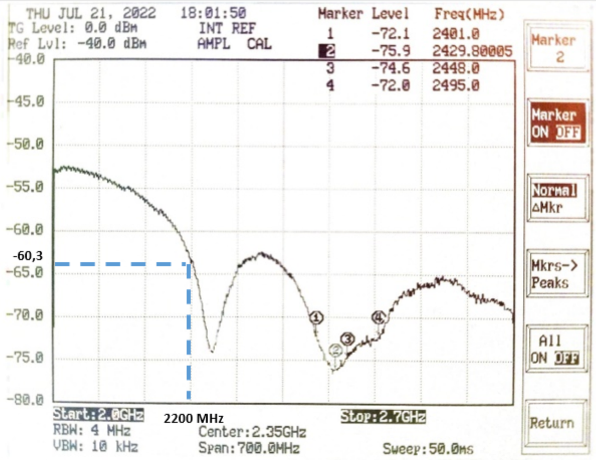

Figure 10. The results of the level measurement read the return loss of the diamond 2x4 microstrip patch antenna using a defected ground structure

TABLE II
TESTING RL AND VSWR MICROSTRIP PATCH DIAMOND 2X4 ELEMENT USING DEFECTED GROUND STRUCTURE.

Frequency (MHz)	**Level (dBm)**			**RL (dB)**	**VSWR**
	Read	**Reference**	**Attenuation DC**		
2401	-72.1	-30.3	-20	-21.8	1.17
2429	-75.9	-30.3	-20	-25.6	1.1
2448	-74.6	-30.6	-20	-24.3	1.12
2495	-72.0	-31.1	-20	-20.9	1.19

Table II shows that the return loss value of the diamond microstrip patch antenna for WiFi (Wireless Fidelity) with a frequency of 2401 – 2495 MHz has met the return loss value requirements return loss less than -10 dB and VSWR less than 2. The resonance frequency shifts to a frequency of 2429 MHz which means that the frequency The resonance is shifted by 30 MHz from the designed resonant frequency, which is 2448 MHz. This can be influenced by factors during the etching process that are less precise.

E. Testing Results Gain and Bandwidth

Table III is the result of testing the gain of a 2x4 diamond patch microstrip antenna using a defected ground structure.

TABLE III
TEST RESULTS GAIN

Frequency (MHz)	**Level (dBm)**		**Gain (dBi)**	**Normalization**
	Antenna Reference	**Antenna Under Test**		
2320	-56.6	-70.6	-11.85	-15.9
2330	-57.3	-72.4	-12.95	-17
2340	-63.4	-67.8	-2.25	-6.3
2350	-62.2	-67.6	-3.25	-7.3
2360	-61.6	-72.2	-8.45	-12.5
2370	-60	-72.5	-10.35	-14.4
2380	-56.9	-68.5	-9.45	-13.5
2390	-57.4	-63.9	-4.35	-8.4
2400	-60.3	-66.2	-3.75	-7.8
2410	-55.2	-66.3	-8.95	-13
2420	-56.6	-65.1	-6.35	-10.4
2430	-58.4	-66.6	-6.05	-10.1

Frequency (MHz)	Level (dBm)		Gain (dBi)	Normalization
	Antenna Reference	Antenna Under Test		
2440	-53.4	-69.9	-14.35	-18.4
2450	-59.2	-62.5	-1.15	-5.2
2460	-57.9	-56.1	3.95	-0.1
2470	-69.4	-67.5	4.05	0
2480	-63.9	-64.1	1.95	-2.1
2490	-62.9	-65.1	-0.05	-4.1
2500	-55	-61.2	-4.05	-8.1
2510	-57	-61.2	-2.05	-6.1
2520	-58	-63.3	-3.15	-7.2
2320	-56.6	-70.6	-11.85	-15.9
			Highest gain= 4.05 dBi	

The following is a graph bandwidth microstrip antenna patch diamond 2x4 elements using Defected Ground Structure based on Table III.

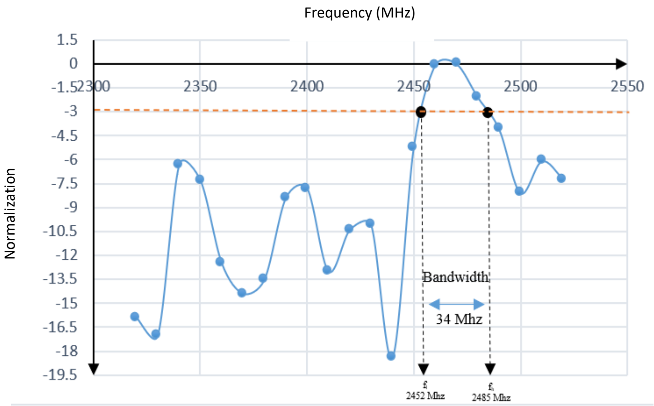

Figure 11. Bandwidth of 2x4 diamond patch microstrip antenna using a defected ground structure

This gain and bandwidth test requires a dipole antenna as a transmitter [14]. The dipole antenna is the choice as a transmitter because the dipole antenna is close to a perfect antenna, which is an isotropic antenna [15].

The bandwidth results for the 2x4 element diamond microstrip patch antenna using DGS can be shown through the intersection of the normalization points with a value of -3 dBi. The graph above shows the bandwidth value of 34 MHz obtained from a frequency of 2452 MHz - 2485MHz. The highest gain results at a frequency of 2470 MHz with a value of 4.05 dBi when compared to a dipole antenna has a gain of 4 times greater than that of a dipole antenna.

F. Radiation Pattern Test Results

Table IV is the result of testing the radiation pattern of the microstrip patch diamond 2x4 elements using Defected Ground Structure.

TABLE IV
MICROSTRIP ANTENNA RADIATION TEST PATCH DIAMOND 2X4 ELEMENT USING DEFECTED GROUND STRUCTURE

Angle (°)	Frequency 2400 MHz	
	Radiation Pattern (dB)	Normalization
0	-59.9	0
10	-60.7	-0.8
20	-63.5	-3.6
30	-63	-3.1
40	-66.2	-6.3
50	-68	-8.1
60	-67.5	-7.6
70	-68.4	-8.5
80	-71.8	-11.9
90	-77.5	-17.6
100	-76	-16.1
110	-72	-12.1
120	-72.4	-12.5
130	-70.1	-10.2
140	-72.9	-13
150	-69.6	-9.7
160	-68.2	-8.3
170	-67.5	-7.6
180	-67.9	-8
190	-70.9	-11
200	-68	-8.1
210	-67.8	-7.9
220	-67.6	-7.7
230	-66.6	-6.7
240	-66.7	-6.8
250	-67.9	-8
260	-69.2	-9.3
270	-70	-10.1
280	-71.7	-11.8
290	-72	-12.1
300	-71.2	-11.3
310	-69	-9.1
320	-67.2	-7.3
330	-64.9	-5
340	-60.6	-0.7
350	-60	-0.1

Based on the data obtained in table IV can be described as a radiation pattern diagram as shown in Fig 12.

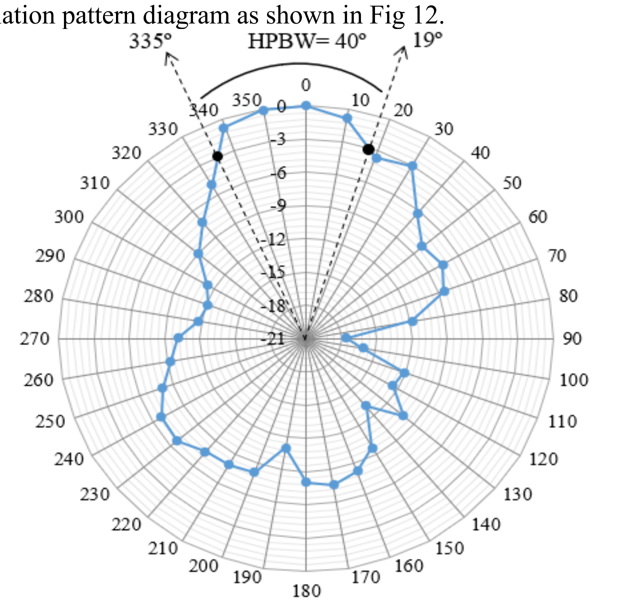

Figure 12. Radiation pattern of the microstrip patch diamond 2x4 elements using Defected Ground Structure.

The value of half power beamwidth (HPBW) is obtained by knowing the angle that has a normalization of -3 dB, namely the angle of 335° as HP(right) and 19° as HP(left). Therefore, HPBW can be calculated using the following equation:

$$\begin{aligned} \text{HPBW} &= \text{HP(right)} - \text{HP(left)} \\ &= (360^\circ - 335^\circ) + 19^\circ \\ &= 40^\circ \end{aligned}$$

Fig. 12 obtained a directional radiation pattern because it has an effective radiation direction at an angle of 0º compared to other angles.

G. The results of the implementation of the built-in and microstrip patch diamond array 2x4 elements using Defected Ground Structure

Table V is the result of the implementation of the built-in and microstrip patch diamond 2x4 elements using Defected Ground Structure.

TABLE V
RESULTS OF BUILT IN AND MICROSTRIP PATCH DIAMOND 2X4 ELEMENT USING DEFECTED GROUND STRUCTURE

Antenna	Receive Signal Strength Indicator (RSSI)
Built-in	-46 dBm
Microstrip circular patch, rectangular, diamond	-39 dBm

From Table V there are RSSI values between the built-in antenna and the patch diamond 2x4 elements using Defected Ground Structure. So the power difference can be calculated using the following equation:

$$\text{Power difference} = \text{RSSI}_{\text{microstrip}} - \text{RSSI}_{\text{built-in}}$$
$$= -46 - (-39)$$
$$= 7 \text{ dBm}$$

The power received by the TD-W8951ND access point when using an external 2x4 diamond patch microstrip antenna using a defected ground structure is 7 dBm stronger when compared to the built-in antenna.

IV. CONCLUSION

The results of testing the diamond 2x4 element microstrip patch antenna using a defected ground structure, the return loss value for the frequency of 2448 is -24.3 dB with a VSWR of 1.12, the bandwidth is 34 MHz, the radiation pattern obtained an HPBW value of 40º so the result of radiation pattern is directional, the results of the RSSI implementation show an increase in the power level for the microstrip antenna, which is 7 dBm.

The results of the diamond 2x4 element microstrip patch antenna in this final project have met the standards of the microstrip antenna. There is a shift in the resonant frequency or working frequency that occurs. This can be seen based on the diamond patch formula, where the frequency shift to the right is caused by the reduction in the dimensions of the diamond patch. This is influenced by factors during the etching process that are less precise so that the results of the microstrip antenna fabrication do not match the simulation results.

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