Journal of Information Systems Engineering and Management
2025, 10(22s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Enhancement Of Rectenna Arrays to Gather Radiofrequency Energy from Various Sources

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ARTICLE INFO

Received: 25 Dec 2024

Revised: 05 Feb 2025

Accepted: 20 Feb 2025

ABSTRACT

In this work, we examine a wireless communication pair that uses radio frequency (RF) signals. The transmitter generates energy from an energy access point first, and then sends data to the recipient.

Wireless sensor networks (WSNs) have garnered a lot of attention recently because to its numerous applications in a wide range of industries, including smart cities, industrial automation, healthcare, and environmental monitoring.

This paper provides a detailed examination of the designs, principles, and performance evaluation of several RF energy harvesting systems in connection to RF energy harvesting techniques in WSNs. There is discussion of modern RF energy harvesting circuits, antenna designs, and power management strategies. In addition, we highlight the challenges and possible paths for this field of research. With regard to RF energy harvesting devices and energy-efficient WSNs, this review aims to provide practitioners and academics with a helpful resource.

Keywords: WSN, RF Energy Harvesting Devices, Numerous Applications, Energy Harvesting Techniques.

I.INTRODUCTION

Wireless networks that run on batteries are usually energy-constrained, much like sensor networks, particularly in situations when sensors are not readily available. Additionally, wireless mobile networks are quite energy-constrained in some catastrophe situations. One possible strategy to increase wireless networks' lifespan is energy harvesting. Ambient radio frequency (RF) signals are a resource for energy harvesting that is environmentally independent when compared to solar and wind.

The advent of Wireless Sensor Networks (WSNs) has revolutionized our capacity to observe and interact with the environmental environment. These networks consist of a large number of small, low-cost, low-power sensor nodes in various locations that wirelessly collect and send data. WSNs have a wide range of applications, including as environmental monitoring, healthcare, smart cities, industrial automation, and precision agriculture. This substantially limits the long-term functioning and sustainability of WSNs, especially in remote or inaccessible places.

The energy restriction issue in WSNs has been addressed by a variety of energy collection techniques. Sensor nodes can obtain energy from ambient sources such as solar, thermal, vibration, and radio frequency thanks to these techniques. Since radiofrequency (RF) waves are so prevalent in the environment—from broadcast radio and television to Wi-Fi and cellular networks—RF energy harvesting has received particular attention among these techniques. This improves the sensor nodes' lifespan and reduces the need for battery replacement or recharging, increasing WSNs' cost- and sustainability-efficiency.

This paper provides a detailed review of RF energy harvesting techniques in WSNs. The principles of RF energy harvesting go into great detail about the sources of RF energy, the characteristics of propagation, and the harvesting methods. We study the architectures and design problems of RF energy harvesting systems with a focus on RF energy harvesting circuits, antenna designs, and power management strategies. Also evaluated are contemporary RF energy harvesting techniques and how well they work in WSNs. We also point to challenges and future research directions in this area, including the development of energy-efficient communication protocols for RF-powered WSNs, the optimization of RF energy harvesting efficiency, and the integration of RF energy harvesting with other energy harvesting techniques.

II.FUNDAMENTALS OF RF ENERGY HARVESTING

To convert radio frequency (RF) to direct current (DC), semiconductor-based rectifying components in a range of topologies are used in almost all contemporary energy-harvesting circuits. Closed-spaced thermionic diodes and microwave heating principles were used in early RF to dc conversion techniques. Even though semiconductors can only manage comparatively small power levels on their own, their small form factor and inexpensive cost make them perfect for a wide range of applications. Since Schottky diodes have a smaller junction

Capacitance and a lower voltage threshold than PN diodes, they are preferred in SPS systems. The maximum frequency is increased by the low junction capacitance, and this low threshold enables more effective operation at low powers.

For SPS systems, massive arrays of RF rectifiers are employed to generate vast amounts of electricity. Discrete components are usually utilized in SPS harvesting arrays because Schottky diode production is not supported by standard CMOS methods.

However, RFID applications use CMOS technology with diode-connected transistors, which, thanks to adjustable rectifiers and lower parasitic values, greatly boost energy-harvest efficiency at lower powers. Additionally, the same die can have digital logic added to it. CMOS techniques are the leading technology for RFID energy harvesters due to the extremely low power levels required by these realized electronics and the cost savings by combining the complete device on a single integrated circuit (IC) (low cost is crucial for the RFID industry).

Radiofrequency Energy Sources The presence of ambient radio frequency sources in the environment is necessary for RF energy harvesting to function. The most popular sources of radio frequency energy are broadcast radio and television, Wi-Fi, Bluetooth, and cellular networks (such as GSM, 3G, 4G, and 5G). These sources transfer power levels and operate in various frequency ranges.

The available RF energy density in the surrounding environment is influenced by the distance from the radio source, the transmit power, the antenna gain, and the propagation characteristics of the environment. The inverse-square law states that the RF energy density decreases as the distance from the source squares. Thus, the closer the sensor node is to the RF source, the higher the available RF energy density.

III. DESIGN AND ARCHITECTURE OF AN RF ENERGY HARVESTING SYSTEM

The antenna is responsible for converting environmental radio waves into electrical impulses. The antenna design is influenced by the operating frequency, polarization, and gain parameters. Among the frequently used antenna types for RF energy collection are dipole, patch, and slot antennas. Designing the antenna with a high gain and a good impedance match with the rectifier will enhance power transfer.

The rectifier is a crucial component of the RF energy harvesting circuit since it converts RF signals into DC voltage. The most popular rectifier topologies are single-diode rectifiers, voltage doublers, and Dickson charge pumps. The simplest design is the single-diode rectifier, which only has one diode and a capacitor. The Dickson charge pump and the voltage doublers are more complex topologies that can achieve higher output voltages and efficiency. The rectifier topology is determined by the input power level, the output voltage requirement, and the load impedance.

The power management unit stores the collected energy and regulates the DC voltage from the rectifier in storage devices such as rechargeable batteries or super capacitors. Power management units typically consist of a voltage regulator, a maximum power point tracking (MPPT) circuit, and a storage device. For optimal energy collection efficiency, the voltage regulator maintains a steady output voltage for the sensor node, and the MPPT circuit ensures that the rectifier operates at its maximum power point. The sensor node is powered by the storage device, which also stores the collected energy in case ambient radio frequency energy is not available.

The antenna design is crucial to successful RF energy harvesting because it determines how much RF energy can be captured and transmitted to the rectifier. For RF energy harvesting, the main considerations in antenna design are operating frequency, polarization, gain, and impedance.

The operating frequency of the antenna must match the frequency of the nearby radio sources in order to maximize energy acquisition. The polarization of the antenna should match that of the RF sources in order to eliminate polarization mismatch losses.

The type of antenna you utilize depends on the operating frequency, size constraints, and gain requirements. Dipole antennas are tiny, straightforward, and have a limited strength and bandwidth. Patch antennas can be constructed to be circularly polarized and have a higher gain despite being larger. Slot antennas are compact and easy to integrate with other circuit components, despite their lower gain. Yagi-Uda and log-periodic antennas provide enormous bandwidth and great gain, despite being larger and more challenging to build.

Energy storage is necessary to maintain the acquired energy and power the sensor node when ambient radio frequency energy is not accessible. The energy capacity, leakage current, and discharge characteristics all affect the choice of storage device. Super capacitors are used extensively for short-term energy storage due to their high power density, low leakage current, and rapid charge/discharge cycles.

Batteries are best suited for applications requiring longer operating durations and fewer cycles of charge and discharge, whereas super capacitors are best suited for applications requiring many cycles of charge and discharge and short-term energy storage.

IV.INNOVATIVE RF ENERGY HARVESTING METHODS

4.1. RF ENERGY HARVESTING IN BROADBAND AND MULTIBAND

A wide range of frequency bands, such as TV broadcast channels, Wi-Fi, 3G/4G, and GSM, are available for ambient radio frequency energy. Multiband and broadband radio frequency harvesting techniques aim to simultaneously gather energy from multiple frequency bands in order to maximize the amount of energy.

For multiband RF energy harvesting systems, numerous antennas and rectifiers tuned to various frequency bands are utilized. One DC output is created by combining the rectifier outputs using a power combiner. In Figure 4.1, an RF energy collecting system with two bands is displayed.

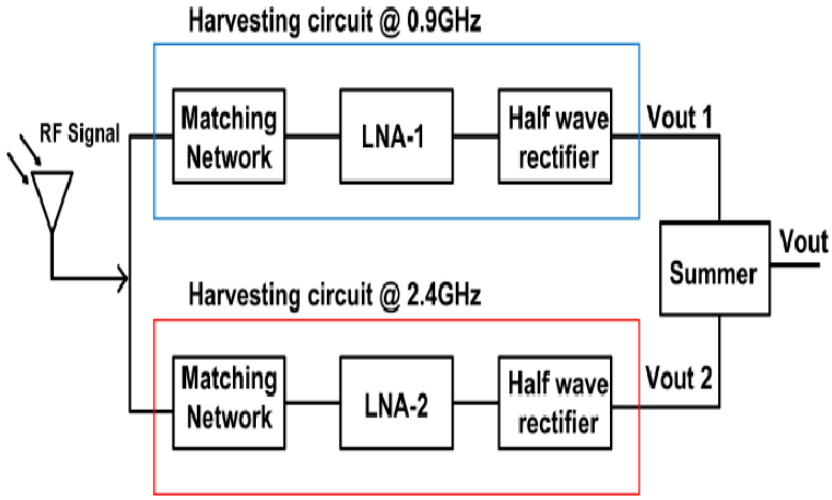

Figure 4.1: Dual-band RF energy harvesting system block diagram.

Systems that use a broadband rectifier and a single wideband antenna are used to harvest energy from a wide frequency range. High gain and good impedance matching are the goals of the broadband antenna across the entire frequency range of interest. The broadband rectifier is constructed with a wide dynamic range and exceptional efficiency due to the variation in input power levels from different frequency bands.

Multiband and broadband radio frequency harvesting techniques can significantly increase the amount of energy gathered compared to single-band systems since they can simultaneously collect energy from multiple frequency bands. Because they require many antennas, rectifiers, and power combiners, they also increase the system's complexity and cost.

4.2. COLLABORATIVE RF ENERGY HARVESTING

The technique by which many sensor nodes collaborate to collect and disperse RF energy in a WSN is known as cooperative RF energy harvesting. In this approach, certain sensor nodes serve as energy harvesters and others as energy providers. The energy sources deliver radio frequency energy to the energy harvesters, which they use to power their own operations or transfer the energy to other nodes.

Various architectures, such as relay-based, cluster-based, and multi-hop systems, can be employed to achieve cooperative radio frequency energy harvesting. The energy harvesters in relay-based topologies distribute the energy they have gathered to other nodes in a network made up of energy sources and harvesters. The sensor nodes are arranged in clusters in the cluster-based architecture, where the heads act as energy suppliers and the cluster members as energy harvesters. In the multi-hop design, the energy harvesters form a multi-hop network to transmit the collected energy to distant nodes.

The life of WSNs is extended via cooperative RF energy harvesting, which enables the sensor nodes to collect and disperse RF energy. However, because the coordination and communication of the sensor nodes is necessary to manage the energy collecting and sharing process, it also adds overhead and complexity.

4.3. HYBRID RF ENERGY HARVESTING

In addition to RF energy gathering, other energy harvesting techniques include solar, thermal, or vibration energy harvesting. The goal of the hybrid approach is to overcome the shortcomings of individual energy collecting techniques while offering the sensor nodes a more reliable and durable energy source. The RF energy harvester collects ambient radio energy, while the solar energy harvester collects solar energy. A power management circuit combines the outputs of the two harvesters to provide the sensor node with a single DC output.

In comparison to single-source systems, hybrid radio frequency (RF) energy harvesting systems can offer sensor nodes a more reliable and ecologically friendly energy source. Nevertheless, they increase the system's complexity and cost because many energy harvesters, power management circuits, and storage devices must be used.

V. LOSSES IN ENERGY-HARVESTING CIRCUITS

5.1. HARMONIC GENERATION

Although the diode nonlinearity offers a way to transfer RF energy to dc, it also causes loss. Reduced energy harvester efficiency results from the diode's production of frequency harmonics from the incident power while it is functioning. This lowers the percentage of energy that is converted to DC. The amount of energy lost to harmonics grows in tandem with the incident voltage. Trade-offs between threshold voltage, reverse breakdown effects, and harmonic generation all point to an ideal efficiency level.

5.2. IMPEDANCE MATCHING

An energy-harvesting circuit that is not appropriately matched to its antenna will reflect some of the incoming power back into space rather than collect it. There is an inherent reduction in the power available for rectification if the power is not absorbed. Because of the nonlinearity of the rectifying parts, matching is particularly challenging in energy harvesting circuit design because the impedance will vary as a function of both frequency and input power.

VI.RESULTS

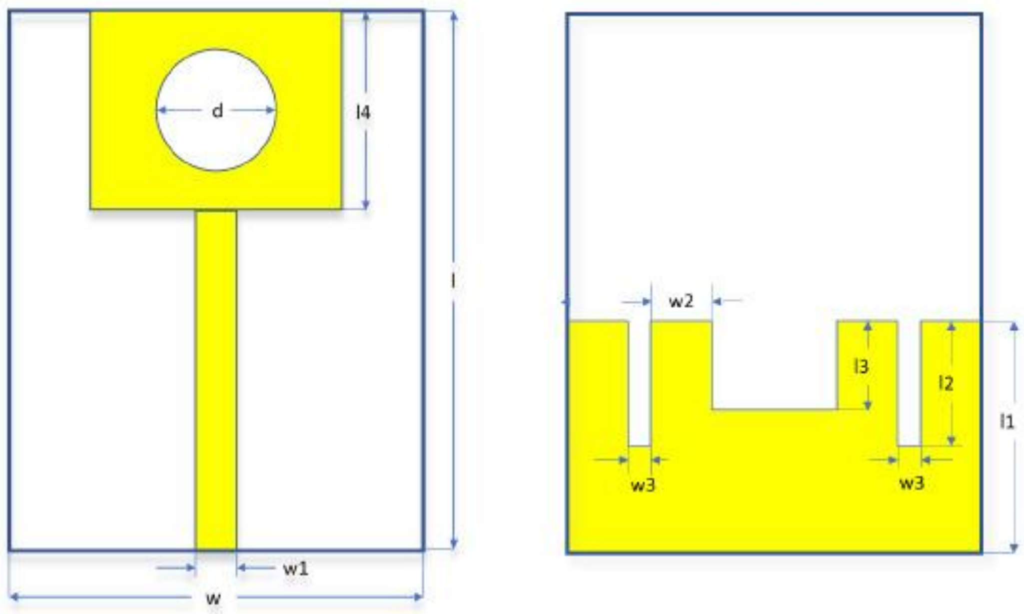

Figure 6.1. Antenna Used

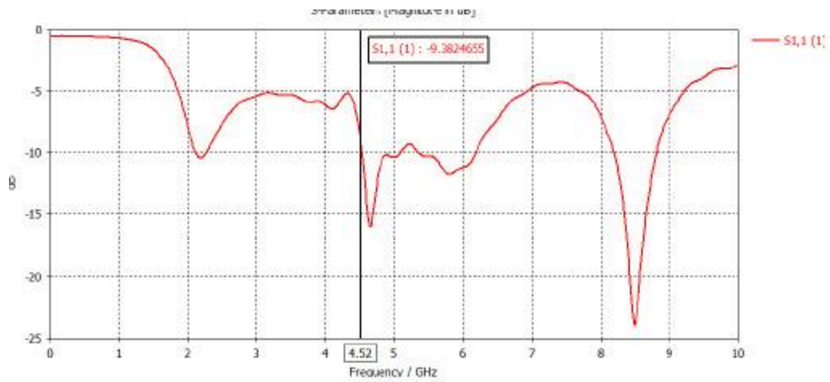

Figure 6.2.Before Optimization

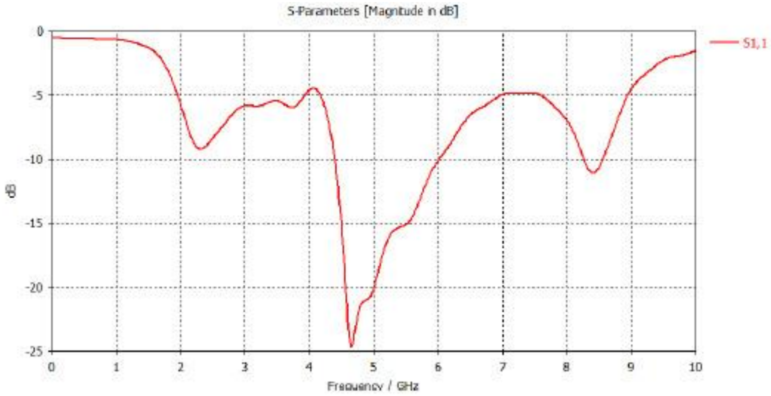

Figure 6.3.After Optimization

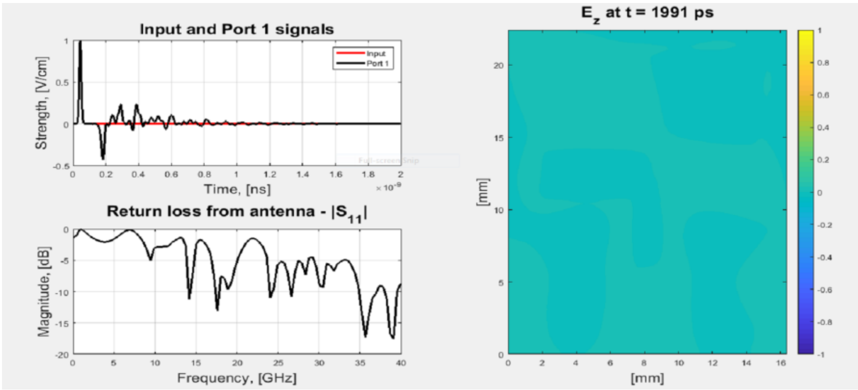

Figure 6.4.FDTD 3D Micro-strip Antenna Result

VII.CONCLUSION

In this article, the several methods for collecting radio frequency (RF) energy for wireless sensor networks (WSNs) were thoroughly examined. This session addressed the fundamentals of radio frequency (RF) energy harvesting, including radio frequency energy sources, propagation characteristics, and harvesting techniques. Additionally, we discussed the architectural and design challenges associated with radio frequency (RF) energy harvesting devices, with particular attention to the circuits, antenna designs, and power management algorithms of these equipment. We wrapped up our discussion by discussing the difficulties this subject faces and potential avenues for further research. Enhancing efficiency, decreasing interference, harnessing hybrid energy, and creating network protocols and algorithms are some of these.

In the future, research should concentrate on developing novel architectures, techniques, and algorithms for radiofrequency energy harvesting. The scalability and performance of RF-powered wireless sensor networks (WSNs) should be improved by these techniques and algorithms, which should be able to handle these problems. The implementation of energy-aware design methods, interference mitigation techniques, and energy-aware routing and MAC protocols, hybrid energy harvesting structures and algorithms, and other potential study directions are examples of promising research approaches. More reliable, efficient, and scalable RF energy harvesting systems are expected to be developed as a result of this field's ongoing research and development.

These systems will power the next generation of wireless sensor networks (WSNs), creating new opportunities for services and applications in a variety of fields, including industrial automation, smart cities, and environmental monitoring.

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