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RFID Energy Harvesting for Smart Appliances

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Abstract

In order to overcome the energy constraints of RFID devices, this project designs and simulates an RFID energy harvesting system using MATLAB Simulink. The simulation takes into account practical aspects such as signal strength and efficiency by simulating the behavior of RF harvesters, power management, and energy storage devices. By capturing radio wave energy for passive RFID tags, RFID energy harvesting provides an economical and environmentally friendly alternative to batteries for low-power applications. The objectives of the project include designing an effective RF energy harvester, building a power management circuit, and thoroughly testing the device. The goal of this work is to create an RFID circuit that accepts input as a low radio wave with a 600-mV input wave and generates a voltage of 1-4 V that is enough for smart appliances.

Keywords — energy harvesting, RFID, antenna, tag, header

Introduction

The fields of optics, electricity, and magnetism gained prominence during the 1600s and 1800s. The discovery of electromagnetic energy occurred in the 1800s, when Hertz successfully transmitted radio waves for the first time. Radio waves and light were first connected by Michael Faraday in 1845. Radar findings gave rise to RFID technology, which was first used in World War II to identify aircraft. Sending signals to transponders is how the technology works, much like the existing Identify Friend or Foe (IFF) system [1]. RFID was first developed for military use, but as its capabilities grew, it became widely employed in contemporary corporate applications, allowing for the quick and easy retrieval of information and effective monitoring of objects. Thanks to its easy-to-use and rapid tracking features, RFID is becoming a necessary component of many different sectors [2].

Developed in 1948, radio-frequency identification, or RFID, is an automated identifying technology that has superseded barcodes and other conventional techniques. Adopted by a range of sectors due to its benefits, RFID uses tags affixed to items that allow information to be retrieved or stored when the object is in close contact to a reader. Operating at ultra-high, high, or low frequencies, the technology performs better than alternatives.

RFID codes that allow for unique identification of each tag, such as the

Electronic Product Code (EPC) or Unique Item Identifier (UII), are essential for many applications [3].

Security issues still exist even if RFID allows wireless scanning up to several meters away. 82.27% tag identification accuracy is attained by an Artificial Neural Network (ANN) classifier without incurring additional expenditures. A practical and affordable RFID tag encryption technique is presented in thisstudy.

RFID technology relies on electromagnetic fields and radio waves, with frequencies categorizing its applications. Low frequencies, ranging from 30 to 300 KHz, are utilized in RFID, particularly 125 to 134 KHz, offering a short range of under 2 meters. High frequencies (3 to 3 MHz) have a range of less than 1 meter, with HF penetrating water more effectively than LF. Ultra-high frequency (UHF) spans 3000 MHz to 3 GHz, commonly at 868 MHz, boasting a range of up to 100 meters and a transfer rate of 1 Kbits/s [4]. The microwave frequency at 2.45 GHz serves for longer distances with a high transfer rate.

System Overview

There are three types of RFID tags: semi-active, passive, and active. Passive tags are the most favored among them because of their long lifespan and low cost. Passive tags don't have an external battery like active tags do, therefore activating the tag is essential for communicating with the reader. Through the use of an antenna, tags establish communication, producing electromagnetic waves that power the energy collecting circuit. For passive RFID tags, an effective energy collecting circuit is therefore necessary. In order to improve circuit efficiency, a high-gain antenna must be developed. Software manages the communication between tags and RFID readers in RFID systems. An antenna, a transceiver (reader) with a decoder, and a transponder (RF tag) are the main parts of this system.

Within RFID systems, software facilitates communication between RFID readers and tags. The RFID tags depicted in the accompanying image are commonly referred to as transponders, serving as both transmitters and receivers in the RFID system [5]. Comprising an antenna, a microchip (memory), and encapsulating material, the RFID tag is structured around these three fundamental components.

RFID readers facilitate data exchange between tags and the main computer. Tags transmit information to the reader, which then relays it to the computer through common interfaces [6]. The reader's antenna captures radio waves from the tag's antenna in a reading zone whose size depends on communication frequency and reader power. In various work settings, three common reader types include handheld, stationary in specific spots, and strategically placed fixed readers.

RFID antennas activate tags, enabling data reading and writing. As the vital link between tags and transceivers, managing data communication, antennas vary in size [7]. They capture tag data in door frames or monitor traffic on toll booths. The electromagnetic field can be continuously active in scenarios with multiple tags or activated by a sensor device. Compatible frequencies ensure seamless data transfer, with high-frequency systems providing extensive read ranges and rapid reading speeds.

The supporting infrastructure, includes related software and hardware required for

RFID systems. Figure 1 shows the software manages the interaction between the RFID reader and the RFID tags.

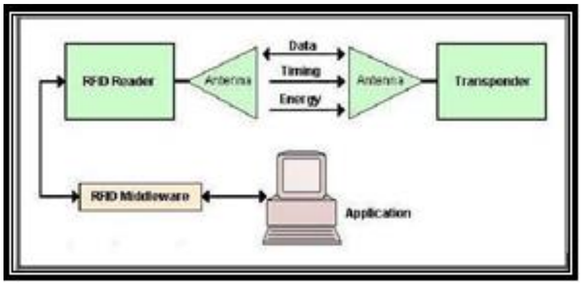


Figure 1: Role of supporting infrastructure in RFID energy harvesting system

Proposed Model

Our objective is to design an RFID energy harvesting system that uses recovered RF energy to power distant sensors. The objective of this system is to improve real-time resource use and collect environmental data. In particular, inventory management and logistics will use the RFID energy harvesting gadget. It will supply power to passive RFID tags that are used to track objects in warehouse environments, taking into account variables like temperature changes and the presence of metal objects. The proposed model design of the RFID energy harvesting system is shown in Figure 2. The goal of this project is to improve data collecting efficiency and resource management in situations when conventional power sources might not be feasible or available.

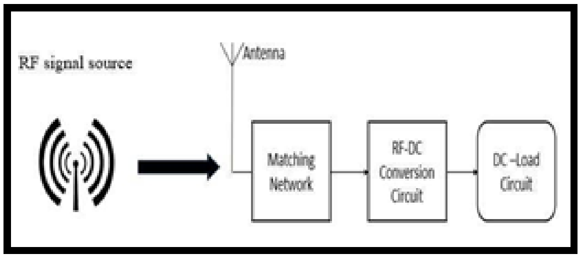


Figure 2: Proposed model of RFID energy harvesting system

Working Methodology

A. Understanding the behavioral Model

To obtain the desired frequency we need to design and understand the behavioral model of RFID energy harvesting circuit.

B. Designing RFID Transmitter

- A fundamental RF (Radio Frequency) transmitter is an electronic device that is designed to generate and emit electromagnetic signals [8] within the radio frequency spectrum. Its primary function is wireless information transmission. Commonly utilized in devices like remote controls, key fobs, and wireless microphones for short-range communication, basic RF transmitters are prevalent. However, it's crucial to recognize that for intricate communication systems like mobile phones, Wi-Fi routers, and broadcasting equipment, more advanced RF transmitters are employed. The Figure 3 shows a basic RF (Radio Frequency) transmitter.

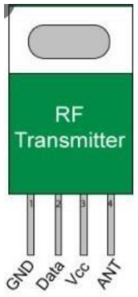


Figure 3: RFID transmitter

- Using MATLAB, we have designed, simulated the RFID transmitter and observed the desired output.

- Figure 4 & 5 represents simulated magnitude waveform of RFID signal came from RFID transmitter using MATLAB code.

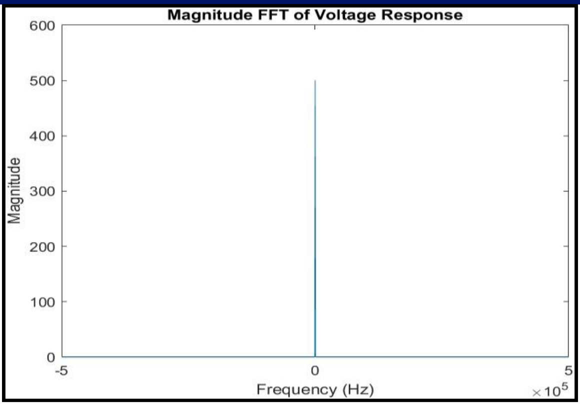


Figure 4: Voltage response of RFID transmitter

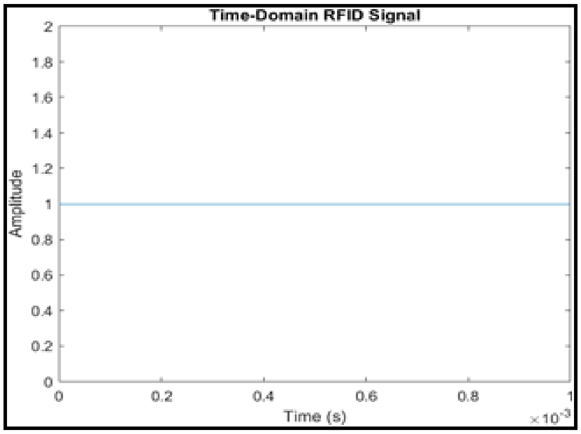


Figure 5: Time domain response of RFID transmitter

Designing structural Model of impedance matching network

An impedance matching network is essential in RFID energy harvesting systems to maximize power transmission between a radio frequency antenna and an electricity harvester circuit [9]. It's designed to minimize signal reflection, so the power is delivered as efficiently as possible. This network is able to enhance the overall performance of energy harvesting processes by adjusting the level of electromagnetic interference and generates more power out of incoming radio frequency signals, thereby increasing system efficiency. After designing the RFID energy harvesting system, we have taken that output to impedance matching network. To study and analyze the behavioral model of the impedance matching network we have wrote a MATLAB code for the same. Figure 6 shows voltage response of impedance and phase value of impedance matching network with the help of MATLAB code in whichwe have 500 mV.

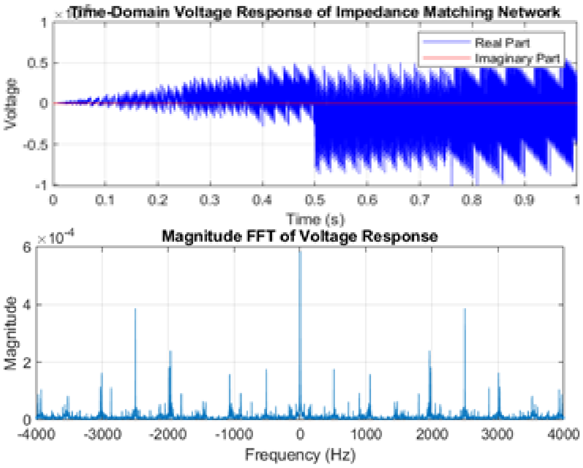


Figure 6: Voltage response of impedance matching network

Further we have also, simulated the impedance matching network on MATLAB Simulink. Whose proposed model has been represented in Figure 7.

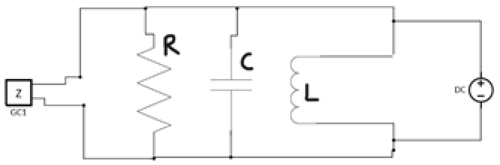


Figure 7: Proposed model of impedance matching network

We have produced the graph of impedance & frequency using this circuit, which shows a linear connection between them. Another graph shows how the phase angle decreases as frequency increases. Both of them are seen in Figures 8 and 9, respectively.

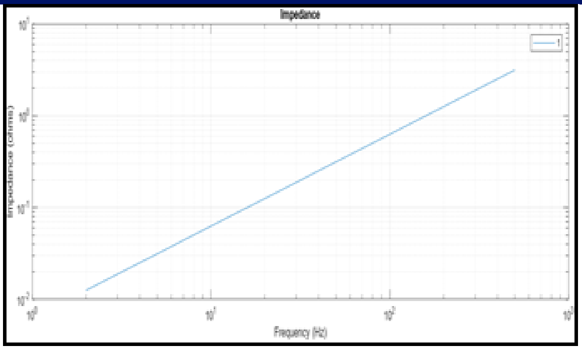


Figure 8: Impedance response of matching network

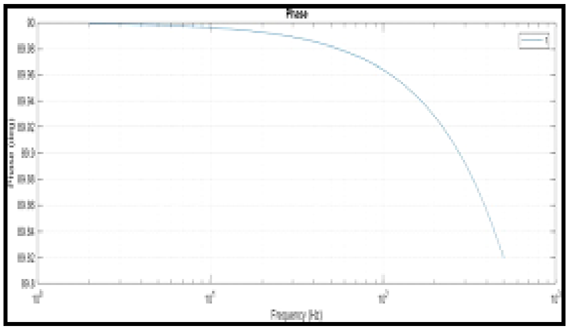


Figure 9: Phase response of matching network

Designing Voltage multiplier

A voltage multiplier, a crucial element of energy harvesting, will convert low current DC output from the rectifier to higher AC or DC voltages [10]. It is an essential component of RFID systems with weak signal power, adapting harvested energy to electronic components. For driving loads like sensors, or storage components, the CockcroftWalton circuits gradually increase input voltage by using capacitors and diodes. Figure 10 represents voltagemultiplier circuit we have used to complete our objective.

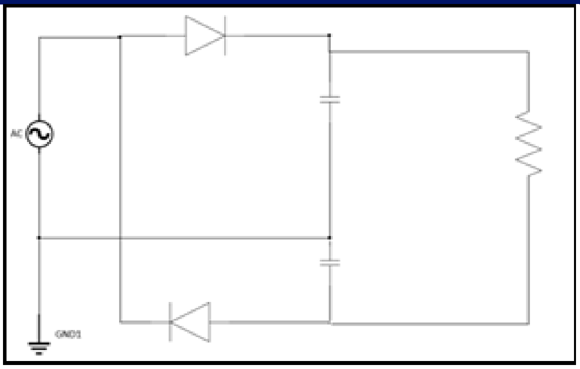


Figure 10: Proposed Voltage multiplier circuit

The circuit has been tested to the different input voltages, and we have come up with an output which will work in a variety of applications. Input and output voltages 600 mV and 890 mV, as indicated in Figure 9 and 10 respectively, are part of the voltage multiplier circuit.

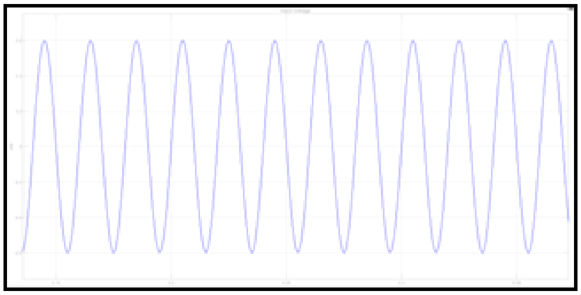


Figure 11: Input voltage of block voltage multiplier at (Vin) 600mV

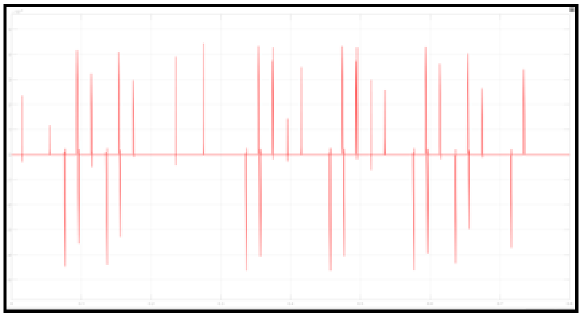
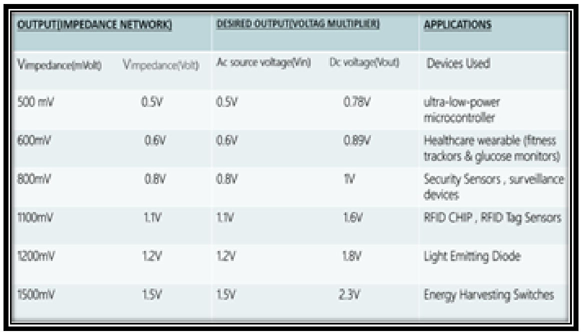


Figure 12: Output voltage of block voltage multiplier at(Vout) 600mV

Result

We've got the RFID energy harvesting system that can generate DC voltages of 0.8V, 1V, 1.5V and 2V, which allows us to look at a variety of Low Power Applications for use in this voltage range. As well as the corresponding applications of this technology, Table 1 shows input and output voltages acquired with a the RFID energy harvesting circuit.



OUTPUT(IMPEDANCE NETWORK)		DESIRED OUTPUT(VOLTAG MULTIPLIER)		APPLICATIONS
Vimpedance(mVolt)	Vimpedance(Volt)	Ac source voltage(Vin)	Dc voltage(Vout)	Devices Used
500 mV	0.5V	0.5V	0.78V	ultra-low-power microcontroller
600mV	0.6V	0.6V	0.89V	Healthcare wearable (fitness trackors & glucose monitors)
800mV	0.8V	0.8V	1V	Security Sensors , surveillance devices
1100mV	1.1V	1.1V	1.6V	RFID CHIP , RFID Tag Sensors
1200mV	1.2V	1.2V	1.8V	Light Emitting Diode
1500mV	1.5V	1.5V	2.3V	Energy Harvesting Switches

Table 1: Various applications of RFID energyharvesting at different outputs

Here are a number of possibilities for RFID energy harvesting.

A. Wireless sensor network: Low power wireless sensor nodes to monitor environmental parameters such as temperature, humidity, light, or gas levels.

B. IOT (Internet of Things) devices: Small Internet of Things devices that transmit data over short distances. Smart home sensors, asset tracking systems and farm monitoring nodes are examples [14].

C. Healthcare Wearables: Low power wearable devices are used to track your health, such as fitness trackers or continuous glucose monitors.

D. Smart Agriculture: In order to optimize irrigation and crop management, agricultural surveillance systems shall measure soil moisture, temperature or other parameters.

E. RFID tag sensors: RFID tags, such as those on shipments of temperature sensitive goods, fitted with sensors designed to monitor conditions in the transport.

F. Asset Tracking: Low-power asset tracking systems for monitoring the location and condition of valuable assets in logistics or manufacturing.

G. Smart cities infrastructure: Low power devices for monitoring and controlling a range of aspects of smart city infrastructure, from waste management to lighting or parking.

Conclusion

As technology evolves, improvements in the efficiency and miniaturization of RFID energy harvesting components are expected. This will lead to the development of more compact and cost-effective systems, making them increasingly viable for a broader range of applications. Enhanced energy storage solutions, coupled with RFID energy harvesting, may pave the way for autonomous and self-sustaining devices, reducing dependence on traditional power grids.

Furthermore, the incorporation of artificial intelligence (AI) and machine learning (ML) algorithms into RFID energy harvesting systems is an exciting prospect. These technologies could optimize energy harvesting processes by predicting usage patterns and dynamically adjusting harvesting strategies to maximize efficiency [11]. Such intelligent systems could adapt to varying environmental conditions, ensuring reliable and consistent power generation. Our goal which was to develop an RFID circuit that accepts input as a low radio wave with a 600-mV input wave and generates a voltage of 1-4 V has been designed and implemented successfully that is enough for smart appliances [12][13].

In summary, the future of RFID energy harvesting is marked by a trajectory towards increased versatility, efficiency, and integration with emerging technologies [13]. As these systems mature, they hold the key to unlocking sustainable, self-sufficient, and intelligent solutions that address the evolving energy needs of our interconnected world.

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