National Journal of Antennas and Propagation
Original Research
National Journal of Antennas and Propagation, ISSN: 2582-2659 Vol. 7, No. 1, 2025 (pp. 329-335)
WWW.ANTENNAJOURNAL.COM

Optimization of Bandwidth and Return Loss of Circular Microstrip Antennas with Circular Slots for IoT Communication

Rohim Aminullah Firdaus[1*], Ersyzario Edo Yunata[2], Safina Ayu Damayanti[1], Folin Oktafiani[3], Riski Ramadani[1]
[1]*Department of Physics, State University of Surabaya, Surabaya, Indonesia.*
[2]*Department of Physics, Faculty of Sciences and Technologies, Airlangga University, Surabaya, Indonesia.*
[3]*Research Center for Telecommunication, National Research and Innovation Agency, Bandung, Indonesia.*

KEYWORDS:
Circular Slot
Inset-Fed
Microstrip Antenna
Internet of Things
Parameter Optimization

ARTICLE HISTORY:
Received 10.07.2025
Revised 29.07.2025
Accepted 01.08.2025

DOI:
https://doi.org/10.31838/NJAP/07.01.36

Abstract

This study presents a circular microstrip antenna design for Internet of Things (IoT) applications, featuring integrated circular slots that enhance the performance of existing antennas, particularly in terms of bandwidth, return loss, and impedance matching. The main innovation in this design lies in the utilization of circular slots in the center of the patch, which differs from similar designs that typically use slots with other geometric shapes or conventional inset-fed methods. The addition of circular slots results in a more efficient current distribution, significantly reducing return loss to −38.7 dB and widening the bandwidth to 1.99 GHz, making this antenna highly suitable for IoT applications that require stable and efficient data communication at 2.4 GHz. The uniqueness of this design lies in its ability to optimize omnidirectional radiation characteristics through better impedance matching, as reflected in the very low VSWR value of 1.021. With the combination of inset-fed and circular slot techniques, this antenna demonstrates superior performance compared to conventional designs in terms of transmission efficiency and signal reception. This research highlights the significant potential for developing more efficient and effective microstrip antennas to support the rapidly growing IoT systems.

Author's e-mail: rohimfirdaus@unesa.ac.id; ersyzario.edo@fst.unair.ac.id; safinaayu.21011@mhs.unesa.ac.id; oktafiani@gmail.com; riski.20056@mhs.unesa.ac.id

Authors' Orcid ID: 0000-0002-1837-0961; 0000-0003-2465-7237; 0009-0003-4818-2157; 0000-0003-1562-1814; 0009-0001-1946-9517

How to cite this article: Rohim Aminullah Firdaus et al., Optimization of Bandwidth and Return Loss of Circular Microstrip Antennas with Circular Slots for IoT Communication, National Journal of Antennas and Propagation, Vol. 7, No. 1, 2025 (pp. 329-335).

Introduction

Internet of Things (IoT) is a rapidly growing technology that requires reliable, efficient, and compact antenna systems [1-3]. Antennas, as the main component in IoT systems, can efficiently transmit and receive data [4]. As time passes, the shift toward smaller and easier-to-install antennas is becoming increasingly pronounced, making integration into compatible communication technology more feasible [5-7,29]. A certain type of antenna with a compact size is the microstrip antenna [8,9,32]. However, current microstrip antenna designs are still limited because the resulting bandwidth is too narrow, necessitating additional techniques to overcome this issue [10,11,28].

Microstrip antennas are available in various shapes, including circular, rectangular, and square. Among these geometric shapes, circular antennas excel in bandwidth and radiation efficiency compared to the other two shapes; thus, they are often used for patch antennas [12,13]. However, patch antennas require improvements to meet specifications and enhance their efficiency. Many studies have developed circular antennas using inset-fed, array, and slot methods. First, circular antennas have been developed with the addition of inset-fed and T-slots, producing a frequency of 2.45 GHz, a return loss of 19 dB, and an omnidirectional radiation pattern [14,30].

A separate study presented a L element linked to the circular patch, yielding antenna specifications of a 2.4 GHz resonance, an impedance matching of 1.8, and a return loss of 16 dB [15]. Subsequent advancement employed the 1×2 array technique with a singular feedline, yielding a frequency of 2.4 GHz, a return loss of −11.7 dB, and an impedance matching of 1.7 [16]. Furthermore, numerous designs are yet to attain the ideal operating frequency of 2.4 GHz for IoT, accompanied by consistent radiation characteristics. Moreover, several researches have employed analogous designs utilizing a slot methodology, albeit with varying geometric configurations of the slots. A microstrip antenna including L-shaped slots was designed to enhance bandwidth at 2.4 GHz, although the return loss persisted at approximately −20 dB [17]. Another research has developed a circular microstrip antenna with a U-shaped slot on the patch antenna. The development of this antenna produces a working frequency of 2.4 GHz, but the antenna with the application of this U-lot is still not optimal because the electromagnetic distribution is not evenly distributed on the patch, and the resulting return loss is only −18 dB [18]. From the limitations that have been discussed, this study attempts to optimize the characteristics of a circular antenna with a circular slot that is rarely applied in previous studies. The application of a circular slot helps improve impedance matching and reduces reflection. This circular slot also has the characteristic of changing the current distribution on the patch surface evenly so that it produces a more stable radiation pattern in IoT applications. In addition to having characteristics to increase the efficiency of the radiation pattern, this antenna with a circular slot can also reduce return loss and expand bandwidth so that the proposed antenna has the potential to improve the IoT node network that is not achieved by array methods or other less optimal slot shapes.

Materials and Methods

This research on circular microstrip antennas for IoT applications focuses on improving the performance of the existing circular antennas by incorporating a circular slot in the center of the patch. The circular slot was chosen because it has the ability to increase the bandwidth and radiation efficiency of the antenna [19]. The circular slot is placed in the center of the patch with the aim of modifying the current distribution on the surface of the circular antenna, so that it becomes more even and has implications for reducing return loss and expanding the bandwidth of the antenna. In addition, the proposed antenna also applies a narrower inset feed dimension with the aim of directing a more even distribution throughout the patch, so that the current can reach the entire surface better and obtain higher impedance matching [20]. Meanwhile, in this study, the patch antenna was chosen with copper material because of its high electrical conductivity, so that it can minimize power loss, and current can flow efficiently [21]. Then, the substrate material used is FR-4 because it has a dielectric constant suitable for the frequency of 2.4 GHz f [22,31]. Figure 1A–C shows the proposed antenna design along with the components applied to the circular antenna. In addition, Table 1 shows more detailed dimensions of the circular antenna proposed in this study.

The data collection technique involves measurements using a vector network analyzer (VNA) to obtain characterization results for parameters such as return loss, bandwidth, gain, and VSWR. The radius of the circle (*a0*) is derived from the following equation [23].

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

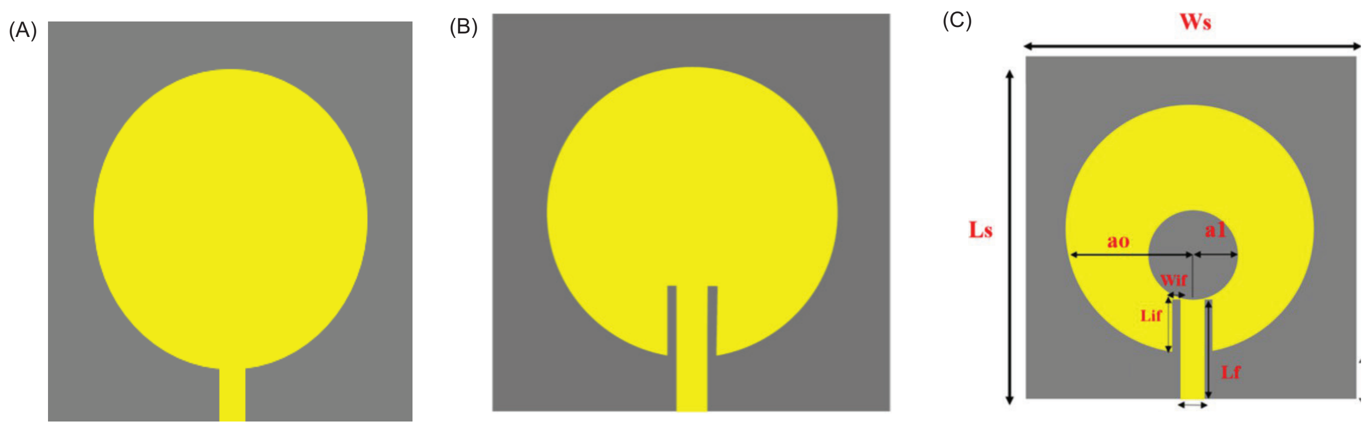

Fig. 1: Basic circular microstrip design (A), with inset-fed addition (B), and antenna with circular slot addition (C).

Table 1: The Size of the Proposed Antenna.

Dimension	Size (mm)	Dimension	Size (mm)
Ws	38.5	h	1.6
Ls	38.5	t	0.035
a0	14.32	Wf	3
a1	4,58	Lf	12.05
Wif	1	Lif	7

In Equation 1, there are elements of resonant frequency (F), substrate height (h), and substrate relative dielectric constant (ε_r) that affect antenna performance. The equation utilizes the constants π (pi) and the natural logarithm (*ln*) to account for geometric effects on the antenna. In addition, a constant of 1.7726 is applied to adjust the formula to match the experimental results [23]. The radius obtained from the equation is used to determine the optimal size of the antenna patch, allowing the antenna to operate at the resonant frequency of 2.4 GHz.

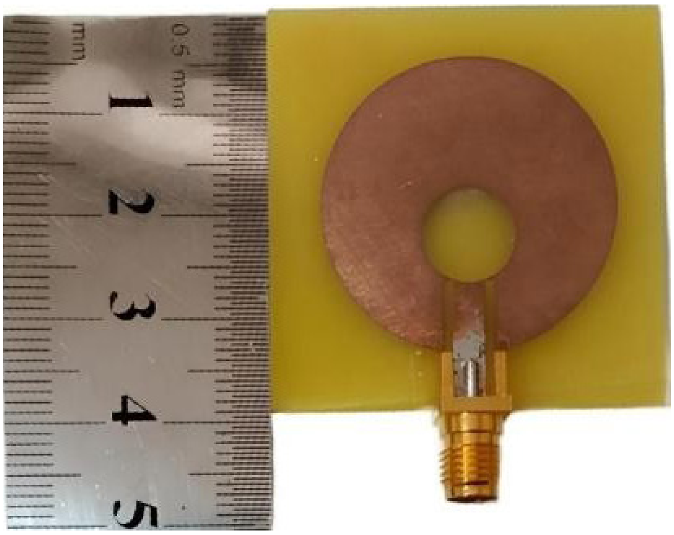

Fig. 2: Circular antenna fabrication incorporating circular and inset-fed slots.

Results and Discussion

The MPC antenna features a circular slot measuring 14.32 mm × 14.32 mm × 0.035 mm and antenna dimensions of 38.5 mm × 38.5 mm × 1.6 mm. It incorporates circular and inset-fed slots, as successfully fabricated and illustrated in Figure 2.

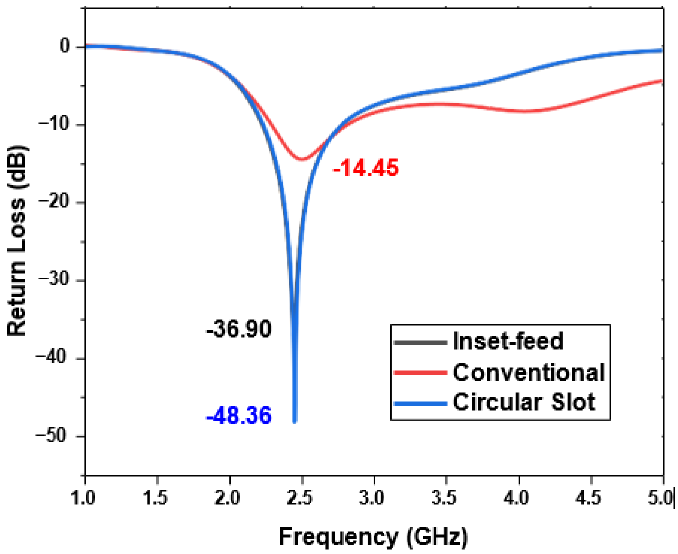

Fig. 3: Effect of Inset-feed, Conventional, and Circular Slot treatments on the circular antenna.

In Figure 3, it is evident that the inclusion of circular slots in the antenna design can enhance bandwidth and improve return loss values. This is reflected in the significant increase in return loss values from −48.36 dB in the conventional design to −14.45 dB in the design with circular slots. In addition, the previous circular antenna widely applied the inset feed method, which was able to reduce the return loss value to −36.90 dB. The addition of circular slots, in combination with an inset feed, resulted in improved antenna characteristics, with a return loss of −48.36 dB. This improvement indicates a decrease in reflection, suggesting that more power is absorbed or emitted by the antenna rather than being reflected. The addition of these slots functions as a capacitive element, creating a gap and allowing charge accumulation on both sides of the slot. As a result, capacitance increases, lowering the resonance frequency and widening the antenna's bandwidth.

In addition, the graph shows that the slot position affects the resonance frequency. When the slot position is shifted from 1 mm to 2.7 mm from the center, the current path length increases, resulting in a decrease in the resonance frequency to 2.4 GHz. Conversely, with a slot position of 1 mm, the current path is shorter, resulting in a resonance frequency of 2.7 GHz. The inset feed used also contributes to an increase in the return loss value, leading to improved efficiency of the transmitted power. Overall, the addition of circular slots and the change in slot position result in an antenna design with improved return loss characteristics.

The measurement of the return loss value of the proposed antenna is −38.7 dB at a frequency of 2.40 GHz, as shown in Figure 4. This return loss value indicates that the power transmitted to the antenna is used efficiently because its reflection power is minimal. In addition, the return loss of the antenna designed in this study produces a smaller value than the existing circular antenna, thus proving that the proposed antenna has succeeded in improving the characteristics of the existing antenna. The reduction in the return loss value of this antenna is also caused by the addition of a circular slot on the patch that changes the distribution of the electric field along the patch surface, thereby improving the antenna performance. However, in the simulation results and actual measurements, there are differences in the characterization results, where the return loss of the simulation results is lower at the same frequency. The deviation that occurs in the actual measurement and simulation is caused by the presence of electromagnetic interference in the surrounding area that cannot be avoided [22]. However, the deviation that occurs in the measurement is not too far from the simulation, and the return loss value is still superior to the previous conventional antenna.

Furthermore, Figure 4 also presents the bandwidth measurements of the antenna designed with a circular slot. Observing both low and high frequencies, the bandwidth of this antenna is 1.99 GHz for a working frequency of 2.4 GHz. The bandwidth characteristics of this antenna are greater than those of previously developed antennas. This indicates that the addition of the circular slot contributes significantly to increasing bandwidth by reducing return losses. The circular slots act as capacitive elements, expanding the frequency range that can be efficiently transmitted, thereby allowing more energy to be received and transmitted by the antenna. However, deviations between simulation results and characterization are attributed to environmental factors, such as electromagnetic interference, which can impact antenna performance in real-world testing.

The measured VSWR value from the measurement results is 1.021, as shown in Figure 5. The impedance matching results of the proposed antenna are lower than those of previous studies that applied the inset-fed method, which achieved a VSWR value of only 1.7. This study utilized circular slots to enhance impedance matching in the inset-fed design, enabling the measured VSWR value to reach 1.021, which is lower than that reported in previous studies. In addition, simulation results show higher VSWR values compared to actual measurements, with values around 1.063 at the same frequency, as shown in Figure 5. Several factors may explain these differences, such as electromagnetic interference from the surrounding environment during the measurement process, which cannot be accounted for in simulations conducted under ideal conditions. The second factor is differences in testing conditions. Measurements were performed using a VNA in an environment that was not entirely free of obstacles (i.e., anechoic), which could cause interference that affected the measurement results [24]. In spite of the differences, the deviation between the measured and simulated VSWR values is slight, and the antenna design still demonstrates better overall performance, with significantly lower VSWR measurements compared to previous studies.

Furthermore, Figure 6 shows a comparison of the radiation patterns between the simulation results and the measurement results of the proposed antenna. In general, both show similar main radiation directions,

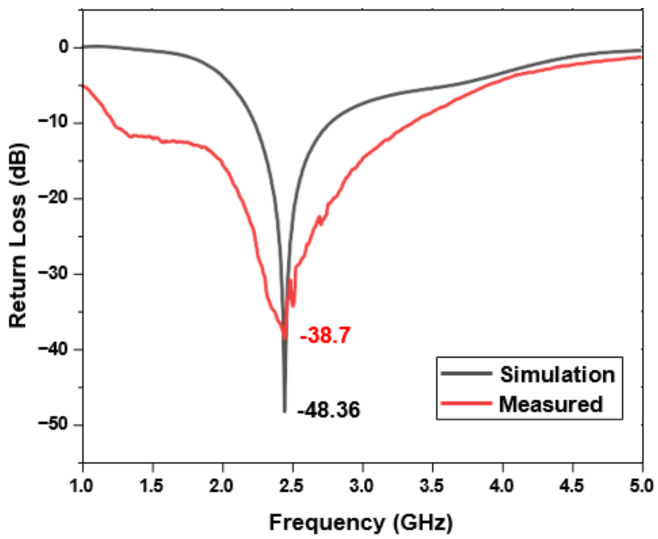

Fig. 4: Return loss of the antenna that has been measured with vector network analyzer.

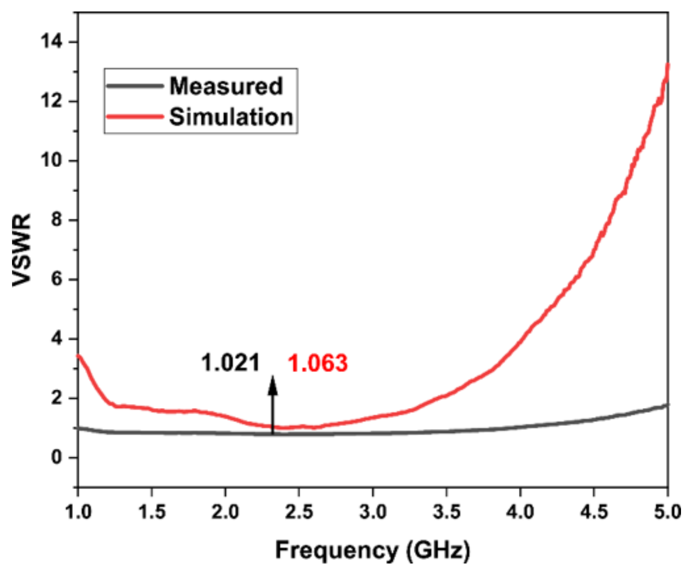

Fig. 5: VSWR characterization results.

namely, perpendicular to the antenna surface (broadside), indicating that the simulation model accurately represents the actual characteristics of the antenna. Some differences are observed at angles around 0° and 180°, which are caused by electromagnetic interference from the surrounding environment during the measurement process and the limitations of ideal free space (anechoic) conditions [25–27].

The radiation pattern of the proposed antenna exhibits similarities to those of circular microstrip patch antennas with slots, as reported in the existing literature. This similarity is particularly evident in the main radiation direction and power distribution patterns in the E and H planes, as presented in Table 2. However, the significant advantage of this antenna lies in its higher gain value compared to antennas with a slot configuration on a circular patch. This indicates that the proposed antenna not only maintains omnidirectional radiation characteristics but also offers better radiation efficiency. Therefore, this antenna is highly suitable for application in IoT systems, which require uniform signal coverage with sufficient gain to ensure reliable data transmission.

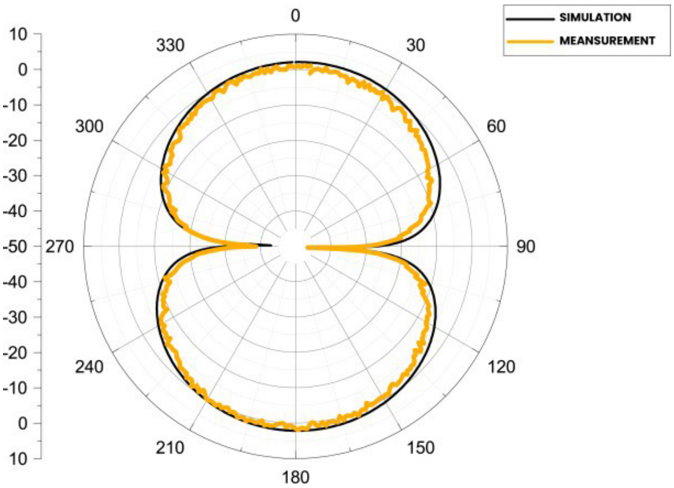

Fig. 6: Radiation pattern of the antenna with the addition of a circular slot and inset feeding.

Table 2 compares the results of the proposed circular slot MPC antenna with previous studies. This antenna demonstrates superior performance in terms of return loss, bandwidth, VSWR, gain, and radiation pattern.

Table 2 shows a comparison of the characteristic results of the proposed antenna with existing circular antennas and demonstrates superior performance. The proposed antenna operates at a frequency of 2.40 GHz, which is the primary frequency for IoT applications such as Wi-Fi and Bluetooth. In this case, this operating frequency is highly suitable for supporting wireless communication in IoT devices that require high data transmission efficiency. One of the main advantages of this antenna is its very low VSWR value of 1.021, indicating nearly perfect impedance matching. This result indicates that the proposed antenna has high efficiency in transmitting signals and minimizing reflected power, a critical factor in reducing power loss and improving overall system efficiency, especially in IoT applications that rely on short-range communication and require power savings. The designed antenna exhibits a minimum return loss of −38.7 dB, indicating excellent power transmission efficiency. Low return loss indicates that the power absorbed by the antenna and transferred to the environment is greater than that reflected. This is beneficial for IoT applications that require reliable and efficient data transmission. The antenna exhibits a significant gain of 2,351 dBi, which improves signal quality and extends the communication range. This high gain performance facilitates more reliable and optimal wireless connections, essential for IoT devices that frequently operate in environments with significant interference or a large number of connected devices. The antenna has a bandwidth of 1.56 GHz, far exceeding current antenna designs. This increased bandwidth provides substantial benefits in IoT applications, facilitating the antenna's

Table 2: Comparison of this Research with Previous Publications.

Ref	Frequency (GHz)	VSWR	Return Loss (dB)	Gain (dBi)	Bandwidth (GHz)	Radiation Pattern
[17]	2.40	1.8	−16	-	0.05	Omnidirectional
[16]	2.45	-	−19	-	0.114	Omnidirectional
[19]	2.4	−1.2964	−17.78	-	0.11	Directional
[20]	2.4	>2	≤10	-	0.300	Omnidirectional
[22]	2.45	-	−28	-	0.066	Omnidirectional
[18]	2.40	1.7	−11.7	-	0.208	Omnidirectional
[23]	2.40	-	−23.11	-	-	Omnidirectional
This work	2.40	1.021	−38.7	2.351	1.56	Omnidirectional

capacity to handle increased data and enabling more devices to communicate over a wider range without experiencing interference or signal degradation. The antenna produces an omnidirectional radiation pattern, allowing it to transmit and receive signals uniformly in all directions. This attribute is well-suited for IoT applications that require uniform signal coverage across an area, especially in sensor networks or decentralized IoT device communication systems. The proposed antenna is well-suited for IoT systems, as it meets various performance criteria critical for these applications. Its small dimensions and superior efficiency make it optimal for integration into IoT devices with limited form factors. Microstrip antennas, characterized by their compact dimensions and lightweight construction, facilitate their implementation in many IoT devices, including wireless sensors and wearable technologies, which require small-sized and optimally performing antennas. Furthermore, the antenna's technical specifications—which include superior impedance matching, low return loss, high gain, and wide bandwidth—ensure reliable and efficient data transmission between IoT devices. In IoT environments, characterized by multiple devices connected simultaneously, this antenna improves connection reliability through superior signal transmission and reception efficiency.

Conclusion

This research has developed an antenna fabrication with a circular design equipped with a circular slot for IoT applications. From the characterization carried out, the proposed antenna design is able to reduce the return loss value smaller than the existing antenna, which reaches −38.7 dB. In addition, the resulting bandwidth becomes wider around 1.99 GHz, and the VSWR value becomes very low to 1.021. The results of the antenna proposed in this study are able to improve upon the characteristics of the previous antenna by implementing a circular slot in the middle of the patch. This effectively ensures that the current is distributed more evenly on the patch in the antenna because it deflects the current to the left and right sides of the patch, thereby increasing radiation efficiency and performance stability at 2.4 GHz. In addition, it is also known that the combination of inset-fed antenna techniques and circular slots is able to produce an omnidirectional radiation pattern with a large gain. From the results obtained, the circular antenna with a circular slot and inset feed is able to improve the characteristics of other conventional antennas and offers superior performance in terms of return loss, VSWR, bandwidth, and gain, so that it has great potential for IoT applications that require capable connectivity to communicate with device nodes.

References

1. Xu, J., Yao, J., Wang, L., Ming, Z., Wu, K., & Chen, L. (2018). Narrowband Internet of Things: Evolutions, technologies, and open Issues. IEEE Internet of Things Journal, 5(3), 1449–1462. https://doi.org/10.1109/JIOT.2017.27833 74
2. Khan, M. U., Sharawi, M. S., & Mittra, R. (2015). Microstrip patch antenna miniaturization techniques: A review. IET Microwaves, Antennas & Propagation, 9(9), 913–922. https://doi.org/10.1049/iet-ap.2014.0602
3. Shafique, K., Khawaja, B. A., Sabir, F., Qazi, S., & Mustaqim, M. (2020). Internet of Things (IoT) for next-generation smart systems: A review of current challenges, future trends and prospects for emerging 5G-IoT scenarios. IEEE Access, 8, 23022–23040. https://doi.org/10.1109/ACCESS.2020.2 970118
4. Hassan, A., Nizam-uddin, N., Quddus, A., Hassan, S. R., Bharany, S., Rehman, A. U., & Hussen, S. (2025). Designs strategies and performance of IoT antennas: A comprehensive review. Discover Computing, 28(1), 39. https://doi.org/10.1007/s10791-025- 09536-y
5. Long, W., Chen, R., Moretti, M., Zhang, W., & Li, J. (2021). A promising technology for 6G wireless networks: intelligent reflecting surface. Journal of Communications and Information Networks, 6(1), 1–16. https://doi.org/10.23919/JCIN.2021.9387 701
6. Mazhar, T., Malik, M. A., Haq, I., Rozeela, I., Ullah, I., Khan, M. A., Adhikari, D., Ben Othman, M. T., & Hamam, H. (2022). The role of ML, AI and 5G technology in smart energy and smart building management. Electronics, 11(23), 3960. https://doi.org/10.3390/electronics11233 960
7. Alimi, I. A., Patel, R. K., Muga, N. J., Pinto, A. N., Teixeira, A. L., & Monteiro, P. P. (2021). Towards enhanced mobile broadband communications: A tutorial on enabling technologies, design considerations, and prospects of 5G and beyond fixed wireless access networks. Applied Sciences, 11(21), 10427. https://doi.org/10.3390/app112110427
8. Shandal, S., Mezaal, Y. S., Kadim, M., & Mosleh, M. (2018). New compact wideband microstrip antenna for wireless applications. Advanced Electromagnetics, 7(4), 85-92. https://doi.org/10.7716/aem.v7i4.860
9. Ezzulddin, S. K., Hasan, S. O., & Ameen, M. M. (2022). Microstrip patch antenna design, simulation and fabrication for 5G applications. Simulation Modelling Practice and Theory, 116, 102497. https://doi.org/10.1016/j.simpat.2022.102 497
10. Yahya, M. S., Soeung, S., Abdul Rahim, S. K., Musa, U., Ba Hashwan, S. S., Yunusa, Z., & Hamzah, S. A. (2024). LoRa microstrip patch antenna: A comprehensive review. Alexandria Engineering Journal, 103, 197–221. https://doi.org/10.1016/j.aej.2024.06.017
11. Ghewari, P., & Patil, V. (2025). Advancements in microstrip patch antenna design using nature-inspired metaheuristic optimization algorithms: A systematic review. Archives of Computational Methods in Engineering. https://doi.org/10.1007/s11831-025- 10254-3
12. Azam, F., Shah, S. I. H., Bashir, S., & Koziel, S. (2024). Review of recent advancement on nature/bio-inspired

antenna designs. IEEE Access, 12, 37493–37512. https://doi.org/10.1109/ACCESS.2024.3 372864

13. Hafeez, S. A., Malathi, K., & Sathesh, M. (2024). Design and analysis of novel rectangle shape microstrip patch antenna to minimize the return loss in comparison with circular microstrip patch antenna. AIP Conference, 020166. https://doi.org/10.1063/5.0198474
14. Tengli, A. C., & Hadalgi, P. M. (2018). Design of inset-fed quad-band circular microstrip antenna for 2.4/5 GHz WLAN, WiMAX and X-band satellite applications. AIP Conference, 030021. https://doi.org/10.1063/1.5047739
15. Yuwono, R., & Syakura, R. (2015). 2.4 GHz circularly polarized microstrip antenna for RFID application. Advanced Computer and Communication Engineering Technology, 10(2), 37–42. https://doi.org/10.1007/978-3-319- 07674-4_4
16. Shanthi, P., Shah, Yashvi Mehul, & Siddharoodha, C. A. (2019). Design and analysis of 1x2 circular patch antenna array for 2.4 GHz applications. International Journal of Recent Technology and Engineering (IJRTE), 8(4), 463–466. https://doi.org/10.35940/ijrte.D7005.118 419
17. Husna Khouser, G., & Choukiker, Y. K. (2018). Cross polarization reduction in patch antenna using DGS. 2018 IEEE Indian Conference on Antennas and Propogation (InCAP), 1–2. https://doi.org/10.1109/INCAP.2018.877 0959
18. Khalifa, F. E. I., Ibrahim, A. A., Ibrahim, M. Z., Fathalrahman, M. M., & Alhassan, M. A. (2018). Design of dual-band microstrip antenna with U-shaped slot. International Journal of Engineering Trends and Technology, 55(1), 35–40. https://doi.org/10.14445/22315381/IJET T-V55P208
19. Jeun-Wen Wu, & Jui-Han Lu. (n.d.). Slotted circular microstrip antenna for bandwidth enhancement. IEEE Antennas and Propagation Society International Symposium. Digest. Conjunction with: USNC/CNC/URSI North American Radio Sci. Meeting (Cat. No.03CH37450), 272– 275. https://doi.org/10.1109/APS.2003.12192 30
20. Sharma, I. B., Jha, C. S. G., Sharma, M. M., Garg, J., Karla, B., & Srimal, S. (2021). A design of multiband simple microstrip patch antenna by using inset-feed. 2021 IEEE Indian Conference on Antennas and Propagation (InCAP), 194–197. https://doi.org/10.1109/InCAP52216.202 1.9726194
21. Vinay Kota, S. S., Bonam, V. S., Kumar, S., & Kumar, R. (2022). Microstrip patch antenna using coconut coir substrate and its comparison with FR4 based antenna. 2022 2nd International Conference on Intelligent Technologies (CONIT), 1–5. https://doi.org/10.1109/CONIT55038.20 22.9848397
22. Al-Gburi, A. J. A., Ismail, M. M., Mohammed, N. J., Buragohain, A., & Alhassoon, K. (2024). Electrical conductivity and morphological observation of hybrid filler: Silver-graphene oxide nanocomposites for wearable antenna. Optical Materials, 148, 114882. https://doi.org/10.1016/j.optmat.2024.11 4882
23. Balanis, C. A. (2005). *Antenna Theory Analysis And Design Third Edition (3rd Ed.)*. Wiley.
24. Hubrechsen, A., Remley, K. A., Jones, R. D., Williams, D. F., Gu, D., Smolders, A. B., & Bronckers, L. A. (2021). The effect of noise on reverberation-chamber measurements of antenna efficiency. IEEE Transactions on Antennas and Propagation, 69(12), 8744–8752. https://doi.org/10.1109/TAP.2021.30838 22
25. Hofmann, W., Bornkessel, C., & Hein, M. A. (2018). Influence of electrically large structures on the EMC-compliance of a semi-anechoic chamber. 2018 IEEE *MTT-S International Conference on Microwaves for Intelligent Mobility (ICMIM)*, 1–4. https://doi.org/10.1109/ICMIM.2018.844 3499
26. Bainsla, A., Singh, P., & Sahoo, G. (2020). A dual band slotted circular microstrip patch antenna for bluetooth and commercial WLAN applications. SSRN Electronic Journal, 433–438. https://doi.org/10.2139/ssrn.3546463
27. Kingsuwannaphong, T., & Sittakul, V. (2016). Compact circular polarization microstrip antenna. 2016 International Conference on Communication and Signal Processing (ICCSP), 0862–0865. https://doi.org/10.1109/ICCSP.2016.775 4269
28. Sadulla, S. (2025). IoT-enabled smart buildings: A sustainable approach for energy management. National Journal of Electrical Electronics and Automation Technologies, 1(1), 14–23.
29. Velliangiri, A. (2025). An edge-aware signal processing framework for structural health monitoring in IoT sensor networks. National Journal of Signal and Image Processing, 1(1), 18–25.
30. Karthika, J. (2024). Integration of RF energy harvesting modules in IoT nodes for sustainable wireless communication. National Journal of RF Circuits and Wireless Systems, 1(2), 47–55.
31. Suguna, T., Ranjan, R., Sai Suneel, A., Raja Rajeswari, V., Janaki Rani, M., & Singh, R. (2024). VLSI-Based MED-MEC architecture for enhanced IoT wireless sensor networks. Journal of VLSI Circuits and Systems, 6(2), 99–106. https://doi.org/10.31838/jvcs/06.02.11
32. Ismail, N., & Al-Khafajiy, N. (2025). Comprehensive review of cybersecurity challenges in the age of IoT. Innovative Reviews in Engineering and Science, 3(1), 41–48. https://doi.org/10.31838/INES/03.01.06