DESIGN ON RAINFALL'S VIBRATION BASED POWER GENERATION MODULE FOR RURAL AREA IN MELAKA

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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This report submitted in accordance with requirement of the Univerisiti Teknikal Malaysia, Melaka (UTeM) for the Bachelor Degree of Engineering Technology Industrial Power with Honours

by

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FACULTY OF ENGINEERING TECHNOLOGY

2016

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **DESIGN ON RAINFALL'S VIBRATION BASED POWER GENERATION MODULE FOR RURAL AREA IN MELAKA**

SESI PENGAJIAN: **2016/17Semester 1**

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor Degree of Engineering Technology Industrial Power with Honours. The member of the supervisory is as follow:

……………………………………

(Encik Muhamad Faizal Bin Yaakub)

ABSTRACT

The project purpose is to design a power generation module that can harvest energy from the rainfall's vibration for rural area in Melaka. Malaysia has equatorial and tropical climate throughout the years with high temperatures in the earlier months and rainy season in the following months. According to Tenaga Nasional's Berhad website portal, the electrical tariffs in Malaysia start increasing since 2014. The objectives are to design a module for alternative power generation which generates electricity by harvesting the natural energy that produced from the raindrops, to analyse the kinetic energy conversion method and its efficiency that affects towards the module, and to verify the module performance which capable to collect data results. Some background research and Multisim simulations will be done. The designing hardware development will be conducted to make it suitable to apply in rural area of Melaka. The data results will be collected from the lab scale testing.

ABSTRAK

Projek ini direkabentuk untuk kegunaan tenaga semula jadi daripada getaran air hujan yang boleh menghasilkan elektrik untuk kegunaan pengguna elektrik di Melaka. Melaka mempunyai cuaca yang sesuai untuk projek ini iaitu cuaca panas di permulaan tahun dan cuaca hujan di bulan yang seterusnya. Mengikut sumber daripada laman web Tenaga Nasional Berhad, elektrik tariffs di Malaysia mula meningkat sejak tahun 2014. Objektif untuk menjalankan projek ini adalah untuk mereka bentuk projek modul dengan menggunakan tenaga semula jadi dalam penghasilan elektrik, meneliti effek tenaga kinetik kepada projek modul dan untuk mengenalpasti kualti projek modul ini. Latar belakang projek modul akan dilakukan serta simulasi daripada software Multisim akan dijalankan. Tujuan untuk merekabentuk projek modul ini supaya dapat diaplikasikan kepada pengguna di Melaka. Data eksperimentasi akan dicatat di dalam ruangan seterusnya.

DEDICATION

To my beloved parents

Kamarudin Bin Abu Hassan

Kamisah Binti Ali

To my supervisor:

Encik Muhamad Faizal Bin Yaakub

ACKNOWLEDGMENT

By the name of Allah, the Most Compassionate Most Merciful. I would wish to show my gratitude to Allah for providing me the blessings to complete this report. I represent my gratitude to Universiti Teknikal Malaysia Melaka (UTeM) for yielding me the opportunities to make this final year project report. I am grateful to my supportive and helpful supervisor, Encik Muhamad Faizal bin Yaakub for assisting and guiding me in the completion of this research. In all truthfulness, without him, the project would not have been a complete one. Encik Muhamad Faizal bin Yaakub has always been my source of motivation and direction. I am truly grateful for his continual support and cooperation in assisting me all the way through the semester

Last but not least, I would wish to give my thanks to my mother, my father, and all my family who has always been in that respect for me. Finally, I would like to express my appreciations to all my friends, colleagues, and everyone who has helped me in this journey. Without their support, I would not have been able to finish my project report.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

The project's introduction, background, problem statement, objectives and project scope will be focused in this chapter. The process and development of the module will be explained more in details throughout the following chapters.

1.0 Introduction

Malaysia is a country that located in the Southeast Asia and has two regions that made up of Peninsular Malaysia and East Malaysia (the Malaysian Borneo). Malaysia is widely known as one the country with tropical climate because of the country is located near the equator of the world. It has equatorial climate with being hot and humid throughout the years. The average amount of rainfall in Peninsular Malaysia is around 2500mm while in East Malaysia is around 5080mm of the rain. The average temperature in Malaysia has range from 20ºC to 30ºC. In the early months of the year, the amount of rainfall is below average. When the rainy season appeared at the end of the year, it caused the amount of the rainfall to increase beyond the average.

Melaka is one of the states that located at the Peninsular Malaysia. There is still villages existed which located in the rural area. Recently, Melaka had experienced flood due to the heavy rain on 7 June 2015. The purpose of this project is to design a power generation module that can harvest the energy from the rainfall's vibration and suitable to be implemented in the rural area of Melaka.

Figure 1.0.1: Peninsular Malaysia and East Malaysia

The energy sector in Malaysia is handled by the Tenaga Nasional Berhad (TNB) which is the largest electric utility company in the Southeast Asia. Recently, the demands in electricity are increasing especially in 2014 and broke a record with the highest electricity demand of history in 2016. The power generation module will be designed and developed. This project will generate electricity to help and support the community that lives in the rural area of Melaka by decreasing their electric bills.

1.1 Background

In this project module, the component of the hardware that will be used is the piezoelectric sensor. The first type of piezoelectric chosen is the Polyvinylidene DiFluoride (PVDF). The PVDF sensor will detect mechanical energy such as strain or vibration energy and convert it to electrical energy. The PVDF sensor is small, flexible and high sensitivity at low frequencies. The structure of the plate is a Polymer film with screen printed silver ink electrodes and laminated with polyester substrate. It also has 2 crimped contacts. The bending of the plate will create high strain and high voltages are generated. The output of the PVDF sensor is sufficient to trigger MOSFET or CMOS stages.

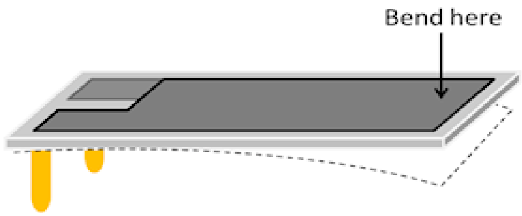


Figure 1.1.1: PVDF piezoelectric transducer

Besides that, the PVDF sensor can act as accelerometer or vibration sensor. The PVDF sensor has been used widely in the several applications such as vibration sensing in washing machine, low power wakeup switch, low cost vibration sensing, car alarms, body movement of machine or robot, and security systems. The PVDF sensor is tested as flexible switch and the results are written in a datasheet as below.

Tip deflection (mm)	Charge output (nC)	A/C Voltage Output (V)
2	3.4	7
5	7.2	15
10	10 - 12	20 - 25
Max (until 90°)	>30	>70

Table 1.1.1: PVDF piezoelectric as flexible switch

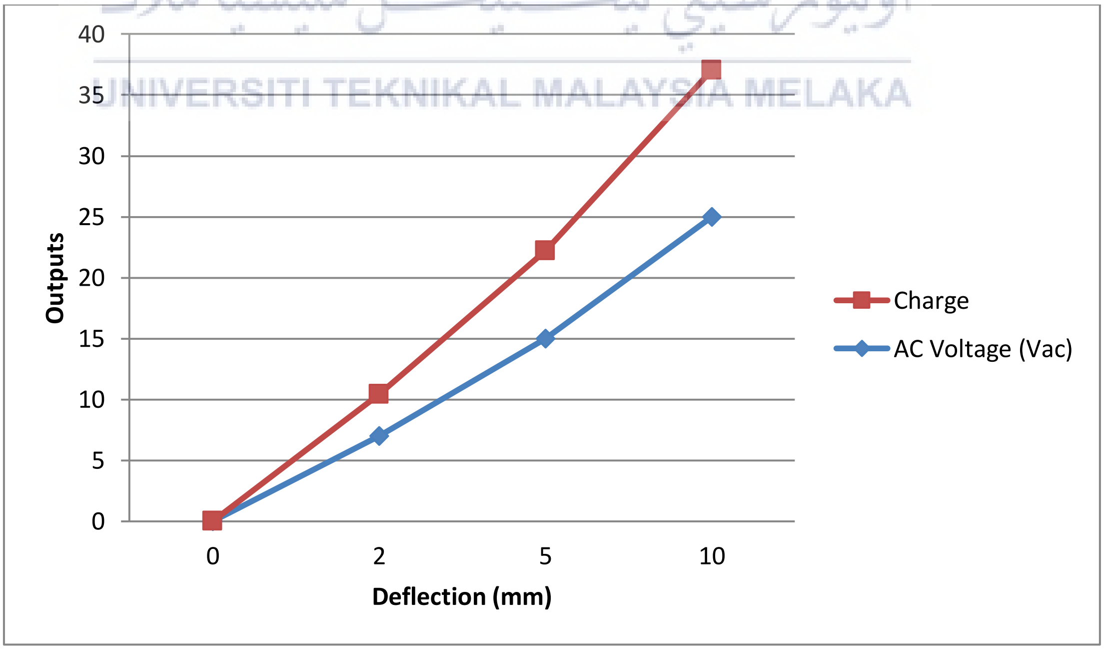


Figure 1.1.2: Graph of Voltage output vs Tip deflection

The second type of piezoelectric transducer chosen is the Lead Zirconate Titanate (PZT). This type of piezoelectric transducer is made from ceramic materials called ceramic perovskite hence when the compound changes its shape when an electrical field is applied. Besides, the PZT has constant sensitivity and inexpensive transducers compared to PVDF. This PZT is one of the piezo ceramics that can withstand any mass or vibration that applied but the PZT’s high sensitivity will degrades over time. Most likely the degradation is related with increased temperature.

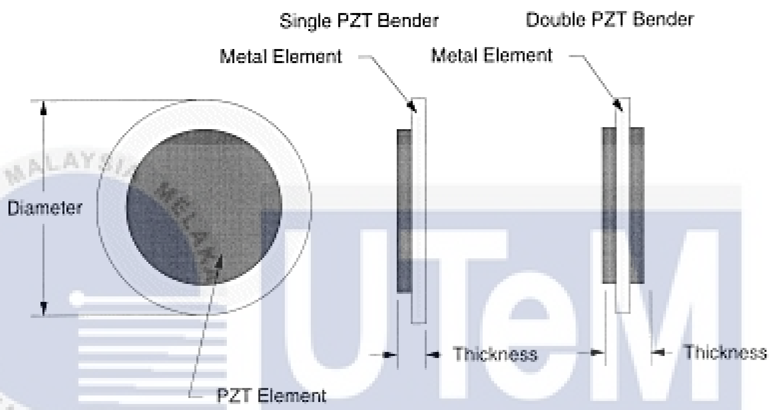


Figure 1.1.3: PZT piezoelectric transducer

The PZT is widely and commonly used as components of ultrasound transducers and ceramic capacitors, scanning tunnelling microscope actuator tubes and atomic-force microscopy actuator tubes. It also used in high value ceramic capacitors and also the FRAM chips. Furthermore, PZT is used in electronic circuits for reference timing as ceramic resonators.

1.2 Problem Statement

Recently, the interest in renewable energy sources and its reliable working is rapidly growing and giving much attention without using conventional thermal power or nuclear plants according to the demand for energy in developing countries by MET (2015a). Energy in the surrounding area can be capture and the latest energy that can be harvest is by converting mechanical energy from raindrop's vibration into electricity that can be used to power sensors or other device by Zyga (2008). Malaysia has equatorial and tropical climate with being hot and humid throughout the years. It will be high temperatures in earlier months and rainy season in the following months. The method of harvesting energy from rainfall is a good alternative as sustainable power system where it is installed in the tropical region with rain season by Wong et al. (2016a) especially in the rural area of Melaka.

The energy demands arise as the years pass on by Warude et al. (2015a). According to Tenaga Nasional Berhad (TNB), the electrical tariffs in Malaysia start increasing in 2014 due to the high demands. The TNB record stated that the demand in electricity start to increase on 28 May 2014 with 16,583MW. In the following years, the latest electrical tariff showed that the electrical bills are also increasing in 2016. According to TNB, the highest electricity demand in Malaysia's history with 17,175MW on 9 March 2016. This record had broken the previous record of 16,901MW in 6 June 2014. This means that the renewable energy sources are focused to avoid environmental and energy crisis by Warude et al. (2015b). The type of piezoelectric plates that will be use is the Polyvinylidene Fluoride (PVDF). Energy generations are done by binding the plates to make the structures vibrate and gain physical strain for generation of electricity by Dakua and Afzulpurkar (2015). When a single raindrop hitting the piezoelectric plates, it generates voltages less than a dozen of volts but no evaluation on power is proposed by Miceli et al. (2014).

The piezoelectric materials are used as mechanisms to transfer ambient motion which is vibration, into electrical energy and stored or used to power devices by Sodano and Inman (2004). In real rainfall, the raindrops' impact has different position of the piezoelectric by Wong et al. (2016b). The powering devices require a size that is suitable with the application, sufficient power and extended lifetime using permanent and ubiquitous energy sources by Park (2010). To solve the problems this module is require to build and to apply in the rural area of Melaka for community usage. Based on the problems, there is a need to design, to configure and to verify this module that will harvest the energy from the rainfall. The most suitable solutions for the low power supply are by using the piezoelectric materials to be use in this project module.

1.3 Project Objectives

This project is the design of rainfall's vibration based power generation module for rural area in Melaka was developed to give more convenience to the user. There are several objectives as follows:

1. To design a module for alternative power generation which generates electricity by harvesting the natural energy that produce from the raindrops. The designated module has to be suitable to use and apply in the rural area.

2. To analyze the output parameters that relates with kinetic energy conversion method and its efficiency that affects towards the module. The effect from the kinetic energy of the raindrops is the impact of the raindrops on the module surface which produce vibration energy.

3. To verify the module performance and efficiency between two types of piezoelectric transducers. The data results are from the field study and lab scale testing. The data parameters involve voltage, current, calculated output power that applied during the rain time.

1.4 Project Scope

According to the Malaysian Meteorological Department, there will be rainy season which means the quantity of the rain in this season is above the average of the amount of rain for every end of the year in Malaysia. This project will focus on the alternative power generation which can harvest the natural energy from the raindrops to produce electricity. The project will be applied in the rural area of Melaka. In 7^{th} June 2015, Melaka was one of the states in Malaysia that experienced flood due to the heavy rain. The simulation that will be used is Multisim software to present the signal output. The hardware of the module will be design using the PVDF (Polyvinylidene Fluoride) piezoelectric.

Field study and field data collection will be taken in the working area only. The instruments that will be use to obtain the data results are parameters of multimeter and calculated power. The multimeter will show the output of voltage and current while the calculated power will present the output power. The cost due to this module will be examined for the community usage. This project has some limitation. The test and measurement are limited to a certain rainy days. The field test will be conduct in Ayer Keroh, Melaka, Malaysia. The project will focus on the development of the module.

CHAPTER 2

LITERATURE REVIEW

2.0 Conditions and weather changes in Malaysia

Malaysia is known as an Asian country that located at the east side of the world which has equatorial and tropical climate throughout the years with high temperatures in several months at the beginning of every year and rainy season in the following months. The sky is always cloudy and the wind is lightly even though the country is located near to the equator of the world. The country has climate with uniformly temperature, high humidity and greater amount of rainfall throughout the years. As the following years passed by, Malaysia is a country whereby the amount of rainfall increases which has proven during year 1975 to 2010 by Syafrina et al. (2014a). Hourly rainfall data between the years 1975 and 2010 across the Peninsular Malaysia were analysed for trends in hourly extreme rainfall events. The analyses were conducted on rainfall occurrences during the northeast monsoon (November–February) known as NEM, the southwest monsoon (May–August) known as SWM, and the two inter-monsoon seasons, March–April (MA) and September–October (SO) by Syafrina et al. (2014b). Malaysia has never run out from direct sunlight except during the northeast monsoon. According to the Meteorology Malaysia (MET) (2015b), the amount of rainfall in Malaysia shows from January 2015 to March 2016.

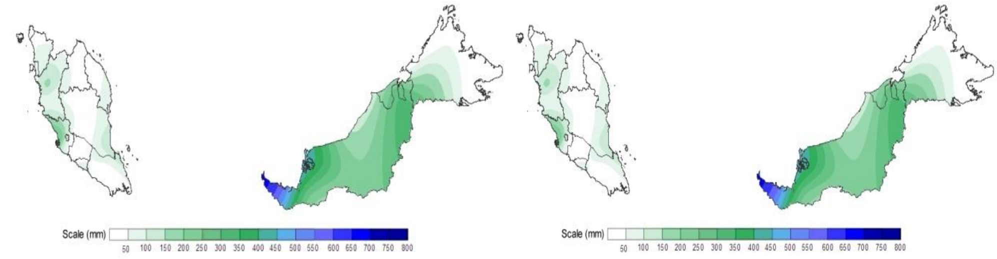


Figure 2.0.1: Northeast Monsoon (NEM) on January 2015 and February 2015

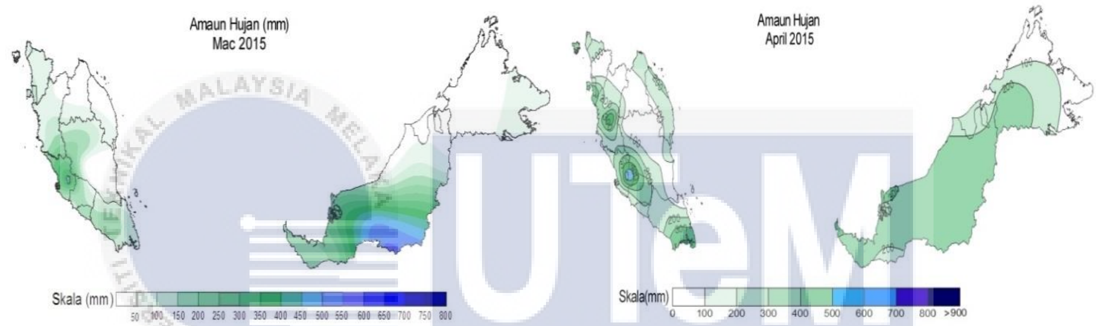


Figure 2.0.2: Two Inter-Monsoon (MA) on March 2015 and April 2015

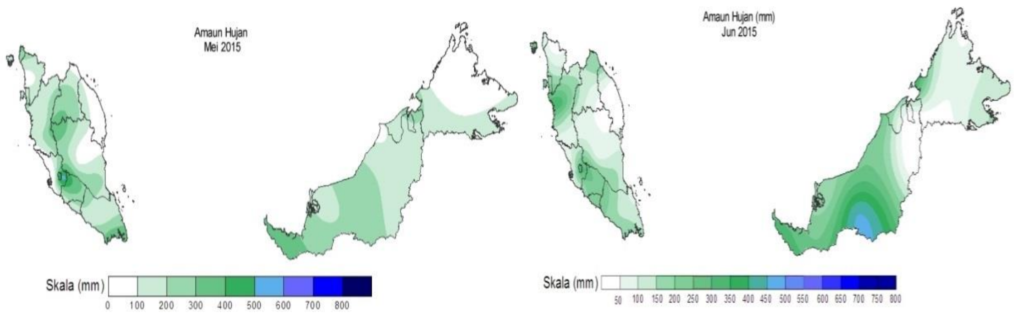


Figure 2.0.3: Southwestern Monsoon (SMM) on March 2015 and Jun 2015

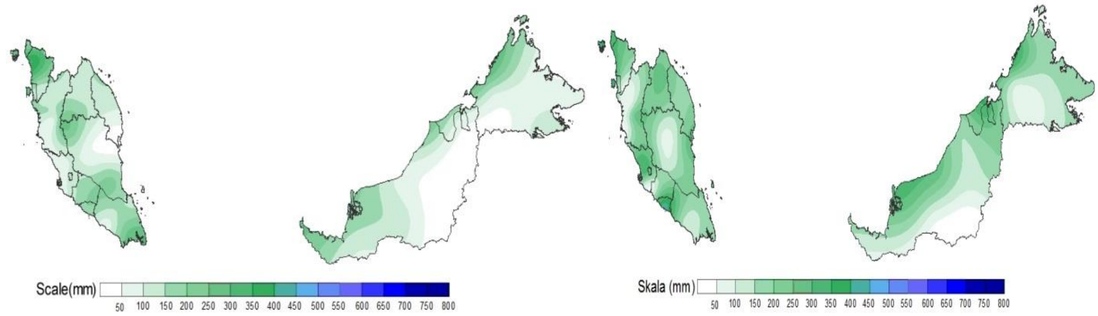


Figure 2.0.4: Southwestern Monsoon on July 2015 and August 2015

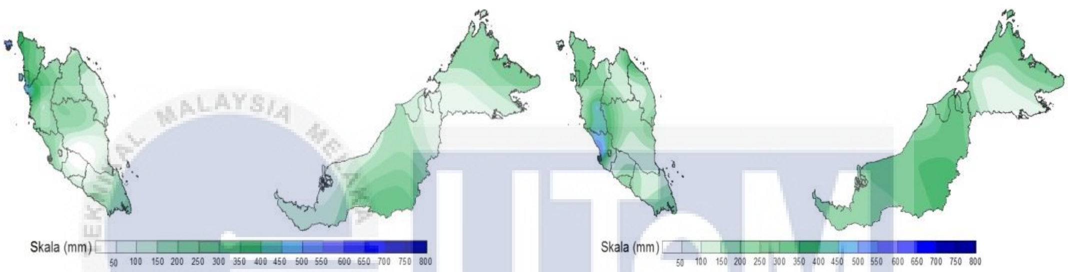


Figure 2.0.5: September 2015 and October 2015 (SO)

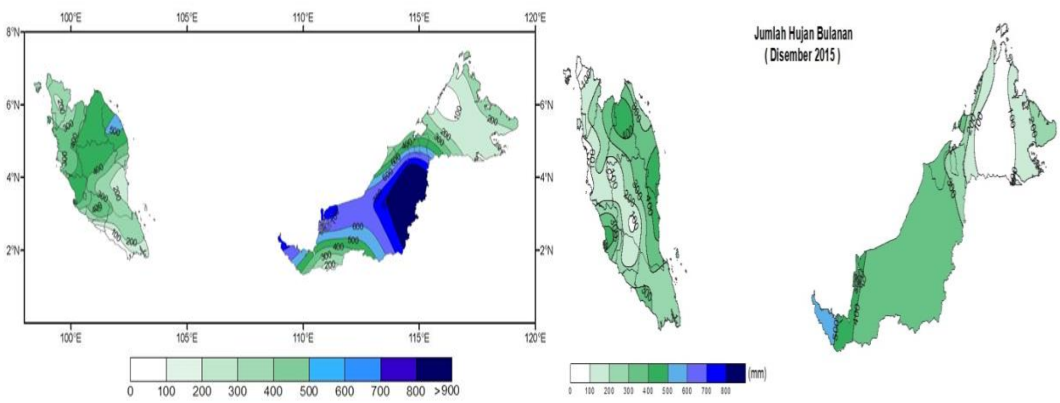


Figure 2.0.6: Northeast Monsoon on November 2015 and December 2015

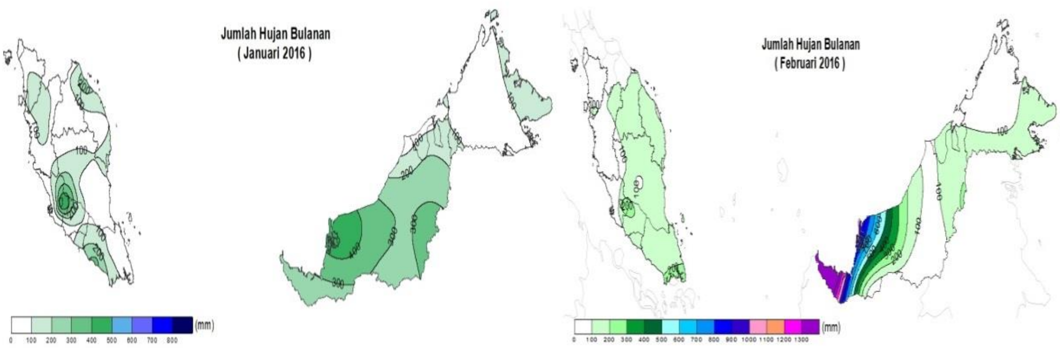


Figure 2.0.7: Northeast Monsoon on January 2016 and February 2016

Melaka is one of the states that achieved status as a developing country in 2010 and starting to achieve the country's vision towards 2020. According to the Melaka Green Technology policies, the state government has set three objectives such as to increase the process of developing in the state, to strengthen the state status of the city, and to improve the state status through the use of sustainable technologies and practically apply the Green Technology. Melaka has goals to achieve the title of "State Urban Green Technology" and 7 major sectors of UN-UAE framework focusses are in power, time reduction, urban design, urban environment, transportation, environmental health and air. In order to achieve one of these goals the study will be focused and conducted in Melaka.

There is monsoon season occurrence at Malaysia. The monsoon season is divided into four types of occurrence such as Northeast Monsoon (NEM) which occurred between November to February, two inter-monsoon season which occurred in March and April (MA), Southeast Monsoon (SWM) which occurred during May until August, and occurred in September and October (SO) by Syafrina et al. (2014c). The total amount of rainfall in the eastern region of Peninsular Malaysia has the higher indices during the Northeast monsoon by Syafrina et al. (2014d). That explained the flash floods that happened in the eastern states of Peninsular Malaysia such as Kelantan, Terengganu and Pahang. The NEM occurrence affects Sarawak too as show in the map figures which taken from the MET portal website. Furthermore, the Northeast Monsoon occurrence has indices for the highest number of very wet hours and extreme hours compared to others by Syafrina et al. (2014e).

According to the bar chart 1 below which is taken from World Weather and Climate Information website (2015), the amount of rainfall in Melaka when the NEM occurred between November until February 2015 shows a decreasing trend. However, it shows that the amount of rainfalls in Melaka has the highest value in November 2015 because it is the earlier of NEM season. During two inter-monsoon seasons (MA), the western region of Peninsular Malaysia represents the higher indices of the amount of rainfall by Syafrina et al. (2014f). These affect the Melaka area and it is proven by the bar chart figure 2.0.8 below that shows an increasing trend from March to April. The average amount of rainfall in Melaka is maintained from May to August when the SWM season happened by Syafrina et al. (2014g).

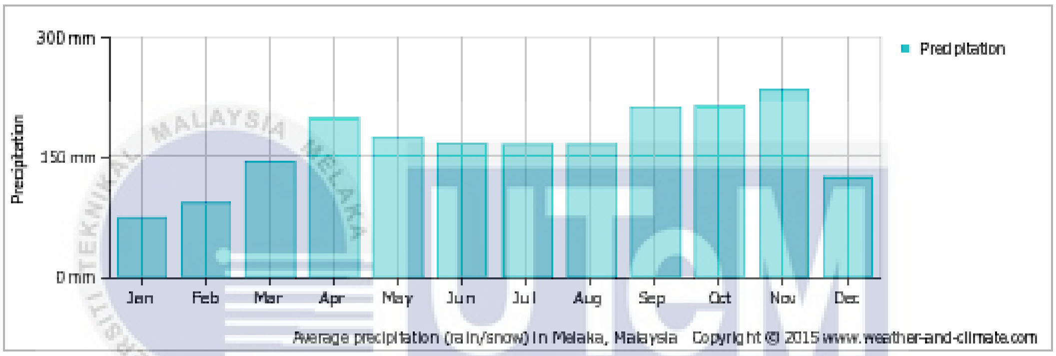


Figure 2.0.8: Average precipitation (rain/snow) in Melaka, Malaysia by by Syafrina et al. (2014h).

2.1 Power generation from the rain source

Alternative energy harvesting has many ways in this engineering field. One of the energy harvesting is from the water source which is the rain. A micro hydro generator is installed in a household for the usage of water consumption that can generate electricity by Yan et al. (2011a). This generator is built and developed by a concept from hydropower systems which the types are conventional and pumped storage. The selection of generator and the size of the turbine are important which depends on the results. In this previous study by Yan et al. (2011b), the permanent magnet generator and the turbine are set up in a small scale according to the turbine design in the market. After the prototype is completed, several tests were conducted which are turbine test, open circuit test and system test to determine the how much power can be generated. The prototype of Micro Hydro Generator has been built which consists of turbine and generator. This project is able to generate approximate 7 V and 17 mA. With the help of circuitry part, this generated power is able to charge up hand phone by Yan et al. (2011c).

Throughout another previous study by Martin and Shrivastava (2013a), a domestic power generation using rooftop rain water harvesting method is used. The harvested rain water is stored in a tall building and the underground storage tank is for collecting the rain water for other uses by Martin and Shrivastava (2013b). In this Rooftop Hydroelectric Generation, the rain water in the storage above flows through the channels from the roof and runs down to the turbines that connected to a generator. The excess storage of rain water on the underground will be used for other uses such as plants and gardens. The designing of the micro hydroelectric power generation is upgraded by adding the vacuum to pump the water from the underground storage flowing back to the above storage during non-rainy days. The designing involves storage tanks, pipe network, and flow control valves for this Rooftop Rain Water Harvesting system. The wettest place generates power of 5kW throughout this power generation by Martin and Shrivastava (2013c). The data of average power is taken and shown in the table 1.

HEAD IN FEET	AVERAGE POWER IN WATTS (W)					
	JAISALMER (DESERTED PLACE)			MEGHALAYA(WETTEST PLACE)		
	AREA (A_1)	AREA (A_2)	AREA (A_3)	AREA (A_1)	AREA (A_2)	AREA (A_3)
15 x 10	22.09	33.15	44.18	503.68	753.502	1006.9
20 x 10	29.46	44.19	58.9	671.57	1004.67	1342.55
30 x 10	44.19	66.29	88.36	1007.36	1507.00	2013.8
40 x 10	58.96	88.39	117.81	1343.15	2009.34	2685.09
50 x 10	73.65	110.48	147.26	1678.93	2511.67	3356.37
60 x 10	88.38	132.58	176.71	2014.72	3014.01	4027.6
75 x10	110	165.73	220.89	2518.4	3767.51	5034.6

Table 2.1.1: Calculated average power of the Rooftop Hydroelectric Generation by Martin and Shrivastava (2013d)

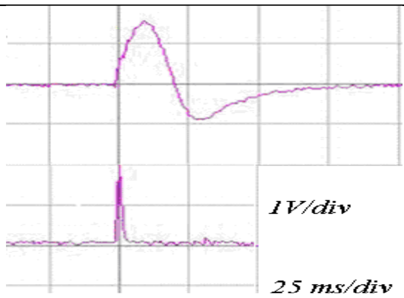
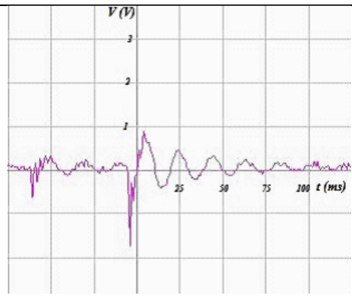
2.2 Piezoelectric components

Besides the micro-turbines, the piezoelectric sensors can be used to generate electricity from the rainfall. The piezoelectric sensor can measure the piezoelectric effects such as changes in pressure, acceleration, temperature, strain and force. These piezoelectric effects are converted into electrical charges. There are various types of piezoelectric components that are used for quality assurance, process control, and for research and development in industries. The piezoelectric components have been used in industrial sensing applications and other applications such as in aerospace, medical, nuclear instrumentation, as a tilt sensor in consumer electronics, a pressure sensor in touch screens of mobile phones and involved in the automotive industries. However, the famous and mostly used piezoelectric sensors recently are the Polyvinylidene Difluoride (PVDF) and the Lead Zirconate Titanate (PZT).

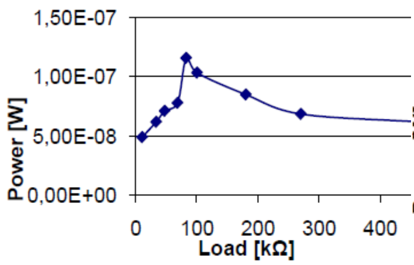
The PVDF piezoelectric sensors are commonly used in harvesting energy from vibration of the rain. When a rain drops on the PVDF, it gave impacts and produced a perfectly inelastic shock by Zyga (2008b). The shock produced vibration on the surface of the PVDF. The largest raindrop caused the largest vibration and the greatest amount of electrical energy is generated by Zyga (2008c). Before the impacts, the speed of the rainfall also must be reviewed carefully. The rain that falls with a slow speed generates the most energy while the rain that falls with a high speed often lose some energy and it happened because of the splash occurred during the impact on the PVDF by Zyga (2008d). Besides that, the recoverable energy depends on the properties of the piezoelectric such as the size of piezoelectric membrane, the size of raindrops and its frequency by Zyga (2008e). The energy that produced per drop may vary from value 2 micro Joule until 1 milli Joule by Zyga (2008f). Simulations can be done before the experimented system begins. The simulation on the PVDF piezoelectric shows that a single large raindrop can produce 12 milli Watts while the experimented system generated 1 micro watt of continuous power by Zyga (2008g). The generated electricity has a little amount produced. The converted power starts from a few of micro watts to 10 milli Watts according to converter area of several square centimeters.

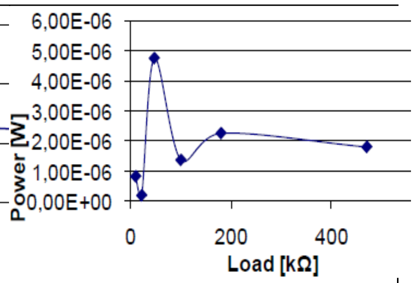
In the piezoelectric world, the differences between the types of piezoelectric materials are widely discussed. The existences of the PVDF and the PZT have advantages and disadvantages. Both of the piezoelectric components have many differences even though both components have the same function by converting the strain or mechanical (vibration) energy into electrical energy. In Miceli et al. (2014b), the study had tested and proved about the differences between the two piezoelectric components. The differences are shown in the table below.

Table 2.2.1: Differences on piezoelectric PVDF and PZT by Miceli et al. (2014c)

DIFFERENCES PIEZOELECTRICS	Lead Zirconate Titanate (PZT)	Polivinylidene Difluoride (PVDF)
Graph of Voltage-Time *(Exposed by real and artificial rain. Voltages obtained with uncounted numerous of droplets)*	 • In PZT, there are two signals obtained for the PZT transducer. The first signal presents the typical behavior which produced a large positive pulse, followed by a second smaller one. The second signal obtained is the presence of the positive pulse only. The signal waveforms are always conditioned by the presence of the water film on the PZT transducer. There is supposed to be the third pulse that	 • In PVDF, the presence of an underdamped system cause the output voltage has an oscillating behavior. • The vibration energy from the drop of water is absorbed and released to the electrical system in a longer interval than PZT transducers.

	followed the second pulse, but it rarely present. • In other cases, the signal obtained single peaks which happened because of the physical stress did not change but happened to the tension. The negative or positive peaks of the tension happened due to the condition which the state of piezoelectric plate had burdened with a water film. The impact caused the compression status ranged and generating a negative or positive peak of voltage.	

<table>
<tr>
<td>Graph of Average power-Resistor (Exposed by artificial rain and set both types of piezoelectric in same condition. Power obtained from a single droplet)</td>
<td>

• The loads used are 10, 33, 47, 68, 82, 100, 180,270 and 470 kΩ.</td>
<td>

• The loads used are 10, 22, 47, 100, 180 and 470 kΩ.</td>
</tr>
</table>

Some characteristics of the raindrops are identified such as a single drop of water can have a diameter that varies between 0.2 to 6mm, the droplets are not able to give maximum energy due to splashing, voltage values generated by the impact vibration from droplets, the performances were set by an irregular water film on the transducers by increasing the mass and resulting a damping to increase by Miceli et al. (2014d). The results concluded from the previous study by Miceli et al. (2014e) are the PZT should not be used to avoid contaminating the environment, the strength limits of piezoelectric are important to maximize the energy conversion and the comparison on the amount of the power obtained is proved that PVDF is greater than PZT.

Recently, Warude et al. (2015c) performed a method by using the numerical analysis which is the ANSYS structural analysis to determine the deformation of PVDF piezoelectric membrane. The analysis had recorded for the various sizes of the raindrops as the table 3 below.

Table 2.2.2: The analysis for the various sizes of raindrops by Warude et al. (2015d)

Type of Rain	Size of Rain	Force	Strain	Energy (J)
Light Stratiform Rain (LSR)	Small	$1.0e^{-7}$	$4.673e^{-10}$	$2.66608e^{-20}$
	Large	$2.72e^{-5}$	$2.8976e^{-5}$	$1.0228e^{-10}$
Moderate Stratiform rain (MSR)	Small	$2.1e^{-6}$	$9.8132e^{-9}$	$1.17307e^{-17}$
	Large	$6.97e^{-5}$	$3.0666e^{-7}$	$1.1455e^{-14}$
Heavy Thunderstorm (HT)	Small	$4.2e^{-6}$	$1.9626e^{-8}$	$4.67209e^{-17}$
	Large	$2.959e^{-4}$	$6.112e^{-6}$	$4.55061e^{-12}$

Figure 2.2.1: A raindrop hits the PVDF piezoelectric

Raindrops from a height due to gravity have velocity increases as it descends by Warude et al. (2015e). This gave results on the gravitational force and the drag force to be in equilibrium and these stages reach a constant velocity which called terminal velocity. Moreover, the raindrops change according to air resistance. The raindrops with size below 1mm are almost spherical means especially when the size increase, the change in shape increases by Warude et al. (2015f). The kinetic energy is wasted in other forms after the impact on the surface which is the noise energy.

Mass of raindrop and terminal velocity gives kinetic energy after the impact to piezoelectric membrane which is the vibrational energy by Warude et al. (2015g). Rain drop size has very important role. The numerical simulation of one rain drop impact can be analyzed but rain falls in random. Hence, the accuracy for impact vibration is difficult to achieve. The energy obtained is very minor to power MEMS and small electrical sensors and appliances by Warude et al. (2015h).

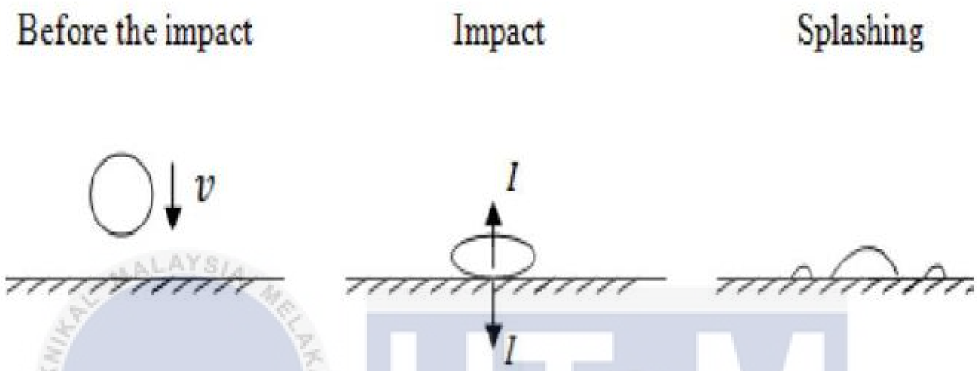


Figure 2.2.2: The raindrop hitting a surface by Warude et al. (2015i).

The developed spray-type rain simulator is able to generate rain with different rain conditions by Wong et al. (2016c). There are three rain conditions such as light, moderate, and heavy rain. The rain intensities are 15.4 mm/h, 93.0 mm/h, and 189.3 mm/h respectively by Wong et al. (2016d). The results concluded an increase in energy harvested and output power when the rain intensity increases by Wong et al. (2016e). The data such as total energy of 38.89 μJ, 52.05 μJ, and 114.68 μJ are obtained for light, moderate, and heavy rain respectively after a period of five minutes by Wong et al. (2016f). In actual rainfall, rain droplets give impact in different positions. Results from this experimental study by Wong et al. (2016g) revealed that a 4.5 mm diameter water droplet falling from a height of 0.82 m. When impacting, the tip of the piezoelectric beam is able to produce a peak power of 0.16 mW. The rain simulator that developed is able to simulate three different rainfalls with low, medium and high rain intensity. The rain intensity for light rain, moderate rain and heavy rain are 15.4 mm/h, 93.0 mm/h, and 189.3 mm/h respectively. The intensities are simulated via three different nozzles which are QPHA-15 which simulated light rain,QPHA-6.5 which simulated moderate rain, and QPHA-10 which simulated heavy rain by Wong et al. (2016h).

According to the Drop Size Distribution (DSD) graphs, the raindrop diameter for all the rain types is concentrated at droplet size of 0.25 mm and the DSD value increases as the rain intensity increases. The voltage generated by the piezoelectric energy harvester exhibits response due to random excitation. In actual rainfall, raindrop will impact on random positions on the piezoelectric beam by Wong et al. (2016i). When the raindrop impacts nearer to the clamp of the piezoelectric beam, less voltage is generated. This is due to smaller strain generated by the impinging raindrop at the clamp end compared to the tip of the piezoelectric beam. The total energy harvested in the previous study by Wong et al. (2016j) over a period of five minutes for light, moderate, and heavy rain are 38.89 µJ, 52.05 µJ, and 114.68 µJ. The power generated by light, moderate, and heavy rain is 0.1448 µW, 0.1731µW, and 0.3946 µW. The increase in power generated is when the rain intensity increases show that higher rain intensity will output higher power. In actual rainfall, the intensity and DSD of the rainfall is expected to vary from time to time. Hence, the power generated by the energy harvester is oscillated as the intensity and DSD vary by Wong et al. (2016k).

CHAPTER 3

METHODOLOGY

3.0 Introduction

Methodology is a system of methods that implemented in a project or field study. The methods are important and must always be careful because of the detailed information of the steps will be used throughout the whole project. The steps of doing this project from the beginning until the end will be described in this section. The methods are divided for the software and the hardware section. The main component in this project is the piezoelectric transducers which are Polivinylidene Difluoride (PVDF) and Lead Zirconate Titanate (PZT) that each has function in changing the mechanical energy to electrical energy from sensing vibration from the impact of the rainfall.

3.1 Literature Review and Preliminary Works

The first activity of this project is searching some journals and paper works from the previous studies. The literature review research is done by the information collection which the information are related to this project module such as the problem issues, the conditions and weather changes in Malaysia, the power generation from the rain source and the piezoelectric components. The weather conditions in Malaysia are referred to the Malaysian Meteorology Department's website and the weather and climate website while the problem issues referred from Tenaga National Berhad (TNB) as shown below.

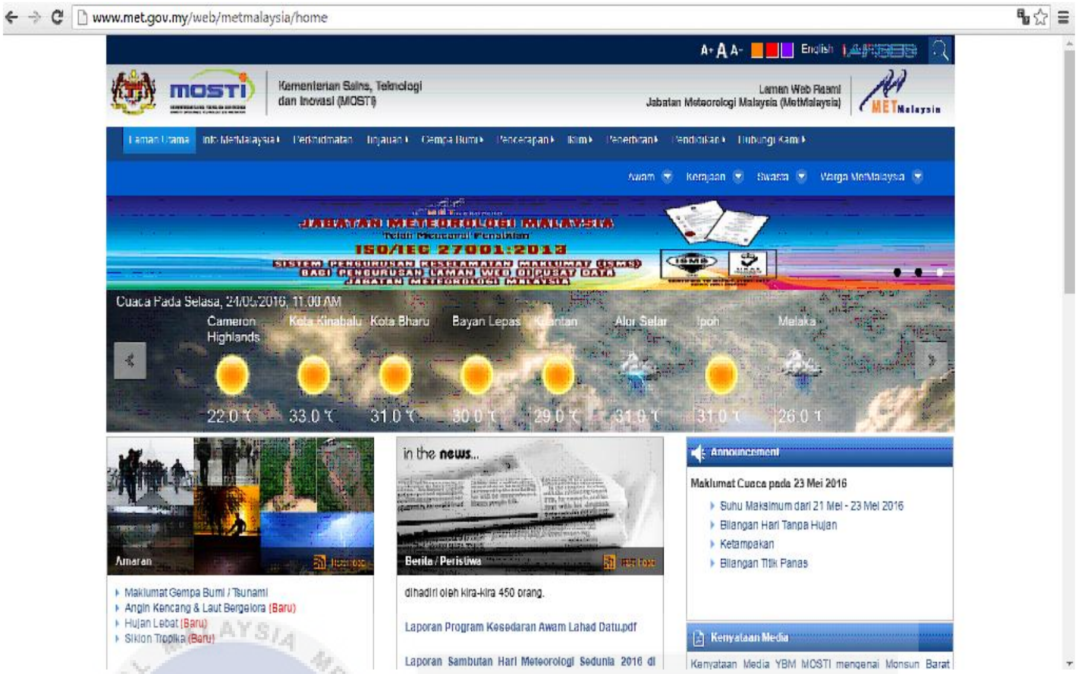


Figure 3.1.1: Malaysian Meteorological Department Website (2015c)

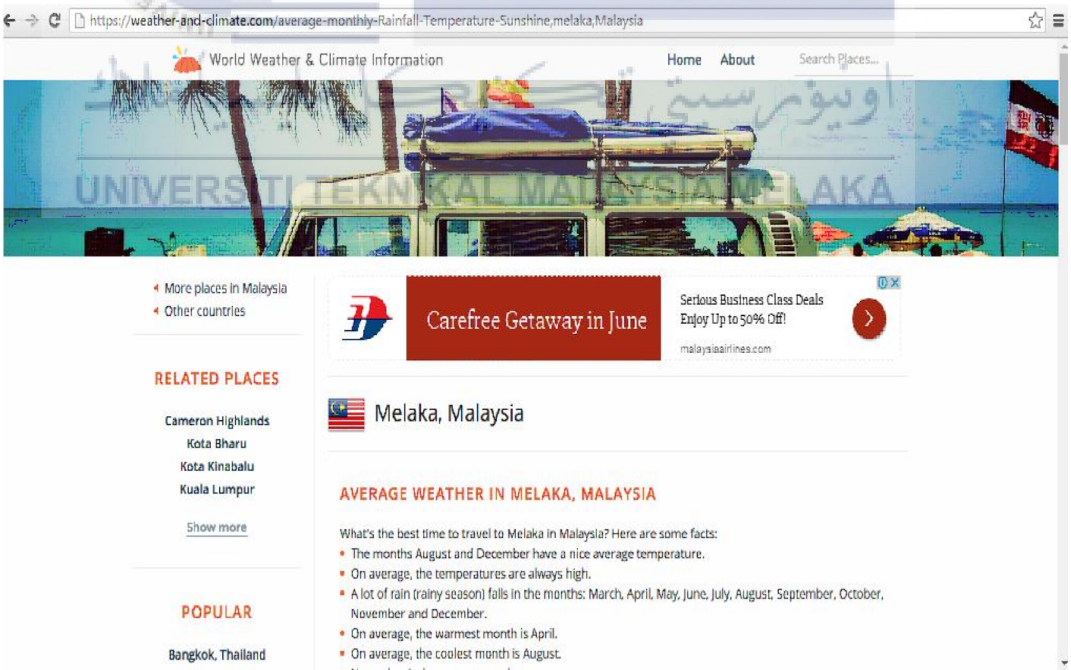


Figure 3.1.2: World Weather and Climate Website (2015b)

Figure 3.1.3: TNB 2014 Electricity Demand by The Star (2014)

Figure 3.1.4: TNB 2016 Electricity Demand by The Star (2016)

Besides that, there is also a little information about the natural energy involve from the raindrop, the raindrop behavior, the kinetic energy conversion and the vibration energy during raindrop impact. The journals are reviewed and summarized whereby the achievements and comparisons from the other studies can be seen clearly.

3.2 Simulation of the module

The second activity of this project is to apply the electrical circuit in the simulation. The suitable software is searched among the variety of the software and finally the chosen one is the Multisim software. Several electrical circuits are studied and tested in Multisim software to view the outcome of the electrical circuit. The chosen Multisim software is shown below.

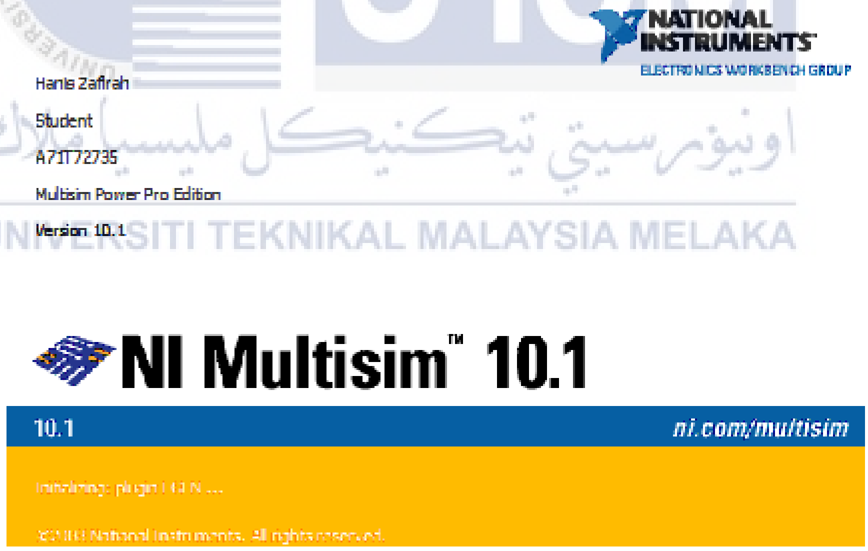


Figure 3.2.1: Multisim Software

The piezoelectric component which is used in the electrical circuit does not exist in the library section of the Multisim software. Hence, a piezoelectric component has been replaced with AC Voltage source. This is because of the output of the piezoelectric component is an Alternate Current (AC). The output voltage of the piezoelectric is small and must be converted into Direct Current (DC), so the voltage multiplier is proposed. Voltage multiplier is an electrical circuit that converts AC electrical power from a lower voltage to a higher DC voltage by using a network of capacitors and diodes in the circuit. It can generate a few volts for electrical appliances up to million volts for high-energy physics experiments and lightning safety testing. The type of voltage multiplier that used in this simulation is the Voltage Quadrupler. The function of the Voltage Quadrupler is to produce an output voltage four times the peak voltage. The piezoelectric component (AC Voltage source) is connected to the Voltage Quadrupler in the circuit as assembled as in Circuit 1.

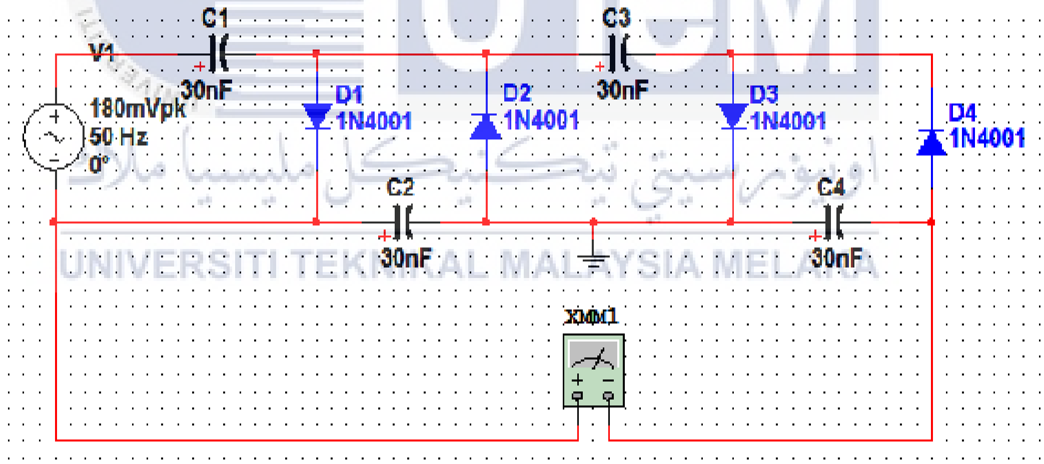


Figure 3.2.2: Voltage Quadrupler

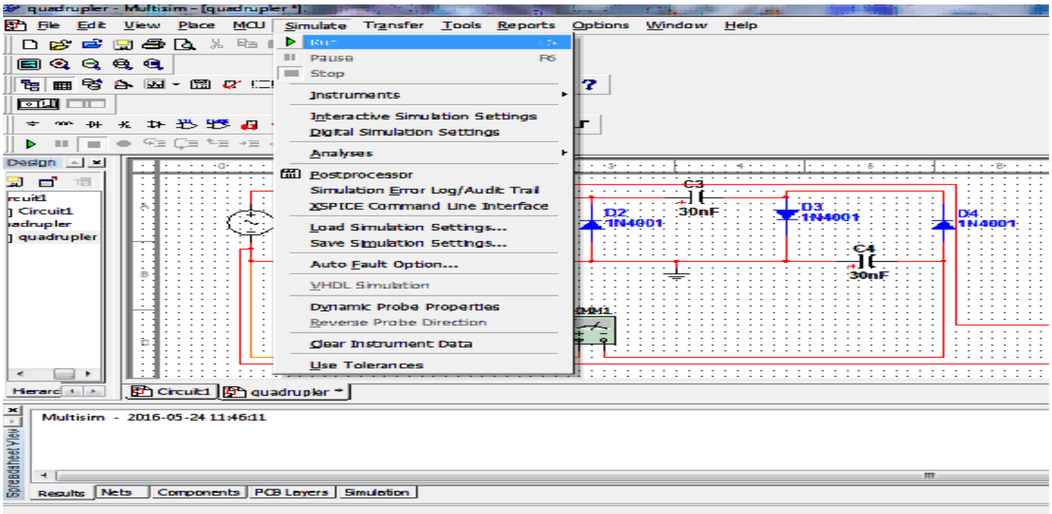


Figure 3.2.3: The simulation is run

When the circuit is run in picture 1, C_1, C_2, C_3 and C_4 will be charged through the D_1, D_2, D_3 and D_4. The total output of the circuit is four times greater than the original voltage value from the piezoelectric. The output voltage value of the piezoelectric is randomly taken as 180mV and the voltage output after using the Voltage Quadrupler is 378.425mV as shown in Circuit 2. The oscilloscope is placed to view the input and output signal of the voltage. The input signal is shown as sine waves in figure 1 and the output signal is shown increasing in figure 2.

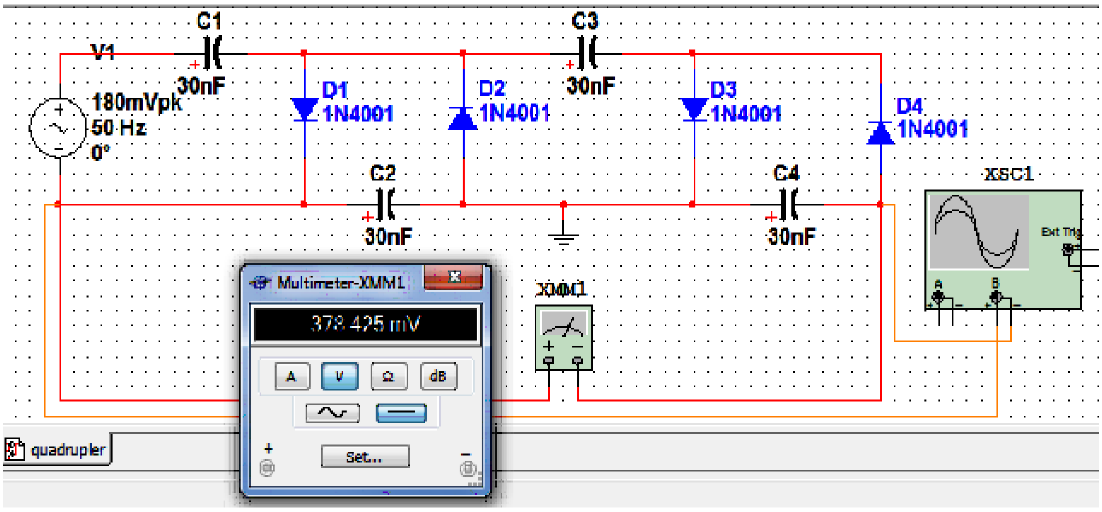


Figure 3.2.4: Voltage output after using Voltage Quadrupler

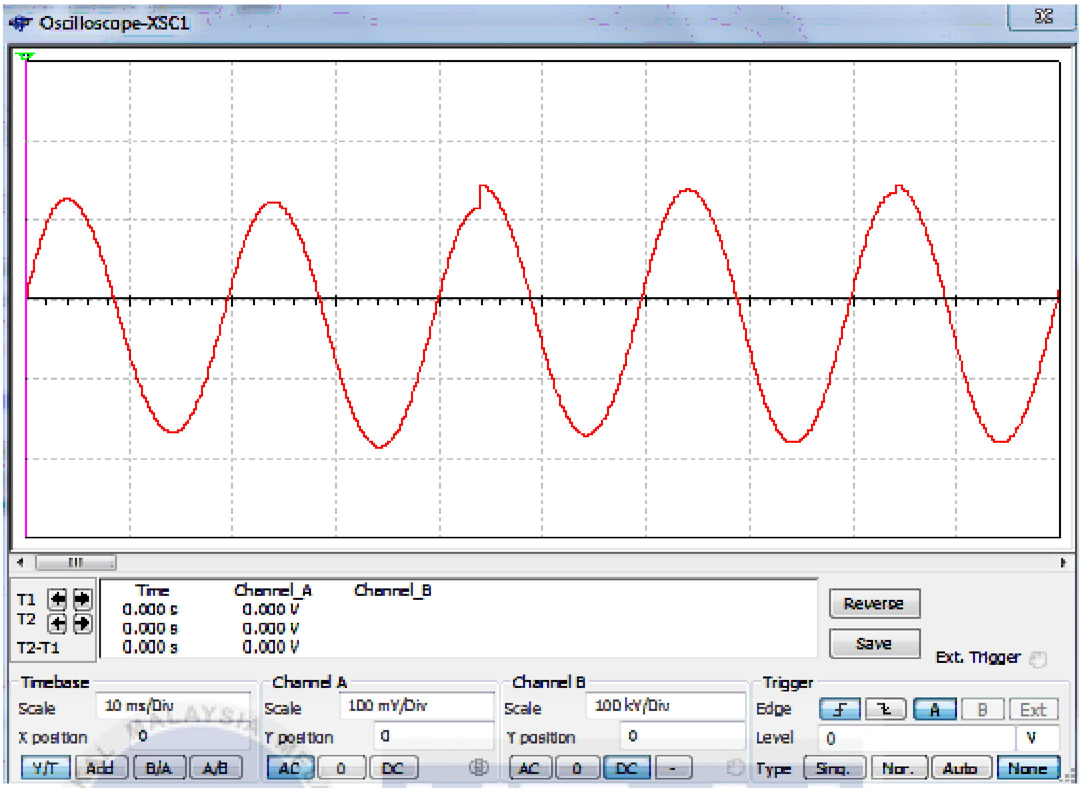


Figure 3.2.5: Voltage input signal before

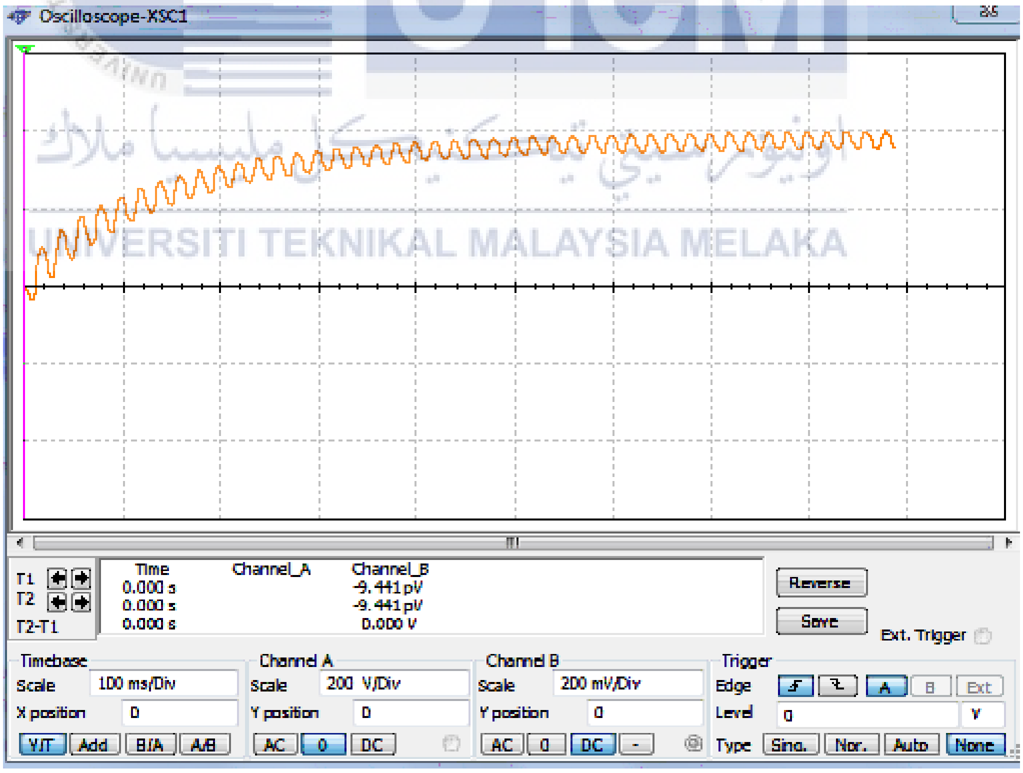


Figure 3.2.6: Voltage output signal after

3.3 Design and development of the module

The third method is the part where design and development of the module begins. The structure of the module will be designed with a fixed size of sensors. The designing process of the module has to make it suitable to use and apply in the rural area of Melaka. The type of component is selected and prepared to build the structure of the module according to the design plan. The instruments such as multimeter and oscilloscope will be prepared to use for measurement. The module will be tested and configured in the next method.

Figure 3.3.1: Rural area in Melaka

3.4 Module testing and data collection

The last method is the module testing and data collection during this project implementation. The module will be set up during a period of rain time in a rural area/house of Melaka. The main part of a house that will be implemented this module is the rooftop. During that period of time, the project module will be observed. The module will be tested and the performance will be verified based on the data results. Lab scale testing and field testing are included to experiment the module and obtain the results. The results of the lab scale testing and field testing will be recorded and analyzed.

3.5 Flow chart of the module

Methodology must be checked and the methods must be followed properly. The beginning until the end of this project is summarized in a flow chart 1 below.

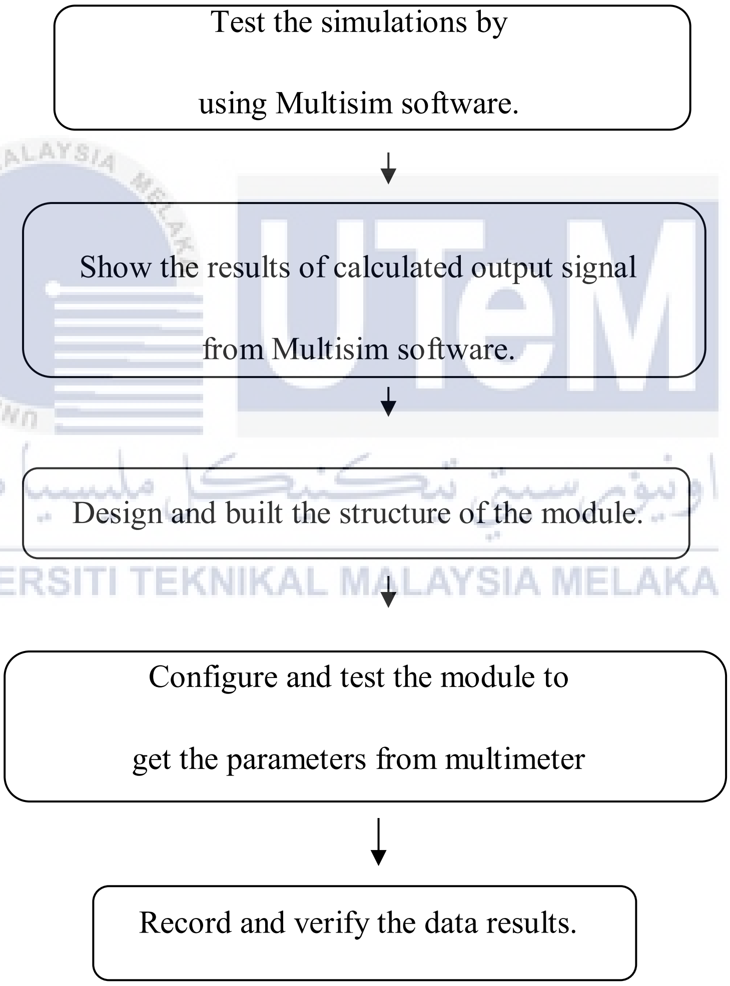


Figure 3.4.1: Flow chart of the simplified methods

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The module hardware of the project is completed and the results and discussion regarding to the project are obtained by the student to be inserted in the testing report. The project module testing and data analysis will be further explained in this chapter.

The circuit of the hardware is designed and simulated through the Multisim software. The project module will be tested to make analysis and obtain data such as voltage and current output. Power output will be calculated and graph from oscilloscope will be captured.

In this section will be explained more about simulation and circuit designs, module hardware development which is module circuit and module housing structure, hardware testing, troubleshooting and improvement, data experiment, analysis of data, calculation, module costs and discussions.

4.2 Simulation and circuit designs

In this part will explain about the circuit simulation by using Multisim Software. Multisim software is an electronic schematic capture and simulation program hence it is a part of suite of circuit design programs with National Instrument Ultiboard. The circuit simulation is important for practical application in designing, prototyping and testing electrical circuit. Furthermore, the simulation will help to make sure that the flow of the project become smooth and easy.

There are several circuit simulated for this project module. Some circuits are identified and assumed theoretically to be suitable for the project module. The circuits are Voltage Multiplier, Darlington Transistor and several simple circuits to store the charge from the piezoelectric transducers. There is no piezoelectric transducer in the Multisim software which means the piezoelectric transducer is replaced with AC Voltage Source.

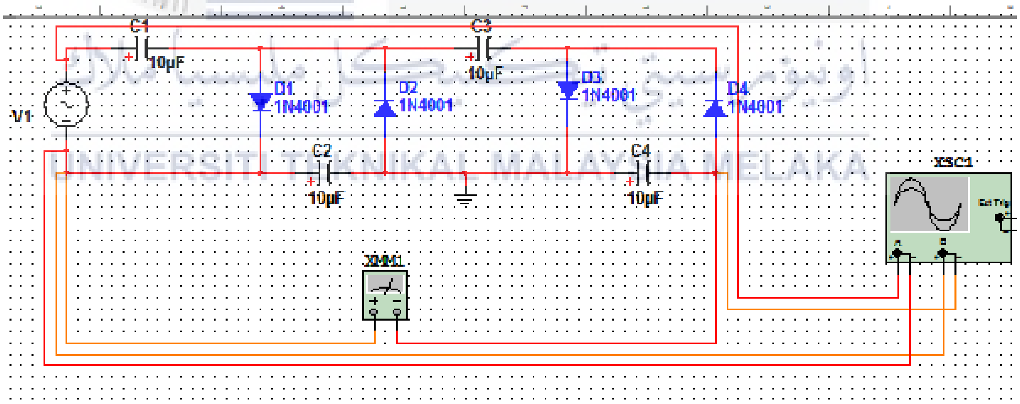


Figure 4.2.1: Voltage multiplier circuit

4.3 Module hardware development

Before connecting the piezoelectric transducers in the circuit, the piezoelectric transducers are checked and tested one by one. There are two types of piezoelectric transducer used and tested for this module which is the Lead Zirconate Titanate (PZT) and the Polivinylidene Difluoride (PVDF). The output data is obtained and recorded in the table at the following section of data experiment of piezoelectric transducers testing.

Figure 4.3.1: PZT round disc and PVDF rectangular plates

After piezoelectric transducers testing using multimeter and the oscilloscope, the circuit is completed first and the hardware housing is constructed. There are several troubleshoots and improvement on the project module circuit and hardware structure. Electrical components and equipment that used during the development of the project are listed as below.

No.	Electrical Component
1	Piezoelectric Transducer (PZT)
2	Piezoelectric Transducer (PVDF)
3	Wire (single core)
4	Diode 1N4001
5	Capacitor 33nF
6	Resistor 1Ω
7	Light Emitting Diode (LED)
8	Switch
9	Strip board

Table 4.3.1: Electrical Component List

No.	Equipment
1	Multimeter
2	Oscilloscope
3	Cutter
4	Scissors
5	Strong glue
6	Solder
7	Breadboard
8	Water resistant tape
9	Sticky tack

Table 4.3.2: Equipment list

4.3.1 Module Circuit

The electrical components are assembled exactly as planned in the simulation circuit. Continuity test is done and checked after the circuits are finished being soldered on the strip board. The continuity test is important to determine the electrical path between the components and to check whether the path is connected or not. Furthermore, continuity test needs to be done because of the strip board has linear line connection and the continuity test also will detect any shortage occur in the electrical circuit.

There are several circuit tested because of the designed circuit that planned to use earlier using the simulation which is the Voltage Multiplier circuit does not working when applied in the actual circuit. In this section, the applied circuits are labelled according to their types and tested as the following. The data results will be recorded in the data experiment section.

TYPE A (Piezoelectric Transducers)

For TYPE A-1, the Lead Zirconate Titanate (PZT) piezoelectric transducers are connected and tested.

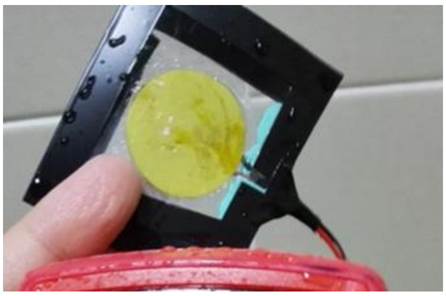


Figure 4.3.1.1: Series connection

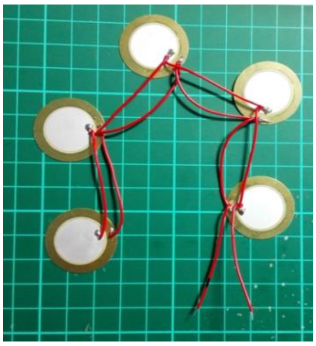


Figure 4.3.1.2: Parallel connection

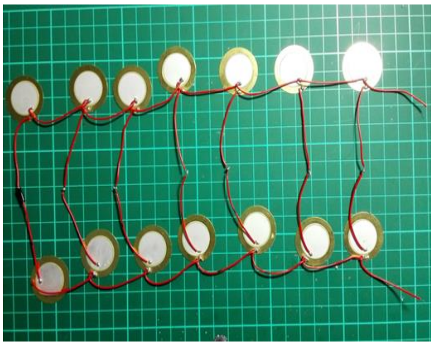


Figure 4.3.1.3: Series-Parallel connection

For TYPE A-2, the Polivinylidene Difluoride (PVDF) piezoelectric transducers are connected and tested in series and parallel connection.

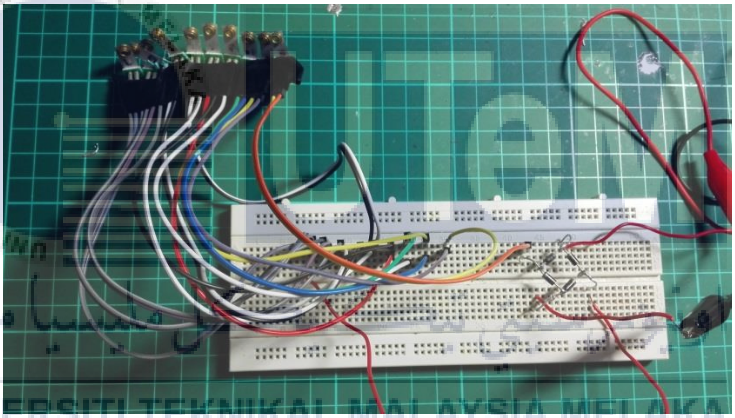


Figure 4.3.1.4: Series Connection testing for PVDF

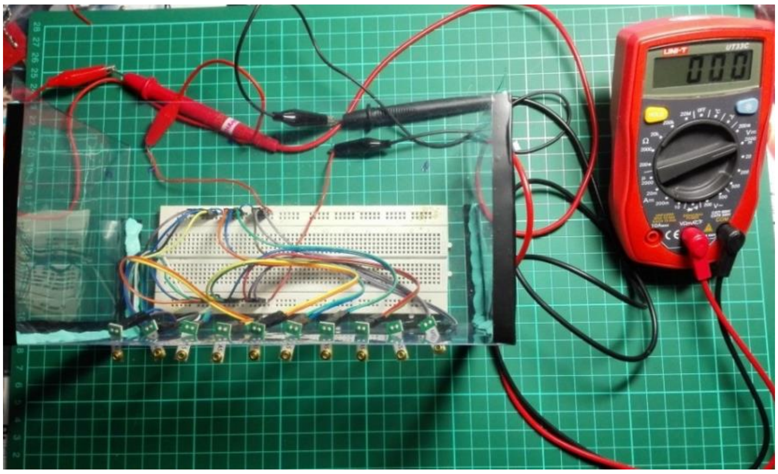


Figure 4.3.1.4: Parallel Connection testing for PVDF

TYPE B

For TYPE B-1, the piezoelectric transducers are connected with diode bridges for 1 set only.

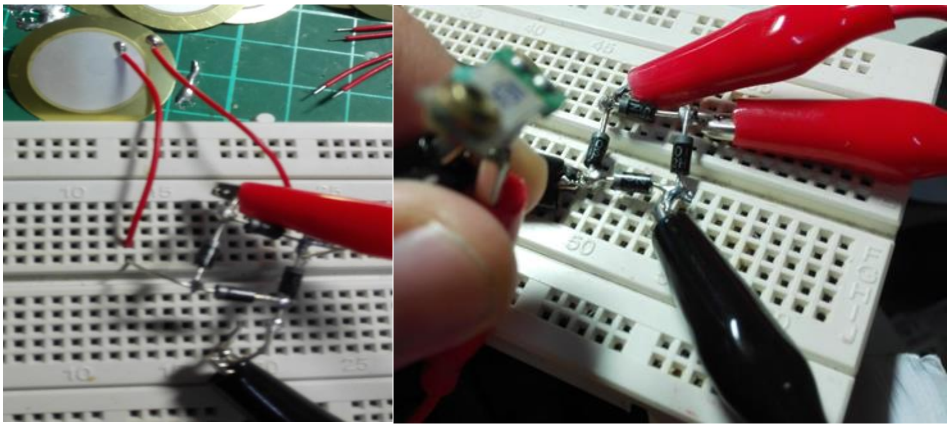


Figure 4.3.1.5: TYPE B-1 circuit example

For TYPE B-2, the piezoelectric transducers are connected with diode Bridges for 2 sets in parallel connection.

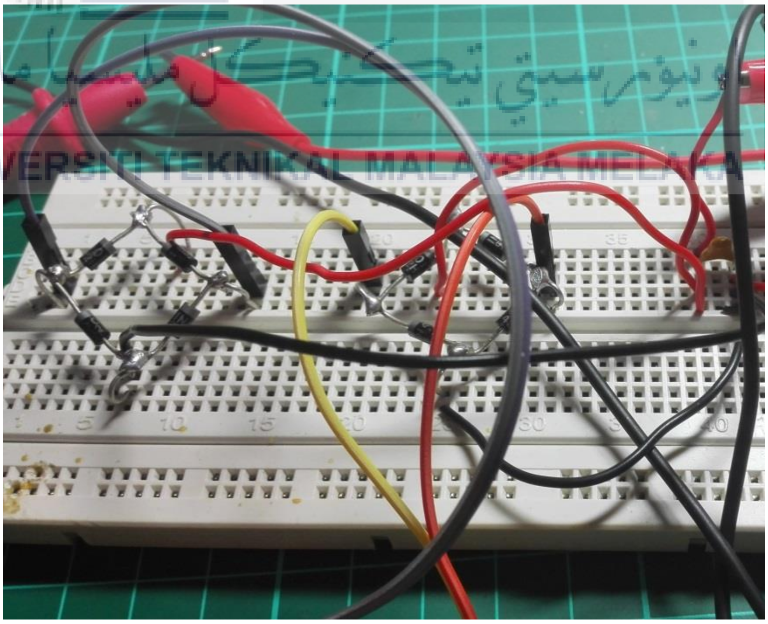


Figure 4.3.1.6: TYPE B-2 circuit example

TYPE C

For TYPE C-1, the piezoelectric, diode bridges and non-polar capacitor 33nF are connected for 1 set only.

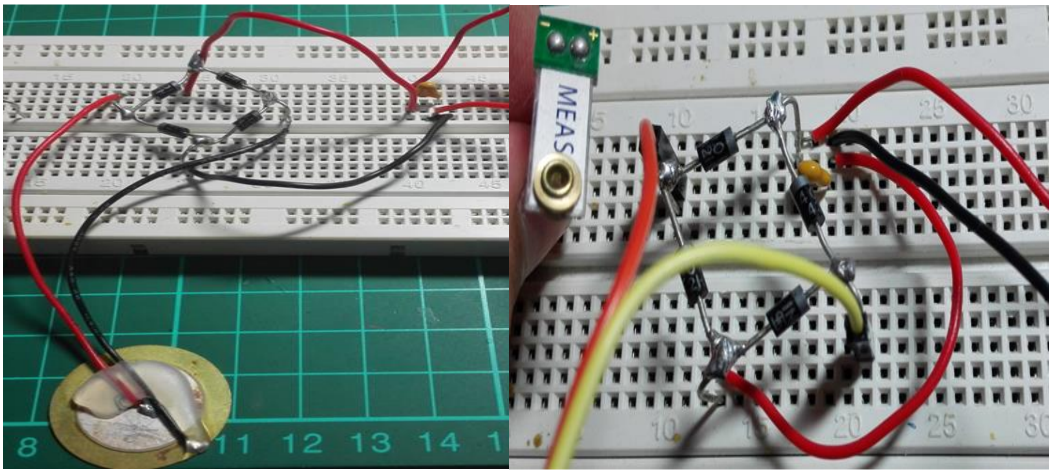


Figure 4.3.1.7: TYPE C-1 circuit example

For TYPE C-2, the piezoelectric transducers, diode bridges and capacitor non-polar 33nF are connected for 2 sets in parallel as below.

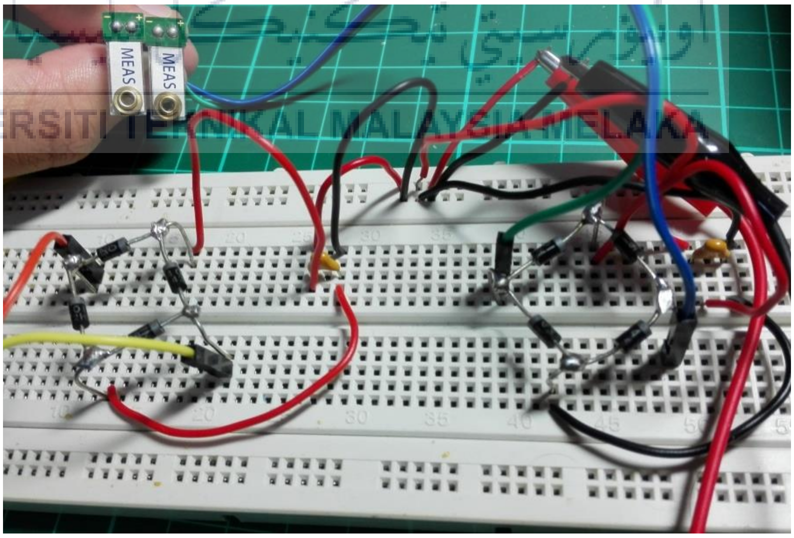


Figure 4.3.1.8: TYPE C-2 circuit example

TYPE D (First design)

In this TYPE D circuit, the electrical components used are 10 Piezoelectric Transducers, 10 Diode Bridges and 10 Non-polar Capacitor 33nF are connected as parallel to resistor 480Ω

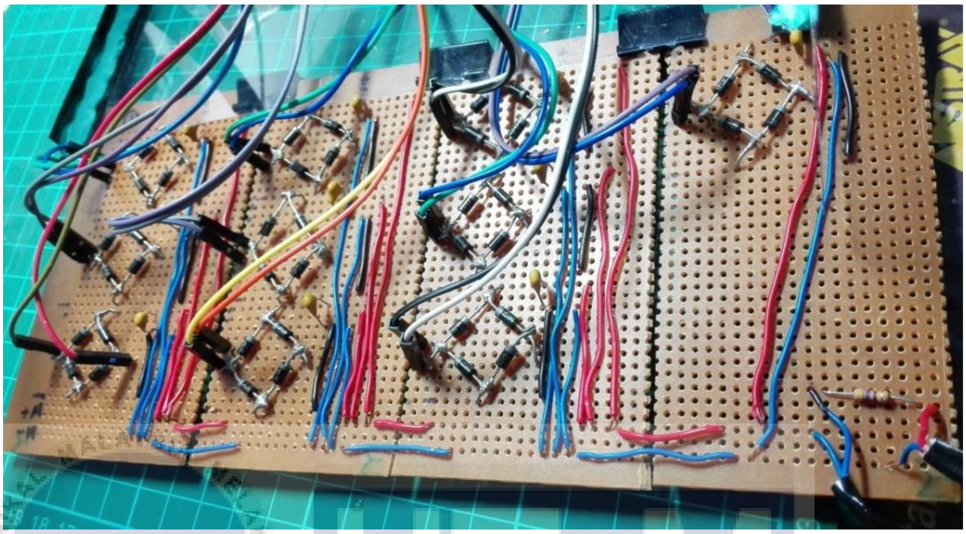


Figure 4.3.1.9: TYPE D (first design) circuit example

TYPE E (Second design)

In this TYPE E circuit, the electrical components used are 10 piezoelectric transducers and 10 diode bridges are connected as parallel to 1 non-polar capacitor 33nF, 1 resistor 1Ω and 1 Diode 1N4001. The circuit design is same as TYPE D but has a few changes which are the resistor 480Ω and all ten pieces of Non-polar Capacitor 33nF are removed.

TYPE F (Third Design)

In this TYPE F circuit, the electrical components used are TYPE F-1: 10 Piezoelectric and 10 diode bridges connected as parallel to 1 Non-polar Capacitor 33nF, Switch, 1 Diode 1N4001 and load (LED). The circuit design is same as the previous design which is TYPE F but a few final changes had been made to fulfill the reading multimeter requirements.

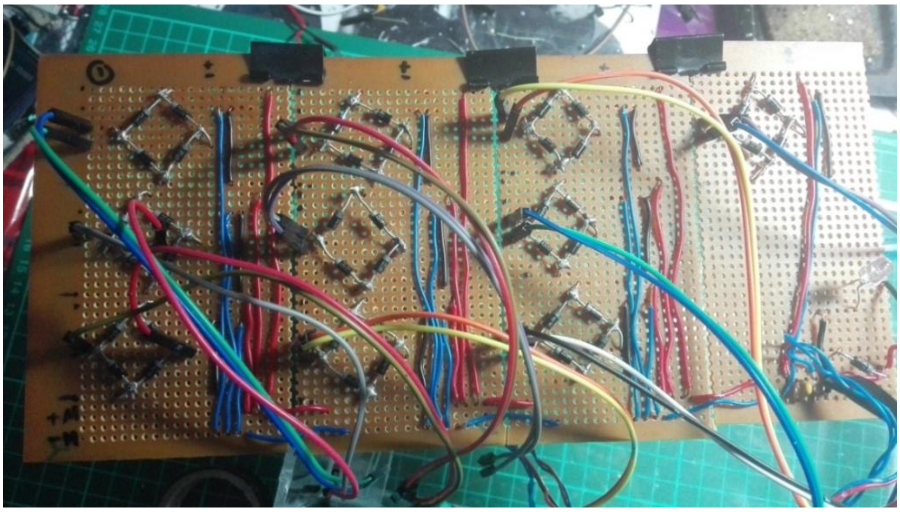


Figure 4.3.1.10: TYPE I (third design) circuit example

TYPE G (Voltage Multiplier Circuit)

There are 4 diodes1N4001, 4 capacitors and a piezoelectric transducer ia assembled and connected as the circuit schematic below.

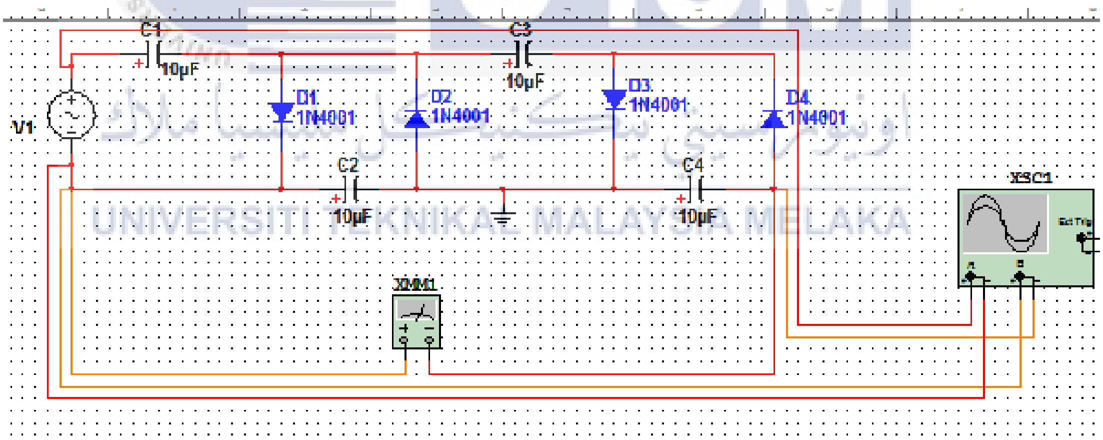


Figure 4.3.1.11: TYPE G Voltage Quadrupler circuit

Type F circuit is used in this project module after several circuits are tested. The data results of the all circuits testing will be stated and presented in the data experiment section while further explanation will be briefed in the discussion section.

4.3.2 Module housing structure

The structure of the project module is designed and built after completing the module circuit. All connections on the circuit are checked by continuity test. The module housing is designed to be suitable for the rooftop environment. Moreover, there are two designs of the project module housing structure to be implemented for this project such as Design 1 which the piezoelectric transducers PZT are placed in both sheets of plastic sized A4. This design is to make sure that no water will invade the housing and no water will touch the circuit.

Figure 4.3.2.1: Piezoelectric transducer PZT is being tested

Figure 4.3.2.2: Module Housing structure Design 1 for PVDF transducers

The PZT piezoelectric transducers are tested first using this design. There is no circuit in the project module housing. However, the Design 1 of the project module housing is not long lasting because the effect of the water impact that caused the project module housing from being in a good condition to being worn out. The PZT module hardware is replaced with a new one.

Figure 4.3.2.3: In a good condition and worn out

Furthermore, the Design 2 of the project module housing is one of the designs for piezoelectric transducer PVDF to be placed in a box of rectangular prospect glass. The measurement of the housing structure has 24 cm length, 11.5 cm width and 14 cm height. The distance between the transducers and the bottom of the housing structure is cm. The actual project module housing is shown as below.

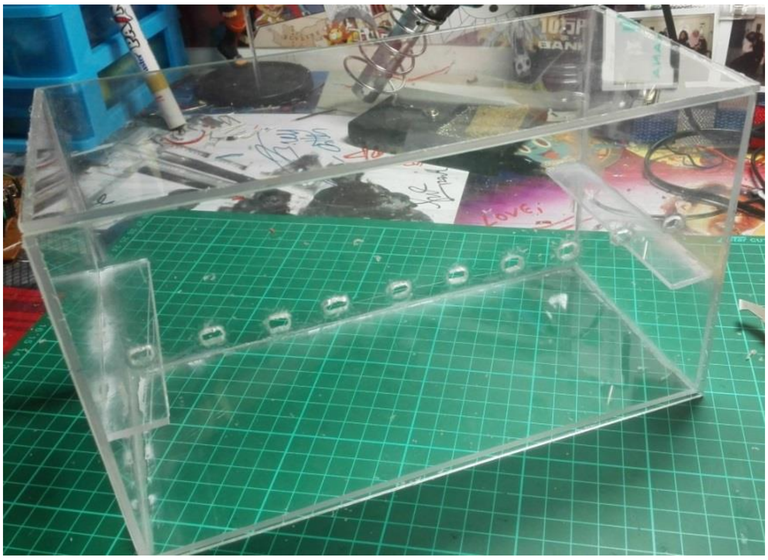


Figure 4.3.2.4: Module Housing structure Design 2 for PVDF transducers

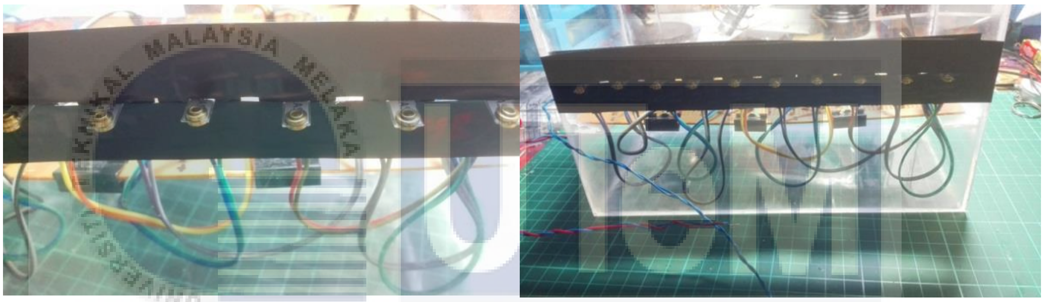


Figure 4.3.2.5: Module Housing with Piezoelectric Transducers

Figure 4.3.2.6: Inside project module housing structure

4.3.3 Lab scale testing

1) Oscilloscope testing

Piezoelectric behaviour of PZT and PVDF piezoelectric transducers are observed from digital oscilloscope equipment at faculty's laboratory. The behaviour of the piezoelectric transducer shows that the transducer has high output impedance characteristic.

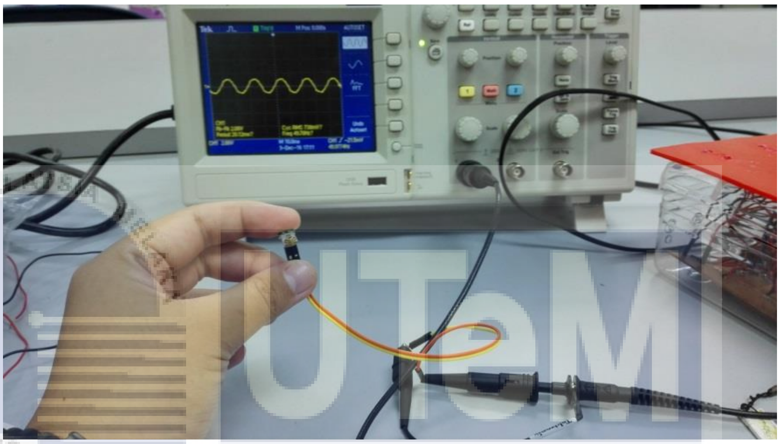


Figure 4.3.3.1: Each piezoelectric transducer is measured using oscilloscope

PVDF

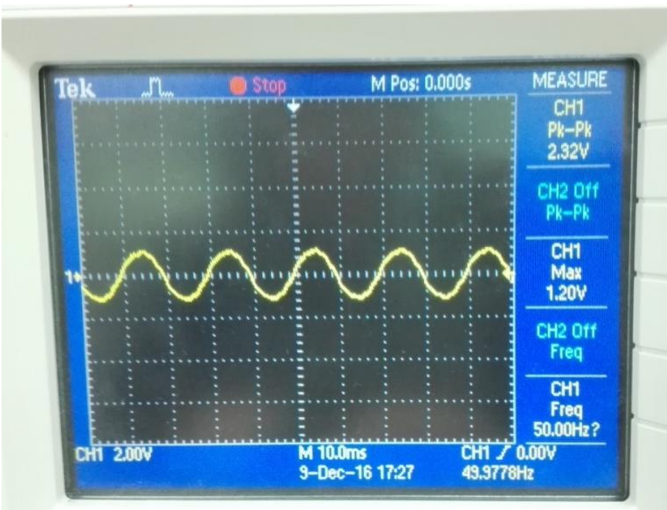


Figure 4.3.3.2: No external energy is applied

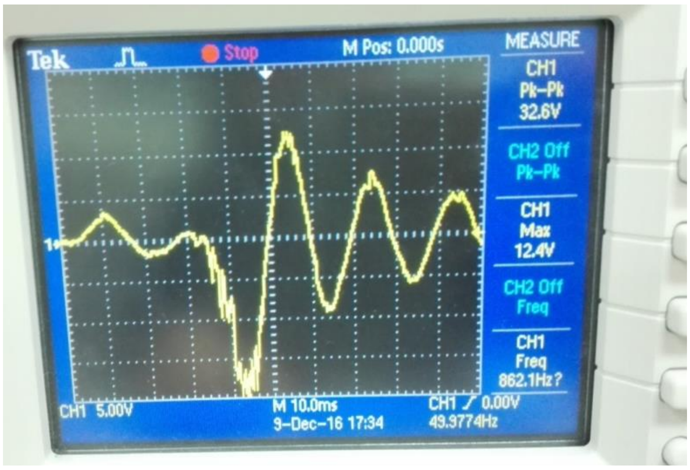


Figure 4.3.3.3: External energy is applied

PZT

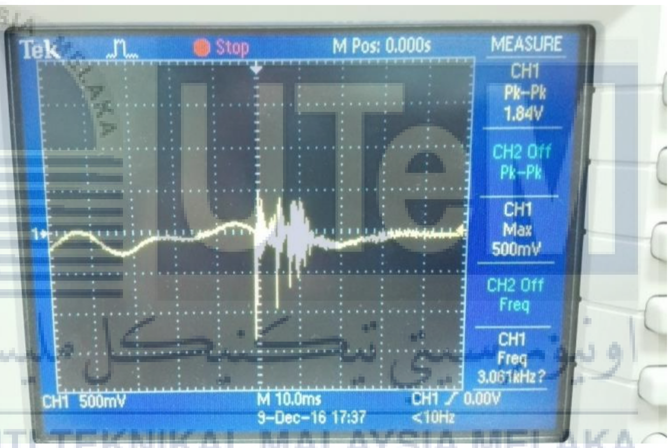


Figure 4.3.3.4: When sound disturbs

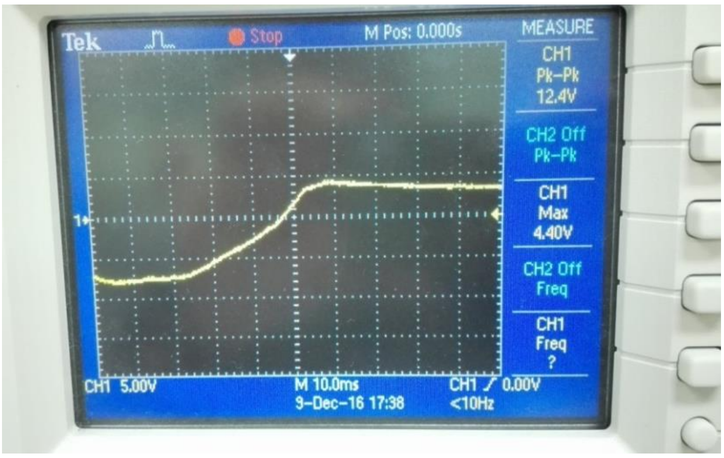


Figure 4.3.3.5: External energy is applied

Besides that, the piezoelectric transducers did not have polarity which is proved during the oscilloscope testing and observation. The AC signals of the transducers are sometimes start with positive cycle and sometimes start with negative cycle.

2) PZT testing

The project module hardware is tested under a shower with height distance 138metres between the shower and the hardware.

Figure 4.3.3.6: Circuit testing for PZT under a fixed height shower

3) PVDF testing

The project module hardware is tested under a shower with height distance 138metres between the shower and the hardware.

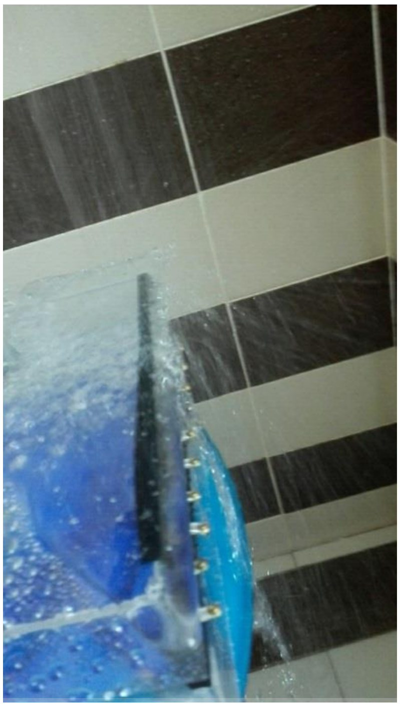


Figure 4.3.3.7: Circuit testing for PVDF under a fixed 138m height shower

4.3.4 Field testing

Figure 4.3.3.8: PZT and PVDF project module

The field testing had been conducted but the recorded data cannot be taken because of the water had invade the module housing structure. The housing is only suitable to be used for lab scale testing only due to impermanence.

4.4 Troubleshooting and improvement

There are a lot of problems occurs during the project module development and the project module needs to troubleshoot. The function of troubleshoot is to trace and correct faults that occurred upon the project module. The Voltage Multiplier circuit which is the Voltage Quadrupler is successfully simulated by Multisim but the expected results are not same with the actual results.

The multimeter cannot read some output values of the circuit types such as TYPE D the first design circuit and TYPE E the second design circuit. The circuit is altered and changed to make the readings of the multimeter appear hence the final improvement of the circuit is the third design circuit TYPE F.

Loads which used in this testing progress are 480Ω and 1Ω and finally removed because the resistor disturbs the voltage and current reading greatly. Load used in the final circuit is only the LED.

During the project module testing, there are water leak inside the PVDF project module. The circuit became wet and the output values of voltage and current cannot be read. This caused problems to the project module testing progress due to short circuit. New housing design will not be constructed because lack of time to redesign. The housing structure stays and had made a few changes. The circuit is covered with plastic and a cloth to prevent any direct water contact.

Figure 4.4.1: Latest project module PVDF housing structure

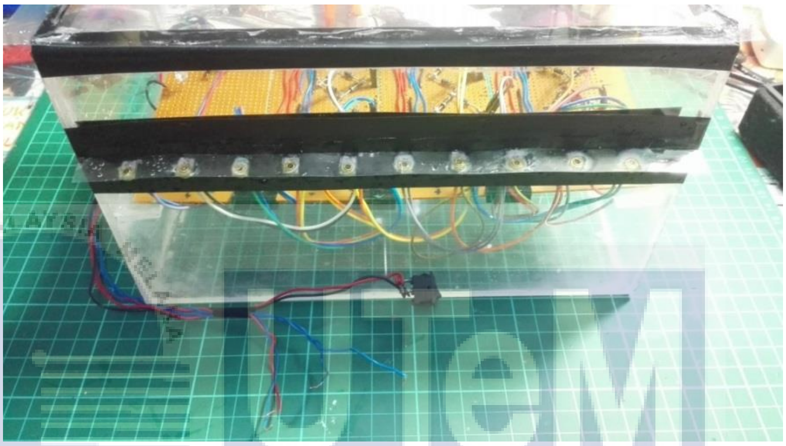


Figure 4.4.2: Upgraded housing module

The project module for PZT had no problem regarding with the water leakage hence the module is changed its plastic surface because of the worn out and upgraded with a rubber on each piezoelectric transducer PZT. This due to the water impact will give more impact on the piezo ceramic discs to get higher voltage and current outputs.

Figure 4.4.3: Latest project module PZT housing structure

4.5 Data Experiment

The observation and data experiment of the project module of piezoelectric transducers circuit testing will be presented in this section. There are several types of circuit testing conducted because a few of the circuits are failed to get the data reading.

TYPE A circuit data testing

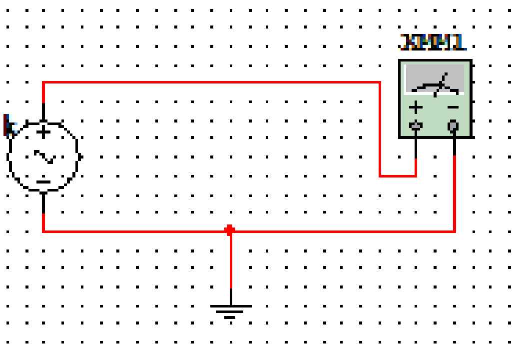


Figure 4.5.1: Electrical Schematic TYPE A

For TYPE A, PZT and PVDF piezoelectric transducers are connected to multimeter without any added circuit and the piezoelectric transducers are tested one by one. Vibration was given on the piezo plates for 10 seconds. The data testing is obtained and recorded as table below.

Table 4.5.1: Type A for PZT and PVDF

Labelled Piezoelectric plates	PZT AC Voltage (V)	PVDF AC Voltage (V)
1	4.6	3.8
2	7.0	3.3
3	5.3	4.5
4	13.3	4.1
5	6.2	5.9
6	7.8	4.1
7	5.5	4.2
8	5.9	4.4
9	11.0	4.4
10	9.8	4.2

The PZT piezoelectric transducers are assembled and connected into two type of connection which is series connection and parallel connection and then connected to a diode bridge. Only the series and parallel piezoelectric transducers are connected to a diode bridge. The results using PZT and PVDF piezoelectric transducer are collected as table and graph below.

Table 4.5.2: Series connection of PZT

DC Voltage (V)	DC Current (uA)
0.10	0.80
0.20	1.00
0.30	1.30
0.40	1.60
0.50	2.00
0.60	2.20
0.70	3.00

Table 4.5.3: Parallel connection of PZT

DC Voltage (V)	DC Current (uA)
0.10	2.00
0.20	3.00
0.30	3.70
0.40	4.50
0.50	5.60
0.60	6.20
0.70	7.00

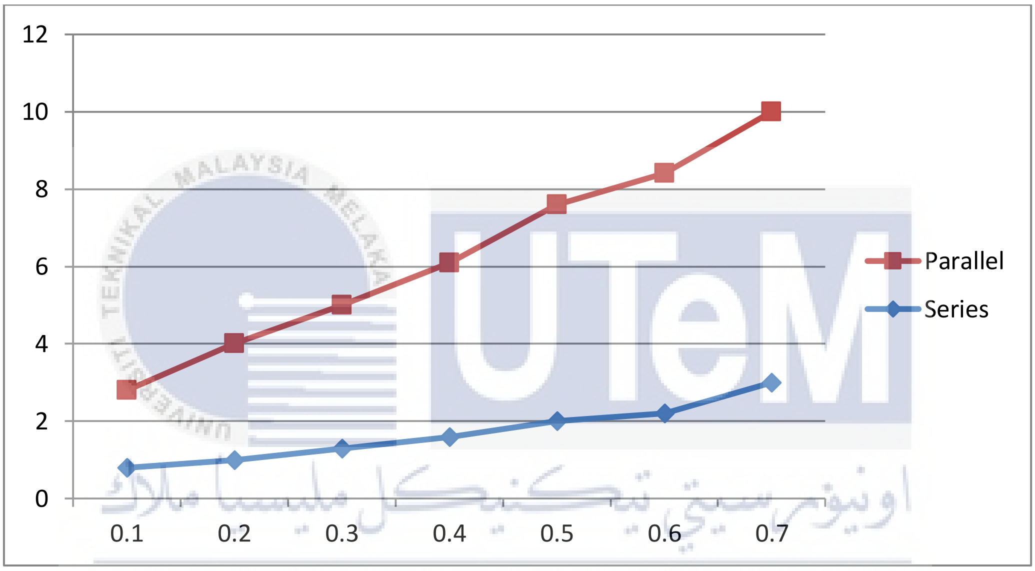


Figure 4.5.2: Graph DC Voltage VS DC Current of Series and Parallel PZT connection

When no vibration is applied, the AC Voltage output of piezo is 0.002V. The parallel connection results show that the piezo is more efficient than series connection. However, in parallel circuit of piezoelectric transducer the AC outputs will cancel out each other. The observation is seen when the vibration is given non-simultaneously to the piezoelectric transducers. This causes difficulties to obtain and capture the measurement outputs due to the vigorous changes of the outputs that occur.

TYPE B circuit data testing

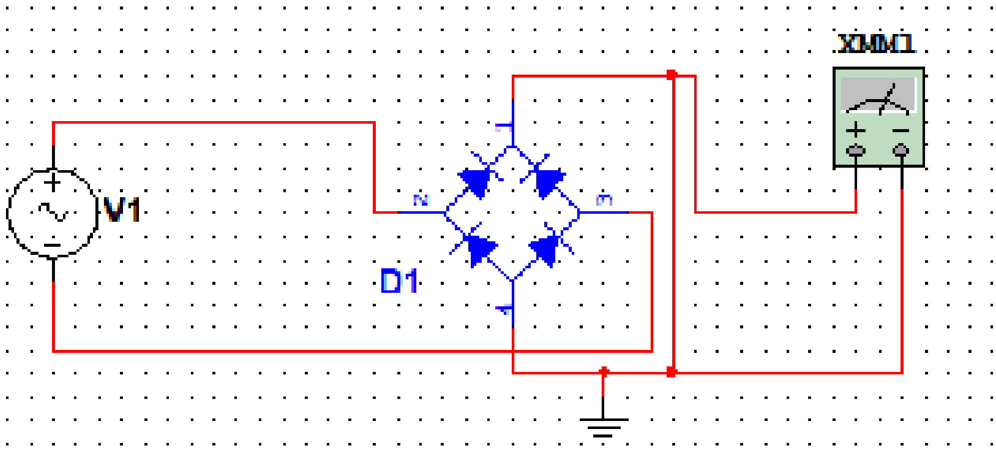


Figure 4.5.3: Electrical Schematic TYPE B-1

For TYPE B-1, a piezoelectric transducer is connected to a diode bridge in one set as the electrical schematic shown. Vibration was given on the piezo plates for 10 seconds. The data results are taken and recorded as the table below.

Table 4.5.4: Type B-1 for PZT and PVDF

Labelled Piezo plates	PZT		PVDF	
	DC Voltage (V)	DC Current (uA)	DC Voltage (V)	DC Current (uA)
1	2.42	2.40	6.33	1.00
2	2.21	3.10	5.13	1.10
3	2.43	3.20	6.70	1.30
4	2.58	3.60	5.56	0.70
5	2.50	2.20	5.49	0.60
6	2.25	2.30	5.55	0.90
7	2.24	3.40	5.24	0.50
8	2.78	2.70	5.45	1.20
9	2.16	2.80	5.98	0.50
10	2.23	2.90	5.35	0.70

When the piezoelectric in normal condition with no vibration occur, the PVDF value showed 0.06Vdc and current 0.00uA while PZT showed Voltage dc 0.39VDC current 0.00uA.

TYPE C circuit data testing

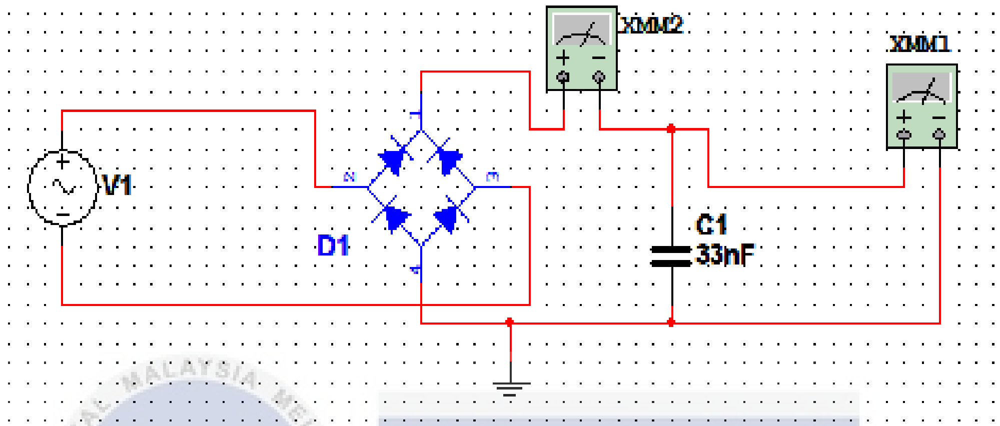


Figure 4.5.4: Electrical Schematic TYPE C-1

For TYPE C-1, a piezoelectric transducer is connected to a diode bridge and a non-polar capacitor 33nF in one set as the electrical schematic shown. Vibration was given on the piezo plates for 10 seconds. The data results are taken and recorded as the table below.

Table 4.5.5: Type C-1 results of PZT and PVDF

Labelled Piezo plates	PZT		PVDF	
	DC Voltage (V)	DC Current (uA)	DC Voltage (V)	DC Current (uA)
1	2.52	15.40	3.72	0.80
2	3.11	14.90	4.26	1.00
3	3.76	14.10	3.65	1.40
4	2.74	25.30	3.66	0.80
5	3.28	12.00	3.30	0.90
6	3.20	14.30	3.78	0.60
7	2.67	26.00	3.20	0.50
8	3.34	10.20	4.10	0.80
9	2.58	18.40	3.65	0.40
10	2.47	9.20	4.67	1.10

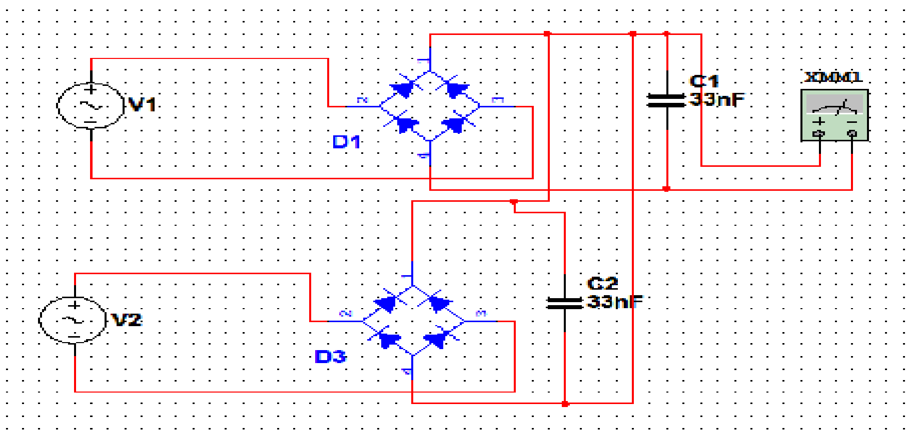


Figure 4.5.5: Electrical Schematic TYPE C-2

For TYPE C-2, two sets of piezoelectric transducer, diode bridges and 33nF non-polar capacitors are connected in parallel as shown in the electrical schematic. The data results are taken and recorded in the table below.

Table 4.5.6: Type C-2 results

Labelled PVDF plates	Maximum DC Voltage (V)	Maximum DC Current (uA)
1	3.39	1.00
2	3.19	1.00
1 and 2 (simultaneously)	4.34	2.00

Figure 4.5.6: Multimeter shows the results of maximum DC Voltage obtained from PVDF

Figure 4.5.7: Multimeter shows the results of maximum DC Current obtained from PVDF

TYPE D (First design)

For TYPE D which is the first design, 10 sets of 10 piezoelectric transducers, 10 diode bridges and 10 non-polar 33nF capacitors are connected first and all the sets have been connected as parallel to resistor 480 Ω as shown in the electrical schematic below.

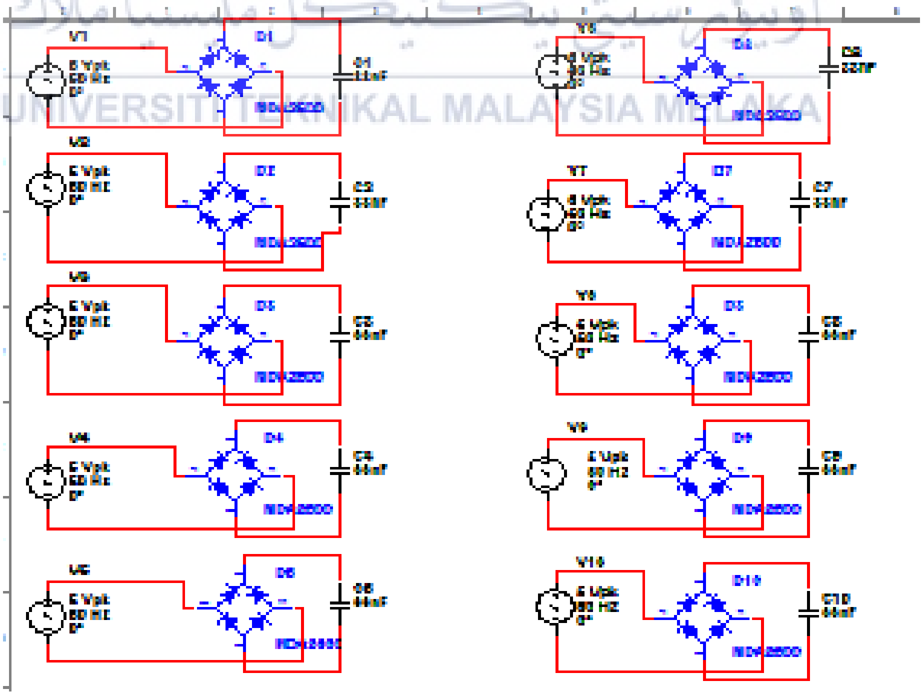


Figure 4.5.8: Electrical Schematic TYPE D (part 1)

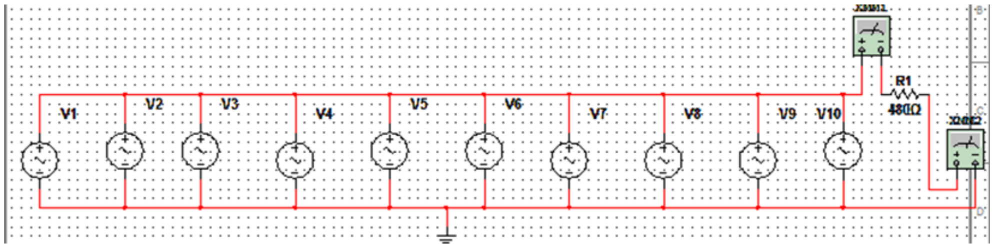


Figure 4.5.9: Electrical Schematic TYPE D (part 2)

From this circuit design first test, only voltages output value can be read and current output shows only 0uA. The maximum voltage reading is 5.57Vdc. For the second test, the resistor is change position as parallel. The results are vice versa from the first test. The current can be read but the voltage output shows 0V. The maximum current output is 2uA.

TYPE E (Second design)

For TYPE E which is the second design, 10 piezoelectric transducers and 10 Diode Bridges are connected as parallel to 1 non-polar capacitor 33nF, 1 resistor 1Ω and 1 diode 1N4001 as shown in the electrical schematic below. The data results are taken and recorded in the table below.

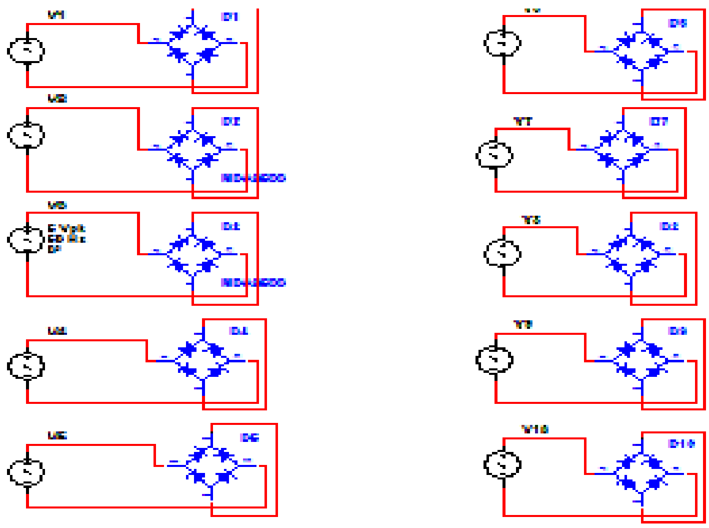


Figure 4.5.10: Electrical Schematic TYPE E (part 1)

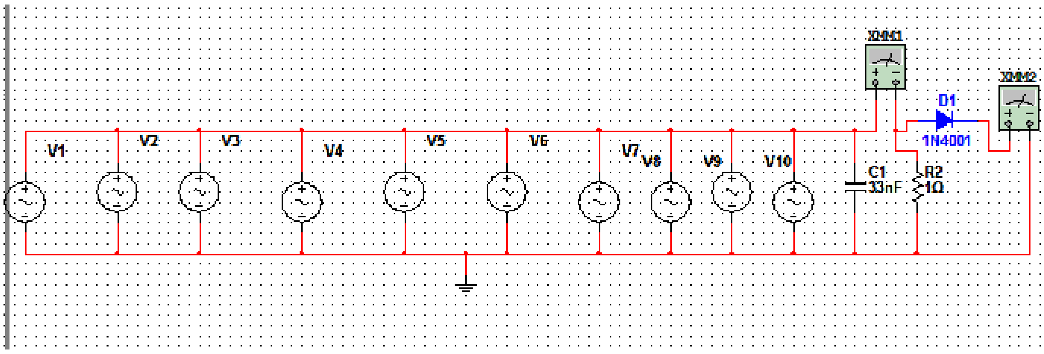


Figure 4.5.11: Electrical Schematic TYPE E (part 2)

Voltages that obtained during testing for one set PVDF transducer and diode bridge as part 1 figure is 16mVdc and 1uA while two sets of the results are obtained 38mVdc and 2uA.

TYPE F (Third Design)

For TYPE F-1: 10 Piezoelectric and 10 diode bridges connected as parallel to 1 Non-polar Capacitor 33nF, Switch, 1 Diode 1N4001 and load (LED/Resistor 1Ω)

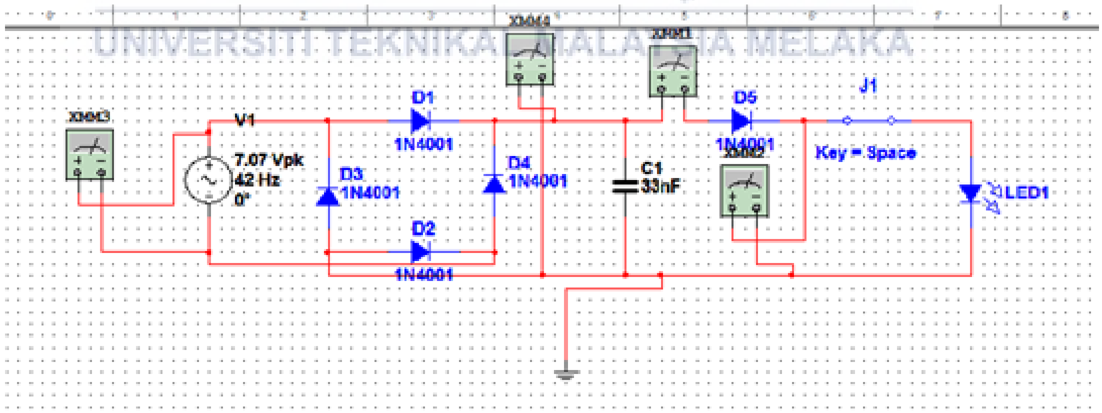


Figure 4.5.12: Electric schematic TYPE F

TYPE G (Voltage Multiplier Circuit)

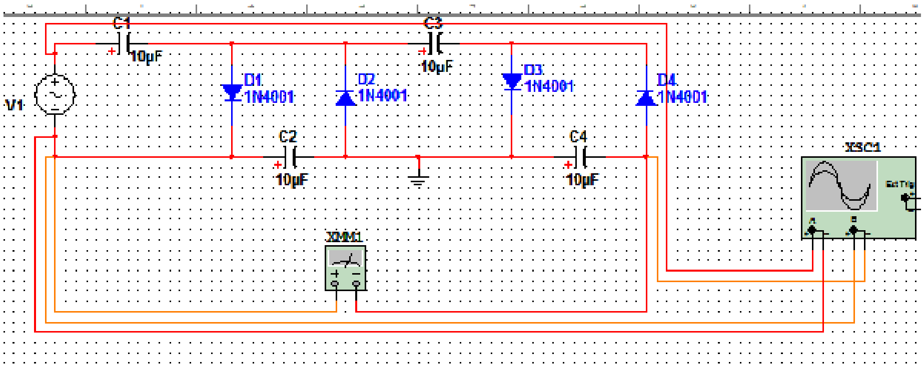


Figure 4.5.13: Voltage multiplier

As for failed and not suitable circuit test, the circuit is Voltage Multiplier. The voltage data output does not multiply four times as expected results in the simulation. A single piezoelectric transducer should be producing at least 2V after being rectified using diode bridges, but the voltage multiplier showed 0.9V as the results. The current output does not show on the multimeter even though every connection has been checked.

4.5.1 Lab scale testing

1) PZT module testing

Results obtained are 2Vdc up to 3dc and the current produce 10uA up to 26uA. When load is added the voltage output is 2V and the max current produced is 5uA.

2) PVDF module testing

By using the third design circuit which is TYPE F, the experiment is tested. The project module hardware is tested under a shower with height 138metres between the shower and the project module hardware. There are three conditions tested during the lab scale testing such small, medium and large output of water from the shower. The water shower output is controlled by the shower knob. Small output of water is applied for 30seconds. Experiment data is recorded the table below.

Table 4.5.7 Small output of water for PVDF module testing

Small output of water on PVDF module	
DC Current (uA)	DC Voltage (V)
0.00	0.01
0.00	0.11
0.00	0.16
0.00	0.18
0.00	0.21
0.00	0.30
0.00	0.32
0.00	0.35
0.00	0.45
0.00	0.49

Medium output of water shows the reading of the current. Experiment data is recorded the table below.

Table 4.5.8 Medium output of water for PVDF module testing

DC current (uA)	DC Voltage (V)	Calculated power (uW)
0.10	2.90	0.29
0.20	3.98	0.80
0.30	3.79	1.14
0.40	3.99	1.60
0.50	4.00	2.00

Large output of water shows the reading of the current. Experiment data is recorded the table below.

Table 4.5.9 Large output of water for PVDF module testing

DC current (uA)	DC Voltage (V)	Calculated Power (uW)
0.10	4.49	0.45
0.20	4.47	0.89
0.30	5.38	0.71
0.40	5.01	2.00
0.50	5.56	2.78

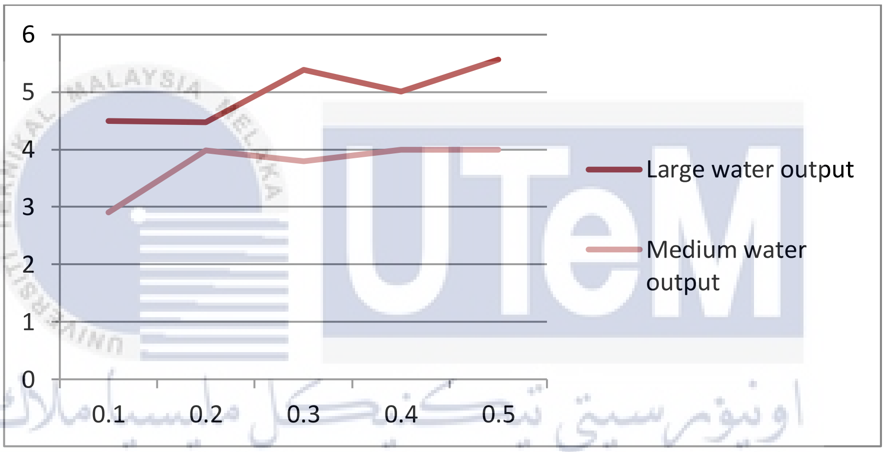


Figure 4.5.14: Graph Voltage vs Current

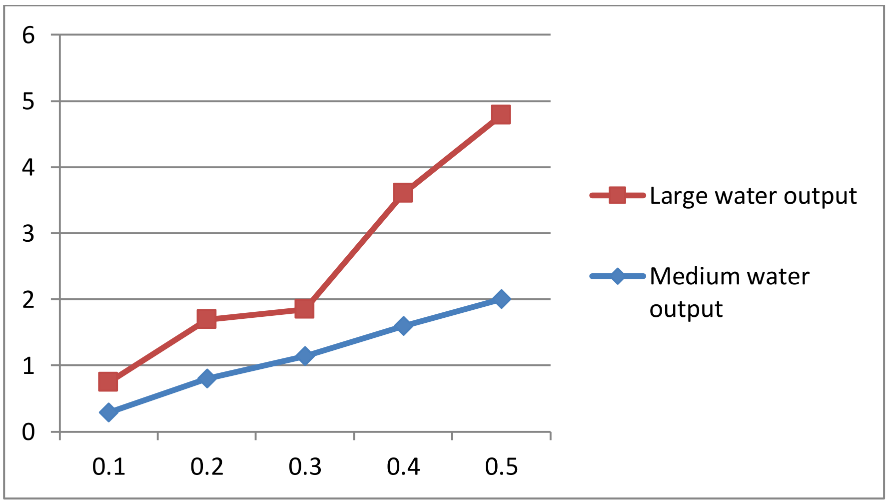


Figure 4.5.15: Graph Calculated Power vs Current

Calculations

PVDF module energy

$E = ½ \times V^2 \times C$

$E = ½ \times 5.56V^2 \times 33nF$

E = 0.5100744uJ

E = 0.51uJ

E/seconds = 0.51uJ / 30 seconds

E/ seconds = 0.017uJ

To charge phone batteries

4.7wh = 16920J

1wh = 3600J

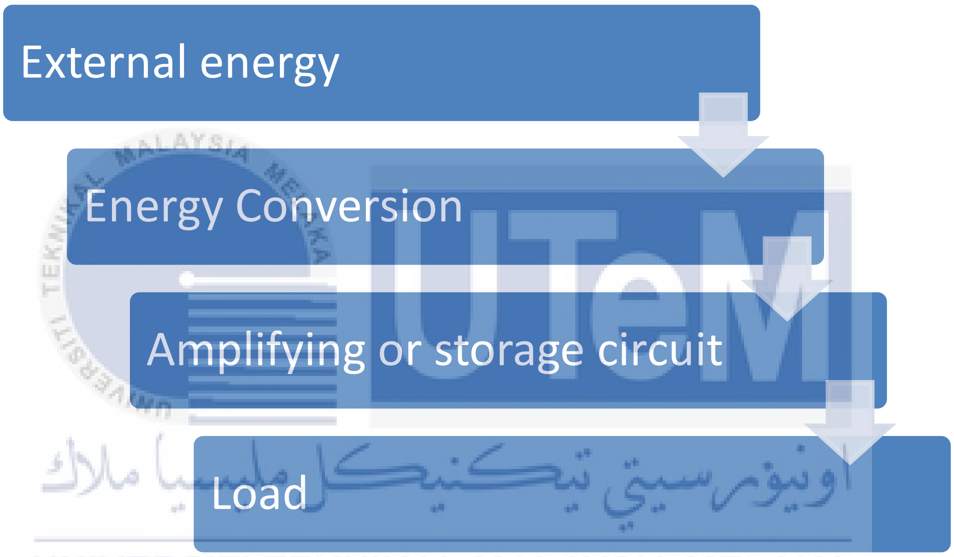
How many seconds to charge a phone?

= 16920J/0.017uJ

= 0.995T secs

4.6 Discussion

This section discusses about the whole results of this project module hardware. This project module hardware is focusing on how the external energy from the vibration or pressure affects the piezoelectric transducers. The energy conversion is done by the diode bridges of 1N4001 which converts AC output into DC output. Amplifying circuit is tested such as the Voltage Multiplier. The load is used to test several circuits such as resistors and LED. The figure below shows the concept of the module.



The concept of the module

The expected results and the actual results obtained are not the same and far too different. First of all, the circuit test which has been simulated which is the Voltage Multiplier, before does not match the actual requirements that needed in this project module. The voltage data output does not multiply four times as expected results in the simulation.

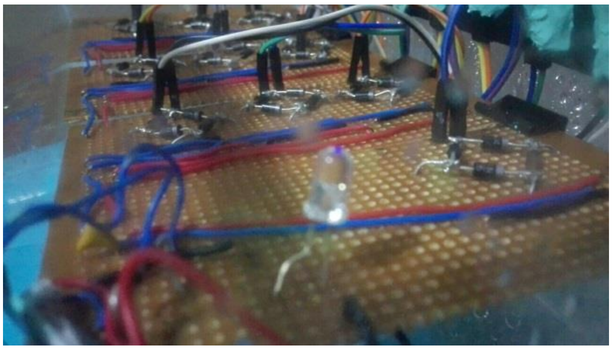
A single piezoelectric transducer should be producing at least 1 or 2V after being rectified using diode bridges, but the voltage multiplier showed 0.9V as the results. The current output does not show on the multimeter even when every connection has been checked more than twice. The piezoelectric transducers are too small to operate the actual circuit. Due to this, a lot of troubleshoot are being done.

The PZT piezoelectric transducer in parallel circuit with no added circuit connection has obtained by given vibration on each PZT plates hence produces the highest AC Voltage output which is 11Vac. The DC voltage obtained by adding diode bridges has produced the highest which is 2.78Vdc while DC current produced 3.60uA.

Every time the water hits the piezoelectric plates non-simultaneously, the voltage reading decreases and looked like the output value cancelling out each other. Furthermore, when a certain pressure is given to the plates simultaneously the voltage showed the result without any disturbance or voltage drop. The piezoelectric transducer that set as parallel without diode bridges is not suitable to use in this module.

The project module hardware is tested under a shower with height distance 138metres between the shower and the hardware. The greater the amount of water source, the greater output power produced by the piezoelectric transducer. The maximum output of the module is 5.56V and 0.5uA.

The calculated output power of the PVDF module per 30seconds is 2.78uW. This output is sufficient to light up an LED but not a light bulb or charge a battery phone. The piezoelectric transducer takes time to store the charge in the capacitor. Amplifier circuit is needed to connect with this module so that the module can act as a power generator.



4.6.1 The LED is lights on during the lab scale testing

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 Conclusion

The piezoelectric transducer able to produce power output but the results are too small especially the PVDF piezoelectric transducer. The piezoelectric transducer needs a longer time to store the energy produced. The PVDF piezoelectric transducer requires a lot of time to store energy compared to the PZT piezoelectric transducer. The PZT piezoelectric transducer has a greater output power than the PVDF piezoelectric transducer but the sensitivity of the PZT piezoelectric transducer will degraded according to time. The project module does not fully suitable to be implemented to housing area due to high cost and lower output power produced.

5.1 Recommendation

In future, the recommendation needed is to widen up the scope of the project module hardware development. The piezoelectric transducers have high output impedance and high voltages compared to current. The amplifying circuits that will be used for future scope such as buck boost or op amp must be added and connected to the project module circuit.

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www.met.gov.my - Malaysian Meteorological Department Official Website.

www.weather-and-climate.com – World Weather & Climate Information Official Website.

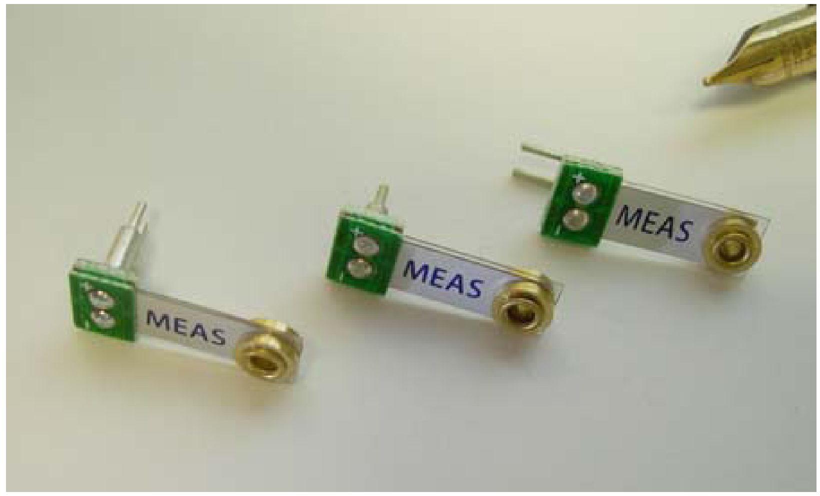
www.tnb.com.my – Tenaga Nasional Berhad’s Official Website.

APPENDICES

1) Gantt Chart
2) Piezoelectric Transducer Datasheet

MiniSense 100 Vibration Sensor

High Sensitivity
Good Frequency Response
Excellent Linearity
Shielded Construction
Analog Output
Withstands High Shock



The Minisense 100 is a low-cost cantilever-type vibration sensor loaded by a mass to offer high sensitivity at low frequencies. The pins are designed for easy installation and are solderable. Horizontal and vertical mounting options are offered as well as a reduced height version. The active sensor area is shielded for improved RFI/EMI rejection. Rugged, flexible PVDF sensing element withstands high shock overload. Sensor has excellent linearity and dynamic range, and may be used for detecting either continuous vibration or impacts.

The mass may be modified to obtain alternative frequency response and sensitivity selection (consult factory).

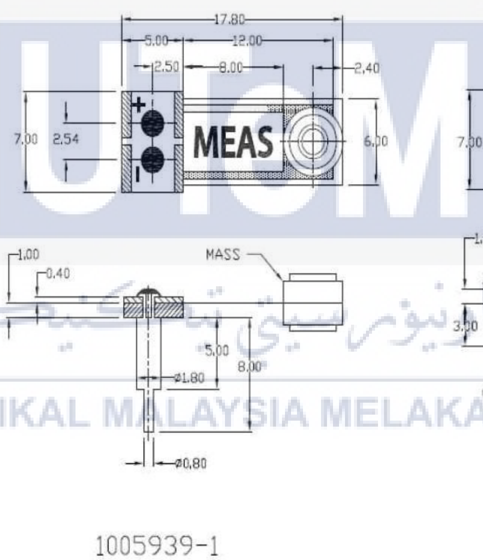
APPLICATIONS

- Washing Machine Load Imbalance
- Vehicle Motion Sensor
- Anti-Theft Devices
- Vital Signs Monitoring
- Tamper Detection
- Impact Sensing

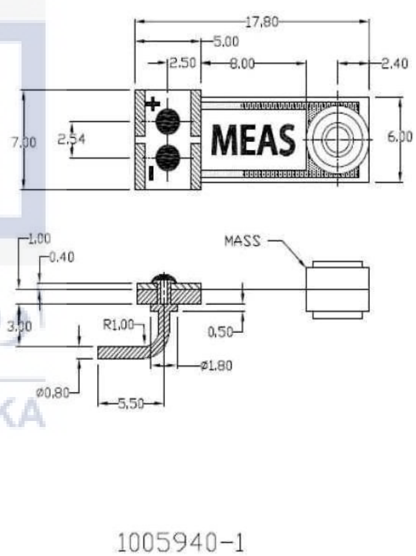
FEATURES

- High Voltage Sensitivity (1 V/g)
- Over 5 V/g at Resonance
- Horizontal or Vertical Mounting
- Shielded Construction
- Solderable Pins, PCB Mounting
- Low Cost
- < 1% Linearity
- Up to 40 Hz (2,400 rpm) Operation Below Resonance

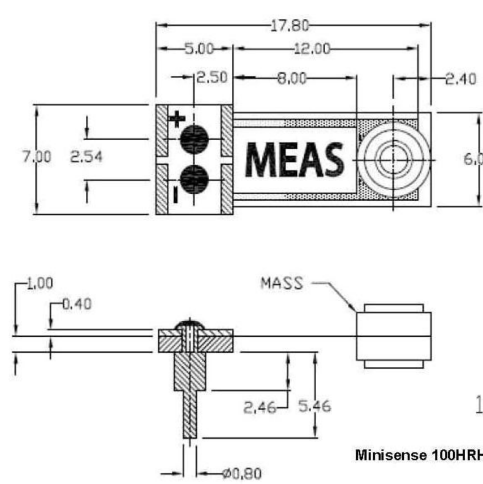
Dimensions (in millimeters)



Minisense 100H (P/N 101005939-1)



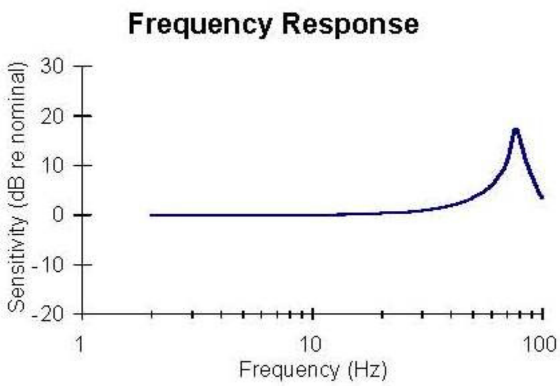
Minisense 100V (P/N 1005940-1)

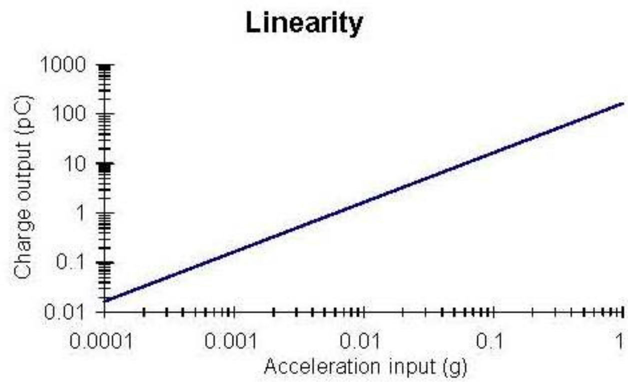


Minisense 100HRH (P/N 1006015-1)

MiniSense 100 Vibration Sensor

performance specifications





Typical properties/specifications

Typical Properties (at 25 °C)

Parameter	Value	Units
Voltage Sensitivity (open-circuit, baseline)	1.1	V/g
Charge Sensitivity (baseline)	260	pC/g
Resonance Frequency	75	Hz
Voltage Sensitivity (open-circuit, at resonance)	6	V/g
Upper Limiting Frequency (+3 dB)	42	Hz
Linearity	+/-1	%
Capacitance	244	pF
Dissipation Factor	0.018	(none)
Inertial Mass	0.3	gram

Environmental Specifications

Storage Temperature	-40 to +80 deg C	
Operating Temperature	-20 to +60 deg C	
Weight	Minisense 100H	0.5 gram
	Minisense 100V	0.6 gram

functional description

The MiniSense 100 acts as a cantilever-beam accelerometer. When the beam is mounted horizontally, acceleration in the vertical plane creates bending in the beam, due to the inertia of the mass at the tip of the beam. Strain in the beam creates a piezoelectric response, which may be detected as a charge or voltage output across the electrodes of the sensor.

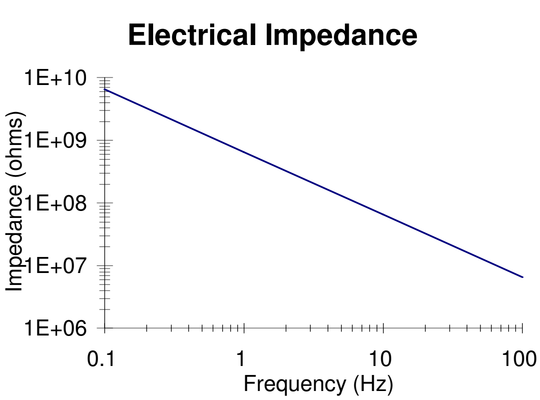
The sensor may be used to detect either continuous or impulsive vibration or impacts. For excitation frequencies below the resonant frequency of the sensor, the device produces a linear output governed by the "baseline" sensitivity quoted above. The sensitivity at resonance is significantly higher. Impacts containing high-frequency components will excite the resonance frequency, as shown in the plot above (response of the MiniSense 100 to a single half-sine impulse at 100 Hz, of amplitude 0.9 g). The ability of the sensor to detect low frequency motion is strongly influenced by the external electrical circuit, as described below (see "Electrical Description").

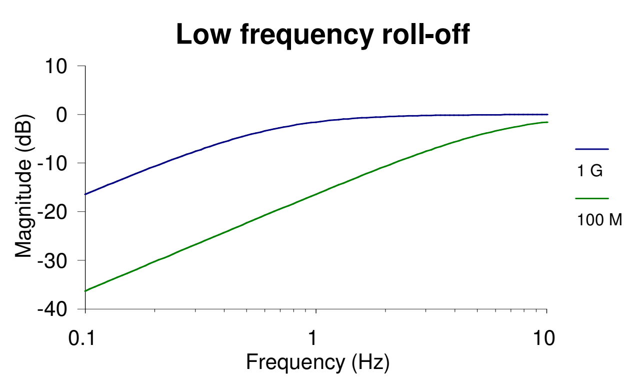
electrical description

The MiniSense 100 behaves electrically as an "active" capacitor: it may be modelled as a perfect voltage source (voltage proportional to applied acceleration) in series with the quoted device capacitance. Any external input or load resistance will form a high-pass filter, with a roll-off frequency as tabulated above, or calculated from the formula $f(c) = 1/(2\pi RC)$. The impedance of the sensor is approximately 650 M ohm at 1 Hz. The active sensor element is electrically shielded, although care should be taken in the PCB design to keep unshielded traces as short as possible.

Lower Limiting Frequency (-3 dB roll-off)

External R (Ω)	LLF (Hz)	Desired LLF (Hz)	Required R (Ω)
10 M	65	10	65 M
100 M	6.5	1	650 M
1 G	0.65	0.1	6.5 G



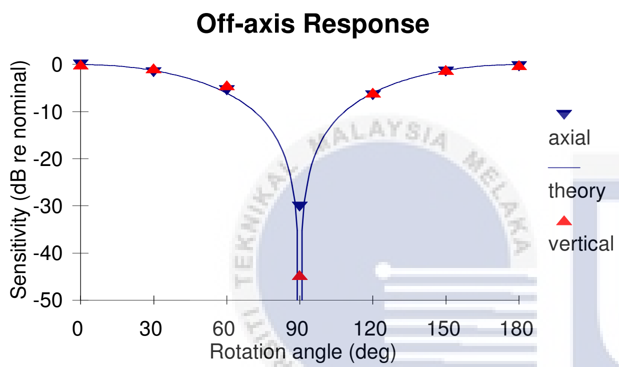


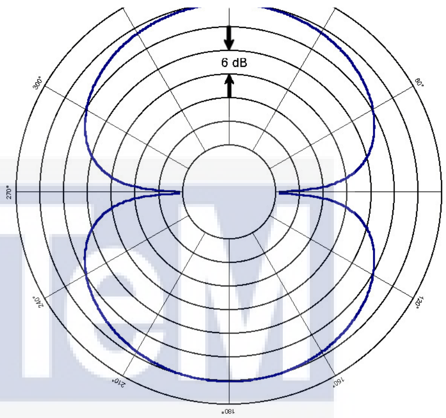
off-axis sensitivity

The sensitivity of the Minisense 100 follows a cosine law, when rotated horizontally around its axis, or vertically around its mid-point. At 90 degrees rotation in either plane, both baseline sensitivity and sensitivity at resonance are at a minimum. In theory, sensitivity should be zero in this condition. It is likely that some sensitivity around the resonance frequency will still be observed – but this may be unpredictable and is likely to be at least -16 dB with reference to the on-axis response. Note that the sensitivity at 30 degrees rotation is -1.25 dB (87% of on-axis response), at 60 degrees, it falls to -6 dB (50%).

The plots below show the change in sensitivity observed for either:

1) Rotation about major axis of sensing element, or
2) Rotation about mid-point of sensing element.





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ordering information

Description	Model No.	Part No.
Horizontal Mounting	LDTC-V	1005939-1
Vertical Mounting	LDTC-H	1005940-1
Horizontal Mounting Reduced Height	LDTC-RH	1006015-1

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