Implementation of Thermoelectric Generator Module and solar cells as External Energy Source to ZIgbee Tag

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
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(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

____

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Project Supervisor

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May 2014

CERTIFICATION OF ORIGINALITY

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

Ahmed Adel Elsharkawy
Your Full Name

ABSTRACT

Nowadays, wireless technology has emerged in every field of life, just as industrial field, agriculture field and countless of important applications especially the health care products, one of the IEEE protocols which used in health care application is the Zigbee standards because it has the ability to transmit data for long distance with low-power consumption, that’s why here Zigbee will be used to transmit the data of the patient (temperature and hear rate). To power up the Zigbee circuit a lithium battery will be used to power up the circuit and it will be recharged through USB in addition Thermo-electric Generator (TEG) which uses the change in temperature between the room temperature and the body heat to produce electricity which will be used directly to power up the circuit . Since the output voltage of the TEG has 2 problems:

1- Not stable
2- Not enough to power up the circuit

That’s why the output voltage will go through 2 stages the first one voltage stabilizer then voltage booster to boost the voltage. The TEG output is not enough at all to power up the circuit that is a solar cells will be used as a secondary power source to power up the circuit.

ACKNOWLEDGEMENTS

In the opportunity of writing this report, I would like to express my gratitude to all those who helped me to successfully complete my final year project, starting and ending with my Lord, Allah, who granted me the opportunity to join such a good university UTP.

Moreover, I would like to thank my family, which supported me during my final year project period and never burdened me with any loads although I've been far away from their side for almost one year. I would like also to thank my friends and colleagues in my university (UTP) specially my Egyptian country-mates who have been very supportive and encouraging.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TEG …………………………………………………… Thermo Electric Generator

DC………………………………………………………. Direct current

Chapter 1
Introduction

This Chapter will explain about the background of study, the scope of study and the objectives of the project which mainly will be about the Zigbee tag and how to provide enough electrical power to power up the tag by using Thermoelectric generator (TEG).

1.1 Background of Study

The wireless technology has emerged through time proportionally with its application in industries. The healthcare industry is one of them. Before this a power consumed wireless based devices were used, but they were not efficient as they consume so much power. So in this project a tag which uses Zigbee standards is being used as it can work on low power and can transmit data for long distances.

This power source provides disadvantage in terms of lifetime, non – rechargeable and higher cost in longer run. Thus, with also current emerging technology of TEG, it is seen that it will be useful to be implemented to the monitoring device as TEG's basic idea is to produce electricity from the temperature differences between the hot and the cold plates , these temperature difference can produce electricity and the larger the difference the larger the electricity produced.

1.2 Problem Statement

Current power source implemented with transceivers has limitations in terms of:

- High degradation of battery due to sensors that consume high power
- Low transmission range coverage due to low battery source
- Interruption of data collection due to battery drainage
- High maintenance cost as repeatedly replacement of battery
- Current designed device unable to produce sufficient voltage and current to supply the tag

1.3 Objectives

Objectives as following:

- To redesign the current designed recharging circuit with proposed circuitry to provide sufficient voltage and current
- To design a power source to be integrate with self – charging circuit for the battery
- To enable integration with wireless transponder and become self – charging wireless transponder

1.4 Scope of study

The first scope of the project is about the communication engineering which will cover the tag that uses the Zigbee standards to transmit the data. The second scope of the project is Energy and power system and how to produce enough electrical power to power up the tag. The final scope of the project is the power electronics part how to boost the voltage to meet the minimum requirements of the TAG.

Chapter 2
Literature review

2.1 Zigbee

It is a protocol the engineers try to use simple organisms that will join together to solve a complicated problem with low power consumption and long distance transmitting. [1]

There are two different types of networks Peer to peer topology and star topology as shown in figure 1.

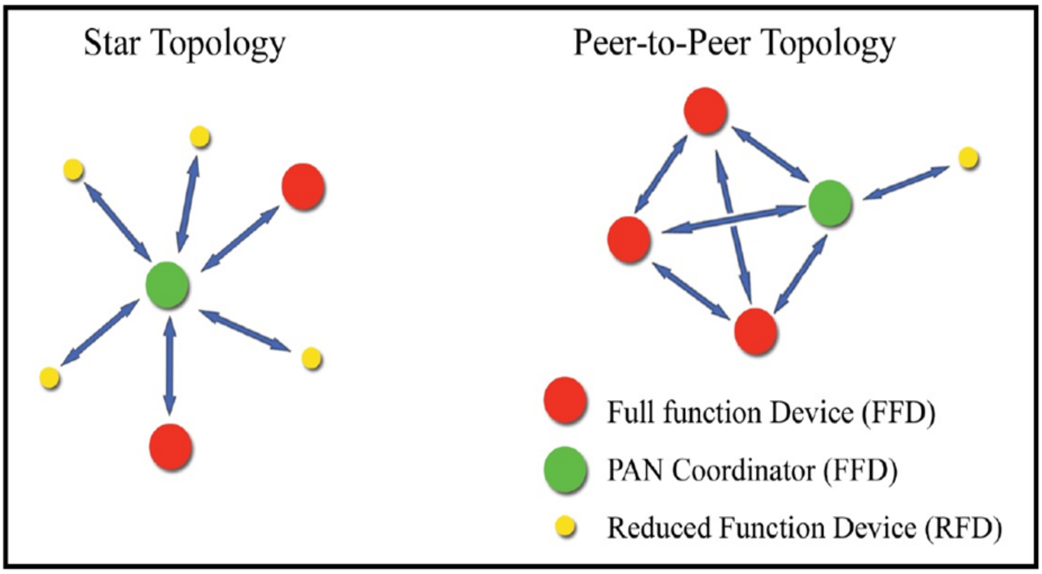

Figure 1 Network Topologies

There are so many different applications of Zigbee wireless networks such as:

- Home flexibility: To make life inside home more simple and less complex by adding wireless technologies to the basic home appliances.
- Industrial flexibility: To help the industries to be less complex and to speed up the plant process control.

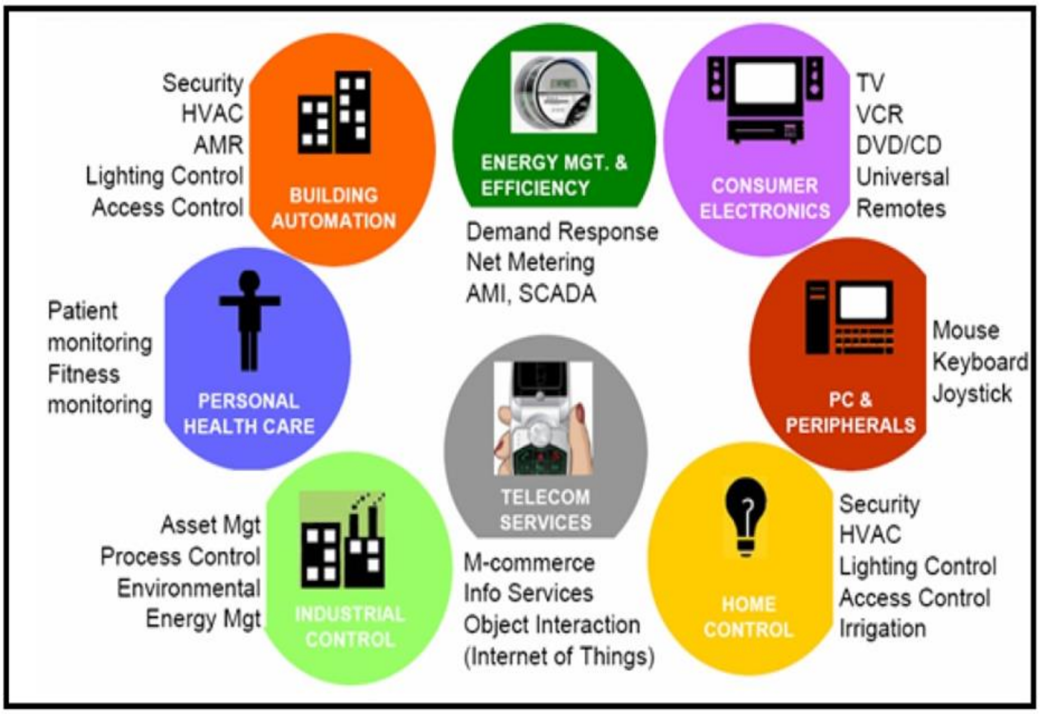

Figure 2 ZIgbee applications

- Energy management and efficiency: To produce the power consumptions and to transmit the data over long distances and to reduce the environmental pollution by providing smart and reliable way of transmitting data.[2]

2.2 Thermoelectric generator (TEG)

The human body consider as a good source for producing electricity, as known that the human body gain and lost heat during the normal operation day , this heat can be used to produce electricity may be this electricity can be used to power in the different health applications.[3]

The human body produces energy as heat but it has limits according to Carnot efficiency, if a normal body heat is assumed and low room temperature also assumed [4]:

$$\frac{T_{body} - T_{ambient}}{T_{body}} = \frac{310 - 293}{293} = 5.5\%$$

In a much wormer environment the Carnot efficiency will drop to:

$$\frac{T_{body} - T_{ambient}}{T_{body}} = \frac{310 - 300}{293} = 3.2\%$$

Activity	*Kilocal/hr*	*Watts*
sleeping	70	81
lying quietly	80	93
sitting	100	116
standing at ease	110	128
conversation	110	128
eating meal	110	128
strolling	140	163
driving car	140	163
playing violin or piano	140	163
housekeeping	150	175
carpentry	230	268
hiking, 4 mph	350	407
swimming	500	582
mountain climbing	600	698
long distance run	900	1,048
sprinting	1,400	1,630

Figure 3 Human energy for certain activities

There are some solutions to produce electricity from the human body heat such as the thermoelectric generator (TEG). TEG produce electricity from the difference in the temperature between the hot and the cold plates, it is not like the traditional generators which use moving parts to produce electricity. TEG is not efficient on the large scale but very efficient on small scale because it is small, simple and not expensive. [4]

TEG depends on a two effects to produce electricity from heat the first effect called Seebeck effect [5],the basic idea of this effect is that heating one side of a wire made of two different materials will produce electricity.

$$V_{AB=(\alpha_A-\alpha_B)*\Delta T}$$

Where α_A, α_Btwo different materials with different Seebeck constants

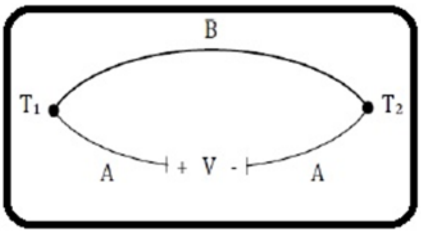

Figure 4 Seebeck effect

The second effect called the Peltier effect, it is a consequence of Seebeck effect, and the heat will transfer from the hot body to the cold body:

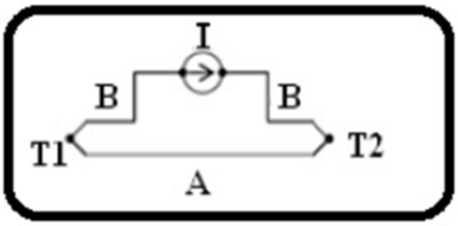

Figure 5 The Peltier effect

A group of researchers in United States of America has came up with a brilliant design to use the TEG as a power source by using the body heat and changed to electricity as they used MEMS TEG and added to the top of wrist watch as shown in figure 6, the prototype produced almost 100 uW which is enough to charge a battery. [6]

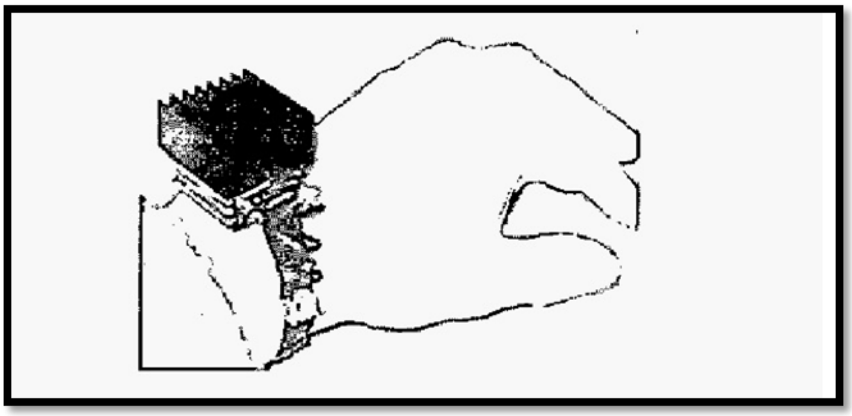

Figure 6 TEG supplied by wrist band

Another researchers designed a suitable DC-DC converter to boost the small voltage coming out from the TEG they did not use any switches in the converter then the switches will consume power instead they used a Reed switch based DC-DC converter as shown in figure 7, which work on magnetic field [7].

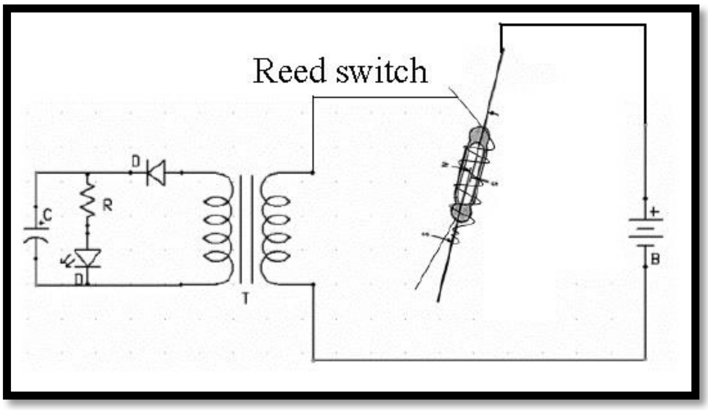

Figure 7 Reed switch based DC-DC converter

Group of researchers fabricated their own TEG by using polydimethylsiloxane (PDMS) and thermoelectric components as shown in figure 8. The PDMS is very flexible which will help the TEG to be placed over the body. [8]

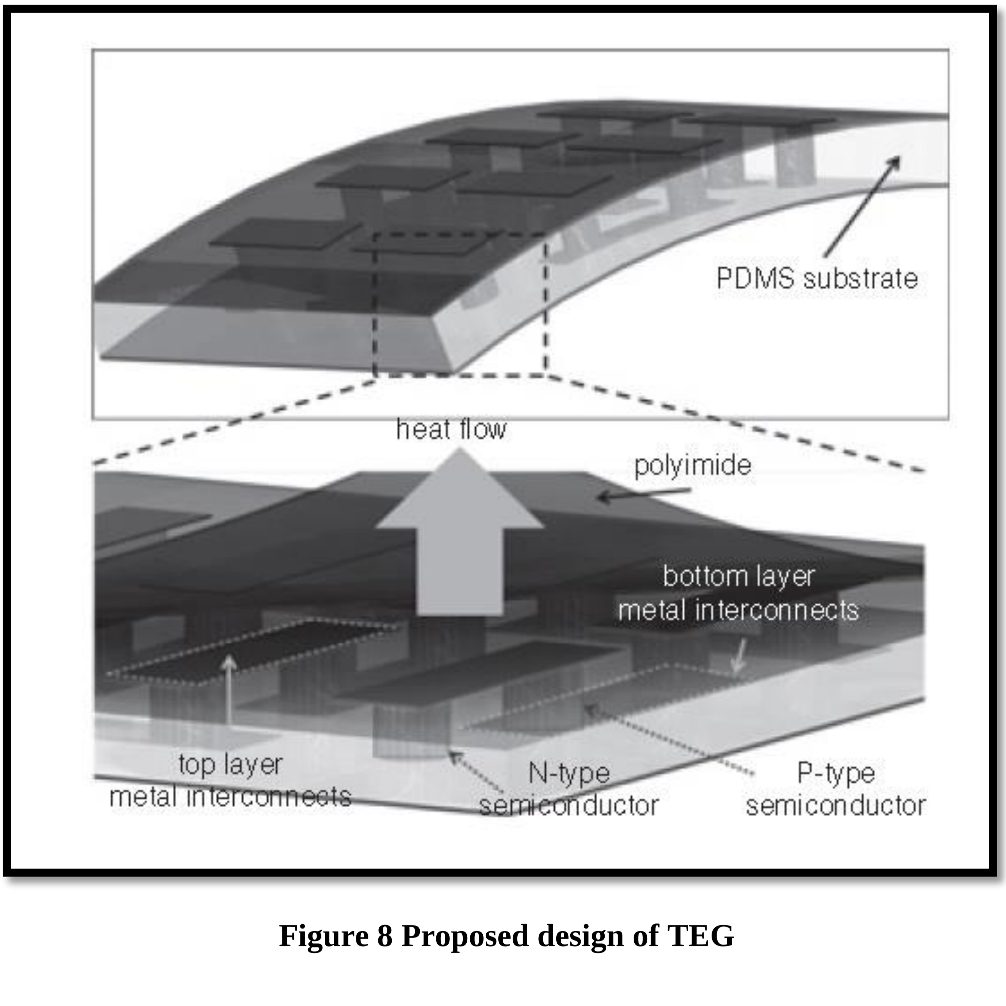

Figure 8 Proposed design of TEG

2.3 Solar Cells

Due to the output is not enough from the TEG so Solar cells will be used under the room light to produce voltage, the solar cells' type which being used here is thin film silicon, It is a type of solar cells where one more layer can be added of photovoltaic to form a solar cells and these solar cells can be setup to form a solar array. According to a research paper the researchers tried to use solar cells to charge a mobile phone battery they found that the solar cells can produce energy equal to $1/10\ to\ 1/5$ of the ordinary cell phone battery they found the solar cells under the indoor conditions can support the mobile phone charger.[9]

Another team of researchers has investigated the thin film solar cells under low radiation source they found that an efficiency of 17.5% and the results are shown in table 1. [10]

a-Si solar cell				
Condition	Desk Light	LED Light	Windowsill	Fluorescent Lamp
Voc (V)	0.765	0.781	0.795	0.743
Jsc (mA/cm^2)	0.189	0.344	0.589	0.082
F.F.	0.724	0.724	0.724	0.724
Eff. (%)	17.11	17.68	13.96	17.51
CIGS solar cell				
Condition	Desk Light	LED Light	Windowsill	Fluorescent Lamp
Voc (V)	0.467	0.479	0.504	0.443
Jsc (mA/cm^2)	0.226	0.373	0.929	0.090
F.F.	0.650	0.650	0.650	0.650
Eff. (%)	11.21	10.55	12.53	10.36
DSSC				
Condition	Desk Light	LED Light	Windowsill	Fluorescent Lamp
Voc (V)	0.661	0.670	0.691	0.639
Jsc (mA/cm^2)	0.176	0.245	0.560	0.076
F.F.	0.680	0.680	0.680	0.680
Eff. (%)	12.92	13.22	10.85	13.10
OPV				
Condition	Desk Light	LED Light	Windowsill	Fluorescent Lamp
Voc (V)	0.519	0.528	0.546	0.498
Jsc (mA/cm^2)	0.138	0.191	0.396	0.060
F.F.	0.630	0.630	0.630	0.630

Table 1 Different solar cells under indoor conditions

Chapter 3
Methodology

3.1 Flow chart of the project

This section will include a flowchart for the project and the steps that will be followed till reach the final step. As at the beginning of this semester few research papers have been well read and covered to complete a whole idea about the TEG and who to implement in the project.

The second step is to design a recharging circuit capable of charging the lithium battery first to design it by using LT Spice software then if it produce the required voltage (3.7 V) the second step is to implement it on a breadboard then transfer it to a printed circuit board (PCB) by using eagle cad software, last step is to solder the components on the PCB.

Third step is to find a suitable Thermo-electric generator (TEG) which will provide a suitable power to power up the circuit. For sure, due to the low temperature difference the voltage will be small so a booster circuit will be designed to boost the voltage to 3.7v.

The final step is to combine the recharging circuit with the TEG with the proposed DC-DC converter circuit all together with the Zigbee circuit. A complete flowchart for the methodology is shown in figure 9.

Since the output of the TEG is not enough to power up the circuit so Solar cells will be used and a booster circuit will be also used.

A Step-up DC/DC converter is a circuit to step up the Dc voltage from one level to another level it depends on the attachment circuit with it mostly depends on the value of the resistors Usually a voltage regulator is fed by a higher input than output voltage, for example 12V as input to 2V as output. This circuit will work as a booster will take a low voltage (as low as 0.7V) and step it up as desirable between 2.7-5.5V. Since it is a regulator, the output voltage will be constant as long as input voltage is lower than output voltage.

The base of this design is the IC “Max757”:

The “MAX757” is “CMOS” step-up DC-DC switching regulators for small, low input voltage or battery-powered systems. 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 MAX757 are greater than 87%. Here are the features of this IC as shown in figure9:

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

Figure 9 Features of the MAX757

And here is the Input voltage vs the output current for the IC as shown in figure 10:

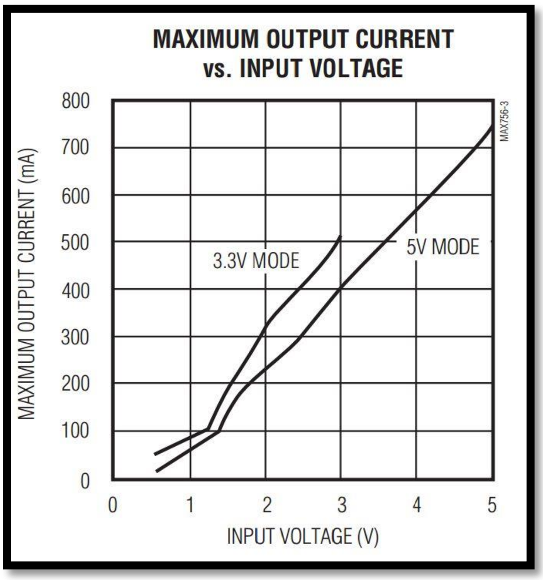

Figure 10 Current Vs. Voltage

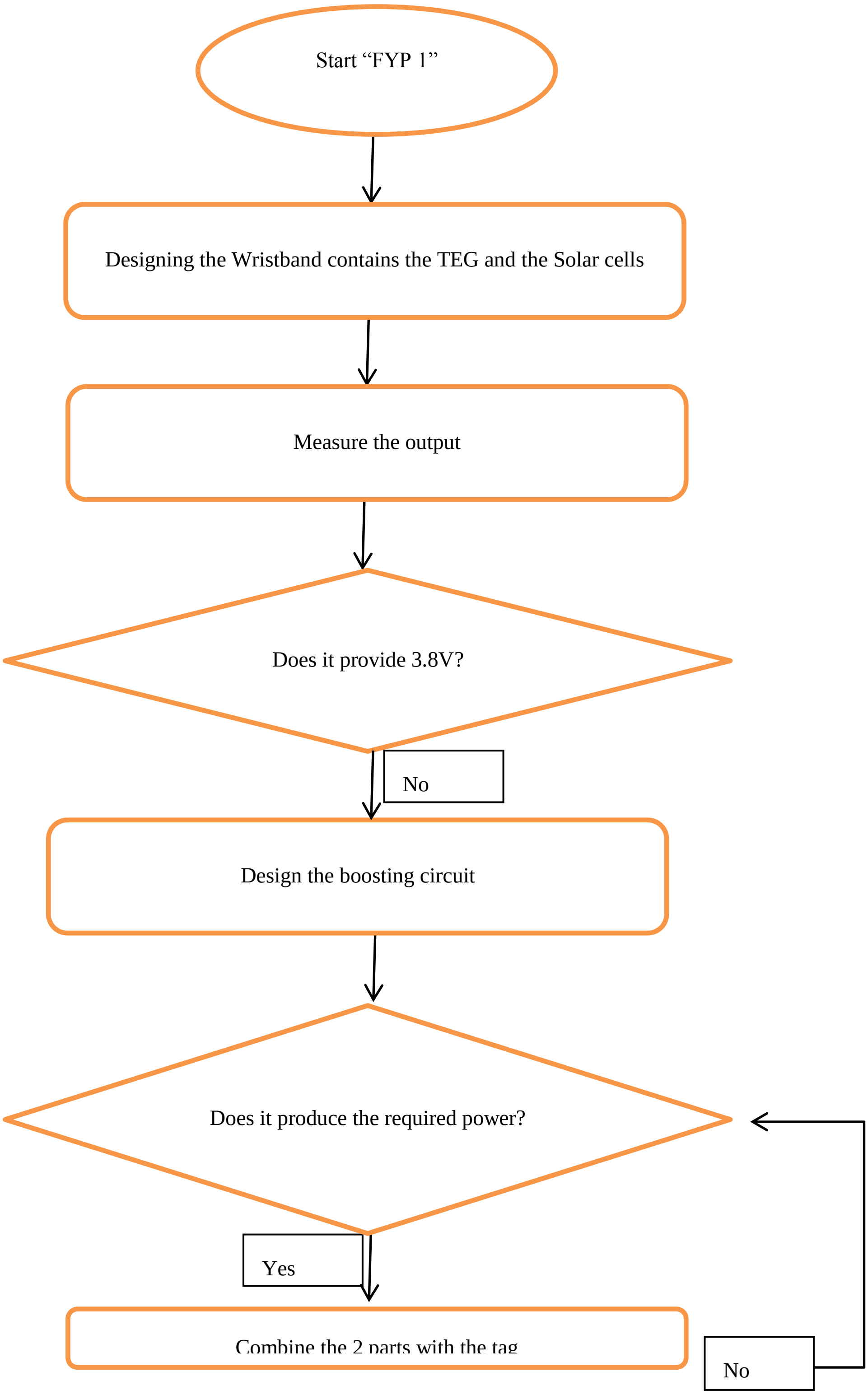

Figure 11 Proposed Flow Chart of FYP Project

3.2 Key milestones and gantt chart

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Designing the wristband and add the TEG on it														
2	Search and test the solar cells		○												
3	Submission of Progress report														
4	Combine the Solar cells with the TEG														
5	Design the Boosting Circuit and getting ready for ELECTREX										○				
6	Test the TEG and the solar cells with the booster circuit														
7	Submission of Final Report Draft													○	
8	Submission of final Report and Technical paper														○

Table 2 Key milestone

Chapter 4

Results and discussion

4.1 Tools

4.1.1 Software

1. T-Spice Simulation software

Where the recharging circuit is designed using this software as shown in figure 10

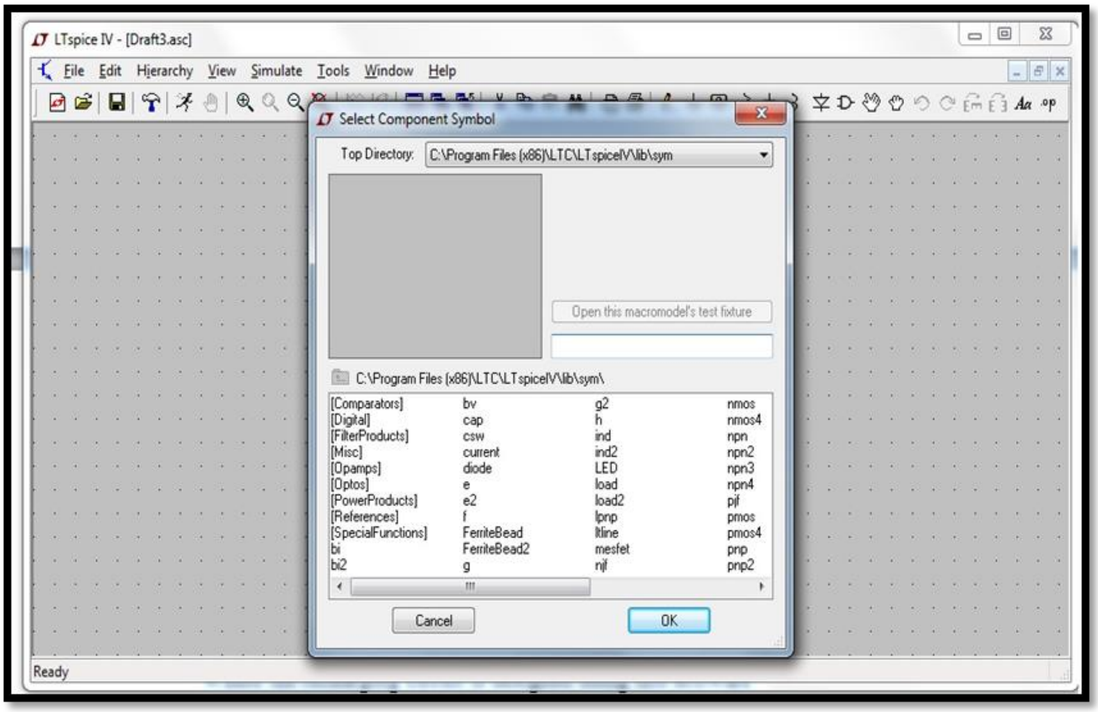

Figure 12 T-spice Software

2. Eagle Cad Software:

   This software is being used to design the printed circuit board which will be used as the recharging circuit, this software consisted of 2 main parts the first one is the schematic part where the circuit is being built as shown in figure 11.

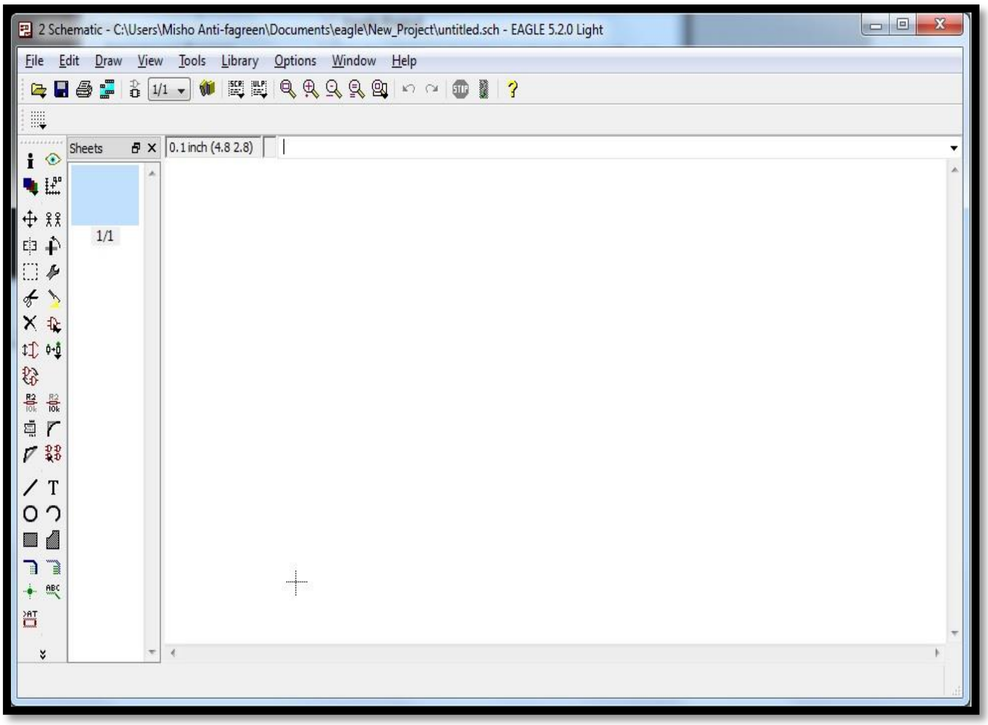

Figure 13 Eagle software schematic

The second part of eagle software is the board section where the schematic is changed automatically to a board as shown in figure 12

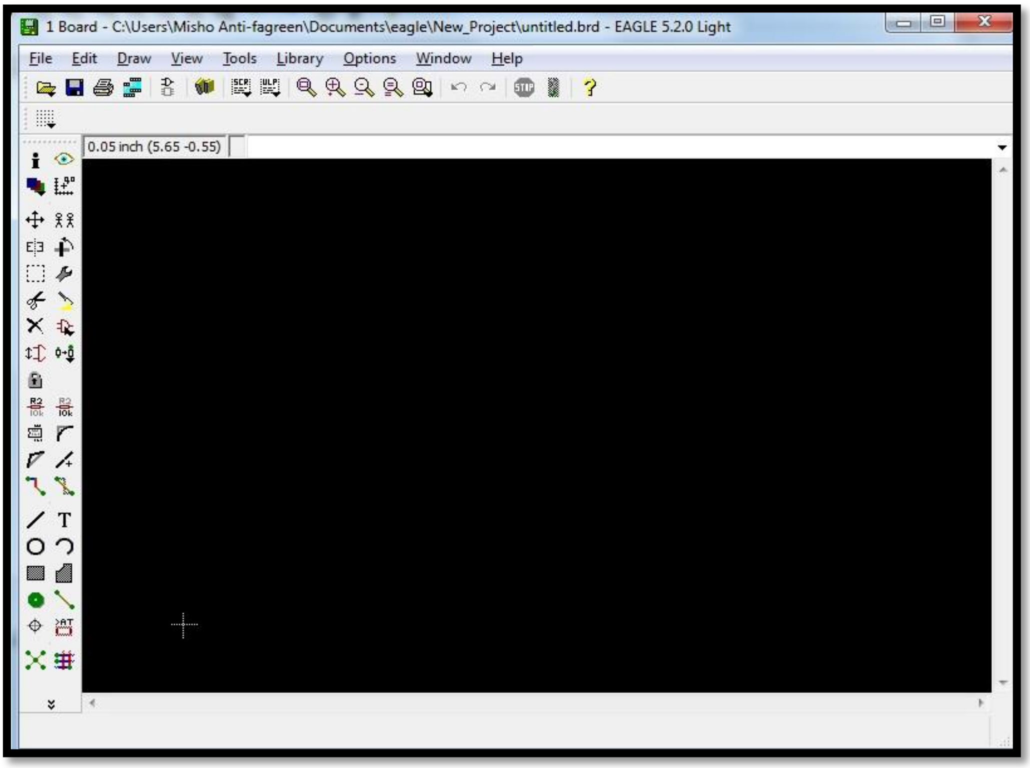

Figure 14 Eagle software board

4.1.1.1 Hardware

- Bread board
- Resistors: 27KΩ, 680ΩX (3), 1MΩ, 2.2kΩX (2), 1KΩX (2), 220Ω
- Capacitors: 110u, 100n
- LEDs: Red, Blue, Green
- Transistor: BD140
- Operational Amplifier: LM358N X 2
- **Thermo-Electric Generator (TEG): TGP-651 as shown in figure 15**

  Characteristic of the TEG:

  1. No need for maintenance
  2. Extended life-time
  3. Compatible with automated placing & reflow production lines
  4. Since the small size if this TEG it can be placed over the human hand
  5. Since the optimization in its mechanical design produces the perfect thermal performance
  6. The maximum temperature is 100 °C Relatively high output voltage

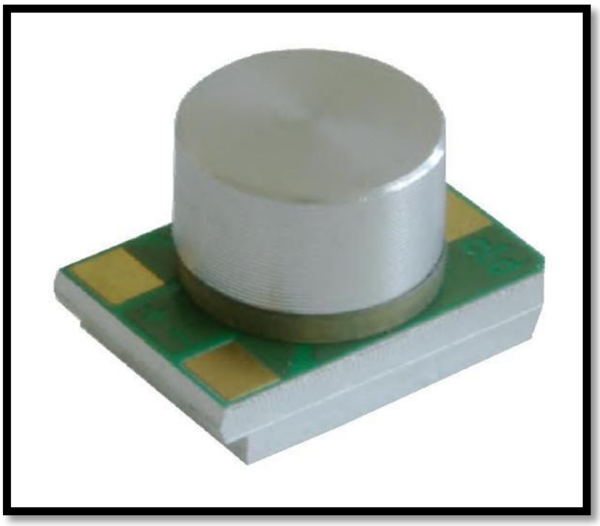

Figure 15 TEG

- **IC “Max757”:**

1. Start-up voltage “Min.” (at “$10mA$ load”): 1.1V
2. Maximum output load (at input voltage= $2V$):
   $200mA\ at\ 5V, 300mA\ at\ 3.3V$
3. Maximum output load (at input voltage= $1V$): $50mA\ at\ 5V, 75mA\ at\ 3.3V$
4. Start-up voltage “Min.” (at300mA load): $1.7V$
5. Input voltage range: -0.3 to $+7V$
6. Output voltage range: 2.7 to $5.5V$
7. Efficiency: Max 87% (the input and the output important here)
8. Minimum operating voltage (at $20mA$ load): $0.7V$

- **Thin film Solar cells:**

1. Voltage under sun light: $3V$
2. Current under sunlight: $50mA$
3. Power produced: $0.15\ W$
4. Size: $55mm\ x\ 50mm\ x\ 2mm$

- **Design of the booster:**

The design is from the Datasheet of the IC “as an application” as shown in figure 16, since there is no multisim for this special IC it has not ant library on the multisim

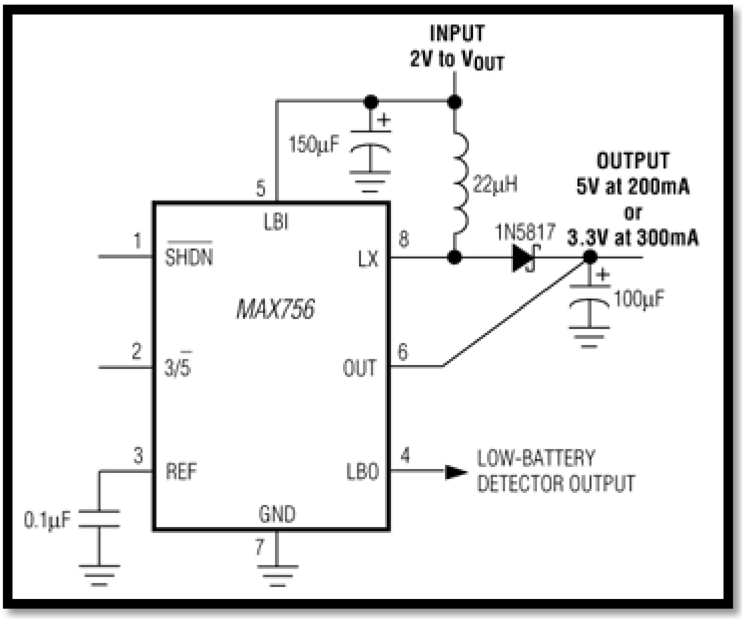

Figure 16 Primary design

Here is a modification on the design to accept low voltage inputs as shown in figure 17:

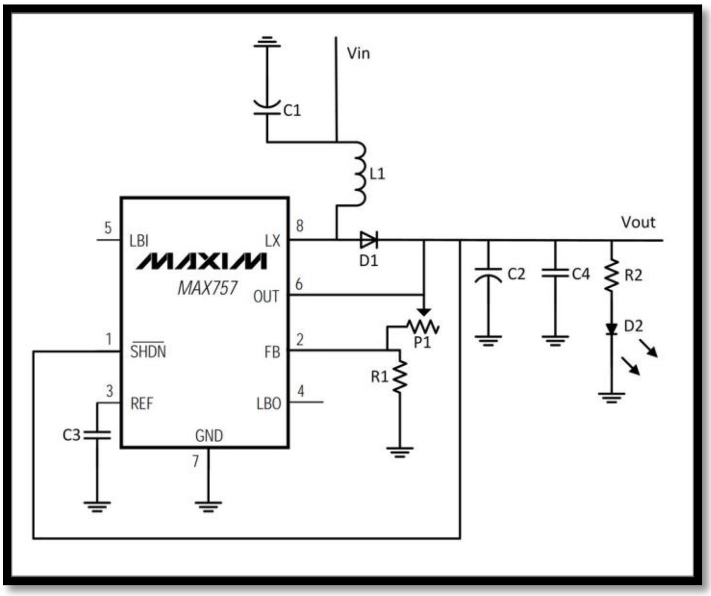

Figure 17 Final design for the booster

4.2 Results

This is the design of the recharging circuit as shown in figure 14 by using LT-Spice

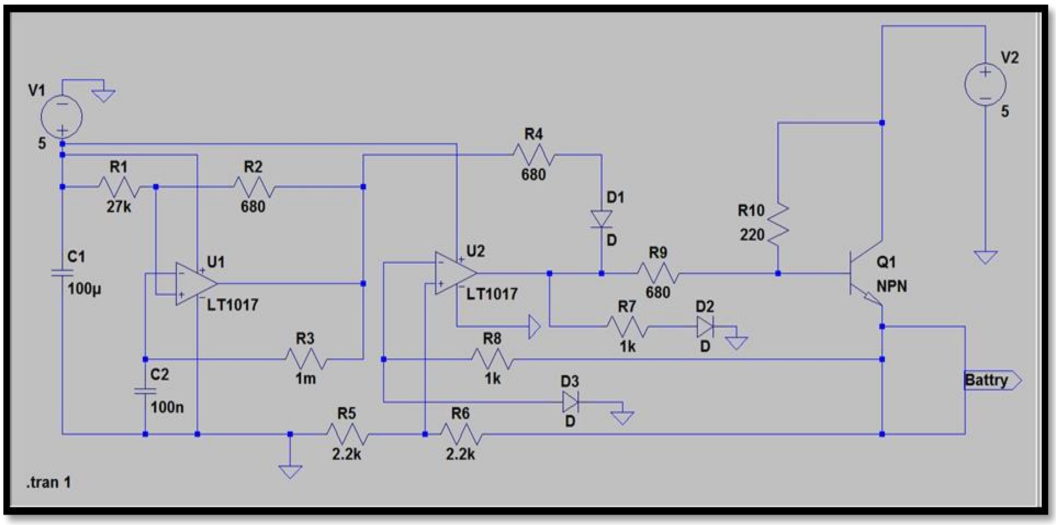

Figure 18 Design of recharging circuit using T-Spice

And here is the output

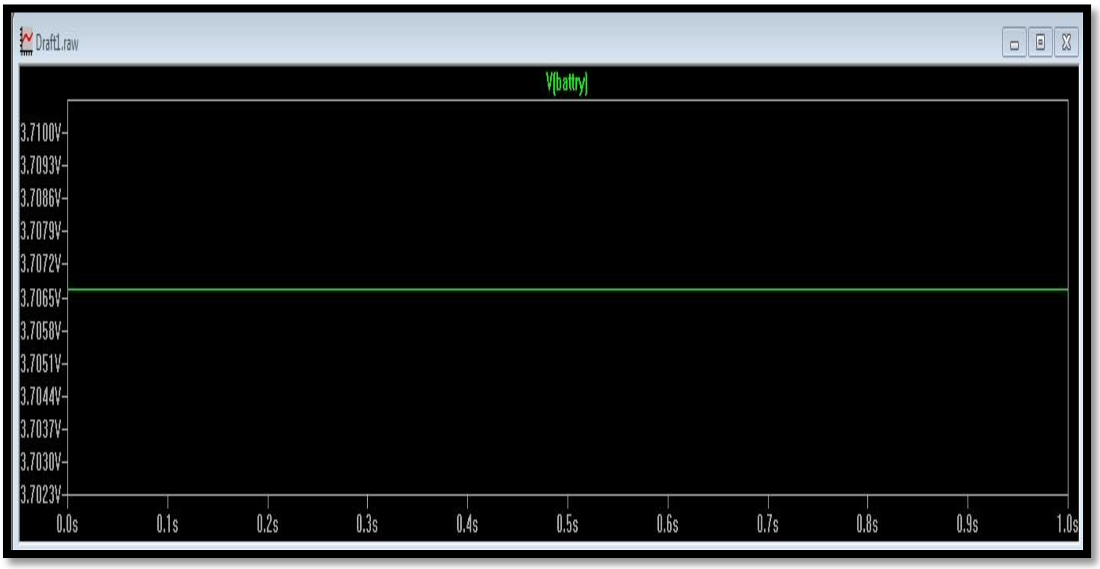

Figure 19 Output of the recharging circuit

As shown from figure 19 the output is equal to 3.7v which is good enough to charge the battery.

Here is the schematic of the circuit in the Eagle-Cad Software to change the circuit into PCB

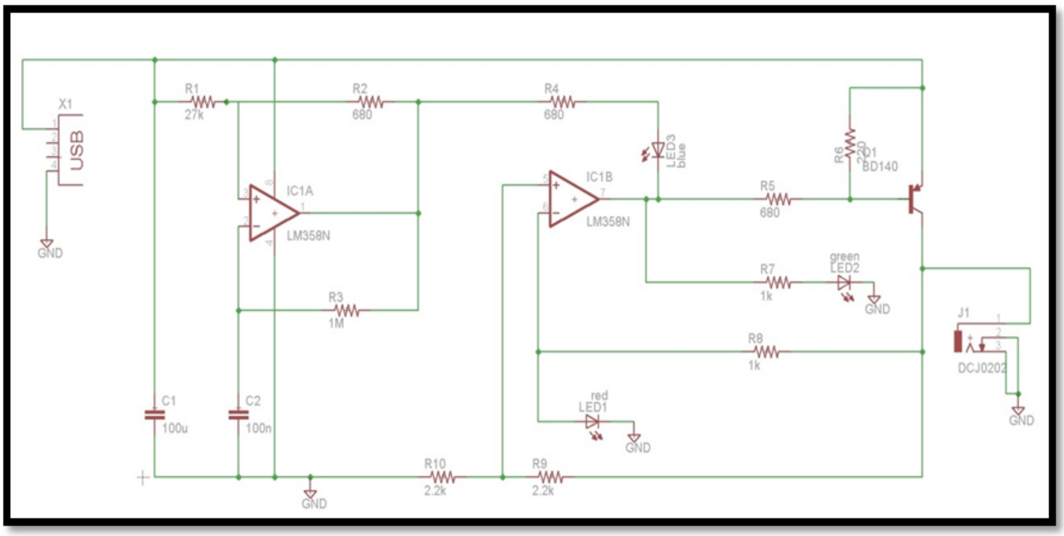

Figure 20 Schematic of the recharging in the Eagle software

Here is the primary design for the PCB as shown in figure 21:

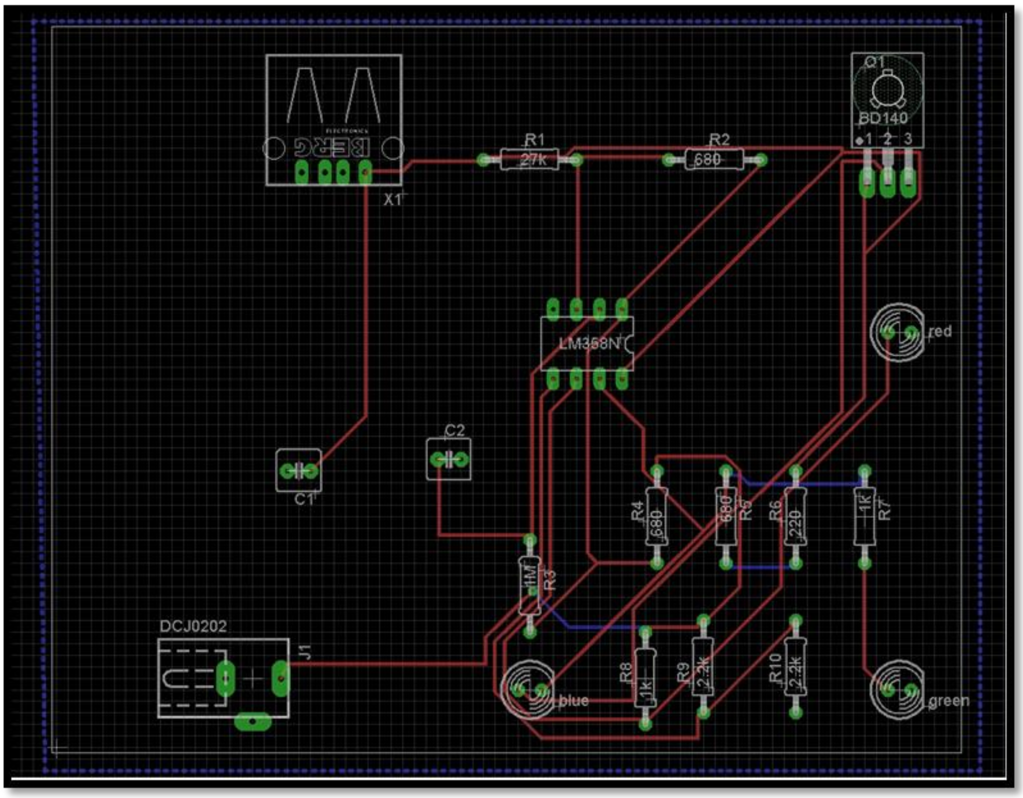

Figure 21 Primary design of recharging circuit

Here is the final design of the recharging circuit on PCB

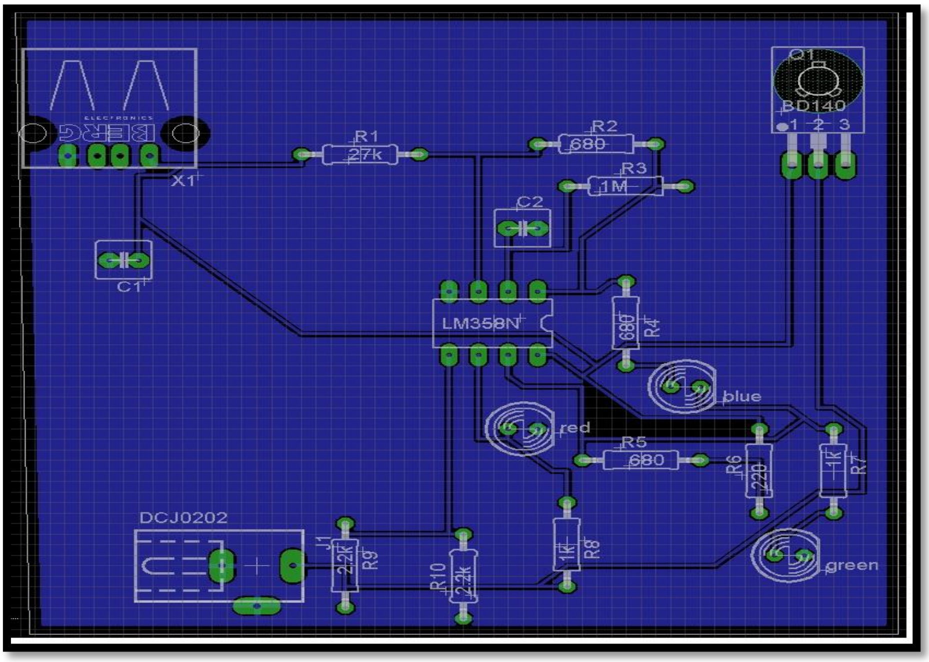

Figure 22 Final design of the recharging circuit on PCB

Here is the Recharging circuit after manufacturing

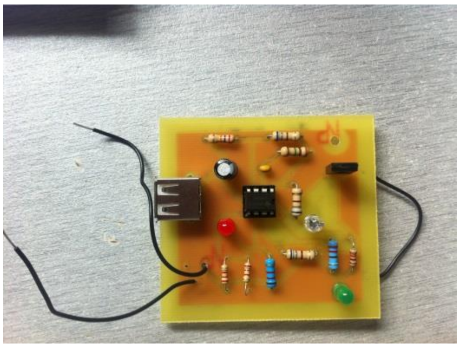

Figure 23 Recharging circuit final product

The TEG has already been purchased as shown in figure 20 and being tested by the output voltage produced is very small not enough to power up the Zigbee circuit the output voltage was almost 50mv so a new design is being used to increase the output voltage by installing a heat sink to the TEG on the cold side to increase the area which will interact with the room temperature which will increase the voltage, several types of metal has being used as shown in the figures (21,22,23) and here are the results :

Type of material	Output voltage
No *contact with metal*	40 mv
Alumnium	270 mv
mild steel	240 mv
Can	180 mv
Paper	80 mv
Stainless steel	120 mv
Thick Metal	300 mv

Table 3 Different types of materials

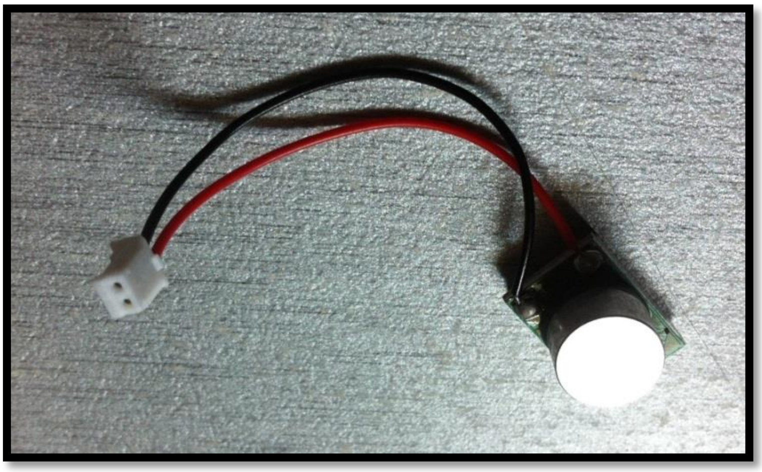

Figure 24 TEG final product

Figure 25 Aluminum

Figure 26 Thick metal

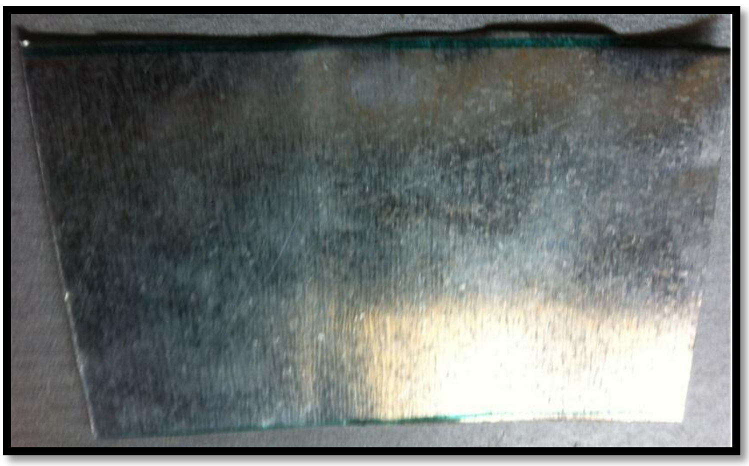

Figure 27 Stainless Steel

Now there are 2 major problems:

1- The output voltage is not stable “change with the change of the body temperature”
2- The output voltage is not enough to power up the circuit

   Since according to the Seebeck formula for the TEG the output voltage can be calculated:

   $S = 0.013125\ V/K$ “Given with datasheet”

   $T_h = 34.2 + 273 = 307.2° K$ “Measured”

   $T_c = 27.8 + 273 = 300.8° K$ “Measured”

   $\Delta T = T_h - T_c = 307.2 - = 307.2 - 300.8 = 6.4° K$ “Measured”

   So the output voltage is equal to:

   $V_o = S * \Delta T = 0.0131 * 3.4 = 0.04V$

   Output current:

   $R_c = 0.323\ \Omega$ “The internal resistance for the TEG from the datasheet”

   $R_l = 30\Omega$ “The load resistance”

   So the output current will be:

   $I_o = (S * \Delta T)/(R_c + R_l) = 0.04/30.323 = 0.001A$

   The efficiency:

   $K_c = -0.05\ W/K$ “Thermal Conductance”

   So the heat input Q_h

   $=(S.T_h.I) - (0.5\ I^2\ RC) + (K_c.\Delta T) =$

   $(0.013125x307.2x0.001) - (0.5x0.001^2x0.323) + (-0.05x6.4) =$

   0.00316

   Efficiency $= \frac{I.V}{Q_h} * 100\% = 1.3\%$

As seen from the calculations the efficiency is very low that was the main reason behind choosing a supporting power supply to replace the TEG

The solution for these two problems is to re-design a hand band as shown in figure 24 where the TEG will be placed under it, the hand band consist of 2 parts:

1- Heat insulating material “To keep the body temperature constant”
2- Above the TEG a piece of Aluminum would be installed as a heat sink to decrease the temperature
3- The output voltage will go through 2 stages the first stage is voltage stabilizer to stabilize the voltage, the second step DC-DC converter to boost the voltage.

4- Solar cells will be used to work under room light to be used as a secondary power source.

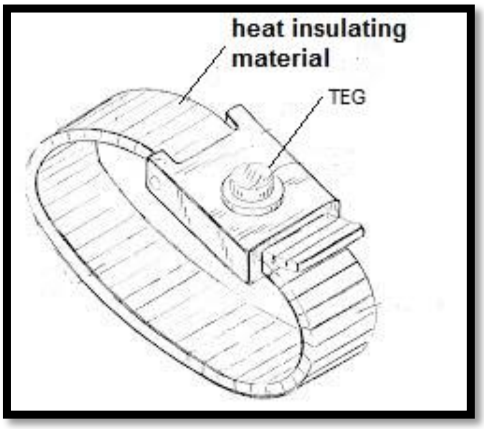

Figure 28 Primary design of the wrist band

Final prototype for the wrist band:

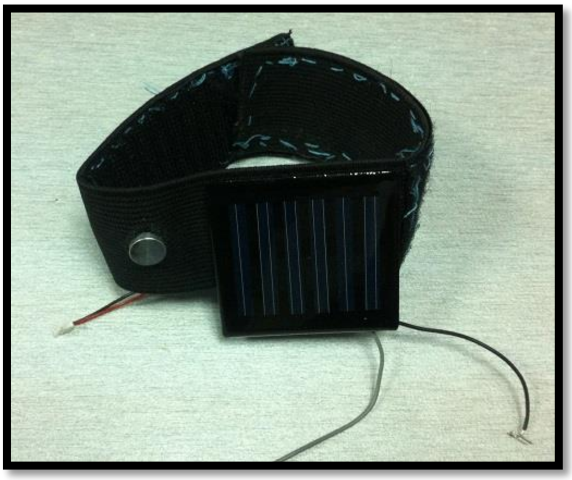

Figure 29 Final design

Solar cell were used under room light temperature and it was tested under several conditions and the results was shown in table 4

FF	Efficiency	Voc(v)	Isc(mA)	Pmax(W)	Area	Sun Level
0.574	6.369	2.95	49.9	0.14	100	1
0.575	6.387	2.9	43.536	0.128	100	0.33
0.483	1.773	0.9	0.12	0.000354	100	0.1

Table 4 Solar cells output power under different conditions

The design of the Dc-Dc booster circuit is shown in figure 32:

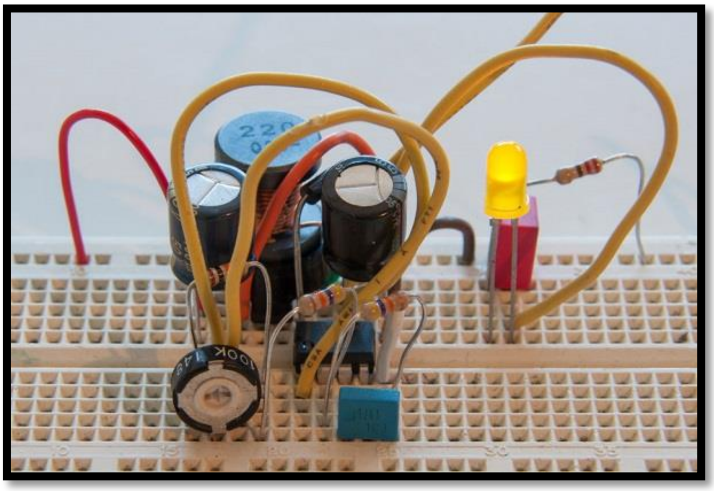

Figure 30 Designing of the Dc-Dc booster circuit

As shown in figure 31 and figure 32 the Dc-Dc booster can boost the power from 0.000354W to 0.3W which theoretically is sufficient to power up the TAG and here are the results

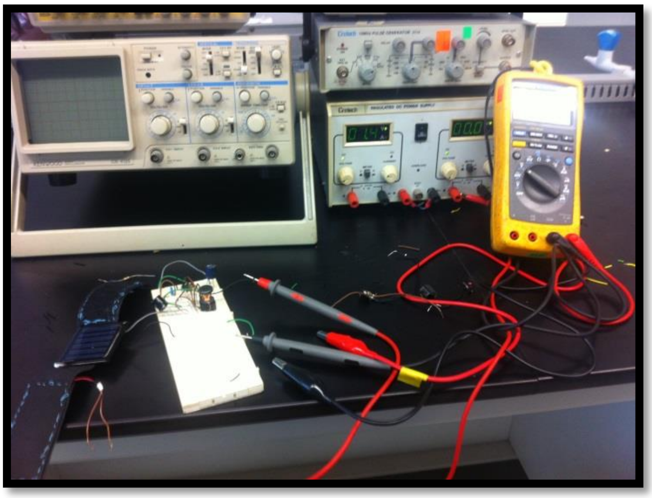

Figure 31 primary test for the booster circuit

Figure 32 output voltage of the primary design

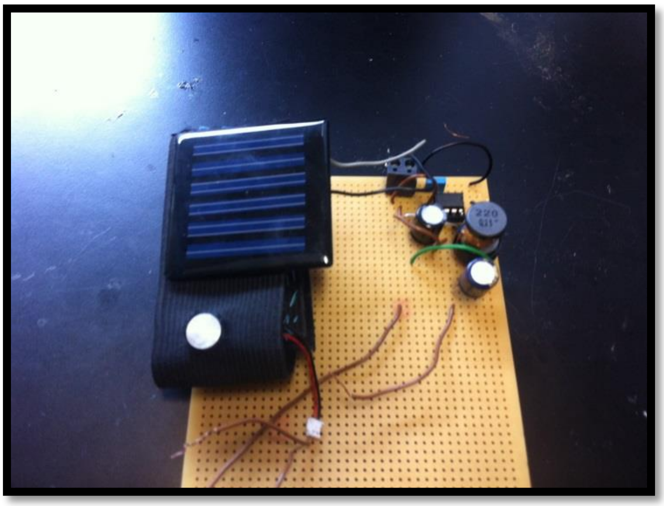

Figure 33 final prototype of the booster

By using the special device “Pasco 850 Universal Interface” as shown in figure 34 to find the output voltage and output current the results was shown in table 5 and 6:

Figure 34 Pasco 850 Universal Interface

The Dc-Dc booster circuit is connected to the Pasco device as shown in figure 35

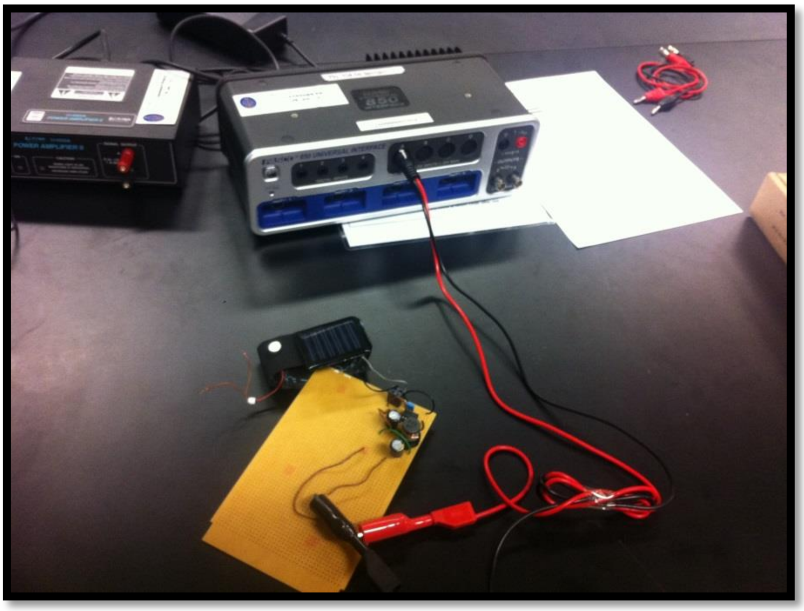

Figure 35 Dc-Dc booster connected to Pasco

Run #1	Run #1
Time (s)	Voltage (V)
0	0.655
0.05	0.655
0.1	0.655
0.15	0.655
0.2	0.655
0.25	0.655
0.3	0.655
0.35	0.655
0.4	0.655
0.45	0.655
0.5	0.655
0.55	0.655
0.6	0.655
0.65	0.655
0.7	0.655
0.75	0.655
0.8	0.655
0.85	0.655
0.9	0.655
0.95	0.655
1	0.655

Table 5 Output voltage vs Time

The results in a graph form are shown in figure 36:

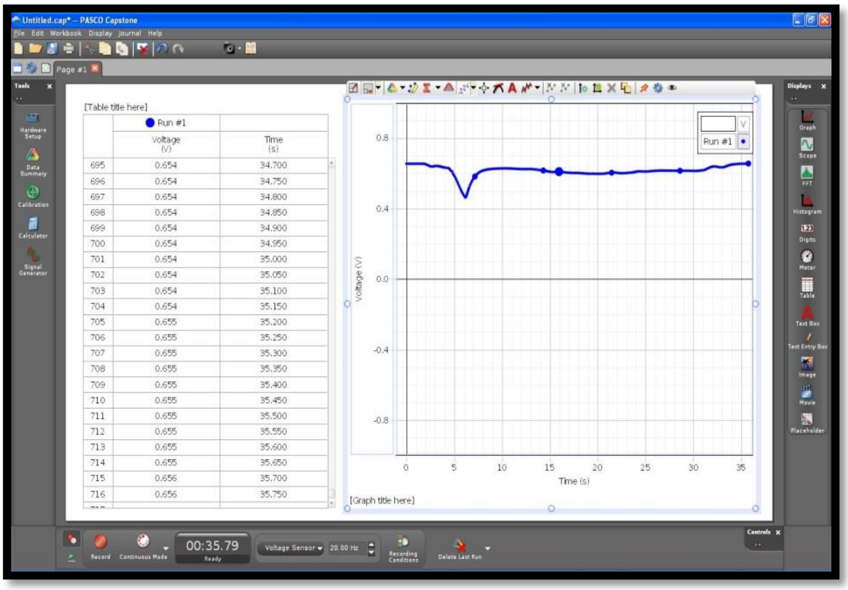

Figure 36 the output voltage

The output current:

Run #2	Run #2
Time (s)	Current (A)
0	0.614
0.05	0.614
0.1	0.614
0.15	0.615
0.2	0.615
0.25	0.615
0.3	0.615
0.35	0.615
0.4	0.615
0.45	0.615
0.5	0.615
0.55	0.615
0.6	0.615
0.65	0.616
0.7	0.616
0.75	0.616
0.8	0.616
0.85	0.616
0.9	0.616
0.95	0.616
1	0.616

Table 6 The output current

And the output current in a graph form is shown in figure 37:

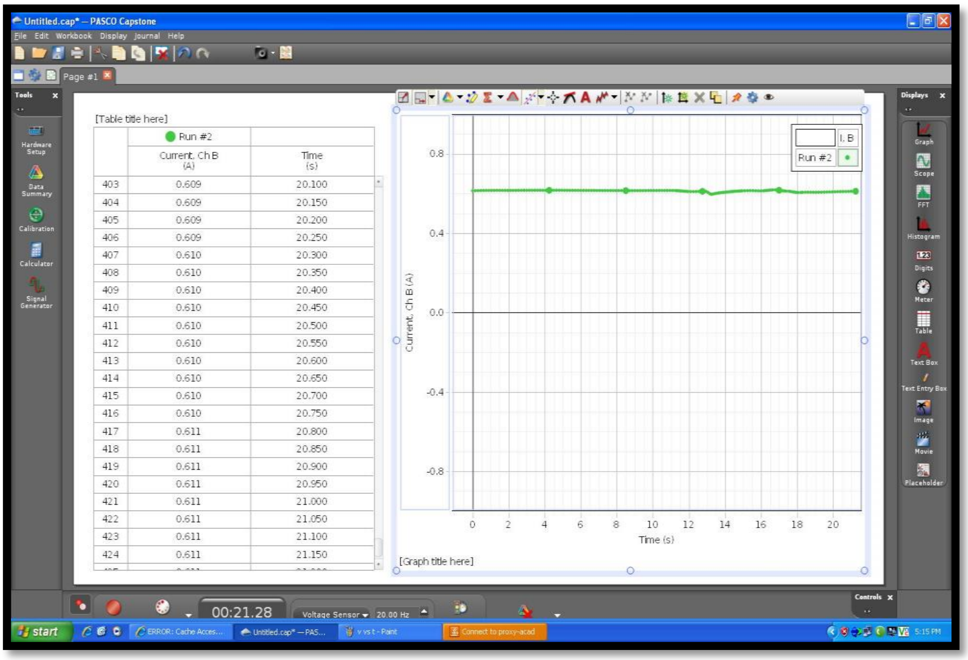

Figure 37 The output current

The output power is shown in table 7:

Time (s)	Power (W)
0	0.40217
0.05	0.40217
0.1	0.40217
0.15	0.402825
0.2	0.402825
0.25	0.402825
0.3	0.402825
0.35	0.402825
0.4	0.402825
0.45	0.402825
0.5	0.402825
0.55	0.402825
0.6	0.402825
0.65	0.40348
0.7	0.40348
0.75	0.40348
0.8	0.40348
0.85	0.40348
0.9	0.40348
0.95	0.40348
1	0.40348

Table 7 The output power

The output power in graphical form is shown in figure 38:

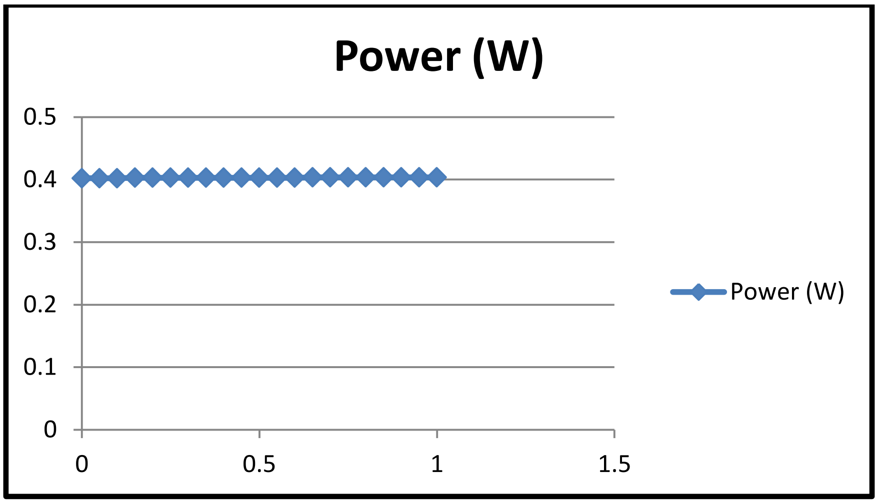

Figure 38 The output power

Chapter 5
Conclusion and Recommendations

5.1 Conclusion

Thermo-electric Generator (TEG) has many important application because it consider a source of clean energy, so it can be used widely in health care applications, the project mainly is to design a TEG circuit which can power up a ZIgbee circuit, but there are problems which is facing the design such as the voltage of the TEG is not enough to power up the circuit, so solar cell will be used and the its output will go through a DC-DC converter will be used to power up the circuit , the output power of the solar cells under the room light was very low almost 0.0003 but the Dc-Dc booster boost the output up to 0.4W which should be sufficient to power up the tag.

5.2 Recommendations

The circuit can be improved by adding other solar cells on series with the current solar cells to boost the voltage a little

Chapter 6

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