Design and Implementation of Microstrip Array Antenna 2x4 Circular Patch with Defected Ground Structure Dumbbell Hexagonal Head 2.4 GHz Frequency for Wi-Fi Application

Tania Izza Sholikhah[1], Koesmarijanto[2], Hendro Darmono[3]

[1,3] Digital Telecommunication Network Study Program,
Department of Electrical Engineering, State Polytechnic of Malang, Malang, Indonesia

[2] Telecommunication Engineering Study Program,
Department of Electrical Engineering, State Polytechnic of Malang, Malang, Indonesia

[1]taniaizza6@gmail.com, [2]koesmarijanto@polinema.ac.id, [3]hendro.darmono@polinema.ac.id

Abstract - **Wireless technology is a wireless communication technology that is currently widely used by the public to exchange information. The current information exchange is growing as communication requirements rise. The antenna design needs to be improved in order to boost bandwidth. Microstrip antennas are one kind of antenna that can be used for wireless communication. Meanwhile, to improve the bandwidth value of the antenna can be done using the Defected ground structure or DGS technique. The results of testing the microstrip array circular patch antenna with DGS at 2462 MHz frequency show that it has a maximum gain of 15.7 dBi at a frequency of 2530 MHz and a return loss value of -19.3 dB with a VSWR value of 1,242. There is a type of directional radiation pattern in the antenna of the Microstrip Array with DGS. This study's findings indicate that the Circular Array Microstrip antenna with DGS has a bandwidth of 73 MHz while the Circular Microstrip Array without DGS has a lesser bandwidth of 28 MHz.**

Keyword: Bandwidth, Circular Patch, DGS, Microstrip Antenna, Wi-Fi.

I. INTRODUCTION

Technology has now experienced rapid development, especially wireless technology. Wireless technology has the meaning of a wireless or wireless communication technology that is currently widely used by the public to exchange information.

One example of the development of wireless technology is Wi-Fi or Wireless Fidelity which uses the IEEE 802.11 standard at a frequency of 2.4 GHz and 5 GHz. Wi-Fi has 14 channels for a frequency of 2.4 GHz [1]. The Wi-Fi network uses radio waves as the transmission process. So that the transmission process requires an antenna device that can be used to receive and emit radio waves. The current exchange of information is increasing with the higher communication needs. To meet these needs, it is necessary to have a device that has a wide bandwidth so that the communication carried out can run well. To increase bandwidth the thing that needs to be done is to improve the antenna design.

One type of antenna that can be used to do wireless communication is a microstrip antenna [2]. The microstrip antennas and arrays have been widely used in recent years because of their good characteristics [3]. As the benefits of microstrip antenna are dependent on its low profile qualities such as small, light, thin, simple to make, and inexpensive [4, 5]. A conventional microstrip antenna has a poor efficiency and a small bandwidth, thus it needs more advancements to alter its behavior [6]. Meanwhile, to improve the bandwidth value of the antenna can be done using the DGS technique. It is anticipated that DGS deployment will improve performance without diminishing the advantages of microstrip. It is hoped that the existence of this research antenna using DGS techniques can increase antenna bandwidth.

Defected Ground Structure (DGS) is a method reducing surface wave by partially etching the ground structure of an antenna [7]. The DGS is similar to the electromagnetic band gap (EBG) structure, but simpler [8]. Defected ground structure (DGS) can modify guided wave properties to provide a band-stop or band-pass like filter and can easily define the unit element [9]. Numerous articles have developed DGS for use in n linearly polarized (LP) decoupling microstrip antenna arrays in various sizes and configurations [10]. The gain of the antenna with DGS compared to the typical microstrip antenna has improved and the size is reduced [11]. The method of defected ground structure with a vertical dumbbell shape is used to widen the bandwidth of the antenna [12].

II. METHODS

A. Circular Patch Antenna Planning

1) Antenna Patch Design

The antenna designed has a resonance frequency of 2448 MHz. In addition, the antenna designed also has a wavelength in the free space λ_0 = 122.5 mm, while for the wavelength of the antenna transmission λ_d = 57.24 mm. To calculate the radius of a circle, you can use the following formula [13]:

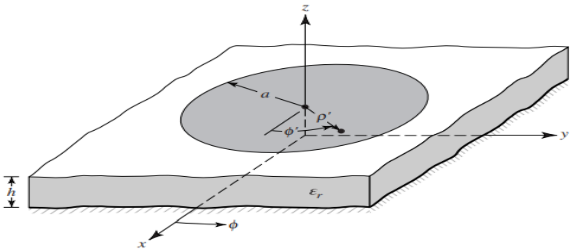


Figure 1. *Circular patch*

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

Information:
a = radius of circle (mm)
h = substrate thickness (mm)
ε_r = the relative dielectric permittivity of the substrate (F/m)
F = logarithmic function of the radiating element

To find F, you can use the following equation:

$$F = \frac{8{,}791\ x\ 10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

So that the radius of the circular patch is 14.8 mm.

2) Design of Antenna Transmission Line

To find out the impedance value for each channel, it can be calculated using the following equation [14]:

$$Z_{in} = 60\ \frac{\lambda_d}{2a} \quad (3)$$

Information:
Z_{in}= antenna impedance
λ_d = antenna transmission wave
a = radius of circle (mm)

So, the value of the impedance on one line is 116,027. After knowing the impedance of each line then calculate the width of the transmission line using the following equation [3]:

$$w_f = \frac{120\ \pi\ h}{Z_p\sqrt{\varepsilon_r}} \quad (4)$$

Information:
w_f= feed channel width
h = substrate thickness
Z_p= Line impedance
ε_r= dielectric constant

The length of the quarter wave transformer on the transmission line can be calculated using the following equation [15]:

$$L_z = \frac{1}{4}\lambda_d \quad (5)$$

Information,
L_z = length of microstrip line (mm)
λ_d= wavelength on microstrip transmission line (mm)

III. RESULTS AND DISCUSSION

A. Return Loss Test Results

1) Test Results of Return Loss and VSWR of Microstrip Array Circular Patch Antenna Without DGS

Based on testing the return loss and VSWR values for circular microstrip array antennas without DGS, the AUT power level value can be seen in Figure 2 while the reference level value can be seen in Figure 3.

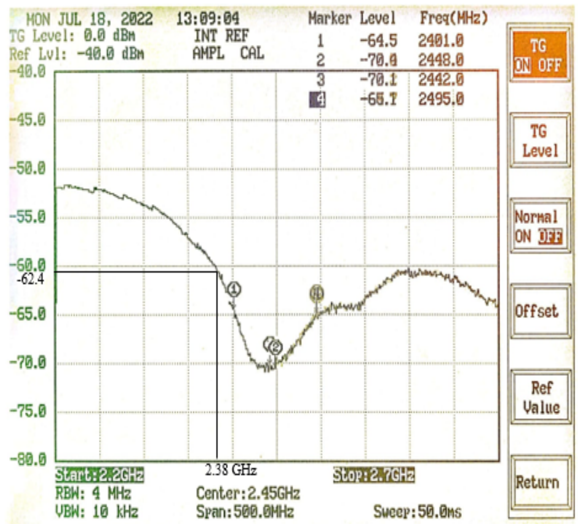


Figure 2. Test results of return loss antenna microstrip array circular patch without DGS

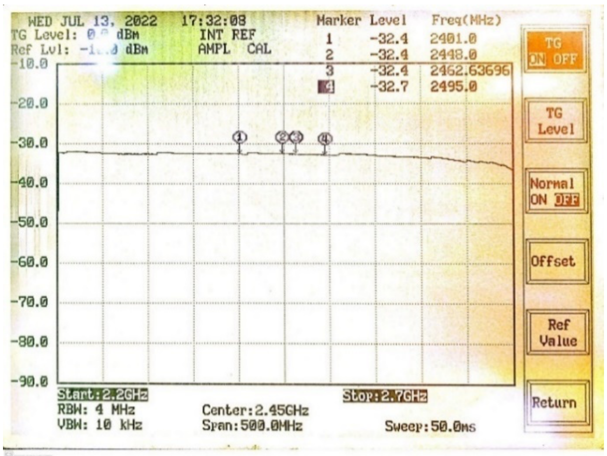


Figure 3. Reference level value

The power level that has been obtained during testing is used to calculate the return loss value with the following equation:

$$RL = Level_{AUT} - Level_{reference} - Att_{DC} \quad (6)$$

Information:
RL= Return Loss
$Level_{reference}$ = reference data level
$Level_{AUT}$ = antenna power level under test
Att_{DC}= attenuation of the directional coupler

To calculate the return loss value at the resonant frequency of the antenna design, which is 2448 MHz using equation 6 as follows:

$$RL = Level_{AUT} - Level_{reference} - Att_{DC}$$
$$RL = -70{,}1 dBm - (-32{,}4\ dBm) - (-20\ dB)$$
$$RL = -17{,}7\ dB$$

After calculating the return loss value then look for the value of the reflection coefficient used to calculate VSWR. To find the value of the reflection coefficient can use the following equation:

$$RL = 20 \text{ Log } |\Gamma| \quad (7)$$
$$-17{,}7\ dB = 20 \text{ Log } |\Gamma|$$
$$|\Gamma| = 10^{\frac{-17{,}7}{20}}$$
$$|\Gamma| = 0{,}130$$

Meanwhile, to calculate VSWR can use the following equation:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (8)$$
$$VSWR = \frac{1 + 0{,}130}{1 - 0{,}130}$$
$$VSWR = 1{,}298$$

Based on Figure 2 marker 2, namely the frequency of 2442MHz, there is an under-test antenna level value of -70.1 dBm. while for Figure 3 there is a reference value of -32.4 dBm.

TABLE I
RESULT OF CALCULATION OF RETURN LOSS AND VSWR

Marker	Frequency	Return Loss	*VSWR*
1	2401MHz	-12.1 dB	1.659
2	2448 MHz	-17.6 dB	1.301
3	2442MHz	- 17.7 dB	1,298
4	2495 MHz	-12.7 dB	1,600
5	2380 MHz	-10 dB	1,923

2) *Test results of Return Loss and VSWR of semicircular microstrip array antenna with DGS*

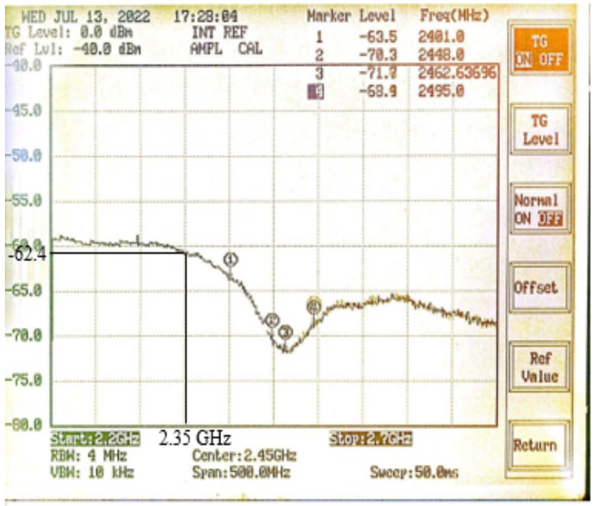


Figure 4. Return loss test results of circular microstrip array antenna with DGS

To calculate the return loss value at the resonant frequency of the antenna design, which is 2462 MHz using equation 6 as follows:

$$RL = Level_{AUT} - Level_{reference} - Att_{DC}$$
$$RL = -71.7 dBm - (-32{,}4\ dBm) - (-20\ dB)$$
$$RL = -19.3\ dB$$

After calculating the return loss value then look for the value of the reflection coefficient used to calculate VSWR. To find the value of the reflection coefficient can use equation 7 as follows:

$$RL = 20 \text{ Log } |\Gamma|$$
$$-19{,}3\ dB = 20 \text{ Log } |\Gamma|$$
$$|\Gamma| = 10^{\frac{-19{,}3}{20}}$$
$$|\Gamma| = 0{,}108$$

Meanwhile, to calculate VSWR can use the equation 8 as follows:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$VSWR = \frac{1 + 0,108}{1 - 0,108}$$
$$VSWR = 1,242$$

Based on Figure 4 marker 3, which is a frequency of 2462MHz, there is an under-test antenna level value of -71.7 dBm.

TABLE II
RESULT OF CALCULATION OF RETURN LOSS AND VSWR

Marker	Frequency	Return Loss	VSWR
1	2401 MHz	-11.1 dB	1.770
2	2448 MHz	-17.9 dB	1.290
3	2462MHz	-19,3 dB	1,242
4	2495 MHz	-16.2 dB	1,236
5	2350 MHz	-10 dB	1,923

3) *Test Results of Microstrip Array Circular Patch Antenna Gain*

Testing the gain value on a circular array microstrip antenna with and without DGS can be seen in the following table:

TABLE III
RESULT OF CALCULATION OF GAIN

Frequency (MHz)	Circular Array Microstrip Antenna Gain without DGS (dBi)	Circular Array Microstrip Antenna Gain with DGS (dBi)
2360	0.4	-1.0
2380	1.3	-4.2
2400	-0.5	3.4
2420	-6.7	1.2
2448	-15.3	1.9
2470	-4.1	2.9
2500	-2.7	0.0
2530	2.5	15.7
2550	5.9	15.3
2580	-10.2	-0.2

Based on the gain test table above on a circular array microstrip antenna without DGS and with DGS, it can be shown in the following graph:

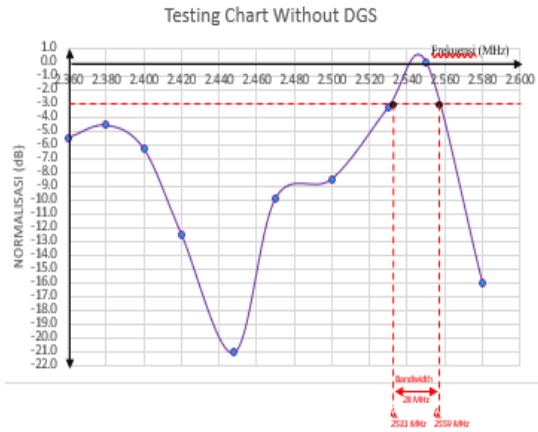


Figure 5. Graph of gain testing of circular patch microstrip array antenna without DGS.

The highest value of antenna gain testing is at a frequency of 2550 MHz, which is 5.9 dBi. As for the resonant frequency of the design of the circular patch microstrip array antenna, there is a frequency of 2448 with a value of -15.3 dBi. For the average value of antenna gain in the frequency range of 2200 – 2700, which is -6.0 dBi.

The bandwidth obtained is as follows:

$$BW = f_1 - f_2 \quad (9)$$
$$BW = 2559\ MHz - 2531\ MHz$$
$$BW = 28\ \text{MHz}$$

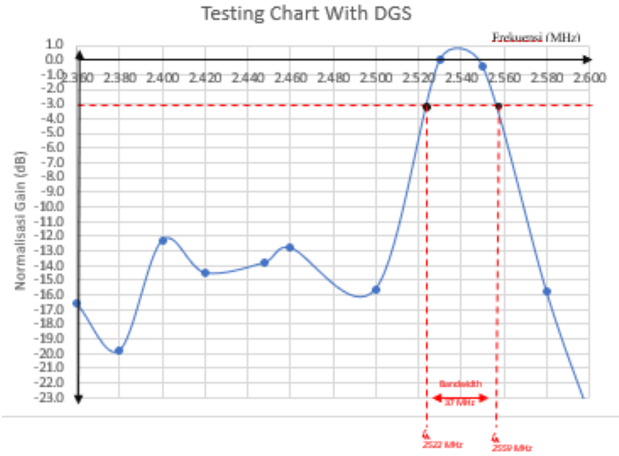


Figure 6. Graph of gain testing of circular patch microstrip array antenna with DGS.

The highest value of antenna gain testing is at a frequency of 2530 MHz, which is 15.7 dBi. As for the resonant frequency of the design of the circular patch microstrip array antenna, there is a frequency of 2448 with a value of 1.9 dBi. For the average value of antenna gain in the frequency range of 2200 – 2700, which is 2,359 dBi.

4) *Radiation Pattern Test Results*

The radiation pattern testing of the two AUTs can be seen in the following table.

TABLE IV
RADIATION PATTERN TEST RESULTS

Corner (°)	2488 MHz Power Level (dBm)	2488 MHz Normalization (dB)	Corner (°)	2488 MHz Power Level (dBm)	2488 MHz Normalization (dB)
0	-51,5	-7,5	190	-64	-0,2
10	-59	-3,5	200	-64,2	-4
20	-62,,1	-2,9	210	-68,2	-8,8
30	-65	-5,3	220	-59,4	-0,2
40	-70,3	-3,7	230	-59,6	-0,1
50	-66,6	-1,9	240	-59,7	-1,6
60	-68,5	-3,1	250	-61,3	-4,9
70	-71,6	-0,6	260	-66,2	-4,8
80	-71,4	-3,3	270	-71	-2,5
90	-68,1	-1.6	280	-68,5	-1,1
100	-66.5	-1,9	290	-67,4	-3,9
110	-64,6	-0,8	300	-63,5	-5,6

Corner (°)	2488 MHz Power Level (dBm)	Normalization (dB)	Corner (°)	2488 MHz Power Level (dBm)	Normalization (dB)
120	-65,4	-0,8	310	-57,9	-1,6
130	-66,2	-0,4	320	-56,3	-2,2
140	-66,6	-2	330	-58,5	-1,5
150	-64,6	-0,9	340	-57	-1,6
160	-65,5	-0,4	350	-58,6	-7,6
170	-68,9	-2,3	360	-51	-0,5
180	-66,6	-2,6			

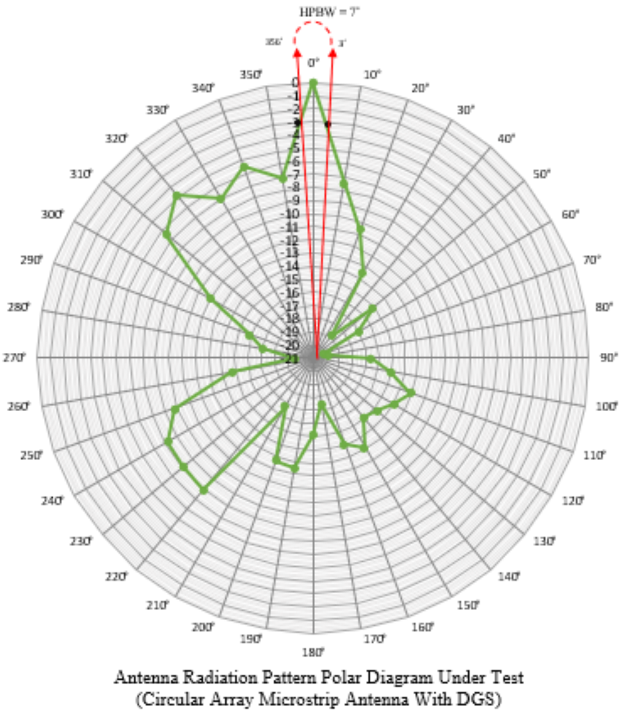


Figure 7. Directional radiation pattern of circular microstrip array antenna with DGS

The HPBW value can be calculated by marking the normalization value of -3 dB, namely the HP (left) angle of 356˚ and HP (right) 3˚ so that it can be calculated using the following formula:

$$HPBW = HP\ (left) + HP\ (right) \quad (10)$$
$$HPBW = (360^{\circ} - 356^{\circ}) + 3^{\circ} = 7^{\circ}$$

So, the HPBW value obtained by the radiation pattern of the microstrip antenna with DGS is 7˚.

5) *Comparison of Simulation and Testing Values*

Comparison of the value of the simulation and test results on a circular array microstrip antenna is used to determine whether or not the value is the same or not generated by the simulation or test. If in the simulation and testing there is a large enough difference in values, then there are several factors causing it. Comparison of simulation values and testing of circular microstrip array antennas patches with DGS are shown in the following Table V.

TABLE V
COMPARASION OF SIMULATION AND TESTING WITH DGS

Frequency (MHz)	Return Loss (dB) Simulation	Return Loss (dB) Testing	VSWR Simulation	VSWR Testing	Reflection Coefficient Simulation	Reflection Coefficient Testing
2401	-11,039	-11,1	1,7807	1,770	0,2805	0,278
2448	-35,88	-17,9	1,0327	1,290	0,0160	0,127
2495	-19,966	-16,2	1,2232	1,2236	0,1003	0,154

6) *Comparison of Bandwidth and Gain Values in Simulation and Testing*

The results of the comparison of bandwidth and gain values for simulation and testing are shown in Table VI. The 2x4 circular patch microstrip array antenna without DGS in the simulation produces a bandwidth value of 65 MHz. Meanwhile, in testing the bandwidth obtained is 28 MHz. In testing the antenna without DGS the bandwidth value is small, this is due to a shift in the resonant frequency. Meanwhile, the 2x4 circular patch microstrip array antenna with DGS in the simulation produces a bandwidth value of 152.9 MHz. While the bandwidth test obtained is 37 MHz. The bandwidth generated by the antenna with DGS between the simulation and the test is quite different, this is due to the shifting of the resonance frequency.

TABLE VI
COMPARASION OF BANDWIDTH AND GAIN VALUES FOR SIMULATION AND TESTING

Frequency (MHz)	Without DGS Simulation	Without DGS Testing	With DGS Simulation	With DGS Testing	Parameter
2401 – 2495 MHz	65 MHz	28 MHz	152.9 MHz	37 MHz	***Bandwidth***
	5.718 dB	5.9 dB	4.907 dB	15.7 dB	***Gain***

7) *Circular Array Microstrip Antenna Implementation*

Then implement the Netis WF2210 as a receiving antenna to determine the received signal strength. The AUT antenna will capture the Wi-Fi signal from the access point which then the strong signal received from the Wi-Fi capture will be displayed using the Net Spot software.

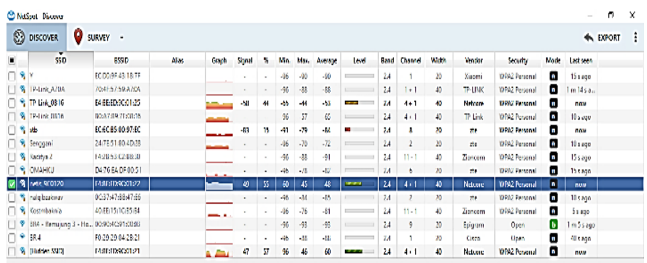
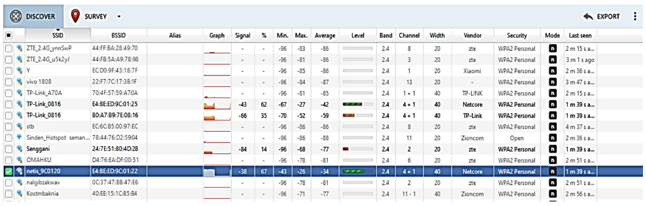


Figure 8 Signal received by the build in antenna



DISCOVER SURVEY EXPORT

SSID	BSSID	Alias	Graph	Signal	%	Min.	Max.	Average	Level	Band	Channel	Width	Vendor	Security	Mode	Last seen
ZTE_2.4G_ynnSwP	44:FF:BA:28:49:70			-	-	-96	-83	-86		2.4	8	20	zte	WPA2 Personal	n	2 m 15 s a...
ZTE_2.4G_u5k2yJ	44:FB:5A:A9:78:98			-	-	-96	-81	-86		2.4	3	20	zte	WPA2 Personal	n	3 m 1 s ago
Y	EC:D0:9F:43:18:7F			-	-	-96	-85	-86		2.4	1	20	Xiaomi	WPA2 Personal	n	2 m 36 s a...
vivo 1808	22:F7:7C:17:3B:1F			-	-	-96	-84	-87		2.4	13	20	-	WPA2 Personal	n	3 m 47 s a...
TP-Link_A70A	70:4F:57:59:A7:0A			-	-	-96	-81	-85		2.4	1 + 1	40	TP-LINK	WPA2 Personal	n	2 m 15 s a...
TP-Link_0816	E4:BE:ED:9C:01:25			-43	62	-67	-27	-42		2.4	4 + 1	40	Netcore	WPA2 Personal	n	1 m 39 s a...
TP-Link_0816	B0:A7:B9:7E:08:16			-66	35	-70	-52	-59		2.4	4 + 1	40	TP-Link	WPA2 Personal	n	1 m 39 s a...
stb	EC:6C:B5:00:97:EC			-	-	-96	-86	-86		2.4	8	20	zte	WPA2 Personal	n	4 m 37 s a...
Sinden_Hotspot seman...	78:44:76:D2:59:04			-	-	-96	-86	-88		2.4	11	20	Zioncom	Open	n	2 m 36 s a...
Senggani	24:7E:51:80:4D:28			-84	14	-96	-68	-77		2.4	2	20	zte	WPA2 Personal	n	1 m 39 s a...
OMAHKU	D4:76:EA:DF:00:51			-	-	-96	-78	-81		2.4	6	20	zte	WPA2 Personal	n	2 m 51 s a...
netis_9C0120	E4:BE:ED:9C:01:22			-38	67	-43	-26	-34		2.4	4 + 1	40	Netcore	WPA2 Personal	n	1 m 39 s a...
nalgibzakwav	0C:37:47:BB:47:E6			-	-	-96	-78	-81		2.4	2	20	zte	WPA2 Personal	n	2 m 51 s a...
Kostmbaknia	40:EE:15:1C:B5:B4			-	-	-96	-71	-77		2.4	11 - 1	40	Zioncom	WPA2 Personal	n	2 m 56 s a...

Figure 9 Signal received by Signal received by microstrip antenna with DGS

The signal received by the build in antenna is capable of receiving a maximum signal of -45 dBm and receiving a minimum signal of -60 dBm. So that the average signal received by the build in antenna is -48 dBm. The capture of signal quality received by the 2x4 circular patch microstrip array antenna with DGS is capable of receiving a maximum signal of -26 dBm and capable of receiving a minimum signal of -43 dBm. So that the average signal received by the 2x4 circular patch microstrip array antenna with DGS is -34 dBm. According to the results of the signal reading received by the two antennas, it can be said that the 2x4 circular patch microstrip array antenna with DGS has better signal reception than the build in antenna. Because the maximum received signal possessed by a 2x4 circular patch microstrip array antenna with DGS is greater.

IV. CONCLUSIONS

Simulation of 2x4 circular patch microstrip array antenna without DGS and with DGS, the return loss values at 2448 MHz frequency are -29.79 and -35.88; VSWR of 1.067 and 1.0327; bandwidth of 65 MHz and 152.9 MHz; gains of 5,718 and 4,907; with a directional radiation pattern.

Measurement of the 2x4 circular patch microstrip array antenna without DGS and with DGS obtained the return loss value for the 2442 MHz frequency of -17.7 dB and the frequency of 2462 MHz of -19.3 dB; VSWR of 1,298 and 1,242; gain is 5.9 dBi at 2550 MHz and 15.7 dBi is at 2530 with directional radiation pattern, and the HPBW value is 7˚.

The results of the implementation carried out at a distance of 20 meters show that the 2x4 circular patch microstrip array antenna with DGS is much better than the build in antenna. This can be shown by the average signal received by the 2x4 circular patch microstrip array antenna of -34 dBm. While the antenna build in Net is WF2210 is -48 dBm.

For further research it is better to check the thickness of the substrate, cooper, and dielectric permittivity on the PCB carefully because it will affect the results of antenna testing, the antenna fabrication process should use printing techniques so that the results obtained during testing are precision, and use other modifications of feeding techniques.

REFERENCES

[1] Aziz N. N., A., Kurniawan Usman, U., & Siti Rohmah, Y., "Analisa Perencanaan Indoor Wifi IEEE 802.11n pada Stadion Si Jalak Harupat," in *e-Proceeding of Engineering*, 2016, vol. 3, no. 3, pp. 44667-4476.

[2] L. Ruhyana, "Antena Mikrostrip untuk Aplikasi WLAN," *Jurnal Fakultas Teknik Kuningan,* vol. 2, no. 2, 51-56, 2021.

[3] D. G. Fang, *Antenna Theory and Microstrip Antenna*, Boca Raton: Taylor and Francis Group, 2010.

[4] N. A. Raj, and R. P. Dwivedi, "High gain antenna with DGS for wireless applications", In *2nd International Conference on Signal Processing and Integrated Networks (SPIN)*, pp 19-24, 2015.

[5] V. Varun, and A. Sunil, "Bandwidth Optimization using Fractal Geometry on Rectangular Microstrip Patch Antenna with DGS for Wireless Applications", *IEEE Int. Conf. MedCom*, 2014.

[6] D. P. Wulandari, H. Wijayanto, and Edwar, "An Investigation of Defected Ground Structure Effect on Bandwidth Enhancement of U-Shaped Microstrip Antenna for Small Ultra-wideband Radar Device", *Journal of Measurements, Electronics, Communications, and Systems*, vol. 05, pp. 20-25, December 2019.

[7] H. Adrian, A. H. Rambe, and Suherman, "Computer simulation and implementation of defected ground structure on a microstrip antenna," *Journal of Physics: Conf. Series* 978 012075, 2018.

[8] A. Parameswaran, et al., "Bandwidth Enhancement of Microstrip Patch Antenna Using Metamaterials," *IOSR Journal of Electronics and Communication Engineering*, vol. 4, pp. 5-10, 2013.

[9] A. Gard, and A. Ghosh, "Review of Techniques to Modify Microstrip Patch Antenna", International Journal of Advanced Research (IJAR), vol. 4, pp. 275-280, 2016.

[10] D. Gao, Z. X. Cao, S. D. Fu, X. Quan, and P. Chen, "A Novel Slot-Array Defected Ground Structure for Decoupling Microstrip Antenna Array," *IEEE Transactions on Antennas and Propagation*, vol. 68, pp. 7027–7038, Oct. 2020.

[11] N. N. Tawfeeq, "Size Reduction and Gain Enhancement of a Microstrip Antenna using Partially Defected Ground Structure and Circular/Cross Slots", *International Journal of Electrical and Computer Engineering (IJECE),* vol. 7, no. 2, pp. 894-898, April 2017.

[12] M. P. Supriadi, N. Madhatillah, and H. Ludiyati, "Pengaruh Defected Ground Structure (DGS) Geometri Vertikal terhadap Antena Mikrostrip Berbahan Material Dielektrik Artifisial", in *Prosiding The 12th Industrial Research Workshop and National Seminar,* August 2021, pp. 638-644.

[13] T. Y. Arif, R. Munadi, & Fardian "Simulasi Throughput WiFi menggunakan Model Lapisan HT-PHY IEEE 802.11n pada NS-3," in *Seminar Nasional dna Expo Teknik Elektro 2014 (SNETE 2014),* August 2014, pp. 200-204.

[14] S. S. Hadi, J. A. Endang, & Erlinasari, "Rancang Bangun Antena Mikrostrip Patch Circular Dengan

Teknik Linier Array Untuk Frekuensi Wifi 2, 4 Ghz." *Elektrik*, vol. 1, no. 1, pp. 9-14, 2019.
[15] D. S. Marotkar, & P Zade, "Bandwidth Enhancement of Microstrip Patch Antenna Using Defected Ground Structure". *International conference on electrical, electronics, and optimization techniques (ICEEOT)*, vol. 3, no. 2, pp. 428-434, 2016.