DEVELOPMENT OF ENERGY GENERATION BY USING PEIZOELECTRIC MATERIAL VIA STRUCTURAL VIBRATION

By

MOUSTAFA MOHAMED ABDEL HAMID BELAL

FINAL PROJECT REPORT

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

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

DEVELOPMENT OF ENERGY GENERATION BY USING PEIZOELECTRIC MATERIAL VIA STRUCTURAL VIBRATION

by

Moustafa Mohamed Abdel Hamid Belal

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

Approved:

_____

Dr. Nor Zaihar B. Yahaya
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June or December 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.

_____

Moustafa Mohamed Abdel Hamid Belal

ABSTRACT

The heart of this project is to find a way to use lost energies. In this case vibrations caused by machines or walking is a lost energy that need to be used. As low power electronics and wireless technology starts to develop recently, it was necessary to think of new power sources that produce low power and easily to be harvested. The harvesting of power from different sources started to become commonly used in the last years. With the time the power harvesting circuits will replace the normal finite power supplies used. Piezoelectric material technology produced a new way that uses some of the energy being wasted or ignored in the surrounding, in this case vibration energy that usually lost. Theses materials is already put in to use to harvest power; however, the power produced by these material is very small to be able to power most electronic systems. The research made into this matter has always ended up with the need for methods to accumulate the produced power until an amount of enough energy is produced. At the end of this project the outcome should be a stable source of power to charge a mobile battery or a power bank

ACKNOWLEDGEMENTS

I would like to thank all the people who have helped me with this project. Starting with my supervisor Dr. Nor Zaihar B. Yahaya who has helped me a lot during this project with advice and hints to get the best performance.

Many thanks go to my friends and colleagues for the help and support they provided for me. Furthermore many thanks go to my family for their continuous assistance. Last but not least I want to thank the University for giving me the opportunity and all the needed support to finish my studies successfully.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The piezoelectric material is a new field that needs more research and attention. This project is focused on the way to harvest power from the material. But first there must be a good understanding to the material and the problems that may be faced during the project. In this introduction an brief background about the material and the problems faced in this field. A problem statement for the project and objectives to state and predict the outcome of the project. Scope od study that shows the sides covered in this paper. Then followed by a brief of the costing of the project.

1.1 Background of study

As the historical review of this project, it was coulomb who first theorized that there might be a way to produce electric potential from pressure applied on certain material. Later, Huay and Becquerel had some experiments suggesting that simple friction or contact electricity might have caused charges that produces by compression.[2]

All the researchers who have worked to investigate on this topic have shown the need to assemble a method to harvest and store the generated energy till there is enough amount of energy to power whatever they have in mind. At that time a capacitor was the most common storage medium. However, the capacitor was not good enough as it only can provide small amounts of power. A rechargeable battery can be used as a good alternative to capacitor.

1.2 Problem statement and objectives

As stated that the demand for portable energy sources has increased over the past few years. The power sourced needed to supply the new widely used electronic devices. A power source that produces low power, associated with environment and imposed regulations and that can be portable. The demand on these kind of low power sources has supported the research to find these methods of generation of energy to power portable devices. The main objective of this project is to describe the use of the piezoelectric material in the field of harvesting power. The power is harvested from people motion and walking. By the end a prototype should be fabricated that can generate enough power for simple portable devices application.

The development has been made in this field has made construction of modern devices that capable of producing enough voltage and currents for energy harvesting.

Therefore the design of an efficient micro generator has to consider:

1- To understand the basic operation of piezoelectric material
2- To design and simulate the circuit of generation and harvesting energy
3- To design and simulate the charging circuit
4- To test and fabricate the prototype

1.3 Scope of work

This research is focused on a new technology that has the potential to have a good place in the market. The work is basically based on power electronics as how the function of each component can be used in the project. It has also been using the basic principle of circuit designing.

1.4 Significance of the project

The project is a good application to find a way to use lost energies. By the end of this project the prototype should a good example to that. A way to harvest energy generated from vibration or walking using a low cost device that is stable and easy to use. This project should save some of the wasted energy.

1.5 Contribution of work to society

This project is going to help save energy, and supply enough power to some of the application in the daily life.

Some of these applications

- In crowded areas such as railway stations, sub-ways, bus terminals
- The electricity can be used to charge batteries and used for streetlights and nightlights
- Emergency signs

1.6 Cost

Most of the materials used are available in the UTP EEstore. A total cost for the prototype is calculated to be RM145 (the piezoelectric material is RM93 alone).

CHAPTER 2
LITERATURE REVIEW

The majority of literature for piezoelectric materials is directed toward vibration, ultrasonic sensors, and transducers. The basic element of the process of generation of power using piezoelectric material is stress. Stress is essential for the piezoelectric material to be functioning. Voltage and current are generated within the material due to the stress (i. e. Compression from outer forces). However the stress applied to the material must be released for the material to start producing power again. The process of generation power using piezoelectric material required alternating stress or vibration

2.1 To understand the basic operation of piezoelectric material

The material as shown in Fig.1 is made of two conductors fabricated from metal and piezoelectric material layers. For generating, one of the two conductors end is fixed while the other end is loaded with small ballast to mechanical resonance system. At certain resonant frequencies, the mechanical system has the ability to vibrate. That can also happen even if the frequency of the actuating vibrations varies and irregular. Maximum energy is produced at resonant frequency.
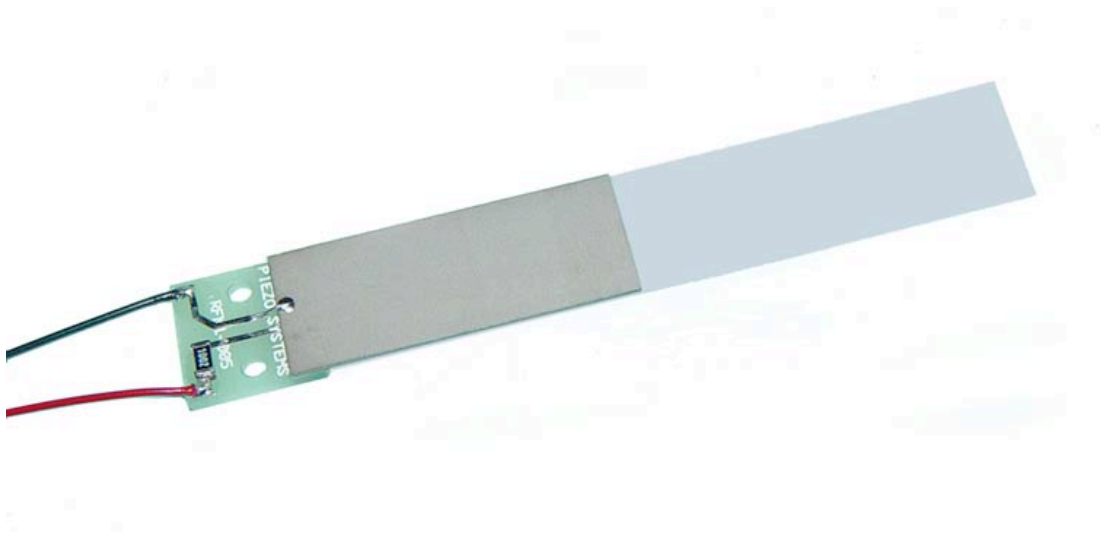

Fig.1: Piezoelectric material

There are some materials that are able to produce electricity with the help of some stimulus. Piezoelectric materials are one type of these materials. These materials are in solid state with the right stimulus it can produce electricity. Solar panels use photovoltaic materials that is able produce electricity using the effect of light. There are also thermoelectric materials that produce electricity when heat is applied to its surface. With the same concept the piezoelectric material need external exciter or stimulus to generated electricity, which in this case is stress and strain, as shown in Fig.2. What these materials have in common is they are all semiconductors, which means that they are generally fabricated from silicon or germanium with the addition to some other elements that make them conventional electronics.[5]
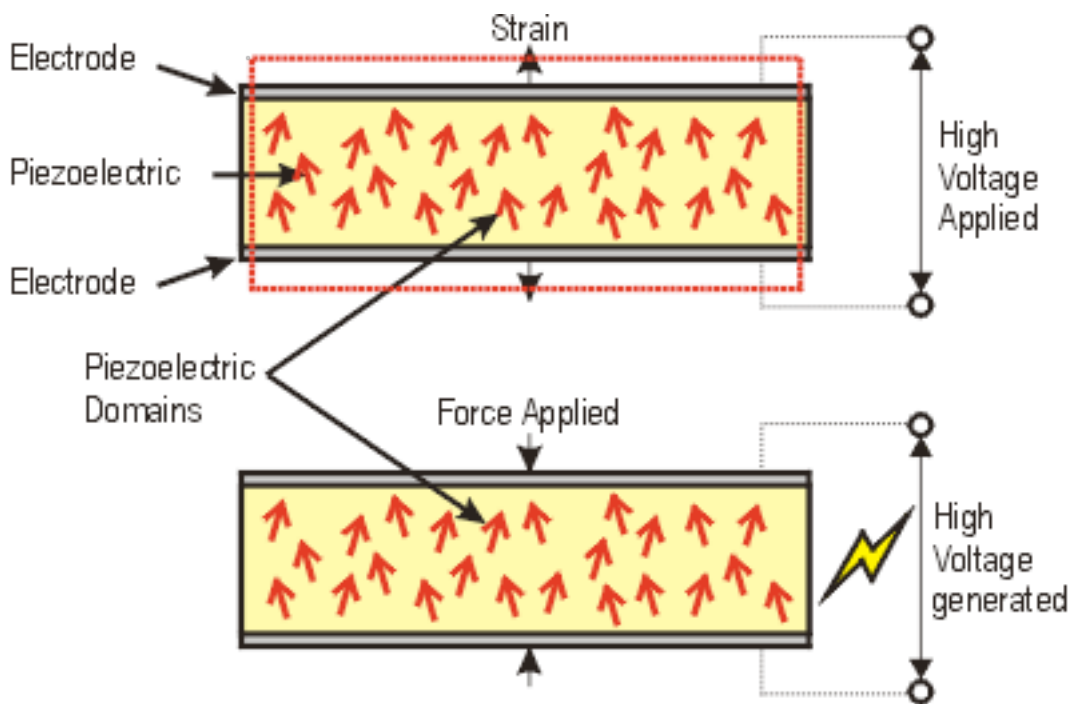
Fig.2: Piezoelectric effect [10]

The Piezoelectric materials are commonly used for the transformation of mechanical energy produced by the ambient vibration to electrical energy. The energy produced could be harvested and stored in order to be used later to power other devices. As more research was made into the matter it was found that the power generated using the piezoelectric material is not enough to power electric devices. Therefor, it was necessary to produce methods to accumulate and store the power harvested. The power is to be stored till there is enough power could be used to supply the portable devices. The competitive market nowadays has forced the research to find a way for the power harvesting energy to stay strong under the circumstances.

The charge obtained from piezoelectric material can be predicted by eq (1). The calculation should be in the charge mode and some condition going to short circuit. The calculation is for small charge density caused by external stress. the generated charge density given by:

$$D = \frac{Q}{A} = d_{3n} F_n \qquad (n = 1,2,3) \qquad \text{eq (1)}$$

Where D is the surface charge density developed, Q the charge developed, A the conductive electrode area, d_{3n} the appropriate piezoelectric coefficient for the axis of applied stress or strain F_n the stress applied in the relevant direction.

The mechanical axis n of the applied stress (or strain), by convention, is 1 for length (or stretch) direction, 2 for width (or transverse) direction and 3 for thickness direction. In the voltage mode, the emf is given by:

$$emf = g_{3n} F_n \; t \qquad (n = 1,2,3) \qquad \text{eq (2)}$$

Where g_{3n} is the appropriate voltage piezoelectric coefficient for the axis of applied stress and t the film thickness.

2.2 To design and simulate the circuit of generation and harvesting energy

It was found the power produced by two piezoelectric can supply a transmitter to send a 12-bit radio frequency identification (RFID) code every 3-6 steps. This proved that the power generated using the piezoelectric technology can supply to transmit this frequencies has open doors for more research to develop it.

Researches have shown that the problem that has been faced is the use of the capacitor as storage for the power. As the capacitor has a poor energy storage characteristics, that it can be only used to send small pulses. And this results limited applicable ways for harvesting of power. Therefore, the research was made into the ability to charge a battery by using the power generated from the piezoelectric material. The study stated that for a battery to be fully charged from the discharged state, it would only take one hour to do so. Using vibration consistent with same vibration observed in vibrating machine.[3]

As it is shown in the following Table I, a comparison between portable energy is made the vibration cause power that can be compared well to other sources of harvesting power, including batteries, fuel cells, and solar, temperature, and pressure devices.

Table 1: Comparison between portable energy and power sources [10]

Power Source	Power ($\mu W/cm^3$)	Energy (J/cm^3)	Power/yr ($\mu W/cm^3/yr$)	Need of secondary Storage	Need of Voltage regulation	Commercially available
Primary battery	N/A	2880	90	No	No	Yes
Secondary battery	N/A	1080	34	N/A	No	Yes
Micro fuel cell	N/A	3500	110	Maybe	Maybe	No
Ultracapacitor	N/A	50-100	1.6-3.2	No	Yes	Yes
Heat engine	10^6	3346	106	Yes	Yes	No
Radioactive (^{63}Ni)	0.52	1,640	0.52	Yes	Yes	No
Solar (outside)	15000^1	N/A	N/A	Usually	Maybe	Yes
Solar (inside)	10^1	N/A	N/A	Usually	Maybe	Yes
Temperature	$40^{1,2}$	N/A	N/A	Usually	Maybe	Soon
Human power	330	N/A	N/A	Yes	Yes	No
Air flow	380^3	N/A	N/A	Yes	Yes	No
Pressure variation	17^4	N/A	N/A	Yes	Yes	No
Vibrations	375	N/A	N/A	Yes	Yes	No

The researchers has been successful to design some vibration-based generators. The electromechanical transducers used were from three different types electromagnetic, electrostatic and piezoelectric. All three different types are based on the same principle. To be able to understand the way mechanical energy is converted to electrical , one must observe and understand the movement of the components of the generator such as rotor and stator in the macroscopic generator. For vibration, it is the wave that travel in or on some solid materials. With a material that can be affected with any wave surround it, its easy to find a source of mechanical movement to drive the generator.

The frequencies of the vibrating objects are lower than what is required for ultrasonic. As piezoelectric material has to be under stress to produce power, or current could be applied to the material generating stress. The frequency produced from human walking is a very low frequency. The frequency produced from walking can be 1-2 steps per second. The steps making pressure on the surface of the piezoelectric material and releasing making the vibration alternating causing alternative current within the material itself. The frequency is 1-2 vibration per second. Therefor the energy wasted in this process could be stored.

2.3 To design the charging circuit

To design a battery charger it must be taken into consideration some faults that might affect the performance of the battery afterwards

1. SHORT-CIRCUIT OUTPUT if it happens it can affect the components of the charger as it all works according to some current limits. However, the charger can be working if something like that happen but it all depends on the the way the charger is designed

2. REVERSE BATTERY CONNECTION can cause a serious problem if the suitable solution is not in the circuit. However, these solutions are applicable with low currents and cheap. But as the current increase these components price increase. A fuse can work as a perfect solution

3. OUTPUT OVER-VOLTAGE protection should be present in case of a fault in the charger control circuit. Well-designed electronic circuits are very reliable but components can still occasionally fail on a random basis. If this happens, a second circuit should prevent the battery from receiving continuous over-charging. [6]

This Table II shows the summary made for the literature review .

Table II: Summary of literature review

No.	Authors	Ref. no	Tittle	Discussion	Results/Findings
1	H.A. Sodano, G. Park and .D.J Inman	[1]	Estimation of Electric Charge Output for Piezoelectric Energy Harvesting	The best way to store the power obtained from piezoelectric material	Excluded the use of storage capacitor
2	S.R. Anton and H.A. Sodano	[3]	A review of power harvesting using piezoelectric materials	The best design for charging circuit	The battery to be charged only in one hour
3	D. Hill, A. Agarwal, N. Tong,	[5]	Assessment of piezoelectric materials for roadways energy harvesting	Discussing how the variation of vibrations can affect the power generated	It was found to be very efficient to use the technology on roadways and bridges
4	K.K. Mahapatra	[6]	Design of a Lead Acid Battery Charger System	Introduces damages that can affect the battery	Introducing the ways to protect the battery while charging
5	J. G. Rocha, L. M. Goncalves, P. F. Rocha, M. P. Silva, S. Lanceros-Méndez	[10]	Energy Harvesting From Piezoelectric Materials Fully Integrated in Footwear	Comparison between portable energy and power sources	The complete design of circuits however no results listed

CHAPTER 3

METHODOLGY

3.1 Procedures

The project should be in planned steps and phases in order to ensure that the work done is done in the best way that could be done.

3.1.1 Research and literature review

The project starts with a research about the topic to see the feasibility of the project. The main purpose of the research is in order to get an insight and understanding energy harvesting method. Research also is made on the basic concepts of piezoelectric material and power harvesting. At the end of CHAPTER 2 there must be a very good understanding of the topics in hand. A second stage research must be done to ensure more understanding of from research papers, journals, articles, and other sources available on the Internet. The core of this project gets more attention which are charging circuit and amplifier circuit.

3.1.2 Designing and simulation the circuit

As mention in the previous point the charging circuit is one of the most important pillars of this project. The circuit is designed to meet the requirements of charging the battery, which should be that the charging voltage is 3.7 V. another important design, is the current amplifier circuit. The main purpose of this circuit is to increase the output current to ensure that the load charge in shorter period. The circuits is analyzed and simulated by using one of the simulators available. The simulator used in this project is LTspice.

The simulation is carried out till the desired results are obtained. If the results obtained from these trails are not meeting with the requirements then, improvement should be done. After that stage the collection of the components starts.

3.1.3 Testing and Prototyping

The testing of this project is done in University Technology Petronas project labs that provide the needed multimeters and oscilloscopes to evaluate the results obtained from the experiments. The results obtained must fulfill the requirements. If not then there must be improvements made to the design. As sometimes the actual work does not fit with the simulation.

3.2 Proposed Topology

The piezoelectric harvesting circuit is basically consisting of two circuits. A circuit to convert the AC signal obtained from the piezoelectric material to DC signal that can be used to supply the charging circuit that charges a simple portable device battery working on 5V of DC voltage.

A modern energy harvesting system consists of four main blocks:

1) Energy source with an output current that is insufficient to use as a direct power supply -therefore harvesting is required

2) Rectifier to create DC voltage suitable for energy storage

3) Energy storage circuit using storage capacitor

4) DC/DC buck converter to transform the storage voltage to the required output voltage

The design for the energy harvesting circuit and the charging battery circuit is made to decrease high voltages on the input side and increase the low current on the output side going to the charging circuit and out of it. The circuit was designed so that the

power produced can be stored in the batteries. The block diagram of the process is shown in Fig .3
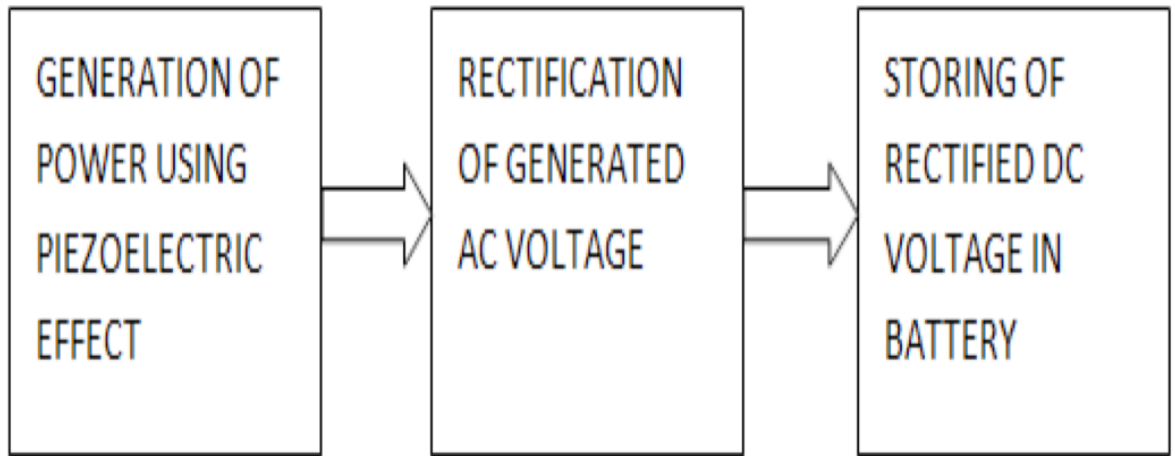

Fig.3: Block diagram of the process

Initially, the circuit consists of a full wave rectifier that is placed between the PFCB and the OP-AMP so that it converts the AC signals into DC signal. The use of the full wave bridge has proven to be the right for this design, converting both negative and positive cycles of AC signals produced by the PFCB and supply DC voltage to charge the battery through the charging circuit.

The circuit simulation in Fig.4 shows the circuit designed for the current amplifier. Hence the current need to be increased in order to decrease the battery charging time.
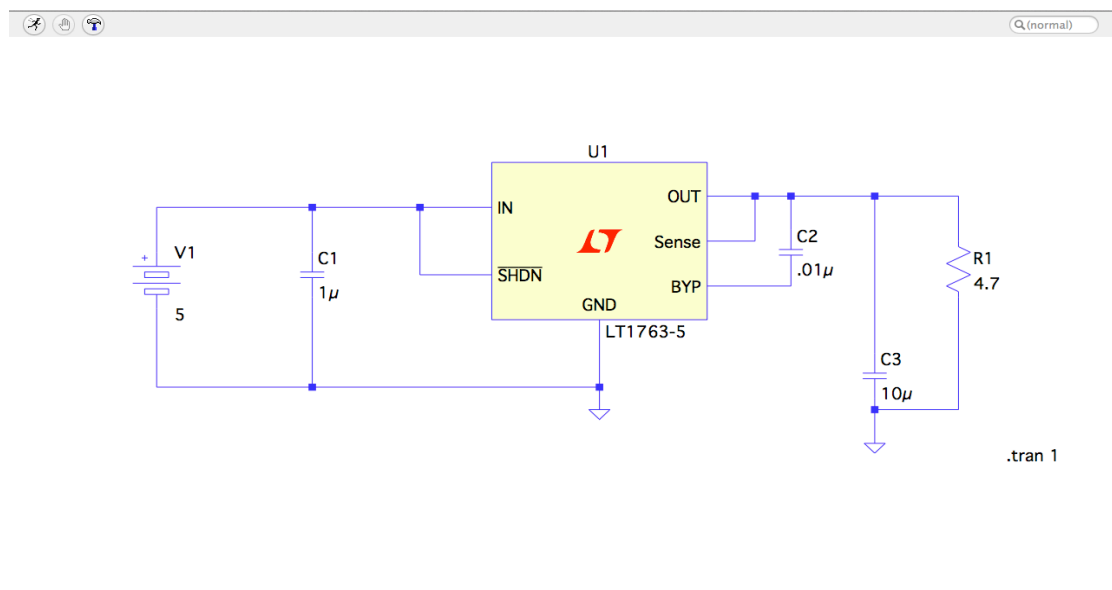

Fig.4: Design of current amplifier

12

the voltage regulator LY1763 is used as a suitable current booster. The device itself can be found in many application such as noise-sensitive instrumentation system, mobile phones and some battery-powered systems. The low dropout voltage has the ability to increase the current up to 500 mA. However, the voltages drops by 300mV. The series of LT1763 have fixed output voltages of 1.5 V, 1.8 V, 2.5 V, 3.3 V and 5 V. in this project the one used is LT1763-5 to limit the output votage to 5 V

The charging circuit design as shown in Fig.5. LTspice is used to simulate the circuit. The circuit has three LED indicators D1, D2 and D3 with different colors. Each indicator has a function D1 indicating the circuit is plugged to the power source. D2 indicating that the battery is charging while D3 indicating that the battery has reached full charge.
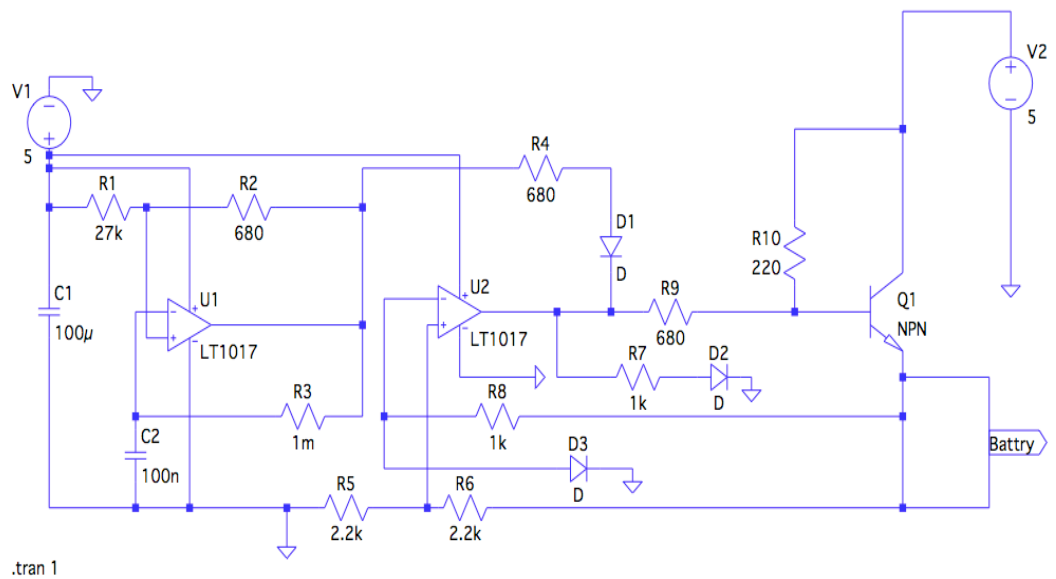

Fig.5: Charging circuit design using LTspice

For simulation the piezoelectric is usually modeled as AC voltage source. The piezoelectric characteristics and features are similar to the AC voltage source however, a composite of capacitors and resistors can be connected in series to smooth and reduce voltage overshoots. For test purposes, using a pencil tip to apply pressure on the piezoelectric material as a way provide disturbance. Then by using a multi-meter and oscilloscope to capture the reading for the voltages and currents.

3.3 Tool & Software required

Tools and software that required throughout the implementation of this are:

1. LT-Spice Simulation

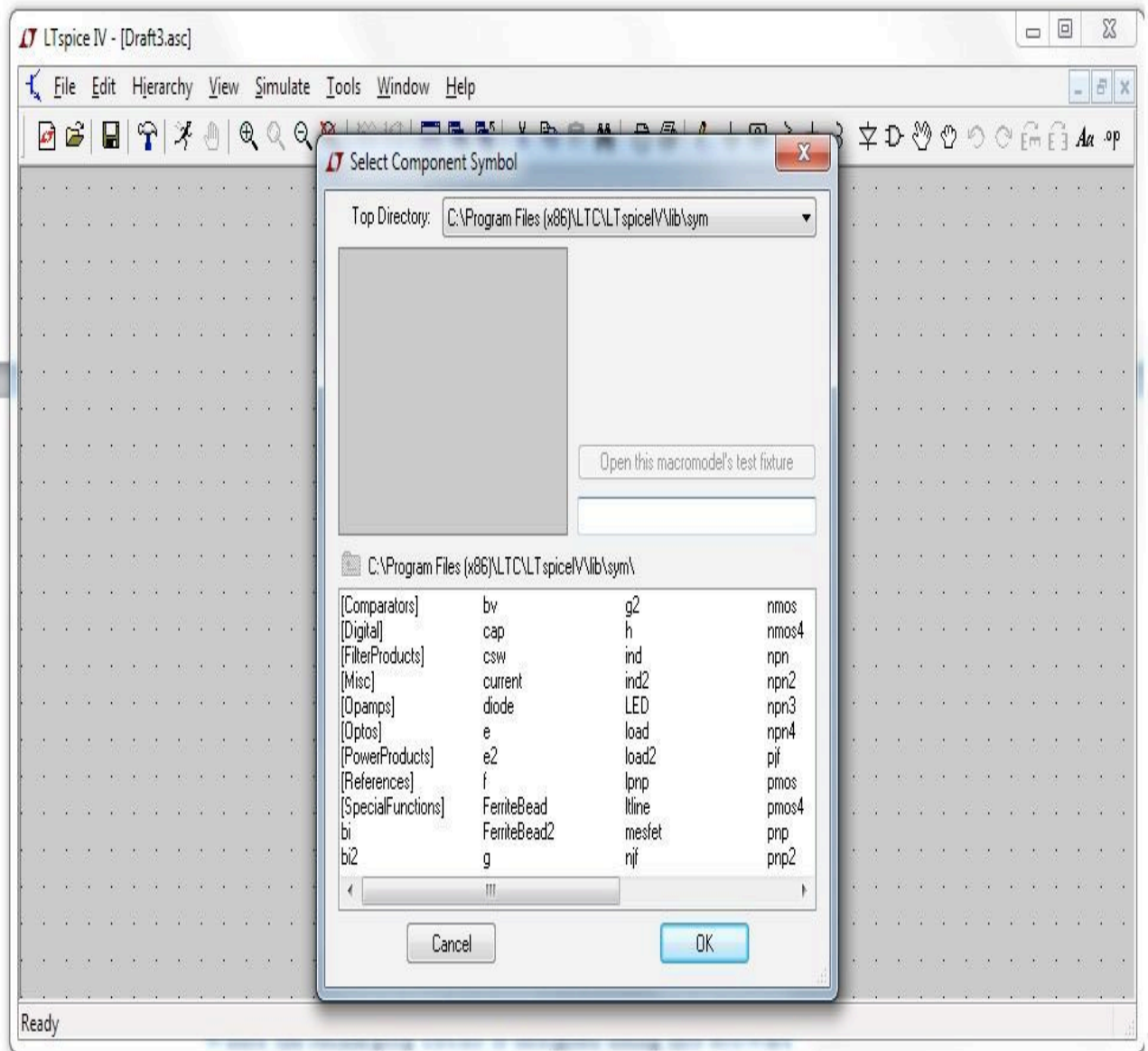This software is used in simulating the circuits as shown in Fig. 6

Fig.6: LT-spice Software

2. Eagle Cad software

In order to design the printed circuit board another software is used. The design in this software is divided into two part. First is the schematic part where the circuit is being built as shown in Fig. 7

Fig.7: Eagle software schematic

In the second part of this process, the schematic obtained from the first part is changed to a board automatically. This can be seen in Fig. 8

Fig.8: Eagle software board

Flow Chart

The FYP flow chart shown in Fig .9 is made to illustrate the steps made to carry out this project. Starting from the research to the fabrication of the prototype, showing the steps done and what should be deliver by the end of each step.

Fig .9 Flow chart FYP

Gantt Chart

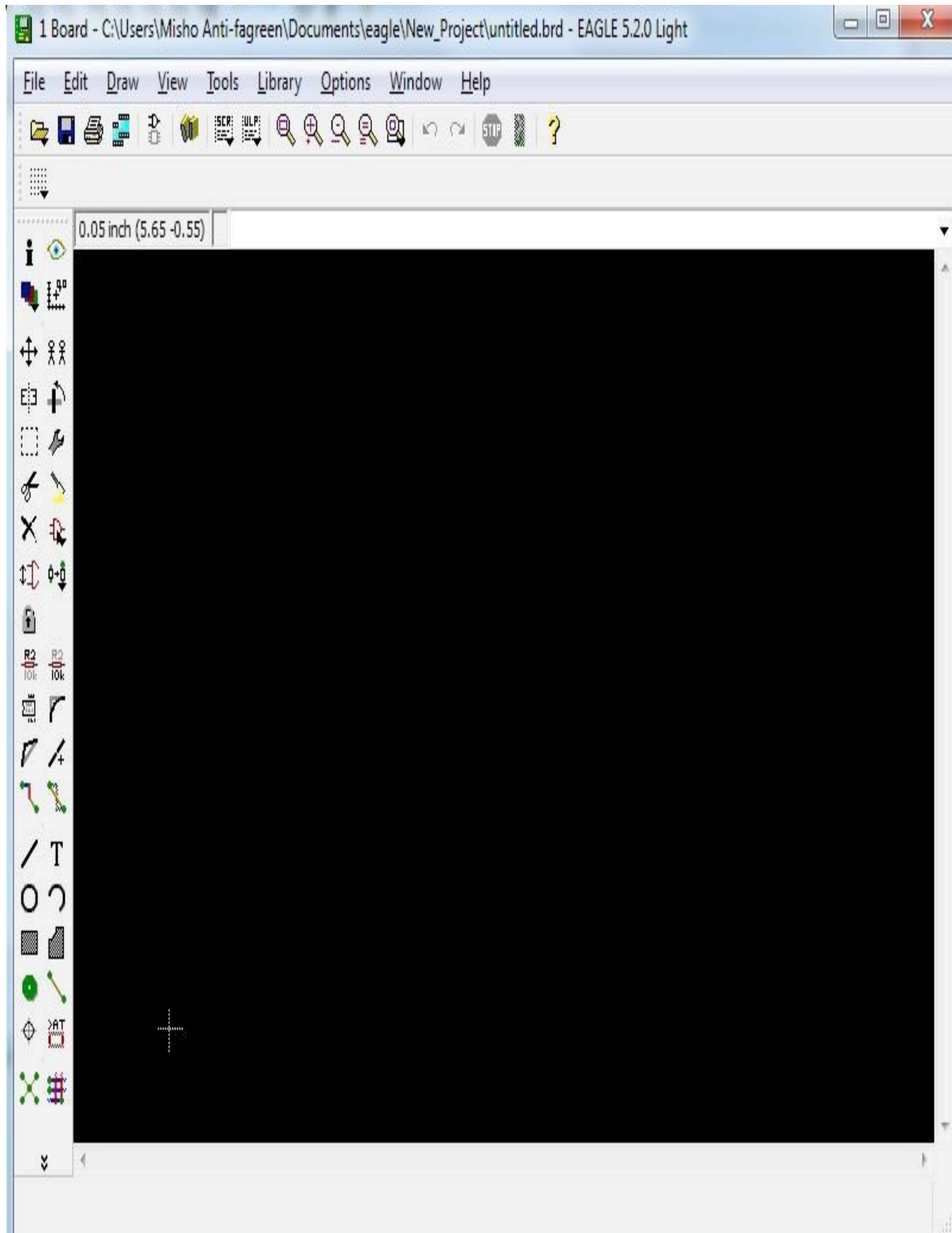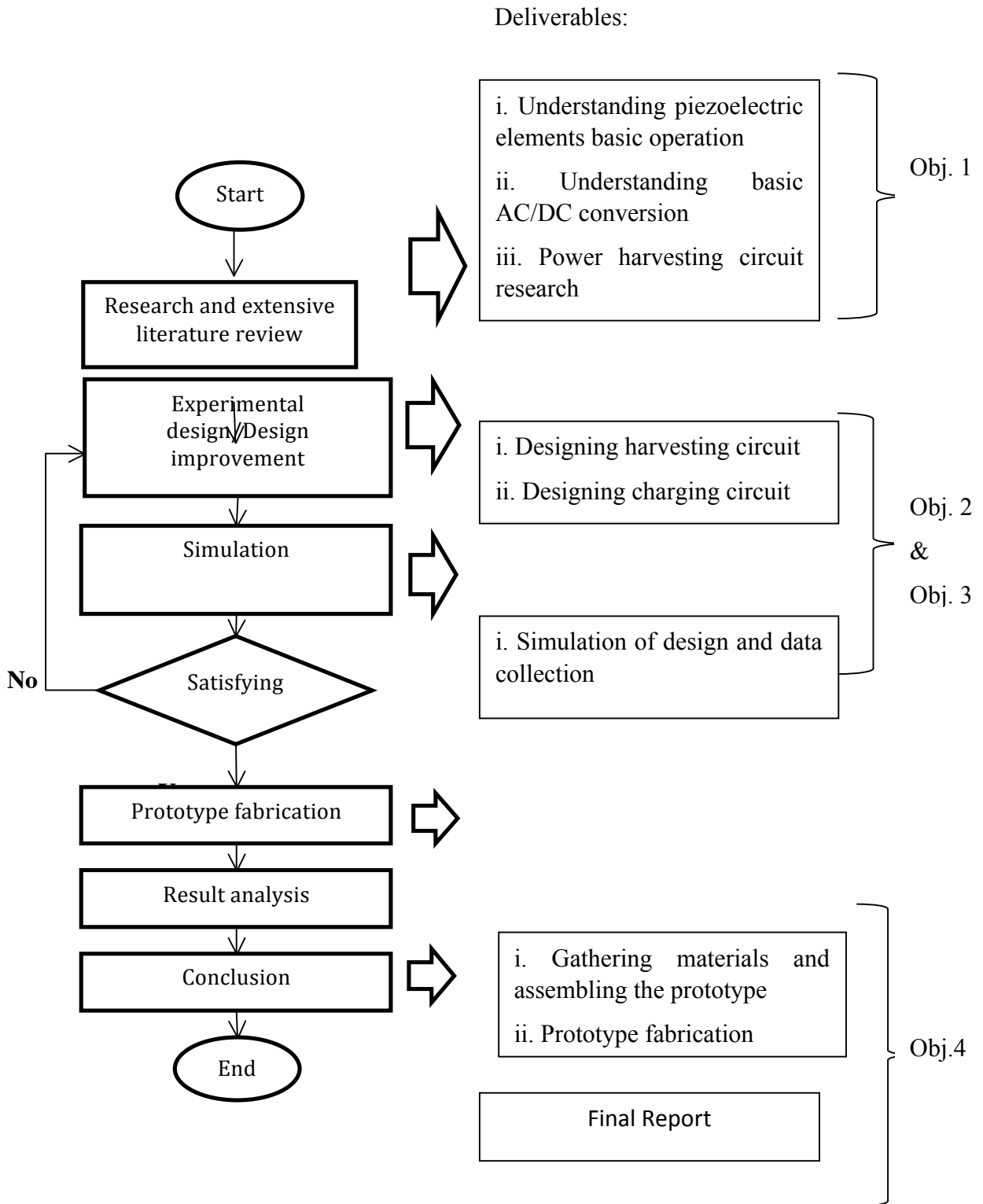Table III is Gantt chart showing the planning of FYP1 tasks and the time made for each task. The table is also categorized based on objectives to show how much been achieved in the time given.

Table III: Gantt Chart for FYP1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic		■												
	OBJECTIVE 1														
2	Literatures Review		■	■	■	■									
3	Submission of Extended Proposal							■							
4	Proposal Defense								■						
5	Project work continues									■					
	Objective 2&3														
6	harvesting circuit and charging circuit design										■	■	■	■	
7	Submission of Interim Draft Report													■	
8	Submission of Interim Report														■

As the work continues for FYP2 the work is planned and scheduled following this Gantt chart

Table IV: Gantt chart of FYP2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Research on the generation circuit	■	■	■	■										
2	Selection of materials					■	■	■							
3	Progress Report								■						
4	Generation circuit design and testing									■	■				
5	Fabrication of the prototype											■	■		
6	Preparing for PRE-SEDEX and designing poster												■		
7	Draft report and final report submission													■	■
8	Technical paper submission														■

CHAPTER 4
RESULTS

In this chapter, the results obtained from the simulation will be discussed. The simulation is done for both the charging circuit and the current amplifier.

4.1 Charging Circuit

The charging circuit was designed according to the requirements of the battery. The battery requires minimum voltage of 3.3 V and current of 0.5 A. The battery has capacity of 1600 mAh. The main goal was of the project is to get the fastest time to charge the battery. If the experiments get the desired outcome the battery should be charged in almost 2 hours. As shown in the design of the charging circuit in the previous chapter it was made to ensure the safety of the battery and the safety of the charging circuit itself. The simulation got the desired voltage for the battery as 3.7 V. the outpot voltage is shown in Fig 10.

Fig. 10:Charging circuit output

4.2 Current Amplifier

The current amplifier circuit is the heart of this project as it shows the progress made throughout the whole project as the main indicator of this project to be a success is if the current obtain is significantly high enough to charge the battery in the fastest charging time. The low dropout voltage regulator serves its purpose as the best way to boost the current from the tiny output of the piezoelectric material up to 800 mA. The best feature of this regulator that it can limit the voltage at 5 V. So no need to add over voltage protection at the charging circuit. The output of this stage is shown in Fig. 11.
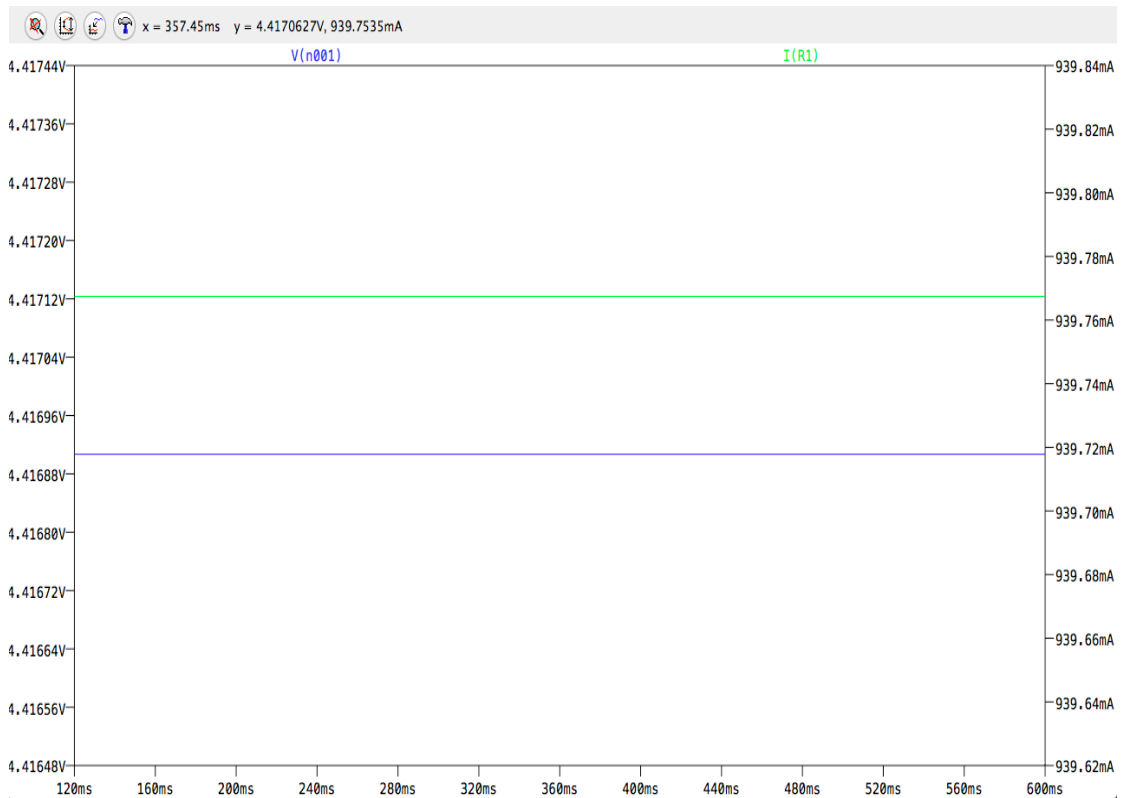

Fig. 11: output of the current amplifier circuit

CHAPTER 5
CONCLUSION

The report is organized as follows:-

Chapter 2 compiles the literature review generally on the basic of energy transformation that explains about the basic of energy transformation

Chapter 3 describes the methodology of the project on the design and simulation phase. The project's grant chart for this semester also included here. The selected method to do the project which is will use in coil design is highlighted and elaborated.

Chapter 4 provides some preliminary results and discussion of the present work. This chapter also discusses some findings and issue that being observed throughout the simulation process.

Chapter 5 draws the conclusion of the work.

This project is about developing a new product or device that can benefit the user which to supply the mobile devices or power banks. To develop the project, there are several objectives that must be accomplished which are:-

· To give backup system use piezoelectric when supply failed.

· To apply the renewable energy by use the piezoelectric harvesting energy

· To obtain the desired result of output voltage value to recharge batteries

The piezoelectric material technology has shown the potential to compete other sources of generating electricity. The field is yet growing and need more research into it. This research aims to propose the best use of piezoelectric material in generating power. Table V shows the progress made during FYP1 and FYPII based on how much the work done met the criteria of the objectives planed.

Table V: Conclusion based on objectives

Objective	Description	Percentage completion (%)
Objective 1. Details understanding about the project	1. Understanding piezoelectric material generation of current 2. Battery charger circuit for low voltage mobile application	100% 100% Total completion= 100%
Objective 2&3 To model and stimulate the project	1. Designing generation and rectification circuit 2. Designing and simulateing charging circuit	80% 90% Total completion=85%
Objective 4 To test and fabricate the prototybe	1. Prototype fabrication based on best stimulated circuit	80% Total completion=80%

REFERENCES

[1] H.A. Sodano, G. Park and .D.J Inman, "Estimation of Electric Charge Output for Piezoelectric Energy Harvesting," Journal of Strain, Vol. 40, pp. 49-58, 2005

[2] A. Ballato, March 1995, "Piezoelectricity: Old Effects and New Applications". IEEE

Ultrasonics Transactions, Ferroelectric Frequency Control, Vol. 42, pp. 916- 926

[3] S.R. Anton and H.A. Sodano, A review of power harvesting using piezoelectric materials (2003-2006), Smart Materials and Structures 16 (2007) R1–R21. .

[4] Chawanda A, 5 March 2012 ,"Piezoelectric Energy Harvesting Devices: An Alternative Energy Source for Wireless Sensors" .

[5] D. Hill, A. Agarwal, N. Tong, " Assessment of piezoelectric materials for roadways energy harvesting" Energy Research and Development Division FINAL PROJECT REPORT. JANUARY 2014

[6] K.K. Mahapatra, "Design of a Lead Acid Battery Charger System" Department of Electronics and Communication Engineering National Institute of Technology, 2009

[7] Zhao .S, October 19th, 2012 "Energy Harvesting from Random Vibrations of Piezoelectric Cantilevers and Stacks ", Georgia Institute of Technology .

[8] Y. C. Shu and I. C. Lien, "Analysis of power output for piezoelectric energy harvesting systems", Smart Materials and Structures 15 (2006), pages 1499-1512.

[9] Faltus .R, Jáně .M, Zedníček .T, 29 June 2012"Storage Capacitor Properties and Their Effect on Energy Harvester Performance Radovan "

[10] J. G. Rocha, L. M. Goncalves, P. F. Rocha, M. P. Silva, S. Lanceros-Méndez "Energy Harvesting From Piezoelectric Materials Fully Integrated in Footwear", November 23, 2009

[11] Pearce .D, Materials December 1999, "Ceramic Piezoelectrics - Springs and Loudspeakers", World Volume 7, Number 12, pp748-750