ENERGY HARVESTING FROM ELECTROMEGNETIC RADIATION

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This thesis is submitted as partial fulfilment of the requirements for the award of the
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This report is dedicated to my beloved father and mother

Hamzah bin Ismail and Misliyah binti Katman

Siblings

And

To all my lecturers, for their guidance and encouragement
To all my friends, for their support and sincerity

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ABSTRACT

The focus of this work is on the harvesting the energy via electromagnetic radiation. The energy harvesting energy device consists of two main subsystems. The first subsystem is the receiving antenna that responsible to capture all the RF surrounding and later it will convert into DC output. The second subsystem is rectifier system or a charge pump, it can convert the RF as an input power into DC output power and it pump is design by modifying voltage multiplier which consists of diodes and capacitors. The antenna can transmit and receive the energy through the air from the current in the form of electromagnetic waves which is radio waves at several operating frequency. In this project, coil antenna also known as spring antenna to be the receiver antenna for the system. In theory, it can produce an output which is multiple from the input power supply depends on the stages used. The higher the frequency, the higher the output can be produced. Besides that, the amount of frequency can be harvested based on the size and the range of the frequency that can be absorbed by the antenna.

ABSTRAK

Fokus kerja ini adalah mengenai penuaian tenaga melalui radiasi elektromagnet. Peranti penuaian tenaga terdiri daripada dua subsistem utama. Subsistem pertama adalah antena penerima yang bertanggungjawab untuk menangkap semua RF disekitarnya dan kemudian ia akan ditukar kepada keluaranDC. Subsistem kedua ialah sistem penerus atau pam caj, ia boleh menukar RF sebagai kuasa masukkan ke DC keluaran kuasa dan ia adalah reka bentuk dengan mengubah suai pengganda voltan yang terdiri daripada diod dan kapasitor. Antena boleh menghantar dan menerima tenaga melalui udara dari semasa dalam bentuk gelombang elektromagnet yang gelombang radio di beberapa frekuensi operasi. Dalam projek ini, gegelung antena juga dikenali sebagai spring antena untuk antena penerima untuk sistem. Secara teori, ia boleh menghasilkan keluaran yang pelbagai dari bekalan kuasa masukkan bergantung kepada peringkat kegunaannya. Semakin tinggi frekuensi, keluaran yang lebih tinggi boleh dihasilkan. Selain itu, jumlah kekerapan boleh dituai berdasarkan kepada saiz dan julat frekuensi yang boleh diserap oleh antena.

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LIST OF SYMBOLS

Ω	-	Ohm
λ	-	Wavelength
c	-	Speed of light
B	-	Magnetic flux
H	-	Magnetic field intensity
E	-	Electric field
P_r	-	Received power
P_t	-	Transmitted power
G_r	-	Gain of received antenna
G_t	-	Gain of transmitted antenna
R	-	Distance

LIST OF ABBREVIATIONS

RF	-	Radio Frequency
DC	-	Direct Current
AC	-	Alternating Current
SMD	-	Surface Mounted Device
Hz	-	Hertz
PCB	-	Printed Circuit Board
EM	-	Electromagnetic

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, energy is very important to humans because the technology is increasingly growing by leaps and bounds. There is a lot of energy around the human being and the energy is not a renewable energy and renewable energy. The non-renewable energy has advantages and disadvantages and it is the law of nature because everything there is pros and cons of each. Among the advantages of non-renewable energy is energy produced so consistent and always provide sufficient energy to consumers. The disadvantages of non-renewable energy are generating pollution and energy resources are limited and take a long time to produce the resources of this energy[1]. The fossil fuels are non-renewable energy that is widely used nowadays.

Energy as opposed to non-renewable energy is renewable energy. The renewable energy readily available but requires special equipment to generate such energy. This energy is endless but it increases and decreases according to the situation. For example, solar energy need of the sun to generate the sun and if the sky is cloudy or at night, the energy produced is low. There are many advantages of renewable energy such as not to cause severe pollution, can be obtained easily, and unlimited resources. Among the sources of renewable energy is solar, water, air, wave, geothermal, and others.

In this project, the renewable energy used is the energy of radio frequency. Today more than ever radio frequency signals or RF as it is commonly called is used to transmit all types of information starting over 100 years ago. To maximize the use of RF signal, RF can be converted into DC supply. The concept of wireless energy harvesting and transfer is not new, rather it was demonstrated over 100 years ago by Tesla[2]. This can instrument potentially leading to significant reduction in the costs associated with replacing batteries periodically[3].

1.2 PROBLEM STATEMENT

Most of low voltage devices use electrical energy directly from power supply and batteries either chargeable or non-chargeable and so that is their constraint and limitation. The device that directly connected to the power supply cannot be function when the event power failure occurred. Batteries also need to be changed periodically when the batteries has been drained after used it. Therefore, it involved a cost of wire for the device that direct connected to the power supply and batteries.

1.3 OBJECTIVE

For the completion of this project, the objectives of this project should be achieved to ensure the project is completed successfully. The objectives are:

a. To study how energy can be harvested from electromagnetic radiation.
b. To design a simple configuration of rectenna that consists of antenna and rectifier circuit to produce the DC supply.

1.4 SCOPE OF PROJECT

This project cover the scope to ensure that this project in right path to complete. The scope of project as shown as below:

a. Study and understand why Radio Frequency (RF) used to harvest the energy.
b. Using monopole type of antenna to receive RF and convert it into DC by using rectifier.
c. Design a simple configuration of rectenna circuit.
d. Obtain the analysis from the simulation of hardware and software.

1.5 OUTLINE OF THESIS

Chapter 1 is about the introduction of the energy harvesting. Besides that, this chapter also include problem statement, objective of the project, and the scope of project.

In the chapter 2, it is the literature review of the project that has been done by other people. This literature review is to give a rich resources of quotation to support the analysis of the project later on.

Next is chapter 3, this is the methodology of the project. This chapter shows how the project was conducted from the beginning until the end of the project. Besides that, this chapter contains the components that used in the project.

Chapter 4 is about the result and discussion of the project. This chapter shows all the analysis that has been done and finding of the project. Furthermore, the analysis of the project is followed by the discussion to explain the result.

Lastly, chapter conclusion of the project, this part show the summary of the project. it must be aligned with the objectives of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Energy harvesting is capable of providing sustainable energy to the device obtained from natural or man-made itself. Therefore, it promises a bright future as a durable device with a of energy surrounding without depending entirely on the supply of stored energy such as batteries[4]. There are many source of energy harvesting and one of them is radio frequency (RF). This energy is collected from ambient radio frequency that potentially can produced sustain energy and reduce their dependence on the energy storage which is batteries.

In order to produce the DC supply, the radio frequency will be detected or caught by the receiver antenna and the signal will be sent through the matching network and send to the rectifier to convert RF to DC supply. The important part in this system is radio frequency energy, rectenna, and matching network or circuit.

2.2 BASIC CONCEPT

All the electromagnetic waves travel with the same velocity in vacuum, in the speed of light c which is equal to the product of wavelength λ and the frequency f. The higher the frequency, the shorter the wavelength. The expression of the equation as shown below:

$$c = \lambda . f \tag{2.1}$$

where; c = 3 x 10^8 m/s

The set of equations which describe how electric and magnetic fields propagate, interact and how they are influenced by material properties are Maxwell's equations and an EM wave can be described with these equations, which must be met for a set of particular boundary conditions. Maxwell's equations are summarized in **Table 2.1**[5].

Table 2.1. Maxwell's Equation

Law	Integral form	Differential form
Faraday's law of induction	$\oint_c \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \iint_s \vec{B} \cdot d\vec{s}$	$\nabla \times \vec{E} = -\frac{\partial}{\partial t} \vec{B}$
Ampère's circuital law	$\oint_c \vec{H} \cdot d\vec{l} = \iint_s \vec{J} \cdot d\vec{s} + \frac{\partial}{\partial t} \iint_s \vec{D} \cdot d\vec{s}$	$\nabla \times \vec{H} = \vec{J} + \frac{\partial}{\partial t} \vec{D}$
Gauss's law	$\oiint_s \vec{D} \cdot d\vec{s} = \iiint_V \rho \cdot dV$	$\nabla \times \vec{D} = \rho$
Gauss's law for magnetism	$\oiint_s \vec{B} \cdot d\vec{s} = 0$	$\nabla \times \vec{B} = 0$

In a modern city full of sophisticated technology, there are many different sources of radio frequency energy. For example for these sources of energy are radio frequency energy and telecommunications towers, Wi-Fi router and others. Normally, the frequency generated by such sources within the range of 2GHz, and usually not exceeding 5.8GHz. This stated by O. Lavrova *et. al*[6].

2.3 RF ENERGY HARVESTING CIRCUIT COMPONENTS

Rectenna is the combination between antenna and rectifier circuit. These two parts is very important because the function of antenna is to receive the RF signal and through the rectifier it will be converted into DC. Basically, in rectenna design, antenna and rectifier circuit is designed separately. Efficiency of the design is depends on the antenna design and rectifier circuit design. The main challenge in the RF energy harvesting is the transmitted signal loss at the free-space path due to the distance. The Friis equation below related to the received power (P_r), transmitted power (P_t), with the distance R, and G_r and G_t are the gain of the antenna for received and transmitted respectively.

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \qquad (2.2)$$

2.3.1 Antenna

Antenna is the electrical device that can convert the radio wave into electrical power and vice versa. An antenna can be classified into several types. These are the antenna type which are most common can found in the market, wire antennas, aperture antennas, reflector antennas, microstrip antennas, array antennas, dielectric antennas, active integrated antennas, lens antennas and last but not least leaky wave antennas. The most popular from all these type of antenna is microstrip antenna, it also most applicable compared to the others type of antenna. This is because it is characteristic which is easy to analyse, feeding methods and their attractive radiation characteristics especially low cross-polarization radiation.

Firstly, the antenna is designed separately from the rectifier circuit. The function of the receiver antenna is to catch the radio frequency as a source of free energy that easily can get from surrounding. There are many type of antenna to receive and transmit the signal of RF and one of them is patch antenna also known as a rectangular microstrip antenna. G. Vera *et al.* [7] state that The radiating structure is based on an aperture coupled dual linearly polarized patch antenna.

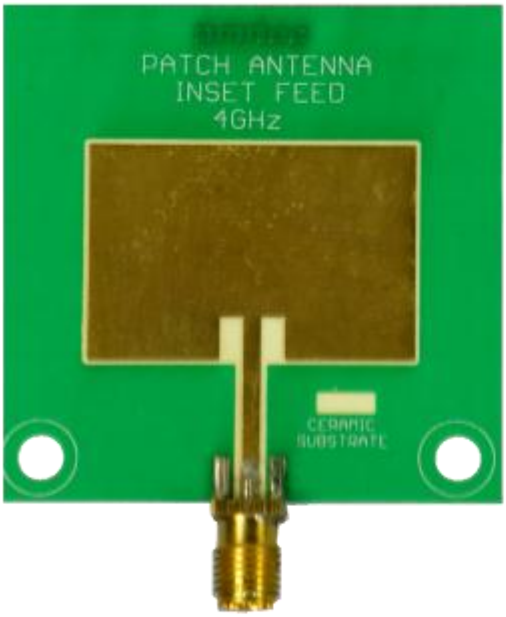

Figure 2.1. Example of Patch Antenna

2.3.2 Rectifier Circuit Design

Conversion from RF to DC is the key to the energy harvesting from electromagnetic radiation. There is different block in RF-DC converter as main and important one which is the rectifier and a doubler block as it mention by M. Beheshti Asl *et al* [8]. Heinrich Greinacher was invented the voltage multiplier circuit.

According to P. Nintanavongsa *et al* [3], there is two major configuration of energy harvesting from RF, first is Villard voltage doubler also known as Cockroft-Walton voltage multiplier, and second is Dickson voltage multiplier but the topology of these two configuration has no significant difference in performance. Nevertheless, the matching task is much simple in Dickson topology because it applied a parallel capacitors in each stages. In the [9], the basic or simplest rectifier consists of two different positions of the capacitor which is parallel or series. Below **Figure 2.2** shows the configuration circuit of the basic rectifier, voltage doubler, and voltage multiplier. According to P. Nintanavongsa *et al* [2], the Dickson topology has been used because of the parallel configuration of capacitor in each stage as shown in **Figure 2.3.**

There are various literatures to describe the type of voltage multiplier and **Table 2.2** shows the comparison of the rectifier as stated by Z. Zakaria *et al* [9].

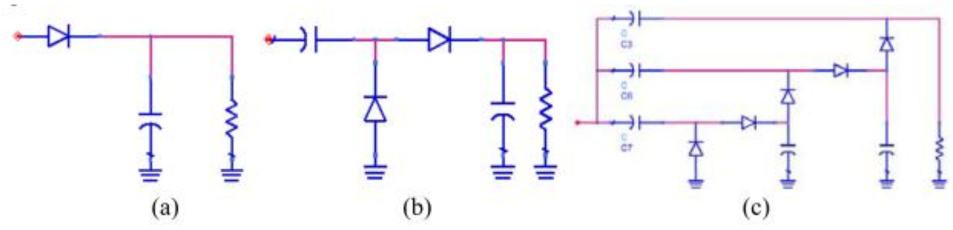

Figure 2.2. Type of rectifier: (a) Basic rectifier (b) Voltage doubler (c) Voltage multiplier

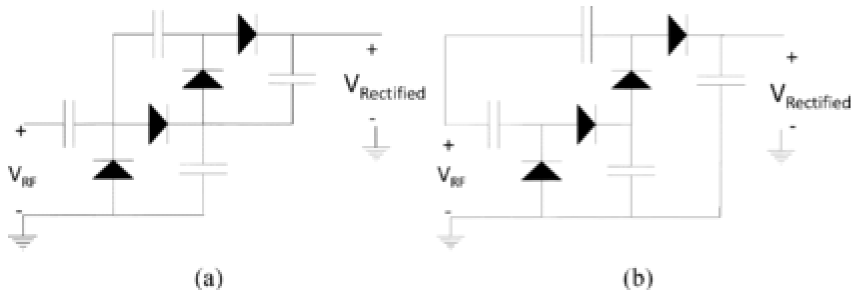

Figure 2.3. (a) Villard multiplier and (b) Dickson multiplier

Table 2.2. Comparison of rectifier

Type of Rectifier	Structure	Rectifier Topology
Basic rectifier	A diode connected in series with a load. A capacitor acted as a filter to smoothen the ripple in the output. Commonly called as a single-stage rectifier	Half-wave rectifier, full-wave rectifier.

Voltage doubler	Uses two stages to approximately double up the DC voltage	Villard circuit, Greinacher circuit, bridge circuit, Dickson charge pump voltage-doubler.
Voltage multiplier	Converts RF energy into DC voltage using network of capacitors and diodes.	Villard cascade voltage multiplier, Dickson multiplier, Cockroft Walton voltage multiplier.

2.3.2.1 Choice of Diodes

Diode selection is the most important requirement for energy harvesting circuits to allow the circuit works with a weak power input from radio frequency. Since energy harvesting circuits operating at high frequency, diode, which has a very fast switching is required. Therefore, Schottky diode are used this is because as a P. Nintanavongsa [2] state that Schottky diodes use a metal–semiconductor junction instead of a semiconductor-semiconductor junction and this allows the junction to operate much faster, and gives a forward voltage drop of as low as 0.15 V. The main advantage of this diode is it has very low forward voltage compare to the silicon type of the diode.

In other paper of research, there is another type of diode that used at rectifier design. This diode is SMD type which is means a very small size of diode and need extra careful in process of soldering. According to student from UTM, Leah Kah Meng [10], diode type SMD which is SOT-323. This because this diode has sensitivity of detection is high, so that this diode is very popular in RF application. Below shows the **Figure 2.6** of SOT-323.

Figure2.4. Schottky diodes

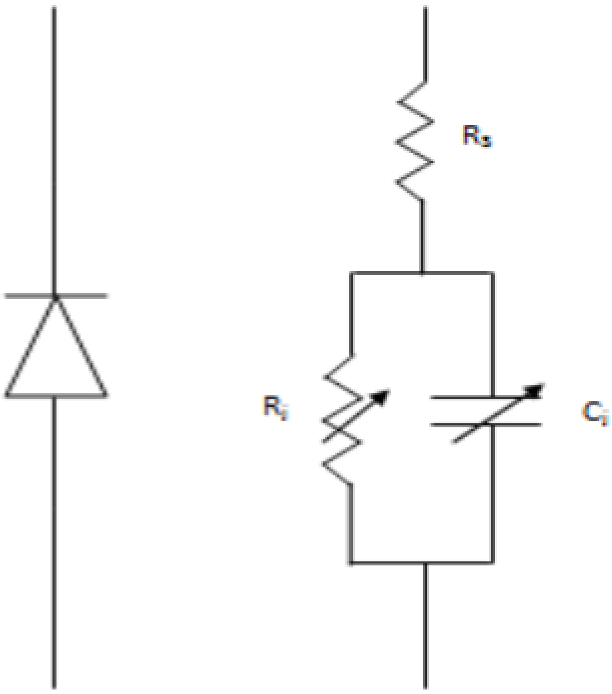

Figure 2.5. Symbol and the equivalent circuit of the schottky diode.

Figure 2.5 shows the symbol and the equivalent circuit of the schottky diode. The equivalent circuit consist of the series of resistance which is R_S. At the nonlinear junction, there is R_j the resistance that has been explained by the DC IV curve characteristic, the capacitance which is C_j.

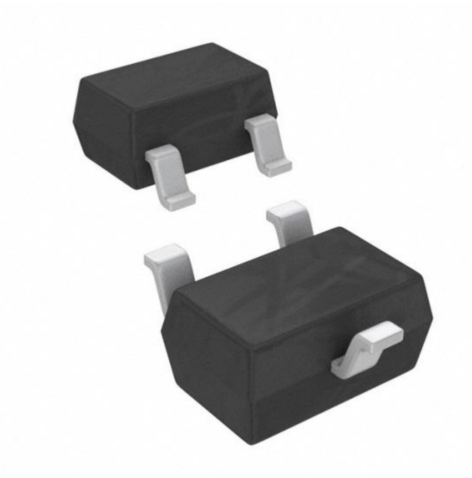

Figure 2.6 SOT-323

2.3.2.2 Impedance Matching Tool

Impedance matching is the designing the electrical load for input impedance or the output impedance of its signal source in order to maximize power transfer and minimize reflection from load [11]. From the impedance matching tool, then the matching network can be design and **Figure 2.7** shows the matching network.

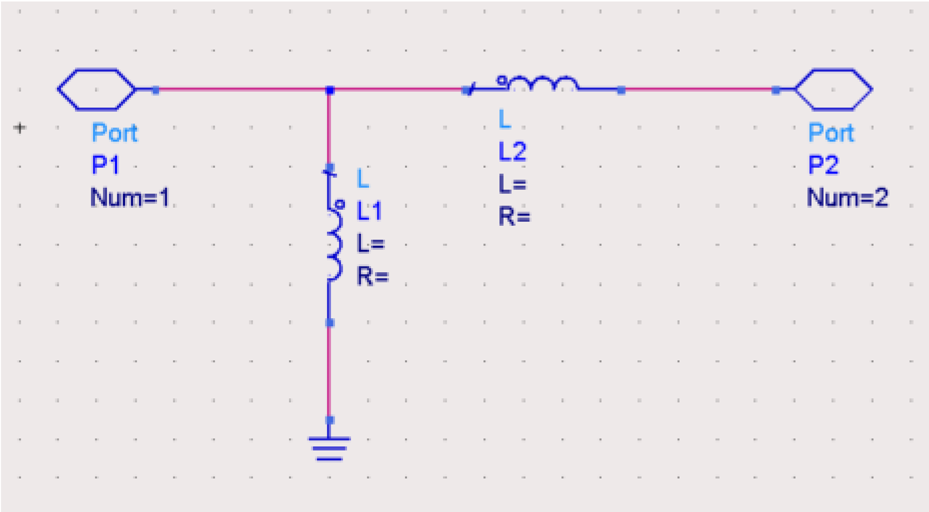

Figure 2.7. Basic matching scheme

From **Figure 2.7**, these two inductor is represent the matching network for the circuit and value of both these inductor are different because it depends on the type of rectifier that used for the design of rectenna.

2.3.3 Number of Stages

The number of the stage gives the major effect to the output of the voltage energy harvesting circuit. The higher the number of stages of the voltage multiplier, the lower the voltage gain and this is because of the parasitic effect of the element of the capacitor for each stage[2]. According to Zahriladha.Z [9], **Figure 2.8** and **Figure 2.9** shows the effect of the number of stages on the frequency and the voltage output of the energy harvesting circuit.

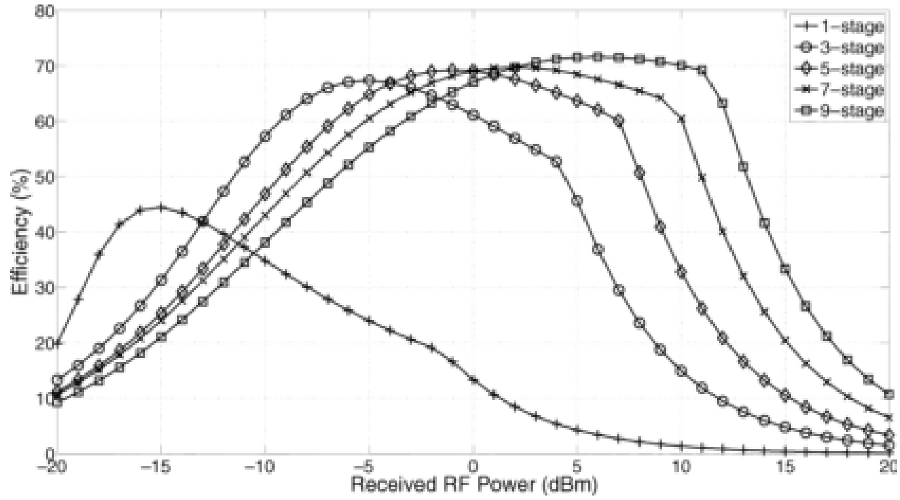

Figure 2.8 The number of stages against efficiency of the energy harvesting circuit

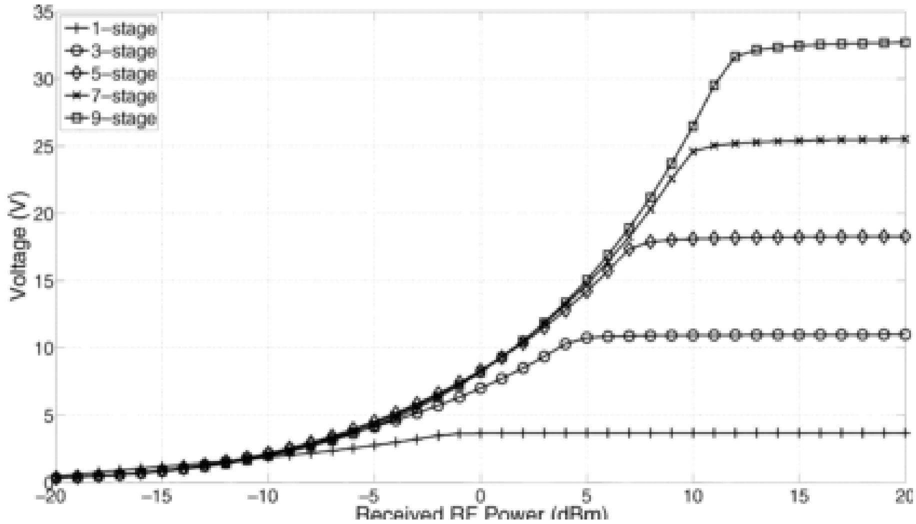

Figure 2.9 The number of stages against the output voltage of the energy harvesting circuit

CHAPTER 3

METHODOLOGY

3.1 WORK OF FLOW

Before embarking on this project, problem statement had been studied and identify in detail. Basically, this project is started by developing the work flow of project and do the literature review on the previous project or work that has been done by other researchers from this related field. To ensure that project can be completed on time, the planning must be done and also act as a guideline for working schedule project. Besides that, the good planning can increase the work of the project to the maximum level in the short time. By studying the literature review, the information was collected from the previous work so that the mistake can be minimize and avoided. **Table 3.1** shows the Gantt chart of the project for the semester 1. This shows what needs to be completed first.

Project Title: Energy Harvesting From Electromagnetic Radiation															
Task	Year	2015													
	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Seminar Attend															
• Briefing about PSM by coordinator		■													
Research Title Given															
• Select Supervisor and project title		■	■												
• Register project title			■												
• Submit problem statement, objective and others			■												
Literature Review															
• Journal research			■	■	■	■	■	■	■	■	■	■	■	■	■
• Compile and update log book			■	■	■	■	■	■	■	■	■	■	■	■	■
• Preparation of hardware						■	■	■	■	■	■	■	■	■	■
• Practice simulation of software used						■	■	■	■	■	■	■	■	■	■
Preparation Proposal Writing															
• Preparation of proposal report						■	■	■	■						
• Submission and check by supervisor						■	■	■	■						
Preparation of Slide															
• Preparation of slide presentation						■	■	■	■						
• Submit slide and check by supervisor						■	■	■	■						
• Submission presentation approval form to Coordinator								■							
Presentation PSM 1 (Seminar 1)															
• Presentation on the project								■							
Submission Report and Preparation of PSM															
• Preparation of full report with correction										■	■	■	■	■	■
• Submit full report and submit log book to supervisor															■

Table 3.1. Gantt chart of the project.

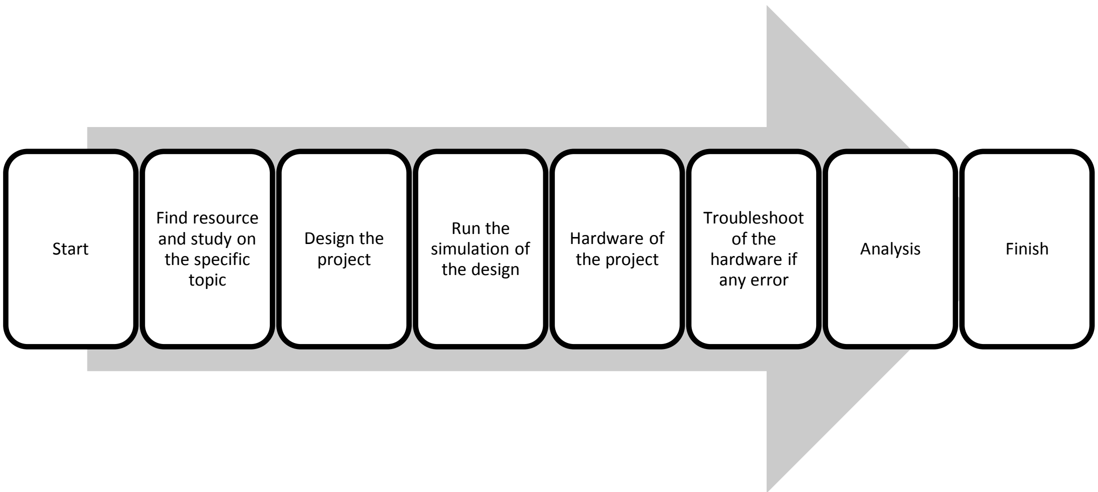

Figure 3.1. Work flow of the project

3.2 SYSTEM OVERVIEW

This is energy harvester using coil or spring antenna as a receiver to receive radio frequency. Generally, it is consist of monopole antenna, matching network, rectifier, and output which are going to the load. In this project, the antenna is an important part to catch the RF signal. The rectifier is use to rectify the energy receive. **Figure 3.2** show the flow chart of the project. **Figure 3.3** shows the block diagram of the project.

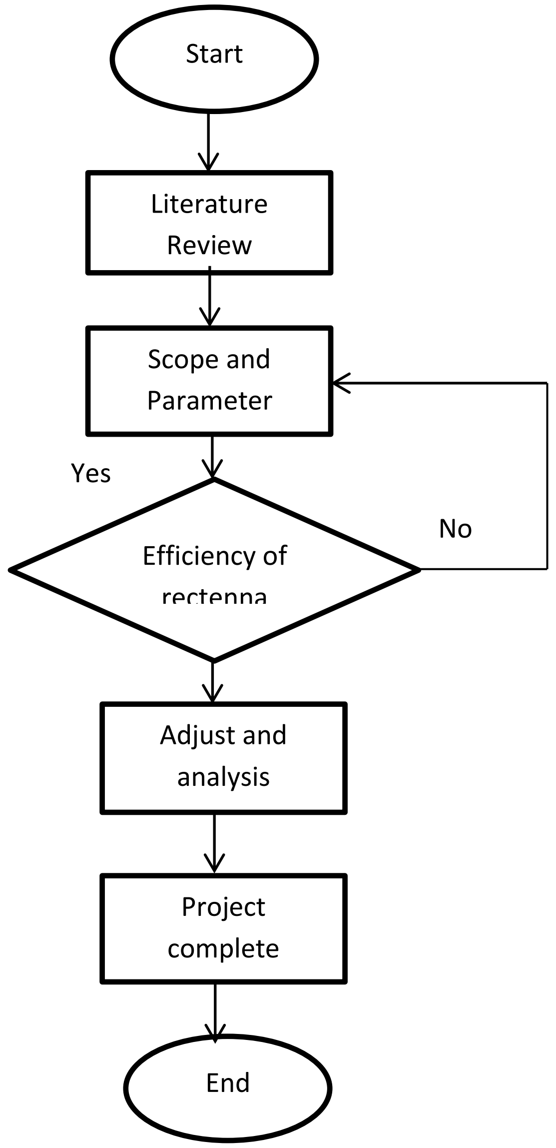

Figure 3.2 Flow chart of the project

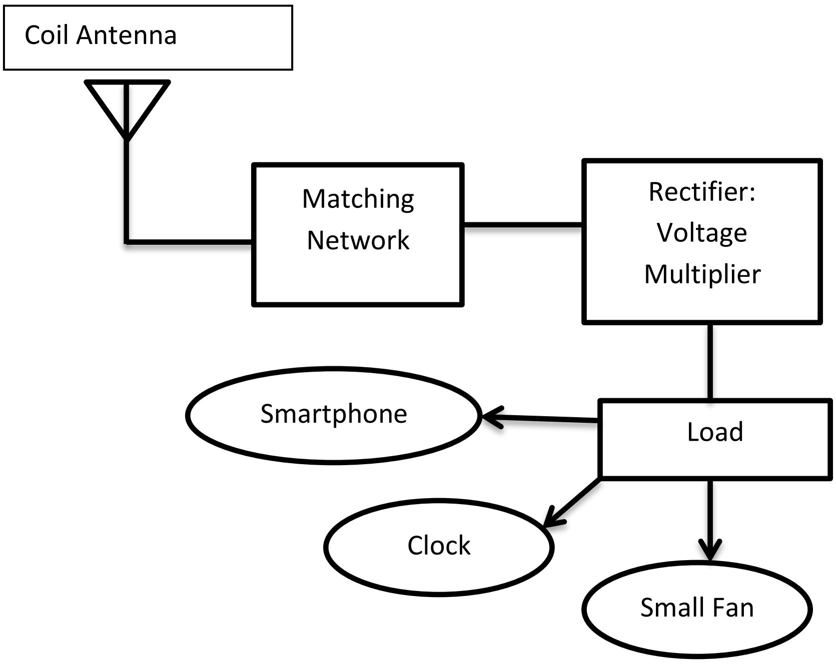

Figure 3.3 Block Diagram of project

3.3 SYSTEM DEVELOPING PROCESS

There are two parts in order to develop of this system, which is the antenna part and the rectifier as DC converting circuit. Coil or Spring antenna has been chosen to apply in this project.

The second part is rectifier that act as converter from RF to DC. This is rectifier also known as voltage multiplier or charge pump. To design the rectifier, PSpice software has been used to simulate and using Fritzing software to do printed circuit board (PCB). The components such as capacitor and diode has been studied and purchase.

3.3.1 Antenna Selection

The type of antenna that used in this project is Coil antenna as shown in **Figure 3.2 below.** This antenna has been selected because to make different from other paper of research. The specification of this antenna as shown in **Table 3.2** below.

Figure 3.4 Coil Antenna

Frequency Range	433, ± 5MHz
Voltage Standing Wave Ratio, VSWR	≤1.5
Input Impedance	50Ω
Maximum Power	10W
Gain	2.15dBi
Weight	1g
Height	17 ± 1 (25T) mm
Connector Type	Direct solder

Table 3.2 Specification of the Coil Antenna

3.3.2 Voltage Multiplier

A voltage multiplier is a circuit that when AC supply is given, then the circuit able to convert it to the DC supply. As basic concept of rectifier, AC can be converted to the DC supply but when the number of stages of voltage multiplier increase, then it can magnify the level of DC supply as output. A simple voltage multiplier was designed to avoid power loss if complex voltage multiplier is used.

In this project, PSpice software has been used to run the simulation as shown in **Figure 3.5** below. To make PCB of this voltage multiplier, Fritzing software has been used as shown in **Figure 3.6** below.

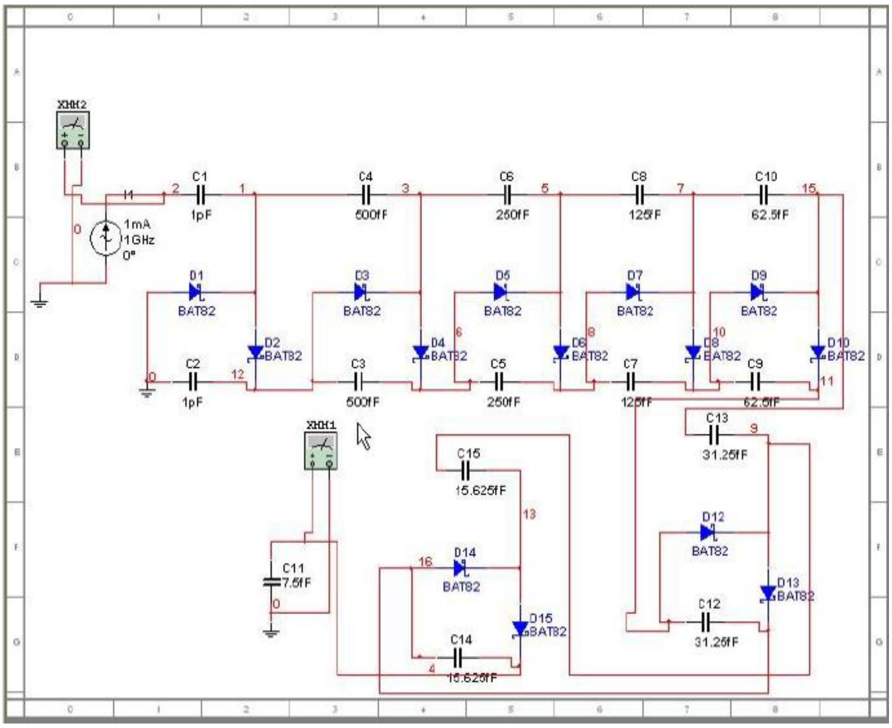

Figure 3.5 7 Stage Voltage Multiplier simulation by using PSpice Software

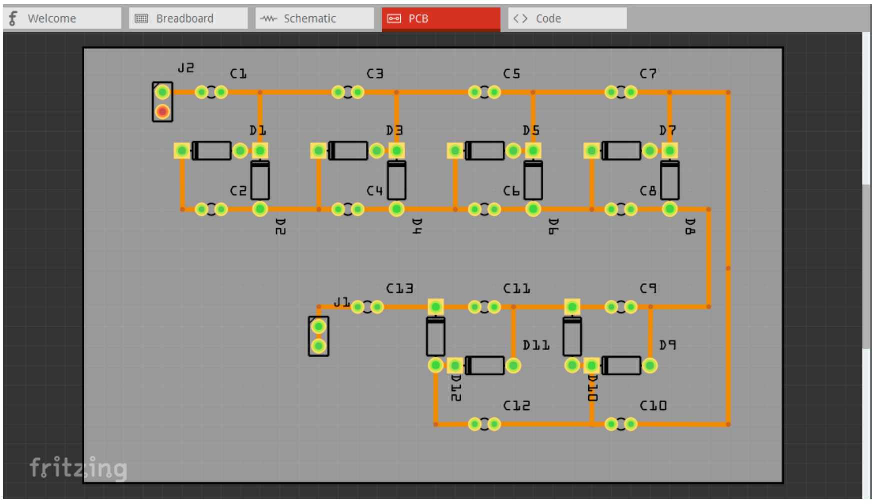

Figure 3.6 PCB layout of 7 Stage Voltage Multiplier using Fritzing software

Not every diode is suitable for this project, there are certain diode can be used in this project. SOT-323 is famous in RF application because it very sensitive of detection. The datasheet of this diode has been attached in **Appendix C.** Besides that, this diode also has high frequency with low turn on voltage. Since most of the components are SMD components, so that it need very careful when soldering process executed.

3.3.3 Measurement

To measure the voltage output and the frequency that can be captured by the antenna, microcontroller is needed. The function of microcontroller is to filter the frequency. When the antenna captured the frequency, there are high and low in RF around us. So, that can cause the harmonic that can make the voltage in the system not stable. The best microcontroller to be used is Arduino Uno because simple and easy to use it. Below in **Figure 3.7** shows the programming for the Arduino to filter the signal and in the **Figure 3.8** shows that the data that has been collected. Full programming can be referred in **Appendix A.**

Figure 3.7 One of example programming for the system

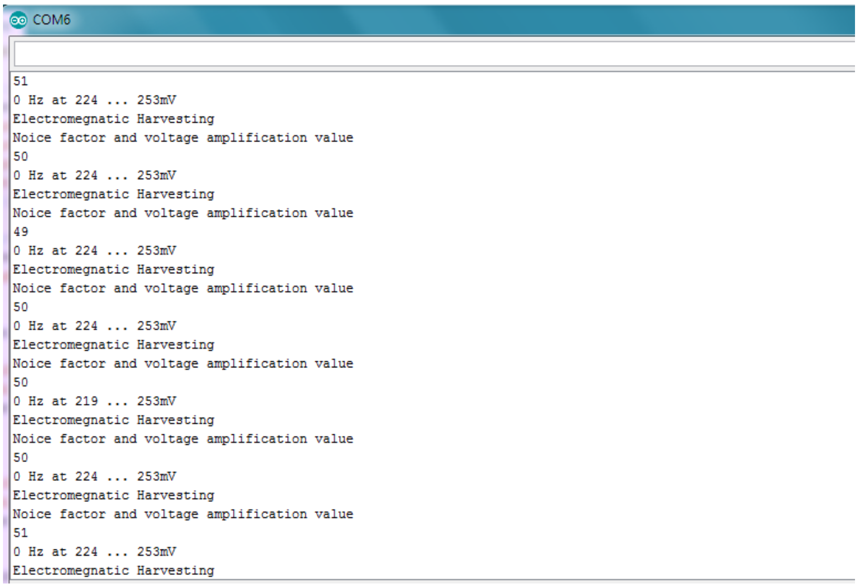

Figure 3.8 Data collection for frequency and voltage output

3.3.4 Component Setup

All the components mentioned above must be consolidated as a winding. first of all, the antenna will be in the solder to the 7 Voltage Multiplier Circuit that has been shown in the **Figure 3.9** below. After connecting the antenna with a voltage multiplier, it will be a rectenna. But to make it able to read frequency, measuring the resulting voltage, and filter frequency received by the antenna, it must be connected to the microcontroller which is Arduino Uno. All connection has been referred to the **Appendix B.**

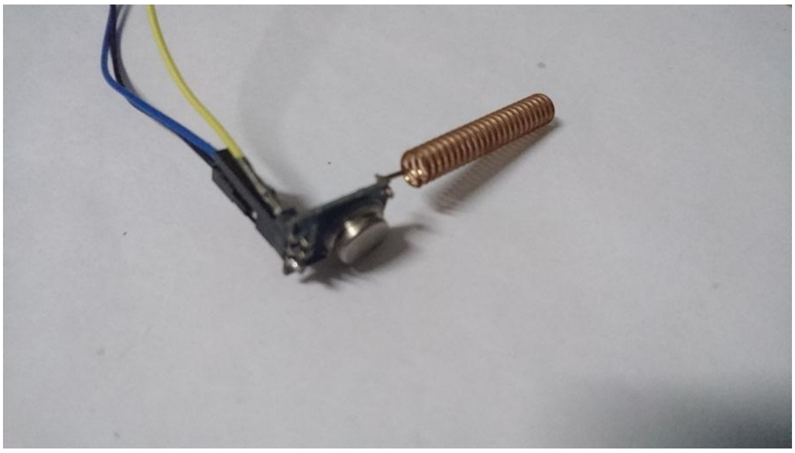

Figure 3.9 Rectenna (antenna combined with rectifier)

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULT OVERVIEW

In this chapter, it discusses the results of which have been carried out. All values used in this chapter is the real value. This experiment was conducted to see whether the frequency can be converted into energy or not. In addition, to find out the designs that have been created can operate properly. This experiment has been conducted in two conditions to see the effect the amount of the frequency on the voltage that will be produced.

4.2 RESULT AND DISCUSSION

When Arduino is connected to a computer and at the same time the antenna begin to receive the signal frequency from surrounding. Speak about the surrounding, there are two different conditions of surrounding. Firstly, the condition surrounding that full of gadget such as laptop, phone, and others equipment that can produced the RF signal. Second, condition in open spaces such as at football field, seaside, and palm oil plantation.

First, execute the experiment in the place that full of gadget and equipment. This is because gadget such as phone, laptop, and radio can produced their RF signal. Because of that, this condition has been chosen to see how much the antenna can capture the frequency and how much voltage can be produced. Since the voltage that has been produced is very small, LED act as load cannot be light up because not enough voltage. So that, the function of LED has been change to be as an indicator for the frequency. **Figure 4.1** and **Figure 4.2** below shows the experimental setup and execution of project and **Table 4.1** shows the data that has been recorded and translate into graph as shown in **Figure 4.3** below.

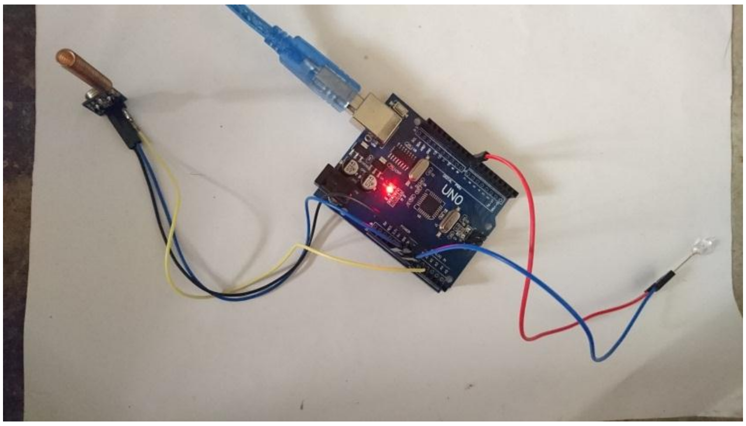

Figure 4.1 Antenna before detect the frequency

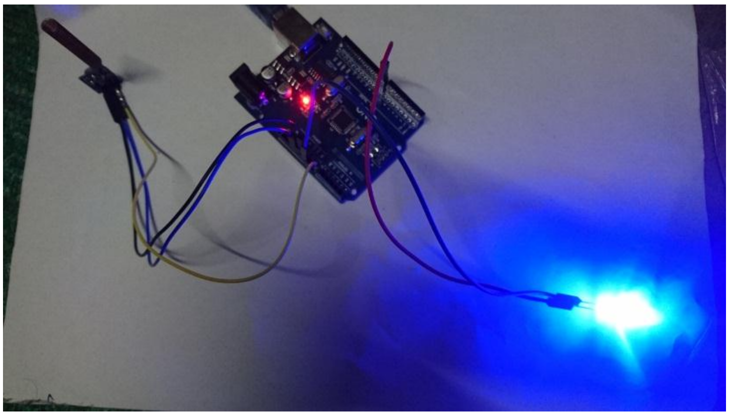

Figure 4.2 Antenna after detect the frequency

In the software part, the range of the frequency that need to be filtered must be set in the coding programming as shown in **Appendix I**. this is to make sure there are no harmonic in the system. In **Figure 4.1** shows that the antenna before detects the frequency from surrounding and as a result LED does not light up because the antenna not yet detects the desired frequency. In the **Figure 4.2** shows that the antenna already detects the desired frequency so that the indicator which is LED light up. The result has been recorded in the **Table 4.1** and graph in the **Figure 4.3** and **Figure 4.4** below.

Table 4.1 Data collection from first environment condition

No.	Frequency Captured 1, MHz	Noise Factor and Voltage Amplification	Voltage Output 1, mV
1	322	70	346
2	322	70	346
3	322	69	341
4	317	69	341
5	317	69	341
6	312	68	332
7	317	69	336

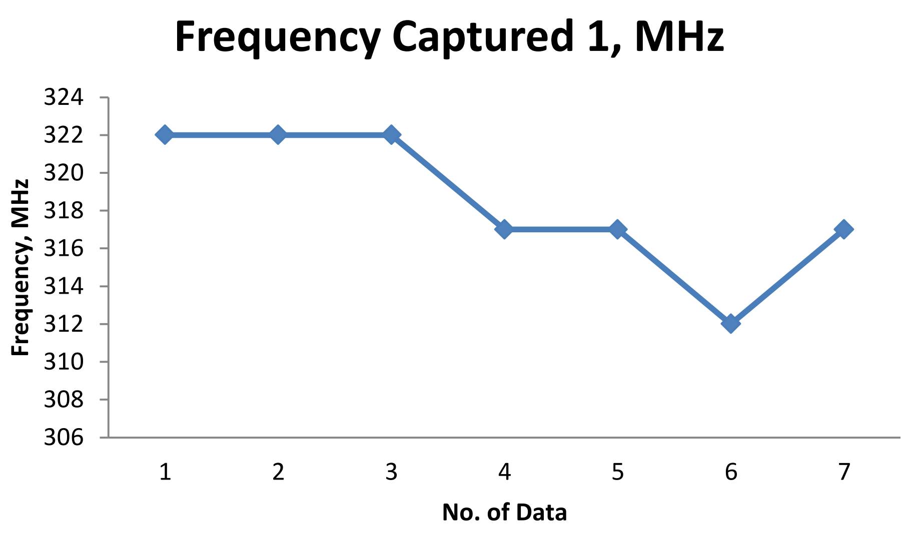

Figure 4.3 Graph Frequency that has been captured by antenna for first condition

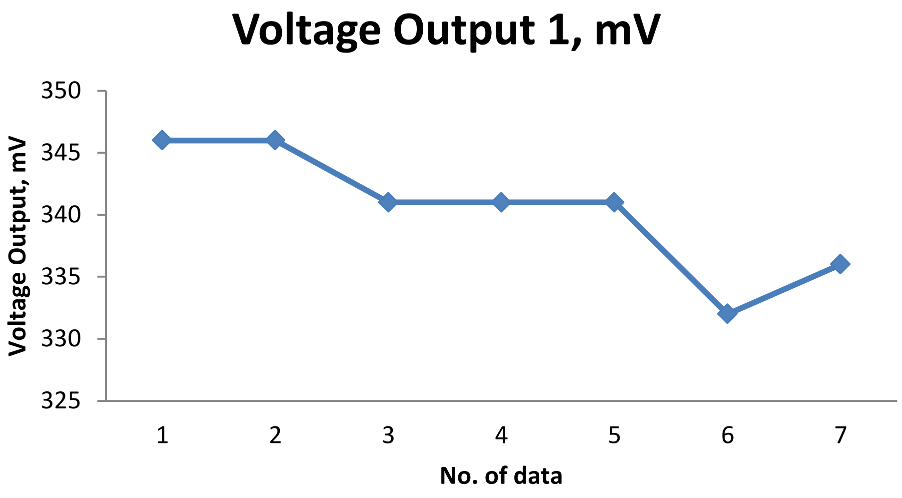

Figure 4.4 Graph of Voltage Output for first condition

From **Figure 4.3** and **Figure 4.4** above, it shows that frequency affects the output voltage. The graph in **Figure 4.3** and **Figure 4.4** parallel as frequency acts as a source of power in this system. If resources are low, then the output will also be too low. Since the output reaches a low value, then load the LED cannot be turned on, but this does not indicate that the frequency cannot produce DC supply. In addition, the factor that cause the value of the frequency that received by the antenna very low is the size of antenna that has been applied to the system.

Second environment condition is open spaces. Open spaces such as palm oil plantation, football, and seaside. This place are low in RF signal but this experiment was conducted to finds out whether it can produce DC supply. The result has been recorded in **Table 4.2** and graph **Figure 4.5** and **Figure 4.6** below.

Table 4.2 Data collection for second environment condition

No.	Frequency Captured 2, MHz	Noise Factor and Voltage Amplification	Voltage Output 2, mV
1	2	2	1
2	5	12	10
3	3	3	6
4	0	1	0
5	0	0	0
6	1	2	3
7	4	10	9

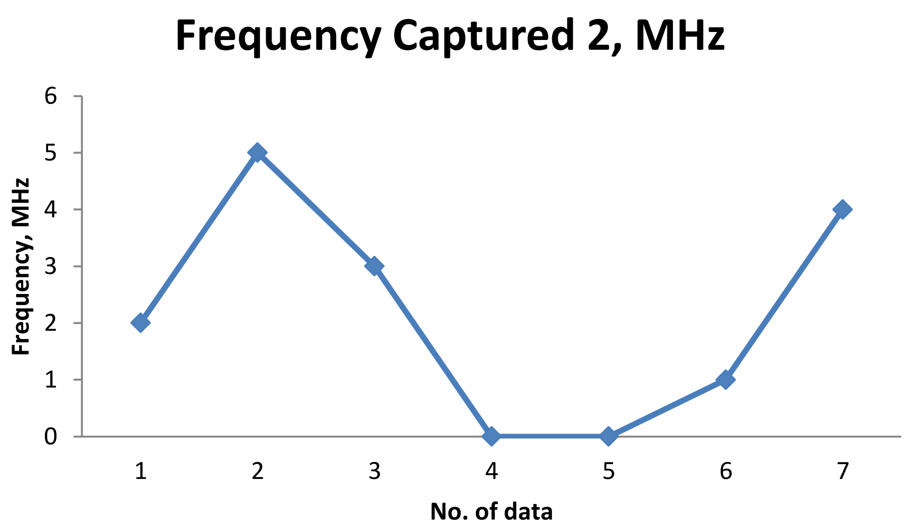

Figure 4.5 Graph Frequency that has been captured by antenna for second condition

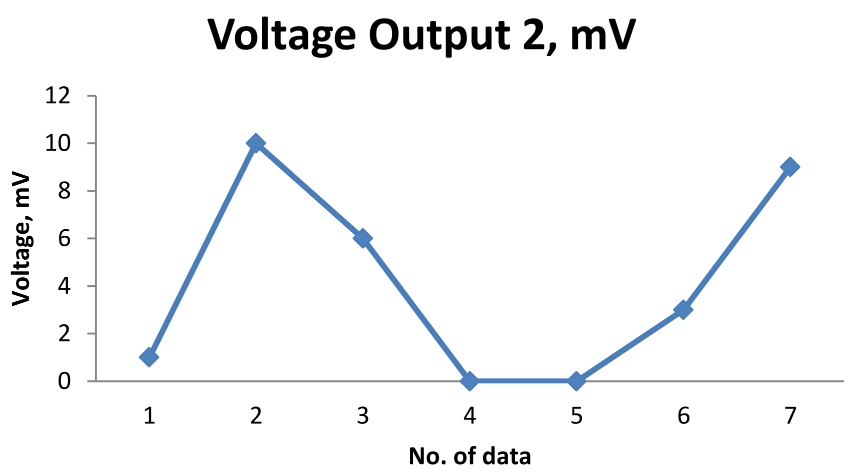

Figure 4.6 Graph of Voltage Output for second condition.

This result explanation same as the first environment condition but for this second environment condition, there are very low in frequency to captured by the antenna. As a result, the voltage output also become very low. The lowest frequency that captured by the antenna is 0MHz and give result to the voltage output become 0mV also.

In **Figure 4.7** and **Figure 4.8** below shows the different between these two environment conditions. From that, the different clearly can be seen and easy to observe.

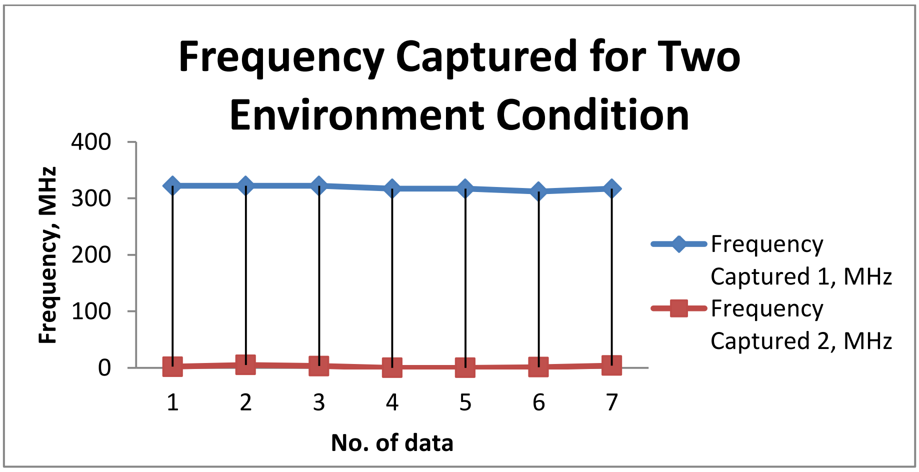

Figure 4.7 Comparison in Frequency Captured between two environment conditions.

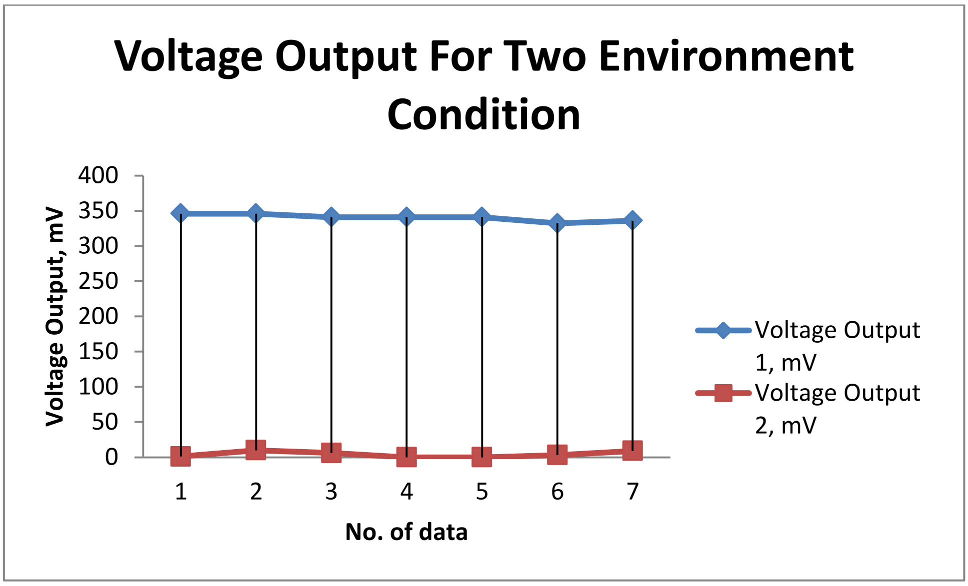

Figure 4.8 Comparison in Voltage Output between two environment conditions.

From **Figure 4.7** and **Figure 4.7**, there are different between these two environment conditions. The difference shown is very significant when viewed directly from the graph shown above. This proves that the radio frequency can produce DC voltage but to produce a DC voltage in large quantities, it would require an antenna that has a large in frequency range, size, and gain. Furthermore, to make this rectenna more efficient, design of the rectifier must be improved. This is because in this project, the rectifier was design in simple configuration. So that, the rectifier can be designed in complex configuration and analysis can be more variable.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

Radio frequency energy can be used as an alternative because it is readily available and used. In order to change the radio frequency to a DC supply, the most important thing is to design a rectifier, because the selection of components will affect the output and efficiency of the system. From the observation, the amount of the frequency has been captured will be effected to the output voltage. The design of this rectenna is simple as demanded according to the objectives of this project.

In the meantime, this is a technology that is highly recommended to the public. By applying this technology, it will make it easier for people in the future to get rid of the constraints and limitations. Among the constraints and limitations are wires and battery used in electrical appliances and turn it into wireless. So, it is also called wireless energy transfer technology.

5.2 RECOMMENDATION

To make the system complete and has the best efficiency, there are a few suggestion to make improvement for the system. First suggestion is adding the AC – DC converter which mean regulator. This is because this system actually has three subsystems which antenna as first subsystem and second subsystem is rectifier. So by adding the third subsystem which is regulator, the function of regulator is maintaining a constant output DC voltage suitable to power the electronic circuitry following the harvester for wide range of input DC voltage variation.

The second suggestion is using variable type of antenna such as patch antenna, monopole antenna, dipole antenna, and others. This is to try and identify any appropriate antenna to be used in this system to achieve maximum output. In the meantime, it can diversify its analysis and find out how to apply it in daily life. Besides that, understanding about the antenna and electromagnetic radiation will be enhanced.

The third suggestion is make this system to be a standalone system. The current system now are depends on the other power source such as batteries and power regulator. If the standalone can be accomplished, so that, this is a considerable successes in wireless energy transfer technology that makes it easy to carry anywhere and used anytime.

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APPENDIX A

THE PROGRAMMING OF THE MICROCONTROLLER ARDUINO

```
long counter =0;
void signalChanged_ISR(){counter++;} //the interrupt service routine
int led = 8;

void setup()
{
  // put your setup code here, to run once:
  pinMode(led,OUTPUT);
  Serial.begin(9600);
  attachInterrupt(0, signalChanged_ISR, CHANGE);
  counter = 0;
}

void loop()
{
  // put your main code here, to run repeatedly:
 int elec= analogRead(A0);
 Serial.println("Electromegnatic Harvesting");
 Serial.println("Noice factor and voltage amplification value");
 Serial.println(elec);
 long min = 1000000; long max = -1000000; // [mV]
 for(int i = 1; i<=1000; i++) // wait exact;y 1 sec
  {
    long voltage = (long) (((float)analogRead(A0))/ 1024.0f * 5.0f * 1000.0f); //[mV]
    if (voltage > max) max = voltage; if (voltage < min) min = voltage;
```

```
    delayMicroseconds(1000);


   }
  if(elec > 10)
{
  digitalWrite(led,HIGH);
   Serial.print(counter/2);
   Serial.print(" MHz at ");
   Serial.print(min);
   Serial.print(" ... ");
   Serial.print(max);
   Serial.println("mV");
  counter = 0;
}
else
{
  digitalWrite(led,LOW);
   Serial.print(counter/2);
   Serial.print(" MHz at ");
   Serial.print(min);
   Serial.print(" ... ");
   Serial.print(max);
   Serial.println("mV");
  counter = 0;
}
```

```
 delay(1000);
}
```

APPENDIX B

ARDUINO UNO CONFIGURATION AND CONNECTION

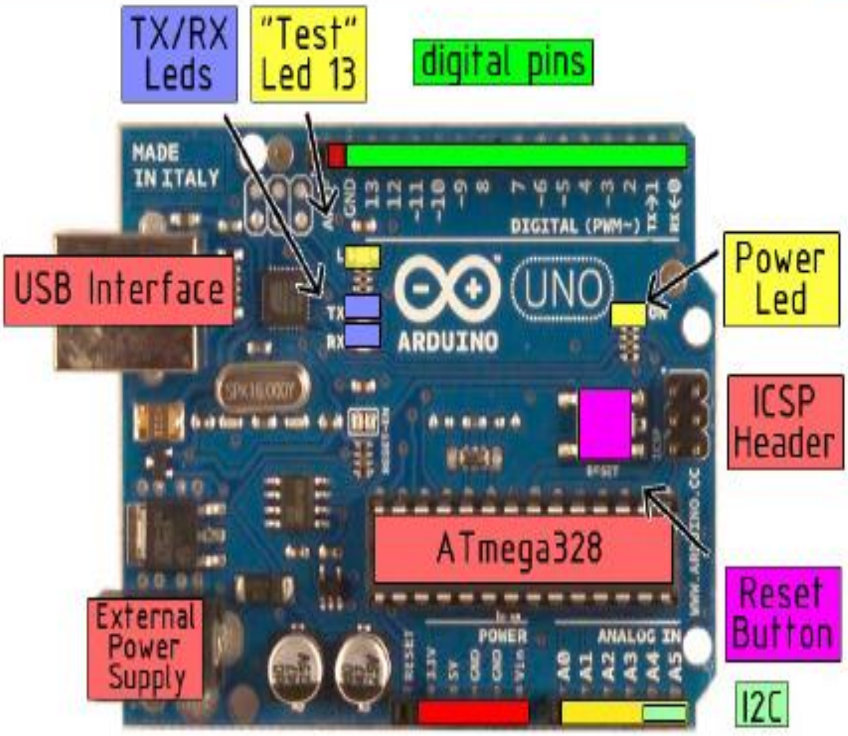
Technical Specification

EAGLE files: arduino-duemilanove-uno-design.zip Schematic: arduino-uno-schematic.pdf

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB of which 0.5 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

the board



APPENDIX C

DATASHEET OF DIODE (SOT-323)