DUAL BAND RECTYFYING CIRCUIT FOR RF ENERGY SCAVENGING

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By the name of Allah the Most Gracious, Most Merciful

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ABSTRACT

Radio Frequency Energy Scavenging is a research area of on demand technology, related to sustainability which could turn into a promising alternative to existing energy resources. Energy scavenging offer a potential solution to the barrier faced by Wireless sensor networks (WSNs) in order to supply power without the need of wiring and also replacement of battery. One of the crucial parts in RF Energy scavenging is rectifying circuit that converts the RF signal to DC signal. In this project a dual frequency of rectifying circuit is designed, simulated, fabricated and measured by using the Advance Design System (ADS) 2011 software. Frequency 1.8 GHz and 2.45 GHz are proposed for this project. This rectifying circuit consists of a single stub matching network, multistage Wilkinson power combiner and voltage doubler. The simulation result of this dual band rectifying circuit is 6.7V while in the measurement the output result is 5.2V at input signal 20 dBm.

ABSTRAK

Penuai tenaga radio frekuensi adalah bidang penyelidikan mengenai teknologi permintaan, yang berkaitan dengan kelestarian tenaga dimana ia menjanjikan alternatif bagi menggantikan sumber-sumber yang sedia ada. Penuai tenaga menyediakan penyelesaian berpotensi bagi masalah yang dihadapi oleh rangkaian sensor tanpa wayar (WSNs) bagi membekalkan kuasa tanpa memerlukan pendawaian dan atau bagi menggantikan bateri. Salah satu bahagian yang terpenting dalam penuai tenaga RF adalah litar penerus yang menukarkan isyarat RF kepda isyarat DC. Dalam projek ini, dwi jalur litar penerus telah direka, disimulasi, dibina and diukur dengan menggunakan perisian Advance Design System (ADS) 2011. Frekuensi 1.8 GHz and 2.45 GHz telah dicadangkan untuk projek ini. Litar penerus ini terdiri daripada "single stub matching network", penggabung kuasa Wilkinson dan litar voltan pengganda. Hasil simulasi dari dwi jalur litar penurus adalah 6.7V manakala bagi hasil ukuran ialah 5.2V pada isyarat masukan 20 dBm.

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LIST OF ABBREVIATION

AC	-	Alternating Current
ADS	-	Advance Design System
DC	-	Direct Current
EM	-	Electromagnatic
FR4	-	Flame Retardant 4
GSM	-	Global System for Mobile
HB	-	Harmonic Balance
ISM	-	Industrial Scientific and Medical
RC	-	Resisitance Capacitance
RF	-	Radio Frequency
RFID	-	Radio Frequency Identification
TEM	-	Transverse electromagnetic
WLAN	-	Wireless Local Network
WSN	-	Wireless Sensor Netwrk

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CHAPTER 1

INTRODUCTION

1.1 Research Background

With the growing technologies of integrated circuits towards low power consumption and low voltage, energy scavenging has been a fast growing topic. Energy scavenger is the process by which energy is derived from ambient sources and converted into suitable direct current (DC) power for wireless application such as sensor network, portable medical devices and radio frequency identification (RFID) tags. The developing in this technology can potentially be used to reduce or eliminate the dependence most wireless applications and low power integrated technology have on wire or non-autonomous power sources.

There is some possible energy that can be used as energy scavenging. Sources of energy scavenging include solar, pressure variation, acoustic noise, air flow and so on have been identified by researchers as alternative energy. Energy scavenging from a solar cell or photovoltaic cell is where it converts the light energy into thermal and uses mechanical heat to generate electricity. A human body also can be one of the sources for energy scavenging. Electrical energy can be generated by walking, jogging and cycling [1]. Electromagnetic energy scavenging refers to the Faraday's electromagnetic induction theory. An oscillating coil in the magnetic field produces a voltage. The voltage or electromagnetic force (EMF) is proportional to the change of magnetic field or flux.[2] Radio frequency (RF) has been a hot topic in energy scavenging because of its availability and easy scavenging system. [3]

Rapid grow of the telecommunication technologies leads to plenty numbers of RF power sources which propagate electromagnetic wave to the air such as wireless local network (WLAN) routers, cellular base station and TV and radio broadcasting towers. RF signals are abundant and always available in ambience and become essentially free power resources [4]. RF waves exist in almost populated areas that they are present at all the time and it can come out with a smaller size as it only required part of an antenna.

Energy scavenging is a key technique that can be used to overcome the barriers that prevent the real world deployment of wireless sensor networks (WSNs) [5]. Research on WSNs has been driven (and fairly restricted) by a typical focus that is Energy efficiency. Hubs of a WSN are ordinarily powered by batteries. Once the batteries exhausted, the hub is malfunctioning. Only in particular applications, batteries can be replaced or energized. Even though it can be replaced, the replacement or energizing operation is taking time and higher in cost and also it can decrease the performance of the network. For proper operation of sensor networks, a reliable energy scavenging techniques are desired. Over the years, there is a lot of work has been done on the research from both academic and industrial researchers in large scale energy from numerous renewable energy sources. Less attention has been paid to small scale energy harvesting techniques. Though, quite a number of works have been carried out on energy scavenging for WSNs [6].

Figure 1.1 shows the basic block diagram of RF energy scavenging. The antenna is used to capture RF source that is coming from several sources such as WIFI, base station and satellite communication. Matching circuit that consists of lumped element, such as capacitor and inductor is giving a good impedance matching at the output antenna for different frequencies. Rectifier circuit will act as a conversion of RF energy to DC power. Voltage doubler will increase the voltage level that will use for charging or storing. In the rectifier circuit, efficiency is very important to define the ratio if DC power delivered to the load. To achieve high conversion efficiency, the usage of multiple frequency bands, antenna arrays, dual-circularly polarized patch antenna, etc. have been developed [7].

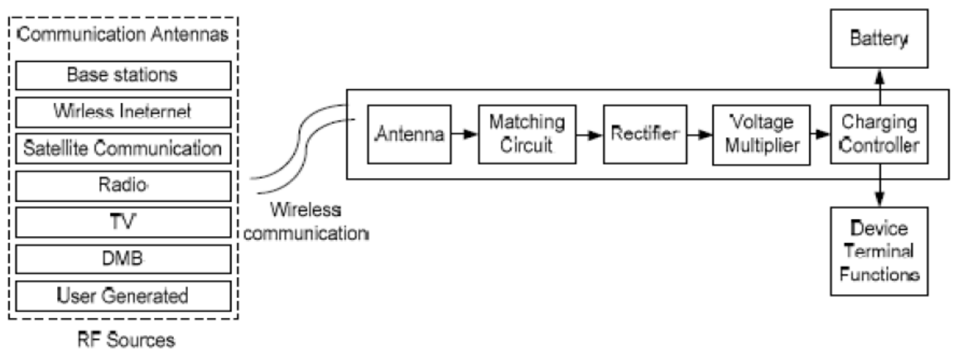

Figure 1.1: Block diagram of RF energy scavenging [8]

1.2 Problem Statement

Deployments of wireless sensor network (WSN) are rapidly increasing where mostly of these sensor nodes are battery-powered. Battery-based device are easy to deploy, but the maintenance cost is expensive. The industry needs low-cost, reliable, and long-term power source to scale WSNs and extend the deployment into hard-to-service areas where wiring or replacing batteries is impractical or very expensive. The uses of RF energy scavenging allow the overcoming of these problems. Although solar energy harvesting is commonly used in WSNs, but it should be noted that solar power suffers from energy shortage during night times. RF Energy scavenging varies with time and space.

In this thesis, it will focus on the designing of dual band rectifying circuit for RF energy scavenging. In this project, it will focus on frequency of 2.45 GHz and 1.8 GHz. The 2.45 GHz is Industrial Scientific and Medical (ISM) and its presence in the WI-FI networks while 1.8GHz presence in the Global System for Mobile (GSM) band that corresponding on mobile telephone systems.

There is researches done in designing a dual band rectifier such as [4]. In [4] although the rectifier can operate at 2.1 GHz and 2.45 GHz, it operates on a single frequency at a time. In this project, dual frequency input can operate simultaneously. This project a little bit complicated. The used of power combiner tests in this project to combine the dual band frequency.

1.3 Objectives

The objective of this project is to study and analyze the behavior of impedance matching, power combiner and rectifier circuit. This project also focuses on design, simulate and fabricate dual band energy scavenging that can operate at frequency 2.45 GHz and 1.8 GHz.

1.4 Scope of Project

The main purpose of this project is to design a dual band frequency rectifying circuit for RF energy scavenging. This project starts with understanding and analyzing rectifying circuit that consists of impedance matching, power combiner and also voltage doubler. The information can be gathered from journals, books and also paperwork on the internet. In this project the dual frequency is combined by using Wilkinson power combiner.

This project also focuses on designing a rectifier circuit that will convert RF energy to DC power. The proposed frequency of this project is 1.8GHz and 2.45GHz. One of the elements of rectifier circuit is a selection of diodes. A diode with fast switching time is important in order to achieve high efficiency. For the impedance matching network, single stub matching network is designed for the individual frequency. The performance of the rectifier circuit also influences by the load resistor. Several values of loads are analyzed to give the best performance for the circuit. To design and simulate all the circuits, Advance Design System (ADS 2011) is chosen which use the Harmonic Balance as simulation method. After all the circuit design is completed, the circuit will be fabricated and performance of the circuit will be measured in the laboratory by using signal generator.

1.5 Project Planning

Figure 1.2 shows the Gantt chart for this project. The Gantt chart shows the flow of this project develops. This Gantt chart helps to make sure the project is right on time. This project started with the briefing on final year project and end with the submission of fabricated circuit and thesis report. This project planning should be followed in order to make sure this project is finished within the prescribed time.

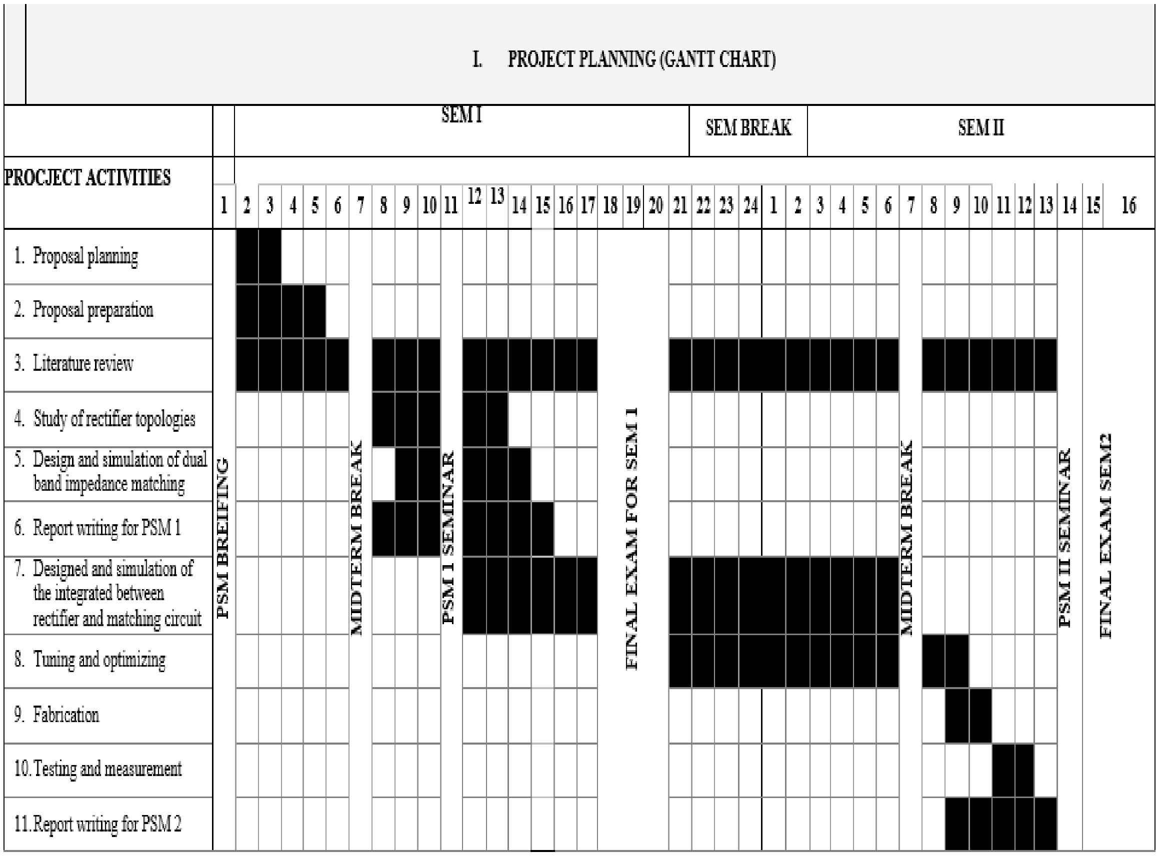

Figure 1.2: Gantt chart of project planning

1.6 Overview of Thesis Organization

There are five chapters in this thesis organized as a fellow:

Chapter 1 describe about research background of RF energy scavenging. It also consists problem statement and objective of this project. The scope of this project and organization of the thesis also stated.

In chapter 2, the theoretical background of rectifier circuit and matching network, Schottky diode and also Wilkinson power combiner is briefly explained as its use in rectifier circuit. Relevant work also presented.

Chapter 3 focuses on methodology for this project. This chapter will shows the calculation part of impedance matching and the Wilkinson power combiner. The transformation of lumped element to transmission line also will explain briefly. Fabrication and measurement part also will explain in this chapter

Chapter 4 focuses on the result of simulation rectifier. The measurement will compared with simulation results. The result and finding are discussed. The setup used for RF measurement is also introduced.

Chapter 5 highlights the outcome and conclusion of the project. It provides recommendations and future work for this project

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Rectification process is obtained by the conversion of input RF power into DC power supply. Elements in rectifier circuit consist of impedance matching circuit, Schottky diode, and also power combiner to combine the dual frequency. The conversion of RF to DC efficiency is transformed by losses of impedance matching circuit and diodes. The nonlinear components of rectifying circuits such as diode will produce harmonics of the fundamental frequency.

The unwanted harmonics produce harmonic radiation and electromagnetic interference to the nearby circuits and antennas and will decrease their efficiency. So, microwave components such as an impedance matching can be added between the antenna and the diode to defeat these harmonics that increase system performance and prevent harmonic interference [9].

2.2 Impedance Matching

The critical part of matching network is to lessen the transmission loss from an antenna to a rectifier circuit and increase the input voltage of a rectifier circuit. As a result, a matching network is typically made with reactive components such as coils and capacitors that are not dissipative. Maximum power transfer can be realized when the impedance at the antenna output and the impedance of the load are conjugates of each other. This procedure is known as impedance matching [6].

The function impedance matching circuit is to provide maximum power transfer to the load of the RF power from the source. The design of matching networks for multi-band or broadband operation of the rectifier is important to send maximum power from the source to rectifying device. The standard RF source impedance is considered 50Ω.[2]

2.2.1 Single Stub Matching

One of matching technique uses a single open circuited or open circuited length of stub connected either in parallel or in series with the transmission feed line at a certain distance from the load [10]. In single-stub tuning, the two variable parameters are the distance, d, from the load to the stub position, and the value of susceptance or reactance of the stub. For the shunt-stub case, the basic idea is to select d so that the admittance, Y, seen looking into the line at distance d from the load is of the form Y0 + j B. Then the stub susceptance is chosen as − j B, resulting in a matched condition.

For the series-stub case, the distance *d* is selected so that the impedance, *Z*, seen looking into the line at a distance *d* from the load is of the form *Z*0 + *j X*. Then the stub reactance is chosen as−*j X*, resulting in a matched condition. [10]

In a transmission line, shunt open circuit are easier to fabricate because it doesn't need the ground plane. Figure 2.1 shows the shunt and series single stub.

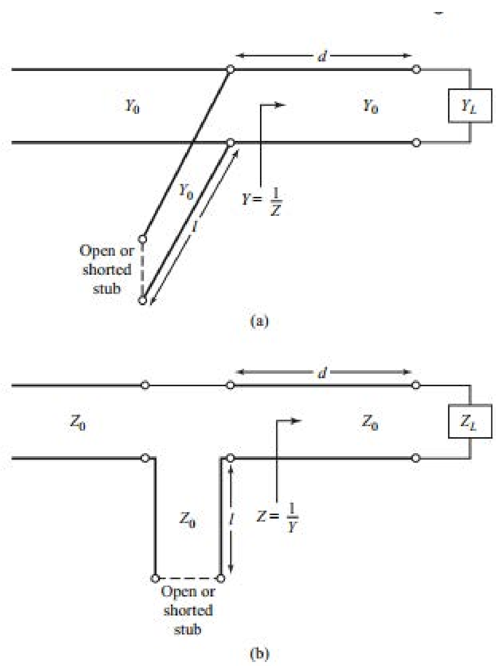

Figure 2.1: Single stub circuit (a) shunt stub (b) series stub [10]

2.2.2 Double Stub Matching

The double-stub tuner uses two tuning stubs, partially eliminates the requirement for variable distance from the load, and is commonly used in laboratory practice as a single frequency matching device. The double-stub impedance matching network is composed of two short circuited sections of transmission line, separated by a length of transmission line, placed along the main signal line. The short circuited sections provide an equivalent shunt susceptance. The short circuited sections are attached perpendicular to the main line. Figure 2.2 shows the equivalent circuit of double stub matching.

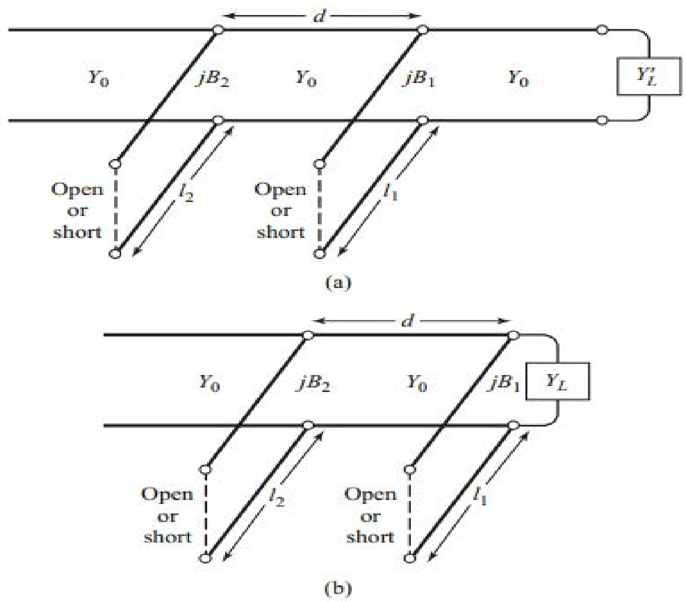

Figure 2.2: Double-stub tuning. (a) Original circuit with the load an random distance from the first stub. (b) The equivalent circuit with the load transformed to the first stub.[10]

2.3 Voltage Doubler

A voltage multiplier or known as charge pump circuit is a circuit that takes advantages of the diode's behavior to rectify a signal. But, it's depending on the signal level, whether the diode allows the current to pass. In voltage multiplier circuit, the uses of capacitor keep the output signal at the same level while diode is functioning as an open circuit. The simplest voltage multiplier consists of a parallel (or series) and a series (or parallel) capacitor [11]