ENERGY SCAVENGING FOR MOBILE AND WIRELESS DEVICE USING HIGH-EFFICIENCY RECTIFIER CIRCUIT

LEE YOUHUI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ENERGY SCAVENGING FOR MOBILE AND WIRELESS DEVICES USING HIGH-EFFICIENCY RECTIFIER CIRCUIT

LEE YOUHUI

This Report Is Submitted In Partial Fulfillment Of Requirements For the Bachelor Degree in Electronic Engineering (Telecommunication Electronic)

Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer

Universiti Teknikal Malaysia Melaka

JUNE 2016

UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : ENERGY SCAVENGING FOR MOBILE AND WIRELESS DEVICES USING HIGH-EFFICIENCY RECTIFIER CIRCUIT

Sesi Pengajian : | | | | | |

Saya ………………LEE YOUHUI…………………………………………………………………………..
(HURUF BESAR)

mengaku membenarkan Laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (√) :

☐ **SULIT*** — *(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD**** — **(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☐ **TIDAK TERHAD**

Disahkan oleh:

(TANDATANGAN PENULIS) (COP DAN TANDATANGAN PENYELIA)

Tarikh: ……………………….. Tarikh: ………………………..

"I hereby declare that the work in this project is my own except for summaries and quotations which have been duly acknowledge."

Signature : ....

Author : LEE YOUHUI

Date : ....

"I acknowledge that I have read this report and in my opinion, this report is sufficient in term of scope and quality for the award of Bachelor of Electronic Engineering (Electronic Telecommunication) with Honours."

Signature : ....

Supervisor's Name : DR Wong Yan Chiew

Date : ....

To dear mother and father and friends that give guidance to me

ACKNOWLEDGEMENT

I was able to carry out this project with the help of my supervisor DR Wong Yan Chiew and friend. I would like to take this opportunity to express my appreciation to all those who helped me throughout my final year project. A special thanks to DR, Wong Yan Chiew for her time and dedication for her guidance.

I also would like to extens my appreciation to my faily and friends. Thanks to their support, financial support and encouragement. Besides, I also like to appreciate my friends that assist me and give me guidance through the whole project.

Last but not least, I would further extend my appreciation to my faculty FKEKK, which teach me and guided me with knowledge and ethic. Furthermore, I would also like to appreciate the guidance and suggestion from panels of seminar who give comment and advice which can improve my project.

ABSTRACT

This project is to develop a high-efficiency RF to DC rectifier using CMOS technology for an energy harvesting system. Energy harvesting or energy scavenging is the process to harvest ambient energy from the atmosphere such as solar energy, RF energy, vibration energy or thermal energy to a usable electrical signal. RF energy harvesting is getting more demand because the density of the wireless communications devices rapidly increases in metropolis area. This power extraction method able to solve the growing demand for power supply to the low-power electronics. Therefore, high efficiency of RF to DC rectifier is crucial. A high-efficiency CMOS based rectifier has been developed enabling the integration of rectifier into any wireless devices and mobile phone. Parametric simulations to the rectifier were done to investigate factors that affect the power conversion efficiency of the rectifier. Circuit parameters that been analysed including the sizing of the transistor, the threshold voltage of the devices, load impedance, inter-stage capacitor and number of stages of the rectifier. By using the optimized parameter set, we successfully achieve 13.3% of conversion efficiency in a single stage rectifier. The conversion efficiency decreases to 8.5% by increasing the number of rectifier's stages to three.

ABSTRAK

Projek ini adalah untuk membangunkan satu RF-kecekapan yang tinggi untuk DC teknologi penerus menggunakan CMOS untuk sistem penuaian tenaga. penuaian tenaga atau memerangkap tenaga adalah proses untuk menuai tenaga ambien dari atmosfera sebagai tenaga solar, tenaga RF, tenaga getaran atau tenaga haba kepada apa-apa isyarat elektrik yang boleh digunakan. RF penuaian tenaga semakin lebih banyak permintaan kerana ketumpatan peranti komunikasi tanpa wayar cepat meningkat di kawasan metropolis. Kaedah pengekstrakan kuasa dapat menyelesaikan permintaan yang semakin meningkat untuk bekalan kuasa kepada elektronik kuasa rendah. Oleh itu, kecekapan tinggi RF untuk DC penerus adalah penting. A penerus CMOS kecekapan tinggi berasaskan telah dan dibangunkan membolehkan integrasi penerus ke dalam mana-mana peranti tanpa wayar dan telefon bimbit. simulasi parametrik untuk penerus itu dilakukan untuk menyiasat faktor yang mempengaruhi kecekapan penukaran kuasa penerus. Parameter litar yang dianalisis termasuk saiz transistor, voltan ambang peranti, beban impedans, antara peringkat kapasitor dan bilangan peringkat penerus. Dengan menggunakan set parameter yang optimum, kami berjaya mencapai 13.3% daripada kecekapan penukaran dalam penerus peringkat tunggal. Kecekapan penukaran berkurangan kepada 8.5% dengan meningkatkan bilangan peringkat penerus kepada tiga.

TABLE OF CONTENT

LIST OF FIGURE

LIST OF TABLE

LIST OF ABRREVIATIONS AND ACRONYMS

RF	Radio Frequency
NMOS	N-type metal-oxide-semiconductor logic
PMOS	P-type metal-oxide-semiconductor logic
P.C.E	Power Conversion Efficiency
ADS2011.1	Advanced System Design 2011.1
DC	Direct Current
CMOS	Complementary metal–oxide–semiconductor
SVC	Self-Threshold Voltage Cancellation
IVC	Inter threshold Voltage Cancellation
DCP	Dickson Charger Pump
DRC	Design Rule Check
LVS	Layout vs. Schematic
DDR	Differential Drive Rectifier
PIFA	Planar Inverted F Antenna

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

Chapter 1 consist of the background of the project for this dissertation. A few major energy harvesting problem was presented in the introduction. Secondly, this section consists of another four major part which consists of the problem statement, the objective of this dissertation, scope of work for this project and Outline of this thesis.

1.1 Introduction

Energy harvesting or energy scavenging is the process to harvest ambient energy from the atmosphere such as solar energy, RF energy, vibration energy or thermal energy to a usable electrical signal. RF energy harvesting is getting more demand because the density of the wireless communications devices rapidly increases in a metropolis area [1]. This power extraction method can solve the growing demand for power supply to the low-power electronic consumption, such as wearable devices, wireless devices, mobile phone and sensors. All this application required a battery as an energy source [2]. Therefore, high efficiency of RF to DC rectifier is crucial.

Since the advancement of nanotechnology, industries able to implement a smaller size electronic circuit with low power application. This development can integrate into a wireless sensor network, biomedical devices, wearable device, and mobile phone. But all these devices required an energy source such as supply battery power to it [2-4]. Furthermore, there is no development in battery technology. Which is a tradeoff for nanotechnology. Besides that, the battery is bulky, limited supply and chemical hazard when implemented in biomedical devices. Therefore, RF harvesting is the solution for this problem. To improve the power conversion efficiency the power consumption, voltage threshold needs to be reduced.

Different topologies of RF to DC rectifier had been discussed in [1, 5-11]. The most popular rectifier discussed are Dickson's charger pump, differential drive rectifier, Villard converter and another type of AC to DC Converter which able to implement in CMOS technology. To improve the efficiency of the rectifier, different types of internal voltage cancellation technique had been introduced. As an example, internal voltage cancellation (IVC), self-voltage cancellation and floating gate techniques. These techniques can improve the power conversion efficiency, which enables the harvester to accumulate the surrounding ambient energy to the energy storage for a lifetime.

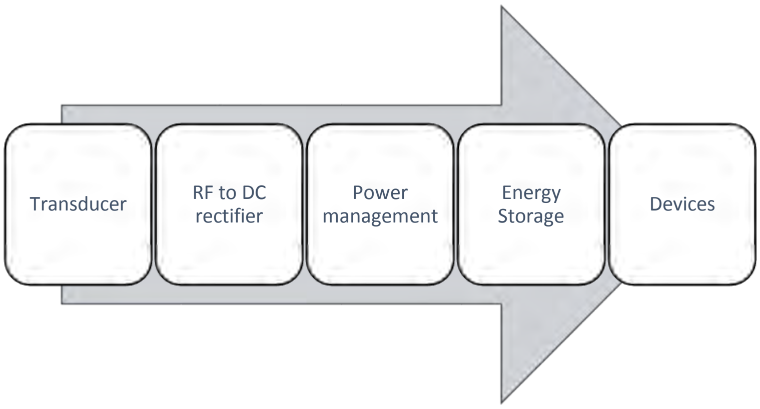

Figure 1-1 Common energy harvesting system

Figure 1-1 illustrate the block diagram of the energy harvesting system. It includes four main components that contribute to the overall system before supplying energy to the devices.

- Transducer

  The transducer is used to harvest the ambient energy then converts usable energy. As an example, RF antenna to convert the RF energy to the electrical energy. It can be AC or DC circuit.

- RF to DC rectifier

  RF to DC rectifier or converter is used to convert the AC electrical energy to useable DC energy. It can be voltage multiplier that rectifies the AC electrical energy to DC electrical energy. The DC electrical energy will be amplified.

- Power management

The power management circuit depends on its applications; it can use to regulate a stable DC voltage by using buck or boost converter and limited by voltage limiter. This system can control the conveying of the electrical path between the devices and the harvester.

- Energy storage

The charge storage is to store the harvested energy, either in a capacitor or rechargeable battery or another type of storage element.

1.2 Problem Statement

Energy harvesting or energy scavenging is the process to harvest ambient energy from the atmosphere such as solar energy, RF energy, vibration energy or thermal energy to a usable electrical signal. RF energy harvesting is getting more demand because the density of the wireless communications devices rapidly increases in a metropolis area [1]. This power extraction method able to solve the growing demand for power supply to the low-power electronics such as wearable devices, wireless devices, mobile phone and sensors. All this application required a battery as an energy source [2]. Therefore, RF to DC rectifier will be the crucial point to improve the efficiency.

1.3 Objective of Project

Conventional RF to DC rectifier uses Schottky diodes to develop, which is bulky and not suitable for smaller devices. Therefore, RF to DC rectifier will be implemented in CMOS process technology. In this project emphasize on the power conversion efficiency and parameter that affect it.

The main objective of the project is:

1. To design and develop a high-efficiency rectifier for an RF harvesting system that able to applied to the wireless device and mobile devices.
2. To investigate parameter that affects the power conversion efficiency in the rectifier.
3. To optimize the RF to DC rectifier

1.4 Scope of work

This project focuses on the higher power conversion efficiency in 130nm silterra process technology. The main scope of the project is:

- To enhance the power conversion efficiency of the rectifier
- To design and simulate an RF to DC rectifier using two types of voltage cancellation technique
- To study two types of rectifier topologies and benchmark with the existing study in the journal.
- To studies the parameter such as the width of the transistor, various input voltages, and different output impedance.

1.5 Organization of the Thesis

This thesis consists of five chapters and the overview of all the chapter as follows:

Chapter 1: This chapter provides a brief introduction to the background, problem statement, and scope of work involved in accomplishing this project.

Chapter 2: a Literature review on the fundamental of Power Conversion Efficiency (P.C.E), an overview of the two types of RF to DC converter which is a Dickson charger pump and a differential drive CMOS rectifier. And technique to improve the P.C.E and the parameter that affect it.

Chapter 3: This chapter gives an overview of the fundamental to design the RF to DC rectifier, simulation and the overall procedure for Analog IC design.

Chapter 4: This chapter describes the simulation and simulation result of this project, including a description and discussion.

Chapter 5: conclusion in chapter 5 and followed by the recommendations for future work.

Next, the thesis has contributed some technical papers which to be published as shown in Appendix part.

CHAPTER 2

LITERATURE REVIEW

This chapter consists of 7 major parts the first parts explains on the Power Conversion Efficiency of the rectifier, then the fundamental of the RF Spectrum and power density in free space. In the third part the RF to DC architectures are a review, then follow up by the difference between single ended rectifier and differential ended rectifier. In this section, a review in the factor that affects the Power Conversion Efficiency, which included: Threshold voltage, sizing and On-off characteristic of the rectifier. A further review of different threshold voltage cancellation was done. Last and not least a further comparing with different rectifier are present this chapter.

2.1 Power Conversion Efficiency

Power Conversion Efficiency or P.C.E is the main criteria will be focused on this project. As the higher the converted harvested energy, the higher the P.C.E in the RF to DC rectifier. From [1, 2] the power conversion efficiency is defined as equation [1].

$$P.C.E = \frac{Pdc}{Prf}$$

Where Pdc is the power from the load terminal, then Prf is the input power from the input terminal at the Voltage peak of the sinusoidal.

2.2 RF Spectrum and Power Density

RF Spectrum consists of different operating band frequency; each band consists of different application and function for wireless communication system. Figure 2-1 shows the spectrum of the RF spectrum that able to harvest from the surrounding.

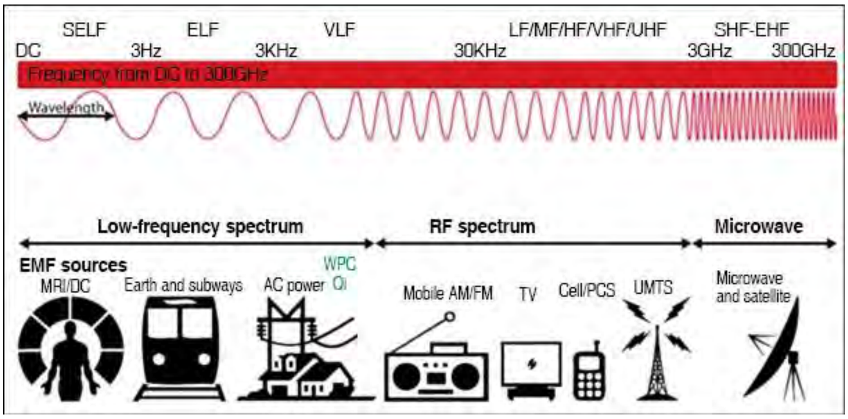

Figure 2-1 RF spectrum and microwave

In this project, the targeted operating band will be RF spectrum, which consists of TV, FM or AM radio, Mobile phone, UMTS and another type of wireless devices. This radio wave consists of magnetic and electric radiation component that enable wireless communication to transmit information. Information is pass through different modulation technique and amplitude inside the signal. Wireless communication devices use the antenna as the transmitting medium to convert electrical signals to an RF signal. This requires certain power to be transmitted to the thin air. Therefore, it can be harvested using an antenna to convert the RF signal to usable electrical signal. The theoretical maximum power available power for conversion is 7.0uW and 1.0uW for the frequency of 900MHz and 2.4MHz respectively within the free space of 40m [12].

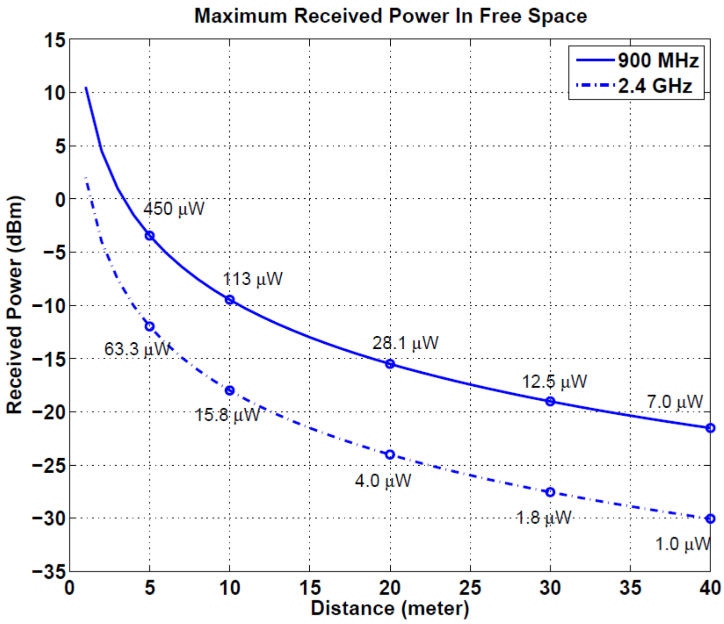

Figure 2-2 Maximum Power Transfer in different free space

2.3 Architecture of RF to DC rectifier

Conventional rectifier used four diodes to create full bridge rectifier, but this rectifier had a high voltage drop which results in the power conversion efficiency to drop. As some of the voltage is used to power up the diode. To achieve high power conversion efficiency, Schottky diode is used as it has lower threshold voltage than a conventional diode. But Schottky diode is bulky and not able to implement in CMOS technology, as the Schottky diode required more cost to fabricate in CMOS technology process.

2.3.1 Dickson Charger Pump Rectifier

The Dickson charger pump is the most common RF to DC converter in the RF harvesting system, [1] and [13] which used a different type of cancellation method. Figure 1 shows the Dickson charger pump which will be used for the prototype of RF to DC rectifier.