DESIGN AND FABRICATION OF VIBRATION BASED ENERGY HARVESTER FOR WIRELESS SENSOR NETWORK

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

December 2012

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.

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Mohd Shahrir Bin Ibrahim

ABSTRACT

Energy harvesting is the process by which energy is derived from the external sources from hydropower, solar energy and many more. This project involves in the design and characterization of vibration based electromagnetic energy harvester system. This type has high potential to be investigated and utilized. The main purpose of this project is to improve the previous design and suitable to be used for low power applications such as the wireless sensor network. In developing the new prototype, both electrical and mechanical improvement of the previous design are considered. Utilizing the fundamental Faraday's law, it serves as a succinct summary of the ways a voltage (or emf) may be generated by a changing magnetic environment. The expectation of the new prototype is the improvement of the overall efficiency in both the output power and also bandwidth. The prototype is design using the engineering software tools such as AutoCAD. Finally, the completed design will be followed by device fabrication. To investigate the performance of the prototype, both the electrical and mechanical characterization have been performed such as the open and close loop voltage, impedance matching, resonant frequency and bandwidth. From the characterization process, it was found that the open-loop and close-loop voltage produces by the device is 5.729 V and 2.920 V, device internal resistance is 560 Ω , device resonant frequency occurred at 29.4 Hz and device bandwidth 9 Hz which are better than the previous prototype.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

EH	Energy Harvester
E.M.F	Electromotive Force
AC	Alternating Current
DC	Direct Current
PVC	Polyvinyl Chloride
VEHS	Vibration Energy Harvester System

CHAPTER 1

INTRODUCTION

1.1 Background Of Study

Energy is important in our daily life. From lighting, house appliances, automotive to telecommunication equipment, all of that utilizes energy. But from where these energy come from? Basically, most of the energy used today is from the fossil fuels. Fossil fuels are the most popular non-renewable energy that always preferred by the civilization. Every year, this type of energy increases their cost. The fuel cost affects the price of each watt that we are using today. To reduce the dependency of the fossil fuels, alternatives energy that is renewable type of energy is being considered.

Intensive research has been conducted to find the alternative energy. By now, only the solar and hydropower are very popular and been used by most of the country in the world. The weakness of both of the energy is it dependency on the natural sources itself, as example hydropower needs water reservoir and the solar needs sun light. Alternative energy which can reduce certain dependency to above mentioned parameters is started to get attention especially in a country where green technology is a priority.

The advantage of using renewable energy is they are produce little pollution, greenhouse gases, and may cost less if produce in large quantity. This interesting technology that can harvest free energy may come from heat, electromagnetic wave, or even vibration. This project involves in developing a vibration based electromagnetic energy harvester system.

1.2 Problem Statement

Nowadays, electronic devices are commonly used such as hand phone, Wi-Fi system, and wireless sensor network. These devices actually utilize low power but still depend on the electrical grid supply to operate. Some of it uses battery as power source which either need to be replaced or recharge. Too many chemical based batteries will harm the environment. On the other hand, instead of using the common method of power source, vibration energy which may comes from vehicle motion on the road is wasted and can be harvested.

1.3 Objectives

The objectives of this final year project are:

I. To capture the energy from the vibration so that it can be used as an alternative source of power up the wireless sensor network or low power electronic component

II. To improve the previous design and fabricate a vibration based energy harvester to harvest vibration energy produced by road traffic.

III. To characterize the performance of the vibration based energy harvester.

CHAPTER 2

LITERATURE REVIEW

2.1 Energy Harvester

Today, renewable energy is getting important and recognition by many countries. One of the important behind of all renewable energy sources is the energy harvester. Energy harvesting is the process to derive the energy from the external sources [1].

Solar energy is the conversion of sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power (CSP). Solar technologies characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy [2]. The main advantages of solar power lie in its ability to generate electricity without producing greenhouse gas emissions and other forms of air pollution. Figure 1 shows the process of solar energy.

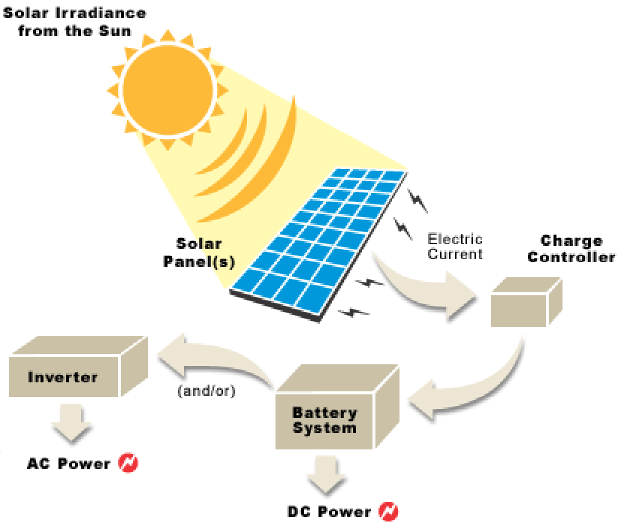


Figure 1: Solar energy

The second type shown in the Figure 2 is the wind energy. The wind is a natural source that exists because of uneven heating of the atmosphere by the sun, the irregularities of the earth's surface and the rotation of the earth. The wind energy harvesting is generated by the rotation of turbine that is converting the mechanical energy to the electrical energy. The motor connected to the turbine will rotate at the same time with the blade which connected with gear box on the shaft. This process can induce the current in the coil winding and lastly can generate a scale of power output that can be used for homes, building and more depend on the type of the turbine be used [3].

Figure 2: Wind energy

The third type is the thermal energy harvesting. The thermal energy is mean of kinetic energy that is derived from the internal energy of a system. The energy exists because of the collision by the random movement between the molecules. This kinetic energy can be eventually converted to the heat energy. The electric energy can be generated from the heat energy through the rotating turbine [4].

2.2 Type of vibration energy harvester

This section elaborates different type of vibration based energy harvester system. Vibration energy can be divided into several types such as electrostatic, piezoelectric and electromagnetic.

The first type vibration energy is the electrostatic energy harvesting. Figure 3 shows the displacement of plates in the capacitor due to vibration. Vibrations separate the plates of an initially charged variable capacitor. The stored charges create an electric field and therefore, a potential difference between the conductors (plates). Basically, the charges stored in the capacitor will be converted into electrical energy.

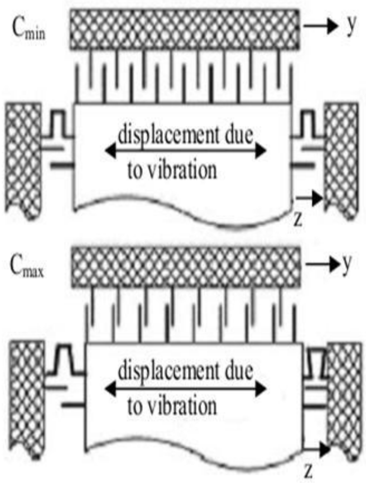


Figure 3: Electrostatic Energy Harvesting.

The second type is the piezoelectric energy harvesting. The piezoelectric components as shown in the Figure 4, where deformations produced by different means is directly converted to electrical charge via direct piezoelectric effect. Piezoelectric effect is the converse effect in which stress is produced in a crystal as a result of an applied potential difference [5].

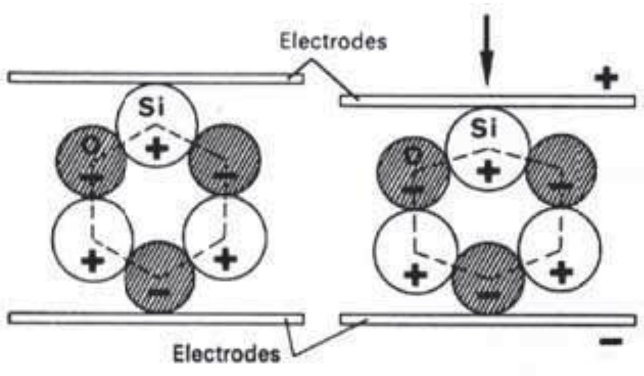


Figure 4: Piezoelectric material structure

The third type is an electromagnetic energy harvester. By the use of the Faraday's law and the electromagnetic force (EMF), the current will be induced when the permanent magnet is move across the coil winding. The vibration will produce a force to move the permanent magnet. This situation can be translated in the figure below where the movement (mechanical energy) is converted to the electrical energy [6].

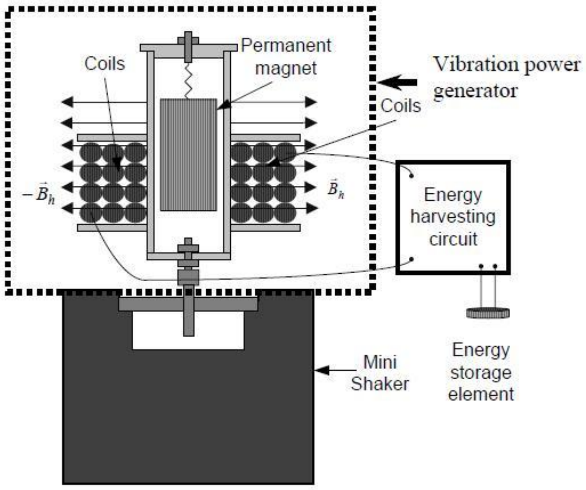


Figure 5: Electromagnetic Energy Harvester

Electromagnetic use Faraday's law as it principle. Faraday's law is the fundamental relationship which comes from Maxwell's equation. It serves as a succinct summary of the ways a voltage (or e.m.f) may be generated by a changing magnetic environment. The induced e.m.f in a coil is equal to the negative of the rate of change of magnetic flux times the number of turns in the coil. It involves the interaction of charge with magnetic field [7]. The relationship between the e.m.f produced and the changing in magnetic flux is given by

Faradays Law equation

$$EMF = -N \frac{\Delta\Phi}{\Delta t}$$

Where N= Number of turns

$\Phi = BA =$ Magnetic flux

B= External magnetic field

A= Area of coil.

The minus sign denotes Lenz Law. E.m.f is short form of electromotive force, the term for generated or induced voltage.

The weakness of the renewable energy is they are difficult to produce stable output. To overcome this problem, it needs to have another device to improve the output at least in the stable capacity. Furthermore, the suitable device can solve this problem is the energy harvester module that will discussed in Section 2.3.

2.3 Energy Harvester module

Energy harvester is a module that can receive instantaneous of input voltages up to +/- 500V of AC/DC voltage [8]. These modules actually use to catch and store the energy from the external sources and give the stable output depending on the type of energy harvester. There are four common energy harvester (EH) can be used in electrical and electronic design. Different type of EH produce different of output in term of voltage and current. The Figure 6 shows the EH module and the different category of EH module is listed in Table 1.

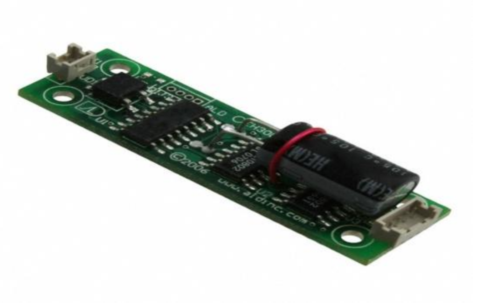


Figure 6: Energy Harvester EH300 Modules

Table 1: Energy Harvester Specification.

Type of Energy Harvester (EH)	Voltage Low (VL)	Voltage High (VH)	Maximum Output Current (Amp)
EH300	1.8V	3.6V	1A
EH300A	1.8V	3.6V	
EH301	3.1V	5.2V	
EH301A	3.1V	5.2V	

2.31 Energy Harvester (EH) working principle

This section explains the operation of the energy harvester module. Figure 7 shows waveforms of EH300/EH301 module.

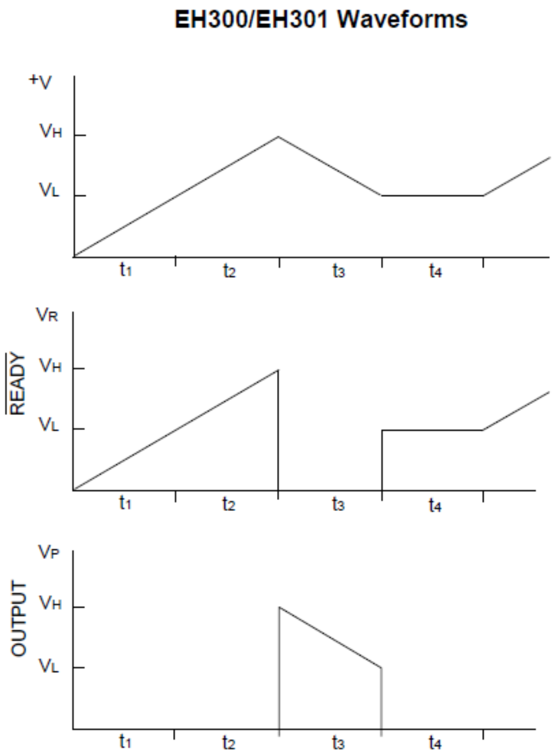


Figure 7: Waveform of Energy Harvester

Based on the waveform in the Figure 7, the function of the EH is noted with V_L and V_H which given the ON/OFF state. The modules are charging the voltage until it reaches the V_H (ON state) which the modules can supply power to the power load. The output V_P will be stayed in ON state until the external energy is lower than the power demand that needs by the power load. +V can increase until internal voltage clamp circuits limit to a maximum clamp voltage (7V). When +V is going down to the level of V_L, it will function in OFF state. In OFF state, there is no output V_P will be supplied. The output will be in ON state when +V has reached the V_H level again.

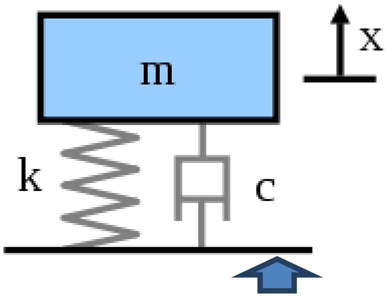
Prior to the designing or fabricating the energy harvester system, one should perform adequate study on its dynamic behavior in order to obtain a desired performance of the device. The understanding in theory and mathematical of the vibration is important in fabricating a good prototype. This will be elaborate in Section 2.4.

2.4 Concept of Operation of Electromagnetic Vibration Energy Harvester

An electromagnetic harvester uses the principle of a spring-mass system to convert energy of vibration into electrical energy. Mechanical motion of the mass is converted into electrical energy by electromagnetic coupling between the magnet attached to the mass and stationary coil [9].

2.41 Vibration Law

The definition of vibration is a rapid oscillation of a particle, particles, or elastic solid or surface, back and forth across a central position. For example, consider the system in the Figure 8, spring is connected between mass and the base. At first, the extended of the spring by a value of x and therefore have stored some potential energy ($\frac{1}{2}$ kx^2) in the spring. At the point where the spring has reached its un-stretched state all the potential energy that we supplied by stretching it has been transformed into kinetic energy ($\frac{1}{2}$mx^2).



Y (*road vibration to the base)*

Figure 8: Vibration system.

Ideally, the system will continue to oscillate forever at the same magnitude, but in real system there is always damping element (denoted as "c") which functioned as energy absorber to dissipate the energy, thus bring the system to rest.

As stated in equation of motion of the system, *y(t)* denotes as the displacement of the base and *x(t)* is the displacement of the mass from its static equilibrium position at time t.

The equation of motion of such system is given as follow [10].

$$m\ddot{x} + c(\dot{x} - \dot{y}) + k(x - y) = 0 \tag{1}$$

If $y(t) = Y \sin \omega t$, the above equation becomes

$$\begin{aligned} &m\ddot{x} + c\dot{x} + kx = c\dot{y} + ky = kY \sin \omega t \\ &\theta = A\sin\left(\omega t - a\right) \end{aligned} \tag{2}$$

where $A = Y\sqrt{k^2 + \left(c\,\omega\right)^2}$ and $a = \tan^{-1}\left(-\frac{c\omega}{k}\right)$. This shows that giving excitation to the base is equivalent to applying a harmonic force of magnitude A to the mass. By using saluting of Eq. (3), the steady-state response of the mass $x_p(t)$, can be expresses as in Eq. (4).

$$\begin{aligned} &x_p(t) = \frac{F_0}{[(k - m\omega^2)^2 + c\omega^2]^{\frac{1}{2}}} \sin\left(\omega t - \phi\right) \\ &x_p(t) = lm\left[\frac{F_0}{k} \,|\, H(i\omega) \,|\, e^{i(\omega t - \phi)}\right] \end{aligned} \tag{3}$$

$$x_p(t) = \frac{Y\sqrt{k^2 + (c\omega^2)^2}}{[(k - m\omega^2)^2 + c\omega^2]^{\frac{1}{2}}} \sin\left(wt - \phi_1 - a\right) \tag{4}$$

$$\phi_1 = \tan^{-1}\left(\frac{c\omega}{k - m\omega^2}\right)$$

where $\omega_n = \sqrt{\frac{k}{m}}$, is the natural frequency of the system and ω is the frequency of the excitation signal. Using trigonometric identities, Eq. (4) can rewritten as

$$x_p(t) = X \sin\left(\omega t - \phi\right) \tag{5}$$

where X and ϕ is given by

$$\frac{X}{Y} = \left[\frac{k^2 + (cw)^2}{(k - m\omega^2) + (c\omega)^2}\right]^{\frac{1}{2}} = \left[\frac{1 + (2\xi r)^2}{(1 - r^2)^2 + (2\xi r)^2}\right]^{\frac{1}{2}} \tag{6}$$

$$\phi = \tan^{-1}\left[\frac{mc\omega^3}{k(k - m\omega)^2 + (c^2\omega)}\right] = \tan^{-1}\left[\frac{2\xi r^3}{1 + (4\xi^2 - 1)r^2}\right] \tag{7}$$

The frequency ratio $r = \frac{\omega}{\omega_n}$, must be kept within $0 < \omega/\omega_n < 1$, to avoid having the response of the system deviate 180° (when $\omega/\omega_n > 1$) from the normal condition.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter elaborates on the methodology of the energy harvester development. The flow of the project development is discussed in Section 3.2 followed by Section 3.3 which discusses on the project activities. In Section 3.4 and Section 3.4 touch about the prototype testing and the prototype design.

3.2 Flow chart

Figure 9 shows a flow chart consisting of the planned process workflow for this project. Initially prior to the new prototype construct, the previous prototype was properly analyzed so that the new improvement can be made. The new improvement will also base on the journals, books and articles. Next, the approval design will be fabricated and tested in the vibration laboratory. Finally, the vibration energy harvester system will be characterized and tested with the suitable applications. If the completed prototype has not obtained the acceptable result, the harvester system will going back to the design and fabrication stage.

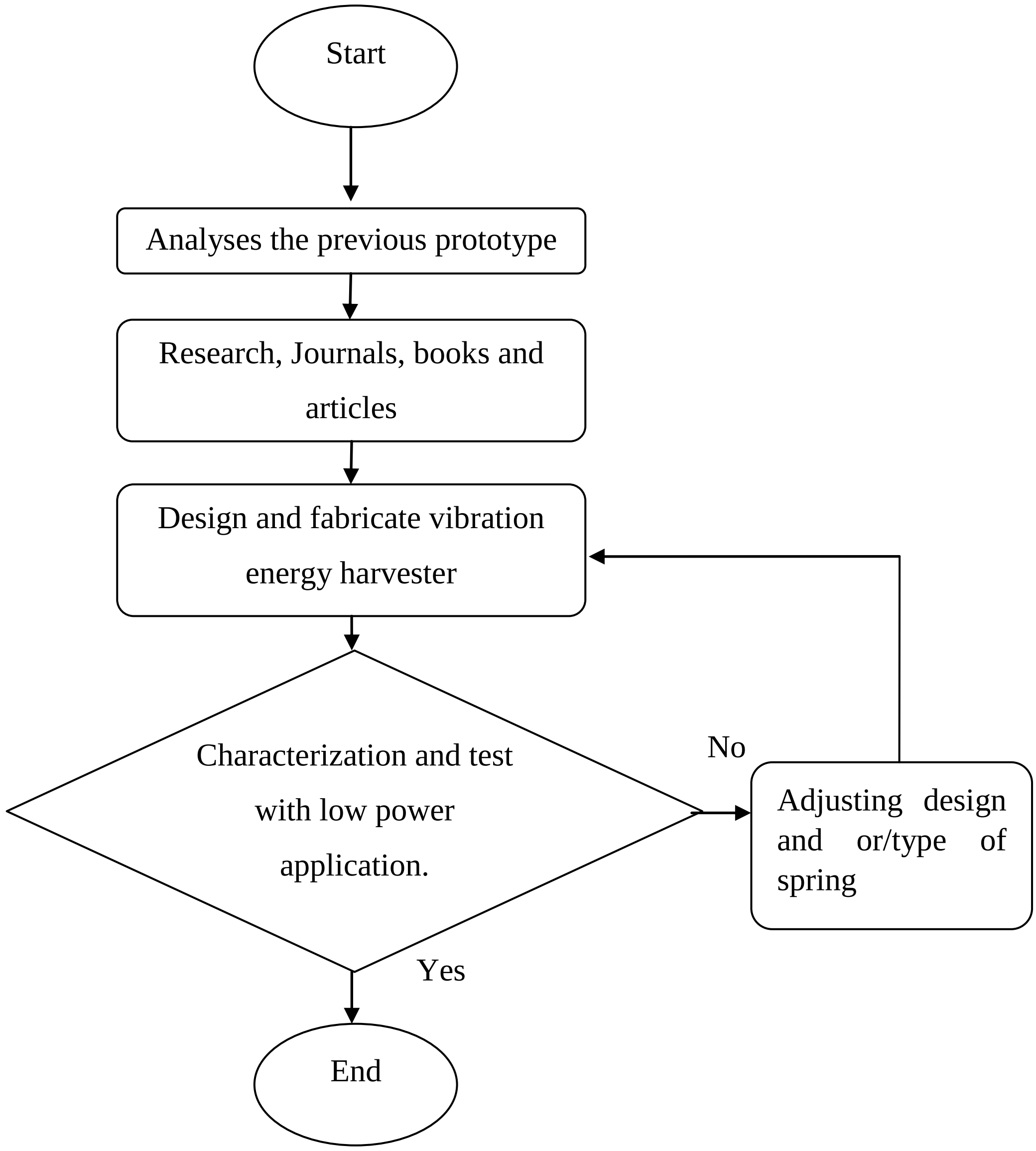


Figure 9: Process of designing and fabricating a vibration driven energy harvester.

3.3 Project Activities

This section explained on the project activities during completion the new vibration energy harvester system. The activities including preliminary research, recognize and improve the weakness of the previous system, design the new vibration energy harvester, fabrication and testing, testing with the low power applications and the last activity is about acquisition of data analysis.

Table 2: Project Activities

Activity	**Description**
Preliminary Research	The process of gathering information regarding the project from the previous prototype to the tools to be used in this project such as hardware and software..
Recognize and improve the weakness of the previous design.	Previous prototype analysis and weakness identification and necessary improvement necessary.
Designing vibration energy harvester	From the weakness of the previous prototype, several t new designs are proposed and drafted using AutoCAD and Google Sketchup software.
Fabrication and testing	The selected design will be fabricated and tested in the dedicated electrical and mechanical laboratories.
Testing the design with the low power wireless sensor network.	The aim of this project is to make sure the wireless sensor network will work by using the power supply from the energy harvester.
Data Analysis	Analysis the result of each characterization obtained from the experiment.

3.4 Prototype design

In this subchapter, the technical information about sketching, fabrication process and specification of the material used are explained. Prior to the drafting the design of the prototype, Google Sketchup, a simple 3D drawing software is used to sketch the improved energy harvester system as shown in the Figure 10 until Figure 12.

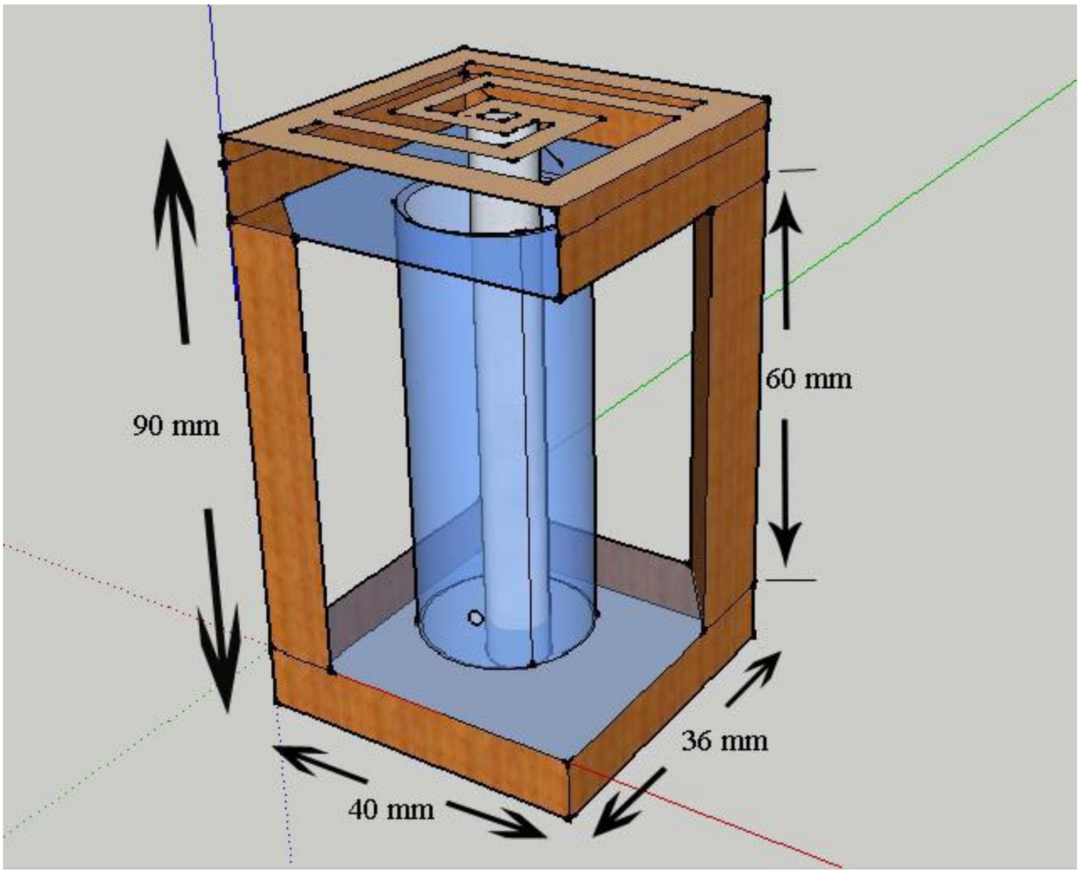


Figure 10: 3 dimension view of the Energy Harvester

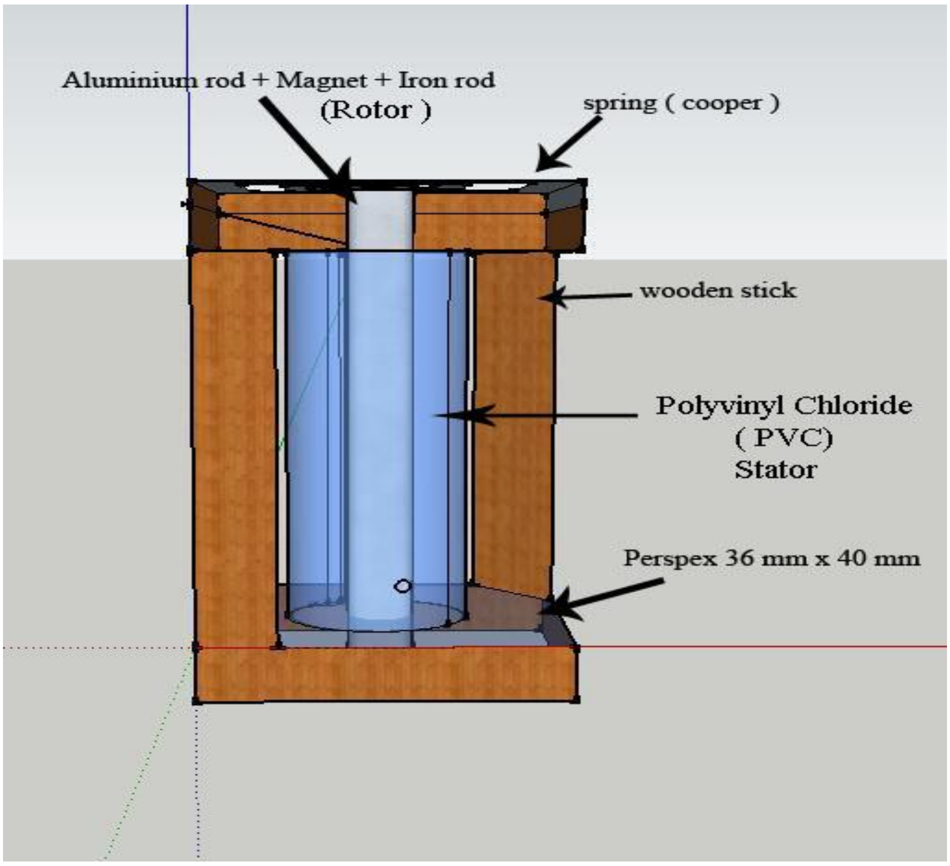


Figure 11: Side view

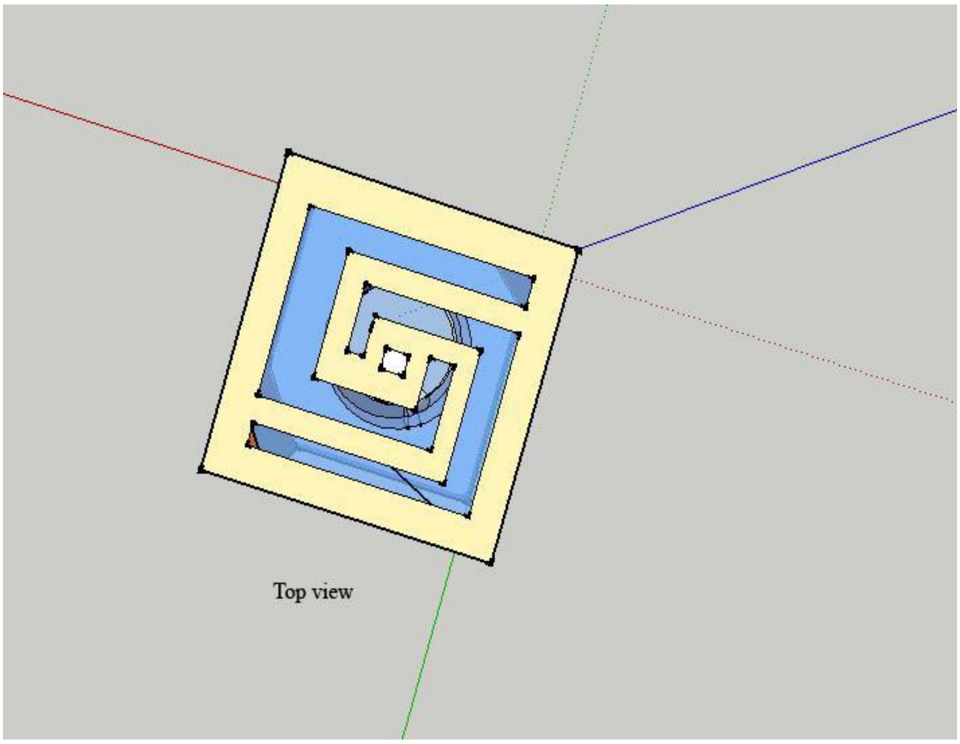


Figure 12: Top view

The prototype consist of three main parts namely stator, rotor and body. Each of main parts is very important to have the working energy harvester system . The explaination will be start with the first part which is stator and followed by rotor and the body part.

i. Rotor

Rotor is the moving part of the device and its comprise of 4 Neodymium cylindrical magnets, each height about 5 mm and 10 mm in diameter. The magnet has a remanence of 1.2 T and weight 2.86 g each. The magnet and the rod was stacked together. At each ends of the stacks, 2 aluminum rods sized 32 mm and 28 mm long with similar diameter attached. The magnet separated in two part, each part has two 2 magnet attach together and between this two parts are connected with 10 mm iron rod. Figure 14 shows how the magnets, aluminium rods and iron rod are integrated together.

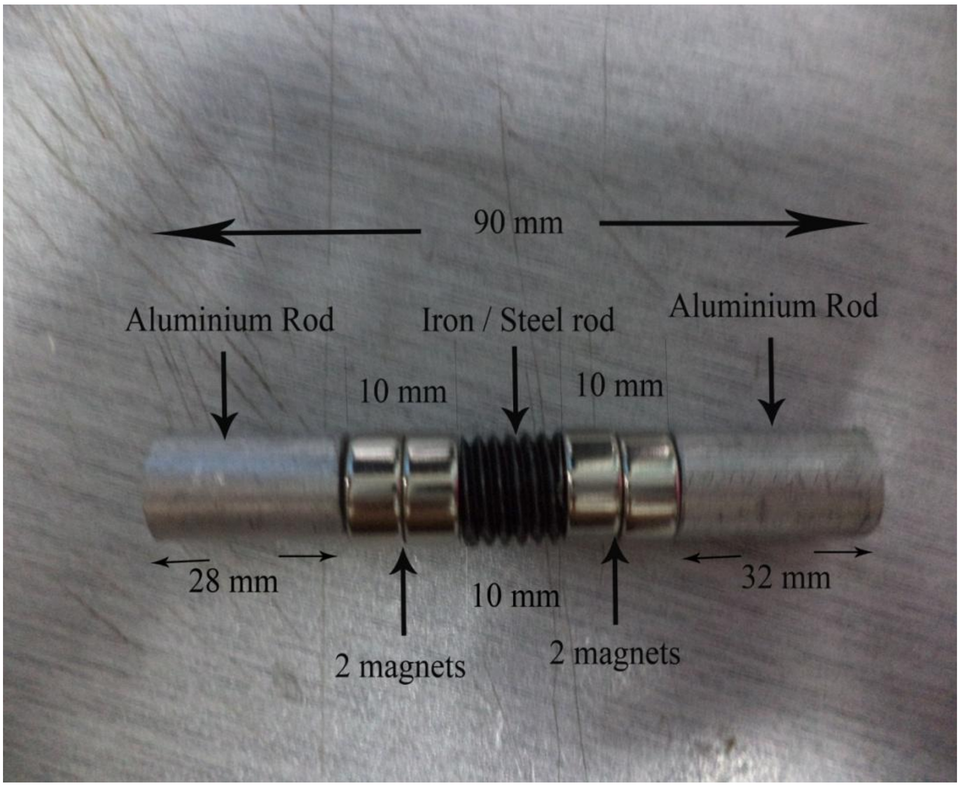


Figure 13: Rotor of the system

The rotor is connected to the centre spring as shown in Figure 15 made of copper sheet at both ends. Cooper sheets as shown in Figure 14 is used to produce 37 mm wide and 40 mm long spring fitted to the prototype . This type of spring is specially designed and fabricated through a Printed Circuit Board (PCB) process which was done UTP PCB Laboratory. As in prototype, this spring provide support and help the rotor to oscillate efficiently as well as to replace the previous type of springs which were made of plastic sheet.

Figure 14: Copper sheet

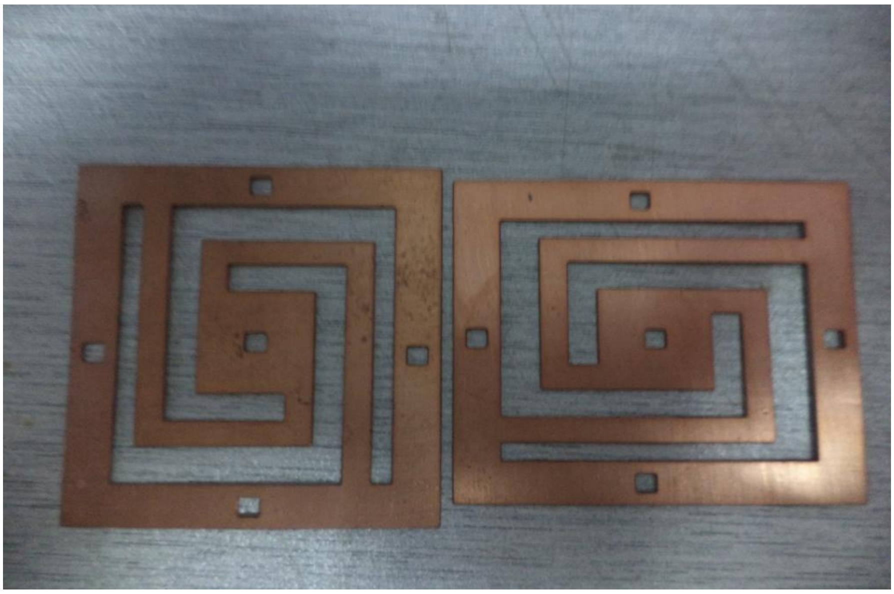


Figure 15: Copper spring after finishing PCB process .

ii. **Stator**

Stator is the stationary part of the system. Here, the stator consist of 65 mm long Polyvinyl Chloride (PVC) pipe and winding. PVC is choses as the stator since ferromagnetic material like iron or steel will attract the stator. As for the winding, enamelled cooper wire with a diameter of 0.10 mm is used to make the coils. The higher the number of turns in the winding, the more magnetic field can be captured. At the same time, the internal resistance also will be increased due to the winding. Therefore, it will reduces the current as the result of higher internal resistance The Figure 16 shows the stator with winding around it.

Figure 16: Stator part of the system

iii. Body

The body of the prototype comprises of wooden stick and two 36 mm x 40 mm perspex sheet with a 16.5 mm diameter hole which is used to hold the stator and rotor. Wooden stick is primarily used in this project due to its light weight and soft in nature that enables to absorb vibration more effieciently. Furthermore, heavier material will increase the overall mass of the prototype that will reduce the capability of the system to vibrate.

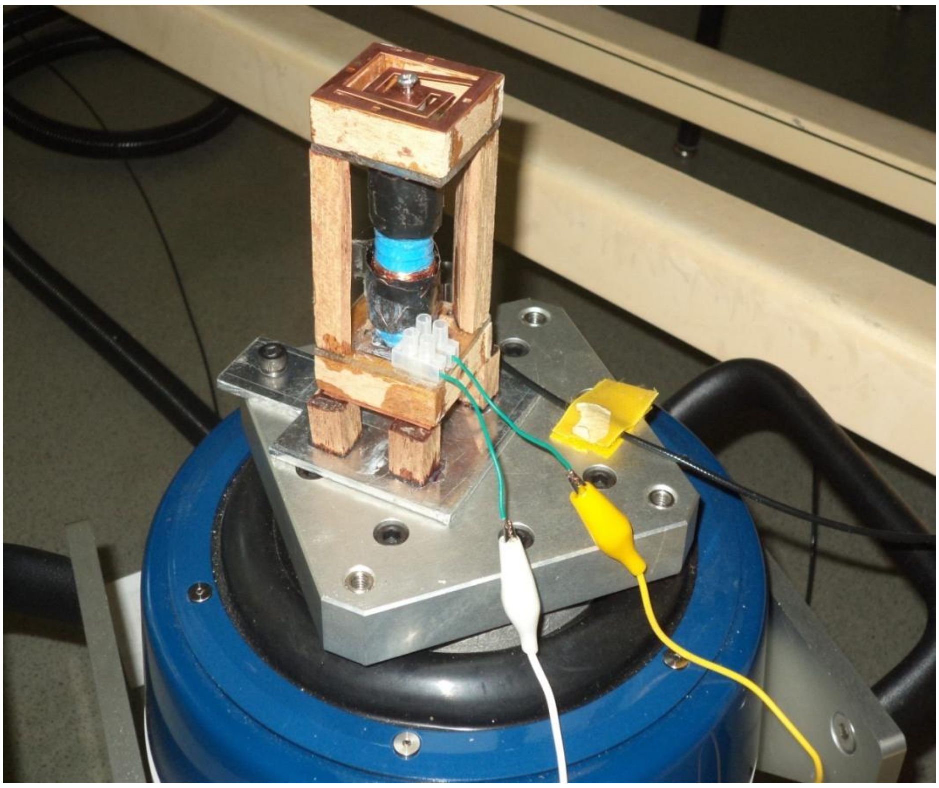


Figure 17: Completed prototype mounted on the shaker.

Figure 18 shows the completed prototype with additional of four 15 mm long wooden stick used as the legs connected to the aluminium base to create a space for the rotor to oscillate. The overall height of the prototype is 110 mm and weight is around 65 g.

3.5 Prototype Testing

After the fabrication of the prototype is completed, the device is tested to observe its performance. The test is done in laboratory using vibration generator to simulate the vibration that existed on the road due to traffic. The prototype is mounted to the shaker and the test condition is defined from the PC (first monitor) through the vibrator generator interface. Next, a signal is send to the vibration controller to produce the predefined signal according to the setup from the PC. The control signal from the controller will go to the amplifier before the signal is further forwarded to the shaker. The shaker will produce a vibration according to the test condition defined earlier. The PC (second monitor) is use to monitor the test results. The process is repeated until acceptable results are obtained. The equipment setup shows in Figure 18.

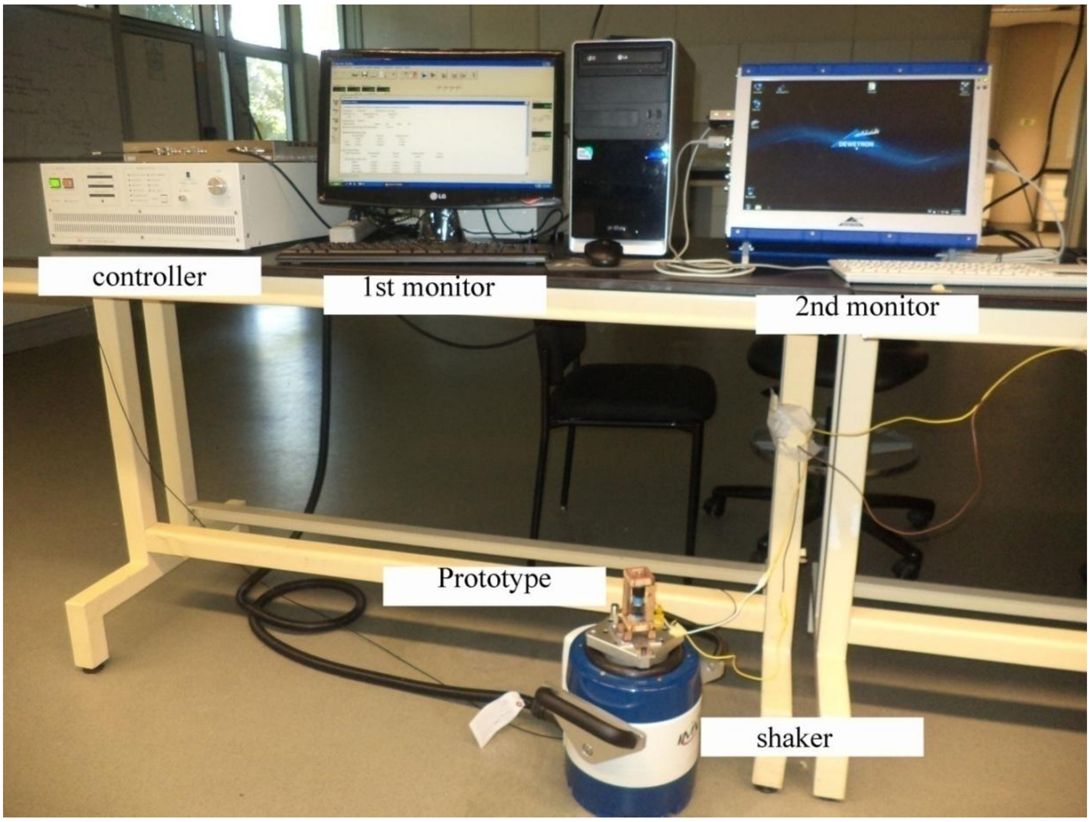


Figure 18: Experimental equipments.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter elaborates the prototype construction and characterization. Prototype construction is discussed in Section 4.2 followed by characterization process in Section 4.3 until Section 4.35. Topic of interest for the characterization of energy harvester consists of the determination of device resonance frequency, damping ratio, bandwidth, impedance matching and power output at various gravity acceleration (G). Additional analysis consists of the integration of energy harvester with the energy harvester is also discussed in Section 4.36.

4.2 Vibration Based Energy Harvester Prototype Development

Energy harvester prototype can be divided into several sections such as harvester base construction, spring design, magnet selection, type of material use, and rotor design. The base of the harvester consists of 4 poles made from wood which are attached to two square Perspex sheet. The harvester includes 4 magnets, combining iron and 2 aluminium rods, coils and moving regions. The flux direction of the 4 magnets is vertical. Thus, 2 poles in the rotor are made by 4 magnets. The two springs made of copper were attached to the vertical rotor. Finally, all the parts are integrated together to form the complete energy harvester system as shown in Figure 19.

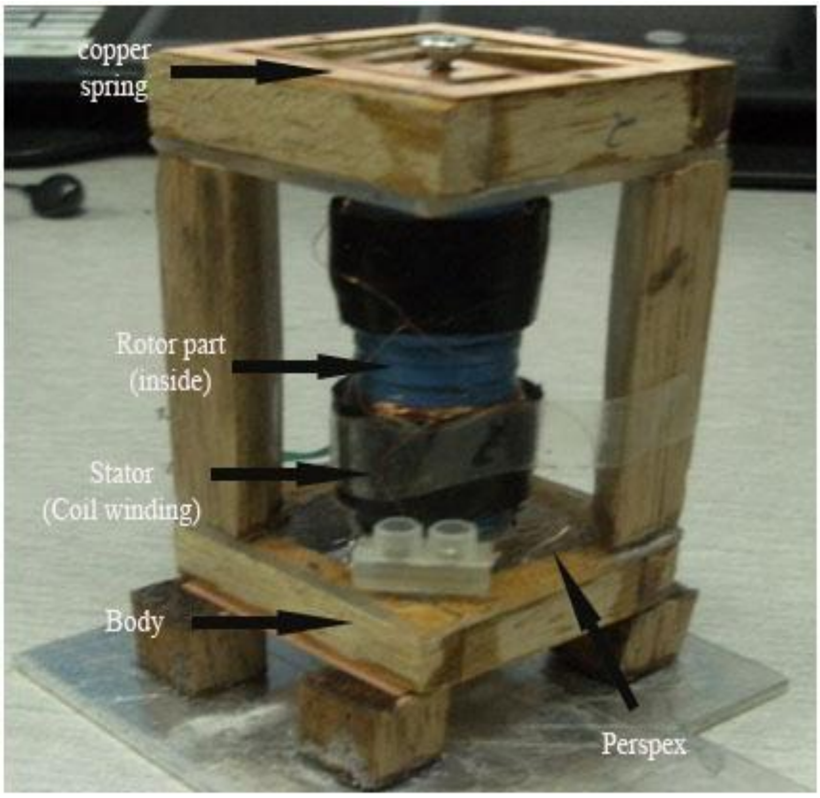


Figure 19: Completed prototype.

4.3 Characterization of energy harvester

This section discusses on the static and dynamic characterization of the energy harvester system which include the determination of device resonance frequency, damping ratio, bandwidth, impedance matching and followed by power output at various gravity acceleration (G).

4.31 Resonance frequency.

Prior to static and dynamic characterization of the prototype, proper equipment setup is required as shown in Figure 20. A total five equipments are utilized to complete the characterization process. The first equipment is the monitor system 1 which used for controlling the shaker. Next is the monitor system 2 which is known as the dynamic analyzer specifically used for data acquisitioning from energy harvester and the reference accelerometer. The third equipment is the shaker system which provides a vibration, shock, or modal excitation source for testing and analysis. The fourth equipment is shaker controller which used to run the desired test within the capabilities of the system, and to stop the test if those capabilities are exceeded or the test fails to perform properly. The fifth equipment is the prototype which gives the output for the testing analysis.

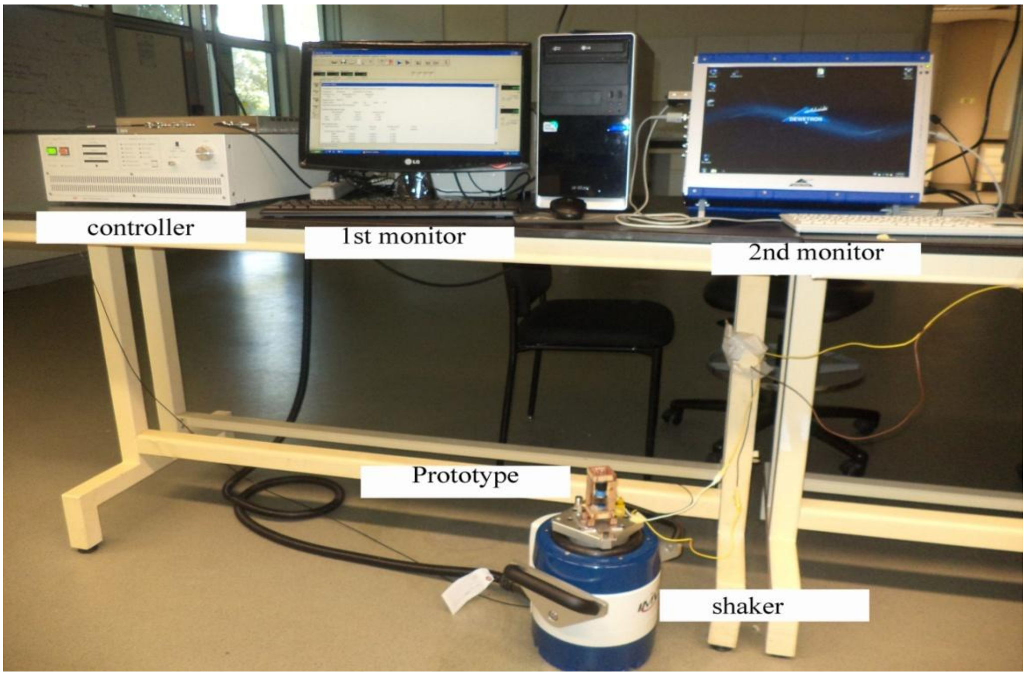


Figure 20: Equipment Setup

The first characterization is prototype resonance frequency determination. The resonance is the tendency of a system to oscillate at a greater amplitude at some frequencies that at others [11]. Starting from 10 Hz with the increment 0.1 Hz, the output (voltage) will oscillate and keep increasing up to some point until it gradually decreases. The Figure 21 shows that the highest amplitude occurred at approximately 29.4 Hz with results 3.4 V peak-to-peak voltage. The acceleration used in this experiment is 2.5 m/s^{-2} or 0.25 G.

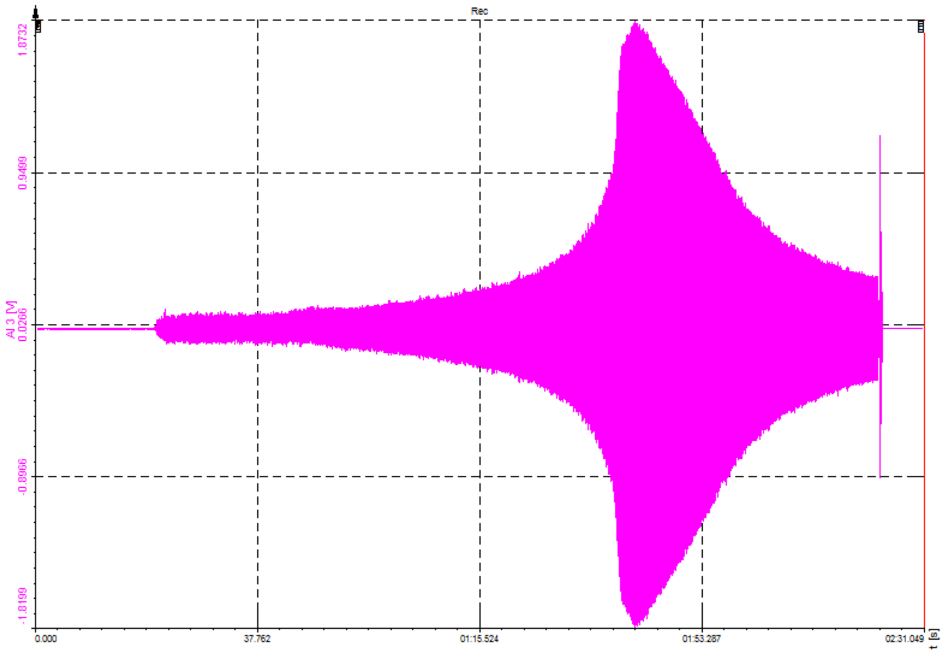


Figure 21: Resonance frequency at 29.4 Hz.

4.32 Damping ratio of the system

Damping is an effect that reduces the amplitude of the oscillations in an oscillatory system [12]. To find the damping ratio, the system needs to be stretched once and let the system rest naturally. This experiment resulted in the decaying sinusoidal graph can be analyzed using dynamic analyzer. The two values of the voltage from the graph, noted as X1 and X2 used to calculate the damping ratio. Figure 22 and Figure 23 show the response of the system under impulse stretch for the load and un-load conditions.

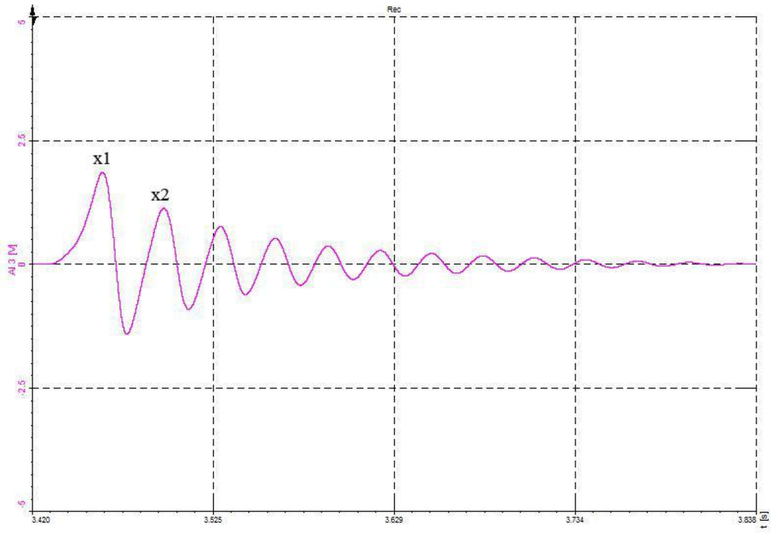


Figure 22: Damping with load 600 Ω .

Calculation for damping ratio with load 600 Ω :

$$\delta = \ln\frac{x1}{x2} = \ln\frac{1.8427}{1.1275}$$
$$\delta = 0.491$$
$$\zeta = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}} = \frac{0.491}{\sqrt{(2\pi)^2 + 0.491^2}}$$
$$\zeta = 0.0779$$

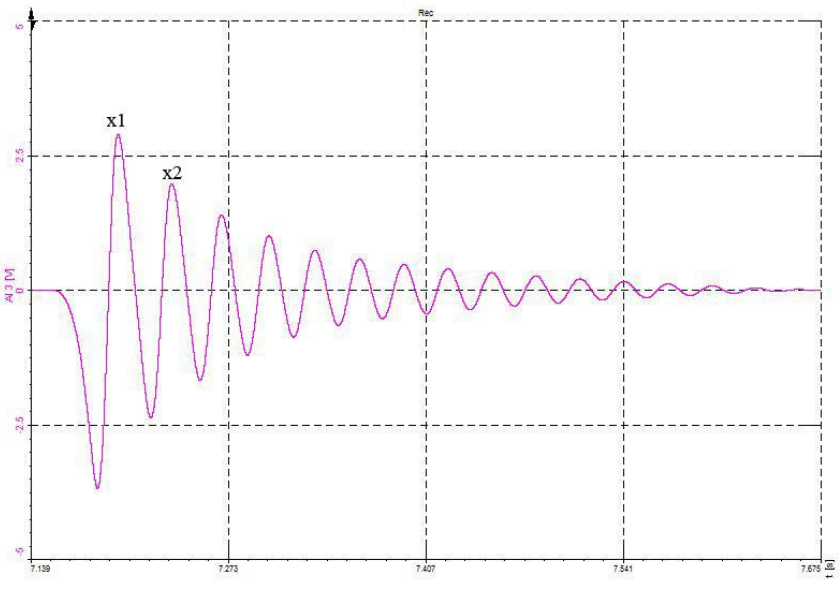


Figure 23 : Damping without load

Calculation for damping ratio without load.

$$\delta = \ln\frac{x1}{x2} = \ln\frac{2.8539}{1.9671}$$
$$\delta = 0.372$$
$$\zeta = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}} = \frac{0.372}{\sqrt{(2\pi)^2} + 0.372^2}$$
$$\zeta = 0.059$$

From both Figure 22 and Figure 23, the value of damping ratio for each experiment can be found by using simple calculation as demonstrated. This value of damping will determine the type damping the system has. Both calculation show the system is under damping, since the damping factor ζ is in the range between $0 \le \zeta < 1$. An under-damped response is one that oscillates within a decaying envelope. The more under-damped the system, the more oscillations and longer it takes to reach steady-state [13].

4.33 Impedance matching

Impedance matching is another important parameter to be determined for optimum power transfer. Impedance matching is determined by the highest power output by the system. Different values of resistors are used to match impedance between the harvester and the load. As explained, the importance of impedance matching is for maximum power transfer and to minimize reflection from the load. Table 2 listed the variation of load used and the average power measured for each load. The maximum power that can be transferred from the harvester is at 600 Ω which produce the output power of 0.862 mW.

Table 3: Impedance Matching at constant acceleration $\frac{1}{4}g$, resonance frequency 29.4 Hz.

Load (kΩ)	Average Power (mW)
0.3	0.795
0.5	0.839
0.6	0.862
0.7	0.861
0.8	0.859
1	0.806
1.5	0.493
2	0.450

4.34 Open loop voltage output of the system in different acceleration of gravity (g)

Normally, the gravity acceleration of the earth is 9.81 m/s^{-2}. In real life, the acceleration of gravity could be changed due to the presence of other factor such as altitude of places and the motion in surrounding for an example the motion of the car on the road. This experiment show the effect of the gravity acceleration to the output in terms of voltage output from the system. The experiment was conducted by running the shaker in four different acceleration at 2.5 m/s^{-2}, 4,9 m/s^{-2}, 7.5 m/s^{-2} , and 9.81 m/s^{-2} . Open loop voltage produced by the energy harvester is shown in Figure 24 while Figure 25 shows the open loop voltage at difference acceleration.

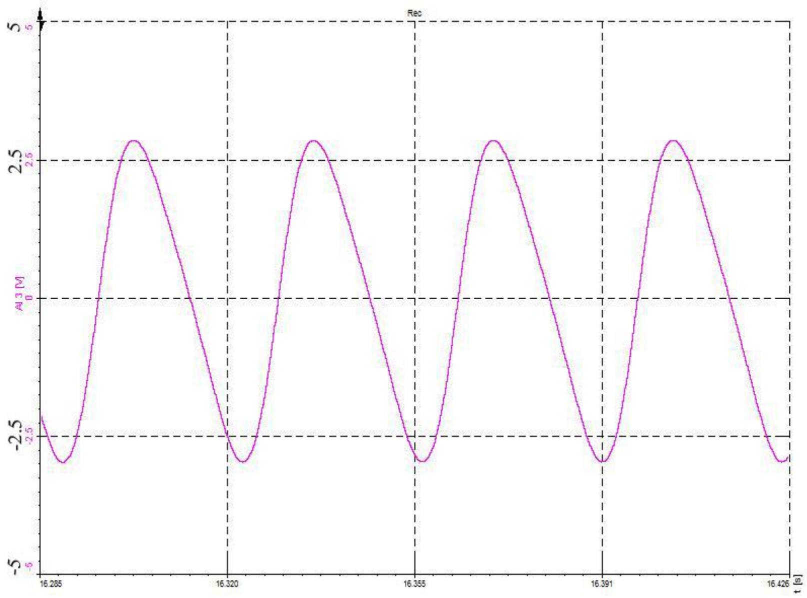


Figure 24: Open loop peak to peak voltage at 0.5G.

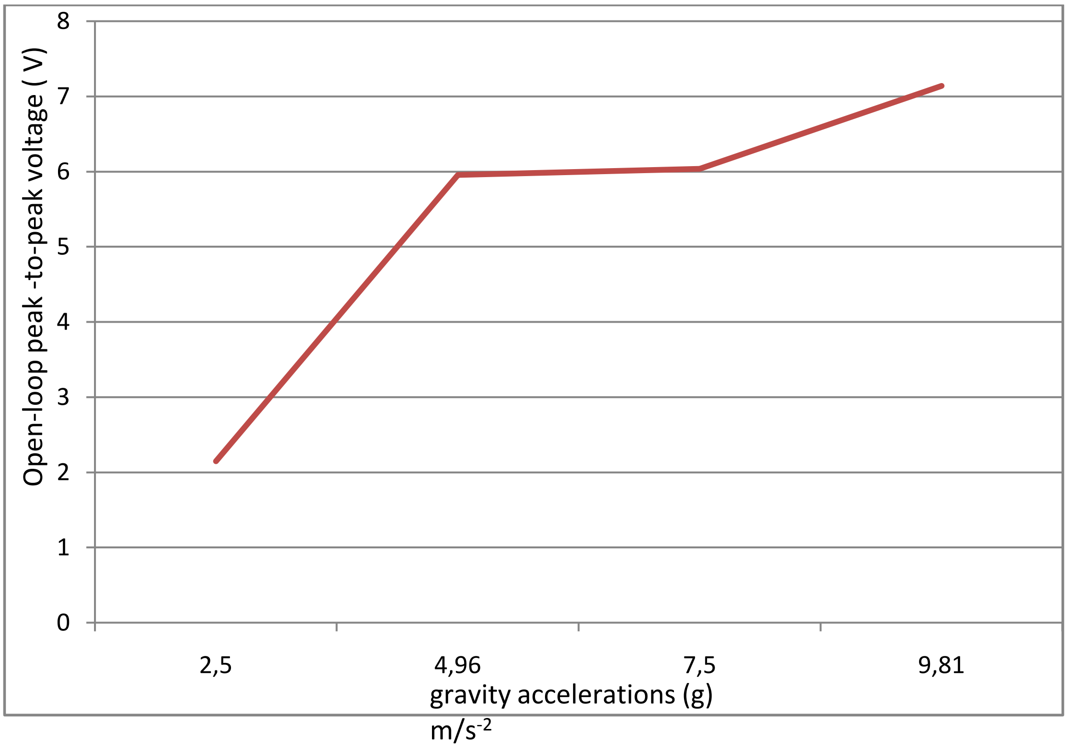


Figure 25: Open-loop peak to peak voltage for various acceleration with constant frequency 29.4 Hz.

Figure 25, it can be concluded that the voltage output keep increasing with the increase of the gravity acceleration.

4.35 Bandwidth of the system.

Bandwidth is a measure of the width of a range of frequencies and for this case, the bandwidth is a range of frequencies where the output is maximum. In order to determine the bandwidth, the sweep type is chose in this testing stage. Sweep rate is used in this characterization is from 15 Hz until 40 Hz. From Figure 26, the maximum power can be transfer is between frequencies of 26 Hz until 35 Hz which give the bandwidth is 9 Hz.

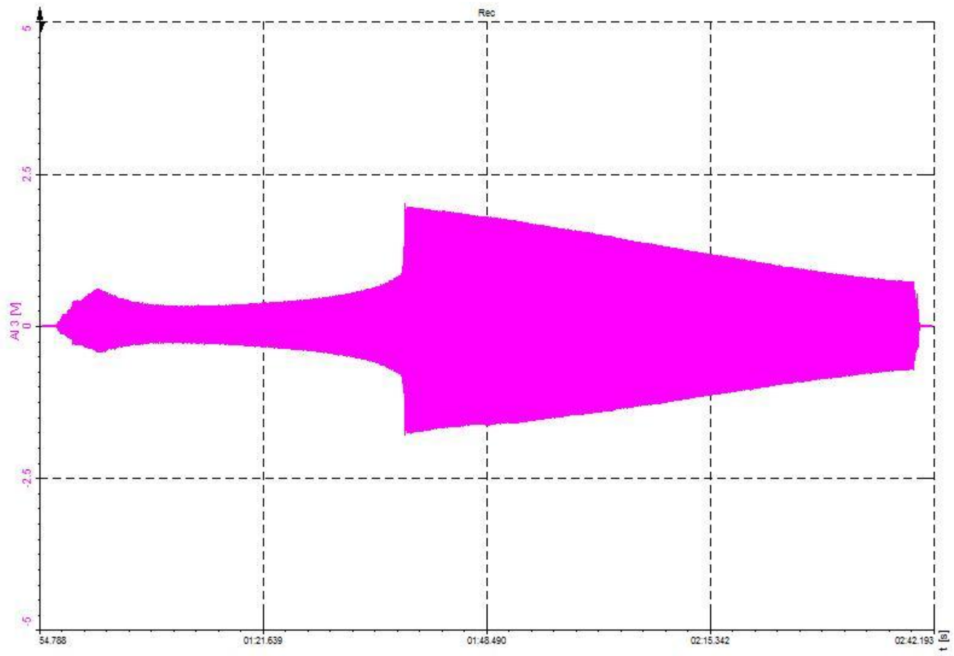


Figure 26: Bandwidth of the system with load 600 Ω and 9.81 m/s^{-2} gravity acceleration.

4.36 Integration of energy harvester with the energy harvester (EH300)

Energy harvesting is defined as the process of capture, accumulation, storage and conditioning of wasted energy from surrounding environmental such as light, temperature and vibration. In this testing stage, the harvester is integrated with the energy harvester as to get the stable and efficient power output. Unfortunately, several tests have been conducted but the problem is the charging time is not acceptable for this experiment. The Figure 27 shows the graph where the harvester is failed to reach the minimum voltage needed by the energy harvester.

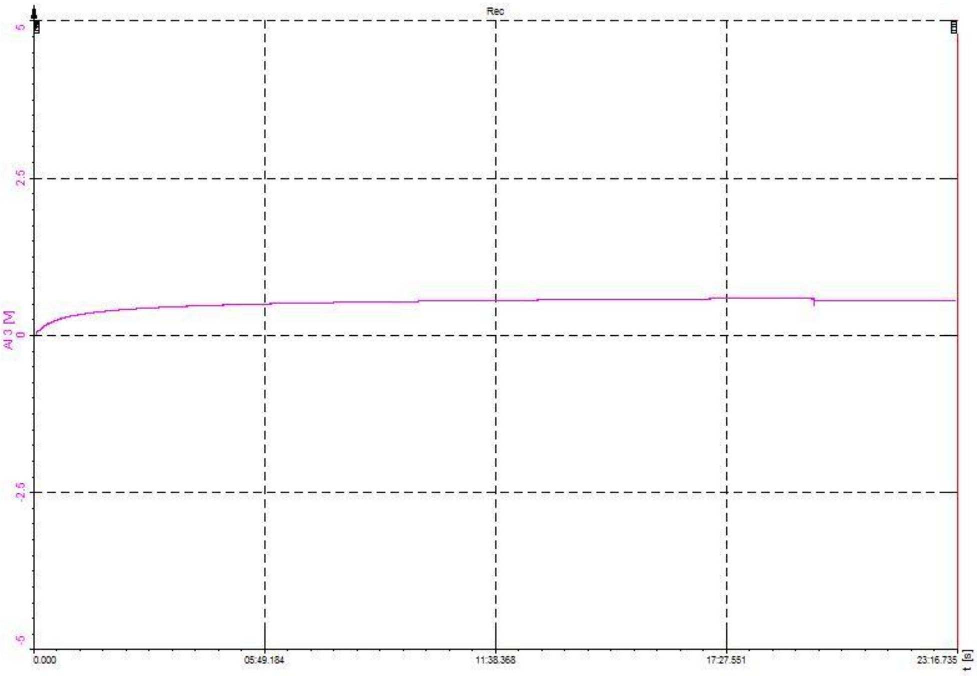


Figure 27: Charging time graph for energy harvester (un-load at 0.5 G)

The result shows that the voltage is at 0.6 V within 10minutes and it did not reach the minimum voltage needed by energy harvester which is 3.6 V. This problem may due to the load of energy harvester itself which does not match with the internal impedance of the harvester.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Energy that is available in our surrounding can be used as an alternative to the fossil fuel. One of the energy available in our proposal is the vibration energy produced by traffic on the road. When a moving vehicle made a contact with the irregularities of the road, a stress wave is generated and will travel to the surrounding area through the soil. In order to harvest this energy, Vibration Energy Harvester System (VEHS) is designed and fabricated. The prototype is first sketched and all the parameters values are presumed. The weaknesses of the previous prototype (from previous FYP) are analyses and improvement in terms of power and voltage for the new prototype are recommended and implemented. Next, the new prototype is properly designed in AutoCAD and Google Sketchup for sketching the body of the system. The new type of material (Copper) for the spring designed using the Eagle software. The spring design is then submitted for Printed Circuit Board (PCB) process which includes mask development and etching using chemical solution followed by a series of static and dynamic test using the vibration generator to characterize the performance of the prototype. Type of characterization including the impedance matching, determination of the bandwidth, resonance frequency of the system and performance with the energy harvester module. Table 3 summarizes the result obtained during characterization stage.

Table 4: Testing result summary at 0.5 G

Parameters	Value
Open loop peak-to- peak voltage (V_{OL})	5.729 V
Closed loop peak-to-peak voltage (V_{CL})	2.920 V
Load (R)	600 Ω
Current (I)	4.866 mA
Power Generated (P_G)	14.214 mW
Internal resistance of the system (R_i)	560 Ω
Resonance frequency (F_r)	29.4 Hz
Bandwidth (BW)	9 Hz

The main objective of VEHS is to provide power to the wireless sensor network. From table 3, it can conclude that the objective of the project was achieved in which the system managed to generate a power of 14.214 mW. This is sufficient since most of the wireless sensor network consume power of 100 µW in average.

5.2 Recommendations

There a many improvements that can be made to produce a more desirable output. For an example, the material used to produce the spring can be selected from materials which have higher yield strength to avoid structure damage during high G test or longer testing duration at lower G operation. This improvement will enhance the efficiency of the system in term of output power and structure robustness. In this project, the spring system which was previously fabricated from plastic sheet was replaced with cooper with thickness of 250 µm. The new material exhibits better stiffness with less structure curling but damage during long acceleration test of more than 1 G. It was found that the new spring system can endure not more than 10 minutes for 1 G gravity acceleration. Improvement in terms of spring shape with equal stress distribution will be able to increase the testing time further.

The prototype can further be improved by reducing its size while maintaining the capability to produce the same or greater amount of output power. In addition, the application of the prototype is not only limited to the vibration of the vehicle on the road. The vehicles itself, machineries, buildings can also produce vibration and suitable energy source for VEHS system.

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