

### SUPERVISOR'S DECLARATION

I/We\* hereby declare that I/We\* have checked this thesis/project\* and in my/our\* opinion, this thesis/project\* is adequate in terms of scope and quality for the award of the degree of \*Doctor of Philosophy/ Master of Engineering/ Master of Science in .....



---

(Supervisor's Signature)

Full Name : Prof Dr. Ajismen Apen  
Position : Professor  
Date : 6/6/2017

---

(Co-supervisor's Signature)

Full Name :  
Position :  
Date :

### STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.



---

(Student's Signature)

Full Name : VIVEKANANDAN A/L PANNEERSELVAM

ID Number : HA13016

Date : 5 JUN 2017

## **TABLE OF CONTENT**

**DECLARATION**

**TITLE PAGE**

**ACKNOWLEDGEMENTS** **ii**

**ABSTRAK** **iii**

**ABSTRACT** **iv**

**TABLE OF CONTENT** **v**

**LIST OF TABLES** **viii**

**LIST OF FIGURES** **ix**

**LIST OF SYMBOLS** **xi**

**LIST OF ABBREVIATIONS**

**CHAPTER 1 INTRODUCTION** **1**

1.1 Project Background 1

1.2 Problem Statement 2

1.3 Project Objective 3

1.4 Scope of the Project 3

**CHAPTER 2 LITERATURE REVIEW** **4**

2.1 Introduction 4

2.2 Type of Energy Harvester 4

2.2.1 Electromagnetic 4

2.2.2 Piezoelectric 5

2.2.3 Pyro-Electricity 6

2.2.4 Thermal Energy Harvesting 6

2.2.5	Electrostatic Energy Harvesting	7
2.3	Source of Vibration	9
2.3.1	Introduction	7
2.3.2	Vibration Characteristic	7
2.4	Theory Of Energy Harvesting	8
2.4.1	Faraday's Law	9
2.4.2	Lenz's Law	9
2.4.3	Magnetic Flux	12
2.5	Boost Converter	13
2.5.1	Basic Operation Of Boost Converter	14
2.5.2	Modes of Operation	14
2.5.3	Pulse Width Modulation	16
2.6	Previous Boost Converter For Energy Harvesting	18
2.6.1	Low voltage energy harvester booster	19
2.6.2	250mV input boost converter	20
2.6.3	Step up Rectifier	21
2.6.4	Boost converter with Feedback control	22
2.6.5	AC-to-DC Converters for Low Voltage Generator	23
2.6.6	Platform Architecture Combining With MPPT and Single Inductor	24
2.7	Conclusion	25
<b>CHAPTER 3 METHODOLOGY</b>		<b>26</b>
3.1	Introduction	26
3.2	Flow Chart	26
3.3	Block Diagram	29
3.4	Design and Simulation of Electrical Circuit	30
3.5	Mechanical Design	31
3.6	Fabrication of Mechanical Component	32
3.6.1	Harvester	32
3.6.2	Magnet	33
3.6.3	Coil Wires	35
3.7	Fabrication Of Electrical Component	36
3.7.1	Rectifier	36
3.7.2	Capacitor	38
3.7.3	Inductor	39
3.7.4	Mosfet	40



3.7.5	Temporary Storage (Capacitor)	40
3.7.6	Temporary Storage (Capacitor)	41
3.7.7	Output (LED Load)	41
3.7.8	Arduino uno	42
3.8	Assemble the Circuit and Mechanical Part	43
3.9	Testing the Functionality of circuit	45
3.10	Experiment	45
3.10.1	Vibration source	46
3.11	Summary	46
 <b>CHAPTER 4 RESULTS AND DISCUSSION</b>		<b>47</b>
4.1	Introduction	47
4.2	Boost Converter	47
4.3	Conducting Experiment	48
4.4	Collecting and Analysis of Data	49
4.4.1	Output Voltage	49
4.4.2	Output Power	54
4.4.3	Output Current	56
4.4.4	Output Power	57
4.4.5	Magnetic field	58
4.5	Discussion	59
4.6	Summary	59
 <b>CHAPTER 5 CONCLUSION</b>		<b>60</b>
5.1	Introduction	60
5.2	Conclusion	60
5.3	Recommendation	62
<b>REFERENCES</b>		<b>64</b>
 <b>APPENDIX A</b>		<b>67</b>
 <b>APPENDIX B</b>		<b>68</b>
 <b>APPENDIX C</b>		<b>79</b>

## LIST OF TABLES

Table 4.1	Voltage harvested at a frequency of 4.43 Hz	49
Table 4.2	Boosted voltage from boost converter	50
Table 4.3	Voltage harvested at a frequency of 5.58 Hz.	50
Table 4.4	Boosted voltage from boost converter	50
Table 4.5	Voltage harvested at a frequency of 6.58Hz	51
Table 4.6	Boosted voltage from boost converter	51
Table 4.7	Output current of the vibration harvester at different vibrating frequency	55
Table 4.8	Output power of three different vibrating frequencies	56

## LIST OF FIGURES

Figure 1.1	Schematic of electromagnetic power harvester	2
Figure 2.1	Resonance-based inertial electromagnetic	5
Figure 2.2	Illustration of pin-pin mounting model of piezoelectric generator	6
Figure 2.3	Periodic Vibration	8
Figure 2.4	Random Vibration	9
Figure 2.5	Electromagnetic induction	10
Figure 2.6	Magnetic flux through a planar surface	11
Figure 2.7	Magnetic flux through a non-planar surface	11
Figure 2.8	Determination of the direction of induced current by the right-hand rule	12
Figure 2.9	Conventional single magnet and coil	13
Figure 2.10	Repulsively stacked multilayer magnets and independent coils	14
Figure 2.11	The boost converter configuration	15
Figure 2.12	The two circuit configurations of boost converter (a) On Time (b) OFF time	15
Figure 2.13	Waveforms of current and voltage in a boost converter operating in continuous conduction mode	16
Figure 2.14	Inductor Current (blue) and switch node voltage (red) waveforms (a) CCM operation (b) DCM operation	18
Figure 2.15	PWM graphs respective to duty cycle	19
Figure 2.16	Simulation outputs of current, switching transistor and output voltage	20
Figure 2.17	Block diagram of the proposed boost converter	21
Figure 2.18	Output DC voltages in function of input AC voltage provided by ideal source, simulation (lines), measurement (symbols)	22
Figure 2.19	Energy harvesting circuit	23
Figure 2.20	Proposed direct ac-to-dc converters: (a) secondary side diode based topology and (b) split capacitor topology	24
Figure 3.0	Project Flowchart	27
Figure 3.1	Project Flowchart (continuation)	28
Figure 3.2	Block diagram of Vibration power harvester	29
Figure 3.3	DC-DC boost converter circuit designs	30
Figure 3.4	Schematic diagram of vibration power harvester	31
Figure 3.5	Mechanical design of vibration power harvester	32
Figure 3.6	PVC Closer	32
Figure 3.7	Harvester body before winding.	34
Figure 3.8	Neodymium Iron Boron Magnet	35
Figure 3.9	Magnet placed inside closer	36
Figure 3.10	Coil wire	37
Figure 3.11	Coil winded Harvester	37
Figure 3.12	Bridge Rectifier	39
Figure 3.13	Full wave rectifier circuits	40

Figure 3.14	Capacitor	41
Figure 3.15	Inductor	41
Figure 3.15	IRFZ44N Mosfet	42
Figure 3.16	Resistor	43
Figure 3.17	Light emitting Diodes	44
Figure 3.18	Arduino uno	44
Figure 3.19	Assembly Harvester with circuit	45
Figure 3.20	Harvester mounted to the Mass spring system	47
Figure 3.21	Testing voltage output from boost converter	48
Figure 3.22	Experiment setup	49
Figure 4.1	PWM output for average duty cycle (50.00%)	52
Figure 4.2	DC-DC boost converter circuits	53
Figure 4.3	Experimental setup	54
Figure 4.4	Voltage versus shaking time for vibration frequency of 4.43 Hz	55
Figure 4.5	Voltage versus shaking time for vibration frequency of 5.58 Hz	55
Figure 4.6	Voltage versus shaking time for vibration frequency of 6.58 Hz	57
Figure 4.7	Output current versus time for 3 different vibrating frequencies	57
Figure 4.8	Output power versus Time taken	58

## LIST OF SYMBOLS

A	Area
$\omega$	Vibration frequency
E	Electromagnetic induction
N	Number of turn
B	Magnetic flux
$V_{in}$	Input voltage
$V_{out}$	Output voltage
$V_b$	Voltage boosted
D	Duty cycle
L	inductor
C	Capacitor
F	Frequency
mV	Milivolt

## ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Prof.Dr.Ajisman Apen for his encouragement, invaluable guidance, and constant support in making this research possible. He is always willing to help me when I am facing some problems in this research. I appreciate his consistent support thanks for his tolerance of my mistake during the research.

My sincere thanks go to all the staff of Manufacturing Engineering Faculty, UMP my friends and my lab mates who always helps me when I need help. Many special thanks to all of them for the support, advice and inspirations.

Lastly, I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream, and sacrifice throughout my life.

## ABSTRACT

A vibration Energy harvester was designed and fabricated. A proper boost converter is designed for the harvester, and then the output voltage of the boost converter is tested with several changes on the shaker parameter. The manipulating variables that were used during this project were frequency of vibration and the shaking time. The frequency used in the experiment is 4.43Hz, 5.58Hz and 6.58Hz. Whereas the time of shaking is 1minute, 2minutes, 3 minutes, 4 minutes and 5 minutes. The type of permanent magnet used is Neodymium Iron Boron. The diameter of permanent magnet used is 20mm and the thickness of the magnet is 5mm. The diameter of coil used in this project is 0.35mm, while the number of coil turn is 1000 turn. The maximum voltage<sup>3</sup> can be achieved for the designed harvester is 1.31V at 6.58Hz for 5 minutes. From the results it can be concluded that increasing the time of shaking and frequency can increase the voltage output further higher.

## ABSTRAK

Satu penjana tenaga melalui getaran telah direkabentuk dan difabrikasi. Satu litar elektrik untuk meningkatkan voltan daripada penjana itu juga telah direkabentuk dan difabrikasi. Litar tersebut telah diperiksa dengan mengubah beberapa pembolehubah. Antara pembolehubah dalam projek tersebut adalah, frekuensi getaran dan masa getaran. Frekuensi getaran yang telah digunakan dalam ujikaji ini ialah 4.43Hz, 5.58Hz dan 6.58Hz. Manakala, masa getaran yang telah ditetapkan ialah, 1minit, 2minit, 3minit, 4minit and 5minit. Magnet yang digunakan dalam projek ini ialah Neodymium Iron Boron. Magnet yang digunakan mempunyai diameter sebanyak 20mm dan ketebalan sebanyak 5mm. Gegalung tembaga mempunyai ketebalan sebanyak 0.35mm dan sebanyak 1000 pusingan telah dibuat keliling penjana tersebut. Voltan maxima yang boleh dicapai pada frekuensi 6.58 dalam masa 5minit ialah 1.31V. Melalui experimentasi yang dibuat, kita dapat memahami, bahawa voltan penjana akan meningkat apabila frekuensi dan masa getaran meningkat.



## **CHAPTER 1**

### **INTRODUCTION**

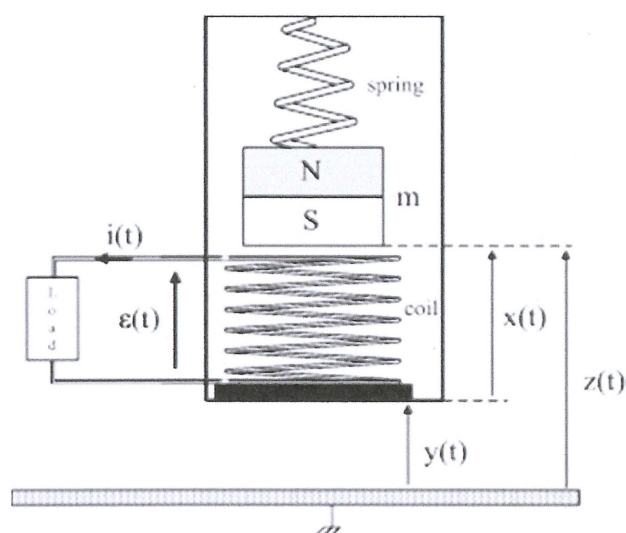
#### **1.1 Project Background**

This project is all about designing a boost converter for experimental study of an energy harvester. Energy harvesting is a process of energy scavenging from the surrounding environment. There are so many methods to harvest energy from the environment such as harvesting electricity from the waste heat released from any system, thermoelectricity, mechanical motion of oceans waves, and some more(Faruk,2007).The energy that can be harvested make wireless system to be battery independent.

Nowadays the technology becomes more advanced and the system starts to become smaller. However, the energy needed to supply the portable devices is still not enough to power them. Scientists continue to research on high density batteries but still the power produced is finite and low, which reduce the life span of the system. The electronic devices that can work in long term have more advantages in a system which limits accessibility.

The application of vibration energy harvester in our life is well discussed (Seah & Eu, 2009).There are several categories for the vibration harvester such as electrostatic (Balato, 2015), piezoelectric (Sodano & Inman,2004), (Zhang,2014) and (Saadon, 2011) and electromagnetic( Glynne-Jones, 2004 ).However, this paper only based on the research of vibration power harvester. Figure below shows on of the schematic of electromagnetic power harvester. The current actually is induced by the magnetic field of the magnet which induces EMF in the coil (Williams, 1996).However, electromagnetic vibration energy harvesters can only produce small amount of voltage usually less than 1V and it's not able to

power up a household or even a normal circuit such as a cell phone powered by a single cell. An electrical circuit is needed to extract, convert, and condition the harvested voltage to be utilized by the load. This paper presents the design, implementation of a DC–DC boost converters which step up the lower voltage produced by the vibration energy harvester to higher voltages and experimental study on the vibrational energy harvester.



**Figure 1.1** Schematic of electromagnetic power harvester

Source: Balato (2017) .

## 1.2 Problem Statement

Energy harvesting is a technology that has been widely used in our world. There are so many ways to harvest energy from the environment for example electromagnetic vibration, ocean waves, solar power or even wind energy. In this project, vibration energy harvesting has been selected as the main energy harvesting source. The challenge of using vibration energy harvester is that, the output from vibration energy harvester is very low and not suitable to power up even a single cell powered phone. Thus, we need an electrical circuit to improvise the output from the vibration energy harvester.

Moreover, electrical devices always need a constant power supply for example a phone battery with 5v charging requirement need constant supply of 5v to be charged fully and supplying with variable power wont charge the phone. Same goes for the outputs from the vibrating energy harvester. Since the environment is not constant and the ambient energy changes according to the time variances, we need to make constant outputs which can supply electrical devices. Other than that, the vibration based energy harvester can only operate in low frequency characteristic of 1 Hz to few kHz. Thus optimum operating conditions for the harvester that can produce maximum output voltage have to be determined.

### **1.3 Project Objective**

The objective of this paper is briefly explained below:

- To optimize the energy Harvested through DC-DC boost converter using PWM method.
- To design and fabricate a Vibration Energy Harvester.
- To analyze the Voltage output of the boost converter by varying different parameters of the Harvester.

### **1.4 Scope of the Project**

The project scope could describe a project of a lot larger size than intended so a set of delimitations are set up. There are many ways of harvesting energy. One can extract energy from almost all kinds of processes and force, e.g. Chemical, kinetic etc. In this project it is chosen only to focus on the vibration energy sources. The number of turn and type of magnet used in this vibration energy harvester is constant. The boost converter obtains developed using MOSFET, diode and more convenient components. Thus, the experiment conducted is only based on different number of magnet and shaker frequency.

## REFERENCES

- A.Hadni, Applications of the pyroelectric effect, J. Phys. E., vol. 14, no. 11, p. 1233, 1981.
- Balato, M., et al. (2017). "Resonant electromagnetic vibration harvesters: Determination of the equivalent electric circuit parameters and simplified closed-form analysis for the identification of the optimal diode bridge rectifier DC load." International Journal of Electrical Power & Energy Systems 84: 111-123
- Balato, M., et al. (2015). Closed-form analysis of Switchless Electrostatic Vibration Energy Harvesters. Ecological Vehicles and Renewable Energies (EVER), 2015 Tenth International Conference on, IEEE.
- Bertacchini, A., et al. (2010). 250mv input boost converter for low power applications. Industrial Electronics (ISIE), 2010 IEEE International Symposium on, IEEE.
- Cao, X., et al. (2007). "Electromagnetic energy harvesting circuit with feedforward and feedback DC–DC PWM boost converter for vibration power generator system." IEEE Transactions on Power Electronics 22(2): 679-685.
- ] C. R. Fuller, Introduction to Mechanical Vibrations, pp. 1–24, 1996
- Dayal, R., et al. (2011). "Design and implementation of a direct AC–DC boost converter for low-voltage energy harvesting." IEEE Transactions on Industrial Electronics 58(6): 2387-2396.
- Dwari, S., et al. (2008). Efficient direct ac-to-dc converters for vibration-based low voltage energy harvesting. Industrial Electronics, 2008. IECON 2008. 34th Annual Conference of IEEE, IEEE.
- E. Torres and G. Rincon-Mora, Energy-harvesting chips and the quest for everlasting life, IEEE Georg. Tech Analog, pp. 1–6, 2005.
- F. Yildiz, Potential Ambient Energy-Harvesting Sources and Techniques, J. Technol. Stud, pp. 40–48, 2007.
- Glynne-Jones, P., et al. (2004). "An electromagnetic, vibration-powered generator for intelligent sensor systems." Sensors and Actuators A: Physical 110(1–3): 344-349



- H. Kulah and K. Najafi, An electromagnetic micro power generator for low-frequency environmental vibrations, pp. 237–240, 2005.
- J. a. Paradiso and T. Starner, Energy scavenging for mobile and wireless electronics, IEEE Pervasive Comput., vol. 4, no. 1, pp. 18–27, 2005.
- Mohan, N., Tore, M.U., and William, P.R. 2002. Power Electronics: Converters, Applications, and Design. 3rd ed. New York: Wiley.
- Mustapha, N. A. C., et al. (2015). "A DC-DC circuit using boost converter for 12(4): 272.
- R. V. Dukkupati, Introduction to Mechanical Vibrations, Solving Vib. Anal. Probl. Using MATLAB, pp. 1–13, 2007.
- Sabate, J., et al. (1990). DESIGN CONSIDERATIONS FOR HIGH-VOLTAGE HIGH-POWER FULL-BRIDGE ZERO-VOLTAGE~ SWITCHED PWM CONVERTER. IEEE APEC.
- S.-D. Kwon, J. Park, and K. Law, Electromagnetic energy harvester with repulsively stacked multilayer magnets for low frequency vibrations, Smart Mater. Struct. vol. 22, no. 5, p. 55007, 2013.
- Seah, W. K. G., et al. (2009). Wireless sensor networks powered by ambient energy harvesting (WSN-HEAP) - Survey and challenges. 2009 1st International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology.
- Sodano, H. A., et al. (2004). "A review of power harvesting from vibration using piezoelectric materials." Shock and Vibration Digest 36(3): 197-206..
- Singh, J., et al. (2011). A sub-threshold passive step-up rectifier for vibration energy scavengers. Proceedings of the 11th Workshop on Micro and Nanotechnology for Power Generation and Energy Conversion Applications, Cell Bench Research Center, KAIST.
- S. Meninger, J. O. Mur-Miranda, R. Amirtharajah, A. Chandrakasan, and J. H. Lang, Vibration-to-electric energy conversion, IEEE Trans. Very Large Scale Integr. Syst., vol. 9, no. 1, pp. 64–76, Feb. 2001.
- S. Roundy, P. Wright, and J. Rabaey, A study of low level vibrations as a power source for wireless sensor nodes, Comput. Commun. vol. 26, no. 11, pp. 1131–1144, Jul. 2003.
- S. Roundy and P. K. Wright, A piezoelectric vibration based generator for wireless

electronics, Smart Mater. Struct. vol. 13, no. 5, pp. 1131–1142, 2004.

Williams, C. B. and R. B. Yates (1996). "Analysis of a micro-electric generator for microsystems." *Sensors and Actuators A: Physical* 52(1): 8-11.

Yildiz, F., Zhu, J., & Pecan, R., Guo, L. (2007). Energy scavenging for wireless sensor nodes with a focus on rotation to electricity conversion. *American Society of Engineering Education*, AC 2007-2254

Zhang, Q. and E. S. Kim (2014). "Vibration energy harvesting based on magnet and coil arrays for watt-level handheld power source." *Proceedings of the IEEE* 102(11): 1747-1761.