Development and Comparison between Charge Pump Circuit and LTC 3108 Circuit for Thermal Energy Harvester

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***Abstract*— Power conditioning circuit is a very important role for any energy harvester. Therefore, choosing a suitable power conditioning circuit is an important process also. In this paper, two power conditioning circuits which are Charge pump circuit and LTC 3108 circuit are designed and compared. At the same time, the TEG is used as input energy for the circuits. From the input of TEG which is 1.18V, Charge pump need 6 minutes to boost the circuit to 4.06V. However, the LTC 3108 circuit only need 10 seconds to boost up the voltage to 4.92V. Then, decade resistance box is connected to the circuits. Regarding the power output, the power output of both circuits is about the same. However, the matching load of the LTC 3108 circuit is 20kΩ but the matching load for the Charge pump is 50Ω only.**

***Index Terms*—Thermoelectric Generator; DC to DC converter; Charge pump; Multivibrator; LTC3108**

I. INTRODUCTION

Nowadays, the energy harvester becomes more popular. Thermoelectric generator (TEG) is one of the harvesters to harvest electrical energy from heat energy. However, TEG is not being used widely because of its efficiency. TEG has around 5-7% efficiency only[1]. Therefore, power conditioning circuit is very popular used to boost up the voltage of TEG[2-4]. There are many types of power conditioning circuit which are charge pump, a boost converter, dc-dc converter and so on.

In this paper, two power conditioning circuits are designed and compared to a term of charging time, voltage output, current output and power output. The power conditioning circuits are discussed in this paper are Charge pump circuit and LTC 3108 circuit. Besides, the input of the power conditioning circuit is from the TEG.

Some of the previous works are related to both of these circuit [2-5]. C.C.Law and et al [2] were proposed using a 4-stage charge pump to boost up the voltage from the TEG. From the human temperature, they able to obtain 3.7°C temperature gradient. Besides, the TEG voltage output is about 4.5mV. Therefore, they did the simulation of charge pump circuit by using the 4.5mV as input. In the paper, the simulation result shows the charge pump success boost the voltage from 4.5mV to 3V.

Besides, Abdulqader.M and et al [3] suggest charge pump boost up the voltage from 0.6v to 1v with the 2mA output current. Additionally, they suggest using the oscillator which can produce pulse without using any external energy.

In addition, Juan M.L and et al [4] discovered off-the-shell integrated circuit (IC) can boost up the voltage as low as 20mV. In this paper, LTC 3108 is used to boost up the voltage input. The input voltage for the LTC 3108 circuit is 27mV. From the result is stated the current of the circuit was 0.7mA when the 30°C temperature gradient applied to TEG.

After the Part I introduction, Theory will be ready in part II. Next, Part III is the experimental set-up for this paper. Then, the result will be discussed in Part IV. Lastly, the conclusion comes at the end of the paper.

II. THEORY

A. *Thermoelectric Generator (TEG)*

Thermoelectric generator (TEG) is a harvester that using heat energy as source and convert it into electrical energy. The thermoelectric generator is using Seebeck effect for the conversion. This effect was named by Thomas Seebeck in 1821. The voltage output of the generator is based on the temperature gradient applied to two dissimilar metal or semiconductor used. At first, this Seebeck is being used as measurement instrumentation which thermocouple to measure the temperature by converting the voltage signal input. However, these dissimilar metals can be replaced by semiconductor because semiconductor has higher Seebeck coefficients. Therefore, it can produce more voltage output compares to dissimilar metal [5,6].

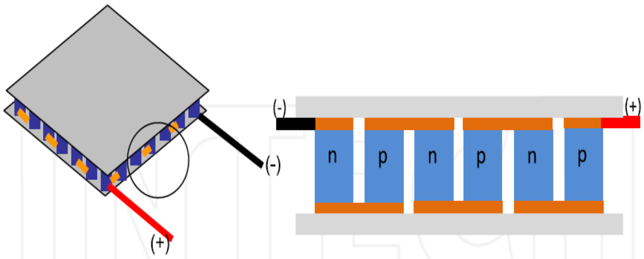

Figure1. Thermoelectric module [6].

Figure 1 shows the schematic diagram of TE module. TE module combines pairs of the thermocouple, one pair of P-N junction consider as one thermocouple. The thermocouple connected electrically in series and thermally in parallel. Besides, the top and bottom of the module are covered with a ceramic plate. Since the ceramic plate good in conducting heat and resistive of electricity [6].

When heat is applied on one of the ceramic surface and heat is dissipated at another ceramic surface, TE module will generate a voltage output. In addition, the Seebeck coefficient, α, is defined as the change in voltage per degree of temperature gradient [5,7]:

$$\alpha = \frac{dV}{dT} \text{ volts/K} \tag{1}$$

Seebeck coefficient also includes voltage V_s produced from a TE module while it is applied temperature gradient which is T_h as hot temperature and T_c as cold temperature [6]:

$$V_s = \alpha (T_h - T_c) \tag{2}$$

The power generated by TE module can be calculated using following formula [8,9]:

$$P_o = I_o^{\,2} \times R_L \tag{3}$$

where P_o is the power generated by the TE module, Io is the current generated and R_L is the load resistor that applied to the closed circuit.

B. Charge Pump

The electronic circuit to step up the voltage input to several times higher and it is called DC to DC converter. The charge pump is a DC to DC converter. [10]. The idea of the charge pump came from the Cockcroft-Walton voltage multipliers for alternative current (AC). After that, this concept is applied to direct current (DC) voltage application as Dickson charge pump[2].

The operation of AC and DC charge pump is typically the same. In AC charge pump, the positive cycle of the sine wave is used to charge the capacitor. Meanwhile, the negative cycle of the sine wave is used to discharge the capacitor. For the DC charge pump, clock signal replaces the oscillation signal (sine wave). In addition, the output voltage depends on a number of stages used in the charge pump [2].

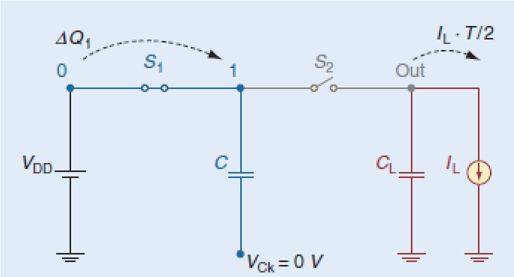

Figure 2. Illustration of charge pump [10]

Figure 2 shows the illustration of the charge pump, there are two switches, S_1 and S_2, a clock pulse which same with V_{DD}, current load I_L, and a bulk capacitor C_L [10].

While the first half period S_1 is closed and S_2 is opened, capacitor, C is charged from the voltage V_{DD} and C_L is discharged by the current load, I_L. Both switches change their state in the second half period, V_{ck} now is equal to V_{DD} so the C is charging to C_L.

C. Multivibrator

An oscillator can generate a different output signal within one period. The oscillator circuit is called the sinusoidal circuit is the output signal that varies sinusoidally. Usually, the output oscillator refers to the pulse wave or square wave [11].

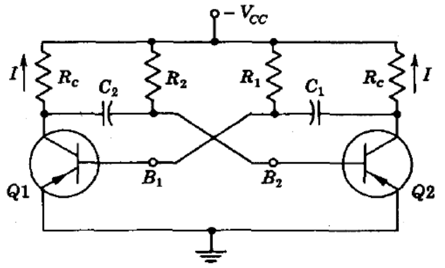

Figure 3.The collector-coupled astable Multivibrator[4]

Figure 3 shows that a free-running collector-coupled Multivibrator with PNP transistor. A stable Multivibrator can supply periodic transition between states because it consists of two quasi-stable states. Transistor of the Multivibrator can remain constantly cut off because capacitive coupling is used for both states [5].

The period of each state of multivibrator can be calculated by using the formula below:

$$T = t_1 + t_2 = 0.69(R_1C_1 + R_2C_2) \tag{4}$$

where R is in Ω and C is in Farads.

If the values of both resistors are equal and values of both capacitors are equal also, multivibrator cycle is given symmetrical output waveform.

$$R = R_1 = R_2;\ C = C_1 = C_2$$

$$T = 1.38RC \tag{5}$$

where R is in Ω and C is in Farads[12].

D. LTC 3108[13]

LTC 3108 is the IC from Linear Technology and manage to surplus the energy as low as the voltage input is 20mV. By using a transformer, it can amplify the low input voltage and rectify by using the capacitor. The controller logic circuit is implemented in the IC, so the output voltage can be controlled.

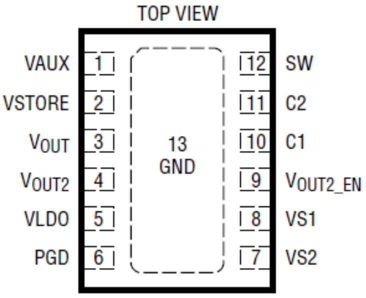

Figure 4. Pin configuration

Figure 4 shows the schematic diagram of IC LTC 3108. By using the different method to connect VS1, VS2, GND and VAUX can obtain the different voltage output. The regulated voltage using Pins VS1 and VS2 as shown in Table 1:

Table 1
Regulated Voltage Using Pins VS1 and VS2

VS2	VS1	V_{OUT}
GND	GND	2.35V
GND	VAUX	3.3V
VAUX	GND	4.1V
VAUX	VAUX	5V

Besides, the supercapacitor or rechargeable battery is suggested to connect to the pin VSTORE. Therefore, the capacitor can start to be charged once the VOUT has reached to regulation.

III. EXPERIMENTAL SET-UP

From this paper, only one TEG module is used as electrical input for both circuits. The serial number of TEG is TEG1-450-0.8-1.0 and the dimension of the TEG is shown in Table 2:

Table 2
The dimension of the TEG

Dimension	Value (mm)
Width	54
Length	57
Thickness	4

Figure 5 shows the lab set up for the characterization. Firstly, the TEG is characterized by using a heater as a heat source and using a heat sink to dissipate the heat from it. The heater is the same size as the TEG and the heat sink is in 19cm diameter with 9cm height. Then, the open circuit voltage output from TEG is measured with different of temperature gradient applied to it. Next, a temperature gradient is applied to the TEG is fixed as 10°C and the decade resistance box is connected to the TEG. Then, the voltage and current from TEG are measured. Therefore, the power load of TEG can be calculated by using equation (3). After that, two graphs will be plotted from this characterization part which is open circuit voltage output from TEG with a different temperature gradient and power output from TEG with variance resistance

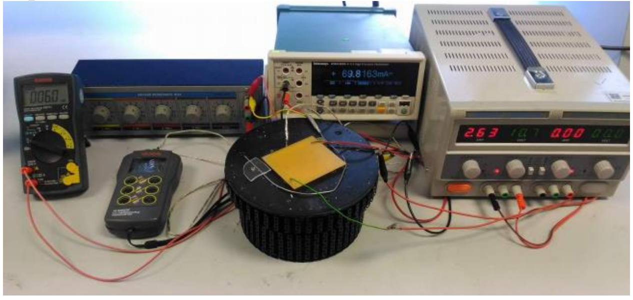

Figure 5. Set up to characterize the TEG

Figure 6 and Figure 7 show the Charge pump circuit that will be used in this paper. From the previous paper [14], the charge pump circuit is developed. In that paper, a variant of design is discussed and the optimized charge pump circuit is chosen. Besides, Multivibrator is also designed to convert DC input to PWM clock pulse. The frequency of the PWM pulse is 1.375Hz and the 3 stage of the Charge pump is used. Shockley diode is used to lessen the voltage drop while the TEG is charging up the capacitor. The operation voltage of Charge pump is 1v.

Figure 8 and Figure 9 show the circuit of LTC 3108. The transformer with a ratio of 1:100 is used to amplify the voltage input as low as 20mV. Besides, the output of the of the LTC 3108 can be controlled by the logic circuit in the IC. Therefore, the output voltage of the LTC 3108 is set as 5V. After fabrication, both of the circuits will connect with TEG to compare the functionality.

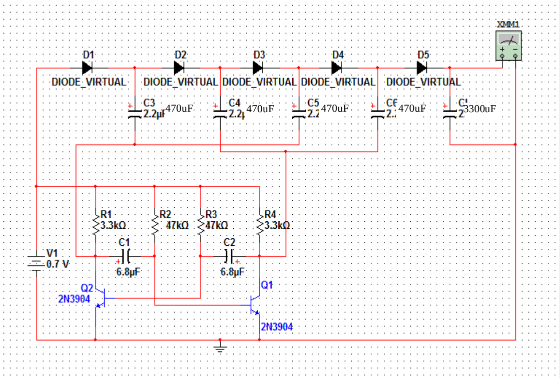

Figure 6. Schematic diagram of Charge pump circuit

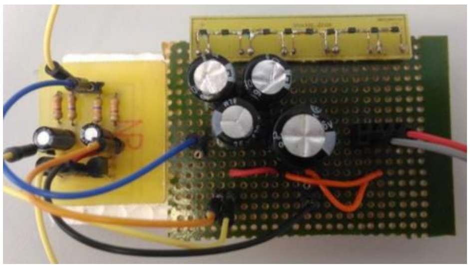

Figure 7. Fabricated Charge Pump Circuit

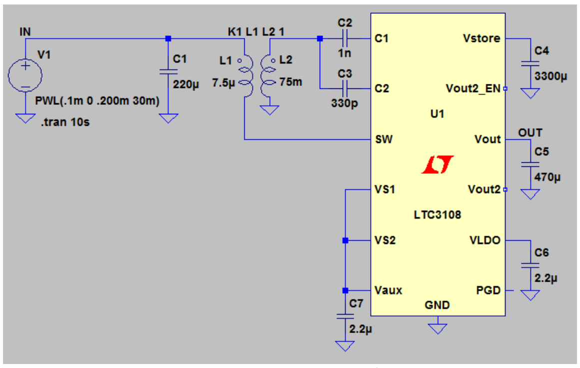

Figure 8. Schematic diagram of LTC 3108

Figure 9. Fabricated LTC 3108 Circuit

Figure 10 and Figure 11 show the experimental set up for Charge pump and LTC 3108 circuit. As shown in the figure, the TEG is being heated by the heater and thermometer is measured the temperature gradient of the TEG. The temperature gradient of TEG remains the same for both circuits. Next, the open circuit voltage output of circuits is measured every 10 seconds to monitor the charging time needed. After that, the decade resistance box is connected to the circuits and measure the output voltage and current. Lastly, all the measurement are plotted on the graph. From the graph will compare the functionality of the circuit

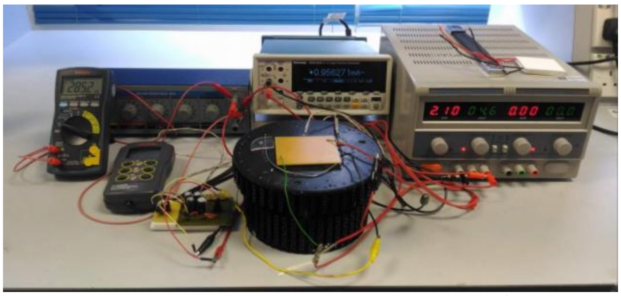

Figure 10. Using Charge pump to boost up the voltage from TEG

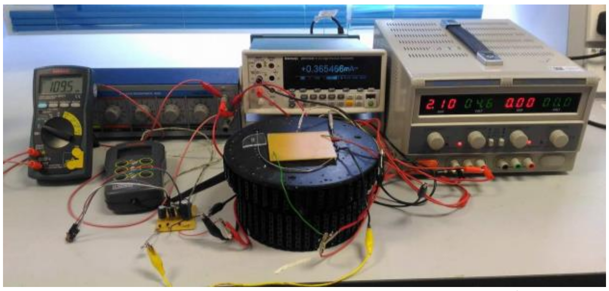

Figure 11. Using LTC 3108 circuit to boost up the voltage from TEG

IV. EXPERIMENTAL RESULT AND DISCUSSION

Figure 12 shows the open circuit voltage output of TEG with different temperature gradient applied to it. The voltage output is directly proportional to the temperature gradient. From the figure, it showed the output voltage per degree Celsius of the TEG is 0.120v/°C.

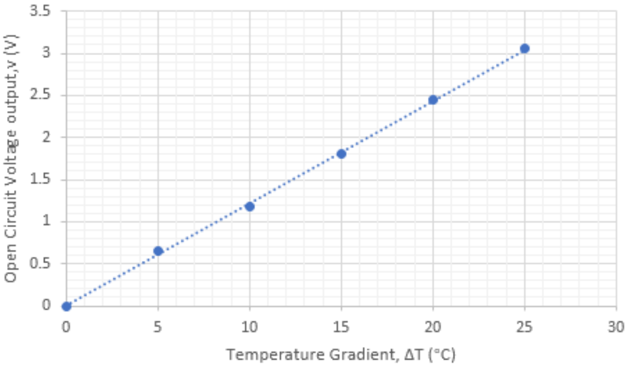

Figure 12. Open circuit voltage output from TEG with variance temperature gradient

Figure 13 shows the power output of TEG, and it is calculated by using equation (3). Two different temperature gradients are used on TEG which is 10°C and 20°C. The matching load of TEG is 30Ω for 10°C and 20°C temperature gradient is applied on TEG. The matching power for TEG is 0.0197W when the temperature gradient is 10°C. Additionally, the matching power is 0.0518W when the temperature is increased to 20°C.

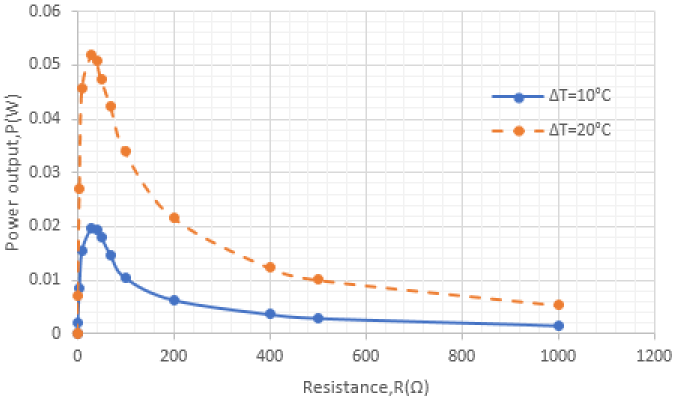

Figure 13. Power output of TEG with variance resistance

Figure 14 shows the charging time for charge pump and LTC 3108 circuit. The temperature gradient of TEG is set as 10°C, because the voltage from TEG is 1.18v. It is beyond the operation voltage for both circuits. The duration of the measuring is 6 minutes, the reading is taken every 10 seconds. For the LTC 3108 circuit, the voltage reached to 4.92v in seconds. But, the charge pump takes time to charge. The voltage output of charge pump for 10 seconds charging time is 0.9v only.

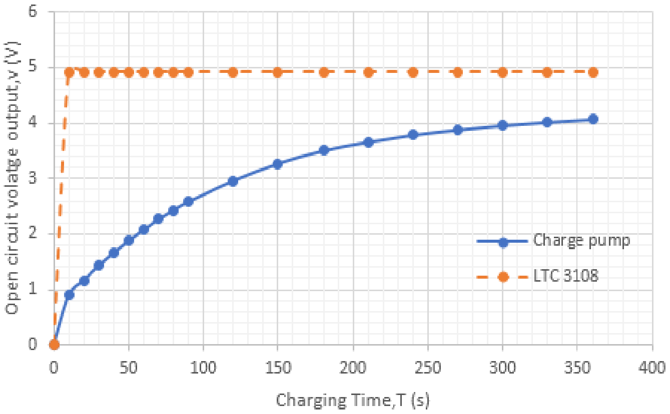

Figure 14. Charging time for both different circuits

Figure 15 shows the voltage output of LTC 3108 is directly proportional to the resistance, while the voltage output of charge pump is saturated. When the resistance is set as 5000Ω, the voltage of LTC 3108 is 2.005v. At the same time, the voltage of Charge pump is 0.744v. LTC 3108 circuit is more efficient to boost up the voltage from TEG.

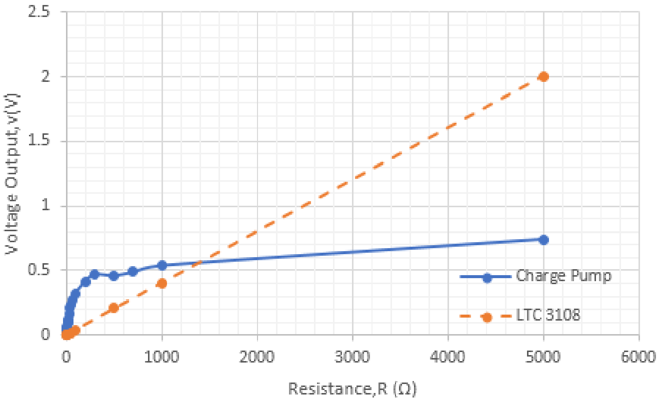

Figure 15. Voltage output from both different circuit with variance resistance

Figure 16 shows the current output of Charge pump is higher than current output of LTC 3108, when the resistance is between 0Ω to 1000Ω. In addition, the current of the Charge pump is decreasing dramatically. However, the current of LTC 3108 is more stable when the resistance is between 0Ω to 5000Ω. When the circuit is shorted and resistance is near to 0Ω, the current of the Charge pump and LTC 3108 circuit are 0.0095A and 0.00042A respectively. Moreover, the current of the Charge pump and LTC 3108 are 0.152mA and 0.409mA respectively when the resistance is 5000Ω. Therefore, the current output of the LTC 3108 circuit is more stable than the current output of the Charge pump circuit.

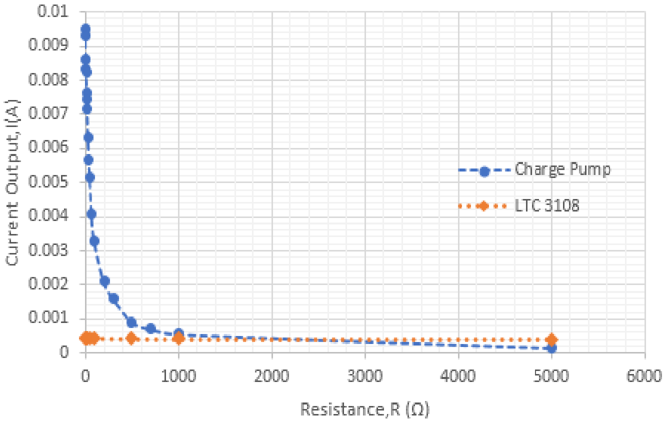

Figure 16. Current output from both different circuit with variance resistance

Figure 17 shows the maximum power output of Charge pump is a bit higher than LTC 3108 circuit. The power output of Charge pump is 1.321mW and the power output of LTC 3108 circuit is 1.24mW. However, the matching load of the LTC 3108 circuit is bigger than the Charge pump circuit which is 20kΩ and 50Ω respectively. Therefore, LTC 3108 circuit can handle higher resistance load.

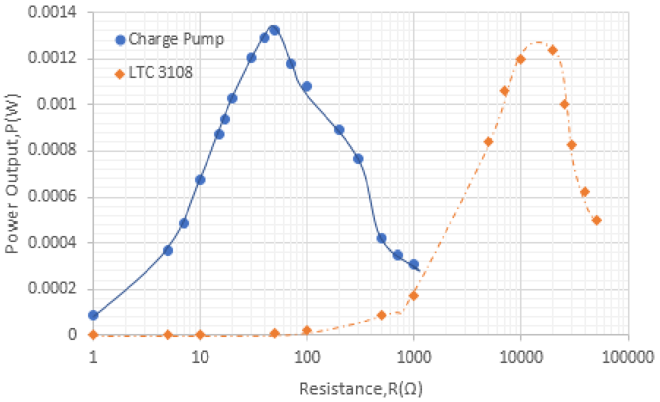

Figure 17. Power output from both different circuit with variance resistance

V. CONCLUSION

From the experimental result, it shows the output of LTC 3108 circuit is higher than Charge pump. Firstly, the charging time for LTC 3108 is shorter than the Charge pump. Next, the voltage and current output are more stable compared to Charge pump circuit. Lastly, the matching load of the LTC 3108 is bigger than Charge pump circuit. The power of Charge pump is 1.321mW but the matching load is 50Ω. Thus, it cannot handle the bigger load. Besides, the power output of LTC 3108 circuit is 1.24mW and the matching load is 20kΩ. Therefore, LTC 3108 is more stable than Charge pump circuit.

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