

# Thermoelectric Power Generation Device

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**Abstract** — This paper presents a device that can generate electricity by using heat. Thermoelectric module is used as a mechanism to convert heat into electricity. In order to produce a useable output power, a step-up circuit was constructed and implemented together with the module. A small and portable power generation device was successfully designed that can generate voltage of up to 5.6V with efficiency of 70%. The device can be used to power up almost any electronic devices which require 5V operating voltage; microcontroller, sensor, smartphone-charger, LED and etc.

**Keywords:** *Thermoelectric, Thermoelectric Generator (TEG), Thermoelectric Cooler (TEC), Charger powered by Fire, Power Generation, Heat Power Generation.*

## I. INTRODUCTION

Thermoelectric by definition is the science involved with thermoelectric generation and refrigeration [1]. It composes of two fundamental effects which are Seebeck and Peltier effect that was discovered in the early 1820 – 1850. While conducting an experiment on galvanic arrangement in 1821, Thomas Seebeck mistakenly connected parts of bismuth and copper together. This event automatically induced a thermoelectric electromotive force (emf) and disturbed a compass which was happened to be nearby. This effect was initially called as thermo-magnetism by Seebeck [2].

Seebeck effect states that when two ends of a conductor was kept at a different temperature, it would create charge flow. Peltier effect on the other hand describes the reverse mechanism of Seebeck effect. It describes how an electrical current when passes through a conductor can create a heat flow.

Consider the image below:

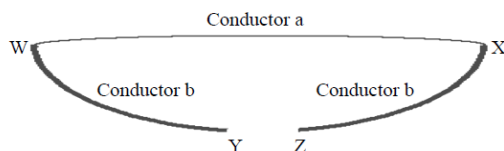


Figure 1: Conductor at Different Temperature

Imagine two terminals W and X are held at different temperatures where W is hot and X is cold. The basic Solid

State Theory states that electrons will diffuse from the hot side to the cold side. The heating process will slowly provide some energy to the electron at W [3]. After some time, electrons at W will have enough energy and finally will be excited and diffuse toward the cooler side X. The electron will keep diffusing to the cooler side until it achieves equilibrium which is when the potential of the charge separation counteract the flow of electrons.

The basic element of thermoelectric is called thermoelectric couple. It is made up from two “pallets”, N-type pallets (doped with donor) and P-type pallets (doped with acceptor). Copper is usually used as a material to physically connect the two pallets together. If there is a difference in temperature between the two sides of thermoelectric couple, thermal energy will starts to flow thus creating a voltage called Seebeck voltage. A resistive load is needed to be connected in order to generate a current flow [4].

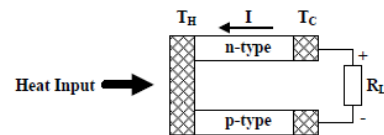


Figure 2: Basic Element of Thermoelectric Couple

For a practical application, several thermoelectric couples are connected in series and sandwiched in between two insulating plates [5] and is called thermoelectric module. A standard thermoelectric module will consist of a minimum of 3 couples and a maximum of up to 127 couples for a better performance.

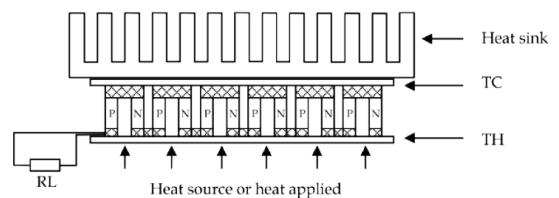


Figure 3: Several Thermoelectric Couple Connected in Series

In order to generate electrical power, the temperature difference between the two plates of thermoelectric module has to be maintained, these are usually referred to the hot side

plate and cold side plate. The amount of electrical power it can produce is directly proportional to the temperature difference, DT and Seebeck coefficient of the material used. In order to create temperature difference, heat sink is normally attached to the cold side of the module [4]. This is to dissipate the heat into the surrounding medium.

Few projects had been constructed previously using TEG module to generate power. A TEG module (TG 100) was used to investigate its capability as a power generation device [6]. This module do not used step-up dc to dc mechanism and can only produce 4.7V maximum voltage. Due to the versatility of TEG, another research had been conducted to study the compatibility of TEG module to be used as a wearable device [7]. However, such a device has a dimension constraint. The effort in producing a small device had caused limited performance of TEG module itself. H. Mamur and R. Ahiska had constructed a portable and high power TEG [8]. This module was able to generate as high as 41.6W output power without using any step-up converter. This high specification module is very costly. However, the performance of TEG shows that it has some potential in industry. Lastly, a standard TEG power generation device for a small appliance was constructed in [9]. A step-up dc to dc converter was also used to increase the voltage of the system.

Figure below shows the block diagram for Thermoelectric Power Generation Device:

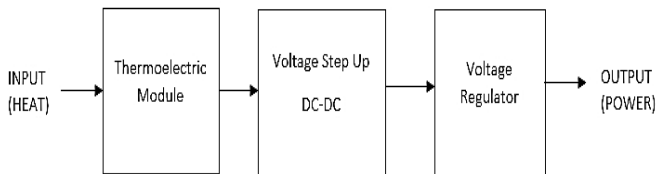


Figure 4: Block Diagram for TEG Power Generation Device

The problem with current TEG module[10]:

- i) Low power output
- ii) Low efficiency

## PROJECT OBJECTIVES

There are three main objectives of this experiment:

1. To investigate the possibility of power generation by using thermoelectric module.
2. To study the reliability of the thermoelectric module power output to power up electronic device.
3. To design a consumer device that can generate power by using fire or heat.

## II. METHODOLOGY

### A. Thermoelectric Module Selection

There are two types of thermoelectric module; TEG and thermoelectric cooler TEC. Though the mechanism is basically the same, but each of the modules is specifically designed to suit its own purposes. Table 1 discusses the differences between these two modules for selection purposes:

| TEG                                          | TEC                                                 |
|----------------------------------------------|-----------------------------------------------------|
| Based on Seebeck Effect                      | Based on Peltier Effect                             |
| Can handle high temperature<br>(Up to 350°C) | Can't handle high temperature<br>(Only up to 150°C) |
| Design to generate optimum power             | Heating or Cooling module                           |

Table 1: TEG verses TEC

Based on the Table 1, since this is a power generation project, it is clear the TEG module is more suitable to be used as compared to TEC. However, there are a lot of TEG modules available in the industry but with different specifications. For example, each module has differences in terms of its maximum temperature and resistivity. Since the main objective is to design a power generation device, it should be able to deliver voltage of 5V. This happens because of the fact that it is the most common operating voltage for today's electronic device. To fulfill this, a powerful and reliable TEG module is needed.

#### i. Materials

There are various type of materials used to manufacture a thermoelectric module. Some of them are Bismuth Telluride ( $\text{Bi}_2\text{Te}_3$ ), Lead Telluride ( $\text{PbTe}$ ), Silicon Germanium ( $\text{SiGe}$ ) as well as Bismuth Antimony ( $\text{Bi-Sb}$ ). However, they come with different performance which can be measured by the Figure-of-Merit (ZT) equation:

$$ZT = \frac{\alpha^2}{\rho\lambda} \quad (1)$$

Where  $\alpha$  = Seebeck coefficient,  $\rho$  = electrical resistivity and  $\lambda$  = thermal conductivity. The figure-of-merit of commonly used thermoelectric material is as follow [11]:

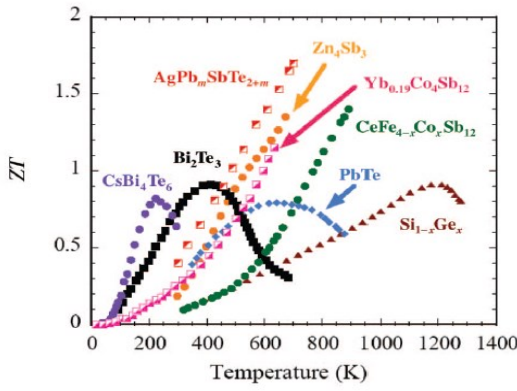


Figure 5: Figure of Merit for Different Materials

As can be observed from graph of Figure 5, although Bismuth Telluride ( $\text{Bi}_2\text{Te}_3$ ) has only  $ZT \approx 1$ , it is the most commonly used thermoelectric material. This is because  $\text{Bi}_2\text{Te}_3$  is the most power competitive and cost efficient of all material.

#### ii. Temperature Difference, DT

Another important factor in producing a high power output of TEG module is the temperature difference. The higher the temperature difference between the cold side and hot side of the module, the higher will be the power output. Thus, the higher maximum temperature of TEG module is selected for this project.

#### iii. Internal Resistance

In order to produce better output, a low internal resistance is needed. Lower internal resistance means higher current can be drawn from the circuit. The current technology allows the thermoelectric module to have the internal resistance value of as low as  $1.2\Omega$ . However, a module that owns the particular value of resistance usually is very powerful and expensive. During the selection process, the author managed to find a module with low resistance ( $3\Omega$ ) at a reasonable price.

#### iv. Power Output

A very powerful thermoelectric module can produce up to 15W; however, the price is very expensive. Table 2 shows the full specification lists for the selected TEG module used in the project.

#### B. Voltage Step-up Circuit

The power output of thermoelectric module is quite low so it cannot be used directly to power up any electronic device. In the early days, the application of thermoelectric module as a power generation device is rather slow. To overcome this problem, a CMOS step-up DC-DC regulators IC produced by Maxim Integrated, MAX757 is used. It has a unique characteristic which is able to accept an input of as low as 0.7V and step it up to 5V-6V. The connection is as shown

in Figure 6 except for the SHDN pin. According to [12], SHDN pin cannot be left floating and should be connected to the LX (output) pin. The efficiency for this chip is as high as 87% [13]. The output is controlled by  $R1$  &  $R2$  which is based from the equation (2). This system use  $R1 = 68K\Omega$  &  $R2 = 22K\Omega$  while  $V_{ref} = 1.5V$ . The expected  $V_{out} = 6V$ .

$$V_{out} = V_{ref}[(R1 + R2)/R2] \quad (2)$$

|                              |                   |
|------------------------------|-------------------|
| <b>TEG Model</b>             | TEP1-1264-1.5     |
| <b>Module Type</b>           | Bismuth Telluride |
| <b>Max Temperature</b>       | 350°C             |
| <b>Max Cold Side Temp</b>    | 180°C             |
| <b>Couples</b>               | 126               |
| <b><math>V_{oc}</math></b>   | 8.6V              |
| <b><math>R_i</math></b>      | 3Ω                |
| <b><math>V_{load}</math></b> | 4.2V              |
| <b><math>I_{load}</math></b> | 1.4A              |
| <b>Power</b>                 | 5.9W              |

Table 2: Full Specification of TEG Module

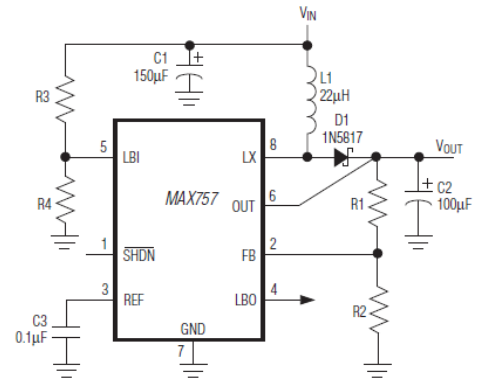


Figure 6 : Basic Connection of MAX757 IC

Some features of MAX757 are listed below.

- Operates down to 0.7 input supply voltage
- 87% efficiency at 200mA
- 500kHz maximum switching frequency
- 8-pin DIP

#### C. Voltage Regulator

The output voltage of the step-up circuit will always vary. The output can sometimes be very high (even 6V) and sometimes be very low (less than 5V). This phenomenon is not very practical and good for power generation device. Consequently, if an electronic device needs a steady voltage of 5V, an overshoot voltage of more than 5V will damage some of the electronic components in the circuit. Thus, a voltage regulator should be used to overcome this problem. The most common voltage regulator would be of the type 7805.

However, it needs 7V input voltage yet the step-up voltage is able to produce only output of 5V-6V. As a result a simple circuit of Zener diode was constructed (5.6V, 1W) to regulate the voltage.

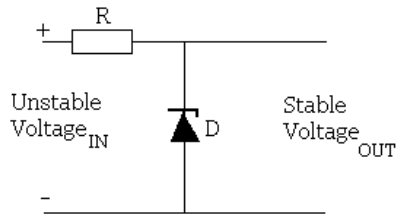


Figure 7: Standard Zener Diode Connection

#### D. Schematic & Model

Figure 8 & 9 shows the schematic and model for the project:

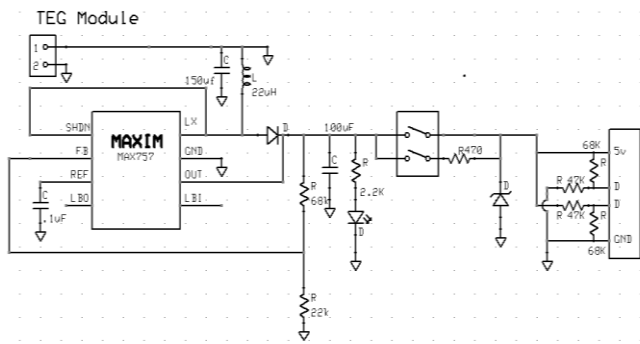


Figure 8: Schematic for TEG Power Generation Device

TEG modules' output will enter MAX757 IC first at pin LX. The value will be vary from 0.7 V to 4.4 V accordingly. A red LED is implemented as an indicator that the system is working. In order to regulate the voltage, a single Zener Diode was added altogether and connected to DIP switch. There are 2 options that was available, 5.6V and 5V. Universal Serial Bus (USB) connection is implemented as it is the most commonly used connection for today's electronic device.

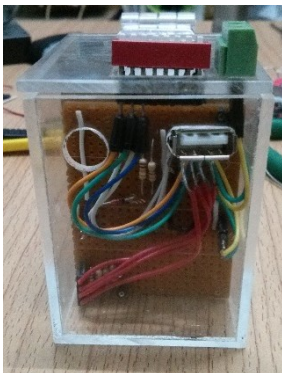


Figure 9 : Completed Model of TEG Power Generation Device

### III. RESULTS AND DISCUSSION

The efficiency and the output of the device were measured by manipulating all the parameters that affected the system. The first parameter that had been considered was temperature difference between the two plates of the module. The measurement was done by using two units of thermometer (100°C maximum). Although the module can withstand a high temperature; as high as 350°C, the experiment was limited by the unavailability of thermometer. The cold temperature was taken at the heat sink (directly touching the cold plate) while the hot temperature was taken directly at the heated plate as shown in Figure 10. Since the measurement was done by using a standard thermometer, the results would be less précised since the temperature was not kept stable at certain times. In fact, it is very difficult to maintain the DT of the system since a small amount of heat is being transferred to the cold side simultaneously.



Figure 10 : Experiment to Test the Performance of the System

Figure 11 shows the IV graph of the system. The minimum voltage needed to drive the system is 0.7V-0.9V. This value (which is achieved at 30°C temperature difference) would be the starting point of the recorded value. As usual, the power in the circuit was calculated from the equation  $P=IV$ . At the maximum power point ( $P_{\max}=0.05W$ ), the corresponding voltage would be considered as  $V_{\max} = 2.28V$  and  $I_{\max} = 0.023A$ . The calculation is based from the equation (3) below:

$$P_{\max} = V_{\max} \times I_{\max} \quad (3)$$

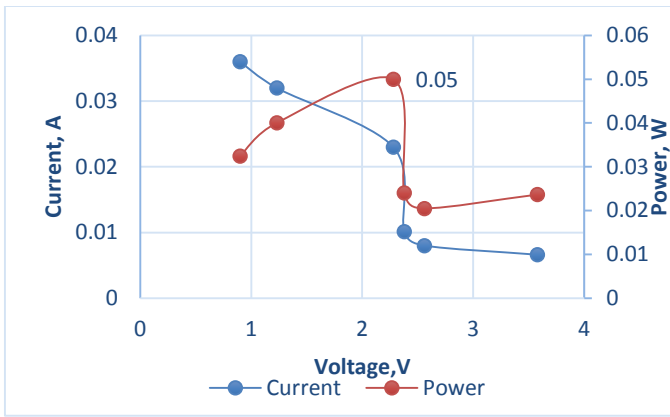


Figure 11 : IV Curve & Power of the TEG Module

Figure 12 and Figure 13 described the characteristic of the voltage and current of the TEG with respect to the DT. According to the specification, the thermoelectric module can produce maximum 4.2V/1.4A at DT = 170°C. As we can see from Figure 12, voltage is linearly increasing. This showed that DT is directly proportional to the voltage. As for the current, it is inversely proportional to the DT. This is due to the fact that at the same time, voltage is linearly increasing. If we take the equation  $P=IV$  into consideration and rearrange it,  $I = P/V$ , then we would see that I is inversely proportional to the V, thus shows that the graph is conformed to the theory.

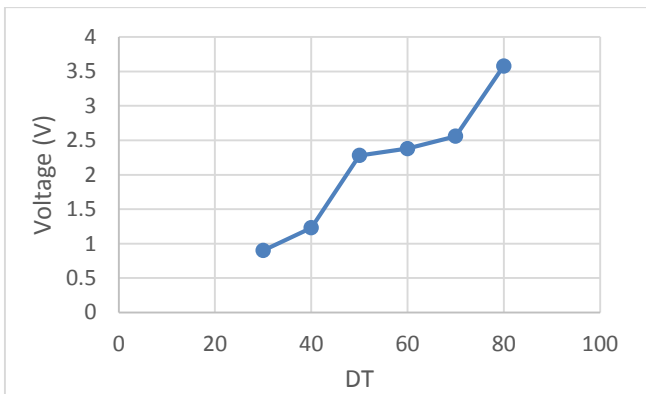


Figure 12: Voltage versus DT

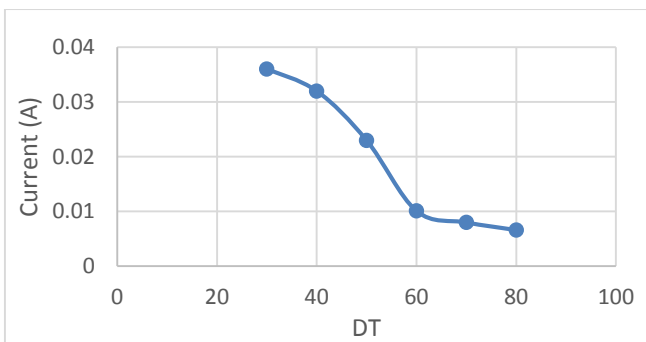


Figure 13 : Current versus DT

Another parameter that we should study is about the efficiency of the system. It is calculated based from equation

(4) and tabulated in table 3. The test for efficiency was conducted in a standard and normal condition except on the heated plate. No temperature was recorded since the temperature was higher than 100°C.

$$\eta = \frac{P_{out}}{P_{in}} \times 100 \quad (4)$$

|                 | $P_{in}$ (W)          | $P_{out}$ (W)        | Efficiency |
|-----------------|-----------------------|----------------------|------------|
| LED (2x)        | 0.35<br>(0.95V/0.37A) | 0.22<br>(5.6V/40mA)  | 63%        |
| Smartphone      | 0.3<br>(0.96V/0.37A)  | 0.18<br>(4.6V/40mA)  | 60%        |
| Microcontroller | 0.234<br>(1.3V/0.18A) | 0.168<br>(5.6V/30mA) | 72%        |

Table 3 : Efficiency of TEG Power Generation Device

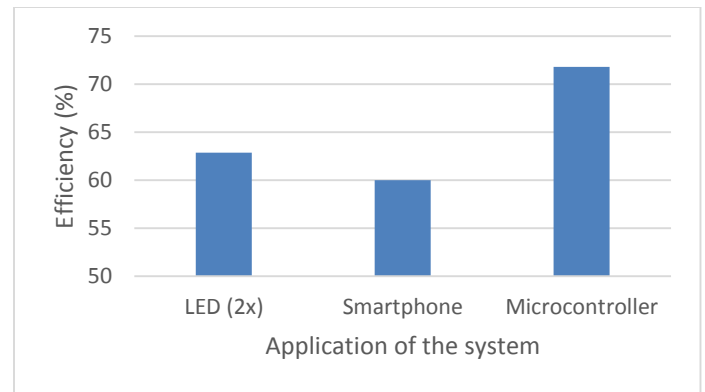


Figure 14 : Efficiency of TEG Power Generation Device

As can be observed from Figure 14, different applications have different efficiencies. Microcontroller has the highest efficiency while charging smartphone has the least. The efficiency can be improved by redesigning and choosing a different component. Besides, the test was also conducted to measure the time taken to turn 'on' the system by using different types of heat sources. The experiment was conducted by using a heat stove with high power, medium power, and two units of candles. As expected, the most efficient heat sources was stove since it only took less than 30 seconds to 'ON' while the candle needs 3 minutes and 50 second.

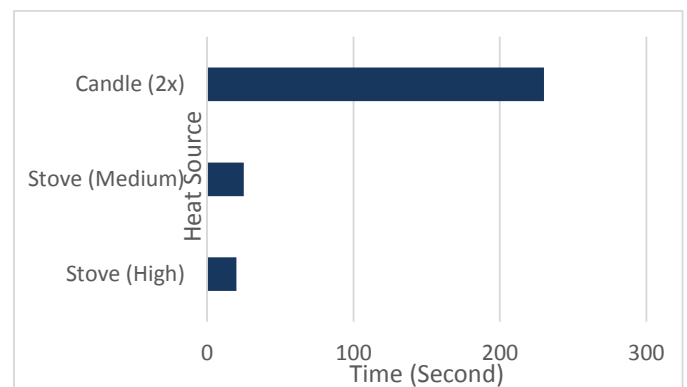


Figure 15 : Time Taken to 'ON' the System





Figure 16 : Charging Smartphone by Using TEG Power Generation Device

#### IV. CONCLUSION & FUTURE RECOMMENDATION

As a conclusion, the initial objective for this project has been achieved. The possibility of power generation device by using thermoelectric was successfully studied. Although the power output is quite low, the device is able to generate as high as 5.6V output. This is quite an achievement. However, the reliability of the system depends on the application. Since the device is only able to charge smartphone at 0.1W, it is not very efficient to charge smartphone. Smartphone should charge at a much higher rate, or at least 0.5W. Lastly, a small and portable power generation device is successfully designed. It can generate voltage of up to 5.6V and has 70% of efficiency. For future recommendation, two unit of thermoelectric module can be use and connected in series to get a higher output power.

#### V. ACKNOWLEDGEMENT

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#### REFERENCES

- [1] C. a. Gould, N. Y. a. Shammass, S. Grainger, and I. Taylor, "Thermoelectric technology: Micro-electrical and power generation properties," *2008 43rd Int. Univ. Power Eng. Conf.*, no. Miel, pp. 11–14, 2008.
- [2] N. Auparay, "Room Temperature Seebeck Coefficient Measurement of Metals and Semiconductors," 2013.
- [3] C. A. Gould, N. Y. A. Shammass, S. Grainger, and I. Taylor, "A Comprehensive Review of Thermoelectric Technology , Micro-electrical and Power Generation Properties," no. Miel, pp. 11–14, 2008.
- [4] C. A. Gould, N. Y. A. Shammass, S. Grainger, and I. Taylor, "Thermoelectric Power Generation : Properties , Application and novel TCAD Simulation Keywords Thermoelectric technology," 1960.
- [5] G. Min, "Design theory of thermoelectric modules for electrical power generation," pp. 351–356.
- [6] C. Bobean and V. Pavel, "The study and modeling of a thermoelectric generator module," *2013 8Th Int. Symp. Adv. Top. Electr. Eng.*, pp. 1–4, May 2013.
- [7] A. Lay-ekuakille, G. Vendramin, A. Trotta, G. Mazzotta, P. Bari, V. Orabona, P. Bari, and V. Orabona, "Thermoelectric Generator Design Based on Power from Body Heat for Biomedical Autonomous Devices," pp. 6–9, 2009.
- [8] H. Mamur and R. Ahiska, "Design and implementation of a new portable thermoelectric generator for low geothermal temperatures," *IET Renew. Power Gener.*, vol. 7, no. 6, pp. 700–706, Nov. 2013.
- [9] "Thermoelectric USB charger - off grid electricity." [Online]. Available: <http://www.instructables.com/id/Thermoelectric-USB-charger/?ALLSTEPS>.
- [10] E. S. Study and T. G. Systems, "Industrial Waste Heat Recovery," no. November, 2006.
- [11] T. M. Tritt and M. A. Subramanian, "Thermoelectric Materials , Phenomena , and Applications : A Bird ' s Eye View," vol. 31, no. March, 2006.
- [12] Joohanson, "Adjustable Voltage Step-up (0.7-5.5V to 2.7-5.5V)." [Online]. Available: <http://www.instructables.com/id/Adjustable-Voltage-Step-up-07-55V-to-27-55V/?ALLSTEPS>. [Accessed: 25-Oct-2013].
- [13] T. Max, M. A. X. Cpa, and T. Range, "Step-Up DC-DC Converters," pp. 1–9.
- [14] C. Lu, S. P. Park, V. Raghunathan, and K. Roy, "Analysis and Design of Ultra Low Power Thermoelectric Energy Harvesting Systems," pp. 183–188, 2010.