Faculty of Electrical and Electronic Engineering Technology

DEVELOPMENT OF RECTIFIER FOR WIDEBAND RF ENERGY HARVESTING SYSTEM

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Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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A project report submitted
in partial fulfillment of the requirements for the degree of
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Supervisor Name : NURULHALIM BIN HASSIM

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DEDICATION

I dedicate this report to my beloved parents,
As well as my beloved siblings,
And to all my families, friends, partner in crime,
Especially those who supported me in the beginning of this project.
Cheers to their constant encouragement and endless, repetitive motivational rants.

ABSTRACT

This research describes the design of an effective rectifier circuit for RF Energy Harvesting. The technique of producing and collecting energy from an external source is define as RF Energy Harvesting. It is a green technology that is globally accessible in our atmosphere. The objective of this research is to design and to implement a rectifier circuit with impedance matching network. A Voltage Doubler rectifier circuit is proposed, from many types of rectifiers to convert RF energy to DC energy. Fixed frequency of 945MHz is proposed for the simulation and measurement of different input power levels. This rectifier is made up of a combination of LC impedance matching network and Schottky diodes (HSMS-285x). The ADS 2016 circuit simulator is used for running this rectifier simulation. From that, we should expect around 70% conversion of energy from RF to DC. From the hardware results, we managed to get a reading of DC energy. This shows that our hardware is functional and the objective is fulfilled.

ABSTRAK

Penyelidikan ini menerangkan rekabentuk litar penerus yang berkesan untuk Penuaian Tenaga RF. Teknik penghasilan dan pengumpulan tenaga daripada sumber luaran ialah apa yang ditakrifkan sebagai Penuaian Tenaga RF. Ia adalah teknologi hijau yang boleh diakses secara global di atmosfera kita. Objektif penyelidikan ini adalah untuk mereka bentuk dan melaksanakan litar penerus dengan rangkaian pemadanan impedans. Litar penerus Pengganda Voltan dicadangkan setelah dipilih daripada pelbagai jenis penerus untuk menukar tenaga RF kepada tenaga DC. Frekuensi tetap 945MHz dicadangkan untuk simulasi and pengukuran tahap kuasa input yang berbeza. Penerus ini terdiri daripada gabungan rangkaian pemadanan impedans LC dan diod Schottky (HSMS-285x). Simulator litar ADS 2016 digunakan untuk menjalankan simulasi penerus ini. Daripada itu, kita harus menjangkakan sekitar 70% penukaran tenaga daripada RF ke DC. Hasil daripada projek, kita berjaya mendapatkan bacaan tenaga DC. Ini menunjukkan perkakasan kami berfungsi dan objektifnya tercapai.

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LIST OF SYMBOLS

kW	-	kiloWatt
MHz	-	MegaHertz
V	-	Volt
dB	-	decibel
GHz	-	GigaHertz
pF	-	picoFarad
A	-	Ampere
Ω	-	ohm

LIST OF ABBREVIATIONS

LC	-	Inductor-Capacitor
RF	-	Radio Frequency
EM	-	Electromagnetic
TV	-	Television
DC	-	Direct Current
AC	-	Alternating Current
EH	-	Energy Harvesting
ADS	-	Advanced Design System
R&D	-	Research & Design
PCE	-	Power Conversion Efficiency
PCB	-	Printed Circuit Board
R	-	Resistor
V	-	Voltage
I	-	Current
C	-	Capacitor
L	-	Inductor
SM	-	Surface Mount
TH	-	Through-hole
PWB	-	Printed Wiring Board
PCA	-	Printed Circuit Assembly
PCBA	-	Printed Circuit Board Assembly
FYP	-	Final Year Project

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CHAPTER 1

INTRODUCTION

1.1 Background

Ambient power, also known as energy scavenging, is a method for obtaining and extracting energy from an external source. Energy harvesting has been demonstrated to be widely applied to small and mobile system devices, such as wearable electronics. There are vast energy production sources, such as wind energy, solar energy and kinetic energy. According to[1], all of the energy harvesting is mainly originated from wind-driven wheel and also from waterwheel.

The collection of power from radio frequency (RF) waves in propagation is one of the most used methods for extracting power in passively operated devices. RF energy scavenging is the process of converting energy from electromagnetic (EM) to electrical domain. Energy harvesting is classified into two categories: small and large scale. RF energy is categorised on a small scale [1] television (TV) broadcasts, wireless networks, and cell towers are examples of radio frequencies produced in everyday life. The RF signal is frequently employed in the sphere of communication [2].

Future microelectronic circuits will rely heavily on RF Energy Harvesting [3]. The power source has a relatively broad transmission range (kW). However, the receiver only receives a limited range. The residual energy is lost as heat. The unused energy might then be converted into a little amount of power or electricity. Figure 1.1 below shows a block diagram that illustrates an ambient RF energy harvesting system.

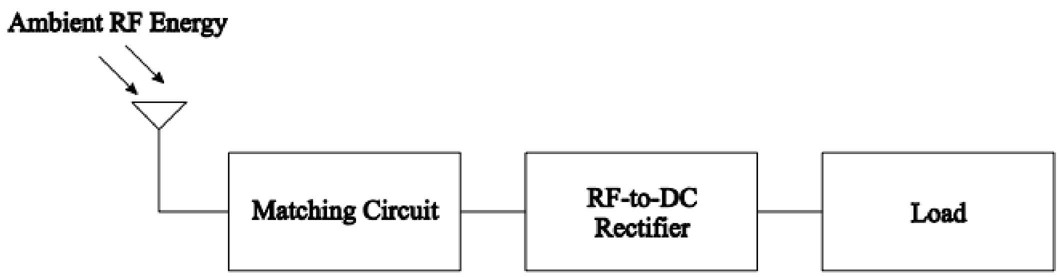

Figure 1.1: Block diagram of an ambient RF energy harvesting system[4]

1.2 Problem Statement

As we using RF energy as our power source to generate DC power, we need to be in an area with high readings of RF energy in order to get maximum values of our results. We gaining our RF energy by using an antenna which plays a role too in harvesting RF energy.

A matching network that converts impedances between an antenna and rectifier provides maximum energy transfer in an RF energy harvesting system. However, in the majority of rectenna designs, a very frequency-specific matching network is positioned between the antenna and the rectifier. This work suggests the usage of a spiral antenna and LC matching network as the matching network between a frequency-independent antenna and the rectifier for RF Energy harvesting. The rectifier circuit may need to be constructed using an active element such as a Schottky diode to generate a more efficient RF-to-DC power conversion output.

1.3 Project Objective

I. To design the rectifier circuit with impedance matching network.

II. To implement the rectifier circuit with impedance matching network.

III. To get high RF-to-DC power efficiency.

1.4 Scope of Project

Scopes are written to ensure that the project will remain within its planned point of limitation. The scope will be functional in order to ensure that the project is on track to achieve its objective. The major purpose of this project is the design of a rectifier circuit for the Energy Harvesting system. Figure 1.2 depicts the fundamental principle of Energy Harvesting, which consists of an antenna that receives/transmits signals within a specific frequency range and is attached to a rectifier (AC/DC converter) [5].

Figure 1.2: Energy Harvesting System[5]

CHAPTER 2

LITERATURE REVIEW

2.1 Rectifiers

Recently, there has been an increase in interest in developing low-power circuits using microstrip antennas [6]. It enables Energy Harvesting (EH) devices to be prepared to feed complicated electronic circuits that perform critical functions in a variety of application areas. According to [3], there are two grounds for administering this study by a number of researchers who are freely available in space and complement the low-energy sources utilised to power low-power electronic gadgets, Green Technology. It consists of an antenna that collects electromagnetic radiation and a converter that converts the gathered RF energy to direct current power, hence eliminating the need for batteries.

In [7], the author developed an energy harvesting device that scavenges energy from the radio frequency electromagnetic spectrum and operates in the GSM 900 band. According to laboratory tests, the rectifier's efficiency is around 72 percent when the input power is modest. According to [3], the system's primary objective is to provide a source of energy for powering low-power devices. By including an impedance combination and a seven-stage voltage doubler circuit, the E-shaped antenna was developed as an alternative to standard broad band microstrip antennas. Multisim software was used for the design and simulation. The DC voltage obtained in the field test was 2.9V, which was sufficient to power the STLM20 temperature sensor.

In [8], a rectifier circuit for ambient energy was presented as a priority for ultra-low power 15 applications. This was accomplished by the design and construction of a 50-stage Dickson rectifier on a 180 nm TSMC CMOS architecture. The IC's input voltage is 900 MHz, which serves as a benchmark for genuine comparison values. Thus, a 50-ohm input impedance network was established at the IC's input. However, a similar network will be used to power a passive system in the harvester's actual setup.

Typically, rectennas cannot be directly compared because to their distinct functions. Control measures and other ideas of efficiency can be applied objectively in different articles. The performance of RF to DC conversion at low input power densities is listed in Table 2.1.

Table 2.1: Types of Rectifiers

References	Frequency (GHz)	Rectifier Circuit	RF-to-DC (%) Efficiency
(Rengalakshmi & Brinda, 2016)	***0.945***	***Voltage Double Rectifier***	***72***
(Kasar et al., 2019)	1	Single-stage	70.5
(Chuc & Duong, 2015)	2.45	Voltage Doubler	70.06
(Tudose & Voinescu, 2013)	2.45	Voltage Doubler	67
(Razavi Haeri et al., 2017)	0.9	50-Stage Voltage Double Rectifier	60
(Song et al., 2015)	1.8-2.5	Full-wave Grienacher	55
(Kundu (Datta) et al., 2017)	2.5	Bridger	50
(Din, 2012)	0.8	7-stage Voltage Double Rectifier	30-50
(ElAnzeery & Guindi, 2012)	0.5-9	N-stage Multiplier	NA

2.1.1 Voltage Doubler Rectifier

In [1], the rectifier converts the RF signal received by the receiving antenna into DC supply voltage. It is made up of a diode and a capacitor, as shown in Figure 2.1. There are various kinds of rectifiers; (i) Standard rectifier; (ii) Voltage multiplier; (iii) Voltage doubler. In the fundamental rectifier circuit, the diode is in series with the load. In this case, a capacitor is utilised to smooth the output.

This straightforward rectifier is also known as a single-stage rectifier. Two diodes and two capacitors are used in the voltage doubler to nearly double the DC voltage. Cascaded connections of diodes and capacitors are utilised to obtain a higher order in the voltage multiplier. The RF signal power received by a conventional 50 antenna is typically below the diode threshold. For the energy collecting circuit, diodes with the lowest threshold voltage are preferred. The HSMS 285x Schottky diode is ideal for environments with weak RF signals.

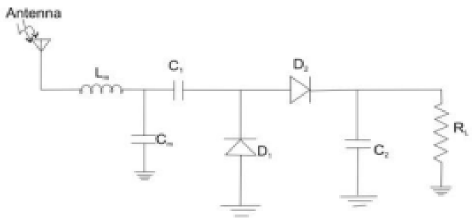

Figure 2.1: Voltage Doubler Rectifier circuit

2.2 Matching Network

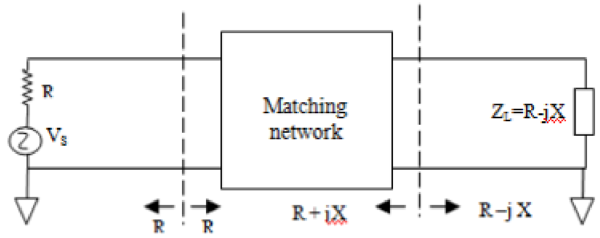

Figure 2.2: Matching Network [7]

Figure 2.2 shows the matching network diagram concept [7]. The maximum power transfer theorem asserts that the maximum power will be transferred from a source to its load if the resistance of the load and source are equal.

To optimise the amount of electricity given to the load (RL), XL and XS should be inverted so that their sum is zero. Consequently, the greatest power from a fixed source impedance to a load occurs when the source and load impedances are complex conjugates.

If there is a mismatch between the receiving antenna (source) and the rectifier, an impedance matching circuit is necessary to match the impedances of the antenna and the rectifier. The primary function of Impedance Matching is to transform the load impedance into the complex conjugate of the source impedance so that the maximum amount of power can be transmitted to the load. When a passive lossless network is used to match a source to a load, the source is conjugate-matched to the input of the matching network, and the load is conjugate-matched to the output of the matching network.

There are a variety of networks that can be utilised for impedance matching. a) Matching impedance with a shunt inductor. b) Impedance matching through the utilisation of an LC Network. b) Impedance matching by utilising a transformer. d) Impedance matching with a pi-Network. e) Impedance matching using a T-network. Matching transmission line impedance.

2.2.1 LC Matching Network

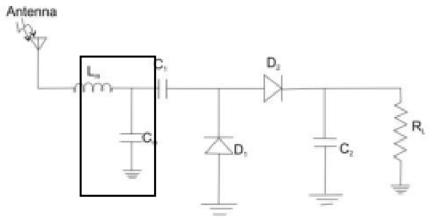

Figure 2.3: Matching Network (highlighted)[7]

The matching network that I have selected is shown in Figure 2.3 above (highlighted). It is a simple LC network impedance matching circuit, which is inserted between the RF source and the rectifier in the RF energy harvester to reduce the number of required circuit components and, consequently, the size of the device. It is made up of a series-parallel arrangement of an inductor and a capacitor. This LC network matches the impedance of the antenna to the impedance of the rectifier circuit at 945MHz. The LC network also functions as a low pass filter that allows 945MHz RF radiation through while rejecting higher order harmonics. Thus, the diode's nonlinear rectification nonlinearly generates harmonics.