THERMAL ENERGY HARVESTING FOR ELECTRONIC DEVICES APPLICATION

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I dedicate this thesis to my dearest family especially my father and mother for their loves and sacrifices and friends who are always there to support me.

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ABSTRACT

Thermal energy is a source of energy produced when matter is heated, which makes the molecules of the matter vibrate faster. The higher temperature, the higher the thermal energy will be produced. Seebeck Effect concept defines that, when there is a different in temperature from each side of matters, electrical energy can be produced. This project conducted by Husna (2015), had two problems; the current produced is not being stored and output voltage and current is too small (28.2mA). Therefore, this project is to overcome problems in the previous project such as energy storage compartment and a very low output result. The current and voltage must be improved to be used for a small electronic devices or appliances. A small rechargeable battery such as lead acid battery, lithium ion or nickel cadmium should be used to store the electrical energy generated. Output current or voltage can be step up to optimum value and can be used to power up the small electronic device. Expected output is 5V voltage and 1A current.

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ABSTRAK

Tenaga haba ialah sumber tenaga yang yang terhasil apabila sesuatu objek dipanaskan dimana, molekul objek tersebut akan bergetar dengan lebih laju. Semakin tinggi suhu, semakin tinggi tenaga haba yang terhasil. Konsep kesan Seebeck mendefinisikan bahawa apabila berlaku perbezaan suhu daripada setiap permukaan objek, tenaga elektrik akan terhasil. Projek ini telah dijalankan oleh Husna (2015) mengalami dua masalah; arus yang terhasil tidak disimpan dan voltan dan arus keluar terlalu kecil (28.2mA). Oleh itu, projek ini adalah untuk mengatasi masalah-masalah projeck sebelum ini seperti tempat penyimpanan tenaga dan keluaran tenaga yang rendah. Arus dan voltan perlu ditinggikan untuk kegunaan peralatan elektronik kecil. Bateri yang boleh dicas semula seperti bateri “lead acid”, “lithium ion” atau “nickel cadmium” perlu digunakan untuk menyimpan tenaga elektrik yang dihasilkan. Arus dan voltan keluar boleh dinaikkan ke nilai yang optimum dan digunakan untuk menghidupkan peralatan elektronik kecil. Keluaran yang dijangkakan ialah voltan 5V dan arus 1A.

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LIST OF ABBREVIATIONS

TEH	-	Thermal energy harvesting
TEG	-	Thermoelectric generator
RTD	-	Resistance Temperature Detector
DC	-	Direct current
AC	-	Alternating current
Emf	-	electromotive force
LED	-	Light emitting diode
USB	-	Universal Serial Bus
PCB	-	Printed Circuit Board
CAD	-	Computer Aided Design
Li-ion	-	Lithium-ion
RAM	-	rechargeable alkaline manganese
CPU	-	Central Processing Unit
WSN	-	Wireless Sensor Network

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LIST OF APPENDIX

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CHAPTER 1

INTRODUCTION

1.1 Introduction

For many years, human uses a lot of nonrenewable energy sources such as fuel, coal, and gas to generate electricity. The generation of electricity using these source of energies will create waste in form of heat or in other words, thermal energy. This thermal waste energy actually can be harvested to form electrical energy. Thus, providing a source of clean renewable energy. Furthermore, thermal energy also can be found everywhere such as from a car body, heat released from laptop, electric kettle, and clothes iron in other words anything that release heat. Thermal energy harvesting or TEH can be quite useful in a place where a source of energy is limited because thermal energy is quite easy to find. Eventhough the output from the thermoelectric generator is quite small, it can be step-up or boost to a higher output level. The generated energy also can be stored in a storing device which is rechargeable battery (lead acid, nickel

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cadmium, etc). The stored energy can be used to power up or charging electronic devices such as smartphone, mp3 player and also small lamp.

1.2 Motivation for Research

As mention in a book with a title "Enhanced thermoelectric performance of rough silicon and nanowires" by Hochbaum, Allon I, approximately 90% of the world's electricity is generated by thermal energy, with 30–40% operating efficiency, power loss about 15 terawatts in the form of heat to the environment [1]. This thermal energy waste is actually can be used as a source of renewable energy to replace recent conventional electrical generator.

So this project expect to contribute the sustainability by providing a clean and environmental friendly way to generate electrical energy. Moreover, this project also aim in developing a low cost thermal energy harvesting device (prototype).

In commercialization aspect, thermal energy harvesting is popular in automotive industries. Automotive thermoelectric generator (ATEG) converts thermal waste energy of an internal combustion engine into electricity based on the Seebeck Effect. Moreover, ATEGs also can convert waste heat from an engine's coolant or exhaust into electricity. ATEGs decreases fuel consumed by the electric generator load on the engine. Nevertheless, the cost of the unit and the extra fuel consumed due to ATEG weight have to be considered. Thermal energy harvesting technology have the opportunities to be commercialize in any industries that uses machine and also for home which the energy can be harvested from home appliances such as kettle and microwave oven.

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1.3 Objectives

The main objectives of this project are:

- To identify the most suitable heat producing device that can supply thermal energy continuously or in a long period.
- To develop an electric circuit for thermoelectric energy storage.
- To design and develop a device that can store and step up the low output for an electronic device usage.

1.4 Problem Statement

Thermal energy is a source of energy produced when matter is heated, which makes the molecules of the matter vibrate faster. The higher temperature, the higher the thermal energy will be produced. Seebeck Effect concept defines that, when there is a different in temperature from each side of matters, electrical energy can be produced. A previous project conducted by Husna (2015), had two problems; the current produced is not being stored and output voltage and current is too small (28.2mA) [2]. Aims of this project is to overcome the problems therefore energy generated can be stored and improve the output current and voltage so it can be used for a small electronic devices or appliances. A small rechargeable battery such as lead acid battery, lithium ion or nickel cadmium should be used to store the electrical energy generated. Output current or voltage can be step up to optimum value and can be used to power up the small electronic device. Expected output is 5V voltage and 1A current.

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1.5 Scope of Work

The scope of the project is set based on the objectives mentioned earlier in the thesis. Initially, the project scope covers on investigating an optimum thermal waste energy source that can serve as an input on the hot surface of the thermoelectric generator (TEG) to enable electrical energy generation. The thermal energy data is collected using Resistance Temperature Detector (RTD) PT100. RTD operate by changing its resistance value when the temperature changes. The resistance value will then be referred to RTD PT100 resistance to temperature table to define its temperature in degrees Celsius. Next, a way to boost or step up the low output current of TEG is explored. The types of integrated circuit or circuit which can step up or boost the low output is identified. After that, the type of storage suitable for the project is investigate to store the generated electrical energy. When all the data needed is completed, the circuit is tested on a breadboard. IF the circuit run successfully, the circuit is then designed using Proteus software before being fabricated using UV board. Simulation analysis of designed circuit will not be covered in the thesis because the IC used in the project, MAX757 was not found in any circuit simulation software. The tested circuit on breadboard consists of DC input voltage (TEG), DC-DC converter (booster), and a load (electronic devices). Once the test process on breadboard is done, a UV board circuit is fabricated based on the designed circuit. Thermoelectric generator (TEG), SP1848 is used to harvest thermal energy in order to produce electrical energy.

1.6 Thesis Outline

This thesis consist of five main chapters. Below shows the chapters and a brief explanation of the chapters.

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I. Chapter 1 - Introduction

This part explain about summary of this thesis and also the importance the project. This chapter also clarify the objectives, problem statement and also scope of project.

II. Chapter 2 – Literature Review

For this chapter, review of papers, book and journals related to thermal energy harvesting were done. All the theoretical part including the current knowledge topic which is based on secondary sources is explained in detail to understand about the project. The types of batteries for energy storage and how to increase electrical output is studied.

III. Chapter 3 – Methodology

In this part, the methodology explain on a systematic, theoretical analysis of the methods applied for the project. This chapter consists the theoretical analysis of the body of methods and principles associated with a branch of knowledge of the project such as thermoelectric concept, thermoelectric energy and others. The whole process was done based on flowchart constructed.

IV. Chapter 4 – Results and Discussion

For this chapter, all the data collected from testing of circuit on breadboard and fabricated board and also from measuring device such as multimeter, RTD is represent and discuss.

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V. Chapter 5 – Conclusion

Finally, the conclusion is written to conclude based on the results of the whole project.

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CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter discussed about previous information which are from many sources such journal, book, past paper and etc. Moreover, this topic will explain the concept of thermal energy, thermoelectric, type of energy storage and step up converter.

2.2 Thermal Energy

Thermal energy or heat is an energy that possessed by an object or system due to movement of particles within it. Thermal energy also can be defined as the ability to do work. Thermal energy is considered as a type of kinetic energy due to motion of

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particles. Thermal energy causing an object having a temperature which can be measured in degrees Celsius or Fahrenheit using a thermometer. The faster the particles move within an object or system, the higher the temperature recorded [3].

Thermal energy also can be understand when there is a difference between the temperature of the environment and a system within it, thermal energy is transferred between them as heat. An object or system does not have heat. Instead, as an object or system gains or loses heat, it increases or decreases its thermal energy.

Figure 2.1: Thermal energy transfer from high temperature to low temperature in form heat.

The adjacent objects that show different temperatures will spontaneously transfer heat to try to reach the same temperature as each other, or equilibrium. However, how much energy it takes to change the temperature of an object is based on what it is made of, a property called heat capacity or thermal capacity [4].

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2.3 Thermoelectric

Thermoelectric is an effect where a direct conversion of temperature difference to voltage and vice versa. Conversely, when a voltage is applied to it, it creates a temperature difference. A temperature gradient causes charge carriers in a material to diffuse from the hot side to the cold side. This effect can be used to generate electricity, measure temperature or change the temperature of objects [5]. Because the direction of heating and cooling is determined by the polarity of the applied voltage, thermoelectric devices can be used as temperature controllers. Thermoelectric effect can be divided into three which are; Seebeck effect, Peltier effect, and Thomson effect.

2.3.1 Seebeck Effect

Seebeck effect can be explain, when there is a temperature difference, diffusion of electrons from the hot side to the cold side of a conductor will occur. The motion of electrons creates an electrical current. When a conductive material is subjected to a thermal gradient, charge carriers migrate along the gradient from hot to cold. In the open-circuit condition, charge carriers will accumulate in the cold region, resulting in the formation of an electric potential difference. The Seebeck effect describes how a temperature difference creates charge flow. Electrons transfer heat in two ways:

a) Diffusing heat through collisions with other electrons
b) Carrying internal kinetic energy during transport.

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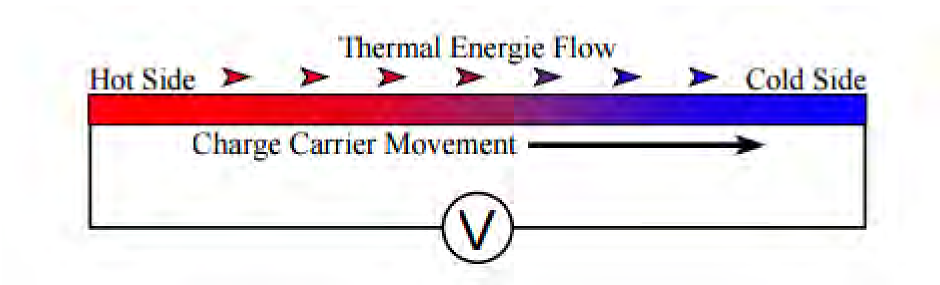

Figure 2.2: Charge carriers flow in response to a temperature gradient.

In figure above, thermal energy flow from hot side to cold side.

The Seebeck effect is an example of an electromotive force (emf) which leads to measurable currents or voltages. Electromotive forces modify Ohm's law by generating currents even in the absence of voltage differences (or vice versa); the local current density is given by:

$$\mathbf{J} = \sigma(-\boldsymbol{\nabla} V + \mathbf{E}_{\mathbf{emf}})$$

Where:

J is the local current density.

V is the local voltage and σ is the local conductivity.

E_{emf} is the electromotive force.

In general, the Seebeck effect is described locally by the creation of an electromotive field:

$$\mathbf{E}_{\mathbf{emf}} = -S\boldsymbol{\nabla} T$$

Where:

S is the Seebeck coefficient, a property of the local material.

$\boldsymbol{\nabla} T$ is the gradient in temperature T.

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2.3.2 Peltier Effect

The Peltier effect is the presence of heating or cooling at an electrified junction of two different conductors. When a current is made to flow through a junction between two conductors A and B, heat may be generated or removed at the junction. The Peltier heat generated at the junction per unit time, $\dot{Q}$, is equal to:

$$\dot{Q} = (\Pi_A - \Pi_B) I$$

Where:

Π_A (Π_B) is the Peltier coefficient of conductor A (B).

I is the electric current (from A to B).

The junctions of dissimilar metals were heated or cooled, depending upon the direction in which an electrical current passed through them. Heat generated by current flowing in one direction was absorbed if the current was reversed.

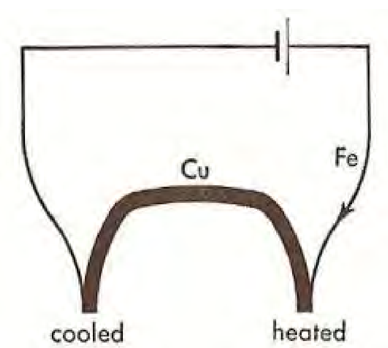

Figure 2.3: Peltier effect

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2.3.3 Thomson Effect

Thomson effect describes the heating or cooling of a current-carrying conductor with a temperature gradient. This Thomson effect was predicted and subsequently observed by Lord Kelvin in 1851.

If a current density is passed through a homogeneous conductor, the Thomson effect predicts a heat production rate per unit volume of:

$$\dot{q} = -\mathcal{K}\mathbf{J}\cdot\boldsymbol{\nabla}T$$

Where:

$\boldsymbol{\nabla}T$ is the temperature gradient.

$\mathcal{K}$ is the Thomson coefficient.

2.4 Thermoelectric Generator

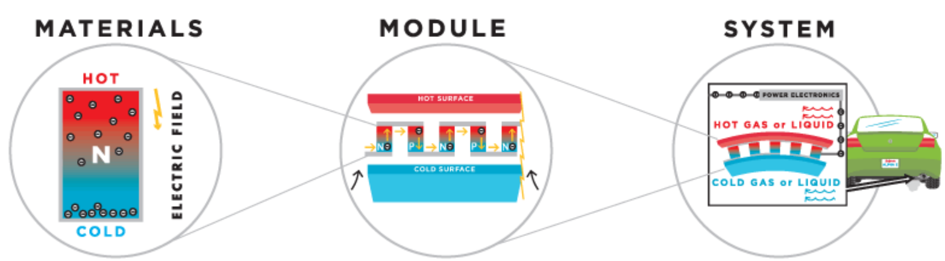

Figure 2.4: How thermoelectric generator works.

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Thermoelectric generator process can be divided into three which are thermoelectric material, thermoelectric module and thermoelectric system.

2.4.1 Thermoelectric Material

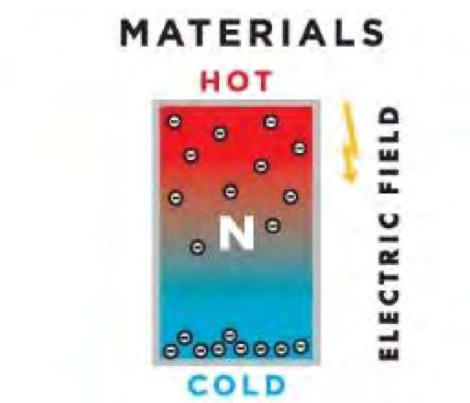

Figure 2.5: Thermoelectric material.

Based on Seebeck effect, electricity is produce when there is temperature gradient where electrons flow from hot side to cold side. Good thermoelectric can be produce by using materials that have high electrical conductivity and low thermal conductivity. Thermal conductivity must be low so that when one side is made hot, the other side stays cold. [6] Nowadays, low thermal conductivity can be achieved by creating nanoscale features such as particles, wires or interfaces in bulk semiconductor materials. These nanoscale features lower the thermal conductivity of the semiconductor and do not affect their strong electrical properties.

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2.4.2 Thermoelectric Module

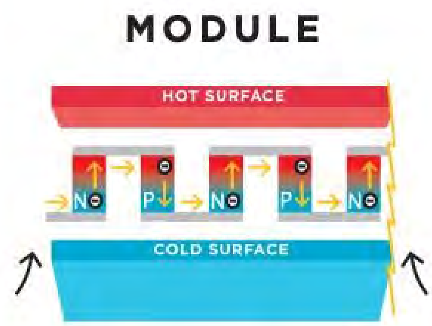

Figure 2.6: Thermoelectric module.

A circuit comprising thermoelectric materials that output usable electricity is called thermoelectric module. A thermoelectric module for power generation must work in a very large temperature gradient and consequently be exposed to large thermally induced stresses and strains for long periods of time. They must also be able to withstand a large number of thermal cycles, which cause mechanical fatigue. A thermoelectric module requires two thermoelectric materials to function: one, an n-type (negatively charged) semiconductor; the second, a p-type (positively charged) semiconductor. The module is designed this way so that a continuous circuit can be made whereby current can flow and power can be produced. With only one type of thermoelectric material, a voltage would be induced but current would never flow.

2.4.3 Thermoelectric System

A thermoelectric power generation system captures heat from a source such as exhaust, water kettle, clothes iron and produces electricity using thermoelectric modules. The hot side will receive heat and stay hot. The cold side must be cooled by

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air, water or another suitable medium. To supply this heating and cooling, technologies known as heat exchangers are used on both the hot and cold sides [7]. A thermoelectric power generation system can be thought of as two heat exchangers, each of which have to move heat to (or from) the hot (or cold) side of the thermoelectric modules. A thermoelectric generator produces AC power only after the original DC power from the thermoelectric modules passes through an inverter. An integrated power electronics system is necessary to deliver AC power to the customer.

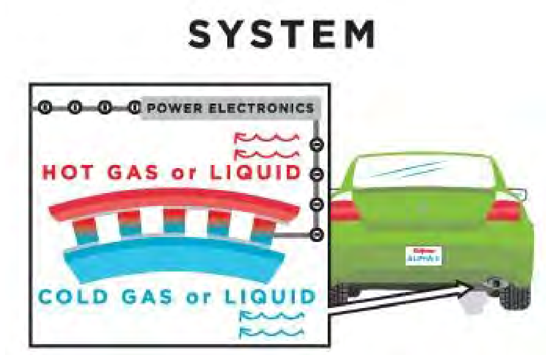

Figure 2.7: Thermoelectric generator.

2.5 Type of Energy Storage

There are 2 types of electrical energy storage which is commonly used today which are supercapacitor and battery.

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2.5.1 Supercapacitor

A supercapacitor is a high-capacity electrochemical with capacitance values in the range of around 100000 uF up to 1000 F with rated voltage of 1.2V up to 3.8V. A supercapacitor consists of two or more conductive plates separated by a dielectric. When an electric current enters a supercapacitor, the dielectric stops the flow and a charge builds up and is stored in an electric field between the plates.

2.5.2 Batteries

A battery is an electrochemical cell that can be charged electrically to provide a static potential for power or released electrical charge when needed. The chemical unit contains three main parts; a positive terminal called the cathode, negative terminal called the anode, and the electrolyte. The battery charges and discharges through a chemical reaction that generates a voltage. The battery is able to produce a constant stream of electricity that can be turned on and off.

a) Lithium-ion Battery (Li-ion)
   A lithium-ion battery is one type of rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging.

b) Rechargeable alkaline battery
   Rechargeable alkaline manganese (RAM)) is a type of alkaline battery that is capable of recharging for repeated use which are manufactured fully charged and have the ability to hold their charge for years.

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Figure 2.8: Alkaline battery, Li-Ion battery and supercapacitor.

2.5.3 Different Battery vs Supercapacitor

Battery and supercapacitor have their own advantage and disadvantage. Table below shows the difference between battery (LI-ion/Alkaline) and supercapacitor.

Table 2.1: Difference between battery and supercapacitor.

	Battery	**Supercapacitor**
Energy density	High	Low
Power density	Low	High
Potential different output	Constant	Changing
Charge/discharge time	Slow	Fast
Internal resistance	High	Low
Charge/discharge lifespan	Low	High

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Batteries have a higher energy density meaning they can store more energy per unit mass, but supercapacitors have a higher power density, which they can release energy more quickly. That makes supercapacitors particularly suitable for storing and releasing large amounts of power relatively quickly, but batteries are used for storing large amounts of energy over long periods of time.

Even though supercapacitors work at relatively low voltages about 2–3 volts, they can be connected in series to produce bigger voltages for use in more powerful equipment. Supercapacitor have little or no internal resistance, which means they store and release energy without using much energy and work at very close to 100 percent efficiency.

Moreover, a supercapacitor typically store about 10 to 100 times more energy per unit volume or mass than normal capacitors, can charge and discharge faster than batteries. Furthermore, it can tolerate many more charge and discharge cycles than rechargeable batteries.

2.6 Journal Reviews

This part discussed and summarizes some of past project that previously done. The source of thermal energy, output and application are also included.

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2.6.1 Thermal Energy Harvesting For Small Device Application

Project done by Nurul Husna Mohd (2015) show the sources of thermal energy was investigated from various source such as jug kettle, clothes iron, heat from laptops, and hair drier. The output voltage recorded from the TEG is 0.89V harvested from clothes iron as input. The harvested electricity is serve as an input for MAX757 voltage regulator IC which also act as voltage booster. The output from the IC is 3.98V voltage with 40.2mA current. The input is used to power up LED diode.

2.6.2 Architectural Thermal Energy Harvesting Opportunities for Sustainable Computing

Journal written by Carole-Jean Wu (2015), investigate on how to take advantage of the heat produced by Central Processing Unit (CPU). There are comparison between the 2 different values of cores (1 and 4 cores) used when SPEC2006 program is executed with light load or heavy load. When the TEG module is sandwiched between the CPU and a fan of ATX size motherboard, an average of 0.5V (0.3W) of electrical energy is harvested for the 1-core workloads and an average of 1.2V (1.05W) for 4-core. The problem appears in the experimental result when the TEG is install, while being able to harvest the otherwise wasted heat into reusable electricity, the CPU temperature increases at the same time [8]. The electric energy generated is used to power a 5.5in portable fan that runs on two 1.5V batteries, with the energy harvested from three TEG modules connected in series to boost the voltage to a sufficient level with a temperature difference of 50°C.

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2.6.3 A Geothermal Thermo-Electric Energy Converter for Charging Lithium-Ion Battery

O. M. Neamţu on 2014 studies about the optimal conditions for thermal power conversion system. Geothermal water source heat is used as a source for TEG application. This paper also investigate in ensuring the energy conversion in combination with storage Li-Ion battery [9]. Matlab-Simulink program is used to design and simulate the thermal energy harvesting and storing circuit. The thermoelectric generator is modeled in the simulation as a random source. An efficient electronic energy transfer DC-DC converter were applied to determine the optimal storage batteries. TEG. TGMT-19W-4V which is a type of TEG were used to harvest thermal energy. The results shows that, the water temperature recorded from geothermal wells located in the University of Oradea is about 82°C to 87°C. 16 cells TGMT-19W-4V is mounted and they provides a power of about 32W. The maximum output voltage recorded is 28V output voltage.

2.6.4 Thermoelectric-Generator-Based DC-DC Conversion Network for Automotive Applications

Molan Li (2011), studies the waste heat recovering techniques, using thermoelectric generator (TEG) technologies in automotive industry. The objectives of the project involve of providing optimal solution for the DC-DC converter utilized in the network, an also developing a systematic and bottom-up design approach for the proposed network which is a distributed multi-section multi-stage network which can harvest more thermal energy. A designed model is integrated into a TEG-converter system and simulated under Simulink or Simscape to verify the merits of MPPT regulation mechanism. The thermal source chosen were Exhaust Gas Recirculation (EGR) cooler and Exhaust Gas Pipe (EGP). There are 3 level of DC-DC converter proposed which is low-level (0.7-0.5V input), mid-level (3-8V input) and high-level

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(18V input). The results shows that when the *R*teg of TEG module and the *R*in of converter are matched, the delivery efficiency is 50% and the power delivered to the converter is maximized, the number of TE couples needed is 56; while the available *V*in for converters at EGR and EGP are approximately 5.9 V and 4.8 V respectively. The achieved overall efficiency for both locations under average scenario is 3.8%. In parallel TEG modules, the two-level conversion network can achieve even higher thermal power utilization than the single-stage system, while having higher overall efficiency [10].

2.6.5 Thermal Energy Harvesting for WSN

Project done by Xin Lu on 2010 show that a low temperature thermal energy harvesting system is applied which collect heat energy from a radiator and use it to power ZigBee electronics [11]. In the experimental results, a maximum of 150mW power can be harvested by the prototype designed and the system can continue to operate normally even when the harvesting voltage is as low as O.45V. Based on the theoretical calculations, by placing two AA batteries in the circuit designed, the ZigBee Wireless Radiator Valve can operate for more than eight years. Moreover, the thermal energy harvesting subsystem was integrated with the DC-DC converter subsystem to test the overall efficiency. Next, the power output of the integrated system was used to charge two supercapacitors which are the 2.3V 10F 3049 as the primary buffer that can be directly charged by the thermal energy harvesting circuit, and which power the ZigBee. When supercapacitor is full on the primary buffer, it continues to charge the secondary buffer which is a two Ni-Cd rechargeable batteries and at the same time power up the ZigBee. The secondary buffer is used when the energy at the primary buffer is in short supply to power the target system.

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2.6.6 High Efficiency Seebeck Thermoelectric Device for Power System Design and Efficiency Calculations: A review of Potential Household Appliances.

Journal by T Stephan John (2014), he proposed a system to harvest thermal energy while cooking with gas stove [12]. The system which consist of few main component which are TEG, tin stand, water supply, pipes, heat sink, gas stove, cook ware, multimeter and thermometer. The idea is to use tin to collect thermal energy when the gas stove is on. The TEG will put on the tin surface to convert it to electrical energy. Based on the result, the highest output was 7.1V voltage, 0.82A current and 5.822W power from 2 TEGs connected in series.

2.6.7 Waste Heat Energy Harvesting using Thermoelectric Generator.

The journal by A. Jacks delightous Peter, Balaji. D, and D. Gowrishankar on July 2013 explained about harvesting waste heat energy using TEG [13]. Based on the journal, the TEG consist of 4 main components which are TEG module, TEG shield, thermal fin and copper electrode. They proposed some improvements for the TEG to produce a higher output (power and voltage) such as increasing the thermal gradient value by using larger fin, coupling more TEG in series and use different type of material for the TEG itself.

2.6.8 Flexible Thermoelectric Generator for Human Body Energy Harvesting.

Published on 2nd August 2012, written by S.E. Jo, M.K. Kim, M.S. Kim and Y.J. Kim, this paper presented the development of TEG that is used to harvest thermal energy from human body heat. They have proposed a flexible TEG which comprise of polydimethylsiloxane (PDMS) and thermoelectric materials [14]. The TEG proposed was fabricated using dispenser printing and tested. Table below shows the results of the test:

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Table 2.2: Output power and output voltage for proposed TEG.

Body Temperature (k)	Ambient Temperature (k)	Output Voltage (mV)	Output Power (uW)
305	298	5	0.1
305	286	7	2.1

2.6.9 Energy Analyses of Thermoelectric Renewable Energy Source.

Jarman T. Jarman, Essam E. Khalil and Elsayed Khalafon studied about the recent development of thermoelectric energy. The application of thermoelectric energy was discussed such as for radioisotope thermoelectric generator (RTEG) in space ships, automobile industry for seat heaters, and also wristwatches. Solar thermoelectric power generation (STEG) technology was discussed on how they operate [15]. Moreover, the thermoelectric materials were investigated to find the best material to develop a TEG.

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CHAPTER 3

METHODOLOGY

3.1 Overview

This part discussed on how to collect information and data for the project. The steps and procedures are also explained in detail to ensure the project runs smoothly

3.2 Project Implementation

Figure 3.1 shows the block diagram of proposed circuit which consist of thermoelectric generator, MAX757 boost converter, batteries and electronic device application.

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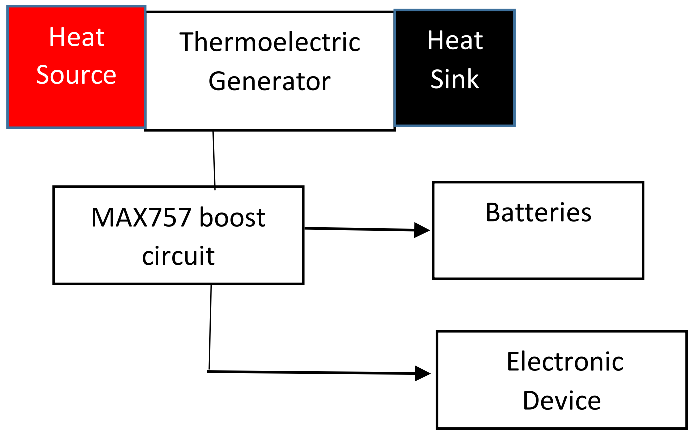

Figure 3.1: Block diagram of propose circuit

3.3 Flowchart of Project

Figure 3.2 shows the overall project flowchart starting from semester 1 until semester 2. Based on the project title, Thermal Energy Harvesting for Electronic Device Application, the first thing to do is study and understand about the thermal energy harvesting which is based on the concept of thermoelectric. Next, based on the objective, a most suitable heat producing device that can supply thermal waste energy continuously or in a long period need to be identified. Various thermal waste energy is identified and investigated by measuring the temperature or heat released by the devices such as clothes iron, kettle and air conditioner using a device called Resistance Temperature Detector (RTD).

Furthermore, a suitable energy storage is identified to store electrical energy. A current step up is also studied to boost the output at an optimum level to be used for an electronic device application. When all the data is collected, they were analyzed and compared. The next step is simulation of circuit proposed. After having all the data

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needed, block diagram is produced and circuit is designed. The designed circuit is tested on breadboard. It is important to make sure the proposed circuit is acceptable or passed before fabricating the circuit.

Then, if the tested circuit on breadboard functioned correctly, then the circuit fabricated using UV board. All the parameter is followed exactly the same to make sure the circuit is function perfectly. Proteus software is used to designed circuit on PCB board. The PCB fabrication is done based on the design in Proteus software. Components for the circuit is obtain by requesting at FKEKK electronic store components or bought at electronic component shops. The components is connected and soldered perfectly. When the prototype is finished, the functionality of each components will be confirmed. If there is problem or error, the circuit will be troubleshoot and corrected. Then, the prototype was used to collect data for future modification and improvement.

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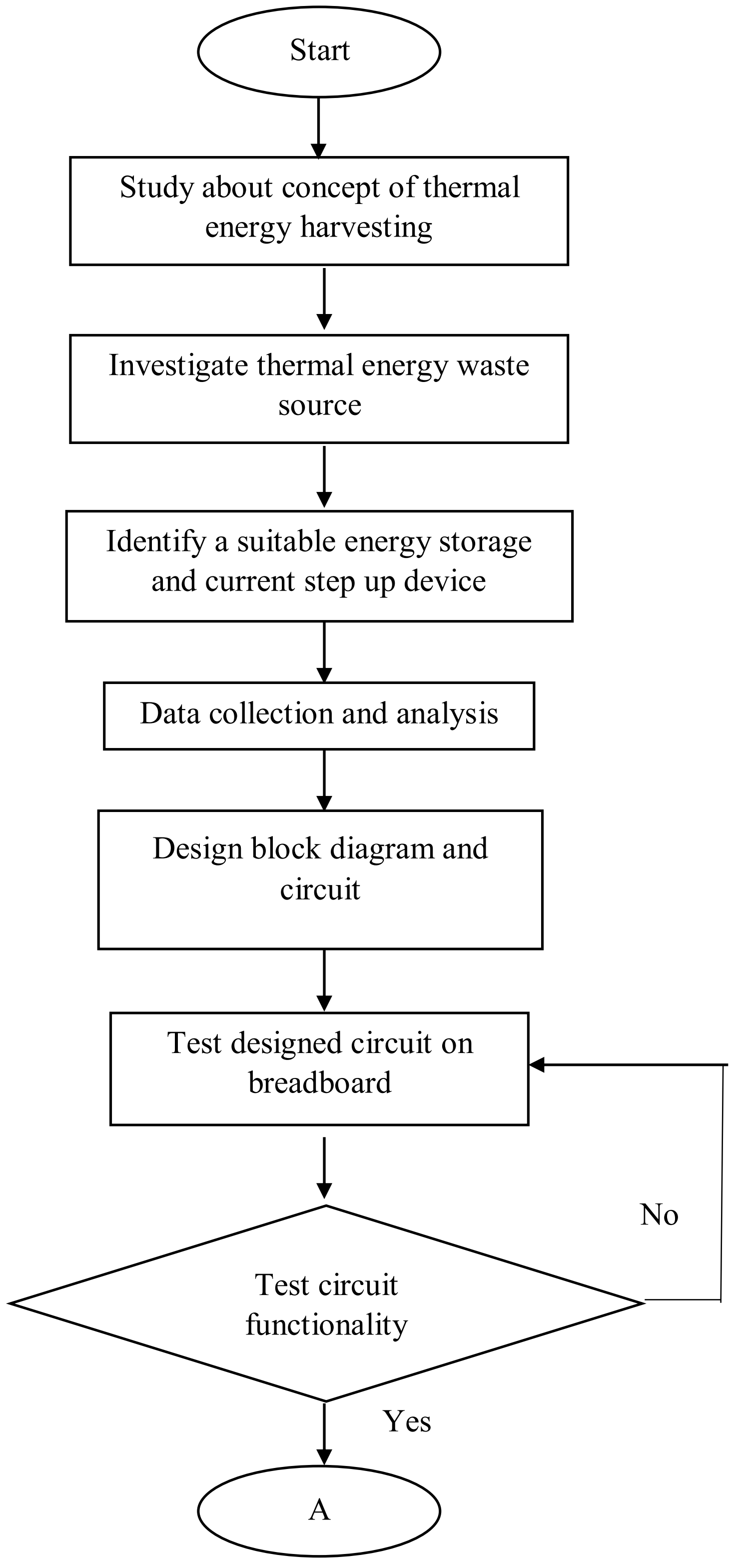

Figure 3.2: Part 1 of project flowchart.

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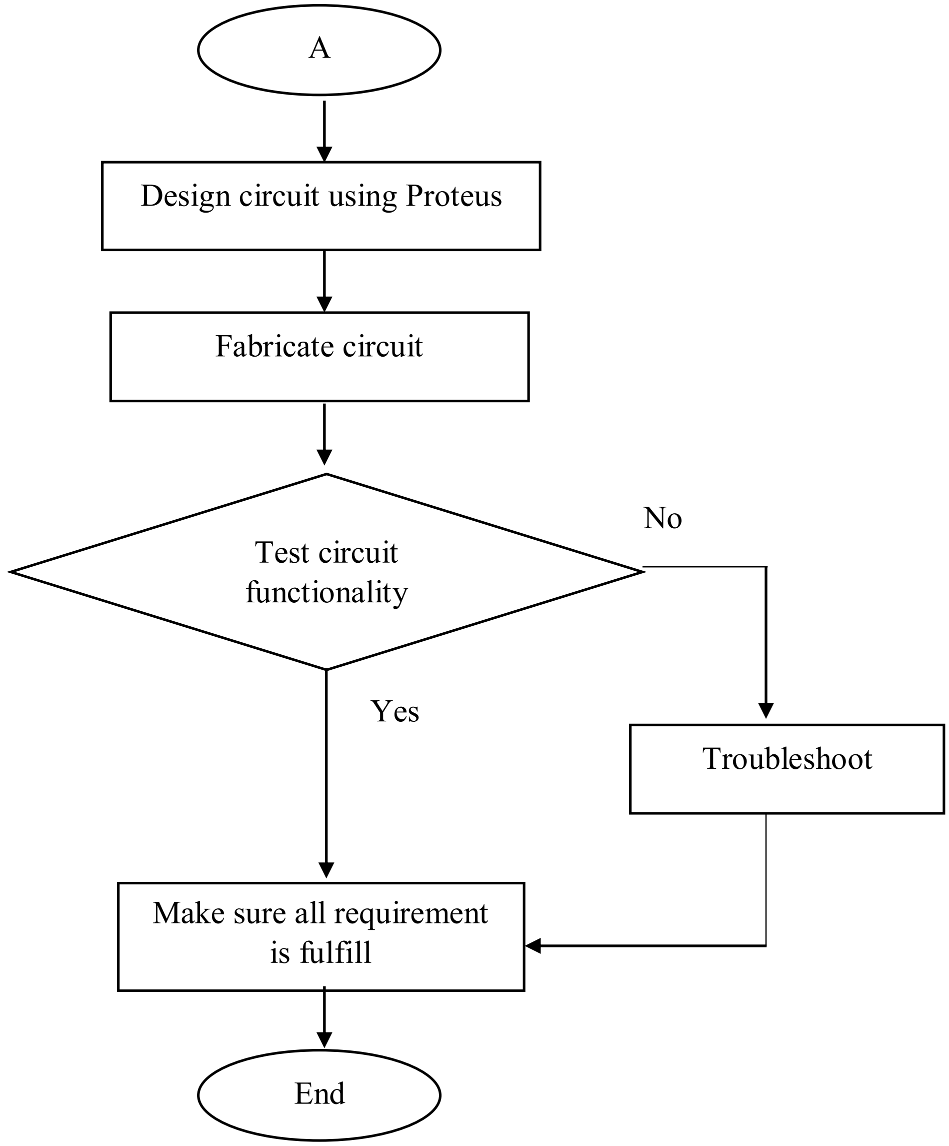

Figure 3.3: Part 2 of project flowchart.

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3.3.1 **Resistance Temperature Detector**

Resistance temperature detectors (RTDs), is a sensor used to measure temperature by correlating the resistance of the RTD element with temperature. Most RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core. The RTD element is made from a pure material such as platinum, nickel or copper. The material resistance changes as the temperature changes and it is this change that is used to determine temperature. RTD is constructed in a number of forms and offer greater stability, accuracy and repeatability in some cases than thermocouples. While thermocouples use the Seebeck effect to generate a voltage, resistance thermometers use electrical resistance and require a power source to operate.

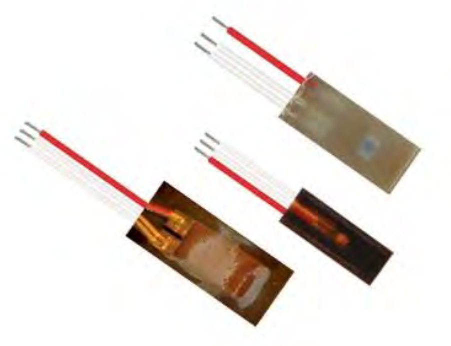

Figure 3.4: Resistance Temperature Detector

3.3.2 Peltier Generator

Peltier generator also known as thermoelectric generator (TEG) is a device which converts thermal energy (temperature difference) to electrical energy. It consist of 2 sides, cold and hot sides. The hot side is the surface where heat source is given while for the cold side, it is usually glued together with a heat sink so that the heat

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dissipate faster in order to create a large temperature difference between the two sides. The TEG used for this project is TEG-SP1848-2715. The specification for the TEG:

- Temperature range: -40 to 120 degrees Celsius
- Output voltage: 0 to 4.8V

Table 3.1: Temperature difference and output voltage and current.

Temperature difference (^{0}C)	**Output Voltage (V)**	**Output Current (mA)**
20	0.97	225
40	1.8	368
60	2.4	469
80	3.6	558
100	4.8	669

Figure 3.5: TEG SP1848-2715

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3.4 Circuit Design and Development

When all the information is investigated and discussed, a circuit is proposed which consist of several electronic components. The circuit is simulate using simulation software before a prototype is done.

3.4.1 Multisim

Multisim is an electronic schematic capture and simulation program which is part of a suite of circuit design program. It is considered as a Computer aided design (CAD) tool that help user to construct or design electronic circuits. Multisim is one of the few circuit design programs to employ the original Berkeley SPICE based software simulation. Multisim includes microcontroller simulation as well as integrated import and export features to the Printed Circuit Board layout software in the suite. At the time it was mainly used as an educational tool to teach electronics technician and electronics engineering programs in colleges and universities. National Instruments has maintained this educational legacy, with a specific version of Multisim with features developed for teaching electronics. Multisim is widely used in academia and industry for circuit education, electronic schematic design and SPICE simulation.

3.4.2 Proteus

Proteus is a simulation based software for various designs with microcontroller. Proteus software is a combination of ISIS schematic capture program and ARES PCB layout program. It is generally popular because of availability of almost all

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microcontrollers in the software. Proteus is a CAD tool to test programs and embedded designs. User can simulate your programming of microcontroller in Proteus software. Once simulating circuit in Proteus Software is done, user can directly make PCB design with it. The tools in this software are very easy to use and very useful in education and professional PCB designing. As professional PCB designing software with integrated space based auto router, it provides features such as fully featured schematic capture, highly configurable design rules, interactive SPICE circuit simulator, extensive support for power planes, industry standard CADCAM & ODB++ output and integrated 3D viewer.

3.4.3 MAX757

MAX757 is a CMOS step-up DC-DC switching regulators for small input voltage. [11] The MAX757 is an adjustable IC that accepts an input voltage as low as 0.7V and produces a higher adjustable output voltage in the range from 2.7V to 5.5V. The full-load efficiencies for the MAX757 is greater than 87%. The key features of MAX757 IC:

- Operates Down to 0.7V Input Supply Voltage
- 87% Efficiency at 200mA
- 60µA Quiescent Current
- 20µA Shutdown Mode with Active Reference and LBI Detector
- 500kHz Maximum Switching Frequency
- ±1.5% Reference Tolerance Over Temperature
- Low-Battery Detector (LBI/LBO)
- 8-Pin DIP and SO Packages

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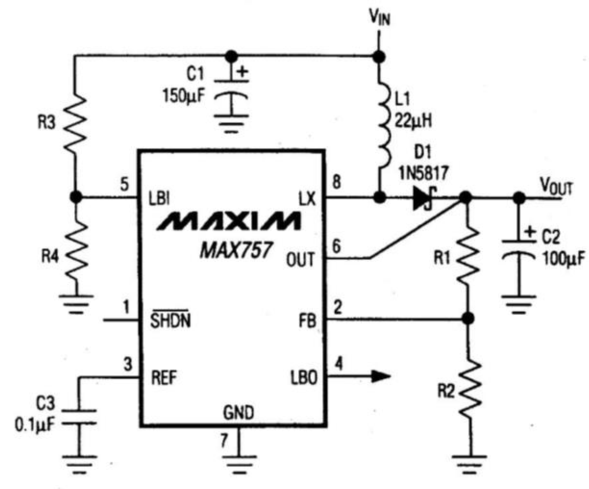

Figure 3.6: MAX757 IC circuit.

3.4.4 Boost Converter

A boost converter or a step-up converter is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

Operating principle:

1. When the switch is closed, electrons flow through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

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2. When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

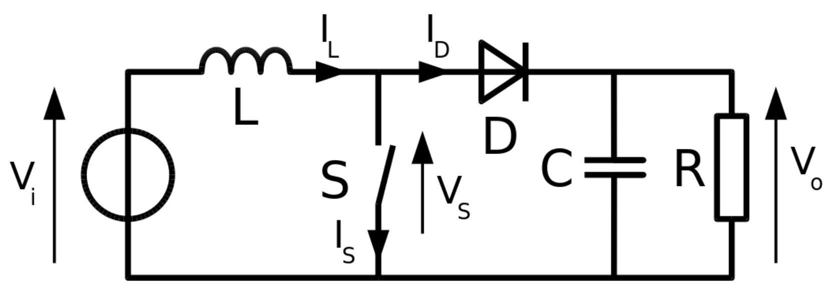

Figure 3.7: Boost converter.

3.4.5 USB Port Module

USB port module is a component that receives input voltage and regulate it to a certain value. The model used in the project is YH11062B. The mini USB produces 5 volts DC voltage regulator with continuous LED. It can receives a DC input of 2.6 to 5V voltages and 0 to 2A current. The specification of the USB port module is as follows:

- Operating Temperature: -20°c to +80°c
- Voltage regulation: ± 2.5%
- Short circuit protection: Yes
- Input Reverse Polarity Protection: None
- Output voltage can be changed through the method bellow, 12V Max

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Figure 3.8: USB port module model YH11062B

3.4.6 Rechargeable AA battery

The rechargeable batteries used for the project are GP rechargeable AA battery. The battery is a nickel-metal hydride battery. The batteries can store about 950mAh capacity. It can be charge and discharge nearly about 300 times. It can be used for light household devices such as alarm clock, radio, remote controller and other small electronic devices.

Features:

- Nominal voltage 1.2V
- Gross weight ~15.2g

Battery handling:

- Batteries should be charged prior to use.
- Remove batteries from the electrical device if the device is not going to be used for a long period of time.
- Do not mix new batteries in use with semi-use batteries.

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- In order to maintain satisfactory cell or battery performance when being stored under extending period of time, fully charge the battery within 12 months period is highly recommended.

Figure 3.9: GP AA rechargeable battery (1000mAh).

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Overview

This part discussed about the data collection of the project. The data collection consist of the measuring and collecting temperature of different type of thermal source. Furthermore, this part also explained about the circuit tested on breadboard and also from fabricated board. Moreover, the data test on the fabricated board designed also is included to be analyzed and discussed more deeply.

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4.2 Sources of Thermal Energy

Thermal waste energy data is collected from various source such as clothes iron, electric kettle, air conditioner, and also car's body temperature. The temperature is measured using a device called Resistance Temperature Detector (RTD). The RTD will change its resistance value when temperature is changes. The resistance value collected is taken after a certain period of time. The resistance value is changed to temperature value in degrees Celsius based on the RTD PT100 table.

4.2.1 Clothes Iron

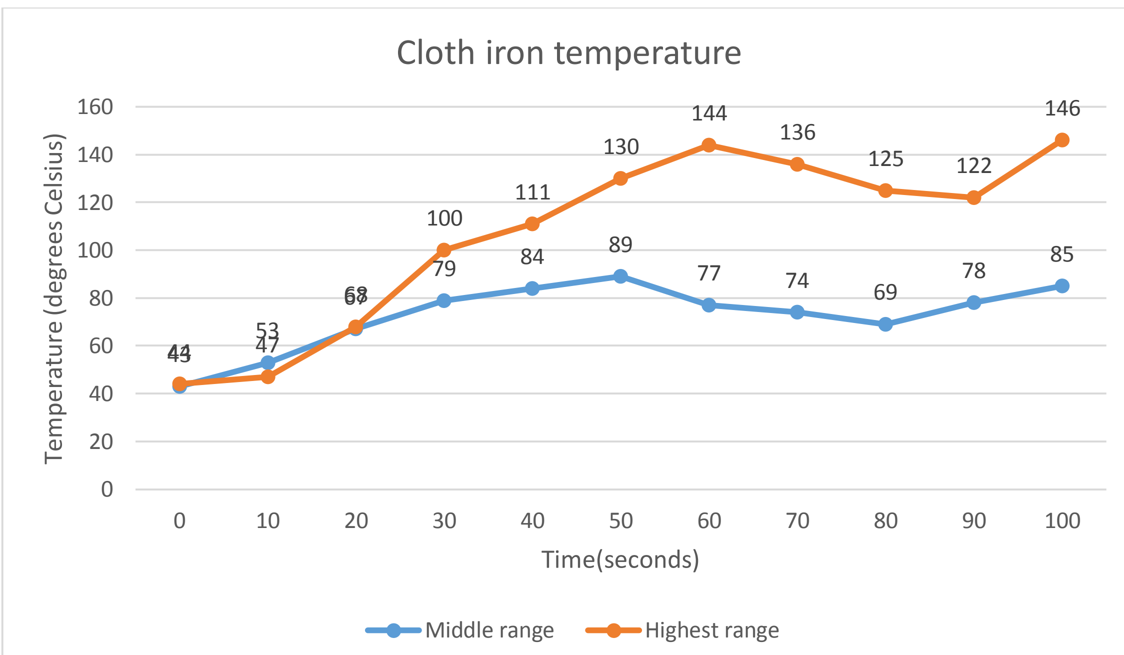

Figure 4.1: Temperature vs time graph for iron cloth.

Based on table 4.1 in appendix, the resistance value is taken for every 10 seconds period until 100 seconds. The cloth iron was set with two ranges, the middle

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range and highest range. Figure 4.1 shows the line graph of temperature versus time. From the graph, the temperature increases as time increases until a certain level. The maximum value measured for middle range was 134.4 Ohms which is equal to 84 degrees Celsius while the maximum value measured for highest range was 155.7 Ohms which is equal to 146 degrees Celsius. The temperature is changing because clothes iron operates by increasing its temperature until a desired temperature. After that, no temperature is applied to the iron surface for a certain period of time causing temperature to drop. Then, after a period of time, the clothes iron temperature is increased again. This process will repeat until the power is off.

4.2.2 Electric Kettle

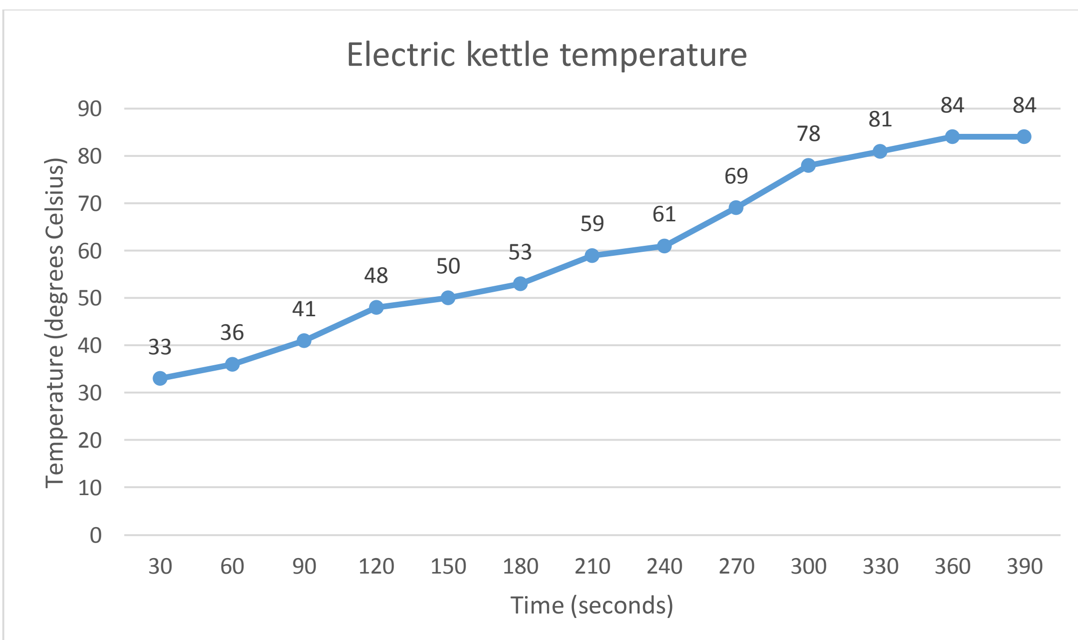

Figure 4.2: Temperature vs time graph for electric kettle.

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Table 4.2 in appendix shows the temperature of electric kettle in a period of every 30 seconds when boiling 1.7 litre of water. The time taken to boil water is 390 seconds which is equal to 6.5 minutes. As shown in the graph 4.2, the temperature of electric kettle increase steadily until the final or maximum temperature reading is 84 degrees Celsius.

4.2.3 Air Conditioner

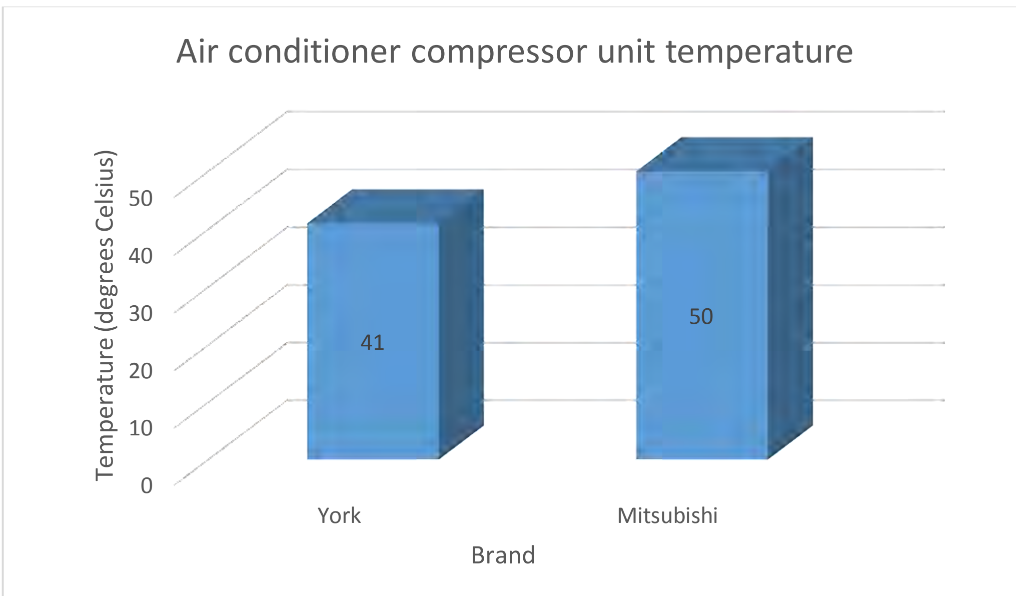

Figure 4.3: Bar chart of temperature of air conditioner compressor unit and their brand.

In table 4.3 and chart in figure 4.3, shows the temperature of two brands of air conditioner. Mitsubishi air conditioner compressor unit shows a higher temperature which is 50 degrees Celsius, means that it generate more thermal energy waste.

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4.2.4 Car's Body Temperature at Noon

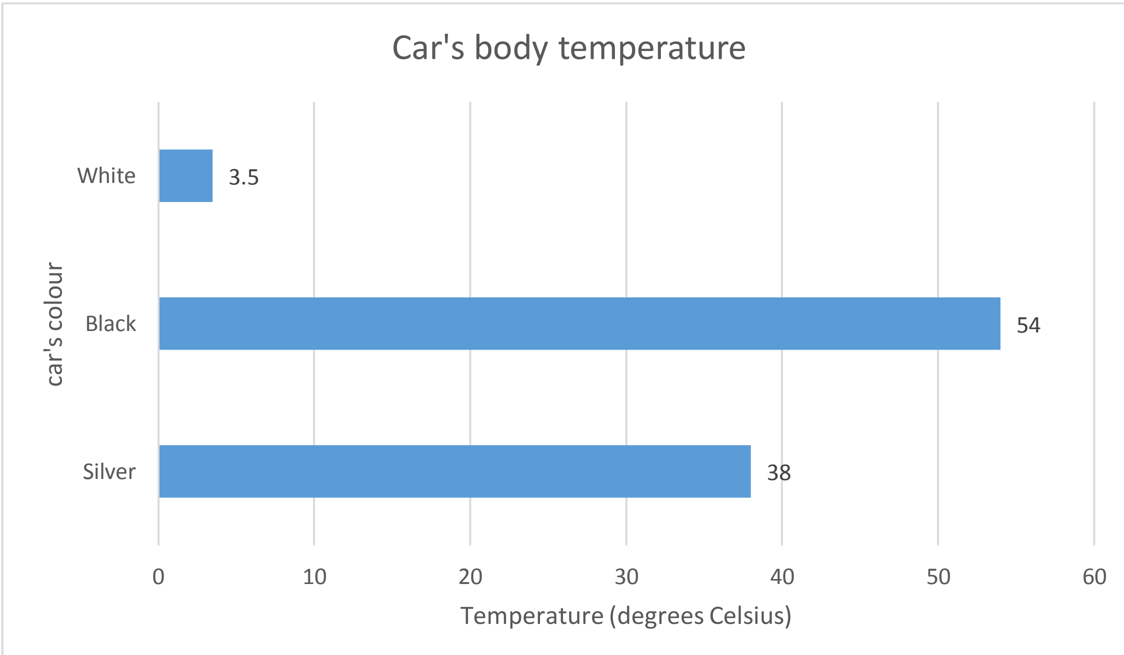

Figure 4.4: Car's body color and their temperature at noon.

Three different color of car is used to measure the temperature exposed under sunlight at twelve noon which are white, silver and black. It shows that, the temperature is highest when the color is black. This is due to black color absorb large amount of sunlight while white or shining color deflect sunlight.

4.3 Experimental Set-up

After achieving all the information needed, an experiment was set up. Circuit in figure 4.5 is for IC MAX757 DC to DC step up voltage. The circuit needs a minimum of 0.7V voltage input to turns on or enables the step up voltage function. The Led in the

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circuit is an indicator to shows that the voltage input was step up or boost to a higher value.

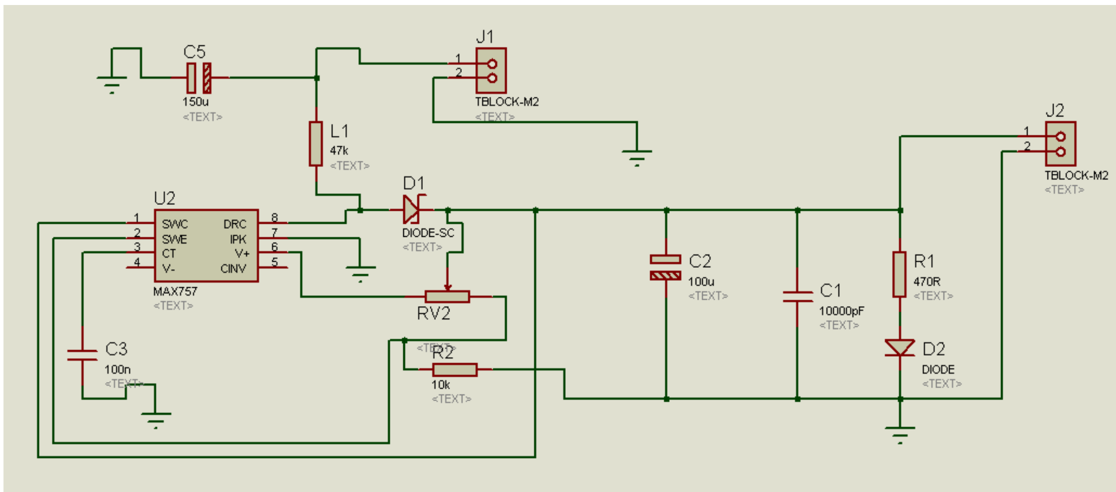

Figure 4.5: MAX757 DC to DC step up circuit.

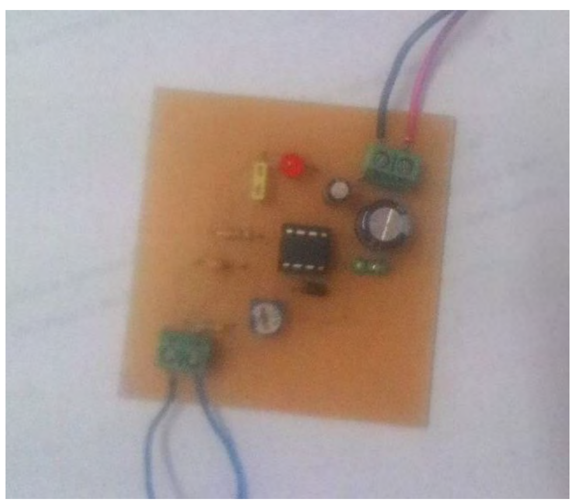

Figure 4.6: Fabricated MAX757 circuit.

The output of the MAX757 is connected to a USB port module, so it can be use to charge phone. Figure 4.7 shows the block diagram for charging phone starting from TEG to the USB port module.

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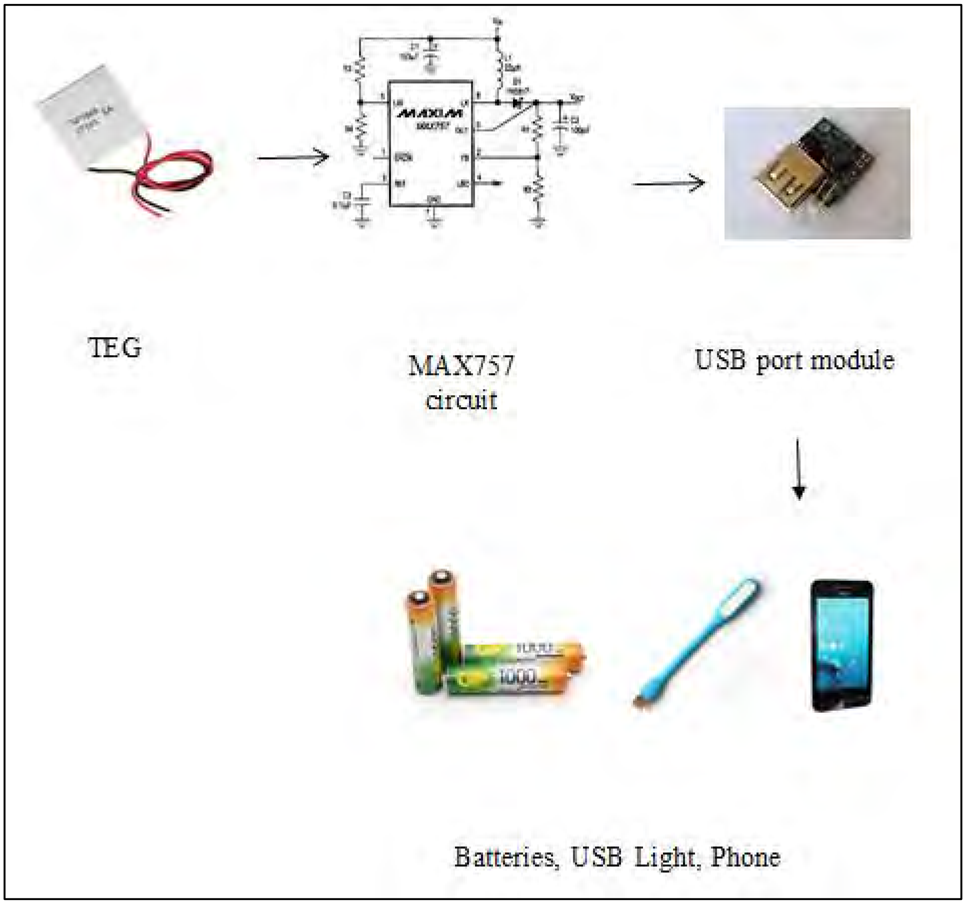

Figure 4.7: Block diagram for charging phone and USB light.

Figure 4.8 shows the output circuit which consists of zener diode, diode, resistor USB port module and rechargeable batteries. The output circuit uses 4.7V zener diode as a voltage regulator to charge phone or voltage reference to charge batteries. Two switches are also added. The first switch is used to on or off the USB module, while the second switch is used to allow current from or to the rechargeable batteries.

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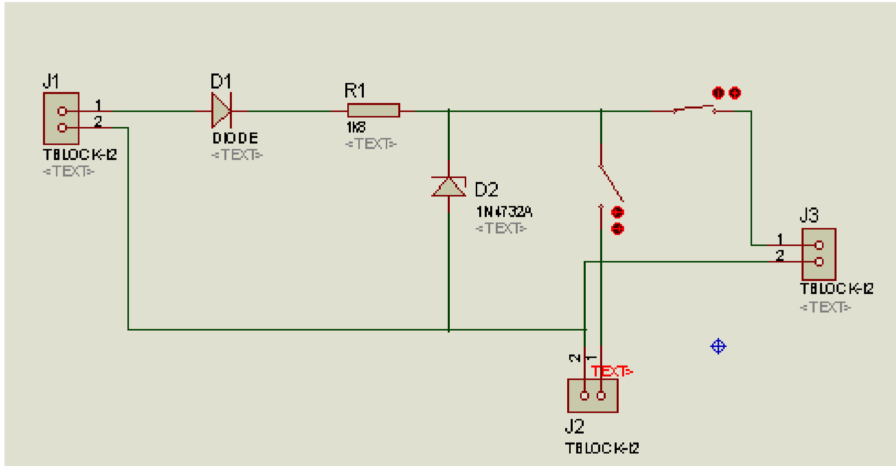

Figure 4.8: Output circuit construction.

4.4 Experimental Result

After the circuit is fabricated, the circuit was tested to collect experimental data. Data was collected when given input from electric kettle and cloth iron.

Figure 4.9: Measuring output current when charging phone.

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The highest output voltage from the MAX757 was 7.86V. Figure 4.9 shows the measuring of current when a phone is charging. Due to the inconstant thermal source temperature level, the current reading was varied and the highest current measured was 23mA. The voltage measured is as an input to the phone was 6.64V. There was a voltage drop when output voltage from MAX757 circuit is given to the USB port module which is about 1.22V.

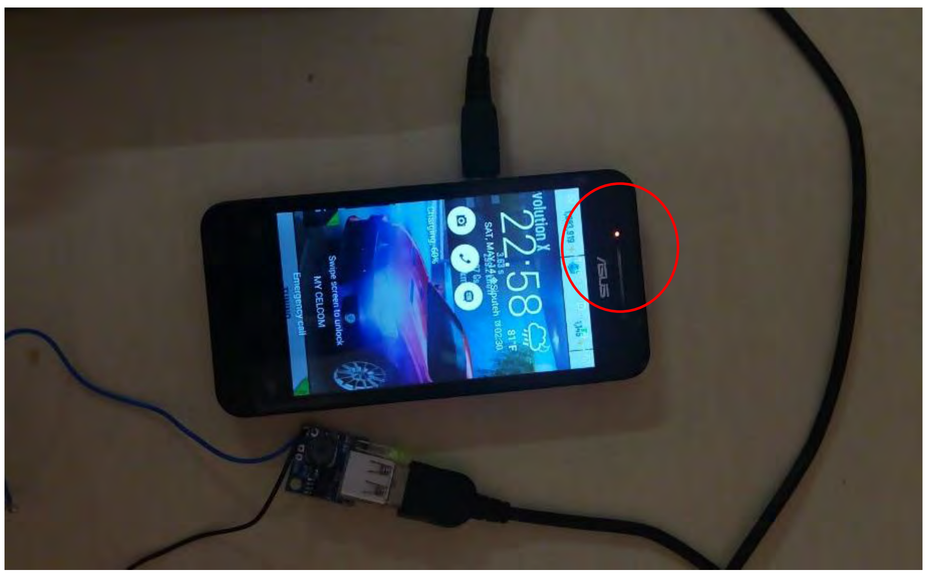

Figure 4.10: Phone is charging.

Figure 4.10 shows an orange Led in the red circle turns on to shows the phone is charging. Eventhough the phone is charging but the current is very small (23mA). The phone battery capacity is 1100mAh. So, it takes about 47 hours to fully charge the phone.

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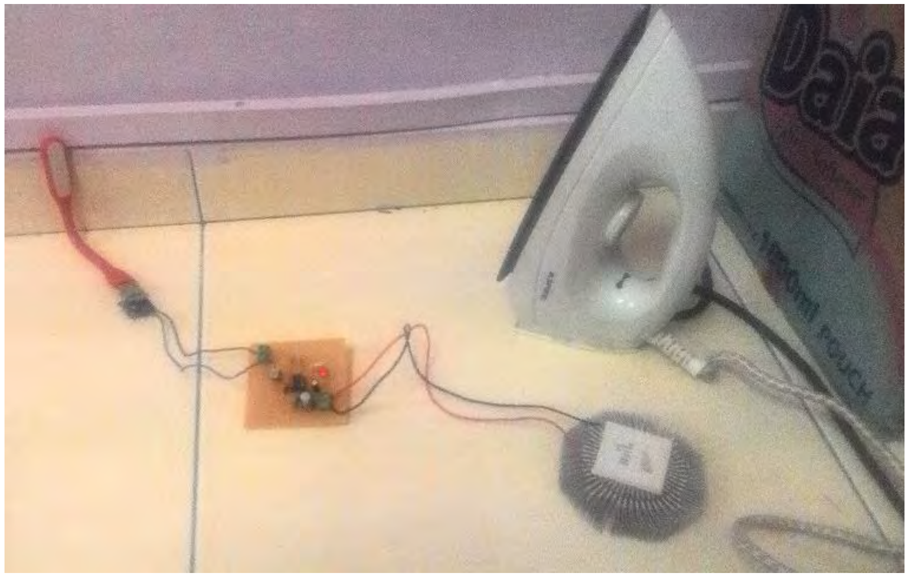

Figure 4.11: Circuit is connected to USB Led light.

The circuit is also tested to turn on a USB Led light as shown in Figure 4.11. The USB Led light turn on as shown on Figure 4.12. The voltage supplied by the MAX757 circuit and USB port module was 3.16V and the current measured was 38mA.

Figure 4.12: USB Led light turns on.

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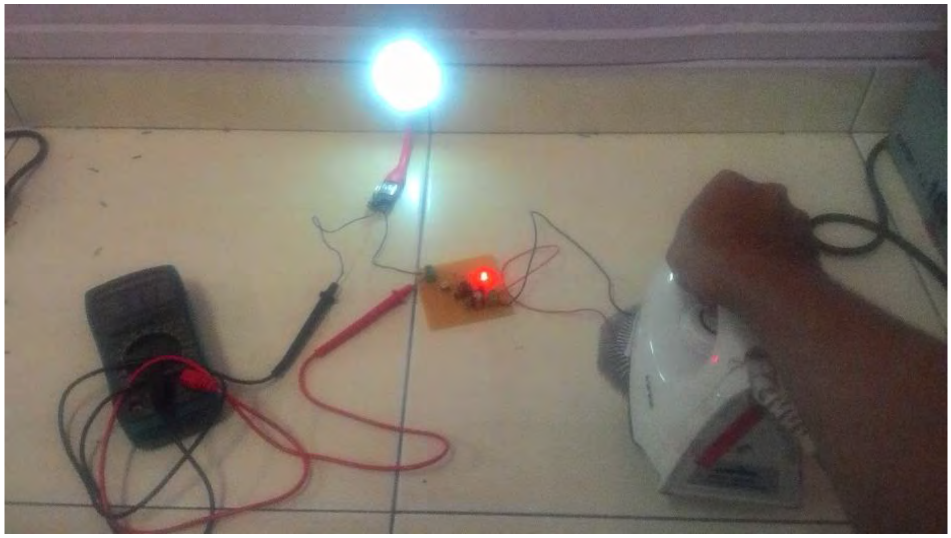

Figure 4.13: Measuring current when powering USB Led Light.

Figure 4.14: Circuit does not turn on when TEG is given heat from electric kettle.

Next, the MAX757 circuit is tested with electric kettle as a source of thermal energy. As we can see in figure above the MAX757 does not turn on. This is due to the voltage input from the TEG is too low. The minimum voltage to turn on the MAX757 IC is 0.7V. The measured voltage from TEG was 0.5V. So, the electric kettle is not ideal to gives as a source of heat for TEG.

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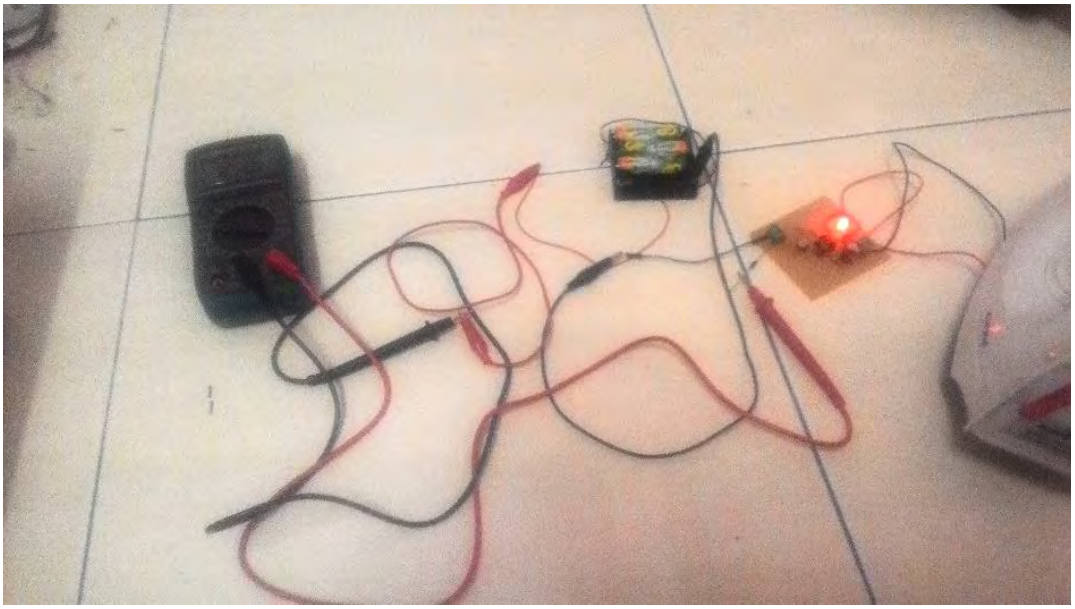

Figure 4.15: Measuring current when charging batteries.

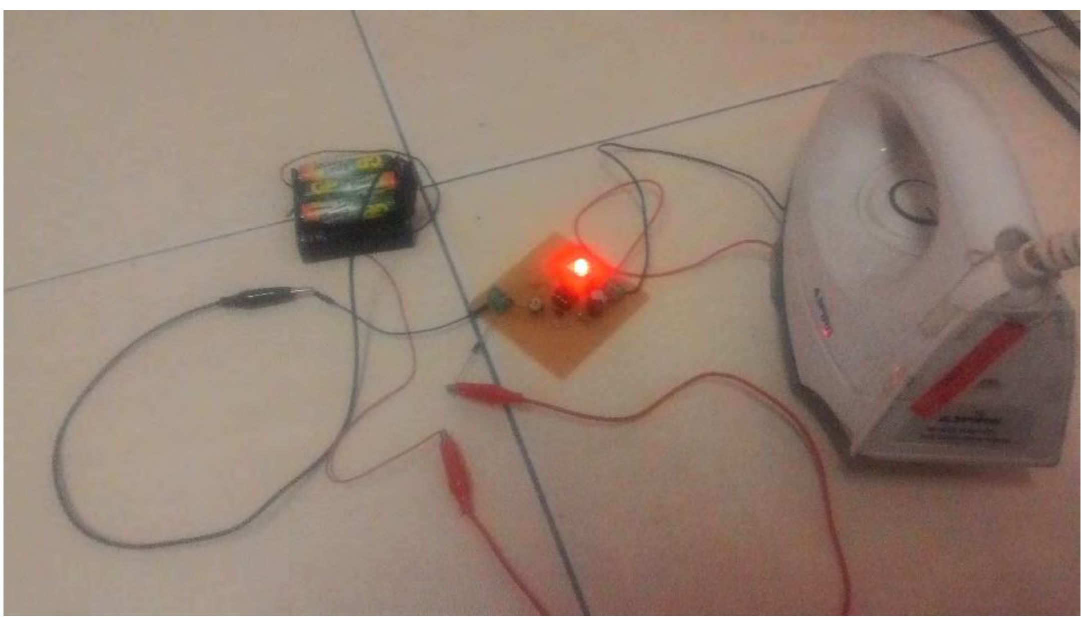

Figure 4.16: Charging batteries.

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The output of the MAX757 is then being used to charge 4 rechargeable batteries. 4 rechargeable batteries is used because the output of the MAX757 circuit is set to have highest current available. The voltage output according to the batteries was 1.2V each which in total should be 4.8V. The measured voltage of the batteries was 5.2V. The important thing before connecting the circuit to the batteries is to add a diode to prevent current flow from batteries to the MAX757 circuit. The current measured when charging was 26.5mA.

4.5 Discussion

Based on the results earlier, there are 4 thermal energy sources which the data were collected. From the data, it shows that cloth iron provide the highest temperature which was 146 degrees Celsius followed by cloth iron at middle range, 89 degrees Celsius and electric kettle at 84 degrees Celsius. The air conditioner compressor unit only supply 50 degrees Celsius (Mitsubishi) and for car's body temperature, 54 degrees Celsius (black color) was measured. The air conditioner compressor unit and car's body temperature provide very low temperature, thus they are not suitable to be a thermal energy sources for the project. The cloth iron at highest range is also not suitable as an input for the TEG because the TEG model only support a maximum of 120 degrees Celsius only.

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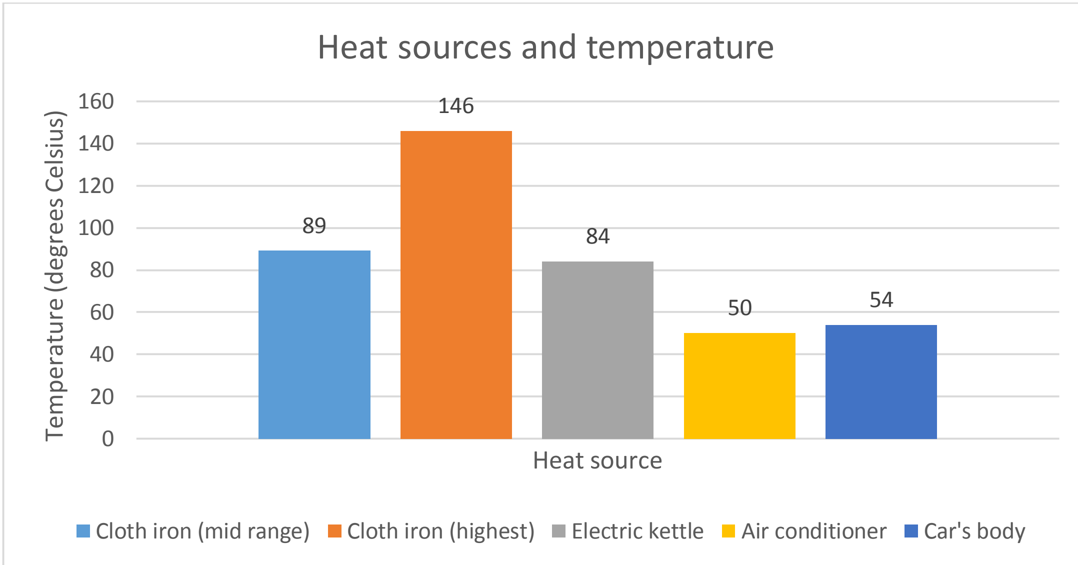

Figure 4.17: Heat sources and highest temperatures.

Next, the thermal energy source from cloth iron at middle range and electric kettle is used to supply thermal energy to the TEG. When the TEG is put on the hot surface of cloth iron, the MAX757 circuit was turned on. However, when the TEG was put on the hot surface of electric kettle, the MAX757 does not turned on. The MAX757 IC needs a minimum of 0.7V to be turned on. It was discovered that the voltage provide by TEG when put on the surface of electric kettle was only 0.5V while for the cloth iron was 1.1V. The insufficient voltage when using electric kettle as thermal energy source causing the MAX757 IC cannot be turned on. Thus, the cloth iron at middle range is the most suitable heat source to power up the MAX757 circuit.

Moreover, a phone was charged at the USB port. The phone need at least 5V power in order to start charging. The output voltage of the MAX757 when using cloth iron as heat source was 7.86V. The circuit was then connected to the USB port module to charge a phone, the voltage decreases to 6.64V. The measured current was really small which was 23mA. Next, the circuit was connected to a USB Led light. The USB Led light turned on brightly.

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Finally, the circuit is then was connected with 4 rechargeable AA batteries with 950mAh capacity each. So, the total capacity is mAh. The rechargeable battery was charging at 26.5mA current. In order to fully charge each rechargeable battery it would take 35 hours. There are 2 switches at the output circuit. First switch is used to the USB port to on, while the second switch is used to charge batteries.

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, there are several thermal energy sources has been investigates on to produce electrical energy over a long period. The thermal energy source from cloth iron at middle range is the most suitable to power up electronic device application because it provides high thermal energy compared to electric kettle, car's body temperature and air conditioner compressor unit. The highest temperature from cloth iron was 89 degrees Celsius and it produces voltage output of 1.1V.

Moreover, electric circuit for thermoelectric energy storage was designed by using rechargeable battery. 4 rechargeable AA batteries with 850mAh capacity each were used as an energy storage when electrical energy is not in used.

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Finally, a device that can store and step up the low output of the thermoelectric generator was developed for electronic device usage. MAX757 was used to step up the voltage and current of the thermoelectric generator. The output voltage from thermoelectric generator was boost from 1.1V to 7.86V but the current produced was 23mA and does not increases. The output of the circuit was used to power up USB Led light and to charge a phone.

In overall, the circuit for thermal energy harvesting was successfully developed. The circuit can store generated electrical energy and the output power also can be used to power up small electronic devices (5V).

5.2 Recommendation

Based on the project conducted, it is recommended to find a suitable thermal energy source to be apply on the thermoelectric generator. Low temperature of thermal energy source will produce only small amount of electrical energy but it is important to check the highest temperature the TEG can endure. If input temperature exceed the highest temperature of TEG can tolerate, the TEG will be broken and cannot be used anymore.

Moreover, the thermoelectric generator (TEG) also need to be designed better. The TEG consist of two surface, right and left which must be set with a hot side or cold side. The cold side of the TEG in the project was connected with an aluminum heat sink. It is recommended to use copper heat sink because it has higher thermal conductivity thus provides higher temperature difference on TEG surface consequently producing higher output voltage.

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In addition, the output current need to be step up so that it is suitable to be given as an electrical power source for electronic devices such as phone, and mp3 player that usually require at least 1A to 0.5A current.

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APPENDIX A

Table 4.1: Clothes iron temperatures.

Time (s)	Middle Range		Highest Range	
	Resistance (Ω)	**Temperature (degrees Celsius)**	**Resistance (Ω)**	**Temperature (degrees Celsius)**
0	116.5	43	117.0	44
10	120.0	53	118.1	47
20	126.0	67	126.2	68
30	130.5	79	138.4	100
40	132.4	84	142.5	111
50	134.4	89	150.0	130
60	129.7	77	154.5	144
70	128.6	74	152.1	136
80	126.6	69	148.0	125
90	130.1	78	146.8	122
100	132.7	85	155.7	146

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Table 4.2: Electric kettle temperature.

Time (s)	Average Resistance for 3 Trial (Ω)	Temperature (degrees Celsius)
30	113.0	33
60	114.1	36
90	116.0	41
120	118.5	48
150	119.5	50
180	120.6	53
210	122.9	59
240	123.8	61
270	126.8	69
300	130.3	78
330	131.2	81
360	132.5	84
390	132.5	84

Table 4.3: Air conditioner compressor unit temperature.

Brands	Average resistance (Ω)	Temperature (degrees Celsius)
York	115.8	41
Mitsubishi	119.4	50

Table 4.4: Car's body temperature.

Color	Average resistance (Ω)	Temperature (degrees Celsius)
Silver	114.9	38
Black	121.1	54
White	117.8	46

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APPENDIX B

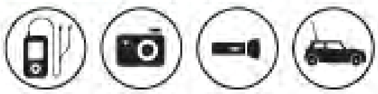
GP Batteries
Powering a Greener Tomorrow

CONSUMER MANUAL

BENEFITS:
- Ready to use once charged
- Stay charged longer when not in use
- Can be charged in most rechargeable chargers
- Cost saving & environmentally friendly

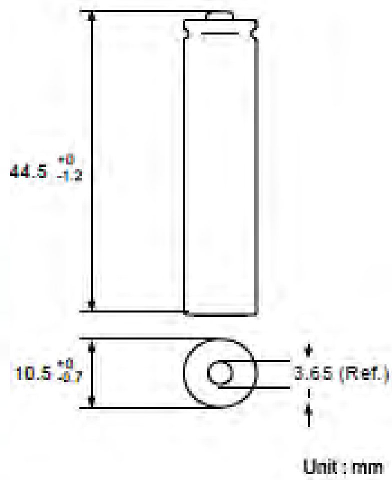
- **GP 1000 series Rechargeable battery**
- **AAA size**
- **Minimum capacity 950mAh**

APPLICATIONS BEST FOR:



OTHER DETAILS:
- Nickel Metal Hydride chemistry
- Nominal voltage 1.2V
- Gross weight ~15.2g

BATTERY HANDLING
- Batteries should be charged prior to use.
- Remove batteries from the electrical device if the device is not going to be used for a long period of time.
- Do not mix new batteries in use with semi-used batteries.
- In order to maintain satisfactory cell / battery performance when being stored under extending period of time, fully charge the cell / battery within 12 months period is highly recommended.



www.gpbatteries.com

Model No.: GP100AAAHC

Manufacturer reserves the right to alter or amend the design, model and specification without prior notice.
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APPENDIX C

maxim integrated

EVALUATION KIT AVAILABLE

MAX756/MAX757

3.3V/5V/Adjustable-Output, Step-Up DC-DC Converters

General Description

The MAX756/MAX757 are CMOS step-up DC-DC switching regulators for small, low input voltage or battery-powered systems. The MAX756 accepts a positive input voltage down to 0.7V and converts it to a higher pin-selectable output voltage of 3.3V or 5V. The MAX757 is an adjustable version that accepts an input voltage down to 0.7V and generates a higher adjustable output voltage in the range from 2.7V to 5.5V. Typical full-load efficiencies for the MAX756/MAX757 are greater than 87%.

The MAX756/MAX757 provide three improvements over previous devices. Physical size is reduced—the high switching frequencies (up to 0.5MHz) made possible by MOSFET power transistors allow for tiny (<5mm diameter) surface-mount magnetics. Efficiency is improved to 87% (10% better than with low-voltage regulators fabricated in bipolar technology). Supply current is reduced to 60µA by CMOS construction and a unique constant-off-time pulse-frequency modulation control scheme.

Applications

3.3V to 5V Step-Up Conversion
Palmtop Computers
Portable Data-Collection Equipment
Personal Data Communicators/Computers
Medical Instrumentation
2-Cell & 3-Cell Battery-Operated Equipment
Glucose Meters

Features

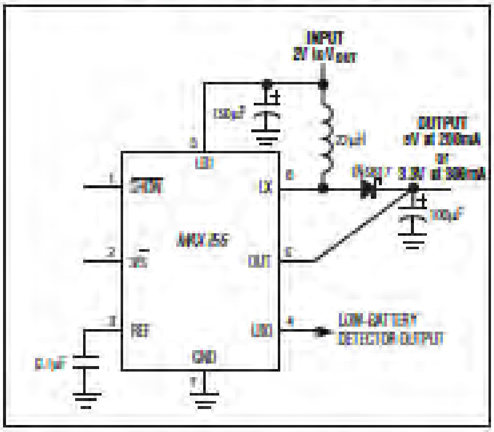
- Operates Down to 0.7V Input Supply Voltage
- 87% Efficiency at 200mA
- 60µA Quiescent Current
- 20µA Shutdown Mode with Active Reference and LBI Detector
- 500kHz Maximum Switching Frequency
- ±1.5% Reference Tolerance Over Temperature
- Low-Battery Detector (LBI/LBO)
- 8-Pin DIP and SO Packages

Ordering Information

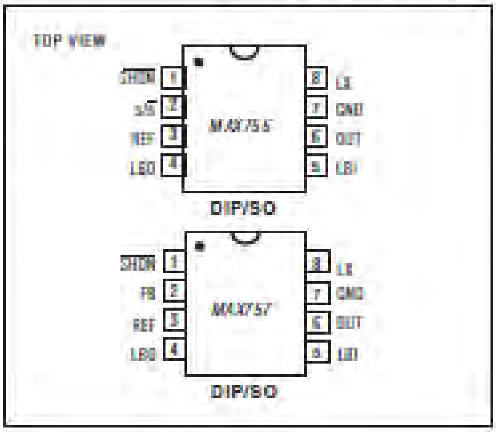
PART	TEMP. RANGE	PIN-PACKAGE
MAX756CPA	0°C to +70°C	8 Plastic DIP
MAX756CSA	0°C to +70°C	8 SO
MAX756C/D	0°C to +70°C	Dice*
MAX756EPA	-40°C to +85°C	8 Plastic DIP
MAX756ESA	-40°C to +85°C	8 SO
MAX757CPA	0°C to +70°C	8 Plastic DIP
MAX757CSA	0°C to +70°C	8 SO
MAX757C/D	0°C to +70°C	Dice*
MAX757EPA	-40°C to +85°C	8 Plastic DIP
MAX757ESA	-40°C to +85°C	8 SO

* Dice are tested at $T_A = +25°C$ only.

Typical Operating Circuit



Pin Configurations



For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim's website at www.maximintegrated.com.

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APPENDIX D

Temperature Conversion Table RT Table

Platinum Resistance (-200°C to 239°C)

Temperature Coefficient - 0.00385 Ohms/Ohm/°C

°C	Ohms	°C	Ohms	C	Ohms	°C	Ohms	°C	Ohms	°C	Ohms	°C	Ohms
-200	18.49	-137	45.11	-74	70.73	-11	95.69	51	119.78	114	143.80	177	167.35
-199	18.93	-136	45.52	-73	71.13			52	120.16	115	144.17	178	167.72
-198	19.36	-135	45.94	-72	71.53	-10	96.09	53	120.55	116	144.55	179	168.09
-197	19.79	-134	46.35	-71	71.93	-9	96.48	54	120.93	117	144.93		
-196	20.22	-133	46.76			-8	96.87	55	121.32	118	145.31	180	168.46
-195	20.65	-132	47.18	-70	72.33	-7	97.26	56	121.70	119	145.68	181	168.83
-194	21.08	-131	47.59	-69	72.73	-6	97.65	57	122.09			182	169.20
-193	21.51			-68	73.13	-5	98.04	58	122.47	120	146.06	183	169.57
-192	21.94	-130	48.00	-67	73.53	-4	98.44	59	122.86	121	146.44	184	169.94
-191	22.37	-129	48.41	-66	73.93	-3	98.83			122	146.81	185	170.31
		-128	48.82	-65	74.33	-2	99.22	60	123.24	123	147.19	186	170.68
-190	22.80	-127	49.23	-64	74.73	-1	99.61	61	123.62	124	147.57	187	171.05
-189	23.23	-126	49.64	-63	75.13			62	124.01	125	147.94	188	171.42
-188	23.66	-125	50.06	-62	75.53	0	100.00	63	124.39	126	148.32	189	171.79
-187	24.09	-124	50.47	-61	75.93	1	100.39	64	124.77	127	148.70		
-186	24.52	-123	50.88			2	100.78	65	125.16	128	149.07	190	172.16
-185	24.94	-122	51.29	-60	76.33	3	101.17	66	125.54	129	149.45	191	172.53
-184	25.37	-121	51.70	-59	76.73	4	101.56	67	125.92			192	172.90
-183	25.80			-58	77.13	5	101.95	68	126.31	130	149.82	193	173.26
-182	26.23	-120	52.11	-57	77.52	6	102.34	69	126.69	131	150.20	194	173.63
-181	26.65	-119	52.52	-56	77.92	7	102.73			132	150.57	195	174.00
		-118	52.92	-55	78.32	8	103.12	70	127.07	133	150.95	196	174.37
-180	27.08	-117	53.33	-54	78.72	9	103.51	71	127.45	134	151.33	197	174.74
-179	27.50	-116	53.74	-53	79.11			72	127.84	135	151.70	198	175.10
-178	27.93	-115	54.15	-52	79.51	10	103.90	73	128.22	136	152.08	199	175.47
-177	28.35	-114	54.56	-51	79.91	11	104.29	74	128.60	137	152.45		
-176	28.78	-113	54.97			12	104.68	75	128.98	138	152.83	200	175.84
-175	29.20	-112	55.38	-50	80.31	13	105.07	76	129.37	139	153.20	201	176.21
-174	29.63	-111	55.78	-49	80.70	14	105.46	77	129.75			202	176.57
-173	30.05			-48	81.10	15	105.85	78	130.13	140	153.58	203	176.94
-172	30.47	-110	56.19	-47	81.50	16	106.24	79	130.51	141	153.95	204	177.31
-171	30.90	-109	56.60	-46	81.89	17	106.63			142	154.32	205	177.68
		-108	57.00	-45	82.29	18	107.02	80	130.89	143	154.70	206	178.04
-170	31.32	-107	57.41	-44	82.69	19	107.40	81	131.27	144	155.07	207	178.41
-169	31.74	-106	57.82	-43	83.08			82	131.66	145	155.45	208	178.78
-168	32.16	-105	58.22	-42	83.48	20	107.79	83	132.04	146	155.82	209	179.14
-167	32.59	-104	58.63	-41	83.88	21	108.18	84	132.42	147	156.19		
-166	33.01	-103	59.04			22	108.57	85	132.80	148	156.57	210	179.51
-165	33.43	-102	59.44	-40	84.27	23	108.96	86	133.18	149	156.94	211	179.88
-164	33.85	-101	59.85	-39	84.67	24	109.35	87	133.56			212	180.24
-163	34.27			-38	85.06	25	109.73	88	133.94	150	157.31	213	180.61
-162	34.69	-100	60.25	-37	85.46	26	110.12	89	134.32	151	157.69	214	180.97
-161	35.11	-99	60.66	-36	85.85	27	110.51			152	158.06	215	181.34
		-98	61.06	-35	86.25	28	110.90	90	134.70	153	158.43	216	181.71
-160	35.53	-97	61.47	-34	86.64	29	111.28	91	135.08	154	158.81	217	182.07
-159	35.95	-96	61.87	-33	87.04			92	135.46	155	159.18	218	182.44
-158	36.37	-95	62.28	-32	87.43	30	111.67	93	135.84	156	159.55	219	182.80
-157	36.79	-94	62.68	-31	87.83	31	112.06	94	136.22	157	159.93		
-156	37.21	-93	63.09			32	112.45	95	136.60	158	160.30	220	183.17
-155	37.63	-92	63.49	-30	88.22	33	112.83	96	136.98	159	160.67	221	183.53
-154	38.04	-91	63.90	-29	88.62	34	113.22	97	137.36			222	183.90
-153	38.46			-28	89.01	35	113.61	98	137.74	160	161.04	223	184.26
-152	38.88	90	64.30	-27	89.40	36	113.99	99	138.12	161	161.42	224	184.63
-151	39.30	-89	64.70	-26	89.80	37	114.38			162	161.79	225	184.99
		-88	65.11	-25	90.19	38	114.77	100	138.50	163	162.16	226	185.36
-150	39.71	-87	65.51	-24	90.59	39	115.15	101	138.88	164	162.53	227	185.72
-149	40.13	-86	65.91	-23	90.98			102	139.26	165	162.90	228	186.09
-148	40.55	-85	66.31	-22	91.37	40	115.54	103	139.64	166	163.27	229	186.45
-147	40.96	-84	66.72	-21	91.77	41	115.93	104	140.02	167	163.65		
-146	41.38	-83	67.12			42	116.31	105	140.39	168	164.02	230	186.82
-145	41.79	-82	67.52	-20	92.16	43	116.70	106	140.77	169	164.39	231	187.18
-144	42.21	-81	67.92	-19	92.55	44	117.08	107	141.15			232	187.54
-143	42.63			-18	92.95	45	117.47	108	141.53	170	164.76	233	187.91
-142	43.04	-80	68.33	-17	93.34	46	117.85	109	141.91	171	165.13	234	188.27
-141	43.45	-79	68.73	-16	93.73	47	118.24			172	165.50	235	188.63
		-78	69.13	-15	94.12	48	118.62	110	142.29	173	165.87	236	189.00
-140	43.87	-77	69.53	-14	94.52	49	119.01	111	142.66	174	166.24	237	189.36
-139	44.28	-76	69.93	-13	94.91			112	143.04	175	166.61	238	189.72
-138	44.70	-75	70.33	-12	95.30	50	119.40	113	143.42	176	166.98	239	190.09

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