UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN OF ANTENNA WITH MATCHING AND RECTIFYING CIRCUIT FOR RADIO FREQUENCY ENERGY HARVESTING SYSTEM

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MASTER OF SCIENCE
IN ELECTRONIC ENGINEERING

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A thesis submitted
in fulfillment of requirements for the degree of Master of Science
in Electronic Engineering

Faculty of Electronic and Computer Engineering

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2015

DECLARATION

I declare that this thesis entitled "Design of Antenna with Matching and Rectifying Circuit for Radio Frequency Energy Harvesting System" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature	:	....
Supervisor Name	:	....
Date	:	....

ABSTRACT

Nowadays, the development of wireless communication has become more important and has received huge demands around the globe. As the technologies of wireless communication systems are evolving, the energy or power that is needed to operate these wireless devices are also increasing. However, limited natural power sources have stimulated a few alternatives of producing renewable energy, including the energy harvesting system. The purpose of this project was to design a radio frequency (RF) energy harvesting system to scavenge RF energy from the ambient. An RF energy harvesting device consists of three primary subsystems. The first subsystem is the receiving antenna, which is responsible for capturing all the RF energy that is later used to power the integrated embedded system. The second main subsystem is the matching circuit, which is used to match the impedance between antenna and rectifier in minimizing power loss, hence improving the efficiency of the overall system. Meanwhile, the third subsystem is the rectification circuitry, which efficiently converts the input RF power into DC output power. Each one of these three subsystems is integral to the operation of the entire harvester system. Thus, a 2.45GHz RF energy harvester was proposed. The presented work consisted of defining the characterizations of all subsystems and was preceded with optimized design process. The prototype of the system was then fabricated in-house for lab measurement and test. From the measurement that had been carried out, the RF energy system produced low DC voltage, which was applicable to operate low voltage applications and devices. The final design of antenna operated at 2.45GHz with 14.16dB gain and a strong directional radiation pattern, while the measured efficiency of the single stage and the cascaded rectifier were up to 13.99% and 42.26% respectively. The simulation and the measurement results were then compared. The antenna was designed with Computer Simulation Technology (CST) Studio suite 2011 software, whereas the rectifier and the matching circuit were designed with Agilent Technology Advanced Design System (ADS) 2011 software. From the measurement results obtained in this project, the integration between the antenna and the rectifying circuit was done successfully to obtain output DC voltage, and subsequently proved the concept of the RF energy harvesting system. The output result obtained from this system is adequate and should be able to operate some applications, for instance, sensors with appropriate supplying voltage to operate.

ABSTRAK

Pada masa kini, pembangunan komunikasi tanpa wayar telah menjadi satu kepentingan dan menerima permintaan yang besar di seluruh dunia. Seperti mana teknologi sistem komunikasi tanpa wayar sedang berkembang, tenaga atau kuasa yang diperlukan untuk mengendalikan alat-alat tanpa wayar juga semakin meningkat. Walau bagaimanapun, sumber tenaga semula jadi yang terhad telah merangsang beberapa langkah alternatif untuk menghasilkan tenaga yang boleh diperbaharui, termasuk sistem penuaian tenaga. Tujuan projek ini adalah untuk mereka bentuk satu sistem penuaian tenaga berasaskan frekuensi radio (RF) dari ambien atau persekitaran. Alat penuaian tenaga RF ini terdiri daripada tiga sub-sistem utama. Sub-sistem pertama adalah antena penerima, yang bertanggungjawab untuk menyerap semua tenaga RF yang kemudiannya akan digunakan untuk menguasakan seluruh sistem bersepadu yang telah diintegrasikan. Sub-sistem utama kedua adalah litar padanan, yang digunakan untuk memadankan galangan antara antena dan rektifier untuk meminimumkan kehilangan kuasa, seterusnya meningkatkan kecekapan keseluruhan sistem ini. Sub-sistem ketiga adalah litar rektifier, yang cekap menukarkan kuasa RF kepada kuasa arus terus sebagai output. Setiap sub-sistem secara keseluruhannya adalah penting untuk operasi sistem penuai. Sebuah penuai tenaga RF pada frekuensi 2.45GHz adalah dicadangkan. Kerja-kerja yang dibentangkan mengandungi penakrifkan sifat bagi semua sub-sistem dan diteruskan dengan proses reka bentuk yang optimum. Prototaip sistem ini kemudian difabrikasikan untuk ukuran prestasi dan ujian makmal. Dari pengukuran prestasi yang telah dijalankan, sistem tenaga RF ini berjaya menghasilkan voltan arus terus rendah yang boleh digunakan untuk mengendalikan aplikasi dan peranti voltan rendah. Reka bentuk akhir antena beroperasi pada 2.45GHz dengan 14.16dB gandaan dan corak radiasi sehala yang besar. Sementara itu, kadar kecekapan yang diukur bagi rectifier seperingkat dan rectifier berganda masing-masing adalah sebanyak 13.99% dan 42.46%. Keputusan simulasi dan ukuran kemudiannya dibandingkan. Antena direka menggunakan perisian CST Studio Suite 2011 manakala rektifier dan litar padanan direka menggunakan perisian Agilent Advanced Design System 2011. Daripada hasil pengukuran, integrasi antara antena dan rektifier telah Berjaya dilakukan bagi menghasilkan keluaran voltan arus terus dan seterusnya mengesahkan konsep sistem penuai tenaga RF. Voltan keluaran daripada sistem ini adalah mencukupi untuk beroperasi bagi beberapa aplikasi seperti sensor yang memerlukan voltan yang bersesuaian untuk berfungsi.

ACKNOWLEDGEMENTS

First and foremost, all praises to Allah SWT for the strengths and His blessing in completing this thesis. In preparing this thesis, I had learned a lot of new things and knowledge. I was also in contact with many people who have contributed towards my understanding and thought. In particular, I wish to express my sincere appreciation to my main supervisor, Associate Professor Dr. Zahriladha Zakaria, for his valuable encouragement, guidance critics and moral support. I am also very thankful to my co-supervisors Dr. Mohamad Zoinol Abidin Abd Aziz and Dato' Professor Dr. Mohd Nor Husain for their guidance, advices and motivation. Without their continued support and interest, this thesis would not have been same as presented here. I am also indebted to my beloved Universiti Teknikal Malaysia Melaka (UTeM) particularly to all technicians of FKEKK who provided me with their assistance throughout my experiments and lab tests. My devoted fellow postgraduate colleagues were definitely deserved to be recognized for their help and support at various occasions. Every seconds of time spent with them gives me that wonderful passion of completing my study. Last but surely, I would like to express my gratitude to my precious parents, Zainuddin Mohd Zin and Nurul Hidayah Ayob, and my beloved brothers for their never-ending love and support in my whole life. I would never have the guts to start this inspiring journey without their encouragement. May Allah bless them all.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
ADS	-	Advanced Design System
BiCMOS	-	Bipolar Complimentary Metal-Oxide-Semiconductor
CPW	-	Coplanar Waveguide
CST	-	Computer Simulation Technology
DC	-	Direct Current
EM	-	Electromagnetic
GSM	-	Global System for Mobile
ISM	-	Industrial Scientific & Medical
PC	-	Personal Computer
PCB	-	Printed Circuit Board
RF	-	Radio Frequency
TV	-	Television
UV	-	Ultra Violet
VSWR	-	Voltage Standing Wave Ratio
WLAN	-	Wireless Local Area Network
WSN	-	Wireless Sensor Networks

LIST OF APPENDICES

LIST OF PUBLICATIONS

The research papers produced and published during the course of this research are as follows:

1. Zahriladha Zakaria, Nur Aishah Zainuddin, Mohd Nor Husain, Mohamad Zoinol Abidin Abd Aziz, Mohamad Ariffin Mutalib, Abdul Rani Othman, "Current Developments of RF Energy Harvesting System for Wireless Sensor Networks", *Advances in Information Sciences and Service Sciences (AISS)*, Vol. 5, No. 11, pp. 328-338, June 2013.
2. Zahriladha Zakaria, Nur Aishah Zainuddin, Mohd Nor Husain, Bazilah Mohd Derus, Mohamad Zoinol Abidin Abd Aziz, Mohamad Ariffin Mutalib, "Investigation of Wideband Coplanar Antenna for Energy Scavenging System", Australian Journal of Basic and Applied Sciences, Vol. 8, No. 4, pp. 270-277, 2014.
3. Zahriladha Zakaria, Nur Aishah Zainuddin, Mohd Nor Husain, Mohamad Zoinol Abidin Abd Aziz, Mohamad Ariffin Mutalib, "Investigation of Compact Tree-Shaped Coplanar Waveguide (CPW) Antenna for RF Energy Harvesting", *Journal of Applied Mechanics and Materials*, Vol. 699, pp. 903-908, November 2014.
4. Zahriladha Zakaria, Nurul Nadia Razak, Nur Aishah Zainuddin, Mohd Nor Husain, Yosza Dasril, "Analysis of Matching Circuit to Improve the Efficiency of RF to

DC Conversion for Ambient RF Energy Harvesting", *Journal of Applied Mechanics and Materials*, Vol. 699, pp. 909-914, November 2014.

5. Zahriladha Zakaria, Nur Aishah Zainuddin, Mohd Nor Husain, Mohd Nabil Imran Kamaruzaman, Mohamad Zoinol Abidin Abd Aziz, Nor Zaidi Haron, Mohd Sa'ari Mohamad Isa, Mohamad Ariffin Mutalib, "Design of Antenna with Rectifying Circuit for Low Power Wireless Sensor Network Application", *Advanced Science Letters*, Vol. 20, No. 10-12, pp. 1788-1792, October 2014.
6. Zahriladha Zakaria, Nur Aishah Zainuddin, Mohamad Zoinol Abidin Abd Aziz, Mohd Nor Husain, Mohamad Ariffin Mutalib, "Dual-Band Monopole Antenna for Energy Harvesting System" IEEE Symposium on Wireless Technology and Applications, pp.225-229, Kuching, Sarawak, 22-25 September 2013.
7. Zahriladha Zakaria, Nur Aishah Zainuddin, Mohamad Zoinol Abidin Abd Aziz, Mohd Nor Husain, Mohamad Ariffin Mutalib, "A Parametric Study on Dual-Band Meander Line Monopole Antenna", IEEE International Conference on RFID Technologies and Applications, Johor Bahru, Johor, 4-5 September 2013.
8. Zahriladha Zakaria, Nur Aishah Zainuddin, Mohamad Zoinol Abidin Abd Aziz, Mohd Nor Husain, Mohamad Ariffin Mutalib, "Investigation of Meander Slots to Microstrip patch Antenna", IEEE International Conference on RFID Technologies and Applications, Johor Bahru, Johor, 4 -5 September 2013.

AWARDS

2014

Bronze Medal – Analysis of Receiving Antenna Structures with High Efficiency Rectifying Circuit for Radio Frequency (RF) Energy Harvesting System, Malaysia Technology Expo (MTE), Putra World Trade Centre (PWTC), Kuala Lumpur, 20^{th} - 22^{th} February 2014.

2013

Silver Medal – Design of Antenna with Rectifying Circuit for RF Energy Harvesting, UTeMEX Expo Penyelidikan dan Inovasi 2013, Universiti Teknikal Malaysia Melaka (UTeM), 12^{th} December 2013.

CHAPTER 1

INTRODUCTION

1.0 Research Background

Energy is a basic necessity for sustaining human life, which pervades each and every one of our activities. In the very early days, muscle power was rendered from human and animals to drive simple implements and machines, which could only run for a limited time and had limitations on their continuous availability. Nevertheless, the greatest transition took place when we learnt to generate energy by transforming one state of energy, possibly latent, to another. After that, vast possibilities opened up where energy could be obtained, stored, and transferred across large distances. Figure 1.1 shows the string of energy demands in worldwide at present.

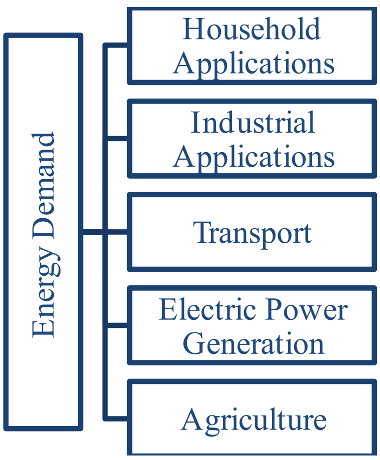

Figure 1.1: Recent Energy Demands for Daily Usage

Besides, as an essential keystone in furthering the reach of technology, it is becoming difficult to meet the insatiable need of energy today. According to International Energy Agency (IEA) (2014), the increasing energy demands have put a strain on the current energy sources. Thus, there is an incessant effort to identify new sources of energy that may partially satisfy the energy demands and conserve our finite natural resources for the years to come.

Renewable energy sources provide an alternative to conventional natural sources, of which there are limited supplies. Renewable energy can be broadly defined as a kind of energy that is generated from natural sources, which is not typically depleted, such as sunlight, wind, rain, heat, and RF signal, among others. Renewable energy is derived from natural processes that are replenished constantly. Some additional features of renewable energy sources that make them an attractive alternative to the classical natural sources are:

- Renewable energy sources are often accessible without geographical and national barriers, although certain regions may be more conducive to their large-scale use.
- Renewable energy sources are generally not harmful, which adversely affect the environment. Hence, they are green technologies and are safe to use.
- These sources are unlimited in the near term, which get used up faster every day. They are generally free to harness, although specialized equipment may be needed for high conversion efficiency.

One of the methods that have been proven to efficiently produce alternative renewable energy is by harvesting or scavenging it from ambient. Energy harvesting can be defined as a process of extracting wasted energy from the surrounding of a system, and then, converting it to usable energy.