DESIGN OF AN EFFICIENT RECTIFIER CIRCUIT FOR RF ENERGY HARVESTING

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This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electronic Engineering Technology (Telecommunication) with Honours.

by

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I hereby, declared this report entitled DESIGN OF AN EFFICIENT RECTIFIER CIRCUIT FOR RF ENERGY HARVESTING is the results of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Electrical and Electronic Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Telecommunication) with Honours. The member of the supervisory is as follow:

Signature: ………………………………………………

Supervisor : Nurulhalim Bin Hassim

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Co-supervisor: Dr A K M Zakir Hossain

ABSTRAK

Penyelidikan ini menerangkan reka bentuk litar penerus yang berkesan untuk frekuensi radio penuai tenaga. Frekuensi radio penuain tenaga adalah proses untuk menghasilkan dan menuai tenaga dari sumber luaran. Ini adalah teknologi hijau yang dapat diakses secara meluas di ruang angkasa. Lengkapkan sumber tenaga rendah yang digunakan untuk menghidupkan peranti elektronik berkuasa rendah. Litar penerus Bridge dicadangkan untuk menukar Frekuensi radio ke Arus terus. Frekuensi tetap 2GHz dicadangkan untuk pengukuran dan simulasi tahap daya input yang berbeza. Terdiri daripada rangkaian penerus yang berpotensi LC dan diod Schottky. Proses simulasi litar ADS 2017 digunakan untuk reka bentuk sistem ini.

ABSTRACT

This research describes the design of an effective rectifier circuit for RF Energy Harvest. RF Energy Harvest is a process for producing and harvesting energy from an external source. This is a green technology that is widely accessible in space. Complement the low-energy sources used to power low-power electronics devices. A Bridge rectifier circuit is proposed to convert RF to DC. Fixed frequency 2Ghz is proposed for the measurement and simulation of different input power levels. Consists of a combination of LC impedance matching network and Schottky diodes. The ADS 2017 circuit simulator is used for this design of the system.

DEDICATION

Alhamdulillah, praise to the Almighty Allah

S.W.T This thesis is dedicated to:

My beloved family,

My Parents,

My Supervisor and Co-supervisor

And all my friends

Thanks for their encouragement and support

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CHAPTER 1

INTRODUCTION

1.1 Background

Ambient power or also commonly known as Energy scavenging is a mechanism whereby energy is obtained and extracted from an external source. Energy harvesting has been shown to be extensively used for small and mobile system device such as wearable electronics. There are humongous sources of energy production such as wind energy, solar energy and kinetic energy. According to (Rengalakshmi and Brinda, 2016)(Re Energy scavenging is originally based on the wind-driven wheel and also waterwheel.

The collection of power from propagating radio frequency (RF) signals is one of the most common power extraction method of passive controlled devices. The process of converting energy from electromagnetic (EM) into electrical domain described as the RF energy scavenging. Energy harvesting is divided into two small and large scale categories. RF energy is on small scale categories (Rengalakshmi and Brinda, 2016). Examples of radio signals generated in our daily lives are TV signals, wireless network and cell tower. Throughout the field of communication, the RF signal is widely used (ElAnzeery and Guindi, 2012).

In future microelectronic circuits, RF Energy Harvesting has an important role to play (Din, 2012). The power source transmits in a very wide (kW) range. However, the receiver receives only a small-scale of range. The energy residue as heat is dissipated. Then, the unused energy could be transformed to produce small amount of electricity.

RF-powered devices are usually used in employments such as structural control, considering difficulty to replace the battery without harming structure as in Figure 1.1.

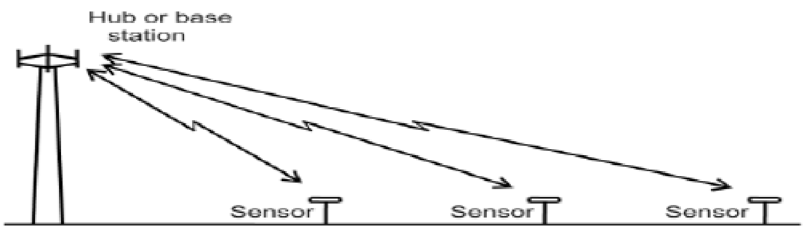

Figure 1. 1: Communication links between the base station (hub) and sensors in passively sensor network(Binti Amilhajan, 2014).

1.2 Problem Statement

Wireless power transmission (WPT) established almost a century ago and began to evolve day by day. Smartphone and IoT technology is an example of the use of wireless application. Many developers and researcher have begun using harvesting ambient RF energy to eliminate battery-based system. The reason for removing the battery-based system is because due to the operating life time and to continuously changing the battery. Moreover, the deposition of the battery creates environmental emissions. There is also an increasing demand for the use of ambient RF energy technology as it allows wireless charging of low-power devices and has resulting benefits for product design, usability and reliability.

In addition, there are many challenges to the design of a circuit for RF energy harvesting, in particular for energy conversion efficiency. Several researchers have performed studies on the nature of the RF energy system. RF energy harvesting is split into two parts for low-power and wide input power ranges. There a few scenarios the need to considered such the amount of RF energy that have not been used and number of the RF tower around that area that may produce the outcomes. To produce a good DC-conversion voltage and optimum efficiency, the rectifier circuit need to be designed by using lump elements and active element such as Schottky diode.

1.3 Objective

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

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

III. To verify the measurements value towards simulation results.

1.4 Scope of work

Scopes are recorded to ensure the project will be inside its expected point of confinement. The scope will be functional to ensure those project is going in the correct course with the achieve the goal. In the process of the designing Energy Harvesting system, the main objective of this project is rectifier circuit. It consists of diode and capacitor. The basic concept of an Energy Harvesting is shown in Figure 1.2 and it consists of antenna that receive/transmit signals within a certain frequency range connected to a rectifier (AC/DC converter) (Keyrouz, Visser and Tijhuis, 2012).

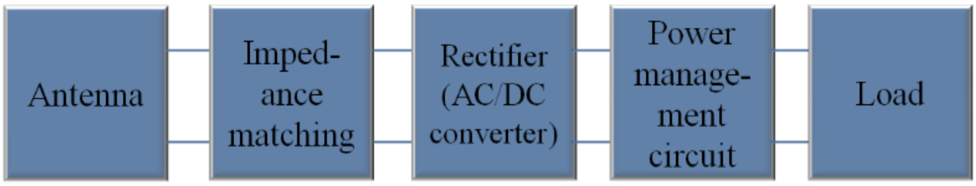

Figure 1.1: Energy Harvesting System(Keyrouz, Visser and Tijhuis, 2012)**.**

Agilent Advanced Design System (ADS) 2017 will be used for design process of rectifier circuit. Bridge rectifier with fixed frequency 2GHz is proposed. It consists of four diodes. The schottky diodes are used because it suitable for the weak RF signal environment, low recovery time and provides high efficiency for RF-to-DC. Next, it will follow by variations of load where the load varying from 50 Ω to 100 kΩ. Then, the lump elements will be including to improves the conversion efficiency of the circuit. After testing and simulation, the rectifier circuits will be manufactured.

CHAPTER 2

LITERATURE REVIEW

2.1 Rectifiers with Low Input Power Applications

Recently, there's a growing interest within the design of low-power circuits by using microstrip antenna (Kundu (Datta) et al., 2017). It allows Energy Harvesting (EH) systems to be ready to feed electronics circuits that execute complex process and play a crucial role in several application areas. Consistent with (Din, 2012) there are two reasons why this work is administered by a number of researchers who are freely available in space and complement the low-energy sources used to power low-power electronic devices, Green Technology. It consists of antenna that collect electromagnetic energy which convert the collected RF energy to dc power, so on replace the necessity for batteries.

The author in (Rengalakshmi and Brinda, 2016) designed an energy harvesting system which scavenges energy from RF electromagnetic spectrum and its operated in GSM 900 band. Based on the lab test the rectifier efficiency are around 72% for low input power. In (Din, 2012) the system is focused to supply source of energy for energizing low power devices. The E-shaped antenna was proposed from the traditional wide band microstrip antennas and including another subsystem which is a π impedance combination and 7-stage voltage doubler circuit. The design and simulation were performed using Multisim software. Based on the field test the DC voltage acquired was 2.9V and was enough to power the STLM20 temperature sensor. In (Razavi Haeri *et al.*, 2017) proposed rectifier circuit for ambient energy that priority in Ultra-low power applications. This was achieved by designing 50-stage Dickson rectifier and manufactured using a 180 nm TSMC CMOS layout. The input voltage for IC is 900 MHz that standardizes for true comparison value. Thus, a 50-ohm input impedance network was set up at the input of the IC. However, an identical network will be used to supply a passive system in the actual configuration of the harvester.

Typically, rectennas cannot be directly compare, as they function in different amounts of control, and different concepts of efficiency can be used in different articles more objectively. Table 2.1 lists the performance satisfactory RF to DC conversion at low input power densities. However, GSM 900 is on the top of public telecommunications band for the RF energy harvesting densities.

Table 2. 1: Comparison of Power conversion efficiency

Reference	Frequency(GHZ)	Rectifier Circuit	RF-to-DC(%)
(Kasar, Gözel and Kahriman, 2019)	1	Single-stage	70.5
(Razavi Haeri *et al.*, 2017)	0.9	50-Stage voltage double rectifier	60
(Kundu (Datta), Acharjee and Mandal, 2017)	2.5	Bridger	50
(Rengalakshmi and Brinda, 2016)	0.945	Voltage double rectifier	72
(Song *et al.*, 2015)	1.8-2.5	Full-wave Grienacher	55
(Chuc and Duong, 2015)	2.45	Voltage Doubler	70.06
(Tudose and Voinescu, 2013)	2.45	Voltage Doubler	67
(ElAnzeery and Guindi, 2012)	0.5-9	N-stage Multiplier	NA

(Din, 2012)	0.8	7-Stage voltage double rectifier	30-50

2.2 Rectifiers with Wide Operating Input Power Ranges

As the development of wireless technologies grow instantly, the density of wireless surrounding increasing due to growing amount of electromagnetic sources. Definition of electromagnetic sources that are the Tx-Rx tower and WiFi-routers. In the past few years, the purpose of making use RF energy has obtained a great deal of demand in terms of saving service expenses and replacing the, also known a battery. Wireless power transmissions (WPT) employs aerial technology is considered a sensible result for converting ambient RF power to functional Dc voltage. Research in the field of rectenna leads to tonnes of development, which is broadly supported WPT and energy scavenging for the past decades(Song *et al.*, 2015). In general, wireless charging implementations (Marian *et al.*, 2012), are protected by three scenarios. As shown in figure 2.1, a solid emitter is where wireless energy is transmitted in close proximity to the sensor region. The RF power level is normally high because the distance is low. The next state is that the RF power can be transmitted from a fairly long distance through a high-power transmitting antenna. The RF power level is lower in this case due to a path failure. The third approach uses RF energy in the atmosphere and RF measure is very inadequate. Thus, it is ideal that a rectenna achieve a high Power conversion efficiency (PCE) from RF to DC over a broad scale input.

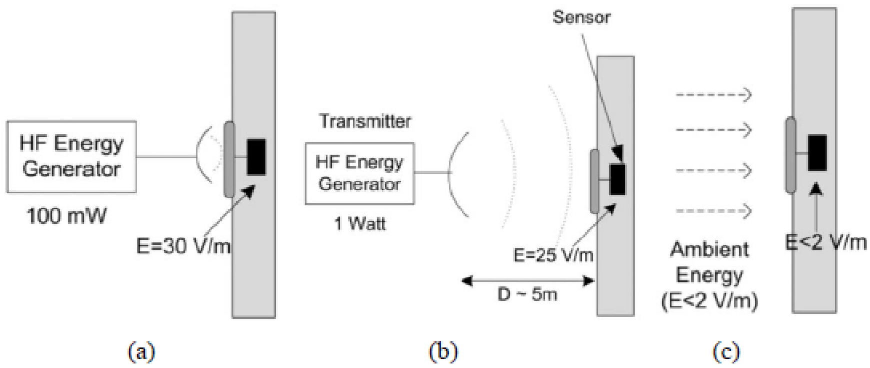

Figure 2. 1: Wireless charging situations. (a) Proximity of load. (b) Remote charging. (c) RF energy scavenging(Hucheng, 2014).

We are aware that the rectifier is in critical in WPT systems for the RF to DC transmission PCE. Various types of rectifiers have been developed for WPT applications (Divakaran, Krishna and Nasimuddin, 2019). The right diode selection depends on input power levels for a rectifier configuration. For low-supply systems a significant part of input supply is use in order to resolve the threshold voltage if input current is low. Diodes with low-input power voltage are favored. In addition, for peak supply applications the diodes with high breakdown voltage are suitable. Therefore, diodes with low threshold voltage and high breakdown voltage must be chosen in order to design a rectifier with wide range input power. Consequently, due to the inherent non-linearity of the diode, each of these conventional rectifiers can only perform a satisfactory RF to DC PCE with a narrow input power (Marian et al., 2012). A new topology is required to fulfill broad functioning wattage range, simplify the design process and reduce advanced manufacturing technology requirements.

In (Kasar, Gözel and Kahriman, 2019) study of single and N-stage of Dickson rectifier would be capable of carrying out RF energy scavenging were suggested. The Dickson rectifier circuit gives feedback to small amount of current and voltage, contributes in efficiency of Power conversion which produce high output voltage. Operating at 1GHz and the maximum PCE is 70.5%-77%. 1.8V Dc voltage is the peak of output voltage and 5.16V in 3 stage. Moreover, the efficiency of the rectifier circuit was determined by using equation (2.11). Where, P_{in} is the input power, P_{DC} is the value power collected at the output from load resistance.

$$PCE = \frac{P_{DC}}{P_{in}} \qquad (2.1)$$

The efficiency analysis was performed according to different input powers according to one of the key output parameters of rectifiers circuits. In (Divakaran, Krishna and Nasimuddin, 2019) the main objective is to apply the operating power supply to the Internet of Things (IoT). Another interesting alternative in cases where solar harvests are not feasible is the RF energy harvesting. However, despite a well-developed RF communication system architecture, the RF energy harvesting systems are facing with several challenges especially for the harvesting of RF signals in the ambient environment. The overall conversion performance, width and form factor can be loosely defined as the challenges. The RF source is an alternative due to its continuous availability but it suffers from low incident power levels. However, dedicate source and effective DC conversion circuits can accommodate wide input operating ranges can be enhanced. Table 2 contrast energy transmission in the near and far fields. The near field transmission is used to power