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RF Energy Harvesting For Charging Low Power Device's

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ABSTRACT

The increasing demand for portable and autonomous electronic systems has created a need for sustainable power sources that do not rely on frequent battery replacement. Energy available in the form of surrounding radio waves can be utilized as a source for powering small-scale electronic systems by converting it into electrical form. In this work, a method is developed to capture such signals and process them into a usable output suitable for low-energy devices like sensor nodes and IoT-based units.

The implemented setup combines a planar antenna structure with intermediate circuitry that conditions the received signal before it undergoes conversion into direct current. The antenna is adjusted to operate near the 2.4 GHz band, which is commonly present in everyday wireless environments. Observations from simulation indicate that the structure is capable of receiving available signals effectively, and the subsequent conversion stage delivers a stable electrical output that can be used for practical low-power applications. Although the harvested energy is limited, the proposed system demonstrates the feasibility of battery-free operation for low-power applications and highlights the potential of RF energy harvesting in future self-sustaining electronic systems.

I.INTRODUCTION

Modern electronic devices, especially low-power systems such as wireless sensors and IoT nodes, typically depend on chemical batteries for operation. While batteries provide convenience and portability, they suffer from limited lifespan and require periodic replacement or recharging. This becomes a significant challenge in applications where devices are deployed in remote, hazardous, or inaccessible environments. In addition, battery disposal contributes to environmental pollution due to the presence of toxic materials.

RF energy harvesting involves capturing electromagnetic waves present in the environment and converting them into usable DC power. Unlike solar or wind energy, RF signals are available both indoors and outdoors, making them suitable for continuous operation. However, the energy levels available from ambient RF sources are typically very low, which makes efficient energy conversion a key challenge.

This project focuses on designing an RF energy harvesting system capable of converting weak ambient signals into usable electrical energy for powering low-power devices. The goal is to improve energy conversion efficiency while maintaining a compact and practical design.

II. LITERATURE SURVEY

Several research works have been carried out in the field of RF energy harvesting to improve efficiency and applicability. Arinze et al. (2025) discussed different antenna structures such as dipole, monopole, fractal, and microstrip antennas operating across multiple frequency bands including 2.4 GHz and millimeter-wave ranges. Their work emphasized the importance of antenna design in improving energy capture, although efficiency under real-world conditions remains a challenge. The IEEE OJAP Special Section (2022) introduced advanced antenna designs including metamaterial-based structures and beam-steering arrays for multi-band and 5G applications. These designs provide improved flexibility and compactness but lack practical implementation details. Jigna et al. (2022) compared RF energy harvesting with other techniques such as solar and vibration-based systems, concluding that RF harvesting offers continuous availability but relatively lower efficiency. Similarly, Ozel et al. (2020) explored RF energy harvesting in wireless sensor networks and highlighted the benefits of hybrid energy systems, while also pointing out challenges in energy management. Furthermore, recent studies on IoT-based RF harvesting systems have focused on compact antenna design and improved rectifier performance. However, limitations such as low output power and dependency on ambient RF signals continue to restrict practical deployment.

III. PROBLEM DEFINATION

In today's world, the number of low-power electronic devices such as wireless sensors, IoT modules, and portable systems is increasing rapidly. Most of these devices depend on batteries for their operation, which have limited lifespans and require periodic replacement or recharging. This creates challenges in terms of maintenance, cost, and environmental impact, especially for devices placed in remote or inaccessible locations. At the same time, there is a vast amount of radio frequency (RF) energy freely available in the environment from sources like Wi-Fi routers, cellular towers, FM radio, and television transmitters.

The objective of this work is to build a system that can make use of weak radio frequency signals already present in the surroundings and transform them into a usable form of electrical energy. A key difficulty in achieving this lies in the very low strength of the available signals, which makes it challenging to obtain a meaningful output using conventional conversion methods, especially within the power range of –10 dBm to –30 dBm.

To overcome this limitation, the proposed design combines different functional stages, including a signal-receiving antenna, an intermediate stage for improving signal transfer, and a rectification unit based on a Schottky diode. The intention is to enhance the overall conversion process so that even small amounts of captured energy can be utilized effectively, enabling the operation of compact electronic devices without dependence on traditional battery sources.

IV. PROPOSED SOLUTION

The proposed system is developed to utilize low-intensity RF signals available in the surrounding environment and convert them into useful electrical energy. The overall operation involves multiple stages that work together to achieve energy conversion suitable for low-power devices.

Initially, electromagnetic signals present in the environment are captured using an antenna. These signals are then conditioned through a matching network to improve energy transfer and reduce losses. The processed signal is further applied to a rectification stage where it is converted into a DC form. The obtained DC output is then stored using appropriate storage elements and can be used to power small electronic devices such as sensors or indicator LEDs.

As shown in Fig. 1, the RF energy harvesting system consists of antenna, matching network, rectifier, and energy storage unit.

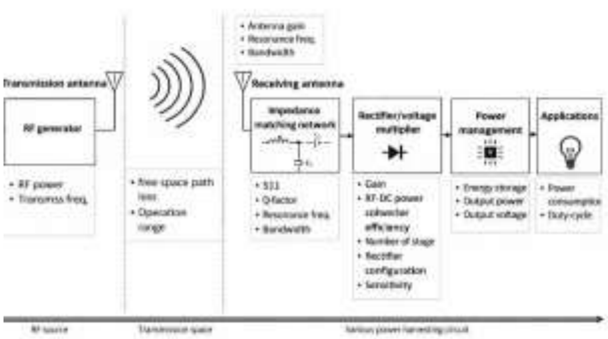

Fig. 1: Block Diagram of RF Energy Harvesting System [9]

V. ANTENNA SIMULATION &DESIGN USING HFSS

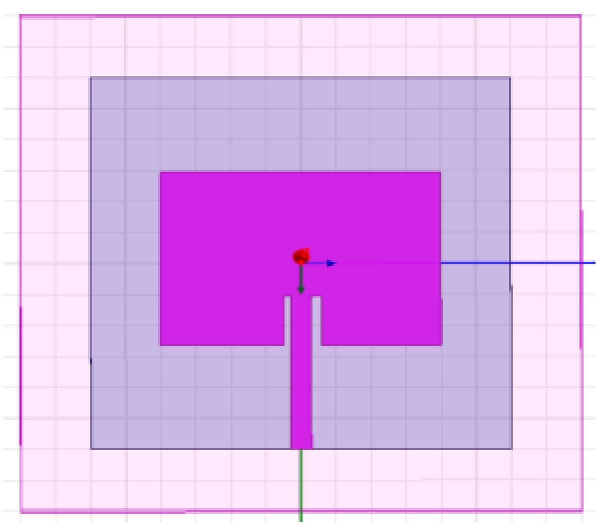

Fig. 2: Rectangular Microstrip Patch Antenna

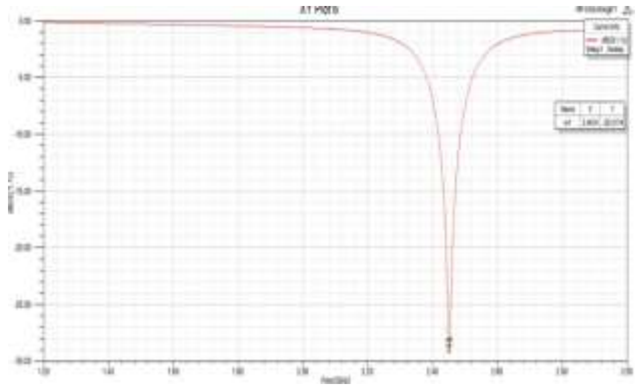

Fig. 3: S-Parameter (S11) Plot

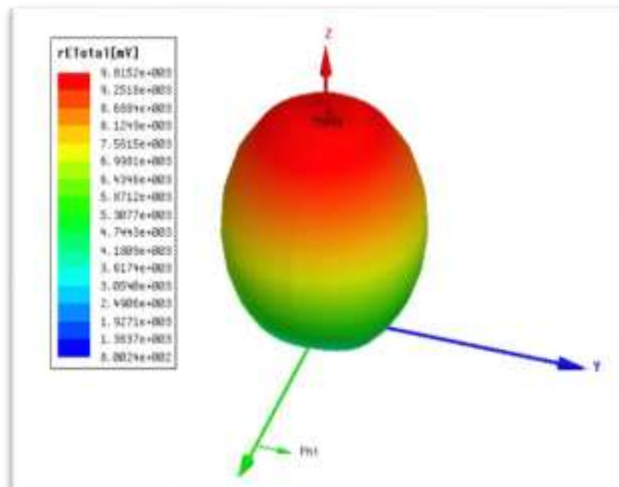

Fig. 4: 3D Radiation Pattern

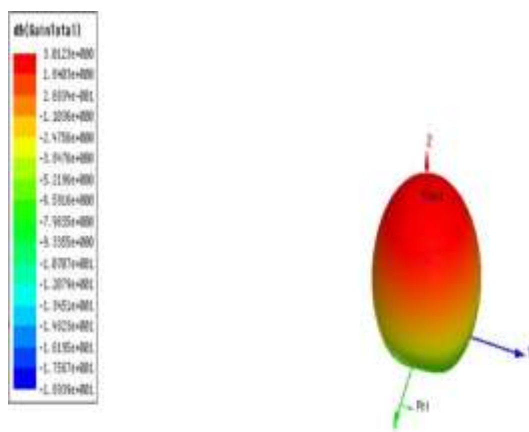

Fig. 5: 3D Gain Plot

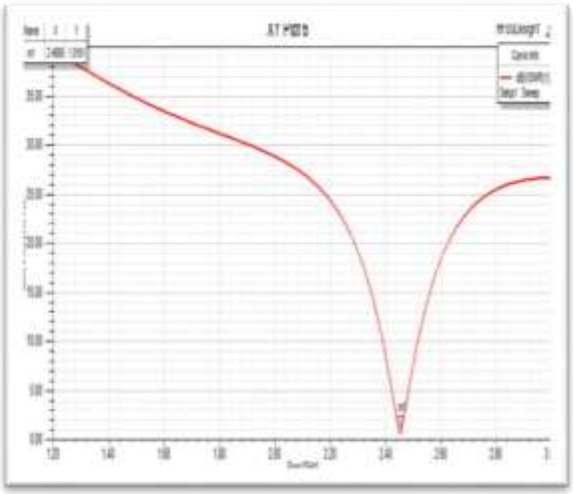

Fig. 6: VSWR Plot

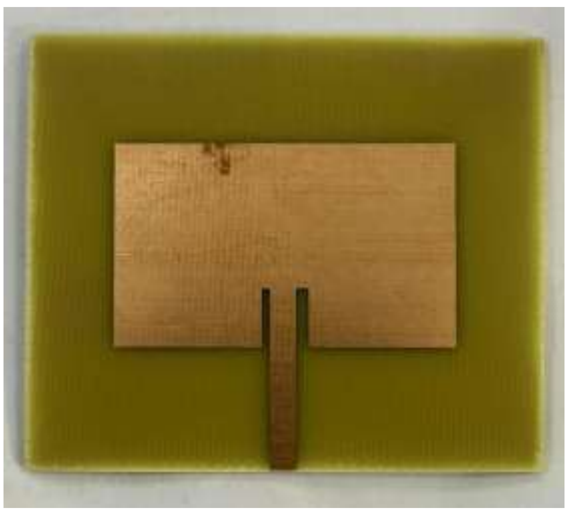

Fig. 7: Fabricated Microstrip Patch Antenna

A microstrip-based antenna structure was developed and analyzed using ANSYS HFSS with the intention of operating around the 2.4 GHz frequency range. The design is implemented on an FR4 substrate having a dielectric constant of 4.4 and a thickness of 1.6 mm, making it suitable for compact wirelessapplications.Simulation observations indicate that the antenna is effectively tuned near the intended frequency, where the reflected portion of the signal is minimal, allowing most of the incoming energy to be utilized by the structure. The behavior of the standing wave parameter also remains close to an ideal value, which suggests that the interaction between the antenna and the feeding arrangement is well balanced with minimal mismatch.Further more,theantenna demonstrates a stable radiation behavior with adequate gain characteristics, enabling it to receive low-power signals present in the environment. These characteristics indicate that the designed antenna is capable of functioning effectively in RF energy harvesting applications.

VI. PARAMETERS VALUE

Category	Parameter	Value	Unit
Substrate	Material	FR4 Epoxy	-
Substrate	Dielectric Constant (εr)	4.4	-
Substrate	Thickness	1.6	mm
Patch	Patch Length (L)	29.7	mm
Patch	Patch Width (W)	40	mm
Patch	Copper Thickness	0.035	mm
Array	Number of Patches	1	-
Array	Patch Spacing	60	mm
Feed	Feed Line Width	3	mm
Feed	Impedance	50	Ohm
Air Box	Size (X,Y,Z)	180 x 180 x 80	mm
Simulation	Resonant Frequency	2.4	GHz

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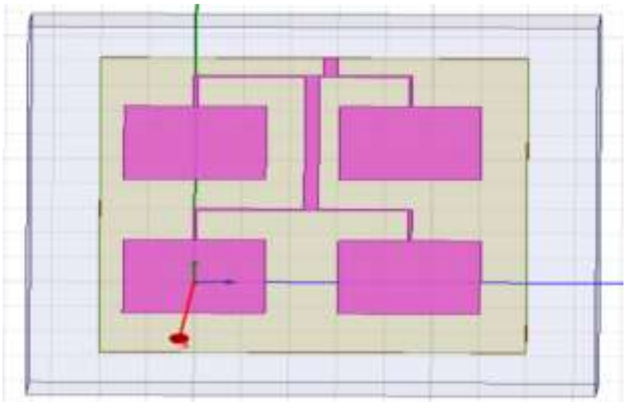

Fig. 8: 2x2Microstrip Patch Antenna

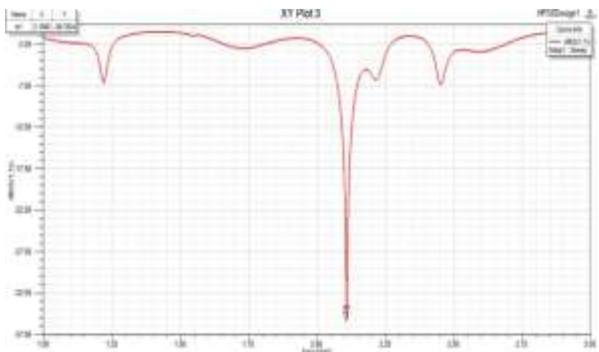

Fig. 9: S-Parameter (S11) Plot

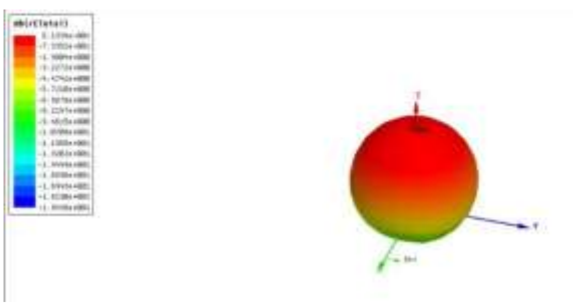

Fig. 10: 3D Radiation Pattern

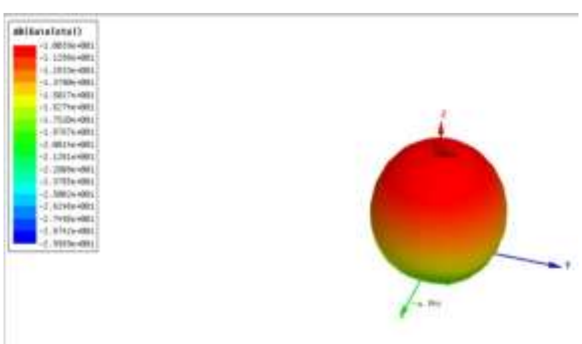

Fig. 11: 3D Gain Plot

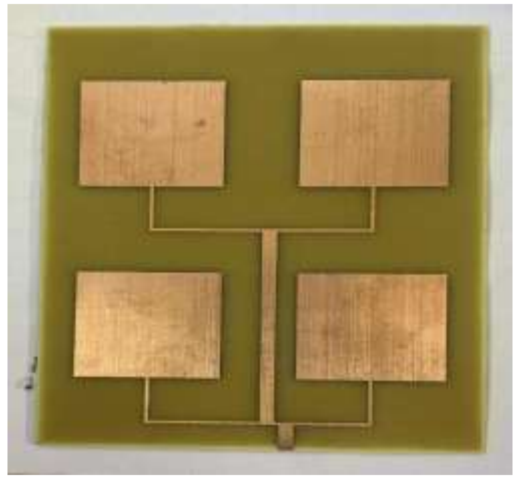

Fig. 12: Fabricated 2x2 Microstrip Patch Antenna

PARAMETERS VALUE

Category	Parameter	Value	Unit
Substrate	Material	FR4 Epoxy	-
Substrate	Dielectric Constant (εr)	4.4	-
Substrate	Thickness	1.6	mm
Patch	Patch Length (L)	29.9	mm
Patch	Patch Width (W)	29.9	mm
Patch	Copper Thickness	0.035	mm
Array	Number of Patches	4	-
Array	Patch Spacing	60	mm
Feed	Feed Line Width	3	mm
Feed	Impedance	50	Ohm
Air Box	Size (X,Y,Z)	180 x 180 x 80	mm
Simulation	Resonant Frequency	2.4	GHz

VI. CIRCUIT DESIGN ON LTSPICE XVII

The RF-to-DC conversion circuit is implemented using LTSpice simulation software to convert the received RF signals into a usable DC output. The circuit consists of a Schottky diode (HSMS-2850), along with passive components required for proper operation.The selected diode is suitable for low-power applications and enables effective rectification even at weak signal levels. Capacitive elements are used to stabilize the output and maintain a consistent voltage level. The circuit configuration is designed to improve overall conversion performance under low input power conditions, making it suitable for practical RF energy harvesting applications.

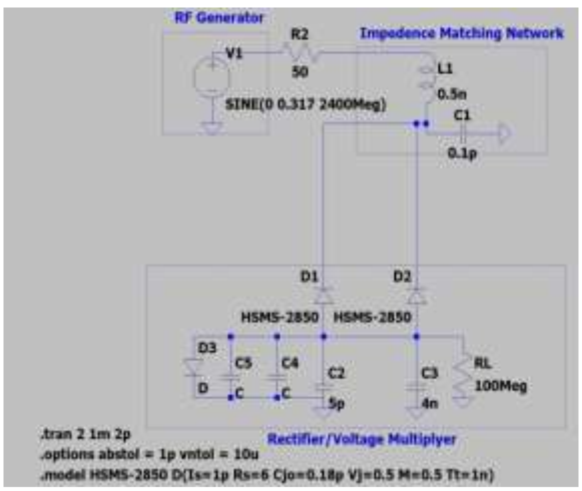

Fig. 8: RF to DC Rectifier Circuit

VII. HARDWARE DESCRIPTION

1. Antenna

The antenna is used to capture ambient RF signals from sources such as Wi-Fi routers, mobile towers, and broadcast transmitters. In this system, a rectangular microstrip patch antenna operating at 2.4 GHz is used.

2. Impedance Matching Network

The impedance matching network is helps in improving energy transfer between stages between the antenna and the rectifier circuit. It matches the antenna impedance with the input impedance of the rectifier.

3. RF to DC Rectifier Circuit

The RF to DC rectifier circuit converts the received RF signal into DC voltage. It is implemented using Schottky diodes due to their suitable for operation under low input power conditions characteristics.

4. Schottky Diode (HSMS-2850)

The HSMS-2850 Schottky diode is used in the rectifier circuit for efficient RF to DC conversion. It operates without external bias and is suitable for low-power RF applications.

5. Capacitor (MLCC)

Capacitors are included to maintain a smooth output by reducing fluctuations in the converted voltage. They also temporarily store the harvested energy, allowing the system to supply power more consistently.

6. Voltage Regulator

The voltage regulator is used to maintain a stable output voltage for the connected load. It ensures that fluctuations in input voltage do not affect the performance of the output device.

7. Load / Output Device

The output of the RF energy harvesting system is used to power low-power electronic devices such as LEDs, sensors, or microcontrollers.

VIII. Advantages

- Battery-free operation reduces maintenance requirements
- Eco-friendly and reduces electronic waste
- Suitable for low-power IoT and wireless sensor applications

• Compact and lightweight design

IX. CONCLUSIONS

RF energy harvesting provides a viable approach for powering low-power electronic devices without relying on conventional batteries. The system developed in this project successfully demonstrates the conversion of ambient RF signals into usable DC power using a microstrip antenna and rectifier circuit. Although the output power is limited, it is sufficient for applications such as wireless sensors and small electronic devices. Future improvements in antenna design, impedance matching, and rectifier efficiency can further enhance performance. With continued advancements, RF energy harvesting has the potential to play a significant role in the development of sustainable and self-powered electronic systems. The system was tested under typical indoor RF conditions to evaluate its performance. The obtained output confirms its suitability for low-power applications

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