

**IMPLEMENTATION OF THERMOELECTRIC GENERATOR  
MODULE AS EXTERNAL ENERGY SOURCE TO RFID TAG**

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering  
in Partial Fulfillment of the Requirements  
for the Degree  
Bachelor of Engineering (Hons)  
(Electrical & Electronic Engineering)

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# **CERTIFICATION OF APPROVAL**

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A project dissertation submitted to the  
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Universiti Teknologi PETRONAS  
in partial fulfilment of the requirement for the  
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(Electrical & Electronic Engineering)

Approved:

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TRONOH, PERAK

May 2013

## **CERTIFICATION OF ORIGINALITY**

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Muhammad Rusydi Bin Mashhor

## **ABSTRACT**

One of the wireless technologies available that are expanding very fast is the RFID technology. There are three (3) different types such as active, passive and semi-active RFID tag. The main concern is that the tag consumes vast amount of power due to the availability of sensors and internal electronic components in the circuitry of the tag. The goal of this project is to solve this matter by finding suitable approach for supplying power externally to the tag. At present RFID tag uses battery to operate and this battery does not last long due to low capacity. From the literature review and detailed research, it is found that the Thermoelectric Generator (TEG) is the best approach to be implemented to solve the issue. TEG is used to harvest heat energy from human body and convert it to electrical energy and directly supply to the tag. Other option such as the replacement of normal battery to rechargeable battery is also in consideration. This will enable a cutting cost of maintenance of the tag. It also shall increase the performance of the active RFID tag.

## **ACKNOWLEDGEMENTS**

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# CHAPTER 1

## INTRODUCTION

This chapter will explain the background and the scope of the project which mainly about Radio frequency identification (RFID) and the harvesting energy by the Thermoelectric generator (TEG). In addition, several problems are discovered from the detailed research and some objectives been derived based on the problems are also included in this section.

### 1.1 Background of Study

Radio frequency identification (RFID) is a system that operates wirelessly for the purpose of identification. The system transfers signal through electromagnetic radiation of radio frequency spectrum. This advance technology is widely use in industries such as commerce or financial payments, transporting and logistics, sports, education institution and hospital [1].

There are several types of RFID in the industry but most commonly used are the passive RFID and the active RFID. For the passive RFID no battery is needed as compared to the active RFID that required internal power supply. The reason for this is active RFID can store data and it runs continuously. Unlike the passive RFID, the data is only show once the reader transmits radio frequency (RF) wave to the tag. The RFID system consists of reader that include antenna and transceiver and RFID tag which also known as transponder. Active RFID is more practical as it can store data and longer distance of coverage if compared to passive RFID. In addition to this, less radiation is emitted by the reader as the tag itself can transmit the radio frequency signal due to the presence of internal power supply of battery [6].

Energy harvesting is becoming a phenomenon these days. It is the process of converting energy from one state of energy to electrical energy. People lean towards to use renewable energy and free source energy to run equipment. By applying this process it will decrease the maintenance and operating cost. There are several sources of energy that can be harvested to get electricity for instance, solar energy, wind energy, thermal energy potential energy and kinetic energy [4].

Thermal energy is more preferable to be harvested for generating electricity as most of the process will produce heat energy that usually is being wasted. Thermoelectric generator (TEG) is a device that converts heat energy to electrical energy based on the variances of temperature of an object. This is known as Seebeck effect or Peltier effect. TEG is the latest technology that is being used in for automotive industry, wrist watch and thermocouples. The process of producing electricity is when the TEG detects changes in temperature of an object and the charge start to move and induce some voltage. This is best applying to human body as our body is continuously produce heat even when we are sleeping. With the differences in temperature of body and the surrounding this will induce small voltage that can operate low power electric circuit [12].

## **1.2 Problem Statements**

Battery is required for active RFID in order for data storage and continuous operation, so it have some downsides which are:

- High degradation of battery due to sensors that consume high power.
- Low RFID coverage due to low battery powered.
- Interruption of data collection due to battery drainage.
- High maintenance cost as repeatedly replacement of battery.

### **1.3 Objectives**

The objectives for this project are:

- To improve the power supply for the tag by implementing TEG as source of supply.
- To reduce the power consumption of the circuit.
- To compare with existing RFID tag that uses Lithium battery as power source in term of performance, cost and reliability.
- To construct a self-charging circuit for the battery.

### **1.4 Scope of Study**

The first scope of this project includes Energy and Power Systems which covers the study of the type of battery that is suitable for the active RFID tag. Besides that, it also involves the study of power flow for the tag and covers the concept of TEG and its mechanism. The second scope is the Communication System which includes the understanding of radio frequency characteristic, RFID and data transmission. This is vital to avoid conflict between the supply power and the transmission data. Lastly, the project also covers the microelectronic part as the circuit consists of electronics component and some controller's configuration.

### **1.5 Feasibility of Project**

With the best facilities that available in University Technology of PETRONAS (UTP), this project can possibly be done conveniently. The university has vast number of laboratory especially for the Electrical and Electronics field of study. This will provide pleasant working environment as this project is related to the Electrical and Electronics field. There is also electrical component store that provide service for student who want to find and borrow for the components. This project can be completed within the time frame if the well planned Gantt chart is followed. As refers to the methodology provided, the goal of this project can be achieved.

## CHAPTER 2

### LITERATURE REVIEW

For this section, the theory of RFID and TEG are being emphasized. Further explanations about the working principle, design concept and applications for both technologies are stated. Moreover, the detailed research and literature review from the journal, article, books and internet are summarized in this chapter.

#### 2.1 RFID

Radio frequency identification (RFID) is a system that operates wirelessly via radio frequency spectrum. The purpose of the system is for monitoring or identifying tagged people or object [1][5]. The data transmission of RFID is by detecting the unique serial number of tag or label which each tag has its own ID [2]. There are two main components of RFID system which is the transceiver or the reader and the transponder which is the label or the tag. RFID system is classified into two types that commonly use, which is active RFID and passive RFID. Both type operate identical transmission principle but small different on functionality.

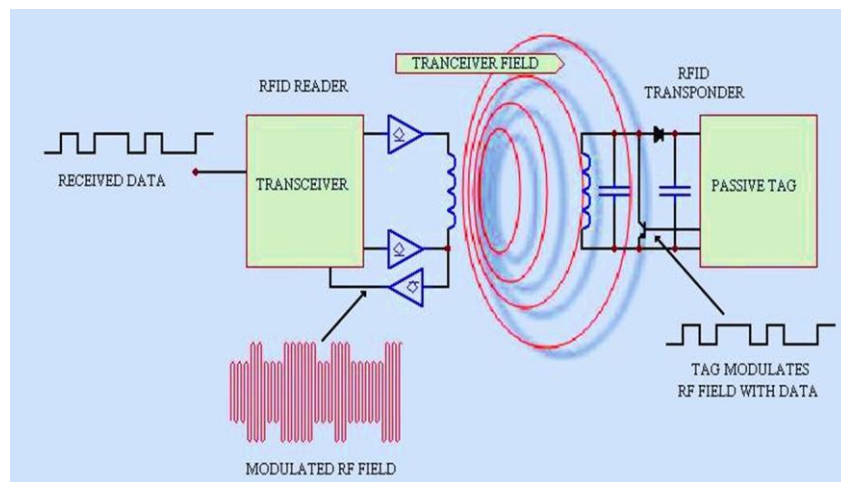


Figure 1: RFID system (passive) [1]

### 2.1.1 Passive RFID

Passive RFID does not require internal power supply. This means that no battery is required to power up the tag. Basically the tag is built with radio frequency (RF) circuit that harvests RF signal transmitted by reader for power supply and data identification. As the tag is passive, the range of transmitting data is low. In addition, the tag cannot store memory as no continuous supply from the reader signal. This is like the read only memory (ROM) principle. It shows data once the reader transmits RF signal to the tag [3].

### 2.1.2 Active RFID

An active RFID tag has an internal power supply provided by a battery, the reason it is called active due to its operation. This tag can be used continuously as long as the battery keeps supplying power. The range of coverage is about 100 meters or more. This is because the tag transmits its own RF signal. The active tag comes with memory storage that can be read or written (RW). For more advanced tags, it is equipped with various types of sensors based on the applications. Besides, active tags are more reliable for challenging RF signal environments or high distortion environments [8].

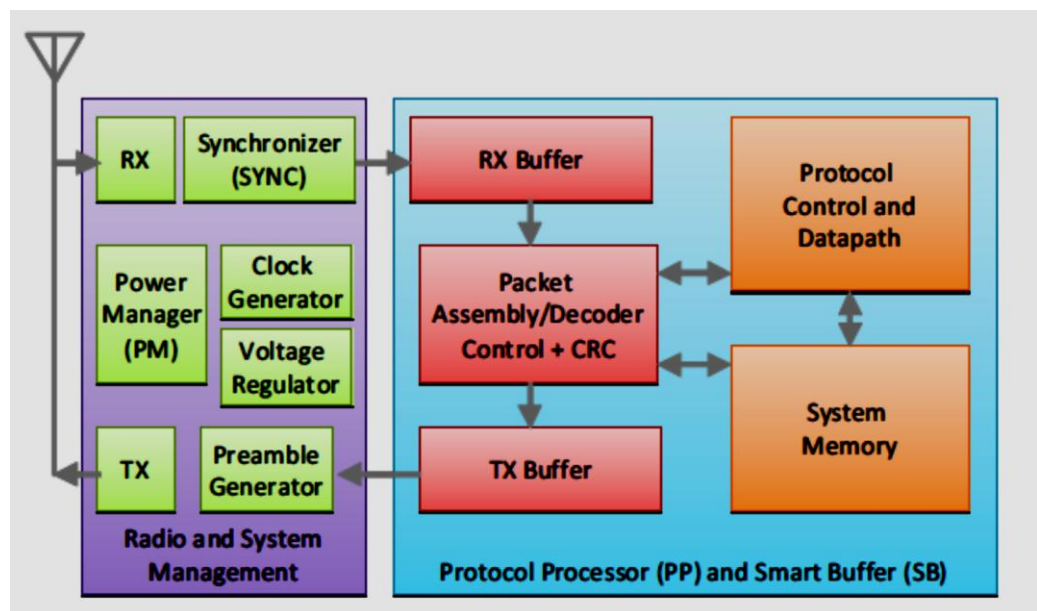


Figure 2: Block diagram of Active RFID tag [8]

## 2.2 Thermoelectric Generator (TEG)

Thermoelectric generator is a device that harvest heat energy and convert it to electrical energy. Voltage is induced as the temperature of an object changes or in the other words the device produce electrical power from the heat flow across temperature gradient. [4] This process is known as Seebeck effect or Peltier effect. The process is direct which means the heat that flow from hot junction to cold junction will create a slight voltage due to different type of material used. TEG is built with tiny positive type element (p-type) and negative type element (n-type) sensitive to heat. With presence of heat, charged is move from p-type to n-type and voltage produce is depending on the amount of heat it receives.

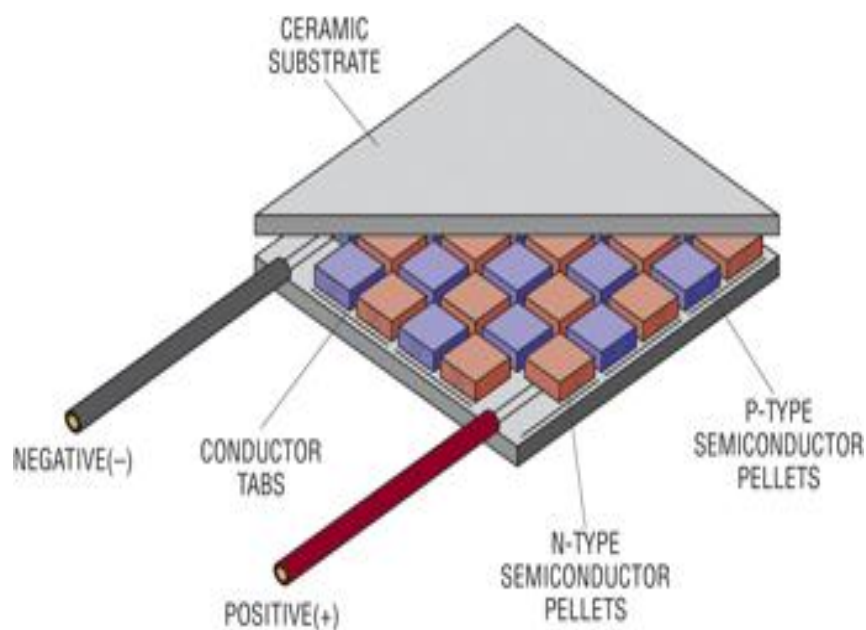


Figure 3: Thermoelectric Generator (TEG) module [4]

### ***2.2.1 Seebeck effect***

Two metal that is connected together and have different temperature will induce electromotive force (EMF) that known as Seebeck effect [7]. The metal should be high electrical conductivity and from different material. This TEG also can be used as cooling element too.

The Seebeck effect is the process where we convert heat energy is converted to electrical energy whereas Peltier effect is converting electrical energy to heat energy. Human body can generate power by using this concept. This concept had been applied for various purposes such as thermoelectric generator and thermocouples. Further studies of Seebeck effect lead to the concept of thermo power which states that the amount of voltage produce is proportional to the temperature gradient.

### ***2.2.2 Peltier effect***

Peltier effect is the opposite of the Seebeck effect which it converts electrical energy to the heat energy. When two metals are connected together and voltage is applied to both junctions, heat will produce. The upper side will create heat but the bottom part will absorb heat and act as cold junction. This concept is implementing for the cooling process of refrigerator. Basically this is the reverse process of Seebeck effect.

### ***2.2.3 Temperature and Voltage Relationship***

Every living thing in this world creates heat energy from their body. The heat energy produced is measured by degree of hotness or coldness which is known as temperature. Normal human body temperature is about 37°C whereas room temperature is about 26°C. This will create a temperature difference of 11°C. As this temperature gradient, it is enough to be applied to TEG module in order to induce a voltage.



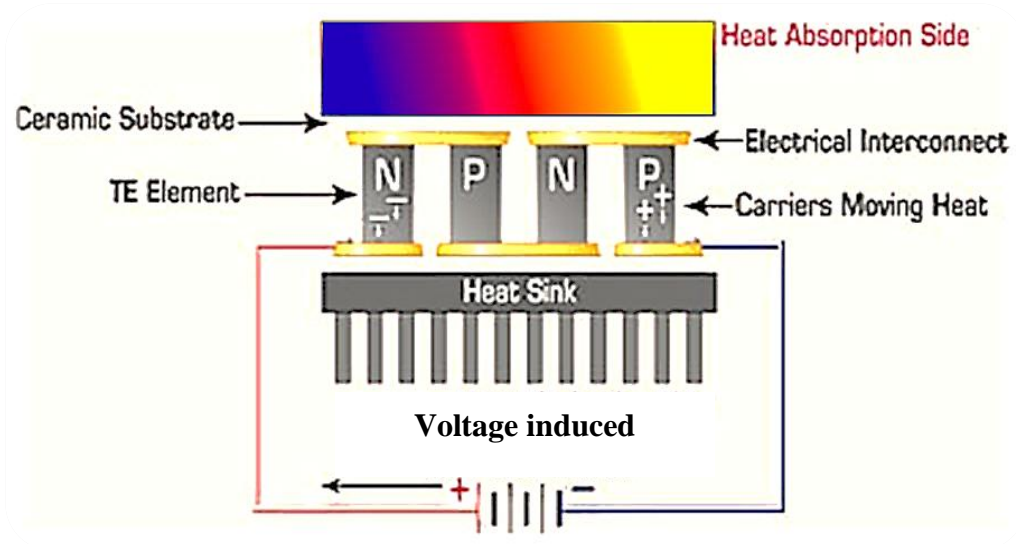


Figure 4: Cross sectional view of TEG [7]

As refer to the Figure 4, the human body is placed at the heat absorption side in order capture heat. The heat absorbed from the hot side then triggers the atom in the p-type element and n-type element. Then, electrons move through the both element and voltage is induced. The relationship of temperature and voltage is explained by the formula below:

$$V = (S_B - S_A) \cdot (T_2 - T_1) \quad (1)$$

Where,

$S_A$  = Seebeck coefficient of material A

$S_B$  = Seebeck coefficient of material B

$T_1$  = Temperature of material A

$T_2$  = Temperature of material B

### 2.3 Techniques and Applications

Several researches had been done by searching the internet, reviewing the journal or article and understanding the concept of previous project that been done by other people. From all the activities before, some information that related to the project are gathered and analyzed. This project is focusing on the active RFID tag and its power consumption.

Standard active RFID tag consume about 20 – 30 mA of current and it depend on the functionality of the tag. For instance if the tag is used to detect the temperature or heartbeat of a patient, sensor is required and most sensors consume high current due to its high accuracy of performance. This will reduce the lifespan of normal battery. In order to overcome the problem, some researcher had design a low powered active RFID tag by using several approaches [2].

Some of the researchers had design a Low Power Active RFID Tag in UHF Band by introducing an additional co-processing digital circuit for the microcontroller of the tag. The Co-Processing Digital Circuit, CPLD EPM240T100 is used to control sleep and wake up mode of the microcontroller by allowing only legitimate data transfer. If real command or data coming to the tag, it will wake up the controller or otherwise it will remain in sleep mode. By using the CPLD EPM240T100, the active RFID tag consumes 20mA in active mode and 14 mA during sleep mode. Besides that, the tag used low powered microcontroller, MSP430F149 which consume less power during operation [8].

Based on the paper, Design and Verification of an Ultra-Low-power Active RFID Tag with Multiple Power Domain, the authors design an active tag chip with multiple power and clock domain. The chip includes wake-up analog regulator, digital power manager, synchronizer and protocol processor. The chip is design to replace the normal active RFID tag that consumes high power and no battery saving mode such as sleeps and wake-up mode [9]. From both article, the authors tend to reduce the power consumption of the active RFID tag by using additional device and low powered component for the tag in order to increase the lifespan of battery.

In order to solve the battery problem, some researchers had introduced an external power source from Thermoelectric Generator (TEG) module. Based on the article from Shigeru Watanabe, he uses TEG for supply power to a wrist watch. The normal wrist watch is redesign with additional TEG is introduced. The author used the original case of the watch as housing as it is made of metal case. TEG is mounted at the bottom part of the watch in order to harvest heat from human body. Both end of TEG are connected to the node of battery connectors. The material of TEG for this paper is Bismuth Tellurium (BiTe) and can generate 2mV/K and specific resistance is about  $1.2 \times 10^{-5}$  ohm. The size of TEG used is about 25mm x 35mm which fit to the bottom casing of the watch. Lastly, the article shows that TEG module is used to power up the wrist watch with optimum power [10].

## CHAPTER 3

### METHODOLOGY

This chapter explains about the steps and procedures that need to be taken in order to complete the project well. Several steps are arranged from starting the project until the end of it. The progress of project is pictured by the aid of flow chart model, Gantt chart table, and detail of procedures in order to keep the project in the right track.

#### 3.1 Procedure Identification

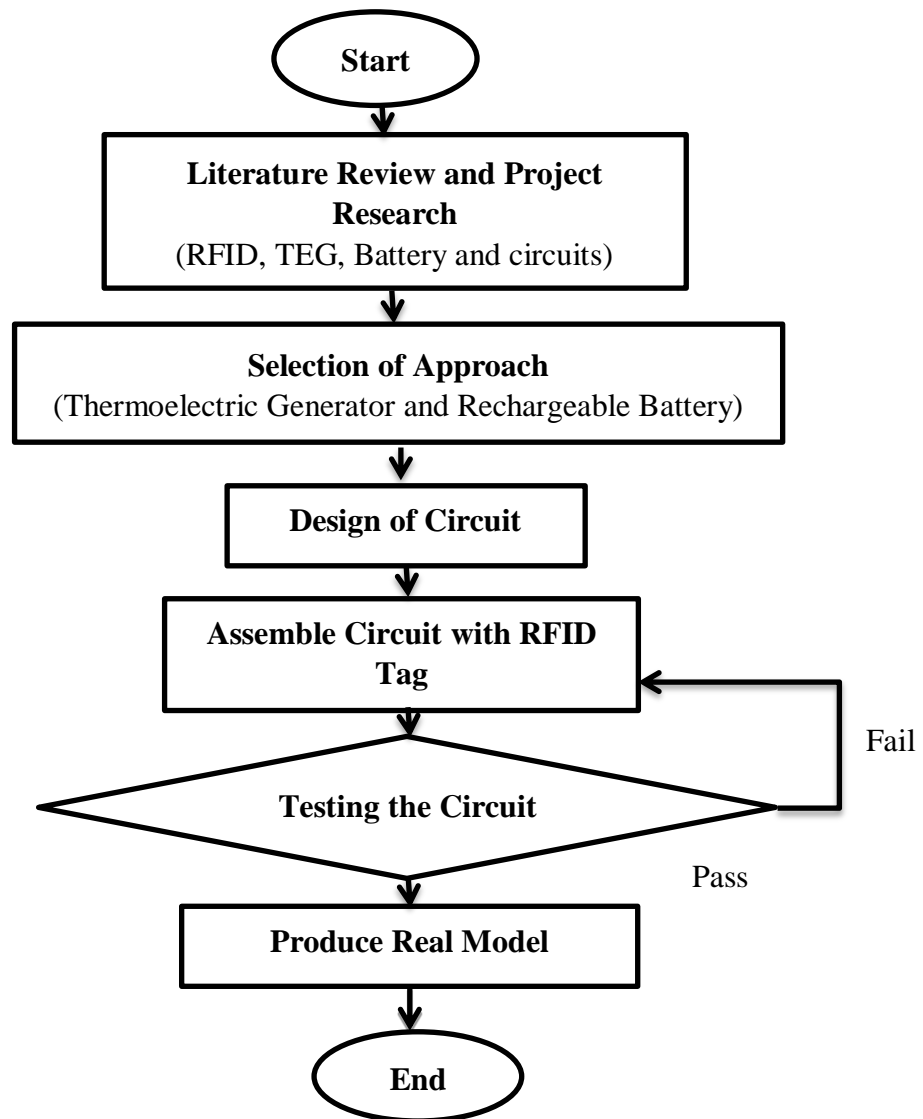


Figure 5: Flow Chart of Procedure Identification

## **3.2 Detail Procedure**

For this part, the detail of procedure is based on the flow chart that had been constructed before:

### **3.2.1 Literature review and Project Research**

Firstly, project title is chosen by the student based on the respective supervisor. Then related data is gathered from various sources such as books, journal, website and lecturers. This will help in better understanding about working principle of RFID, circuit design of TEG and suitable battery wattage.

### **3.2.2 Selection of Approach**

After gone through several article and journal, suitable power supply for RFID tag is identify. For this section, TEG is selected to power up and recharge the battery of the tag. Rechargeable battery rating of 3 Volt and high wattage is selected to replace the current battery.

### **3.2.3 Design of Circuit**

An electrical circuit is design to recharge the battery of the tag by using TEG. This circuit design also covers the voltage and current booster as TEG induce moderate amount of voltage.

### **3.2.4 Assemble Circuit with RFID Tag**

This is the process when the electrical circuit is connected to the RFID tag circuit. The supply power of the electrical circuit should be enough to supply the load (RFID tag).

### **3.2.5 Testing the Circuit**

After assembling the electrical circuit with the tag is done, it is tested by attach the TEG to human body. The reason is to get more accurate result for data collection and further improvement.

### 3.3 Tools

The tools that been used for this project is divided into two categories which is hardware tools and the software tools.

Table 1: Tools for the project

Hardware	Software
Electrical tools	Multisim 11.0
Thermoelectric generator (TEG)	
RFID tag	

### 3.4 Gantt Chart

Table 2: Gantt chart of project for FYP1

NO	DETAIL	WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Title		■	■												
2	Research on the Project and Literature Review (RFID,TEG and Battery)			■	■	■	■									
3	Submission of Extended Proposal Defence							X								
4	Data Gathering, Design Circuit and Testing							■	■	■	■	■	■	■	■	■
5	Preparation for Oral Proposal Defence								■							
6	Oral Proposal Defence Presentation									■						
7	Preparation of Interim Report				■	■	■	■	■	■	■	■	■	■		
8	Submission of Interim Draft Report														X	
9	Submission of Interim Final Report															X

■ Located time

X – Due Date

Table 3: Gantt chart of project for FYP2

NO	DETAIL	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Model Development	■	■	■	■	■									
2	Model Testing and Improvement			■	■	■	■	■	■	■	■	■			
3	Preparation of Progress Report						■	■	■						
4	Submission of Progress Report									X					
5	ELECTREX											X			
6	Preparation of Final Report and Technical Paper									■	■	■	■	■	
7	Submission of Draft Final Report													X	
8	Submission of Technical Paper													X	
9	Final Presentation														X
10	Submission of Final Report														X

■ Located time

X – Due Date



## CHAPTER 4

### RESULTS AND DISCUSSION

In order to assemble the TEG module with RFID tag, a circuit design is proposed and being tested by simulation. The circuit is design to operate the TEG module as external power source of active RFID tag and simulation of it is done by Multisim 11.0 software to obtain the results. After the simulation process, the circuit is developed and test at the laboratory. The circuit development process is continuously done until the desired result is achieved.

#### 4.1 Circuit Design

Several designs are proposed for the TEG electrical circuit. For the first stage of circuit design, two TEGs are being used for supplying and charging of the tag. The connection of components is based on the figure 6.

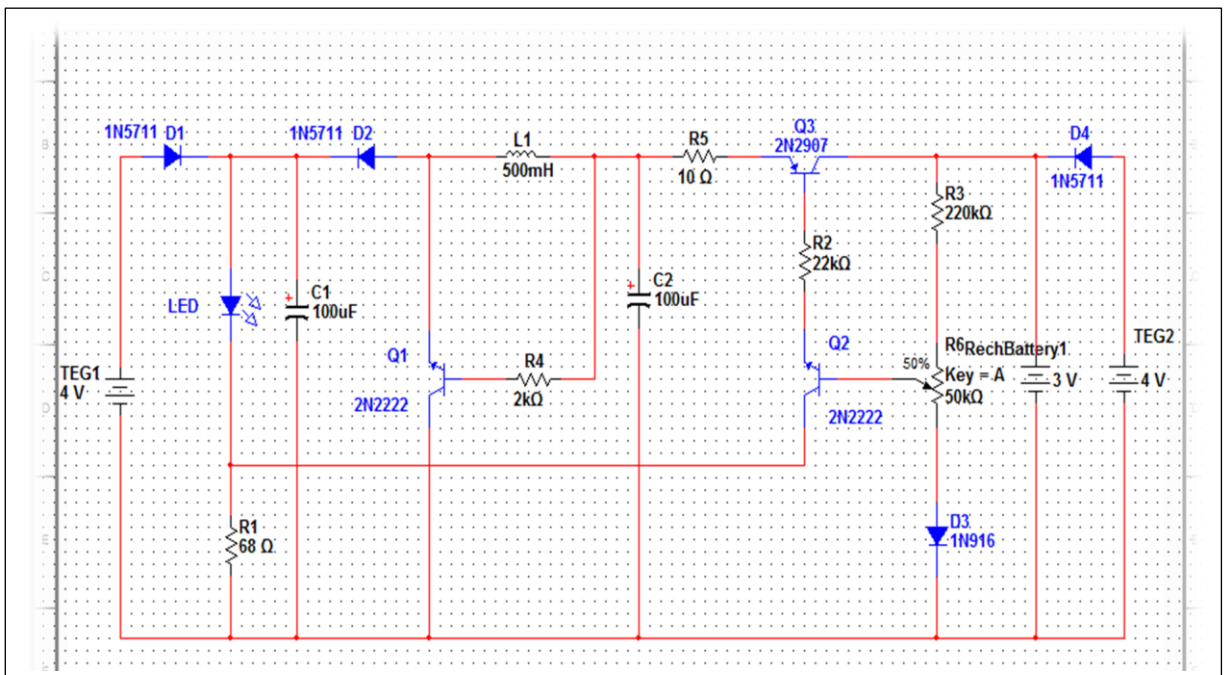


Figure 6: First stage circuit design of project

Further research and simulation had been made from the previous circuit. It is found that the circuit can be simplified and improved. The other simplified circuit is shown as in the figure 7. The TEG is connected to the inductor coil and four unit of BF245C, MOSFET N-channel amplifiers.

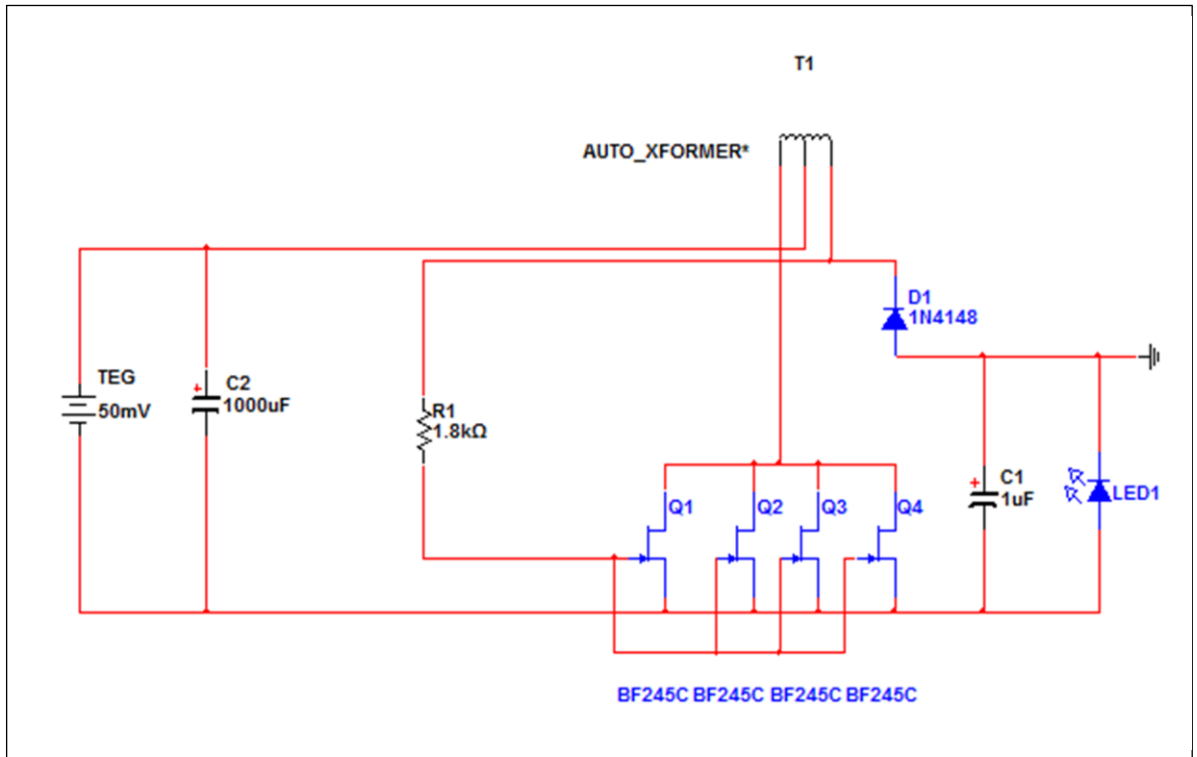


Figure 7: Simplified circuit design of project

#### 4.2 Model Development

Based on the proposed design of figure 6, a circuit is developed to test the connection and the power flow of circuit. Basically, this circuit is divided into two parts which the first part is the source of power supply and the second part is the rechargeable circuit. For power supply part, this circuit used TEG1, voltage booster and 3V rechargeable battery whereas the rechargeable part used TEG2 to charge the 3V battery.

The circuit requires a voltage booster as TEG harvest small amount of energy and this will be further increased by the booster in order to power up the tag and to recharge the battery. The booster circuit includes the autotransformer (inductor coil), capacitor and the transistor. The entire components are connected as shown in the figure below.

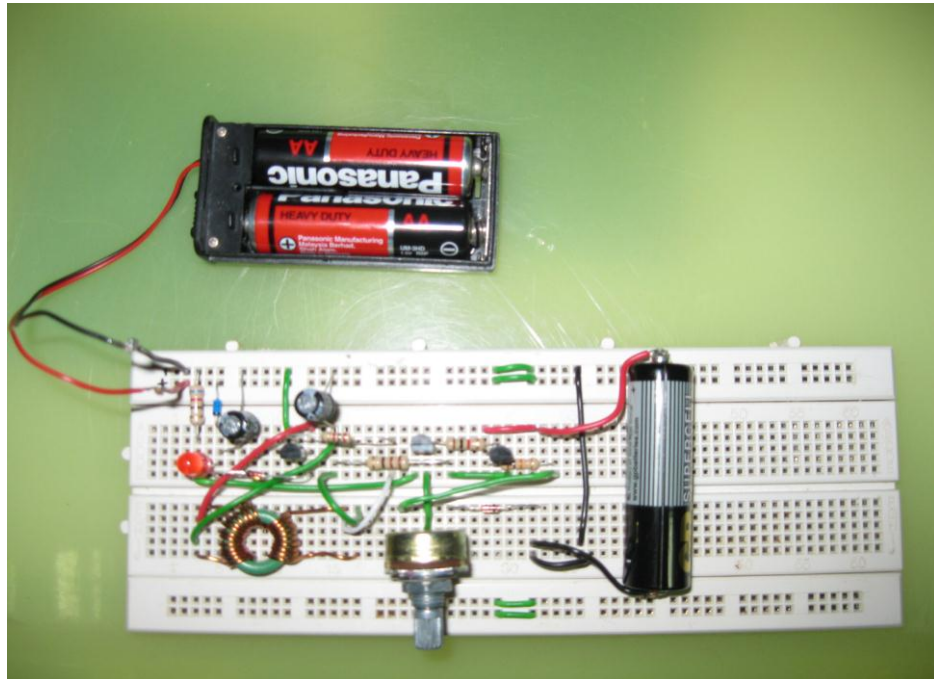


Figure 8: Circuit model

As refer to figure above, two 1.5V batteries are connected in series to produce a 3V supply. The real active RFID tag is quite expensive and to prevent the tag from damage, LED is used to replace the tag as the current and voltage rating is slightly similar to the real tag. The 1.5V battery is used to prove the effectiveness of the voltage booster as it will step up the voltage output and light up the LED. It also represents the TEG module as the value of voltage supply from the TEG is slightly the same. There are several diodes use in this circuit such as Schottky Diode and High-speed Diode, 1N5711 and 1N916 respectively. Both diodes are used for protection and fast switching for transistors. This circuit is for the first stage of circuit development.

After several testing and further research, the circuit is then simplified to be supply only. TEG is used to directly supply to tag. As refer to figure 9, TEG is connected to the 1000uF capacitor and the inductor coil. The inductor coil use in the circuit is to boost up the input voltage from TEG which is about 100mV. The step up ratio depends on the number of turns on the primary and secondary coil. The greater number of turns of secondary coil, the greater the voltage produced.

Besides that, the size of copper wire also affects the output voltage of the circuit. There are several size of enamel wire used in the circuit development such as 18AWG, 20 AWG and 32AWG. Then, the inductor coil is connected to the parallel N-channel amplifiers, BF245C which to stabilize and amplify the output voltage. The 1N4148 is connected to both components in order to make the voltage flow in forward bias and on the other hand to protect the TEG which sensitive of reverse bias voltage as it is made up of p-type and n-type substrate.

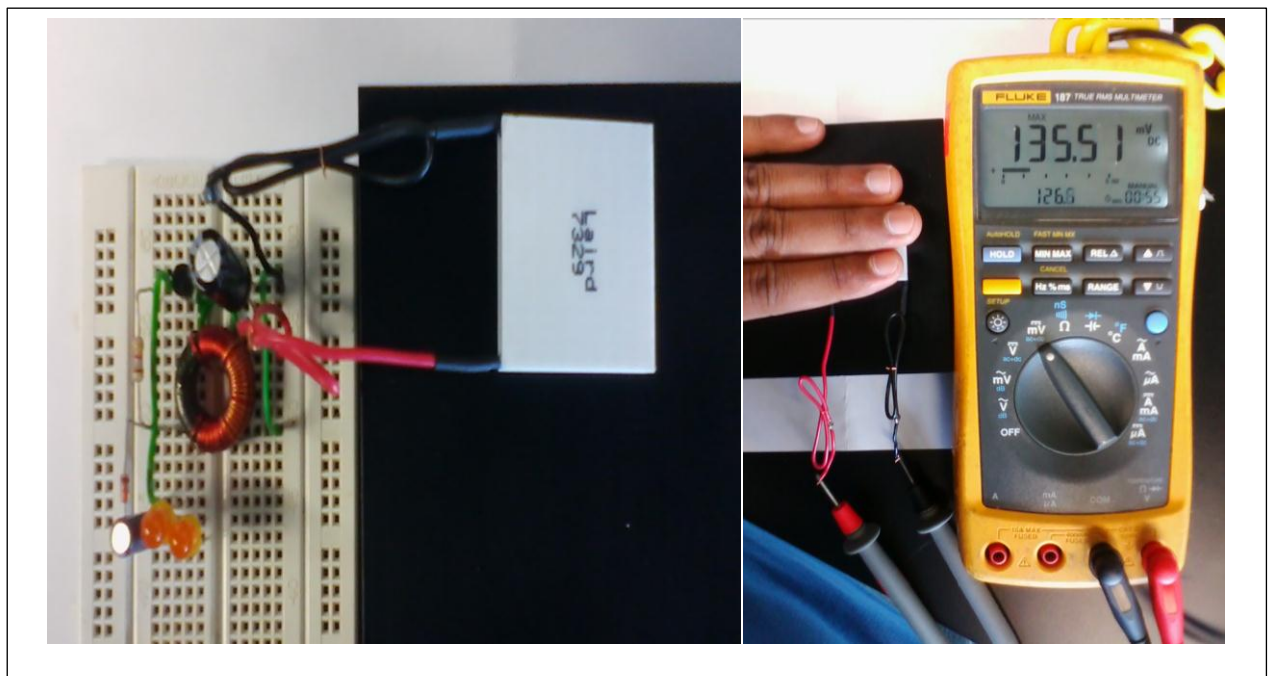


Figure 9: Simplified circuit model

The TEG has two parts which are hot and cold region. The hot region is attached to human body as to capture heat. Whereas the cold region is place to heat sink as the reference to room temperature. The normal temperature for human is 37°C and room temperature is 25°C which create a gradient of 12°C. With this temperature gradient, it can produce output voltage of 135mV.

### 4.3 Results and Discussion

With the aid of Multisim 11.0 software the proposed design is simulated for several times. The circuits are then tested at the laboratory in order to check if any faulty and further improvement. The results from first stage design and the simplified design from the simulations and experiment are as follows:

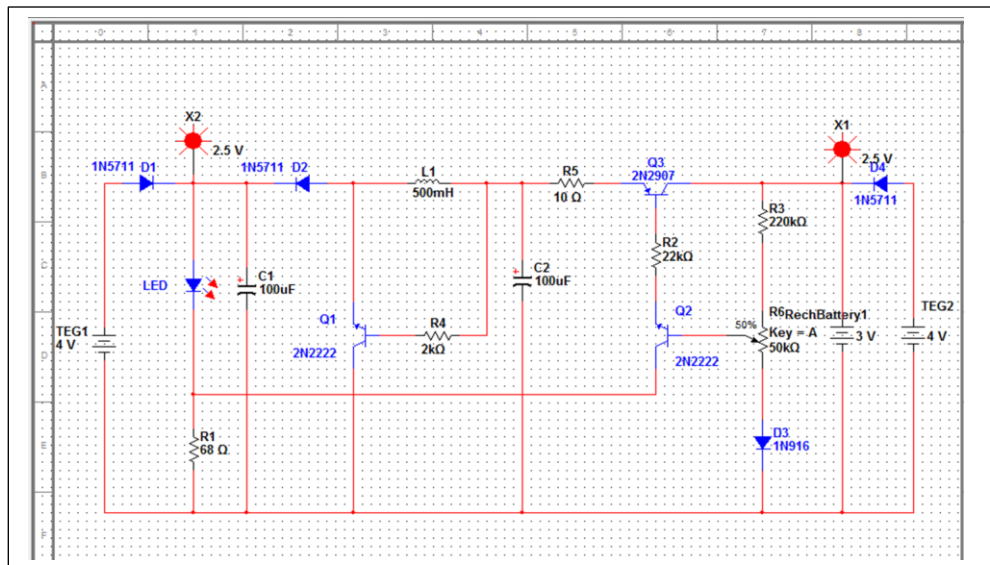


Figure 10: Simulation of circuit (TEG produce voltage)

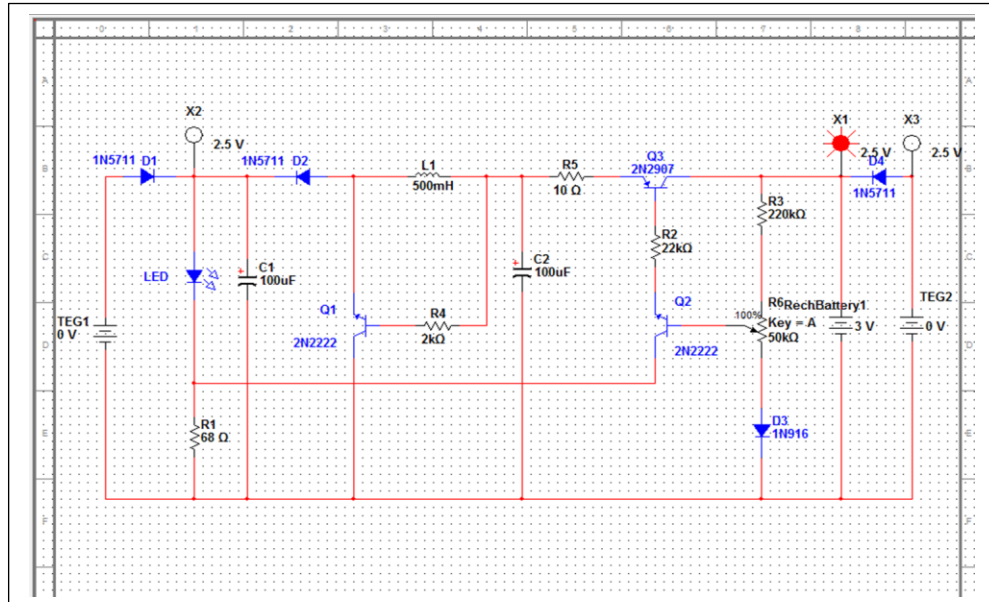
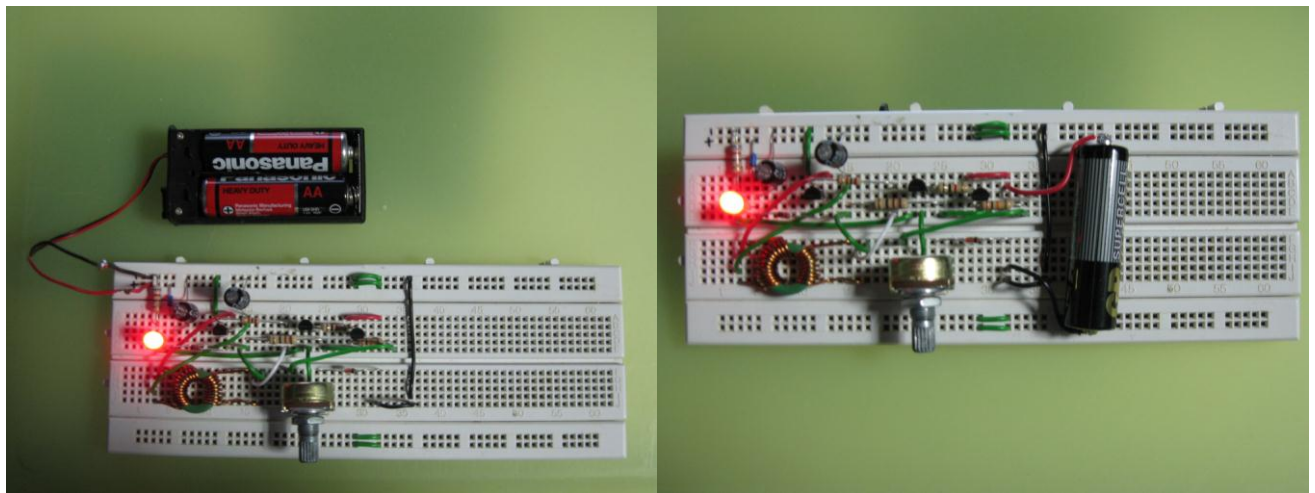


Figure 11: Simulation of circuit (no voltage produce by TEG)

As refer to figure 10, during simulation the TEG is set to produce about 4V. This is to observe the flow of current in the circuit as TEG produce supply. LED is light up by the TEG1 whereas TEG2 is recharged the battery. For the simulation in figure 11, both TEGs are set to be zero in order to determine the flow of current produce by battery. Unfortunately the circuit had minor problem as no light is produced by LED. This shows that no current flow through the LED. With some changes in the value of the components and the connection, a circuit is developed and tested. The results are shown in the figure 12.



(a)

(b)

Figure 12: Circuit Testing (a) supply of 3V battery and (b) supply from 1.5V battery (TEG1)

From the Figure 12(a), the circuit is tested with normal supply from 3V battery. The LED light up as the voltage supply is directly power up the LED with optimal value. This shows the supply part is working. The real active RFID tag requires 3V supply in order to operate efficiently. As for Figure 12(b), the voltage booster is tested. A 1.5V dry cell is used in this experiment as represent the TEG1 and the LED lights up as the same brightness as circuit in Figure 12(a). The voltage output at the LED is measured about 2.7V and 2.2V respectively and the measured current is about 25mA. The circuit is then connected with both supplies as shown in Figure 11. The voltage is boost up until 2.2V whereas the real active RFID tag requires about 3V supply.

Further improvement of circuit is done by simplified it as shown in figure 9. Before the circuit is test at the laboratory, it is simulate using Multisim software. The input voltage from TEG is set to minimum value of 50mV. The input and output of the circuit is measured by using voltmeter and ammeter as shown in Figure 13. The value for both meter are shown in Table 4.

Table 4: Simulation result of simplified circuit

Parameter	Voltage,V	Current,A
Input	0.050	14.236
Output	3.893	6.772

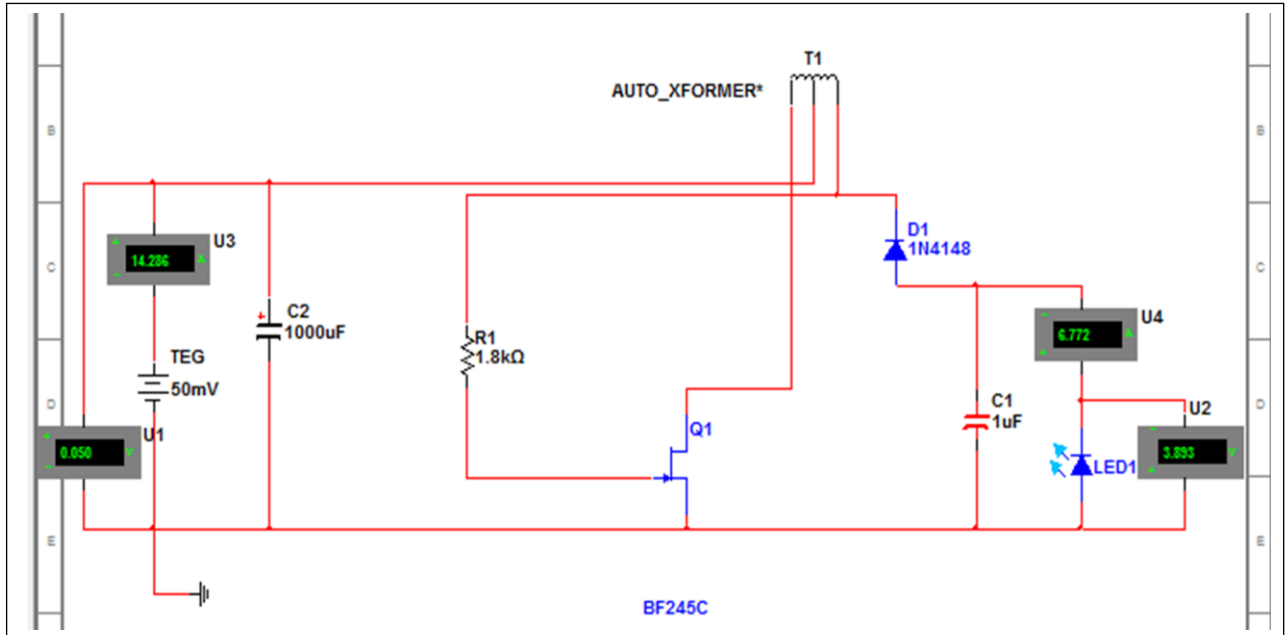


Figure 13: Simulation of simplified circuit with voltmeter and ammeter

From the simulation result the voltage is step up from 50mV to 3.893V but the current is decreased as stated by the Ohm's law, increasing the voltage will decrease the current. The circuit is then develops and test at the laboratory. The circuit is set up as shown in figure 14.



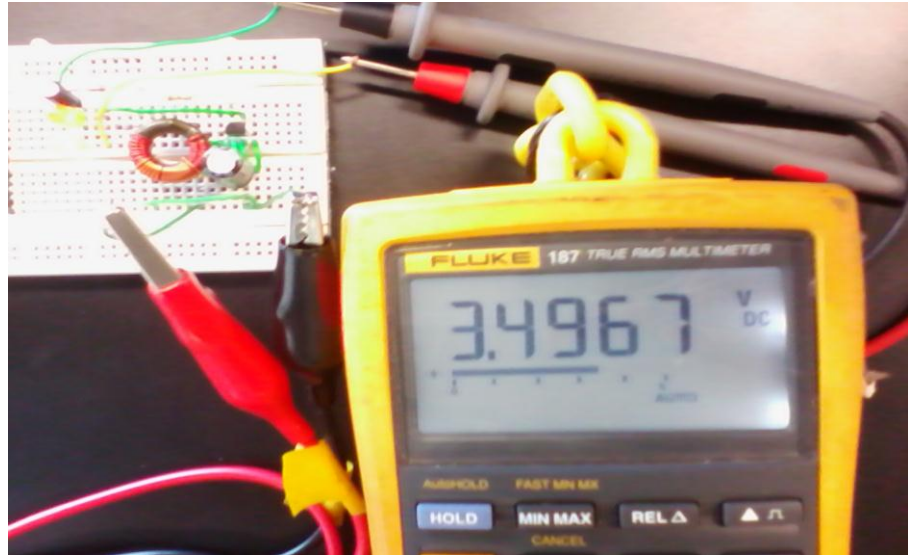


Figure 14: Simplified circuit testing with different inductor coil configuration

The TEG that being used during testing process is Laird PH05 series and the specification can be referred at the appendices section. The process of testing is done by varying the configuration of inductor coil by using different size of enamel copper wire which are 18AWG, 20AWG and 32AWG and altering the turn ratio of the coil. Besides that, the number of BF245C is reduced to one due to high power consumption. The input from TEG is about 150mV and it is been connected to the input circuit to boost up the voltage. After several testing the minimum voltage used for the input is about 1V in order to boost up the voltage to desired output of 3V. As 1V is injected to the input, the output voltage is boost up to 3.5V with the inductor coil ratio of 1:3.



Figure 15: Inductor coil of different configuration

Further testing is done by varying the number of turn ratio of inductor coil such as 1:5, 1:8 and 1:20 and using different size of the enamel copper wire in order to achieve desired output. In order to increase the efficiency of the circuit N-channel amplifiers, BF245C is replaced by the 2SD1302 which has collector to emitter saturation voltage,  $V_{CE(sat)}$  of 0.13V. As compared to BF245C, it required 1V input voltage in order to operate. By using 2SD1302, only small voltage input is required for the circuit to operate. This suited well with TEG as its average output voltage is 150mV. The voltage output from TEG varies with the temperature gradient of the body. During the testing process, the TEG module is placed at three different location of body such as finger, hand palm and wrist. From the observation, it shows that the best place to put the TEG module is at the wrist as it has high temperature gradient to harvest heat energy. This shows in the Figure 16 as maximum output voltage produce from the TEG is about 218mV when it is placed at the wrist.



Figure 16: Maximum voltage output from TEG (218mV)

Table 5: Voltage and current output from different inductor coil configuration

Turn ratio	Voltage input, mV	Voltage output, V	Current, mA	LED
1:3	150	3.3	20	On
1:8	150	3.5	2.0	Off
1:20	150	6.5	1.5	Off

Table 5 shows the result for the testing of the circuit when different number of turn ratio of inductor coil is used. The output voltage and current of the circuit depends on the voltage input from TEG and the value of turn ratio inductor coil as the low voltage from TEG is then boost up by the inductor coil. The highest voltage output is achieved when using the 1:20 turn ratio of inductor coil but the LED is not light up as the value of current is too small.

Although the voltage is 6.5V, the current is only 1.5mA whereas the minimum current required to light up bright blue LED is about 18mA to 20mA. This situation is the similar when using the 1:8 turn ratio of inductor coil. As the number of turns for secondary windings of the coil is high, the voltage produce is also high but the current is low as stated by the Ohm's law. The suitable inductor coil to be used is the 1:3 turn ratio configurations as it can boost the voltage from 150mV to 3.3V and produce 20mA of current and enough to light up a bright blue LED.

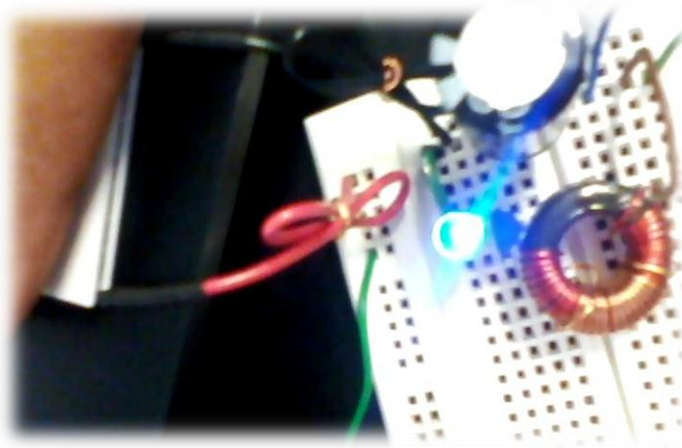


Figure 17: Bright blue LED light up as the voltage and current is sufficient

Theoretically, with 3.3V of voltage and 20mA of current from the circuit, it can be used to supply for normal active RFID tag that consume 3V and 20mA of voltage and current respectively [8]. For complex design of RFID tag that consumes high power, the circuit could not supply enough power and this will reduce the efficiency of the tag. During the early stage of testing process, the circuit is mounted on the bread board in order to ease the improvement of the circuit. After being tested for many times the circuit then is implemented on the Vera board. The circuit that used inductor coil of 1:3 turns ratio is assembled on the Vera board and place in the suitable casing for prototyping.



Figure 18: Prototype of the circuit

## **CHAPTER 5**

### **CONCLUSIONS AND RECOMMENDATIONS**

#### **5.1 Conclusions**

After testing the circuit by simulation and experiment, the circuit can operate with low input voltage from TEG. Several improvements are done by changing the transistor and the coil configuration in order to increase the efficiency of the circuit. The circuit is working well when using 1:3 coil configuration and 2SD1302. The bright blue LED is light up and it shows the TEG module can be used as power supply for small power device that consume current of 20mA and voltage of 3V. As conclusions, this project has vast potential to be commercialise as it can be replaced the battery as source of supply. Besides that, it is a free energy as the electrical energy produce is being harvest from heat of human body. This is definitely meet the objective of the project.

#### **5.2 Recommendations**

Based on the testing and observation, the circuit can be further develop so that it can produce high current and power up device that require large power to operate. This can be done by using high efficiency of TEG module that has latest technology that can produce higher voltage output from low range of heat gradient. Besides that, the electronics components could also be replaced with low power consumption so that the output voltage is higher and increase its efficiency.

## REFERENCES

- [1] J. Landt , “The History of RFID”, Potentials IEEE Volume: 24 Issue: 4 Publication: 2005 Pages: 8-11
- [2] M. Bhattacharya; Chao-Hsien Chu; T. Mullen, “A Comparative Analysis of RFID Adoption in Retail and Manufacturing Sectors”, 2008 IEEE International Conference, Pages: 241 – 249
- [3] S. Nakao; T. Norimatsu; T. Yamazoe; T. Oshima; K. Watanabe; K. Minatozaki; Y. Kobayashi, “UHF RFID mobile reader for passive- and active-tag communication, Radio and Wireless Symposium (RWS)”, 2011 IEEE Conferences , Pages: 311 – 314
- [4] G. Jeffrey Snyder and T. Caillat.,“Using the Compatibility Factor to Design High Efficiency Segmented Thermoelectric Generators”, 2003. MRS Proceedings, Pages 793, S2.1
- [5] A. Jones, R. Hoare, S. Dontharaju, S. Tung, R. Sprang, J. Fazekas, J. Chain, and M. Mickle, “An automated, FPGA-based reconfigurable, low-power RFID tag,” 2007 Microprocessors and Microsystems, Pages: 116-134
- [6] E. Tiliute Doru, Battery management in wireless sensor networks. Electronics and Electrical Engineering. – Kaunas: Technologija, 2007 Pages: 9 – 12.
- [7] J. M. Damaschke,” Design of a low input voltage converter for thermoelectric generator”, IEEE Transaction on Industry Applications. Pages 1203–1207
- [8] Qingbin Meng; Jie Jin; , "Design of Low-Power Active RFID Tag in UHF Band," *Control, Automation and Systems Engineering (CASE), 2011 International Conference on* , vol., no., pp.1-4, 30-31 July 2011.
- [9] K. Agawa, M. Alioto, W. Zhou, T-T. Liu, L. Alarcon, K. hajkazemshirazi, M. John, J. Richmond, W. Li, J. Rabaey., “ Design and Verification of an Ultra-Low-Power Active RFID Tag with Multiple Power Domains.”, *Proc. SASIMI*, 2010, pp.386 -394.
- [10] S. Watanabe, “Wrist Watch Having Thermoelectric Generator.”, U.S 6304520 B1, Oct. 16, 2001.

[11] D.Seetharam and R.Fletcher,; “ Battery-Powered RFID”, Sense ID 2007 1st ACM Workshop on Convergence of RFID and Wireless Sensor Networks and their Applications, vol., no., pp.1-6, Nov. 2007

[12] T. Starner and J.A. Paradiso, “Human Generated Power for Mobile Electronics,” Low-Power Electronics Design, C. Piguet, ed., CRC Press, chapter 45, pp. 1–35, 2004

## APPENDICES



**APPENDIX A**  
**TEG DATASHEET**



Innovative Technology  
for a Connected World



## Ceramic Plate Series CP10,127,05 Thermoelectric Modules

The Ceramic Plate (CP) Series of Thermoelectric Modules (TEMs) is considered 'the standard' in the thermoelectric industry.

This broad product line of high-performance and highly reliable TEMs is available in numerous heat pumping capacities, geometric shapes, and input power ranges. Assembled with Bismuth Telluride semiconductor material and thermally conductive Aluminum Oxide ceramics, the CP Series is designed for higher current and large heat-pumping applications.

### FEATURES

- Precise Temperature Control
- Compact Geometric Sizes
- Reliable Solid State Operation
- No Sound or Vibration
- Environmentally Friendly
- DC Operation
- RoHS Compliant

### APPLICATIONS

- Medical Lasers
- Lab Science Instrumentation
- Clinical Diagnostic Systems
- Photonics Laser Systems
- Electronic Enclosure Cooling
- Food & Beverage Cooling
- Chillers (Liquid Cooling)

### PERFORMANCE SPECIFICATIONS

Hot Side Temperature (°C)	25°C	50°C
Q <sub>max</sub> (Watts)	34.3	39.1
Delta T <sub>max</sub> (°C)	67	75
I <sub>max</sub> (Amps)	3.9	3.9
V <sub>max</sub> (Volts)	14.4	16.4
Module Resistance (Ohms)	3.36	3.78

SUFFIX	THICKNESS (PRIOR TO TINNING)	FLATNESS & PARALLELISM	HOT FACE	COLD FACE	Lead Length
L	0.126" ± 0.010"	0.0015" / 0.0015"	Lapped	Lapped	4.5"
L1	0.126" ± 0.001"	0.001" / 0.001"	Lapped	Lapped	4.5"
L2	0.126" ± 0.0005"	0.0005" / 0.0005"	Lapped	Lapped	4.5"
ML	0.130" ± 0.010"	0.002" / 0.002"	Metalized	Lapped	4.5"
LM	0.130" ± 0.010"	0.002" / 0.002"	Lapped	Metalized	4.5"
MM	0.134" ± 0.010"	0.002" / 0.002"	Metalized	Metalized	4.5"

### SEALING OPTION

SUFFIX	SEALANT	COLOR	TEMP RANGE	DESCRIPTION
RT	RTV	White	-60 to 204 °C	Non-corrosive, silicone adhesive sealant
EP	Epoxy	Black	-55 to 150 °C	Low density syntactic foam epoxy encapsulant

global solutions. local support.

Americas: +1 888.246.9050

Europe: +46.31.420530

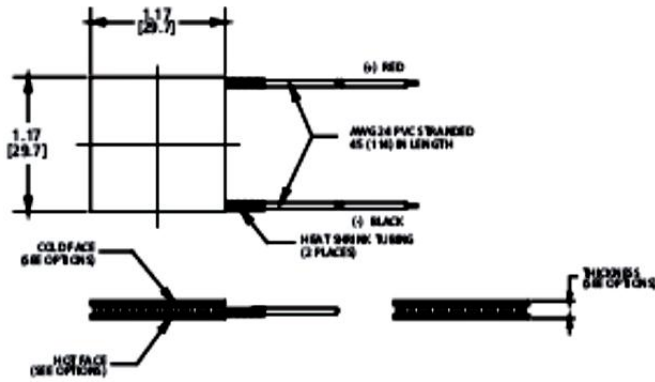
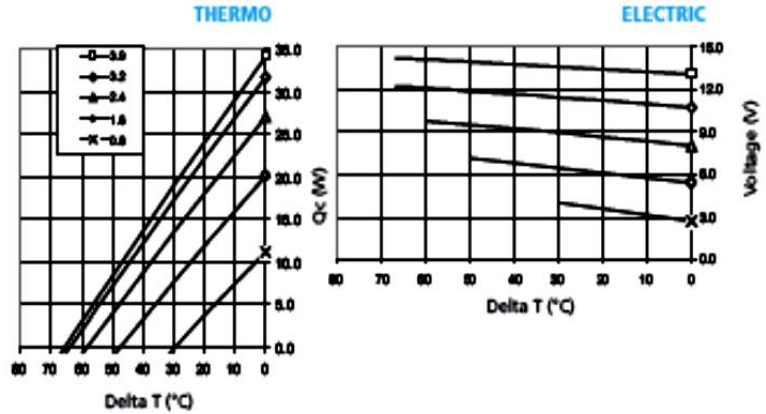
Asia: +86.755.2714.1166

ch.customerpos@lairdtech.com

www.lairdtech.com

# Ceramic Plate Series CP10,127,05 Thermoelectric Modules

Performance Curves at  $T_h = 25^\circ\text{C}$



Ceramic Material: Alumina (Al<sub>2</sub>O<sub>3</sub>)  
Solder Construction: 138°C, Bismuth Tin (BiSn)

**OPERATING TIPS**

- Max Operating Temperature: 80°C
- Do not exceed  $I_{max}$  or  $V_{max}$  when operating module
- Reference assembly guidelines for recommended installation
- Solder tinning also available on metallized ceramics

CP10,127,05 0309

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