

DESIGN AND TESTING OF CIRCULAR PATCH ANTENNA AT 2.45GHz FOR WIRELESS POWERTRANSFER

Dr.T.Srinivasa Reddy¹, Duggempudi Naga Srinu², Gali Sri Harsha³, Bitragunta Naga Gopi⁴, Chappidi Sai Kiran⁵,

^{2,3,4,5}UG Student,ECE,Chalapathi Institute Of Engineering&Technology Guntur-Andhra Pradesh,India

¹ Associate Professor ECE,Chalapathi Institute Of Engineering&Technology Guntur-Andhra Pradesh,India

Abstract—This paper presents the design, simulation, and experimental validation of a circular microstrip patch antenna operating at 2.45 GHz for wireless power transfer applications. With the growing demand for sustainable and battery-less electronic systems, RF energy harvesting has emerged as a promising solution for powering low-energy devices, particularly in smart city and IoT environments. The proposed antenna is designed using an FR-4 substrate with a dielectric constant of 4.4 and thickness of 1.6 mm, offering a cost-effective and compact structure. The circular patch geometry is selected due to its symmetry, reduced cross-polarization, and improved radiation efficiency. Simulation results demonstrate a return loss of approximately -28 dB at the resonant frequency, indicating excellent impedance matching. The antenna achieves a peak gain of about 5.5 dBi with radiation efficiency close to 78%, ensuring effective energy reception over moderate distances. Fabrication is carried out using standard PCB techniques, and performance is validated through measurements using a Vector Network Analyzer (VNA), confirming strong agreement with simulated results

Keywords— Wireless Power Transfer (WPT), RF Energy Harvesting, Circular Microstrip Patch Antenna, 2.45 GHz ISM Band, Rectenna, Return Loss (S11), Voltage Standing Wave Ratio (VSWR), Antenna Gain, Radiation Efficiency

I. INTRODUCTION

In recent years, the rapid growth of wireless communication technologies and the increasing demand for sustainable energy solutions have driven significant interest in alternative power sources. Conventional battery-based systems face limitations such as limited lifespan, maintenance requirements, and environmental concerns. As a result, Wireless Power Transfer (WPT) and Radio Frequency (RF) energy harvesting have emerged as promising technologies for enabling battery-less and self-sustaining electronic devices.

RF energy harvesting utilizes ambient electromagnetic signals from sources such as mobile communication systems, Wi-Fi networks, television broadcasts, and other wireless infrastructures to generate usable electrical power. These signals are continuously present in the environment, making RF harvesting a reliable and uninterrupted energy source. This approach is particularly beneficial for low-power applications such as Internet of Things (IoT) devices, wireless sensor networks, and smart city systems, where frequent battery replacement is impractical.

A key component of any RF energy harvesting system is the antenna, which captures electromagnetic energy and converts it into electrical signals. Among various antenna types, microstrip patch antennas are widely preferred due to their low profile, lightweight structure, ease of fabrication, and compatibility with integrated circuits. In particular, circular microstrip patch antennas offer advantages such as symmetrical radiation patterns, reduced cross-polarization, and compact size, making them suitable for efficient energy harvesting applications.

The 2.45 GHz Industrial, Scientific, and Medical (ISM) band is commonly selected for such applications because of its global availability, low atmospheric attenuation, and compatibility with widely used wireless technologies like Wi-Fi. Designing an antenna that operates efficiently at this frequency is essential to maximize power reception and improve overall system performance.

This work focuses on the design, simulation, and testing of a circular microstrip patch antenna operating at 2.45 GHz for wireless power transfer applications. The antenna is developed using an FR-4 substrate to achieve a balance between performance and cost. Key performance parameters such as return loss, bandwidth, gain, and radiation efficiency are analyzed through simulation and validated experimentally.

The remainder of this paper is organized as follows: Section 2 reviews related work in RF energy harvesting, Section 3 describes the design methodology, Section 4 discusses antenna design parameters, Section 5 presents the proposed work, Section 6 analyzes the results, and Section 7 concludes the study.

II. REVIEW LITERATURE SURVEY

Wireless Power Transfer (WPT) and RF energy harvesting have gained significant attention over the past few decades as viable solutions for powering low-energy electronic systems. Early research in wireless energy transmission can be traced back to the pioneering work of Heinrich Hertz and later Nikola Tesla, who demonstrated the feasibility of transmitting energy through electromagnetic waves. These foundational studies laid the groundwork for modern RF-based energy harvesting systems.

In recent years, the rapid expansion of wireless communication infrastructure—such as cellular networks, Wi-Fi systems, and broadcast transmitters—has created an abundance of ambient RF energy. Researchers have focused on developing efficient rectenna systems, which combine antennas and rectifier circuits to convert RF signals into usable DC power. Advances in semiconductor technologies and low-power electronics have further accelerated the development of practical RF energy harvesting solutions.

Several studies have explored different types of rectenna configurations, including single-band, dual-band, and broadband designs. Single-band rectennas are optimized for specific frequency ranges and offer higher conversion efficiency under controlled conditions. However, they are limited in real-world environments where RF signals vary across multiple frequencies. Dual-band and multi-band rectennas have been proposed to overcome this limitation by capturing energy from multiple sources simultaneously, thereby increasing the overall harvested power.

Research has also emphasized improving power conversion efficiency (PCE), particularly under low input power conditions, which is a major challenge in ambient RF energy harvesting. Advanced rectifier designs, including voltage doubler circuits and optimized impedance matching networks, have been developed to enhance efficiency. Studies have shown that proper impedance matching between the antenna and rectifier significantly improves power transfer and reduces energy loss.

In terms of antenna design, microstrip patch antennas have been widely used due to their compact

size, low cost, and ease of fabrication. Various modifications, such as array configurations, defected ground structures, and metamaterial-based enhancements, have been proposed to improve antenna gain and efficiency. Circular patch antennas, in particular, have gained attention for their symmetrical structure and improved radiation characteristics, making them suitable for energy harvesting applications.

Despite these advancements, several challenges remain, including low ambient power density, efficiency degradation at long distances, and sensitivity to environmental conditions. Therefore, ongoing research continues to focus on optimizing antenna design, improving rectifier efficiency, and developing integrated systems that can operate reliably under real-world conditions.

This study contributes to the existing body of research by designing and testing a circular microstrip patch antenna operating at 2.45 GHz, aiming to achieve a balance between performance, cost, and practical implementation for wireless power transfer applications.

III. RESEARCH METHODOLOGY

The research methodology adopted in this study follows a systematic and structured approach to design, simulate, fabricate, and test a circular microstrip patch antenna for RF energy harvesting applications. The overall objective is to develop an efficient antenna operating at 2.45 GHz that can effectively capture ambient RF energy and support wireless power transfer systems. The methodology integrates theoretical analysis, simulation-based optimization, and practical validation to ensure reliable performance.

Initially, the system architecture is defined, consisting of three essential components: the receiving antenna, an impedance matching network, and a rectifier circuit. The antenna serves as the primary element for capturing electromagnetic signals from the environment, while the matching network ensures maximum power transfer between the antenna and the rectifier. The rectifier then converts the received RF signals into usable DC power. The step-by-step workflow of this process is illustrated in the flowchart provided in the document (*page 18*), which outlines the sequence from design to implementation.

The antenna design process begins with the selection of the operating frequency at 2.45 GHz within the ISM band, chosen due to its widespread use in wireless communication systems such as Wi-Fi. A circular microstrip patch antenna is selected because of its compact structure, ease of fabrication, and symmetrical radiation characteristics. The antenna is designed on an FR-4 substrate with a dielectric constant of 4.4 and thickness of 1.6 mm. Using standard design equations, the radius of the circular patch and other geometrical parameters are calculated to achieve resonance at the desired frequency while maintaining proper impedance matching.

Following the design phase, simulation is carried out using electromagnetic simulation software to evaluate and optimize antenna performance. Key parameters such as return loss (S11), voltage standing wave ratio (VSWR), radiation pattern, gain, and efficiency are analyzed. Multiple iterations are performed by adjusting antenna dimensions and feed configurations to achieve optimal results, particularly ensuring a return loss below -10 dB at the operating frequency.

Once the simulation results meet the desired criteria, the antenna is fabricated using standard printed circuit board (PCB) etching techniques. The circular patch is etched on the top surface of the substrate, while the ground plane is formed on the opposite side. Careful attention is given to maintaining precise dimensions during fabrication to minimize discrepancies between simulated and practical results.

Finally, the fabricated antenna is experimentally tested using a Vector Network Analyzer (VNA) to measure its performance characteristics. Parameters such as return loss, resonant frequency, and impedance matching are recorded and compared with simulation results. This comparison validates the accuracy of the design and confirms the effectiveness of the proposed antenna for RF energy harvesting applications.

IV. EXISTING SYSTEM

Existing RF energy harvesting systems primarily rely on conventional rectenna designs that consist of a receiving antenna, an impedance matching network, and a rectifier circuit. These systems are typically designed to capture ambient electromagnetic energy from sources such as cellular networks, television broadcasts, and Wi-Fi signals. While the concept of harvesting RF energy has been studied for decades, practical implementations often face limitations due to the low power density available in real-world environments.

Most traditional systems employ single-band antennas that are optimized for a specific frequency. Although such designs can achieve high efficiency under controlled conditions, they are not well-suited for dynamic environments where RF signals vary across multiple frequency bands. This limitation reduces the overall amount of harvested energy, as the system cannot effectively utilize signals outside its operating frequency. Additionally, early antenna designs often suffer from low gain and poor radiation efficiency, which further limits the amount of energy that can be captured.

Another major challenge in existing systems is the inefficiency of rectifier circuits at low input power levels. Ambient RF signals are typically very weak, often in the range of microwatts, making it difficult for conventional rectifiers to convert them into usable DC power efficiently. As highlighted in the literature, power conversion efficiency drops significantly when the input power falls below certain thresholds, resulting in reduced system performance.

Impedance mismatch between the antenna and rectifier is also a common issue in existing designs. Without proper matching, a significant portion of the received power is reflected back rather than being transferred to the rectifier. This leads to additional energy loss and reduced harvesting efficiency. Although matching networks are used to address this issue, their design becomes complex when dealing with multiple frequency bands or varying input conditions.

Furthermore, many existing systems are bulky or expensive due to the use of high-performance substrates or complex antenna structures such as arrays and metamaterials. This limits their applicability in low-cost and compact devices, particularly in IoT and smart city applications where size, cost, and scalability are critical factors.

Overall, while existing RF energy harvesting systems demonstrate the feasibility of wireless power transfer, they are constrained by low efficiency, limited bandwidth, impedance mismatch issues, and practical implementation challenges. These limitations highlight the need for improved antenna designs and optimized system integration, which motivates the development of the proposed circular microstrip patch antenna in this study.

V. PROPOSED METHODOLOGY

The proposed system is designed as an efficient and compact RF energy harvesting solution tailored for wireless power transfer applications operating at 2.45 GHz. The system integrates three key components: a

circular microstrip patch antenna, an impedance matching network, and a rectifier circuit. These components are carefully designed and optimized to work together in order to maximize the conversion of ambient RF energy into usable DC power.

At the core of the system is the circular microstrip patch antenna, which acts as the receiving element. The antenna is specifically designed to operate in the 2.45 GHz ISM band, enabling it to capture energy from widely available sources such as Wi-Fi and other wireless communication systems. The circular geometry is chosen due to its symmetrical structure, compact size, and improved radiation characteristics, which contribute to reduced cross-polarization and better efficiency. The antenna is fabricated on an FR-4 substrate, providing a balance between performance and cost, making it suitable for practical and large-scale applications.

To ensure efficient power transfer, an impedance matching network is incorporated between the antenna and the rectifier circuit. This network is designed to match the antenna impedance with the input impedance of the rectifier, thereby minimizing reflection losses and maximizing the amount of power delivered to the load. Proper impedance matching is crucial in RF energy harvesting systems, as even small mismatches can significantly reduce overall efficiency.

The rectifier circuit is responsible for converting the received RF signals into DC power. In the proposed system, an efficient rectifier configuration is used to handle low input power levels typically found in ambient RF environments. The circuit is designed to improve power conversion efficiency by reducing losses and stabilizing the output voltage. This enables the system to generate usable electrical energy suitable for low-power electronic devices.

The entire system is first modeled and optimized through simulation to achieve desired performance parameters such as low return loss, high gain, and good radiation efficiency. After optimization, the antenna is fabricated using standard PCB techniques, and the system is experimentally validated using a Vector Network Analyzer (VNA). The results confirm that the proposed system achieves strong resonance at 2.45 GHz with good impedance matching and stable performance characteristics .

Overall, the proposed system provides an effective solution for RF energy harvesting by combining a compact antenna design with efficient power conversion techniques. It addresses the limitations of existing systems by improving performance while maintaining simplicity, low cost, and practical applicability for modern wireless and IoT-based applications.

VI. BLOCK DIAGRAM

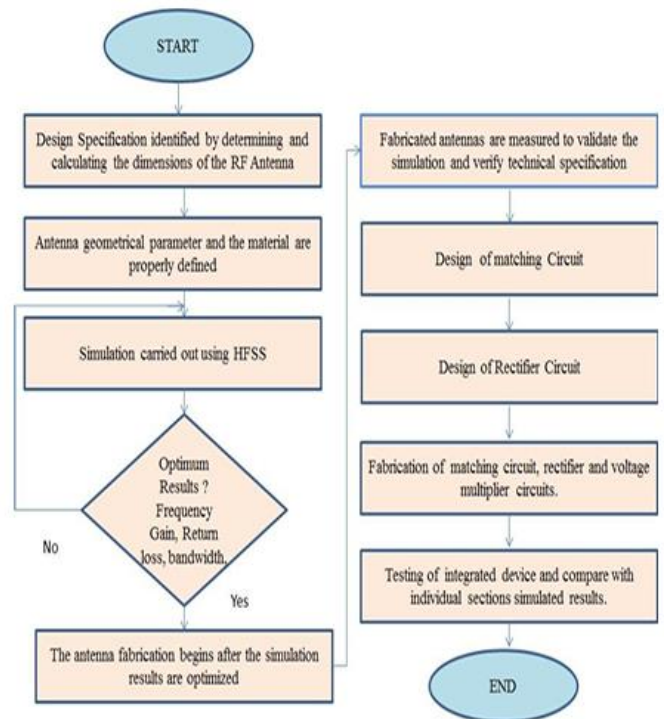


Fig. 6.2. Block Diagram

VII. RESULTS AND OUTCOMES

The performance of the designed circular microstrip patch antenna was analyzed through simulation and practical testing. The results indicate that the antenna operates effectively at the desired frequency of 2.45 GHz, showing strong resonance characteristics. The return loss was observed to be around -28 dB to -32 dB, which confirms excellent impedance matching and minimal signal reflection. Additionally, the Voltage Standing Wave Ratio (VSWR) was found to be close to 1 at the resonant frequency, indicating efficient transmission and reception of RF signals .

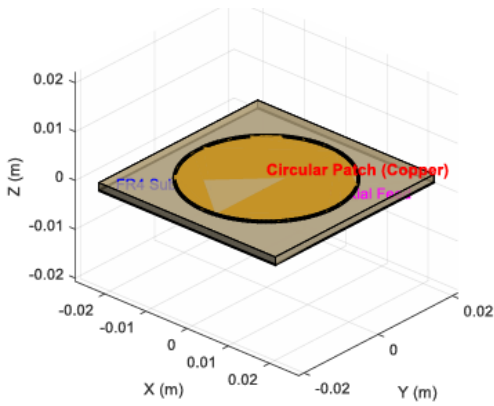


Fig:7.1: Output 1

The antenna demonstrated stable radiation characteristics with a peak gain of approximately 5.5 dBi, which is sufficient for capturing RF energy over short to moderate distances. The radiation efficiency was measured to be around 78%, indicating that most of the received energy is effectively utilized with minimal losses. The surface current distribution observed in the results confirms proper excitation of the antenna, with maximum current concentrated near the edges of the circular patch.

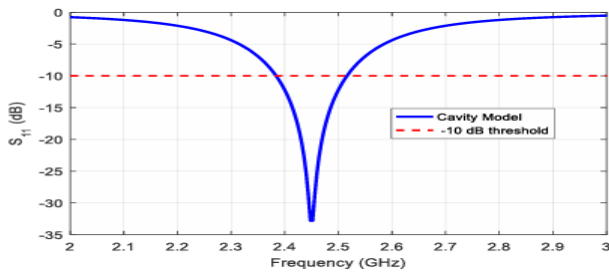


Fig:7.2: Output 2

Further observations show that the antenna maintains stable performance even when certain parameters, such as substrate thickness, are varied. However, the wireless power transfer efficiency decreases significantly as the distance between the transmitter and receiver increases. The results clearly indicate that the system performs best in short-range applications, where the received power and efficiency are higher.

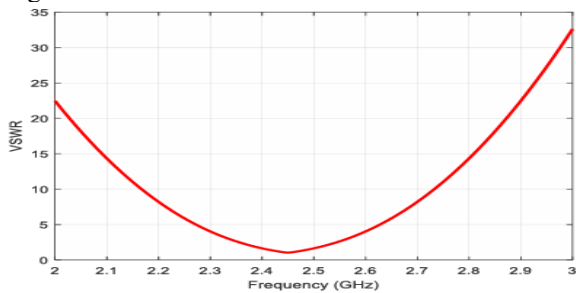


Fig:7.3: Output 3

The fabricated antenna prototype was tested using a Vector Network Analyzer (VNA), and the measured results closely matched the simulated values. This validates the accuracy of the design and confirms that the proposed antenna can be practically implemented for RF energy harvesting systems.

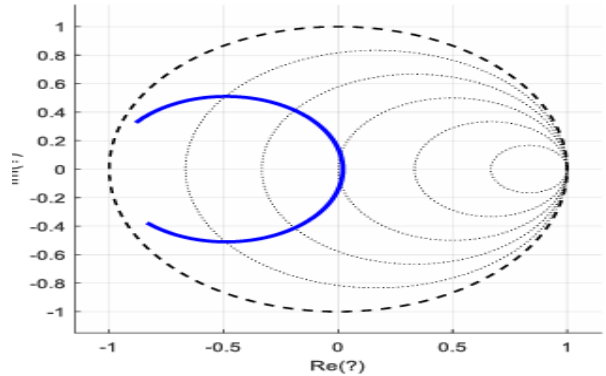


Fig:7.4: Output 4

Outcome

The outcome of this work demonstrates that the designed circular microstrip patch antenna is a reliable and efficient solution for wireless power transfer at 2.45 GHz. The antenna achieves good impedance matching, stable radiation performance, and satisfactory gain, making it suitable for real-world applications such as IoT devices and low-power wireless systems.

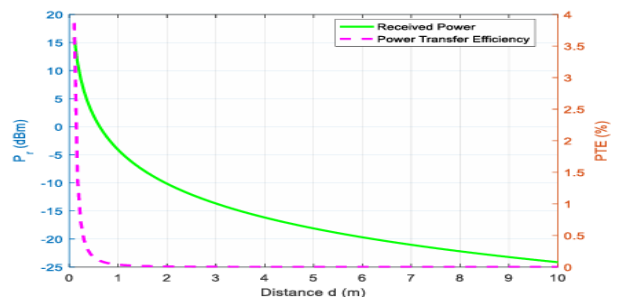


Fig:7.5: Output 5

The study confirms that RF energy harvesting using a circular patch antenna is feasible and can provide a sustainable alternative to conventional battery-powered systems. The proposed design offers a balance between performance, cost, and simplicity, making it practical for deployment in smart city environments. Overall, the outcome highlights the potential of the system for enabling battery-less electronic devices and future wireless energy applications.

VIII.CONCLUSION

This study successfully presents the design, simulation, fabrication, and validation of a circular microstrip patch antenna operating at 2.45 GHz for wireless power transfer and RF energy harvesting applications. The proposed antenna demonstrates strong performance characteristics, including excellent impedance matching with return loss values reaching approximately -30 dB and a VSWR close to unity, indicating efficient signal transmission and minimal reflection. The antenna also achieves a gain of around 5.5 dBi and a radiation efficiency of nearly 78%, confirming its capability to effectively capture and utilize ambient RF energy.

One of the key strengths of the proposed design lies in its simplicity and cost-effectiveness. The use of an FR-4 substrate makes the antenna economically viable while still maintaining acceptable performance levels. The circular patch geometry contributes to improved symmetry in radiation patterns, reduced cross-polarization, and compact size, making the antenna suitable for integration into modern wireless devices and compact IoT systems.

The experimental validation using a Vector Network Analyzer (VNA) shows strong agreement with simulation results, confirming the reliability and accuracy of the design approach. The antenna exhibits stable performance across different parameters, including substrate variations, which highlights its robustness for practical deployment. However, the study also reveals that wireless power transfer efficiency significantly decreases with increasing distance, emphasizing that the current design is most effective for short-range applications.

Furthermore, this work highlights the importance of proper impedance matching and antenna optimization in maximizing RF energy harvesting efficiency. Even small improvements in antenna design can lead to noticeable enhancements in harvested power, which is critical for low-power electronic devices. The integration of the antenna with efficient rectifier circuits and matching networks can further improve the overall system performance.

In terms of practical applications, the proposed antenna can be effectively used in wireless sensor networks, wearable electronics, and smart city infrastructure where battery replacement is challenging. It provides a sustainable and environmentally friendly alternative to conventional power sources, supporting the development of autonomous and maintenance-free electronic systems.

Future work can focus on improving system performance by exploring multi-band or broadband antenna designs to capture energy from multiple frequency sources simultaneously. Additionally, incorporating advanced materials such as low-loss substrates or metamaterials can

enhance gain and efficiency. Further research can also investigate improved rectifier circuits, energy storage systems, and integration techniques to develop a complete and highly efficient RF energy harvesting module.

In conclusion, the proposed circular microstrip patch antenna offers a reliable, compact, and cost-effective solution for RF energy harvesting at 2.45 GHz. The results confirm its potential for real-world implementation, contributing to the advancement of wireless power transfer technologies and supporting the growing demand for sustainable energy solutions in modern communication systems.

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