Design and Fabrication of Circular and Circular Ring Microstrip Patch Antennas Employing Multilayer Parasitic Elements at 2.4 GHz

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***Abstract*— This research discusses the design and construction of circular and circular ring patch microstrip antennas using the multilayer parasitic method at a frequency of 2.4 GHz. Microstrip antennas are used in wireless communications due to their small, compact, and simple shape, although they have weaknesses in terms of Bandwidth, gain, and low efficiency. To address these issues, the multilayer parasitic method is used to improve the antenna gain. This research aims to design microstrip antennas with the desired specifications, such as a VSWR value <2, Return loss < -10 dB, and a gain value of >5 dBi. The objective of this research is to increase the gain value and prove that the multilayer method can enhance the gain. The fabricated multilayer microstrip antenna operates at a frequency of 2448 MHz with a Return loss of -30.06 dB, a VSWR of 1.06, and a frequency range of (2390 - 2496) MHz. At a frequency of 2440 MHz, a gain value of 13.55 dBi with a Bandwidth of 106 MHz was obtained. This antenna is directional because it has effective radiation in a specific direction.**

***Keywords*— Bandwidth, Gain, Microstrip Antenna, Multilayer Parasitic, Wireless.**

I. INTRODUCTION

The rapid development of communication technology has led to an increase in the need for antennas that are able to meet the demands of modern communication [1][2]. Antennas play an important role in wireless communication systems because they function to transmit and receive electromagnetic waves in free space [3][4]. Current needs demand antennas that are able to cover longer distances, have high speeds, and adapt to mobile environments. In this case, microstrip antennas are the main choice because of their compact, simple, and small design, making them suitable for use in telecommunications devices [5][6]. However, microstrip antennas have disadvantages in terms of bandwidth, gain, and efficiency that need to be overcome with certain methods [7][8].

One method that can increase the gain of a microstrip antenna is the multilayer parasitic method [9][10]. This method involves adding parasitic elements in layers, where the elements derive excitation from near-field electromagnetic coupling of the main antenna [11][12]. The use of the multilayer parasitic method allows for smaller antenna dimensions without sacrificing gain performance, which usually requires a larger antenna array [13][14]. With this method, the antenna can have a higher gain while remaining compact in size [15].

This research aims to design a parasitic multilayer microstrip antenna operating at a frequency of 2.4 GHz. Some of the problems to be answered include how to design a parasitic multilayer microstrip antenna, comparison of return loss, VSWR, gain, and bandwidth parameters between simulation results and real results after fabrication, as well as the difference between the reference antenna and the parasitic multilayer antenna in terms of real testing. This research also explores the RSSI difference between the built-in antenna and the parasitic multilayer antenna. With the results of this research, it is expected that there will be an increase in antenna gain using the parasitic multilayer method, as well as providing insight into the design of microstrip antennas.

II. METHOD

This research employs an experimental method, which involves the design and execution of experiments to test hypotheses and validate theories related to microstrip antenna performance. The experimental approach allows for systematic observation, measurement, and analysis of antenna characteristics under controlled conditions. To support the design process and ensure that the results obtained are consistent with the research objectives, several structured stages are implemented throughout the study. The sequence of these stages is illustrated in Figure 1 research flowchart below.

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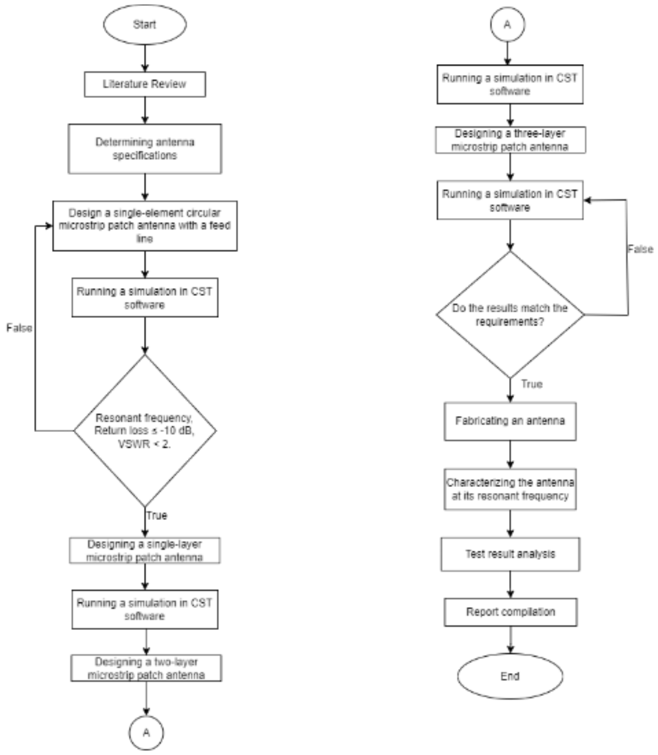

Figure 1. Research flowchart

A. Antenna Design

1) Circular Patch Design

The planned circular antenna has a resonance around 2448MHz. Calculate the radius of the circle with the formula [1] as shown at Equation (1).

$$a = \frac{F}{\sqrt{1+\frac{2.h}{\pi.\varepsilon_r.F}\left[\ln\left(\frac{\pi.F}{2.h}\right)+1{,}7726\right]}} \quad (1)$$

Description:
F: Radiating element
h: Substrate height
ε_r: Dielectric constant
a: Radius

The radius result is 14.7285mm, then find the effective radiation value [1] as shown at Equation (2).

$$a_e = a \times \sqrt{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1{,}7726\right]} \quad (2)$$

Description:
F: Radiating element
h: Substrate height
ε_r: Dielectric constant
a: Radius
a_e: Effective radiation

The result is 16.7mm, then find the value of the Radiation Element using the formula [1] as shown at Equation (3) and the result is 1.67801mm.

$$F = \frac{8{,}791\times10^9}{f\sqrt{\varepsilon_r}} \quad (3)$$

To find the value of the ground plane length and ground plane width using the formula [2] as shown at Equation (4) and (5).

$$W_g = 6h + \frac{\pi}{2}a \quad (4)$$

$$L_g = 6h + 2a \quad (5)$$

Description:
L_g : Ground plane length
W_g : Ground plane width
h : Substrate height
a : Radius of the circle

From the above results, the ground plane length is 42.82mm and the ground plane width is 35.63mm. Then to find the channel length using the formula [3] as shown at Equation (6) and (7).

$$L_f = \frac{\lambda_d}{4} \quad (6)$$

$$\lambda_d = \frac{\lambda_0}{\sqrt{\varepsilon_r}} \quad (7)$$

Description:
λ_d: Wavelength at the radiating element (m)
λ_0: Wavelength (m)
ε_r : Dielectric permittivity

From these results 14.31mm, then to find the channel width using the formula [2] as shown at Equation (8) and (9).

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} \quad (8)$$

$$W_f = \frac{2h}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0.38 - \frac{0.61}{\varepsilon_r}\right]\right\} \quad (9)$$

From the above calculations, the channel width results are 2.8mm, and the width of the transformer is 1.2mm. From all the above calculations, the antenna design results are obtained as shown in Figure 2.

2) Circular Ring Patch Design

The antenna designed as parasitic will be ring-shaped. The calculation of the antenna dimensions is all the same except for the size of the ring circle. Patch calculations can be formulated [4]. From the calculation, the antenna design results are shown in Figure 3.

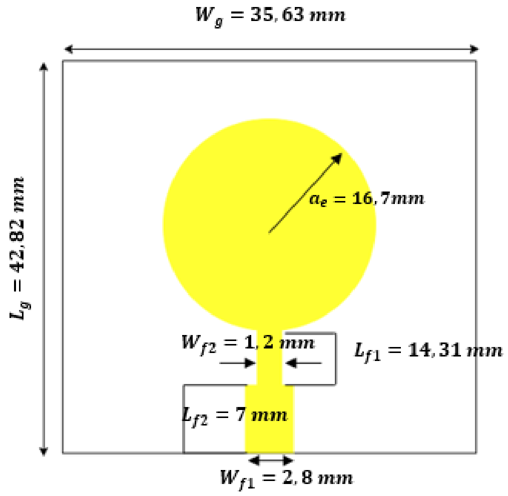

Figure 2. Circular patch antenna design

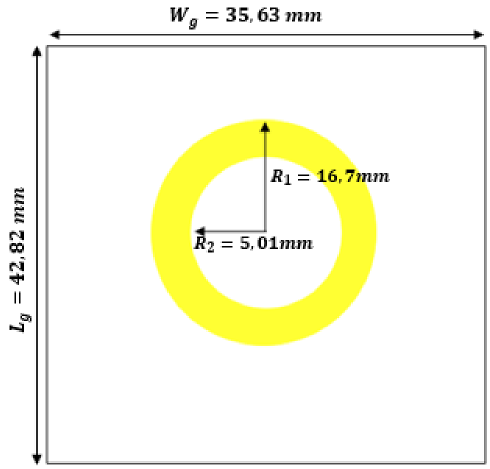

Figure 3. Circular ring patch antenna design

$$R_2 = 0.30R_1 \quad (10)$$

3) Multilayer Design

Layer 1 to layer 4 are arranged in a multilayer manner where the water gap (h) is determined from experimental simulation results. The best simulation results will later become the antenna layer separation distance. The separation of one layer to another uses plastic spacers. The multilayer design is shown in Figure 4. In accordance with the theory regarding the distance between elements [14][15]. The distance h (Air Gap) between the driven (layer 4) and Directors 1 (layer 3) does not exceed 0.15 λ. Then the spacing distance (Air Gap) between Directors 1 (layer 3) with Directors 2 (layer 2) and Directors 2 (layer 2) with Directors 3 (layer 1) ranges between 0.25 λ - 0.35 λ. The determination of h (Air Gap) is also done through simulation where the optimal distance is sought. From the calculation of the distance between layers, the results are shown in Table 1.

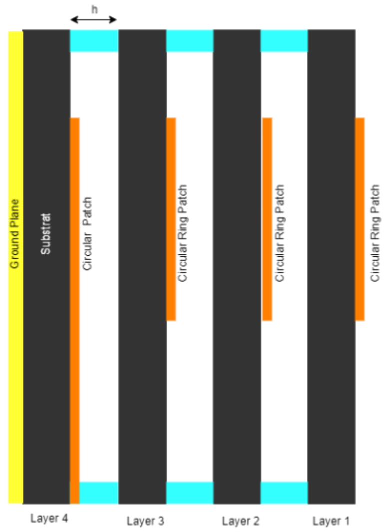

Figure 4. Multilayer design

TABLE I
LAYER SPACING TABLE

Types of elements	Element spacing
DRIVEN – DIRECTORS 1	0.08 Λ = 10
DIRECTORS 1 - DIRECTORS 2	0.24 Λ = 30
DIRECTORS 2 - DIRECTORS 3	0.24 Λ = 30

B. Determination of Material Specifications

The material specifications used in this study are as follows. Specifications for PCBs made of FR-4 material are as follows: This PCB uses Double Layer PCB for Driven and Single Layer PCB for Directors, with a copper thickness of 0.035 mm. The thickness of the substrate is 1.57 mm, and the overall size of the PCB is 35.63 x 42.82 mm. These specifications ensure optimal durability and performance in the designed applications, as shown in Table 2.

TABLE II
SPECIFICATION PCB FR-4

Details	Specification
LAYER DRIVEN	DOUBLE LAYER
LAYER DIRECTORS	SINGLE LAYER
COPPER THICKNESS	0.035 MM
SUBSTRATE THICKNESS	1.57 MM
SIZE	35.63 X 42.82 MM

III. RESULTS AND DISCUSSION

A. Fabrication Results

Figure 5 is a picture of the fabrication of circular patch microstrip antenna and multilayer parasitic patch circular ring.

Figure 5. Antenna fabrication

B. Return Loss Test Result (Simulation Result)

Figure 6 is the simulation result of the return loss of the parasitic multilayer microstrip antenna.

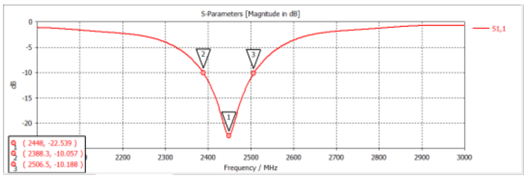

Figure 6. Multilayer return loss simulation results

The results of the simulation show that the return loss occurs at the center frequency of 2448 MHz which is the resonant frequency resulting in a return loss of -22.539 dB. Compared to the minimum requirements for antenna manufacturing, the return loss is ≤ -10 dB.

C. VSWR Test Results (Simulation Results)

Figure 7 is the VSWR simulation result of the parasitic multilayer microstrip antenna.

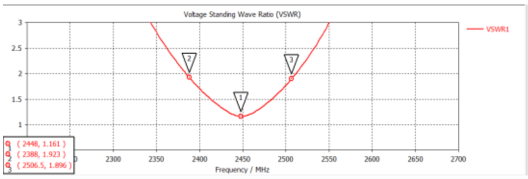

Figure 7. Multilayer VSWR simulation results

The results of the simulation produced a VSWR at a center frequency of 2448 of 1.161. Compared to the minimum requirements for antenna manufacturing, VSRW ≤ 2.

D. Bandwidth Test Results (Simulation Results)

Figure 8 is the bandwidth simulation result of the parasitic multilayer microstrip antenna.

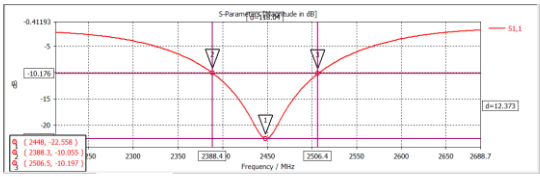

Figure 8. Multilayer bandwidth simulation results

The bandwidth result of the Antenna is 118.2 MHz where the upper frequency is 2388.3 MHz and the lower frequency is 2506.5 MHz.

E. Return Loss Test Results

The return loss test results of the parasitic multilayer microstrip antenna as shown in Figure 9.

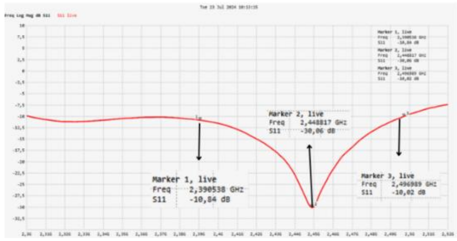

Figure 9. Multilayer return loss measurement results

The test return loss results are -10.84 dB at a frequency of 2390 MHz and -10.02 dB at a frequency of 2496 MHz. The frequency of 2448 MHz has the lowest return loss, which is -30.06 dB.

F. VSWR Test Result

The VSWR test results of the parasitic multilayer microstrip antenna as shown in Figure 10.

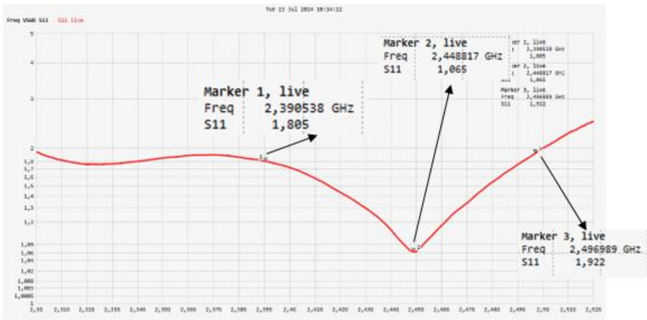

Figure 10. Multilayer VSWR measurement results

The VSWR test results are 1.805 at a frequency of 2390 MHz and 1.922 at a frequency of 2496 MHz. The frequency of 2448 has a VSWR of 1.065.

G. Gain Test Result

Table III is the result of testing the gain of the parasitic multilayer microstrip antenna.

TABLE III
GAIN TESTING

Frequency (MHz)	Level (dBm)		Gain (dB)
	Antenna Reference	Antena Under Test	
2350	-67.3	-62.4	7.05
2360	-70.2	-64.5	7.85
2370	-68.2	-65.2	5.15
2380	-74.2	-66.1	10.25
2390	-70.3	-64.4	8.05
2400	-66.3	-70.2	-1.75
2410	-69.7	-70.1	1.75
2420	-73.2	-72.5	2.85
2430	-71.7	-65	8.85
2440	-73.5	-62.1	13.55
2450	-64.3	-60.1	6.35
2460	-64.9	-64.1	7.95
2470	-62.8	-66.5	-1.55
2480	-63.1	-69.9	-4.65
2490	-63.4	-67.7	-2.15
2500	-71.7	-74.5	-0.65
2510	-66.7	-67.6	1.25
2520	-71.4	-70.2	3.35

Figure 11 shows the gain result of a multilayer parasitic antenna. The gain value has an average of 4.08 dBi and the largest gain recorded is at a frequency of 2440 MHz with a value of 13.55 dBi, the gain value is close to the working frequency of the multilayer microstrip antenna whose frequency is at 2448 MHz.

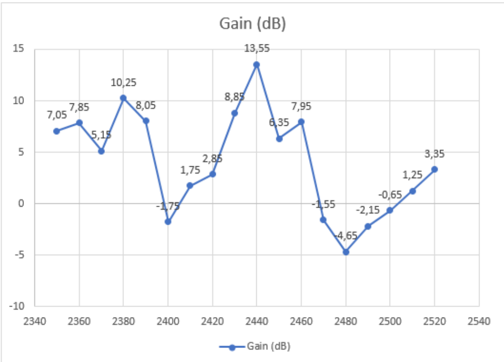

Figure 11. Multilayer microstrip antenna gain (dBi) plot

H. Radiation Pattern Test Results

TABLE IV
RADIATON PATTERN TESTING

Frequency 2440 MHz		
Degree Coner	Power Level (dBm)	Normalization
0°	-59,5	0
10°	-60,2	-0,7
20°	-61,8	-2
30°	-63,5	-4
40°	-65,5	-6
50°	-68,3	-8,8
60°	-72,4	-12,9
70°	-75,5	-16
80°	-75,7	-16,2
90°	-74,2	-14,7
100°	-73,5	-14
110°	-71,3	-11,8
120°	-71,8	-12,3
130°	-74,7	-15,2
140°	-76,6	-17,1
150°	-76,4	-16,9
160°	-74,2	-14,7
170°	-73,2	-13,7
180°	-73,3	-13,8
190°	-71	-11,5
200°	-70,6	-11,1
210°	-71,8	-12,3
220°	-74,3	-14,8
230°	-76	-16,5
240°	-75	-15,5
250°	-71,3	-11,8
260°	-67,5	-8
270°	-65,8	-6,3
280°	-65,6	-6,1
290°	-66,2	-6,7
300°	-65,3	-5,8
310°	-64,2	-4,7
320°	-62,5	-3
330°	-61,5	-2
340°	-60,7	-1,2
350°	-60,1	-0,6

Table 4 is the result of testing the radiation pattern of the parasitic multilayer microstrip antenna. From the results of the table above, the results of the diagram are described in Figure 12.

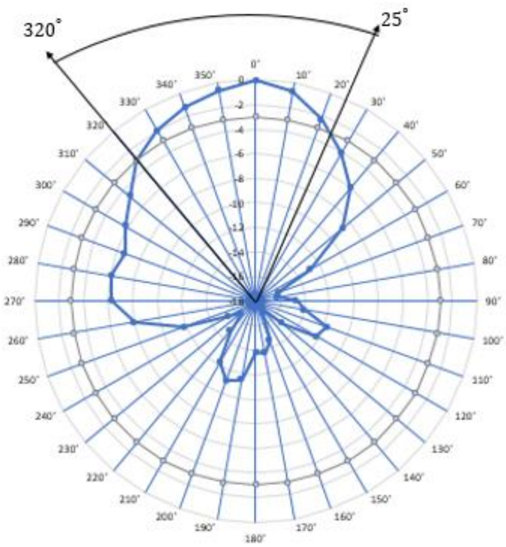

Figure 12. Directional radiation pattern of multilayer microstrip antenna

The Half Power Beamwidth (HPBW) value is obtained by determining the angle that has a normalization of -3 dB, which is 25° as HP (right) and 320° as HP (left). Therefore, HPBW can be calculated using Equation (11).

$$HPBW = HP_{right} - HP_{left} \quad (11)$$

$$\text{HPBW} = (360° - 320°) + 25$$

$$\text{HPBW} = 65°$$

I. Comparison of Simulation Results with Test Results

The simulation and fabrication results of the antenna show the return loss and VSWR values at three main frequencies: 2388 MHz, 2448 MHz, and 2506 MHz. At 2388 MHz, the fabricated return loss is -10.84 dB with a VSWR of 1.80, while the simulation results show a return loss of -10.05 dB with a VSWR of 1.92, showing fairly consistent results. At a frequency of 2448 MHz, the fabricated return loss is lower, reaching -30.06 dB with a VSWR of 1.06, which shows the best performance compared to the simulated value of -22.53 dB with a VSWR of 1.16. Finally, at a frequency of 2506 MHz, the fabricated results have a return loss of -10.02 dB and a VSWR of 1.92, while the simulation results in -10.18 dB with a VSWR of 1.89, showing consistency between the simulation and fabrication results.

J. Results Implementation of built-in antenna with

The purpose of this implementation is to assess the performance of the fabricated antenna used in Wi-Fi. In addition, this implementation also aims to compare the receiving power between the built in antenna and the parasitic multilayer microstrip antenna applied to Wi-Fi.

Antenna implementation on 802.11N wireless was carried out in the AI Polinema building. Implementation of built in antennas and external antennas installed in the room (indoor) with 20 meters. The 802.11N wireless USB antenna is connected directly to a laptop via a USB port.

1) Received Signal Strength Indicator Testing

Table 5 shows the RSSI test results of the parasitic multilayer microstrip antenna and the built in antenna.

TABLE V
RSSI MEASUREMENT RESULTS

Distance	RSSI (dBm)	
	Built in	Antena Mikrostrip Multilayer
5 meters	-40	-34
10 meters	-50	-47
15 meters	-55	-50
20 meters	-57	-50
25 meters	-62	-51
30 meters	-62	-52
35 meters	-63	-57
40 meters	-74	-58

Table 5 shows the comparison of RSSI values between the Built in antenna and the multilayer microstrip antenna at various distances from 5 to 40 meters. Both antennas show a decrease in signal strength as the distance increases, but the Multilayer Microstrip Antenna shows better performance in maintaining signal strength, especially at longer distances.

From the table above, the graph results can be shown in Figure 13.

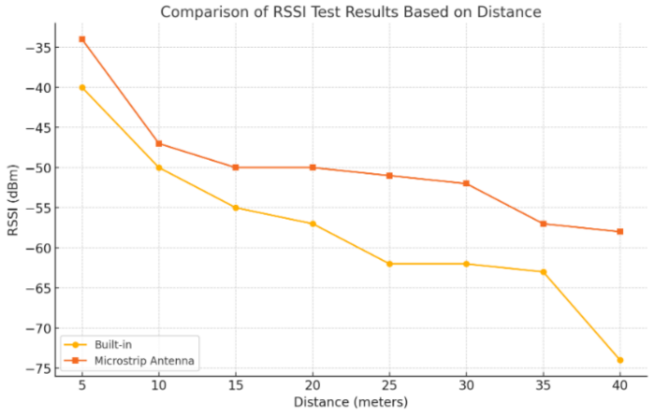

Figure 13. RSSI testing graph results between multilayer microstrip antenna and built-in antenna

2) Throughput Testing

Table 6 shows the throughput test results of the parasitic multilayer microstrip antenna and the built in antenna.

TABLE VI
THROUGHPUT TEST RESULTS

Distance	Throughput	
	Built in	Antena Mikrostrip Multilayer
5 meters	959.553 Byte	1.474.324 Byte
10 meters	813.246 Byte	1.435.855 Byte
15 meters	531.242 Byte	1.166.914 Byte
20 meters	457.933 Byte	1.068.309 Byte
25 meters	454.010 Byte	956.976 Byte
30 meters	281.031 Byte	838.088 Byte
35 meters	115.708 Byte	690.713 Byte
40 meters	7.561 Byte	194.680 Byte

From the table above, the graph results can be shown in Figure 14.

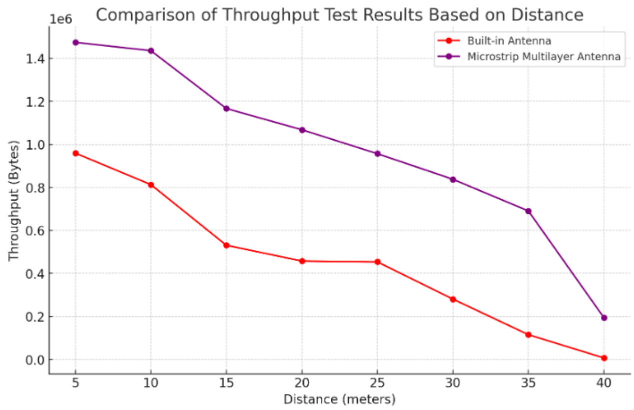

Figure 14. Throughput testing graph results between multilayer microstrip antenna and buil In antenna

Table 6 comparing the performance of the Built in antenna and the multilayer microstrip antenna at distances of 5 to 40 meters shows that the throughput decreases as the distance increases. The multilayer microstrip antenna consistently performs better than the built in antenna, with higher throughput at each distance.

3) Latency Testing

Table 7 shows the latency test results of the parasitic multilayer microstrip antenna and the built in antenna.

TABLE VII
LATENCY TEST RESULTS

Distance	Latency	
	Built in	Antena Mikrostrip Multilayer
5 meters	14 ms	9 ms
10 meters	129 ms	78 ms
15 meters	138 ms	102 ms
20 meters	156 ms	153 ms
25 meters	362 ms	304 ms
30 meters	557 ms	316 ms
35 meters	1081 ms	777 ms
40 meters	1721 ms	1190 ms

From the table above, the graph results can be shown in Figure 15.

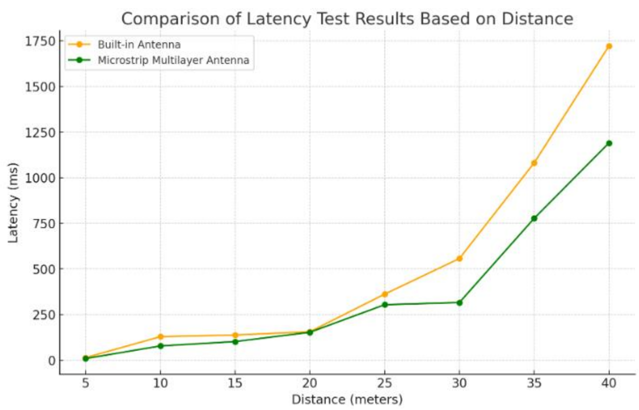

Figure 15. Latency testing graph results between multilayer microstrip antenna and built in antenna

Table 7 compares the latency between the built in antenna and the multilayer microstrip antenna at a distance of 5 to 40 meters showing that the latency increases as the distance increases. From the data, the multilayer microstrip antenna consistently performs better than the built-in in terms of latency at various distances.

IV. CONCLUSION

Based on the research and testing conducted, the multilayer parasitic patch circular and circular ring microstrip antenna for 24 GHz working frequency shows significant performance improvement after fabrication compared to the initial simulation results. The antenna designed using CST Studio Suite 2019 shows an increase in return loss and VSWR which indicates better performance. The antenna bandwidth decreased slightly after fabrication, but the maximum gain increased significantly, while the radiation pattern remained directional. Further tests comparing the microstrip antenna with the reference antenna, showed that the microstrip antenna was superior or equivalent at some frequencies. In addition, compared to the built-in antenna, the microstrip antenna showed better signal strength, especially at longer distances. The overall results indicate that the parasitic multilayer method is effective in improving the performance of microstrip antennas at high frequencies.

REFERENCES

[1] Balanis, Constantine A. (2016). Antenna Theory Analysis and Design. Hoboken: John Wiley & Sons, Inc.

[2] Jhonson, Richard C. (1993). Antenna Engineering Handbook. New York: McGraw-Hill, Inc

[3] Medina, Fachrul Reiza. & Edwar. Perancangan Dan Simulasi Multi-Layer Parasitic Antena Array Mikrostrip 1x2 Dengan Patch Persegi Untul Aplikasi 2,45 GHz. Seminar Nasional Sains dan Teknologi (SEMNASTEK), No. 037, hal 1-11. 2018

[4] Utami, Eva Yovita. Prabelia, Chorintan, Setiaji, Fransiscus Dalu Setiaji. & Yuyu Wahyu. Peningkatan Gain dengan Teknik Multilayer Parasitic pada Perancangan Antena Mikrostrip Persegi Panjang 2,4 GHz. ELKHA (Elektro Khatulistiwa) : Jurnal Teknik Elektro . Vol.11, No.2, hal 72-78. 2019.

[5] Septayadi, Muhamad Erianto. Arseno, Dharu. & Wahyu, Yuyu. Perancangan Dan Realisasi Antena Mikrostrip Patch Persegi Panjang Dengan U Slot Dan Proximity Coupled Untuk Wi-fi 5,5 GHz Design and Realization of Rectangular Patch Mikrostrip Antenna with U Slot and Proximity Coupled for Wifi 5.5 GHz. Telkatika: Jurnal Telekomunikasi Elektro Komputasi & Informatika .Vol.5, No.3, hal 5328. 2018

[6] Sumartono. Wijanto, Heroe. & Wahyu, Yuyu. Perancangan Dan Realisasi Antena Mikrostrip Multilayer Parasitic Pada Frekuensi 2,35 GHz Untuk Aplikasi Lte. Telkatika: Jurnal Telekomunikasi Elektro Komputasi & Informatika.Vol. 1, No. 1, hal 275. 2014

[7] Alam, Syah. Rizka, Nadia Media. Surjati, Indra. & Marlina, Pipit Dewi. Rancang Bangun Antena Mikrostrip Patch Rectangular Dengan Metode Parasitic Untuk Meningkatkan Bandwidth. Jurnal TEKTRIKA : Jurnal Penelitian Dan Pengembangan Telekomunikasi, Kendali, Komputer, Elektrik, Dan Elektronika, Vol.5, No.1, hal 1. Januari 2020

[8] Huang, Yuhan. Li, XiuPing. Li, Qingwen. Qi, Zihang. Zhul, Hua. Akram, Zaid. & Jiang, Xing. Generation of Broadband High purity Dual-Mode OAM Beams Using A four-feed Patch Antenna: theory and implementation. Nature Research: Scientific Reports. Vol. 9. 2019

[9] Mankusa, Zilliah. Wijanto, Heroe. & Edwar. Desain Dan Realisasi Antena Mikrostrip PatchSirkular Pita Lebar Untuk Penerima Berbasis Lora Dan Ads-B Pada Satelit Kubus 2u. Telkatika: Jurnal Telekomunikasi Elektro Komputasi & Informatika. Vol.8, No.5. hal 4891. 2021

[10] Hasan, Salim Abdullah. Ahmed, Abdulsattar Mohamed. Ahmed, Mohanad Nawfal. & Dawood, Younis Shareef. Design and Simulation of 2× 2Micro Strip Circular PatchAntenna Array at 28 GHz for 5G Mobile Station

Application. Intl Journal of Electronics and Telecommunications. VOL. 68, NO. 4. hal 721-729. 2022

[11] Iqbal, Muhammad Wahyu. Sandi, Efri. Diamah, Aodah. Peningkatan Bandwidth Dan Gain Antena Miktrostrip Patch Lingkaran Dengan Menggunakan Parasitik Substrat Pada Frekuensi 3 GHz. JVoTE (Jurnal Pendidikan Vokasional Elektronika). Vol. 02, No. 1. hal 14. 2019

[12] Fajar Wahyu Ardianto, Nachwan Mufti A., dan Budi Syihabuddin. Analisis Simulasi Antena MIMO 4 4 Susunan Persegi dan Sirkular pada Frekuensi 15 GHz. Jurnal Nasional Teknik Elektro dan Teknologi Informasi (JNTETI), Vol. 7, No. 2, hal. 174–182, 2018

[13] Singh, Manoj. Singh, Ananjan. Koul, S.K. Circular Patch Antenna with Quarter Wave Transformer Feed for Wireless Communication. 2006 Annual IEEE India Conference. hal 1-5.

[14] Huang, Yi. Boyle, Kevin. (2008). Antennas From Theory to Practice. Chichester: John Wiley & Sons, Inc.

[15] Safrianti, Ery. Widianto Rendra. Perancangan Antena Mikrostrip Yagi pada Frekuensi Kerja 1,9-2,1 GHz. Seminar Nasional dan Expo Teknik Elektro 2017. hal. 151-157