Tikrit Journal of Engineering Sciences (2025); 32(1): 1861
DOI: http://doi.org/10.25130/tjes.32.1.34

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Performance Evaluation of the Circular Patch Antenna and Size Reduction with Slotted for WLAN Application

Surur Hassan Ali *, **Ali Khalid Jassim**
Department of Electrical Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq.

Keywords:
Perforated flower; Circular microstrip patch antenna (CMPA); Wide bandwidth; WLAN application; Printed antenna design.

Highlights:

- *A compact circular microstrip patch antenna specifically tailored for WLAN applications.*
- *The chosen antenna geometry was circular, suggesting advantages in terms of radiation pattern and impedance matching.*
- *This structure included elliptical slots representing veins and six circular slots on the patch surface, contributing to improved bandwidth and low-level reflected power.*
- *The proposed antenna was deemed suitable for WLAN applications based on these parametric results, indicating its potential for reliable and high-performance wireless communication.*

ARTICLE INFO
Article history:

Received	15 Aug.	2023
Received in revised form	01 Nov.	2023
Accepted	04 Jan.	2024
Final Proofreading	02 Mar.	2024
Available online	14 July	2025

Citation: Ali SH, Jassim AK. **Performance Evaluation of the Circular Patch Antenna and Size Reduction with Slotted for WLAN Application**. *Tikrit Journal of Engineering Sciences* 2025; **32**(1): 1861.
http://doi.org/10.25130/tjes.32.1.34

Corresponding author:
Surur Hassan Ali
Department of Electrical Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq.

Abstract: This paper presents a newly printed antenna with dimensions of $(35 \times 23 \times 1.6)\ mm^3$. The proposed antenna consists of two parts, like plant leaves. A perforated flower has been inserted between these two leaves to enhance performance. These parts are printed on an inexpensive relative permittivity of 4.4 FR4 substrate material. The half-circumference of the circular cover was 17 mm. This work involves designing and simulating a circular microstrip patch antenna (CMPA) utilizing the Computer Simulation Technique (CST). It is designed to work exceptionally well at 5.599 GHz, with a gain of 2.031 dB, a reflection coefficient of -61.38dB, VSWR of 1.0017, and a total efficiency of about 78%, with an input impedance of 50.83 Ω and wide bandwidth of 724 MHz (5.2109 GHz–5.9351 GHz), making it suitable for WLAN applications.

تقييم أداء هوائي التصحيح الدائري وتقليل الحجم باستخدام فتحات لتطبيق شبكة WLAN

سرور حسن علي حسان ، علي خالد جاسم
قسم الهندسة الكهربائية/ كلية الهندسة/ الجامعة المستنصرية/ بغداد - العراق.

الخلاصة
يقدم هذا الورق البحثي هوائيًا مطبوعًا جديدًا بأبعاد (٣٥ × ٢٣ × ١,٦) ملم³. يتكون الهوائي المقترح من جزئين، مشابهين لأوراق النبات . تم إدراج زهرة مثقبة بين هاتين الورقتين لتعزيز الأداء. يتم طباعة هذين الجزئين على مواد ذات ثابت العزل الكهربائي النسبي الرخيصة ذات القيمة ٤,٤ .(FR4) نصف محيط الغطاء الدائري هو ١٧ ملم. يتضمن هذا العمل تصميم ومحاكاة هوائي التصحيح الدائري (CMPA) باستخدام تقنية المحاكاة الحاسوبية (CST).تم تصميمه للعمل بشكل استثنائي عند تردد GHz ٥,٥٩٩ ، مع اكتساب قدره 2.031 dB ، ومعامل انعكاس بقيمة 61.38 dB - ، ونسبة الجهد الموجي المعكوس (VSWR) تبلغ ١,٠٠١٧، وكفاءة إجمالية تبلغ حوالي ٧٨ % ، مع مقاومة إدخال بقيمة 50.83 Ω ، وعرض نطاق ترددي واسع يبلغ 724 MHz (5.2109 GHz–5.9351 GHz) ، مما يجعله مناسب لتطبيقات WLAN.

الكلمات الدالة: تصميم الهوائي المطبوع، الزهرة المثقبة، هوائي التصحيح ذو الشريط الصغير الدائري (CMPA)، عرض النطاق الترددي العريض، تطبيق WLAN.

1.INTRODUCTION

Communications and information technology have advanced at an amazing pace. So, it does not require the device size and performance to be compatible. Antennas are the most important communication devices and play an effective role in modern wireless communication systems. Antennas are electromagnetic wave transmitting or receiving transducers. In other terms, antennas modify electrical signals from electromagnetic waves and vice versa [1]. The simplest and most fundamental form of antennas is the "microstrip patch antenna." It is widely used due to its special characteristics, such as ease of manufacture, low profile, low weight, low cost, and supporting linear and circular polarization [2]. The performance of the microstrip antennas is affected by fundamental factors, including patch geometry, feeding methods, and properties of the dielectric material (substrate) [3]. Several methods for feeding antennas, microstrip lines, coaxial probes, and aperture coupling are the most frequently employed types [4]. The radiation patch surface's edge was directly coupled to the microstrip line feeding [5]. Even though microstrip patch antennas are widely utilized in many wireless communication systems, there is an immediate need for an antenna that can transmit signals at high data rates, high directivity, low return loss, and wide bandwidth. Low gain, restricted frequency bandwidth, relatively large size at low frequencies, and low processing capacity are, however, disadvantages of patch antennas [6]. In recent years, researchers have made intense efforts to suppress deficiencies and limitations faced by patch antennas. Various designs have been proposed to improve its performance, including using a triangular patch [7], rectangular patch [8], elliptical patch [9], irregular Diamond Shape patch [10], circular patch [11], and hexagonal patch [12]. Broadband properties can be achieved with a flexible antenna that uses a traditional circular or elliptical patch. On the other hand, the radiating surface may crack if the flexible antenna is bent. Compared to standard circular or elliptical patches, the ring-type patch has the advantage of not cracking even when bent. Broadband features are also present in ring-type monopoles [13]. Shorting pin loading and patch stacking are two strategies for expanding the bandwidth of microstrip antennas [14,15]. Various slot-loading shapes, such as circular with rectangular fractal slots and H-slot apertures, also enhance the antenna bandwidth in a patch-fed antenna. These slot-loading techniques not only widen the bandwidth but also impact the radiation aspect of the antenna [16,17]. Artificial neural network (ANN) technology is also employed to precisely calculate resonant frequencies in microstrip antennas. Its goal is to decrease computational complexity and time while simultaneously improving rectangular microstrip patch antenna efficiency, gain, and directivity [18]. These days, research interest in creating target-oriented microstrip antennas is high. A thorough analysis of the most recent research on the design and optimization of the slotted circular microstrip patch antenna operating in the C band, conducted by several authors, is provided in [19-22]. Applications using the C Band, such as WLAN, WiMAX, Wi-Fi, and satellite communication, employ slotted antennas. It was concluded that adding distinct slots to the antenna improved performance metrics, including gain, bandwidth, and return loss. The present work proposed a circular microstrip patch antenna design (CMPA) operating at a single resonator frequency of 5.599GHz with a low return loss and wide bandwidth. The MCPA is constructed from two leaves of the plant with a perforated Flower in the middle of these two leaves to symmetrize the shape and obtain optimal performance. A rectangular slot was drilled into the partial ground with different-sized, shaped, and positioned holes added to the patch's radiating surface to enhance the proposed antenna's efficacy while decreasing its size to (35 x 23) mm^2.

2.ANTENNA DESIGN

The CST. Studio 2020 simulation program creates the suggested circular microstrip patch antenna. The height of the substrate (h) (in mm), the resonant frequency (fr in GHz), and the substrate's dielectric constant ($\mathcal{E}_r$) were assumed to be known. Next, the design parameters of the circular microstrip patch antenna (CMPA) were calculated using a set of simplified formulas [23], and the outcomes were satisfactory:

- To calculate the radius of the circular patch(R_a), use the following equations:

$$R_a = \frac{F}{[1+\frac{2h}{\pi F \varepsilon r}\left(Ln\left\{\frac{\pi F}{2h}\right\}+1.7726\right)]^{0.5}} \quad \textbf{(1)}$$

$$\text{also, } \mathbf{F} = \frac{8.791\ x10^9}{fr\sqrt{\varepsilon r}} \quad \textbf{(2)}$$

where

F = Circular patch antenna's logarithmic function (F),

ε_r = Dielectric constant of the substrate,

f_r = Resonant frequency, and

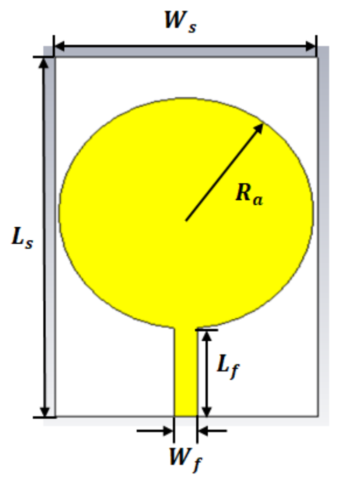
h = Height of substrate.

- To calculate the substrate dimensions, use the following equations:

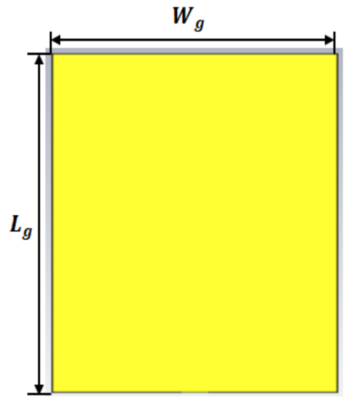
Ls=2 x patch Diameter **(3)**

Ws=2 x patch Diameter **(4)**

where L_s is the length of the substrate, and W_s is the width of the substrate. Once Eq. (1) gave the calculated value for the proposed antenna's radius (Ra), a method of trial and error was used to improve the antenna's performance while simultaneously making it smaller. The iterative procedure known as "sweeping the parameters" involves running simulations repeatedly with various parameter values until the desired outcomes are achieved. This iterative process led to determining the optimal radius value, with Ra being set at 17mm, achieving resonance at a frequency of 5.599 GHz. The fundamental antenna's geometry is illustrated in Fig. 1. Dielectric material (substrate) separated the two conductive layers (a patch and ground plane). The antenna was built with the low-cost FR-4 substrate material, with a loss tangent of 0.025 and a relative permittivity of 4.4. Ra was the radius of the disc-shaped metal cover with the dimensions of (3.1 × 8.22) mm^2. A microstrip feed line was utilized to accomplish an impedance matching of 50 Ω between the conducting patch antenna and the transmission line. Alongside the microstrip line, the patch was printed on the upper surface of the substrate. The ground plane's dimensions, inscribed on the underside of the substrate, were (35 × 23) mm^2.



(a) top view



(b) bottom view.

Antenna 1

Fig. 1 Conventional Antenna Configurations.

It is widely known that selecting a radiating patch shape, in addition to the dimensions of the designed antenna, significantly impacts the efficiency of MSA performance. As a result, the radiation pattern, gain, bandwidth, input impedance, and surface current distribution will change. Table 1 shows the optimal parameters for the proposed antenna.

Table 1 The optimal parameters of the circular microstrip patch antenna.

No.	Description	Parameter	Value
1	Resonate frequency	f_r	5.599
2	Patch radius	R_a	17
3	Feed line width	W_f	3.1
4	Feed line length	L_f	8.22
5	Ground plane length	L_g	23
6	Partial ground length	L_{g1}	13
7	Ground plane width	W_g	35
8	Substrate width	W_s	35
9	Substrate length	L_s	53
10	Substrate height	H	1.6
11	New substrate length	L_{s1}	23
12	Circular holes radius	R_b	0.2
13	Rectangular slot	W_x, L_x	(4.6,2)
14	Flower leg	W_i, L_i	(0.25,6.7)
15	Main elliptical slots	X_{rad1} , Y_{rad1}	(0.111,7.5)
16	Right Sub elliptical slot	X_{rad2} , Y_{rad2}	(0.35,1.5)
17	Left Sub elliptical slot	A, B, and C	(3.57,4.57,1.0 79)

To clarify the antenna's performance behavior, the design is presented in the form of steps: -

2.1.Design Step I

The original antenna patch is modified to take on the form illustrated in Fig. 2. The shape of a patch's leaf was created by intersecting two discs. The other plant leaf was obtained by copying this leaf along the x-axis corresponding to it. The radius of these discs in the original antenna was identical. This modification was intended to accomplish a reasonable bandwidth and size reduction.

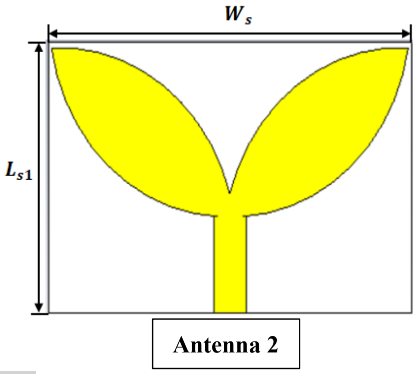


Fig. 2 The Leaf Shape of the Proposed Plant.

2.2.Design Step II

To make the biological shape more symmetrical, increase the radiation power, and ensure that part of the current passes through the area lacking it between the two leaves of the plant, a perforated flower was placed in the middle of the proposed design, as it achieved a better reflection coefficient from -13dB to -27 dB, indicating a good matching impedance, as shown in Fig. 3.

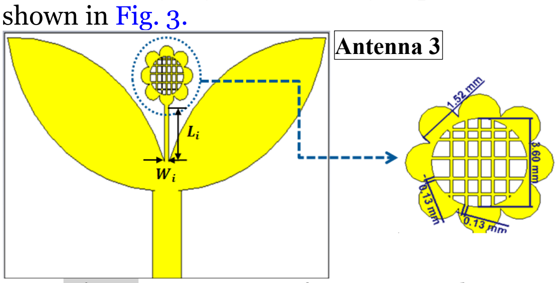


Fig. 3 Antenna Configuration with a Perforated Flower in the Middle.

2.3.Design Step III

A pair of identically sized elliptical openings (in the form of plant veins) were engraved on both plant leaves' surfaces to enhance the proposed antenna's performance. In addition, six circular holes with the same radius Rb of 0.2mm were sliced into the patch surface: four in the upper section and two in the lower section. The etching process was conducted according to the simulation's dimensions. The ultimate form of the proposed CPMA will resemble Fig. 4 (a) and (b).

2.4.Design Step IIII

The antenna was adjusted to 5.599 GHz by removing a portion of the ground length (L_g) and adjusting the parameter of the variable (L_{g1}). The ground plane was also engraved with a rectangular slot measuring (4.6×2) mm^2 to enhance the antenna's bandwidth and efficiency, as shown in Fig. 5.

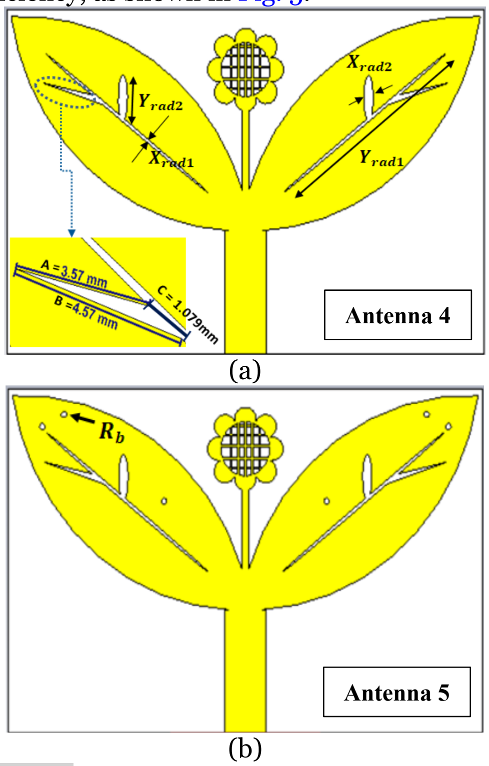


Fig. 4 (a) Elliptical Slots for the Proposed Antenna, (b) The Three Circular Holes are Distributed on Each Side of the Two Leaves of the Plant.

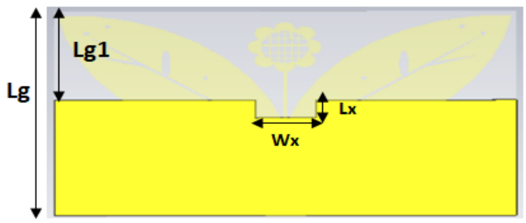


Fig. 5 Partial Ground Structure for the Proposed Antenna.

3.SIMULATION RESULTS AND DISCUSSION

CST simulation software is used to design and model the circular microstrip patch antenna. The present work focuses on performance enhancement and size reduction until the desired outcomes are achieved. The simulation results for (CMPA) are summarized in Table 2**.** The study looks at how well the suggested antenna works regarding its radiation pattern, gain, directivity, bandwidth, VSWR, return loss, and overall efficiency.

3.1.Return Loss

Due to an interruption in the transmission path or an impedance mismatch, return loss (s-parameter) is the amount of electromagnetic power reflected or returned. The following equations describe the correlation between return loss and the reflection coefficient:

$$\textbf{Return loss (RL)} = 10\log\left(\frac{P_r}{P_i}\right) \qquad (5)$$

where P_r = Reflected power
P_i = Incident power.

$$\mathbf{RL(dB)} = -20\,.\log(\gamma) \qquad \mathbf{(6)}$$

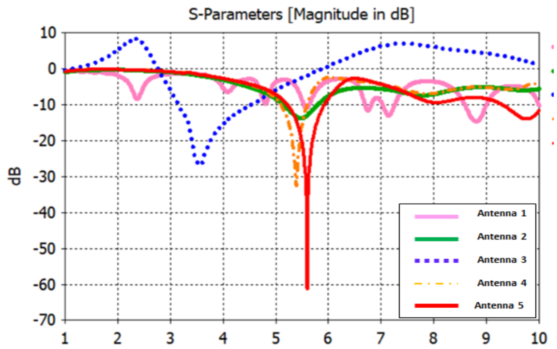
$$\text{where } \gamma = \frac{ZR-ZO}{ZR+ZO} \qquad \mathbf{(7)}$$

where γ refers to the reflection coefficient.
Z_R = Reflected impedance
Z_0 = characteristic impedance in ohms.

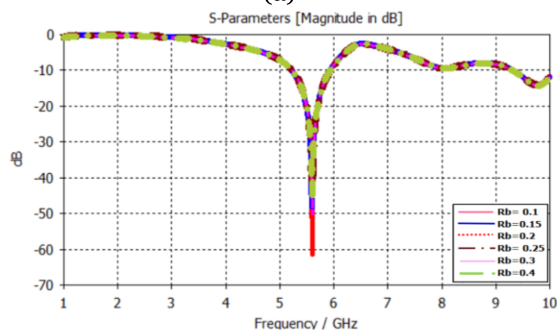
Figure 6 (a) depicts the simulation return loss for each design step. Return loss must be below (-10 dB) to obtain a successful radiation mode. The suggested antenna had a return loss of -61.38 dB at 5.599 GHz, indicating that the impedance match was improved, resulting in less energy loss. A parametric study was also performed using a parameter sweep when the R_b's circular hole radius differed. Thus, the value of R_b was chosen to be 0.2 mm to yield near-optimal impedance matching. The results of the return losses are shown in Fig. 6 (b).

3.2. Bandwidth

An antenna bandwidth is the frequency spectrum within which it can operate effectively. The designed antenna's bandwidth can be computed, as shown in Fig. 7. The proposed antenna was compatible with the 5.15-5.825 GHz WLAN frequency, as indicated by the estimated -10 dB impedance bandwidth of 724 MHz (from 5.2109 GHz to 5.9351 GHz).



(a)



(b)

Fig. 6 (a) S-Parameter Simulation for Each Design Step, (b) S-Parameter According to the Radius Circular Holes Rb.

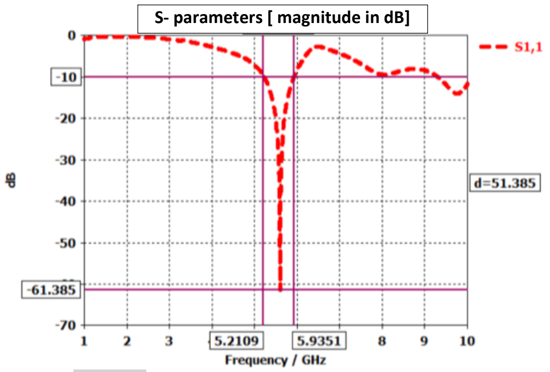


Fig. 7 Bandwidth of the Antenna.

3.3. Standing Wave Ratio (VSWR) of Voltage

The VSWR can be viewed as a measurement of the transmission line's disparity with the load. It is defined as "the maximum voltage to the minimum voltage at any given point." The VSWR is calculated using this equation.

$$\mathbf{VSWR} = \frac{V_{max}}{V_{min}} = \frac{1+\gamma}{1-\gamma} \qquad \mathbf{(8)}$$

(VSWR< 2) is a permissible value for a properly designed antenna. Figure 8 displays VSWR vs., at a resonance frequency of 5.599 GHz, the frequency plot of the proposed antenna manifests. VSWR had a value of 1.00017.

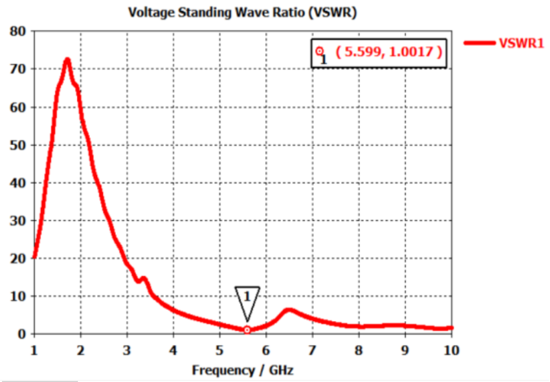


Fig. 8 The Proposed Antenna's VSWR Versus Frequency Plot.

3.4. Gain

Gain is the ability of an antenna to efficiently absorb incident power from a particular direction or, in the opposite case, to concentrate radiated power in that direction. Figure 9 depicts a 3D plot of the designed antenna's far-field gain, whose maximal value was estimated to be 2.031dB for an operating frequency of 5.599 GHz. Certainly, the proposed antenna was explicitly crafted for efficient performance in indoor areas like buildings, homes, offices, and similar environments. Indoor environments usually have less need for high gain, given that the distances to be covered are relatively short and within narrow spaces. Low gain helps reduce the possibility of signal overshoot and interference, especially in close proximity to other networks. Indoor antennas are often designed to be compact and inconspicuous to fit seamlessly into the indoor environment without being obtrusive.

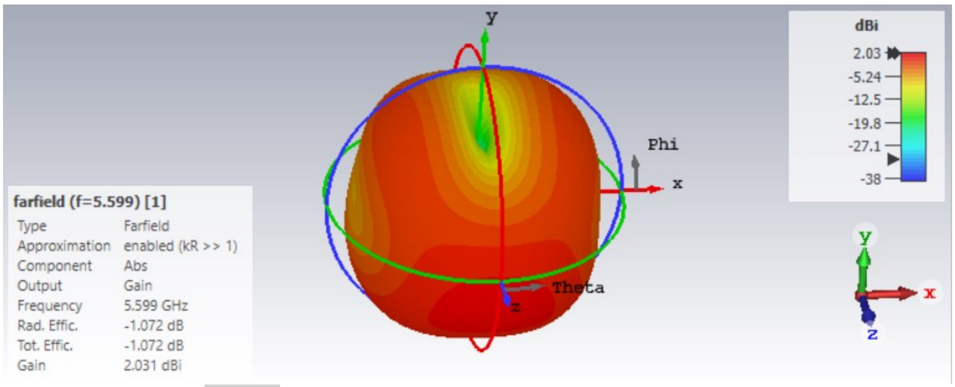


Fig. 9 3D plot of Far-Field Gain at 5.599 GHz.

3.5.Directivity

The directivity of an antenna measures the frequency at which it emits electricity in its preferred direction and is a numerical indication of an antenna's ability to focus energy in a specific direction as opposed to dispersing it over a wide angle range. Figure 10 depicts the 3D plot of the designed antenna's far-field directivity at its resonant frequency of 5.599 GHz. It was indicated that the maximal value of the antenna's directivity was 3.102 dB.

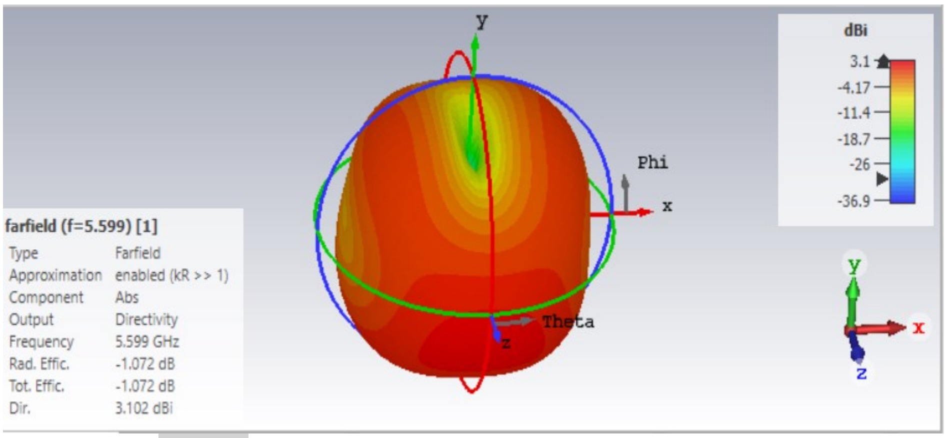


Fig. 10 3D Plot of Far-Field Directivity at 5.599 GHz.

It is clear from above that the proposed antenna has an excellent matching impedance, a low reflection coefficient, and a wide bandwidth. Therefore, the intended antenna sacrifices gain and directivity to achieve these other performance characteristics. The lack of gain and directivity in the proposed antenna can be attributed to several factors, including the small size of the antenna. Small single-patch antennas have fundamental limitations on their gain and directivity and are valuable in improving the efficiency of the antenna design. In addition, the structure of the antenna plays a role in its performance, and antenna improvement methods such as using a tool can help simulate the shape and arrangement of the radiation unit, the grounding unit, and the reflection unit, affecting the gain and direction of the antenna. The materials used in building the antenna can affect its performance. Considering these factors and using appropriate design techniques can improve the antenna's gain and directionality.

3.6.Overall Efficiency

The proportion of the antenna's provided energy to its radiated energy is known as antenna efficiency. Figure 11 depicts the total efficiency of the employed antenna versus frequency. At a resonance frequency of 5.599 GHz, the antenna efficiency peaked at around 78%.

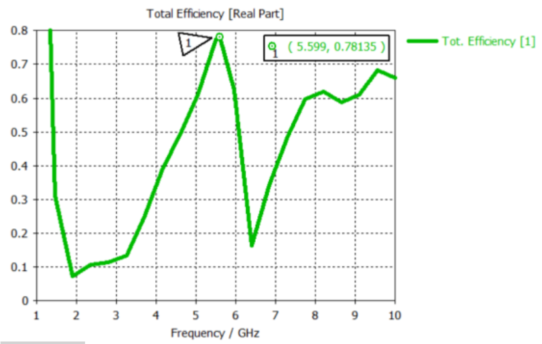


Fig. 11 Total Efficiency vs. Frequency Curve of the Proposed Antenna.

$$\text{Antenna efficiency} = \text{Gain} / \text{Directivity} \times 100\% \quad (10)$$

3.7.Surface Current Distribution

The distribution of surface current at an operating frequency of 5.599 GHz is shown in Fig. 12. According to the current value, the scale depicts the various hues arranged in descending order. The current distribution is more compatible in the regions highlighted in red than those highlighted in green, yellow, and shortly. Additionally, It can be seen that the highlight is centered in the area between the suggested form and the microstrip line.

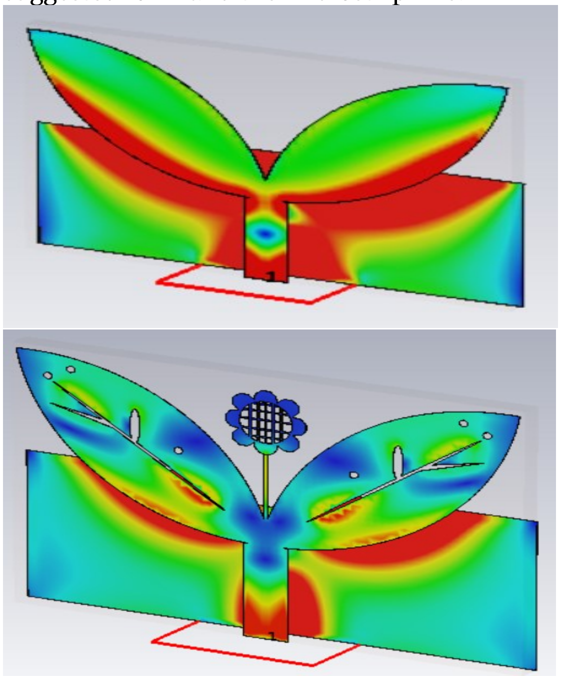


Fig. 12 The Surface Current Distributions of the Optimum Antenna Design.

3.8.Radiation Pattern

The antenna pattern, also known as the radiation pattern, represents the radiation's varying spatial characteristics. In other words, the antenna's pattern denotes how it transmits or receives energy into space and serves as a guide for the antenna's operation. The H-field and E-field designs are presented for consideration.

3.8.1.E-field Pattern

Figure 13 depicts the polar diagram of the proposed antenna's E-field pattern in the far-field at 5.599 GHz. The magnitude of the primary lobe was observed to be 16.8dB V/m, and its direction was 171 degrees.

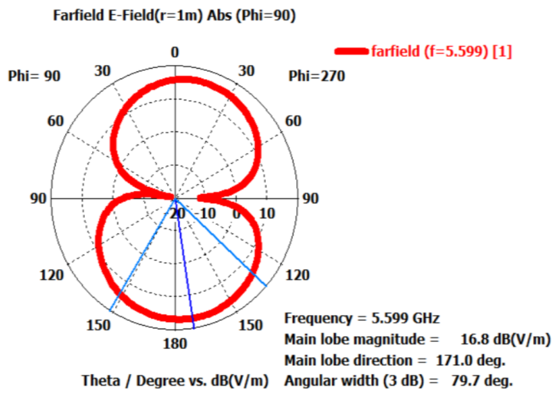


Fig. 13 The Far-field E-field Pattern in the Polar Plot at 5.599 GHz.

3.8.2.H-field Pattern

The polar diagram of the far-field H-field pattern of the suggested antenna at 5.59 GHz is shown in Figure 14. It was noticed that the significant lobe had a magnitude of -34.7 dB A/m and a direction of 171 degrees.

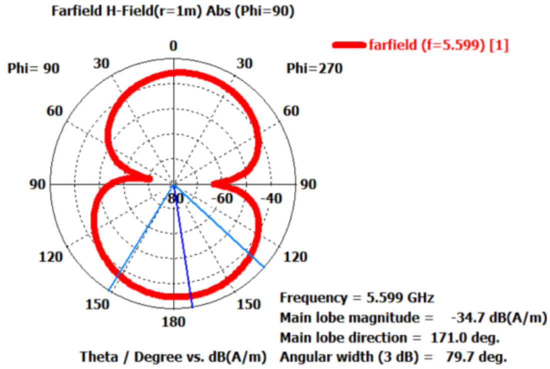


Fig. 14 The Far-field H-Field Pattern in the Polar Plot at 5.599 GHz.

As radiation is the primary function of any antenna, the radiation performances of the suggested antenna are a crucial metric to determine an antenna's performance. Proving that the antenna transmits over a sizable frequency range is the primary goal of the radiation pattern analysis. At the operating frequency of 5.599 GHz, the radiation pattern for the suggested antenna is displayed in Figs. 13 and 14. The E-plane, which includes the electric field, and the H-plane, which contains the magnetic field, are the two planes in which the radiation pattern is simulated. As depicted in the figures, the acquired results demonstrate that the suggested antenna exhibited a nearly bidirectional radiation pattern. Also, by examining the results obtained for the far-field directivity, it can be found that the proposed antenna showed similar results to the well-known $\lambda/2$ dipole antenna.

Finally, the simulation parameters for the suggested circular microstrip patch antenna with a compact construction are summarized in Table 2.

Table 2 Simulation Results of the Parameters of the Suggested Circular Microstrip Patch Antenna.

Parameter	Value
Resonance frequency	5.599 GHz
Return loss	-61.3845dB
Bandwidth	724MHz (from5.2109GHz to 5.9351GHz).
Gain	2.0307dBi
Directivity	3.1023 dBi
VSWR	1.0017
Realized gain	2.031dB
Total efficiency	about 78%
Impedance	50.83 Ω

The performance of the proposed antenna operating on a single frequency band was compared with some existing literature in WLAN applications. Table 3 presents a comparison of the proposed antenna with recent research works.

Table 3 Comparing the Proposed Work with Previously Published Works.

References	Overall Dimension (mm^3)	Operating Frequency (GHz)	Return Loss (dB)	Bandwidth (MHz)	VSWR
[24]	38 × 28 ×1	5.38	-53.189	200.6	1.0044
[25]	45 ×35 ×1.6	3.5	-29.77	233.2	1.0671
[26]	30 × 30 × 1.4	5.5	-31.57	701.9	1.054
[27]	60 × 60 × 1.6	2.4	-24.5996	90	1.188
[28]	80 × 80 × 1.59	2.36	-25.72	48	1.1092
The present work	35 × 23 × 1.6	5.599	-61.38	724	1.0017

4.CONCLUSIONS

A small circular microstrip patch antenna for WLAN applications that operates in the frequency range of (5.2109 GHz to 5.9351 GHz) is shown in this article. To decrease the size of the original antenna and increase the bandwidth, the patch shape was chosen to consist of two plant leaves with a perforated flower placed between these two leaves. To provide a perfect matching impedance, a rectangular slot measuring (4.6×2) mm^2 was etched on the partial ground plane, and six tiny circular holes with a radius of 0.2 mm were placed on the radiant patch. It results in a decreased reflection coefficient. The suggested antenna worked well at 5.599 GHz and has a broader frequency range (724 MHz), a low return loss of -61.384 dB, a gain of 2.03 dBi for a single patch, 3.1 dBi of directivity, and a high overall efficiency of nearly 78%. These parametric results indicated that the small-sized, well-performing circular microstrip patch antenna recommended for WLAN applications is suitable.

REFERENCES

[1] Indhuja NH, Sathiyapriya T, Gurunathan V, Monasri A, Sathish Kumar S, Selvaraj V. **Design of High Gain Compact Microstrip Patch Antenna at ISM Band.** *Journal of Nano- and Electronic Physics* 2023; **15**(4):04011.

[2] Tasona Doko J, Jocelyn T, Tanguy M, Jacques M, Yannick E, Jean-François D. **Dimensioning of Fixed Frequency Patch Antennas Based on Neural Networks.** *International Journal of Scientific Research and Management* 2022; **10**(4):862-870.

[3] Wei N, Huai-Zhi W, Kai-Da X, Yu-Quan L, Xiao-Long Y, Mu Z. **A Compact 4×4 Filtering Microstrip Patch Antenna Array with Dolph-Chebyshev Power Distribution.** *IEEE Open Journal of Antennas and Propagation* 2022; **3**:1057-1062.

[4] Jassim AK, Thaher RH. **Design and Analysis Microstrip Antenna with Reflector to Enhancement Gain for Wireless Communication.** *Bulletin of Electrical Engineering and Informatics* 2020; **9**(2):652-660.

[5] Uma T, Maheswari S, Peer Ahamed S. **Aperture Coupled Rectangular Microstrip Patch Antenna for S Band Applications.** *IOSR Journal of Electronics and Communication Engineering* 2017; **12**(3):31-39.

[6] Raghavendra K, Kakkar D. **Impact of Fractal Geometry on Microstrip Patch Antenna at Futuristic Frequencies.** *Recent Innovations in Computing: Proceedings of ICRIC* 2021; **1**:143-153.

[7] Sekhar MC, Meghana G, Varsha TS, Mohan KS, Reddy KV. **Design of Linearly Polarized Triangular Microstrip Patch Antenna for IoT Applications.** *Proceedings of the International Conference on Signal Processing, Computation, Electronics, Power and Telecommunication* 2023; 1-5.

[8] Rojas JM, Reyes-Ayala M, Andrade-Gonzalez EA, Chavez-Sanchez S, Terres-Peña H, Rodriguez-Rivera R. **2×1 Rectangular-Patch Antenna Array at 2.4 GHz.** *WSEAS Transactions on Communications* 2023; **22**: 49-57.

[9] Jassim AK, Thaher RH. **Calculate the Optimum Slot Area of the Elliptical Microstrip Antenna for Mobile Applications.** *Indonesian Journal of Electrical Engineering and Computer Science* 2019; **16**(3):1364-1370.

[10] Swarnkar SK, Tripathi AK, Ali Z. **Design of Irregular Diamond Shape Microstrip Patch Antenna with U Slot to Enhance Bandwidth for S Band Applications.** *International Journal of Innovative Science, Engineering & Technology* 2019; **6**(5):187-192.

[11] Hossain SD, Sobahan KMA, Al-Amin M. **A Circular Microstrip Patch Antenna to Operate in Dual Band for Wireless Communications.** *Journal of Physics: Conference Series* 2021; **1718**:012014.

[12] Nassir RB, Jassim AK. **Design of MIMO Antenna for Wireless Communication Applications.** *Journal of Engineering and Sustainable Development* 2022; **26**(4): 36-43.

[13] Lee H, Park YB. **Wideband Ring-Monopole Flexible Antenna with Stub for WLAN/C-Band/X-Band Applications.** *Applied Sciences* 2022; **12**:10717.

[14] Chen Y, Wang K, Li Y, Long Y. **Periodic Microstrip Leaky Wave Antenna with Double-Sided Shorting Pins and Pairs of Slots.** *International Journal of Antennas and Propagation* 2020; **2020**(1): 7101752, (1-9).

[15] Yan N, Song D, Luo Y, Ma K. **A Sequentially Rotated Feeding Circularly Polarized Stacked Patch Antenna Array Based on SISL.** *Wiley Journal* 2023; **65**(1):256-263.

[16] Ahmed Z, Muhammad A, Ihsan MB. **Improving the Side Lobe Level, Return Loss and Bandwidth of Notch-Loaded TM30 Mode Patch via Fractal-Slot.** *IEEE Access* 2022; **10**:19917-19924.

[17] Ali SH, Alfalahi AHR, Hachim YA. **A Miniaturized Compact Wideband Partial Ground Antenna Used in RFID Systems.** *Tikrit Journal of Engineering Sciences* 2020; **27**(2):40-45.

[18] Ayoob SA, Alsharbaty FS, Hammodat AN. **Design and Simulation of High Efficiency Rectangular Microstrip Patch Antenna Using Artificial Intelligence for 6G Era.** *Telkomnika* 2023; **21**(6):1234-1245.

[19] Hashim DH, Al-Tumah WAG. **Optimize the Performance of Slotted Circular Patch Antenna by Using Triangular Slots for C-Band Applications and Simulation It Using HFSS.** *AIP Conference Proceedings* 2023; **2845**:070006.

[20] Hannan M, Shanmuganantham T, Shahid M, Sindhanaiselvi D, Ashok Kumar S, Srihari G. **High Gain Multilayered Microstrip Patch Antenna for C Band Applications.** *International Journal of Microwave and Optical Technology* 2023; **18**(2):104-111.

[21] Bandi D, Sanjay SD, Triveni P, Deepika VN, Nikhil VKK, Sai VNS. **Design and Simulation of Ultra Wide and Narrow Band Antenna for C-Band and X-Band Applications.** *Anveshana's International Journal of Research in Engineering and Applied Sciences* 2022; 7(6): 46-49.

[22] Yema K, Salh MK. **Modified Sierpinski Gasket Patch Antenna for UMTS and 2.4/5.2 WLAN.** *Tikrit Journal of Engineering Sciences* 2013; **20**(1):42-50.

[23] Mukta C, Rahman M, Islam AZMT. **Design of a Compact Circular Microstrip Patch Antenna for WLAN Applications.** *International Journal on AdHoc Networking Systems* 2021; **11**(3): 1-11.

[24] Ridoy PM, Elme KM, Shihab R, Saha P, Al-Mursalin MJ, Alam N. **A Simple Design of Microstrip Patch Antenna for WLAN Application Using 5.4 GHz Band.** In: Liang, Q., Wang, W., Liu, X., Na, Z., Zhang, B. (eds) Communications, Signal Processing, and Systems. CSPS 2021. Lecture Notes in Electrical Engineering, vol 878. Springer, Singapore.

[25] Paragya D, Siswono H. **Rectangular Patch Microstrip Antenna with Defected Ground Structure for 5G.** *Elkomika* 2020; **8**(1):31-42.

[26] Mukta C, Rahman M, Islam AZMT. **Design of a Compact Circular Microstrip Patch Antenna for WLAN Applications.** *International Journal on AdHoc Networking Systems* 2021; **11**(3): 1-11.

[27] Ravikiran HK, Jayanth J, Pooja P, Nayana CS, Shreenidhi MA, Dhruva DB. **Gain Enhanced 2.4 GHz Slotted Rectangular Microstrip Patch Antenna With FR-4 Epoxy Substrate.** *Journal of Microwave Engineering & Technologies* 2023; **10**(1).

[28] Khidhir AH. **Implementation of a Circular Shape Patch Antenna at 2.4 GHz for Different Wireless Communications.** *Iraqi Journal of Science* 2023; **64**(1):205-214.