

DESIGN OF PIEZOELECTRIC ENERGY HARVESTING
CIRCUIT FOR HUMAN INTERACTION APPLICATION

CHEONG XIAN SHUNG

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**DESIGN OF PIEZOELECTRIC ENERGY HARVESTING
CIRCUIT FOR HUMAN INTERACTION APPLICATION**

CHEONG XIAN SHUNG

**This report is submitted in partial fulfilment of the requirements
for the degree of Bachelor of Electronic Engineering with Honours**

**Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka**

2018/2019

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Design of Piezoelectric Energy Harvesting Circuit for Human Interaction Application
Sesi Pengajian : 2018/2019

Saya CHEONG XIAN SHUNG mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

SULIT*

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

TERHAD*

(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan.)

TIDAK TERHAD

Disahkan oleh:

(TANDATANGAN PENULIS)

Alamat Tetap: No. 2, Laluan Sri Kuang 5, Desa Rasi, Kuala Kuang 31200 Chemor, Perak.

Tarikh : 31 Mei 2019

(COP DAN TANDATANGAN PENYELIA)

Tarikh : 31 Mei 2019

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this report entitled “Design of Piezoelectric Energy Harvesting Circuit for Human Interaction Application” is the result of my own work except for quotes as cited in the references.

Signature :

Author :

Date :

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature :

Supervisor Name :

Date :

DEDICATION

I would like to dedicate this thesis to my beloved parents Cheong Yoke Hing and Chiu Shuk Yin for never stop giving off themselves in countless ways. Besides, I would like to dedicate this thesis to my dearest sister, Cheong Yi Yian for her prayers and mental support throughout my years of studies.

ABSTRACT

Batteries are one of the most popular power supplies for its portability and convenience. However, batteries have limited life and need to either be replaced, recharged or both which has ongoing costs associated. There is an alternative way to harvest electrical energy which is using piezoelectric material. The disadvantage is that energy harvested from piezoelectric energy harvester is in AC form and it is too low to charge up electronic devices such as smartphones. The project aims to design and develop a prototype that able to harvest electrical energy from human walking movement using piezoelectric materials. Firstly, a prototype of piezoelectric knee-joint energy harvester is developed to harvest electrical energy. The harvested energy will be rectified to 3.3V and stored into a super capacitor. The circuit will be used to power up a Radio frequency system to verify that there is sufficient output power from the circuit designed.

ABSTRAK

Bateri adalah salah satu bekalan kuasa yang paling popular untuk mudah alih dan kemudahannya. Walau bagaimanapun, bateri mempunyai kehidupan terhad dan perlu sama ada diganti, diisi semula atau kedua-duanya yang mempunyai kos yang berterusan. Terdapat cara alternatif untuk menuai tenaga elektrik yang menggunakan bahan piezoelektrik. Kelemahannya ialah tenaga yang dituai dari penuai tenaga piezoelektrik adalah dalam bentuk AC dan ia terlalu rendah untuk mengecas peranti elektronik seperti telefon pintar. Projek ini bertujuan untuk merekabentuk dan membangunkan prototaip yang dapat menuai tenaga elektrik dari pergerakan berjalan manusia menggunakan bahan piezoelektrik. Pertama, prototaip piezoelektrik pemanen tenaga lutut bersama dibangun untuk menuai tenaga elektrik. Tenaga yang dituai akan diperbetulkan kepada 3.3V dan disimpan menjadi kapasitor super. Litar akan digunakan untuk menguatkuasakan sistem frekuensi Radio untuk mengesahkan bahawa terdapat keluaran output yang mencukupi dari litar yang direka.

ACKNOWLEDGEMENTS

First of all, I feel grateful to my final year project supervisor, Assoc. Prof Dr. Kok Swee Leong for providing a golden opportunity to grant me this title of PSM. Under his valuable guidance and suggestions, I can easily understand and apply the knowledge regarding to piezoelectric. Besides, I would also like to say thank you to my parents who shows endless support and motivate me endlessly along the way of completing this project. Many thanks to my friends as well for supporting me mentally.

TABLE OF CONTENTS

Declaration	
Approval	
Dedication	
Abstract	i
Abstrak	ii
Acknowledgements	iii
Table of Contents	iv
List of Figures	viii
List of Tables	xi
List of Symbols and Abbreviations	xiii
List of Appendices	xvi
CHAPTER 1: INTRODUCTION	1
1.1 Overview	1
1.2 Motivation	3
1.3 Problem statements	4
1.4 Objectives	4

1.5	Scope of Work	4
1.6	Report Outline	5
CHAPTER 2: LITERATURE REVIEW		6
2.1	Introduction to Energy Harvesting	6
2.1.1	Electromagnetic Energy Harvester	7
2.1.2	Electrostatic Energy Harvester	8
2.1.3	Piezoelectric Energy Harvesters	9
2.2	Comparison among Electromagnetic, Electrostatic and Piezoelectric Energy Harvester	11
2.3	Criteria to Improve Efficiency of Piezoelectric	14
2.4	Energy Harvesting System	17
2.4.1	Full Wave Bridge Rectifier	17
2.4.2	Boost Converter	20
2.4.3	Storage Device	21
2.4.4	Application	22
2.5	Summary	27
CHAPTER 3: METHODOLOGY		29
3.1	Overview	29
3.2	Project Flow	30
3.3	Hardware Development	33
3.3.1	Development of Knee-joint Energy Harvester Prototype	33

3.3.2	Development of Piezoelectric Energy Harvesting Circuit, RF Transmitter and Receiver Interface Circuit	35
3.3.3	Development of PCB prototype for Piezoelectric Energy Harvesting Circuit, RF Transmitter and Receiver Interface Circuit	38
3.4	Circuit Simulation to Compare Voltage Drop between 1N4007 Full Wave Bridge Rectifier and 2W10 IC-Based Rectifier	42
3.5	Experiment Setup to Compare Voltage Drop between 1N4007 Full Wave Bridge Rectifier and 2W10 IC-Based Rectifier	45
3.6	Experiment Setup to Determine the Charging Time of Capacitor	46
3.7	Application Testing	47
3.8	Summary	48
	CHAPTER 4: RESULTS AND DISCUSSION	49
4.1	Overview	49
4.2	Output AC voltage of Knee-joint Energy Harvester Prototype	49
4.3	Result of Voltage Drop between 1N4007 Full Wave Bridge Rectifier and 2W10 IC-Based Rectifier	51
4.3.1	Simulation Result	51
4.3.2	Experimental Result	54
4.4	Comparison of Charging Time among 330 μ F, 470 μ F and 1000 μ F Capacitors	57
4.5	Result of Application Testing	59
4.6	Summary	61
	CHAPTER 5 CONCLUSION AND FUTURE WORKS	62

5.1	Overview	62
5.2	Future Works	63
	REFERENCES	64
	APPENDICE A	68
	APPENDICE B	70
	APPENDICE C	72
	APPENDICE D	74
	APPENDICE E	76
	APPENDICE F	79

LIST OF FIGURES

Figure 1-1 Percentage of Malaysia Population Having Smartphones versus Years [26]	3
Figure 2-1 Energy Harvesting Technology Hierachy [2]	7
Figure 2-2 Electromagnetic Transducer [11]	8
Figure 2-3 Electrostatic Transducer [9]	8
Figure 2-4 Direct and Inverse Effect of Piezoelectric Material [6]	10
Figure 2-5 Power Output and System Effectiveness between Electrostatic and Piezoelectric MEMS Scale Energy Harvesting Systems. [9]	12
Figure 2-6 Amount of Power Generated by Piezoelectric Transducer and Electromagnetic Transducer [10]	13
Figure 2-7 Two Coupling Modes for Piezoelectric Materials. (a): 33-mode, (b): 31-mode [13]	15
Figure 2-8 Schematic of a Typical Cantilever Based Piezoelectric Energy Harvester [4]	16
Figure 2-9 (a): Unimorph, (b): Bimorph [15]	17
Figure 2-10 Energy Harvesting System	17
Figure 2-11 Full Wave Bridge Rectifier	18
Figure 2-12 Full Wave Bridge Rectifier during Positive Half-Cycle	18
Figure 2-13 Full Wave Bridge Rectifier during Positive Half-Cycle	19

Figure 2-14 Boost Converter Design Circuit	20
Figure 2-15 Rubber mats containing piezoelectric sensors along ticket gates [21]	23
Figure 2-16 Pavagan tile [22]	24
Figure 2-17 Knee-Joint Piezoelectric Energy Harvester with Mechanical Plucking [23]	25
Figure 2-18 Knee-Joint Piezoelectric Energy Harvester with Magnetic Plucking [25]	26
Figure 3-1 Project Flow	31
Figure 3-2 Prototype of Knee-joint Energy Harvester	33
Figure 3-3 The Mounting of Servo Motor under Prototype	34
Figure 3-4 Schematic Diagram of Piezoelectric Energy Harvesting Circuit	36
Figure 3-5 Schematic Diagram of RF Transmitter	37
Figure 3-6 Schematic Diagram of RF Receiver Interface Circuit	38
Figure 3-7 PCB Layout Design of Piezoelectric Energy Harvesting Circuit	39
Figure 3-8 PCB Layout Design for RF Transmitter	39
Figure 3-9 PCB Layout Design for RF Receiver Interface Circuit	40
Figure 3-10 Piezoelectric Energy Harvesting Circuit	40
Figure 3-11 RF Transmitter	41
Figure 3-12 RF Receiver Interface Circuit	41
Figure 3-13 1N4007 Full Wave Bridge Rectifier Using Multisim Simulation	43
Figure 3-14 1N 4007 Bridge Rectifier Using LT Spice	43
Figure 3-15 2W10 IC Rectifier Using Multisim	44
Figure 3-16 2W10 IC Rectifier Using LT Spice	44
Figure 3-17 1N4007 Full Wave Bridge Rectifier	45

Figure 3-18 2W10 IC-based Rectifier	45
Figure 3-19 Circuit Diagram of 1N4007 Full Wave Bridge Rectifier	46
Figure 3-20 Circuit Diagram of 2W10 IC-based Rectifier	46
Figure 3-21 Testing of Knee-joint Energy Harvester to Power Up a RF Transmitter	47
Figure 4-1 Output AC Voltage of Knee-joint Energy Harvester prototype	50
Figure 4-2 Illustration of Magnetic Plucking Action	50
Figure 4-3 1N4007 bridge rectifier with Multisim software	52
Figure 4-4 1N4007 bridge rectifier using LT Spice software	52
Figure 4-5 2W10 IC Rectifier with Multisim Software	53
Figure 4-6 2W10 IC Rectifier with LT Spice Software	53
Figure 4-7 Rectified Output Voltage of Knee-joint Energy Harvester using 1N4007 Full Wave Bridge Rectifier	54
Figure 4-8 Rectified Output Voltage of Knee-joint Energy Harvester using 2W10 IC-based Rectifier	55
Figure 4-9 Charging Time to Reach 3.3 V among 330, 470 and 1000 μ F Capacitors Using 1N4007 Full Wave Bridge Rectifier	57
Figure 4-10 Charging Time to Reach 3.3 V among 330, 470 and 1000 μ F Capacitors Using 2W10 IC-based Rectifier	57
Figure 4-11 (a): Input Setting of RF (b): Pressing of Tic Tac button to Discharge Storage Capacitor	59
Figure 4-12 Output of LED in RF Receiver Interface Circuit	60

LIST OF TABLES

Table 2-1 Advantages and Disadvantages of Electromagnetic, Electrostatic and Piezoelectric Energy Harvesters	13
Table 2-2 Comparison among Half Wave Rectifier, Full Wave Rectifier and Full Wave Bridge Rectifier	19
Table 2-3 Comparison between Capacitor and Lithium Battery [19]	22
Table 2-4 Comparison between Mechanical Plucking and Magnetic Plucking	26
Table 3-1 Program Code of Arduino UNO	34
Table 3-2 1N4007 Full Wave Bridge Rectifier Circuit	43
Table 3-3 2W10 IC-Based Bridge Rectifier Circuit	44
Table 3-4 Experiment Setup to Compare Voltage Drop between Two Rectifiers	45
Table 4-1 Simulation Results between Multisim and LT Spice using 1N4007 Full Wave Bridge Rectifier	52
Table 4-2 Simulation Results between Multisim and LT Spice using 2W10 IC-based Rectifier	53
Table 4-3 Comparison between 1N4007 Full Wave Rectifier and 2W10 IC-based Rectifier in Multisim Simulation	54
Table 4-4 Comparison between 1N4007 Full Wave Rectifier and 2W10 IC-based Rectifier in LT Spice Simulation	54
Table 4-5 Voltage Drop between 1N4007 Full Wave Bridge Rectifier and 2W10 IC-based Rectifier	56
Table 4-6 Time Required to Reach 4 V among 330, 470 and 1000 μ F Capacitors	58

Table 4-7 Number Of Times to Power Up RF Transmitter with Different Value of Capacitors 58

Table 4-8 Message that represents the output of LED indicator 60

LIST OF SYMBOLS AND ABBREVIATIONS

μ	: Micro
AC	: Alternating Current
AlN	: Aluminium Nitride
D	: Electric displacement
d	: Piezoelectric coefficient matrix
D1	: Diode1
D2	: Diode2
D3	: Diode3
D4	: Diode4
DC	: Direct Current
DIL	: Dual in-line
E	: Electric field vector
F	: Farad
h	: hours
Hz	: Hertz
I	: Current
IC	: Integrated Circuit
IoT	: Internet of Things
k	: kilo

KEH	: Knee-joint energy harvester
LED	: Light Emitting Diode
LTC	: Linear Technology
M	: Proof mass
m	: milli
M	: Mega
MEMS	: Microelectromechanical Systems
<i>ms</i>	: millisecond
NiMH	: Nickel-metal Hydride
PCB	: Printed Circuit Board
PKEH	: Piezoelectric knee-joint energy harvester
PM	: Primary magnet
PP	: Polypropylene
PVDF	: Polyvinylidene Fluoride
PZT	: Lead Zirconate Titanate
RF	: Radio Frequency
<i>s</i>	: Strain vector
S	: Compliance matrix
s	: seconds
SM	: Secondary magnet
<i>T</i>	: Stress vector
V	: Voltage
V _{cc}	: Voltage at the common collector
V _p	: Peak Voltage
V _{rms}	: Root-Mean-Square Voltage

W	: Watt
WCSN	: Wireless Communication Sensing Node
z	: Vertical displacement
ZnO	: Zinc Oxide
ϵ	: Electrical permittivity

LIST OF APPENDICES

Appendix A: 1N4001 – 1N4007 datasheet	68
Appendix B: 2W005 – 2W10 datasheet	70
Appendix C: 433 MHz RF Transmitter Module datasheet	72
Appendix D: 433 MHz RF Receiver Module datasheet	74
Appendix E: HT12E datasheet	76
Appendix F: HT12D datasheet	79

CHAPTER 1:

INTRODUCTION

1.1 Overview

Piezoelectricity is defined as the ability of generating electricity in response to applied pressure. When a piezoelectric material is placed under certain mechanical stress, an external electrical field will be produced due to the positive and negative charges accumulated in the centers of the material, resulting in an external electrical field. This is also known as the piezoelectric effect. In short, piezoelectric materials is capable of converting mechanical energy to electrical energy by applying mechanical stress or vibration. It is a trusted ambient energy source and is a good alternative way to reduce batteries usage.

There are many ambient energy sources like solar energy, wind movement, hydro and among these ambient energy, mechanical force such as impact and vibration can

be found or obtained easily. For instance, the mechanical force that comes from human walking. Human motion consists of kinetic energy and such energy often being wasted. Actually, this kind of energy can be harvested using piezoelectric material for obtaining clean and sustainable energy which can be used to power up low power electronic device. Besides, such energy do not need to be replaced like battery and this make it more valuable and efficient to be used as an alternative power source. On top of that, the harvested mechanical energy can be commercialized in many field, for example wireless system sensor network and alarm system.

This project intends to show that harvested energy can be stored and even trigger low power application such as a RF transmitter which doesn't involve any batteries. Piezoelectric cantilever will be implemented as power generator. However, the energy produced must be converted from AC voltage to DC voltage before it can be used to charge or power up electronic devices. Therefore, a knee-joint energy harvester prototype which consists of rectifying circuit will be designed to harvest the mechanical energy from human walking. After rectifying the AC voltage to DC voltage, the voltage will be stored in a super capacitor before feeding into RF transmitter. The performance of system will be verified.