

# Faculty of Electrical and Electronic Engineering Technology



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Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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# DEVELOPMENT OF RECTIFIER FOR WIDEBAND RF ENERGY HARVESTING SYSTEM

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A project report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Telecommunications) with Honours



# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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# DECLARATION

I declare that this project report entitled "Development of Rectifier for Wideband RF Energy Harvesting System" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



## APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electronics Engineering Technology (Telecommunications) with Honours.



# **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.

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#### 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
А	-	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
Ι	- Current
С	- Capacitor
L	S- Inductor
SM	- Surface Mount
TH	F - Through-hole
PWB	- Printed Wiring Board
PCA	Printed Circuit Assembly
PCBA	- Printed Circuit Board Assembly
FYP	- Final Year Project
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Appendix A (FYP 2)

**UTERSITI TEKNIKAL MALAYSIA MELAKA** 

#### **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 ultralow power 15 applications. This was accomplished by the design and construction of a 50stage 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.

References	Frequency	Rectifier Circuit	RF-to-DC (%)
	(GHz)	JIEM	Efficiency
(Rengalakshmi & Brinda, 2016)	0.945	Voltage Double Rectifier	72
(Kasar et al., 2019)	jSi	Single-stage	70.5
(Chuc & Duong, 2015)	2.45	Voltage Doubler	70.06
(Tudose & Voinescu 2013)		Voltage Doubler	67
(Tudose & Vomeseu, 2015)	2.73	Voltage Doubler	07
(Razavi Haeri et al., 2017)	0.9	50-Stage Voltage Double	60
		Rectifier	
(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	30-50
		Rectifier	
(ElAnzeery & Guindi, 2012)	0.5-9	N-stage Multiplier	NA

**Table 2.1: Types of Rectifiers** 

#### 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.

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## 2.3 Antenna

The spiral antenna was created as a frequency-independent antenna because of how nearly constant its input impedance and gain are over a wide bandwidth. The military, satellite, telemetry, global positioning system (GPS), wearable, medical, wireless, and other wireless communications applications currently make extensive use of this antenna.

As in [9], spiral antennas provide a bandwidth-to-area ratio of approximately 10:1 and provide circular polarisation with a low-profile shape. Spiral antennas can provide the essential broadband characteristics, particularly in terms of input impedance and radiation patterns. The antenna radiation pattern is a graphical mathematical function that expresses the radiation properties of the antenna as a spatial coordinate function.

Numerous research has been conducted on the radiation characteristics of spiral antennas with various geometric forms, including circular, rectangular, and certain eccentric forms. As a result of its relatively simple impedance matching, improved radiation efficiency, high spectral efficiency, consistent gain, large bandwidth, and primary benefit of free frequency, this spiral antenna is widely used in many fields [10].

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#### **CHAPTER 3**

#### METHODOLOGY

## 3.1 Introduction

This chapter exemplify and describes the four-step process of the project. The first step is the creation of a flowchart for the project. In the ensuing part, a suitable block diagram for the project is developed. In addition, the project's workflow has been illustrated. This project's hardware and materials, in addition to its software, have been discussed. Consequently, flowcharts will be constructed with a higher level of comprehension. In addition, the materials required for the task and the technique for establishing the circuit association will be briefly reviewed.

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# 3.2 Project Workflow

Workflow in project management refers to the ordered list of tasks that should be completed in contemplation to execute a process step. To have it fit as a workflow, each process step must be reliant on the previous phase's finalization. A flowchart is a sort of diagram that illustrates a process or an activity. A flowchart is also an illustrative delineation of an algorithm, which is a step-by-step method for finishing an assignment. The flowchart explains the steps as multiple types of boxes with arrows connecting them in sequential sequence. Each shape of the flowchart has its on designated meaning that should be used correctly. Therefore, in order to ensure a smooth successful outcome with this project, it is necessary to have a decent flowchart. Not only that, by having lots of journal, research and book publications as our guidance for this project, it can also ensure our project to be near perfect. After the previous process has been implemented successfully, the final phase will be executed. Figure 3.1 depicts a productive workflow for project management.



## 3.2.1 Flowchart of FYP 1



**Figure 3.2: Flowchart** 

Figure 3.2 shows the flowchart, the process of this project. It shows step by step and the process of the workflow of this project.

#### 3.3 Software

The software component is a tool, for designing electrical circuits, as an example, rectifier circuit. This project is completed using Agilent Advanced Design System (ADS) 2016.01, which will be further explained below.

# 3.3.1 ADS

The Agilent Advanced Design System (ADS) is extensively employed in Research and Design (R&D). The function of ADS is to provide a comprehensive system design environment for RF circuits. In addition, ADS offers top-tier RF simulations, particularly for the harmonic balancing simulator. As depicted in Figure 3.3, only a few fundamental steps are required to create a circuit in ADS. Choosing the simulation controller is a crucial aspect of circuit design, as each controller has its own role. For instance, the S-Parameter analysis is utilised for matching networks (Figure 3.4), whereas the harmonic balance is employed for power conversion efficiency (PCE).



Figure 3.3: Quick Start ADS



Figure 3.4: S-Parameter Analysis

## 3.4 Hardware

Hardware is required for the completion of this project, and the adequacy of each component is crucial, as each plays a key part in its own function. If one of the components is insufficiently qualified to fulfil its functions, the circuit will not work properly and there will be a variance in the computation of the output value (voltage) due to the aforementioned reason. The primary components utilised for this project are detailed in Table 3.1, with its pictures for better understanding.

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# Table 3.1: Hardware



#### 3.4.1 Diode

Diodes are semiconductor devices that serve as unidirectional current switches. The diode permits current to flow effortlessly in unidirectional, but dramatically limits current flow in the other direction. For the reason that they transforms alternate current (AC) to direct current (DC), diodes are also known as rectifiers. Diodes are categorised according to their types, voltage, and current carrying capabilities. A diode's anode (positive pole) and cathode (negative pole) determines the polarity. When a positive voltage is passed through the anode, the majority of diodes only allow current to pass.

When a diode permits current flow, it is a forward-biased. When it is biased in reverse (reverse-biased), it functions as an insulator and forbids the flow of current. The arrow on the diode symbol marks in the oppose pathway of electron flow. The diagrams created by engineers demonstrates the current flowing from the positive (+) side of the voltage source to the negative (-) side. It is the same pact utilised for semiconductor symbols with arrows; the arrow points in the authorized direction of "conventional" flow and opposite the allowed pathway of electron flow. Common voltage drop for diodes is between 0.5V and 0.8V.

The diode that I will be using for this project is HSMS 285x Schottky Diode. The HSMS-285x family of zero bias Schottky detector diodes from Avago[11] have been created and tuned for minute signal ( $P_{in} < -20$  dB) operation at frequencies lower than 1.5 GHz ( $P_{in} < -20$  dB). When primary (DC bias) power is unavailable, they are perfect for RF Tag and RF/ID applications. The figure below is the database for HSMS 285x Schottky Diode.

Parameter	Units	HSMS-285x						
Bv	V	3.8						
Сло	pF	0.18						
Eg	eV	0.69						
IBV	А	3 E-4						
Is	А	3 E-6						
N		1.06						
Rs	Ω	25						
PB(VJ)	V	0.35						
PT(XTI)		2						
M		0.5						

Table 3.2: Database HSMS 285x Schottky Diode[11]

## 3.4.2 Resistor

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Resistor [12], is a passive electrical element that obstructs the electric current

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flows. They are present in sensibly all electrical networks and electronic circuits. In ohms  $(\Omega)$ , resistance is measured. An ohm  $(\Omega)$  is the resistance encountered in which one ampere (A) of current passes through a resistor with one volt (V) drop between its terminals.

Ohm's law encapsulates this proportion and can be explained detaily about the proportionality:

$$R = \frac{V}{I}$$

There are several applications for resistors. Limiting electric current, dividing voltage, creating heat, matching and loading circuits, adjusting gain, and setting time constants are a few examples. Globally, they are available with resistance ratings ranging more than nine orders of magnitude. They can be used as electric brakes to dissipate the kinetic energy of trains or as electrical components measuring less than one millimetre square.

There are lots of specific resistor values, which are distinguished by their respective colour codes. Each colour has its own designated special values and each of it also is bit different depending on the position of the colour on the resistor. Figure 3.5 below depicts more detail about the colour codes for the resistor.



Figure 3.5: Resistor Colour Chart [10]

## 3.4.3 Capacitor

A capacitor, denoted by the symbol C, is a device for keeping electrical energy comprising of two contiguous, electrically isolated conductors. A straightforward example of device is the parallel-plate capacitor. If positive charges with a total charge of +Q are deposited on one conductor and an equal number of negative charges -Q are deposited on the other conductor, the capacitor is said to have a charge of Q.

There are quite a few essential applications for capacitors. They are utilized in digital circuits, for instance, so that data saved in big computer memories is not lost after a momentary power outage; the electric energy kept in such capacitors preserves the data during the power outage. Capacitors play an even greater role as filters to deflect erroneous electric impulses and protect sensitive components and circuits from damage caused by electrical surges. The type of capacitor that I will be using is polarized capacitor, in which it has the polarity of positive terminal and negative terminal.

# رسيتى تيكنيكل مليسيا ما Inductor

An inductor is a passive electrical component that resists abrupt current changes. Inductors may alternatively be referred to as coils or chokes. L is the electrical sign for inductor. The main function of the inductor is to decelerates the current surges or spikes by momentarily keeping the energy in an electro-magnetic field and letting out the current back into the circuit when it is appropriate. Inductor is also capable of choking, blocking, attenuating, or filtering/smoothing high frequency noise in electrical circuits; storing and transmitting energy in power converters (dc-dc or ac-dc); constructing tuned oscillators or LC (inductor/capacitor) "tank" circuits; and impedance matching.

Surface mount (SM) inductors are placed on pads with solder paste on a printed circuit board (PCB) and then reflow soldered. The leads of through-hole (TH) inductors are

passed through holes in a printed circuit board (PCB) and then wave soldered to the board's back.

#### **3.4.5 Printed Circuit Board (PCB)**

PCB is the standard term for the unclad board on which user will put the components and for which will provide them with the layout data. PCBs are utilised to mechanically aid and electrically connect electronic elements through conductive paths, routes, and signal traces engraved from copper sheets overlays onto a non-conductive substrate.

When the board has simply copper tracks and no circuit components such as capacitors, resistors, or an agile mechanism have been fabricated into the substrate, it is more accurately cited to as a printed wiring board (PWB) or an etched wire board. Although more accurate and separate from what would be recognised as a true printed circuit board, the printed wiring board has largely dropped out of favour as the boundary between circuit and wire has soften.

Today, all but the easiest commercially made electronic components employ printed wiring (circuit) boards, which enable completely automated assembly procedures that were not conceivable or viable with older era tag-type circuit assembly processes. A PCB that contains electrical parts is known as a printed circuit assembly (PCA), printed circuit board assembly (PCBA), or PCB Assembly (PCBA). In another context of an informal usage, the term "PCB" is applied to both unassembled and assembled boards, with the context defining its precise meaning.

# 3.5 System Design



Figure 3.6: System Design Voltage Doubler using ADS

The figure 3.6 shows my FYP system design of Voltage Doubler rectifier using Advanced Design System (ADS). It includes my rectifier design, matching network and the database of the diode that used for this project, which is HSMS 285x Schottky Diode.

#### **CHAPTER 4**

#### **RESULTS AND DISCUSSIONS**

## 4.1 Introduction

This part will show and explains the findings for this final year project via simulations and hardware results.

#### 4.2 Simulation

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Simulation of the rectifier which is used for RF Energy Harvesting is shown in this section. This simulation is done by using the 2016-ADS. The analysis used to align the network and harmonical balanced analysis is S-parameter, for the RF-DC conversion. Since in ADS, an antenna cannot be generated to feed the power (RF) to the rectifier, the P1 Tone power is used as a source to generates 945 MHz RF waves. Its replicates an antenna, by delivering this wave as the power source.

Figure 4.1 shows my rectifier circuit, Voltage Doubler circuit with the LC matching network.

Figure 4.2 depicts the voltage doubler rectifier's simulated return loss responses. For a 50  $\Omega$  input source, the rectifier resonates at 945 MHz, as indicated by the m4 marker.

Figure 4.3 shows the output DC voltage vs the Load resistance. The output DC voltage increases as the load resistance increase. With a lower value of load resistance, the output voltage rose at a faster pace than with a higher value of load resistance.



Figure 4.2: Reflection Coefficient of Voltage Doubler Rectifier



Figure 4.3: Output Dc Voltage vs Load Resistance

## 4.3 Hardware Results

This part explains and shows my results for my hardware of rectifier for RF Energy Harvesting. As explained before, I used Voltage Doubler as my rectifier and LC matching network. For the antenna part, I'm using a spiral antenna.

Antenna is also a crucial part in this project. Radio waves travel at the speed of light through the air. When the waves reach the reception antenna, they cause the electrons within it to vibrate. This generates an electric current that recreates the signal. When the antenna receives the signal, once the signal goes through the rectifier, the output is a DC voltage in which I will be harvesting from it and use it for any viable purpose. Figure 4.4 below shows the spiral antenna which I used for my project. And Figure 4.5 below shows my rectifier which the components are already soldered on a stripboard. The connector from antenna to the rectifier is a coaxial cable (RG-316) which is typically used in antenna applications.



Figure 4.4: Spiral Antenna



**Figure 4.5: Rectifier Stripboard** 

Now, when the antenna is connected to the rectifier via coaxial cable, if the antenna detects or receives RF energy from surroundings, the received signals will convert to electrical signals in which i able to obtain a DC output voltage in which it can be harnessed to apply and use it for other purposes. Figure 4.6 below shows the reading of a analog multimeter when the antenna is detecting RF from surroundings. Since the RF is so sensitive and small, the readings that we get is minute. But if we change the location of our antenna, if we collect the data from a place that has high density of RF, we able to fully

utilise the antenna and the rectifier can convert the RF to DC energy and we can get high value of readings. Figure below shows the reading of the analog multimeter when the multimeter is connected to the output of the rectifier.



Figure 4.7: Analog Multimeter reading 2





Figure 4.9: Analog Multimeter reading 4

The reason in why we couldn't get a consistent one reading is because of few factors in which our power source, RF. Most areas the RF density isn't high and not readily available. So if we test in areas that doesn't have RF, we cant get a high reading. But if we test in areas that has a high density RF, we can get results, which is our DC voltage reading. That is why if we refer back to those figures that has the reading of the multimeter, the reading is not consistent. There are multiple factors that we still need to process and discuss.

Antenna plays a role too in this project. The factors that effect our antenna such as the resonant frequency, bandwidth, Voltage Standing Wave Ratio (VSWR), and the gain. Each contributes to the efficiency of our antenna.



#### **CHAPTER 5**

#### **CONCLUSION AND RECOMMENDATIONS**

## 5.1 Conclusion

Rectifier is an essential part of the energy harvesting circuit. The result of a 945 MHz Voltage Doubler rectifier circuit has been completed. The DC output voltage is calculated from the changing input power values. The PCE is calculated by measuring the output voltage. From what i gained from this results, i can say that the area that we conduct the data collection is important as RF is not so readily in most areas, as it is directly connected to a cell tower as an example. The area which close by a cell tower has high potent density of RF and thats where we can harness the energy and convert it to DC energy.

The use of a rectifier is important as well if we fully utilise all the components and futher research can be done in order to find the best circuit as the best values needed for each component so we can gain as much of energy as possible.

# 5.2 Future Works

The future works for my FYP can be improved more by:

- Manufacturing my circuit
- Doing real life analysis
- Comparing data with journals and articles
- Discussions to improve more on my project
- Tweaks on my circuit
- Futher research on the antenna needed to use to gain more RF



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# **APPENDICES**

# Appendix A (FYP 2)

ACTIVITY	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MEETING WITH SV														
LOGBOOK MALAY	SIA .	and												
RESEARCH		-									1			
MANUFACTURING AND RESULTS	ليه	۰ J	$\leq$	2			:5:	يتي		فرر	وني			
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DRAFT SUBMISSION														
PRESENTATION PREPARATION														
PRESENTATION														