Faculty of Electrical Techonology and Engineering

PERFORMANCE MEASURE OF SERIES-PARALLEL PIEZOELECTRIC TRANSDUCER CIRCUITY FOR IMPROVEMENT OF OUTPUT VOLTAGE

NUR ATIKAH BINTI ABDUL HADI

Bachelor of Electrical Engineering Technology with Honours

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DEDICATION

This report is dedicated to my beloved family, whose continuous support and encouragement have been the cornerstone of my academic path. They are the recipients of my dedication for my final year project. My project, "Performance Measure of Series-Parallel Piezoelectric Transducer Circuit for Enhancement of Output Voltage," has motivated me to achieve greater heights and follow my passion because of their love and sacrifices. I would also like to express my appreciation to my supervisor, Dr. Nor Hafizah Binti Hussin, whose advice has been very helpful throughout the entire project.

ABSTRACT

Piezoelectric can generates and stores electrical energy for later use using non-renewable resources like the sun's heat and the wind's vibration. A new energy source require to meet the rising demand due to the depletion of fossil fuels and non-renewable energy. In this work, piezoelectric energy harvesting was studied. In this experiment, piezoelectric energy was measured using multimeter. In this project, indicator used for the output of piezoelectric 8x8 matrix led. Vibration is detected by the piezoelectric sensor, which then transforms mechanical stress into electricity. Piezoelectric sensors are linked in series-parallel connection. The pressure-point footstep tile is then modelled after it using board. A 18650 lithium-ion battery stores the small amount of voltage produced by pressure on a piezoelectric sensor. Piezoelectric AC is converted using bridge rectifiers. This initiative will be applied to stairwells, sidewalks, and other busy areas. DC loads, such as a mobile, can be powered using piezoelectric tiles. Piezo sensors undergo mechanical stress, which causes energy to be stored in the battery. The major focus of the study is on ways to improve power generation through circuit design optimisation and output enhancement and amplification adaptation. An analysis of the differences between the output voltage from the different diameter and quantity is carried out.

ABSTRAK

Piezoelektrik boleh menghasilkan dan menyimpan tenaga elektrik untuk kegunaan kemudian menggunakan sumber yang tidak boleh diperbaharui seperti haba matahari dan getaran angin. Sumber tenaga baru memerlukan untuk memenuhi permintaan yang semakin meningkat kerana kekurangan bahan api fosil dan tenaga yang tidak boleh diperbaharui. Dalam kerja ini, penuaian tenaga piezoelektrik telah dikaji. Dalam eksperimen ini, tenaga piezoelektrik diukur menggunakan Arduino. Dalam projek ini, penunjuk yang digunakan untuk output matriks piezoelektrik 8x8 led. Getaran dikesan oleh sensor piezoelektrik, yang kemudian mengubah tekanan mekanikal menjadi elektrik. Sensor piezoelektrik dihubungkan dalam sambungan siri-selari. Jubin langkah kaki titik tekanan kemudian dimodelkan selepas menggunakan papan. Bateri lithium-ion 18650 menyimpan sejumlah kecil voltan yang dihasilkan oleh tekanan pada sensor piezoelektrik. Piezoelektrik AC ditukar menggunakan penerus jambatan. Inisiatif ini akan digunakan untuk tangga, trotoar, dan kawasan sibuk lain. Beban dc, seperti telefon bimbit, boleh dikuasakan menggunakan jubin piezoelektrik. Sensor piezo mengalami tekanan mekanikal, yang menyebabkan tenaga disimpan di dalam bateri. Fokus utama kajian ini adalah pada cara untuk meningkatkan penjanaan kuasa melalui pengoptimuman reka bentuk litar dan peningkatan output dan penyesuaian penguatan. Analisis perbezaan antara voltan keluaran dari diameter dan kuantiti yang berbeza dijalankan.

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Firstly, I would like to express my gratitude to Allah S.W.T. for providing me with the chance to successfully complete my report on "Projek Sarjana Muda" after I patiently overcame many challenges. Without the generosity and goodwill of my supervisor, Dr. Nor Hafizah Binti Hussin, this report would not have been possible to finish. She was ready to help and very patient with me while I completed my senior assignment. In addition, she provided a wealth of material and insightful expertise that helped me finish this assignment. Her willingness to assist me was a major factor in my development, and her encouragement and drive to finish my assignment motivated me significantly. Not to forget, I want to express my gratitude to the other instructors and staff members at the Faculty of Engineering Technology who volunteered their time to assist me in solving the issue. Many thanks for your excellent collaboration and dedication in finishing the job. In addition, I would want to express my gratitude to my parents and other family members. They have taught me the value of perseverance in the face of overwhelming hardship. However, they provided excellent assistance and understanding in finishing our assignment. Finally, but just as importantly, I would want to express my gratitude to the administration of Universiti Teknikal Malaysia Melaka (UTeM) for giving me the better atmosphere and resources I needed to do my research.

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V	-	Voltage
MHz	-	Megahertz
MIPS	-	Million instructions per second

CHAPTER 1

INTRODUCTION

1.0 Introduction

Energy is nothing more than the capacity for work. For the modern human population, power has become a source of assistance. Its requests are growing quickly. Life innovation requires a significant amount of electrical power on a daily basis for its various functions. The world's largest single source of pollution is power generating. As a result, a lot of energy resources are created and wasted. power is typically produced using resources such as water, wind, coal, etc. to generate the power from those resources requires the construction of large plants that require expensive upkeep. In a similar vein, the current work aims to provide a method for electrical power generation from which a regularly rising human population does not negatively impact the natural environment.

The production of electrical energy is discussed in this paper employing the concept of weight energy. A person can be amazed by how much energy they have just by moving around on the floor at a typical pace. Therefore, the average person takes thousands of steps per day. People waste a significant quantity of energy while walking, which might be used and transformed into electrical energy. The electro-kinetic floor is a method of producing electricity by harnessing the kinetic energy of people walking across it.

The energy that is typically generated by the floor can create a quiet environment without any pollution, and it will be cost-effective in that it uses no fuel or other energy source other than the weight of the person moving across the floor as its sole source of kinetic energy. Regarding the present-day world. These days, power and energy are the fundamental driving forces. As a result of the daily rise in energy demand, renewable energy sources are used as their final answers.

Piezoelectric transducers have shown potential as a tool for transforming mechanical vibrations into electrical energy in the quest to advance energy harvesting technology. Piezoelectric components can be arranged in a variety of ways, but series-parallel arrangements have drawn interest due to their capacity to raise output voltage and efficiency overall. In order to increase the output voltage of series-parallel piezoelectric transducer circuits, this study focuses on measuring their performance.

Piezoelectric materials are useful for sensing and energy harvesting because they produce electrical charges in response to mechanical deformation. But improving the output of circuits using piezoelectric transducers is still a difficult task, particularly when combining series and parallel designs. The advantages of both arrangements are combined in the series-parallel design to produce higher voltage output. Parallel layouts improve the current output, but series configurations increase the voltage. By optimising the ratio of voltage to current, this hybrid technique seeks to maximise the total power obtained from mechanical vibrations.

Several factors, including the electrical load, circuit architecture, and mechanical input, affect the performance of series-parallel piezoelectric transducer circuits. Establishing a strong set of performance criteria and measuring methods is crucial to methodically increasing the output voltage. These measurements might include, among other things, frequency responsiveness, power output, impedance matching, and voltage amplitude. Series-parallel piezoelectric transducer circuit performance may be measured and assessed using the complete method proposed in this work. Through a thorough examination of circuit behaviour under various operating situations, our goal is to find areas that may be optimised and improved. The ultimate objective is to offer knowledge that aids in the creation of energy harvesting systems that are more dependable and efficient.

The piezoelectric disc contracts when someone steps on a scale. A crystal is released after the pressure is raised. As a result, a crystal disc detects a full vibration and generates a voltage across it. A voltmeter detects this voltage and displays it on its display. At the same time, store the energy generated by the piezoelectric is 18650 lithium-Ion battery.

1.1 Problem Statement

For most people, having access to reliable, sustainable energy is a basic requirement, and environmental concerns are driving up demand for renewable energy sources. This is a result of increasing demand for energy and population. The population of Malaysia is growing, which raises the need for energy resources. Traditional energy sources, such fossil fuels, are not only unsustainable but also have a negative impact on the environment. Therefore, it is critical to investigate other forms of renewable energy.

Next, the pattern of piezoelectric connections directly influences how mechanical vibrations are distributed among the transducers. So, optimizing the pattern of piezoelectric connections is essential for enhancing the efficiency of a transducer system in converting mechanical vibrations into electrical energy. However, an inefficient power output and underperformance of individual transducers can happen when the unequal loading of piezoelectric transducers coupled in series and parallel. This is because overall output depends on the determination of the most effective arrangement required for each transducer to evenly distribute the mechanical input.

Furthermore, different environmental conditions can impact the performance of energy-harvesting systems. This impact can make the piezoelectric give varying amplitudes or frequencies that affect the efficiency of the connection. Moreover, it needs to be in a specific operating condition across a range of scenarios.

1.2 Objective

The objective of this project is to:

a) To study the piezoelectric sensor in series-parallel connection.
b) To analyze the pattern of piezoelectric connection for the most efficient output.
c) To evaluate the most efficient performance of the piezoelectric connection.

1.3 Scope Of Study

The scope of the project is defined as follows:

a) This project is targeted for outdoor use for flooring systems.
b) The system in this project uses Arduino UNO as the main controller
c) Piezoelectric sensor uses piezoelectric effect to measure pressure or mechanical energy by converting all of it to electrical energy signals.
d) The battery used to store the energy generated by the piezoelectric is 18650 lithium-ion battery.
e) 8x8 matrix led is used as an indicator that shows the output of the project.

1.4 Project Significant

The objective of this project is to increase the output voltage of a series-parallel piezoelectric transducer circuitry by methodically examining and fine-tuning its layout. Using a combination of experimental validation, theoretical modelling, and iterative design, the project aims to determine the critical factors affecting the transducer's performance and create plans to optimise output voltage. This project is important for improving basic knowledge of the behaviour of piezoelectric transducers as well as for real-world applications in energy harvesting, sensing, and actuation, among other areas. The circuitry that has been optimised may help create piezoelectric devices that are more dependable and efficient, which might lead to improved performance and wider use in a variety of technological applications.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The country's population is growing, which also means that more power is needed. The growing population has led to the depletion and squandering of several energy resources[1]. Therefore, it is crucial to reform this energy into a usable state. As technology develops, electronic gadgets are utilised increasingly often. Power generation using conventional methods is becoming inadequate. It is necessary to use a different method of electricity generation. Aside from that, energy is also wasted due to human movement. A piezoelectric sensor is used to convert the lost energy into a form that may be utilised in order to resolve this problem. This sensor converts the pressure that is applied to it into a voltage. The imbalance in the crystalline structure is what causes the piezoelectric action[2].The foot step power generation system is what it is named. A piezoelectric sensor measures changes in pressure, acceleration, temperature, strain, or force by converting those changes into an electrical charge. Hence, piezoelectric devices are more effective in capturing energy from human motion and vibration[3].

2.1 Renewable energy

Any resource that can naturally replace itself over time is said to be renewable. As a consequence, even with human use, it is sustainable. A key tactic to achieving environmental sustainability is the deployment of various clean energy technologies[4]. Renewable resources only have a finite amount of energy accessible at any given time, while having a practically infinite lifespan. In the modern world, non-conventional energy requirements have grown along with electricity usage. Renewable energy sources like the sun and wind are employed to meet this human demand for power. However, these resources are insufficient, and there are several other ways that energy waste is growing.

2.1.1 Different solar energy and footstep energy

Table 1 : Different solar energy and footstep energy

Solar energy	Foostep energy
PV solar panels convert sunlight directly into electricity through the photovoltaic effect.	Footstep power generation involves harnessing the kinetic energy generated by human footsteps and converting it into electrical energy.
When sunlight hits the solar cells, it creates an electric current, which can be used to power homes, businesses, and other electrical devices.	The primary principle behind this technology is the use of piezoelectric materials or mechanisms to convert mechanical pressure or vibrations into electrical energy.
Solar energy provides a reliable and abundant source of electricity	footstep power generation harnesses human motion to generate electricity in specific settings

2.2 Conversion of kinetic energy to electricity energy

The development of a foot-steps power generator for converting kinetic energy into electricity[5]. Kinetic energy is one of the unusual energy sources. The feasibility of kinetic energy to electrical conversion has been thoroughly studied. However, the majority of past studies focused on both the careful material selection and the intricate design of power generators. According to this study, a straightforward and inexpensive way to increase the effectiveness and efficiency of kinetic energy to electricity energy conversions is to install mechanical footfall power generators on the backmost foot region.

The Power Generation from Piezoelectric Footstep Technique was explained[6]. This article's main focus is the wasted electric power produced by people's footfall and the pressure they exert while walking. The imbalance between supply and demand is the main problem in the energy crisis. The "Foot Step Power Production System" uses transducers and the pressure that a footstep creates to transform mechanical energy into electrical energy. The floor that produces power effectively transforms kinetic energy into electrical energy when it generates power. Existing power generation sources are unable to keep up with the expanding global demand for electricity.

Ratnesh Srivastava claims that the number of low power electronic gadgets has significantly expanded in recent years. The technologies are widely utilised to make our daily life more comfortable[7]. Introduction of a step power generation to fulfil this power need. This system's main goal is to convert the normally lost energy that surrounds a system into electrical energy.

2.3 Piezoelectricity

David Voss state that Pierre and Paul-Jacques Curie made the discovery of piezoelectricity in 1880[8]. They noticed that particular crystal kinds, such as quartz, tourmaline, and Rochelle salt, created a voltage on their surface when they were squeezed along specific axes. This effect is known as piezoelectric effect. Piezoelectricity is the electric charge that accumulates in certain solid materials in response to applied mechanical stress. Piezoelectricity is the scientific term for electricity produced by pressure and latent heat. A piezoelectric crystal is made up of several positively and negatively charged interconnecting domains. Due to the symmetry of these domains inside the crystal lattice, the lattice is electrically neutral overall. Voltages are produced when the symmetry of the crystal is somewhat disturbed by stress.

2.3.1 Working principle of piezo sensor

A piezo sensor, also referred to as a piezoelectric sensor as in Figure 2.1 functions according to the piezoelectric effect's basic principles. The term "piezoelectric effect" describes a material's capacity to produce an electric charge under pressure or mechanical stress. In Eßinger et al. ,the authors use a sensor made of a piezoelectric material to remove the external component of the CI by converting the vibrations caused by sound in the long process of the incus into charge

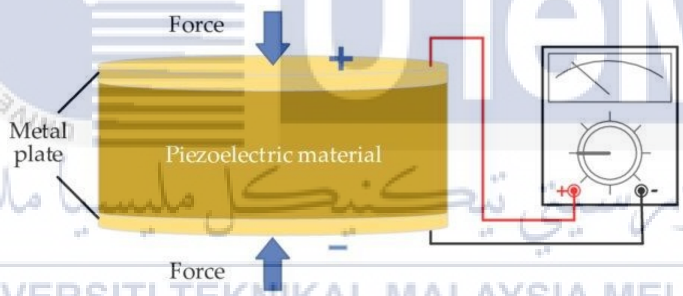

Figure 2.1 Principle of piezoelectric[9]

The following stages can be used to summarise a piezo sensor's operation:

a) Piezoelectric Material: A piezoelectric material, such as quartz, ceramic, or certain kinds of crystals, is used to build the sensor. These substances possess the unusual ability to produce an electric charge in response to mechanical stress.
b) Mechanical Stress: The piezoelectric material deforms or alters its shape when mechanical stress or pressure is applied. This stress may take the form of bending, compression, or tension.

c) Electric Charge Generation: The movement of electric charges within the crystal lattice structure of the piezoelectric material results from its deformation. Positive and negative charges are separated as a result of this displacement, resulting in an electric potential difference or voltage across the substance.

d) Signal Output: Electrodes connected to the piezoelectric material's surfaces capture the electric charge that is created. These electrodes make it easier to transmit the electrical signal to a circuit or measurement tool outside the body

e) Electrical Signal Measurement: Information may be gathered by measuring and processing the voltage that the piezo sensor produces. The electrical signal may need to be enhanced, filtered, or further processed depending on the application in order to extract certain information or initiate the necessary actions.

2.3.2 Advantages and disadvantages of piezo effect

Table 2 : Advantages and disadvantages of piezo effect

Advantages	Disadvantages
• Simple structure	• Brittle material
• No need for external voltage sources	• Poor mechanical characteristics
• High output voltage	• High output impedance
• Configuration compatible with MEMS	• Low output current

2.3.3 Crystal Quartz

Piezoelectric materials have the ability to convert electrical stress into mechanical vibrations and vice versa. One type of naturally occurring piezoelectric crystal is quartz. Atoms of silicon and oxygen are arranged in a repeating pattern to form quartz crystals. The silicon atoms in quartz are positively charged, whereas the oxygen atoms are negatively charged. Normally, the charges in the molecules are distributed uniformly throughout the crystal when it is not subjected to any external force. However, there is a minor shift in the atomic arrangement of quartz as it is stretched or compressed. Positive charges accumulate on one side of the change while negative charges accumulate on the other. Utilising this potential difference, current may be generated by building a circuit that joins the crystal's two ends. Stronger electric current results from applying additional pressure to the crystal. On the other hand, if an electric current passes through the crystal, its form is modified.

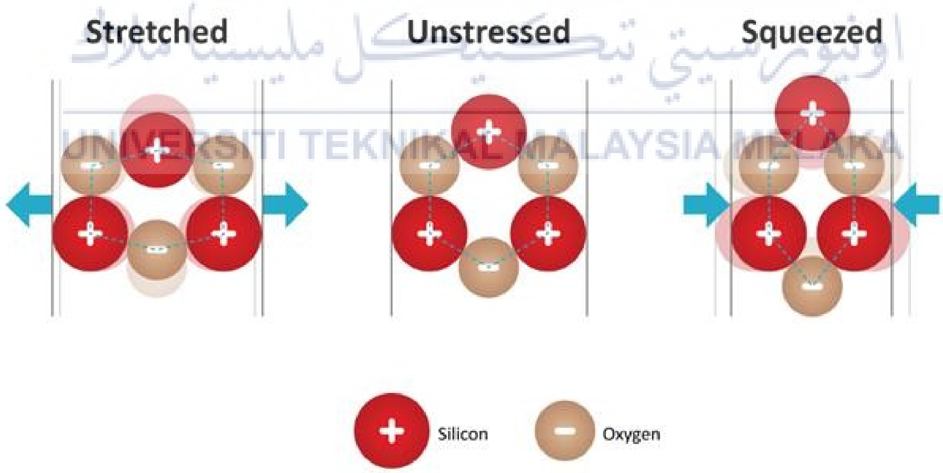

Figure 2.2 Piezoelectric effect

2.4 Footstep Power Generation Using Piezoelectric Sensors

A variety of methods are being used to produce alternative power sources.

2.4.1 Smart Road Piezoelectric Sensor

The words "smart highway" and "smart road" refer to various technologies that may be implemented into highways to enhance the performance of connected and autonomous vehicles (CAVs)[10]. The piezoelectric smart road sensor is one of the alternative techniques. Smart roads are those that can have piezoelectric sensors installed on it to produce electricity. Any moving vehicle causes extremely slight vertical deformations and vibrations on the road surfaces. The need for power is growing, which compels scientists to consider ways to capture otherwise squandered vibration energy from moving objects.

Figure 2.3 Energy Harvesting by Piezoelectric Sensor Array in Road [11]

2.4.2 Flooring tiles

In Japan, the use of the piezoelectric effect for energy production has already started. The use of the piezoelectric effect for energy generation on bus stairs has previously been tested in Japan[12]. A little vibration that may be turned into electricity is created every time a passenger steps on the tiles.The floor tiles are made of rubber, which can reduce vibration. This vibration happens when you run or walk on it. These tiles are supported by piezoelectric materials. When the material detects movement, it may generate power. The produced energy is simultaneously used to charge the battery.. Lighting from lamps or street lights can be used to generate electricity. Each step taken by one individual requires too little energy, but as the number of steps rises, so does overall energy output.

2.4.3 Dance Floors

Europe is another area that started experimenting with the usage of piezoelectric crystals for energy production in nightclubs[13]. The floor is compressed by the dancer's feet, which causes piezoelectric materials to come into contact and generate energy. Electrical energy produced is just 2-20 watt is used. Depending on the dancer's feet's impact

2.5 Available Techniques in past

The idea of producing power by utilising footsteps is not new. There have historically been several methods accessible for this purpose, some of which include

- Fly wheel and gear arrangement
- Stair case faraday’s law arrangement
- Rack and pinion
- Chain sprocket arrangement

2.5.1 Fly wheel and gear arrangement

Figure 2.4 shows fly wheel and gear arrangement. Through the use of an appropriate drive, the thrust power is converted into electrical energy device.The sloping floor is attached to the racks. The burden is released and the same slanted posture is made operable by the spring tide. End bearings link the pinion shaft to the bearing. The pinion shaft is additionally engaged by larger gears, which run at the same speed. The chain connects the biggest sprocket to the smallest gear ring. The torque generated by the smallest sprocket is converted by this huge sprocket. The front and rear high sprockets revolve similarly to the direction in which the smallest sprocket rotates. This movement stops like a pedal on a bicycle. The smaller sprocket's shaft is connected to the wheel and sprocket. The speed of the axis of the smallest sprocket can be increased by turning the steering wheel. The generator shaft and gearwheel are connected by an extra gear. Here, a permanent magnet generator is being used. 12V DC is the generated voltage. Lead acid 12-volt batteries are used for maintaining this D.C voltage.

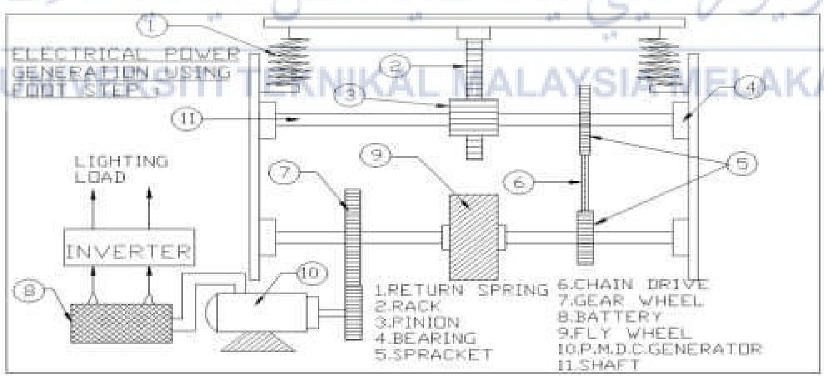

Figure 2.4 Fly wheel and gear arrangement[14]

2.5.2 Stair case faraday's law arrangement

In the spring, those who ascend or descend stairs will push or apply impact force. This impact pressure energy may be used to drive the power flywheel by using a one-way ratchet mechanism with a chain and sprocket drive. The generator pulley and belt drive system are continuously rotated thanks to the flywheel, which stores energy. It comprises of three steps that raise the box-shaped staircase. All stages are connected to the main gear by the chain drive, and the small gear is attached to it after that. The sleeve shaft's ratchet wheel can only revolve in one direction because of the little gear that is connected to it. The two enormous gear wheels are similarly coupled to the same shaft using separate chain mechanisms for each of the two wheels. When a person is walking on the individual level, this specific set of gears causes the ratchet wheel and, consequently, the main shaft, to move.

2.5.3 Rack & Pinion and chain Sprocket arrangement

A type of linear actuator known as a "rack and pinion" consists of two gears that transform rotational motion into linear motion. The frame's linear bar 'gears' are enclosed in the circular gear's teeth. The rack would slide to one side, to the extent of its journey, if rotational movement were applied to the pinion.

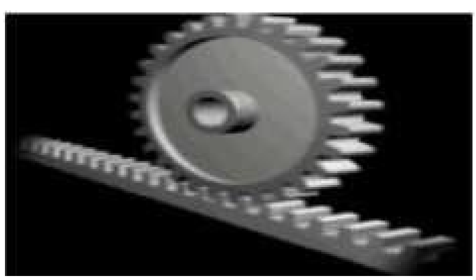

Figure 2.5 Rack & Pinion

A pinion is a reported wheel with teeth that connects to a chain, a route, or another material that has been perforated or dented. The fact that the pinions do not immediately mesh with one another sets it apart from a gear, just as it does from a pulley, which has smooth pulleys and gears with teeth. The slanted channel in this instance is coupled to the spring-and-rack setup. The process involves releasing the load spring and then resuming the tilt operation in the same location. End bearings link the pinion shaft to the bearing.

2.6 Different Types of Piezoelectric Multi-Array Configurations

Piezoelectric sensors are connected in an array arrangement in parallel and series starting with one unit and going up to 22 units for the first stage of simulation. With a step size of one, the simulation aims to evaluate the anticipated output and characteristics of a piezoelectric sensor with an increasing number of sensors. Subsequently, the simulation proceeded by employing three piezoelectric sensor connection units with distinct circuit arrangement kinds. In order to reduce the likelihood of a series impact on the piezoelectric sensor connection and to create the smallest possible array connection for the piezoelectric sensor design, this research focused on a set of three piezoelectric sensors. The state of the piezoelectric when coupled in series is displayed in Table 3. According to preliminary research, no output is recorded if only one piezo is squeezed out of three piezos connected in series. The output will either reduce or not occur at all if the piezo array is adjusted in accordance with the variations shown in the table 3 below. As a result, three piezo elements at the very least are sufficient to test different series and parallel combinations and determine the optimal output for more research. A set of three piezoelectric sensors are then simulated in four distinct configurations: series (S), parallel (P), combination series-parallel (SP), and combination parallel-series (PS). Figure 2.6 depicts the modelling of the piezoelectric sensor connected in series arrangement. Different load resistance (RL) values are used to gauge the device's performance and output power.

Table 3 : Simulated parameter of piezoelectric.

Parameters	Value
Input Current	1.36 µA
Voltage Input, Vp-p	2.68 V
Frequency	1 Hz
Load Resistance	1 MΩ

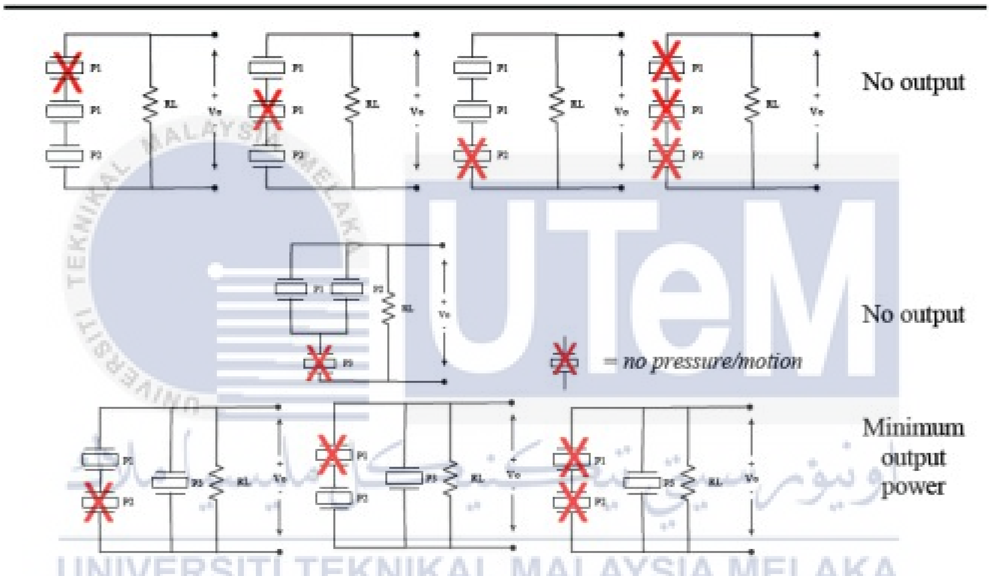

Figure 2.6 Various series effects in a trio of piezoelectric sensors

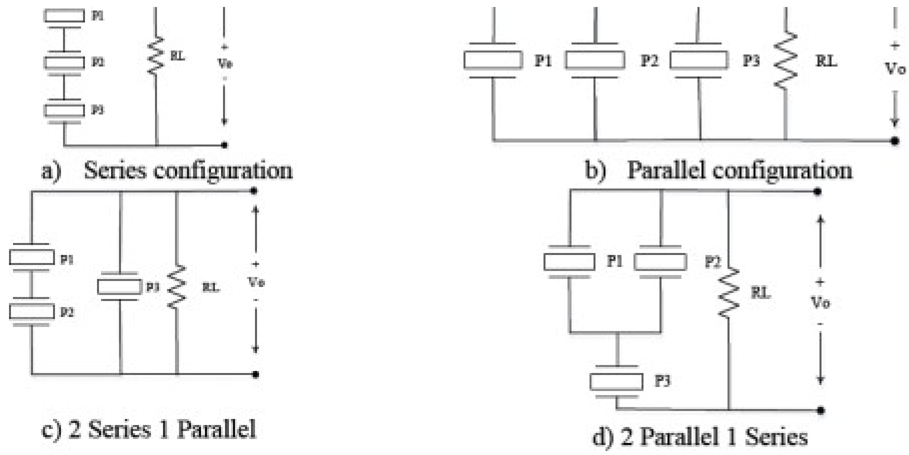

Figure 2.7 Circuit configuration for piezoelectric sensor connection[15]

2.7 Experimental research

This field of experimental inquiry was connected to earlier investigations carried out by M.N.Fakhzan. The following section functions as a reference for this project.

2.7.1 Foot Stop Electric Converter (FSEC)

Vibration-based energy harvesting using piezoelectric material is being done as an experiment[16]. From this experiment, figure in this article show how the Foot Stop Electric Converter (FSEC) operates. The foot is seen touching the top plate in the right-side snap without putting any weight on it. When the body's whole weight is shifted on the top plate, the foot may be seen on the left side of the photograph. When a foot load is applied, a 6 W, 12 V bulb attached to the alternator's output flashes to show the electric output. The device is made to produce a full-power pulse when activated by a person who weighs close to 60 kg. Using an oscilloscope, a voltage vs. time experimental plot was produced. The load (a resistor) and voltage data were used to create a standard plot of power vs. time.

Figure 2.8 Foot Stop Electric Converter (FSEC)

2.7.2 Energy Storing table

An energy container can be used to store the energy that the step generator produces. The generator's output was linked to a 12 V lead acid battery via a bridge ac-dc converter. First, the battery was completely discharged. An applied foot weight and energy from the battery were used to power the FSEC. A 100-watt, 230-volt light was connected to the battery through an inverter. Table 4 provides the lighting time, the bulb for each footstep, and the equivalent energy conserved.

Table 4 Energy storing table[11]

No. of foot steps	Duration of lighting a 100 watt 230 volt bulb (s)	Total energy (J)	Energy / step (J)
250	6	600	2.4
500	12	1200	2.4
750	18	1800	2.4
1000	25	2500	2.4

2.7.3 Analysis done on the piezo tile

In order to evaluate the piezo tile's ability to generate voltage, persons weighing between 40 and 75 kg were compelled to walk on it for the study. The relationship between produced power and a person's weight is shown. The graph shows that when the most weight or force is applied, the most voltage is produced. As a result, when a weight of 75 kg is applied to the tile, a maximum voltage of 40 V is formed across the tile. Figure below show the graph.

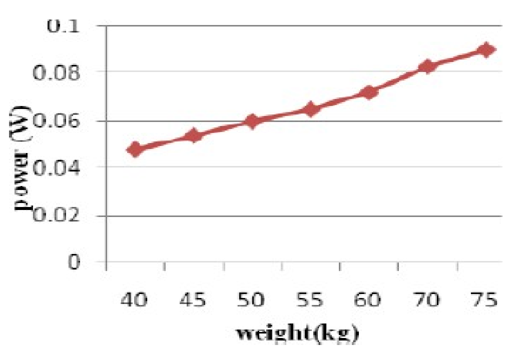

Figure 2.9 Weight V/s power graph of piezo tile

2.8 Summary of previous work

No	Authors	Title	Description
1	Sospeter Gabriel	Design of an Advanced Piezoelectric Footstep Power Generation System.A Case Study of Must – Basement Room	• Component related and Circuit design • Prototype of systems • Relation between the estimation electrical power consumption and number of step of people who pass through the stairs.
2	Abdul Kalam A.Singh S.K.Yadav K.R.Yadav [2]	Foot Step Power Generation Using Piezoelectric Transducer	As a result of their findings, the authors state that getting electricity from piezo sensors involves a variety of procedures. • Minimum voltage produce (1 V per step) • Maximum voltage produce (10.5 V per step)
3	Abhay Manmadhan Jishidha [17]	Foot Step Power Generation	This article's explanation of the footstep power generating project's guiding concept is based on CAES, or compressed air energy storage, which entails using the compressor to compress air at a high pressure before storing the energy generated by the operation[17].
4	Chun Kit Ang [6]	Development of a footstep power generator in converting kinetic energy to electricity	The articles related the testing of nine people with differing weights. Based on the results, this research makes the assumption that each person can maximise the power they create by stepping on the suggested mechanical footstep generator.

2.9 Advantages of series-parallel design

Footstep power generation is a renewable and sustainable energy source that makes use of human motion, especially footsteps. It does not use fossil fuels or damage natural resources since it captures the kinetic energy produced by human movement and transforms it into electrical energy. Next, Footstep power generation generates clean energy without releasing any damaging greenhouse gases or pollutants, making it environmentally friendly. It helps lessen carbon emissions and the environmental damage caused by conventional energy production techniques.

A series-parallel piezoelectric transducer circuit's performance measure has several benefits for raising output voltage. The circuit may maximise voltage production by carefully mixing piezoelectric element combinations in series and parallel. Because voltages add up, series connections boost overall voltage output, but parallel connections improve current capacity. A synergistic enhancement in the transducer's overall power output is possible because to this dual method. The series-parallel arrangement also improves impedance matching, reduces energy loss, and increases power transfer efficiency. As a result, this improved circuit design raises overall performance, which is especially helpful in applications like energy harvesting or ultrasonic sensing systems where a greater output voltage is essential.

2.9 Disadvantages of series-parallel design

Using a series-parallel design to improve output voltage in piezoelectric transducer circuits has several drawbacks, including greater complexity and the possibility of impedance mismatches. Impedance changes brought about by the complex arrangement of series and parallel parts may result in signal reflections and losses. The poor conversion of mechanical energy to electrical energy caused by these impedance mismatches may lower the overall efficiency of the system. The complex circuit design may also provide difficulties for maintenance, troubleshooting, and production. The system's increased complexity may also make it more prone to interference and electrical noise, which would further jeopardise the output voltage improvement's dependability. Therefore, to minimise these issues and guarantee the intended performance improvement, careful thought and circuit design optimisation are crucial.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter focuses on a methodical approach to complete this project. The hardware and software parts of this project's development are separated into two categories. The approach is crucial to completing the project and getting the intended results. Flowcharts and block diagrams are used in this chapter's outline and description of the project's development process to aid with comprehension.

3.2 Methodology

This project will employ a number of tactics to achieve its objectives, including reading materials, the performance measure of series-parallel piezoelectric transducer circuity for improvement of output voltage. The system is built in stages, starting with a project title search, followed by defining the problem statement, project objectives, and scope, followed by a literature search, the construction of the hardware and software, and finally, data gathering. This section explains every technique, piece of hardware, and piece of software employed for this project. The flowchart for the full project development is shown in Figure 3.1.

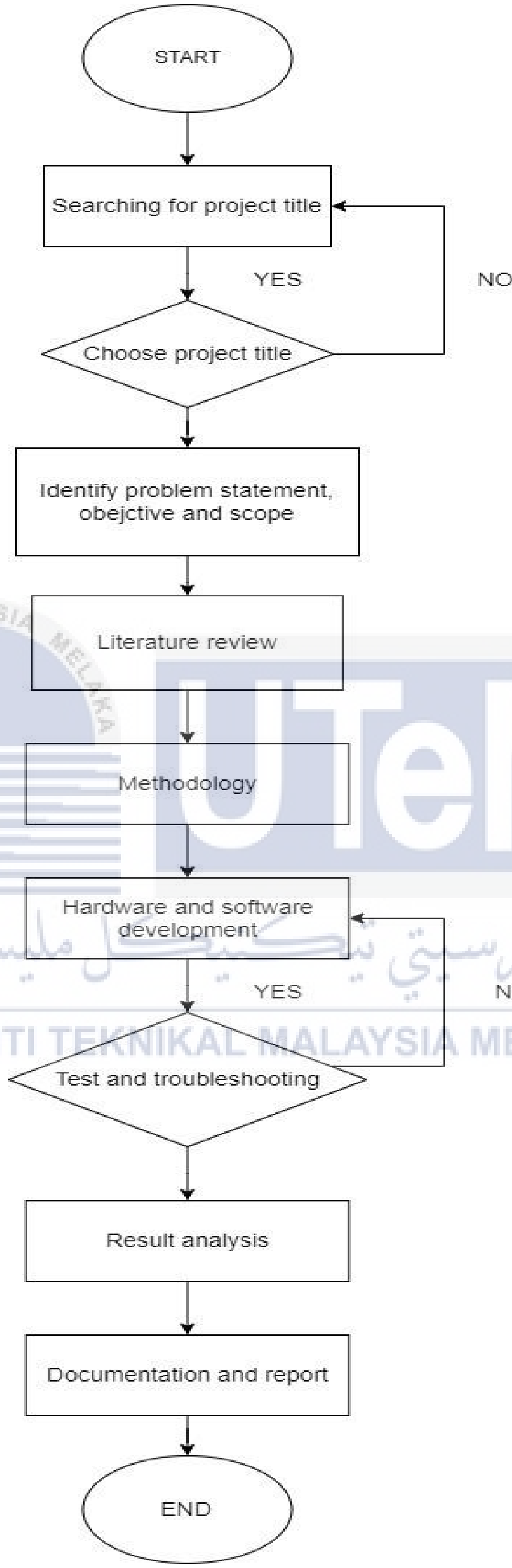

Figure 3.1 Flowchart of Overall project

3.3 Software design method

The system's software design explain comprises system architecture and a block diagram of working systems

3.3.1 System architecture

Energy is generated from the piezoelectric sensor when stepped onto or when a sensor is kept under constant pressure as in Figure 3.2. The sensors are arranged in series-parallel to obtain the required amount of current and voltagesThe sensor is based on the principle of piezoelectricity . Since the generated energy from the sensor is very low, a rectifier circuit is designed to convert AC signal to DC signal. For storing the charge super capacitor is being used and store at 18650 lithium-Ion Battery. The amount of charge stored in the super capacitor or battery is calibrate by multimeter where it was interfaced with Arduino UNO.

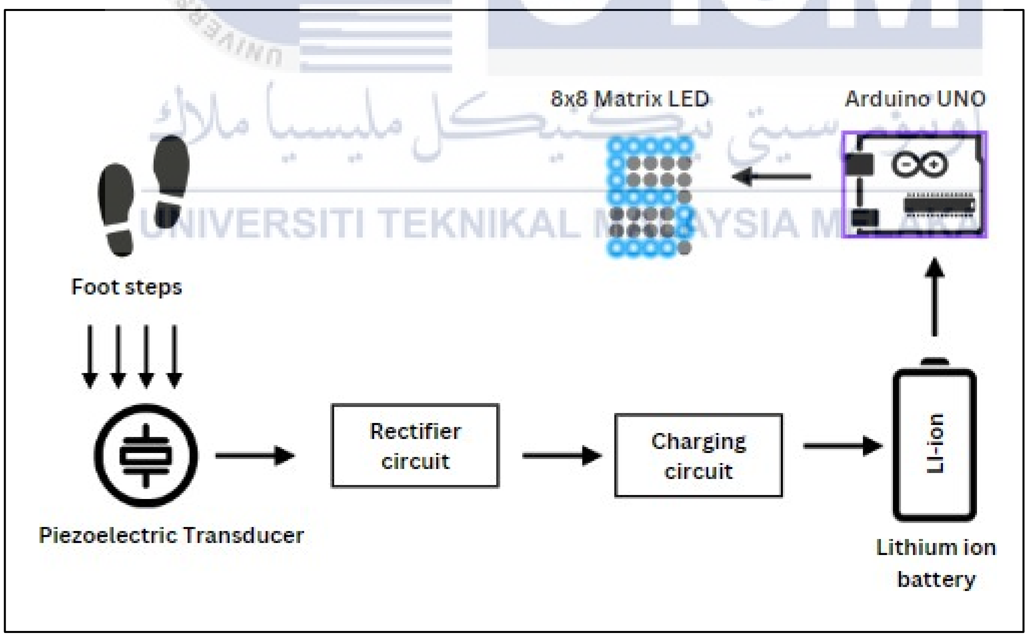

Figure 3.2 System architecture[18]

3.3.2 Block diagram working mechanism of system

Based on Figure 3.3, it shows how the systems work. This project involves the non-continuous output of the piezoelectric material. Consequently, a bridge circuit is used to transform this fluctuating voltage into a linear voltage. The final output ripples are filtered using an AC ripple filter. An lithium ion battery that can be recharged stores the output DC voltage. For this project, the flow start with the generation of power using piezoelectric effect where the pressure is applied and generate AC signal. This AC signal then need to generate to DC signal. For this action, the bridge rectifier circuit is needed as it helps to convert AC to DC. Next, the use of capacitor is needed as it helps as filter to smooth DC sinal by storing electrical charge. It helps to provide a more stable DC output. Lithium ion is help in storing energy that absorbed. Next, to boost the DC voltage, the dc-dc booster is needed to boost up the voltage until 5V. After that, the voltage energy is help to supply for matrix led output.

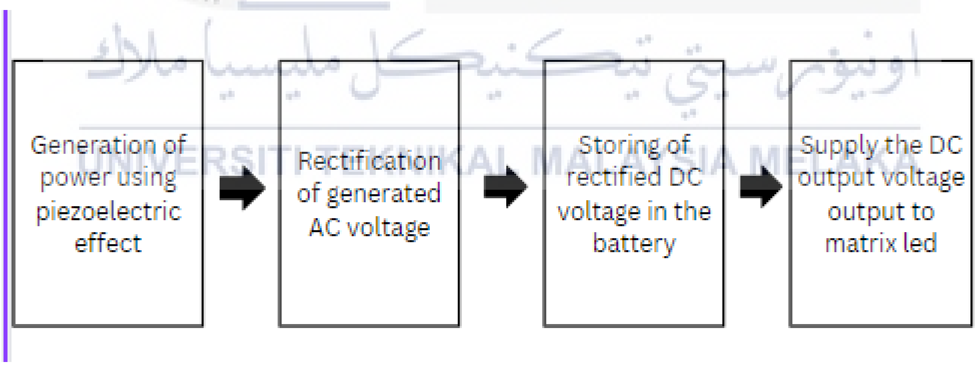

Figure 3.3 Block diagram working mechanism of system[19]

3.4 Software development

This section will give an overview of the software used to build this project, including Proteus 8 Professional and the Arduino IDE. These programmes are used for simulation, circuit design, and coding.

3.4.1 Proteus 8 Profesional

Software called Proteus 8 Professional or Proteus is mostly used to design PCB layouts, schematic simulations, and schematic diagrams. Due to its many microcontroller libraries, this software is also useful for developing and testing programming codes. In this project, the circuit is designed and tested using Proteus before being implemented on the hardware. In Figure 3.4, the Proteus 8 Professional programme is displayed.

Figure 3.4 Proteus 8 Profesional

3.4.2 Arduino IDE

The Arduino Software (IDE), often known as the Arduino Integrated Development Environment (IDE), has a text editor for writing code, a message box, a text terminal, a toolbar with buttons for basic operations, and a number of menus. In order to upload programmes and communicate with them, it connects to the Arduino hardware.

The Arduino IDE is used to build computer programmes known as sketches. These illustrations are produced in a text editor, then saved as files with the.ino extension[19] Text replacement and text searching options are available in the editor. The message area reveals issues and offers feedback when saving and exporting. The terminal displays text produced by the Arduino Software (IDE), together with additional data including complete error messages. The lower right-hand corner of the window shows the configured board and serial port. The toolbar buttons allow users to make, open, and save drawings, validate and submit scripts, and start the serial monitor. Software for Arduino is shown in Figure 3.5.

Figure 3.5 Arduino IDE software

3.5 Hardware development

Developing hardware is a crucial component of many projects, especially those that include innovation and technical development. Hardware development is important for producing the required tools and parts to deploy the system in the context of a series-parallel piezoelectric connection to get a certain voltage to light up the 8x8 matrix LED.. A piezoelectric sensor, Arduino, Atmega328 CPU, DC-DC booster, 18650 Lithium ion battery, and 8x8 matrix led, bridge rectifier and capacitor are required components for this project. For this project, this component function as both an input and an output. Analysing the component and its purpose is vital.

3.5.1 Piezoelectric sensor

Piezoelectricity is the term for the charge that is produced when a mechanical stress is applied to particular materials. Piezoelectric pressure sensors utilise this phenomenon by detecting the voltage that is produced across a piezoelectric element as a result of the applied pressure. This sensor are extremely robust and have many different industrial applications. When pressure is applied to a piezoelectric material, it produces an electric charge across its faces. According to the illustration on the right, this can be measured as a voltage that is proportionate to the pressure. Inverse piezoelectric effects also exist, whereby a material's form changes when a voltage is applied to it. There is a matching charge across the sensor for a given static force. However, due to poor insulation, internal sensor resistance, attached electronics, etc., this will eventually leak away. Therefore, measuring static pressure often isn't a good use for piezoelectric sensors. The output signal will continue to gradually deteriorate until it hits zero even in the presence of constant pressure.

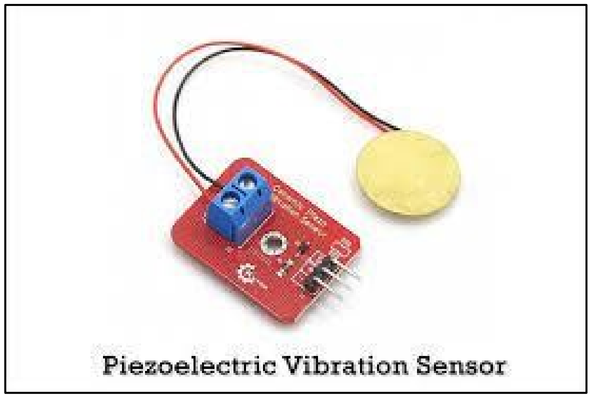

Figure 3.6 Piezoelectric vibration sensor

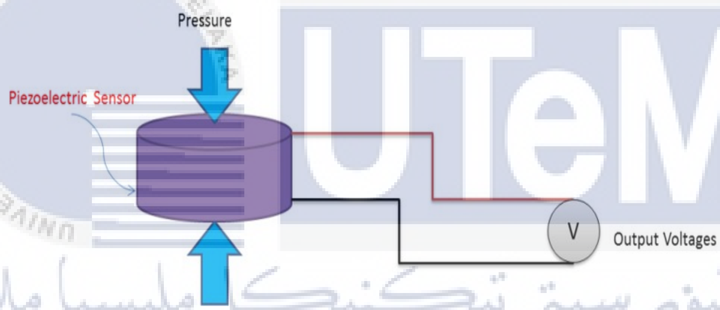

Figure 3.7 Connection of piezoelectric sensor

3.5.2 Arduino Uno and Atmega 328 microprocessor

The main component used in this project to control the programming is Arduino Uno and Atmega 328 microprocessor. The Arduino Uno is an open-source microcontroller board created by Arduino.cc and first made available in 2010. It is based on the Microchip ATmega328P microprocessor.A variety of expansion boards (shields) and other circuits can be interfaced with the board's sets of digital and analogue input/output (I/O) pins.The board features 6 analogue I/O pins, 6 digital I/O pins, and 14 digital I/O pins, six of which can be used for PWM output. It can be programmed using the Arduino IDE (Integrated Development Environment) with a type B USB connector. A barrel connector that can handle voltages between 7 and 20 volts, such as a square 9-volt battery, or a USB cable are both options for powering it.

The ATmega328, a single-chip microcontroller created by Atmel before being acquired by Microchip Technology in 2016, is a member of the megaAVR family. It has a modified Harvard design with an 8-bit RISC processor unit. The 6-channel 10-bit A/D converter, 8 channels in TQFP and QFN/MLF packages, programmable watchdog timer, 1 KB EEPROM, 2 KB SRAM, 23 general-purpose I/O lines, 32 general-purpose working registers, and 3 flexible timer/counters with compare modes are all features of the 8-bit AVR-based microcontroller from Atmel. The gadget may operate between 1.8 and 5.5 volts. The device's throughput is very nearly 1 MIPS/MHz.

Figure 3.8 Arduino Uno

Figure 3.9 Atmega 328 microprocessor

3.5.3 DC-DC Booster Module (0.9-5V)

An electrical module used to control and raise the voltage output from a lower range (0.9V) to a larger range (5V or more) is known as a DC-DC booster module as in Figure 3.10. More precisely, one with an input range of 0.9V to 5V. This kind of module is frequently called a step-up or boost converter. Its main job is to raise a lower input voltage to a higher output voltage by use of a switching regulator circuit. When a gadget or electrical circuit needs a greater voltage than what the power supply can provide, this might be especially helpful. For example, a boost converter would be needed to raise the voltage to the necessary level when powering a 5V device from a lower voltage source, such as a single-cell battery (0.9V to 4.2V for a standard lithium-ion cell).

An inductor, a switching transistor, a diode, and a control circuit that effectively controls the voltage conversion process are commonly found in DC-DC booster modules. These modules are widely utilised in many different applications, including low-power systems, IoT devices, and portable electronics, where effective voltage boosting from low input sources is required.

Figure 3.10 DC-DC Booster Module (0.9-5V)

3.5.4 18650 Lithium-Ion Battery

Batteries are a collection of one or more cells whose chemical reactions create a flow of electrons in a circuit. All batteries are made up of three basic components: an anode (the '-' side), a cathode (the '+' side), and some kind of electrolyte (a substance that chemically reacts with the anode and cathode). When the anode and cathode of a battery is connected to a circuit, a chemical reaction takes place between the anode and the electrolyte. This reaction causes electrons to flow through the circuit and back into the cathode where another chemical reaction takes place. When the material in the cathode or anode is consumed or no longer able to be used in the reaction, the battery is unable to produce electricity. At that point, your battery is "dead." The 18650 lithium-ion battery as in Figure 3.11 is a common cylindrical rechargeable battery format. The name '18650' stands for its dimensions: 18mm in diameter and 65mm in length. These batteries are widely used in various electronic devices, including laptops, power tools, electric vehicles, and many portable consumer electronics. They typically consist of lithium-ion chemistry, offering a high energy density and the ability to deliver a sustained and consistent output of power. The 18650 batteries are known for their reliability, rechargeability, and capacity to provide high currents, making them popular in applications that demand a reliable and high-capacity power source.

Figure 3.11 18650 Lithium-Ion Battery

3.5.5 8X8 Matrix Led

An array of LEDs as in Figure 3.12 placed in a grid pattern with 8 rows and 8 columns, or 64 total LEDs, is referred to as an 8x8 matrix LED. By selectively turning them on or off, each LED in the matrix may be independently controlled to show letters, symbols, or patterns. These matrices are frequently used to display data, create basic graphics, and identify data patterns in a variety of electrical devices and do-it-yourself projects. An 8x8 matrix LED display may be programmed to provide a variety of visual outputs by using additional circuitry or microcontrollers to control the lighting of individual LEDs.

Figure 3.12 8X8 Matrix Led

3.5.6 Bridge Rectifier

Full-bridge rectifier is commonly used as rectifier circuits to convert the AC output of a piezoelectric into a DC voltage. The rectifying circuits consist of 4 diodes. The voltage needs to rectify due to the need for constant supply of voltage. The full wave bridge rectifier operated the full wave rectification of a input AC voltage by using four diodes. To ensure it giving a full wave rectified output voltage, each two diodes conduct during every half cycle.

Besides that, four diodes will include in a full-wave bridge rectifier as in Figure 3.13. The input terminals are the Terminal 1 and 2, so the input AC sources are connected across terminal, so the load is connected across terminal 1 and 2. Terminals 3 and 4 are the output terminals, so the load is connected across 3 and 4. Then, the diodes D1 and D2 are forward-biased and D3 and D4 are reverse-biased at the point when the input cycle is positive. In the direction appeared, the D1 and D2 therefore will lead currents. The voltage produced is matching to the positive half of the input sine wave minus the diode drops.

Lastly, the diodes D3 and D4 get to be forwarded-biased and conduct current in the direction appeared at the point when the input cycle is negative. So that, for both positive and negative of the input wave, current flows in the same direction. Over the load will be show up a full-wave rectified voltage.

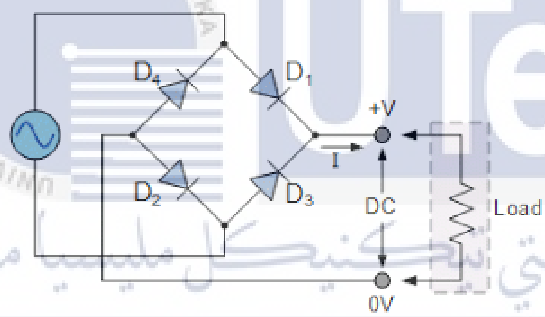

Figure 3.13 Full Wave Bridge Rectifier

3.5.7 Capacitor

An electrical component with two terminals that stores electrical energy in an electric field is called a capacitor. It is made up of two conductive plates separated by a dielectric, which is an insulating substance. The capacitor holds an electric charge on its plates when a voltage is applied across its terminals. The capacity of a capacitor to hold electrical charge is indicated by its capacitance. Although capacitors are measured in farads (F), they are commonly measured in microfarads (µF), nanofarads (nF), or picofarads (pF). When compared to lesser capacitors, a 1000 µF capacitor has a large capacity for electrical charge storage. It is frequently utilised in electrical circuits where time constant, smoothing, or filtering applications call for a higher capacitance.The amount of charge that a capacitor can hold for a certain voltage depends on its capacitance value. When a volt is put across the terminals of a 220 µF capacitor, it can store 220 microcoulombs of charge. Polarised components comprise some electrolytic capacitors, several of which have capacitance values as high as 220 µF. It is crucial to ensure that the terminals in a circuit are connected with the right polarity because every circuit have a positive and a negative terminal.

Figure 3.14 Capacitor

3.6 Load testing

Load testing is kind of performance testing evaluates how well the system performs under realistic and maximal workload scenarios. To ascertain how the system responds to the load, several concurrent users or a large number of transactions are simulated. From this testing, it will involve the different load and the collection data of voltage and current.

3.6.1 Multimeter

Figure 3.15 Multimeter

A digital multimeter, or DMM, monitors and verifies a variety of electrical stimuli, including voltage, current, and resistance. It is a typical piece of diagnostic equipment used by technicians and electrical engineers that combines the operations of a voltmeter, an ammeter, and an ohmmeter. In order to take measurements with a digital multimeter, probes, clamps, or leads are frequently connected to the thing being examined and plugged into the instrument's inputs. It is a standard diagnostic tool for professionals who work in the electrical and electronic industries.

Voltage measurement	
DC ranges	50 mV DC, 500 mV DC, 5 V DC, 50 V DC
AC ranges	50 mV RMS, 500 mV RMS, 5 V RMS, 30 V RMS
Input frequency range (AC voltage)	40 Hz to 1 kHz
DC voltage measurement accuracy (50 mV DC)	0.2% of range
DC voltage measurement accuracy (500 mV DC, 5 V DC, 50 V DC)	0.1% of range
AC voltage measurement accuracy at 50 Hz and 60 Hz (50 mV RMS)	0.2% of range
AC voltage measurement accuracy at 50 Hz and 60 Hz (500 mV RMS, 5 V RMS, 30 V RMS)	0.1% of range

Figure 3.16 Spesification voltage measurement of multimeter

3.6.2 On-Board Test

Analyse the system's performance as it is subjected to various footstep situations, such as variable frequencies, amplitudes, and loads. This research helps establish the system's capacity to provide reliable electricity under a variety of circumstances and its ability to react to real-world events.

3.7 Summary

The suggested approach for starting a new system development project is described in this chapter. Each of the proposed improvements from the chapter must be put into practise successfully if the project's ultimate goal is to be accomplished. All system hardware and software components are described in detail in this chapter. A flowchart and a block diagram are also used to show how the processing system functions and to detail step-by-step processes. This chapter went into detail about the hardware and software used for this project and the reasoning behind it

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This section will be completed, and a selected kind of piezoelectric will be used to gather and discuss data for the inquiry. Because of its adaptability, the Lead Zirconate Titanate (PZT), as seen in Figure 4.1 below, was chosen to complete this project. The diameter and amount of piezoelectric materials will be thoroughly examined in the data analysis. The study will be conducted as the total process is tested and checked for performance. The two primary components of this project that require investigation are the diameter variations and the amount of Lead Zirconate Titanate (PZT) piezoelectric material used to capture electrical energy.

Figure 4.1 The Lead Zirconate Titanate (PZT) piezoelectric material

4.2 Circuit testing and checking

In this section, the full bridge rectifier circuit and piezoelectric circuit are tested. The testing for both circuits was done using a multimeter.

4.2.1 Full Bridge Rectifier Circuit

The schematic diagram for the energy harvesting circuit that will be utilised to test the piezoelectric project is displayed in Figure 4.2. To make sure the circuit can function properly, the continuity of the circuit must be examined initially after the component has been installed completely.

The equipment used in the component for testing and checking are an led indication and a multimeter. The led indicator is used to verify that the circuit is functioning, and the multimeter's job is to measure the voltage reading in order to determine the output voltage. The load in the circuit, an led indicator, has to be connected to the multimeter in order to obtain the output voltage and current. The multimeter's connection is displayed in Figure 4.3 to obtain the data.

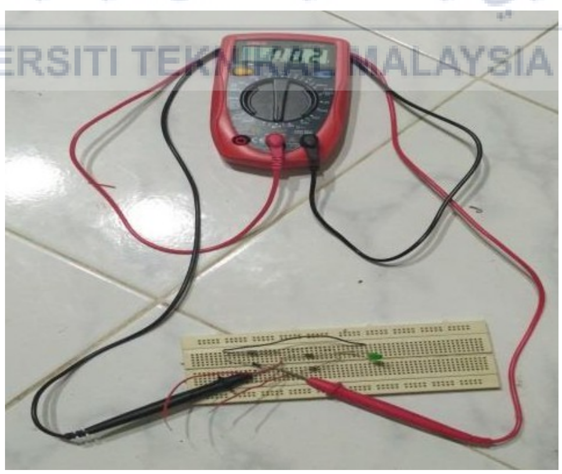

Figure 4.2 Continuity test on full bridge rectifier circuit

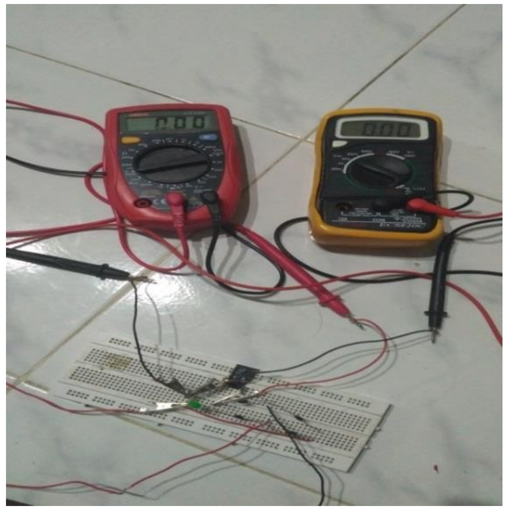

Figure 4.3 Connection of multimeter to the circuit

4.2.2 Piezoelectric Circuit Testing

Below, Figure 4.4 illustrates how the piezoelectric is fully connected. The type of connection being used is a series parallel connection. In this connection, the output are better than series and parallel connection. Theoretically, the output voltage is high in series. In contrast, the output voltage is low but the output current is large when using a parallel connection. To ensure that every piezoelectric has been linked, continuity testing was carried out once the piezoelectric connections were complete.

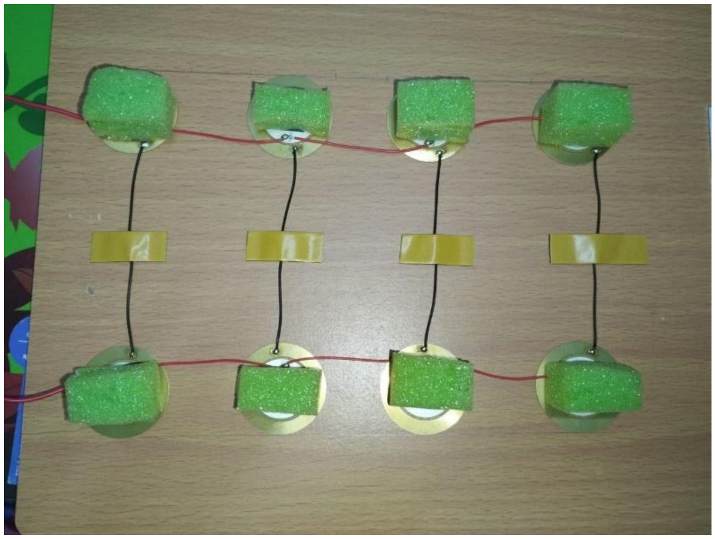

Figure 4.4 Series parallel connection on PZT piezoelectric

4.3 Analysis the different diameter piezoelectric

In this section, the comparison between the different sizes of piezoelectric is done by two diameters, which are 27mm and 35mm. Data measurement for both sizes was also done by using different pressure responses.

4.3.1 Comparison between the different size of piezoelectric

The diameter of the piezoelectric accessible on the market is the first step in the study of this item. Following the survey, two distinct PZT piezoelectric diameter 27 mm and 35 mm were found to be commercially accessible. Figures 4.5 and 4.6 below illustrate how different piezoelectric diameters were employed in this investigation.

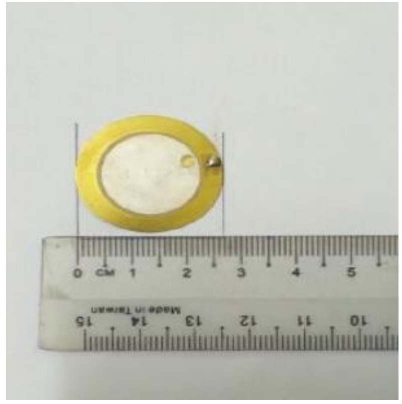

Figure 4.5 27mm diameter PZT

Figure 4.6 35mm diameter PZT

4.3.2 Data Measurement between different diameter piezoelectric

The reading of the multimeter was recorded of each different diameter of piezoelectric in table 4.1 and table 4.2.

Table 4.1 Data collection of the diameter 27mm piezoelectric

Pressure response	Voltage (V)
0-5 push	0.13 V
6-10 push	0.15 V
7-15 push	0.24 V
16-20 push	0.31 V
20-25 push	0.33 V
26-30 push	0.37 V

From this data, the pressure response starts from 0 push until the maximum of 30 push. Here, the data shows that with the increasing pressure given to the piezo plate, the measured voltage at the multimeter also increases. The highest measured voltage at 27 mm in diameter is 0.37 V.

Table 4.2 Data collection of the diameter 35mm piezoelectric

Pressure response	Voltage (V)
0-5 push	0.19 V
6-10 push	0.20 V
7-15 push	0.28 V
16-20 push	0.32 V
20-25 push	0.40 V
26-30 push	0.50 V

Next, the experiment continued with the different diameter, which is 35mm. From this data, the pressure response starts from 0 push until the maximum of 30 push. Here, the data shows that with the increasing pressure given to the piezo plate, the measured voltage at the multimeter also increases. The highest measured voltage at 35 mm in diameter is 0.50 V.

4.3.3 Performance analysis between different diameter

The pressure response against output voltage graph is depicted in Figure 4.7 below, which is based on data gathered from Tables 4.1 and 4.2. The voltage produced with a diameter of 27 mm has a minimum output voltage of 0.13V and a maximum output voltage of 0.38V, as shown by the graph. On the other hand, the output voltage range for a 35mm diameter is 0.19V at the least and 0.55V at the highest. It is shows that 35mm is more sensitive than 27mm.

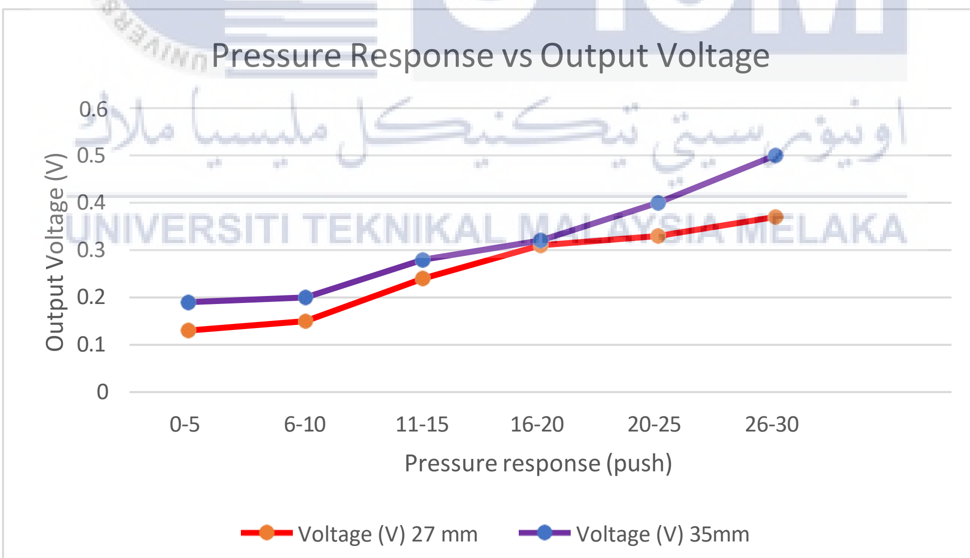

Figure 4.7 Graph of pressure response against output voltage for different diameter

4.4 Analysis the quantity use for different diameter of piezoelectric

In this section, the comparison between the different sizes of piezoelectric is done by two diameters, which are 27mm with 10 pieces and 35mm with 8 pieces. Data measurement for both quantity was also done by using different load.

4.4.1 Comparison between the quantity of piezoelectric with different diameter

The diameter of the 35mm piezoelectric material has been selected following the completion of the initial analysis. The rationale for the selection is that the data measurement indicates that the output voltage higher than those of the piezoelectric with a diameter of 27 mm. Finding the entire amount of piezoelectric that is desired is the first step in this part's study. Different output voltages will result from using different quantities of piezoelectric for testing. As indicated in figures 4.11 and 4.12 below, the total amount for this project that is wanted to be compared is for 10 pieces for 27 mm and 8 pieces for 35 mm. Data measurements will therefore be gathered for every different PZT piezoelectric installation.

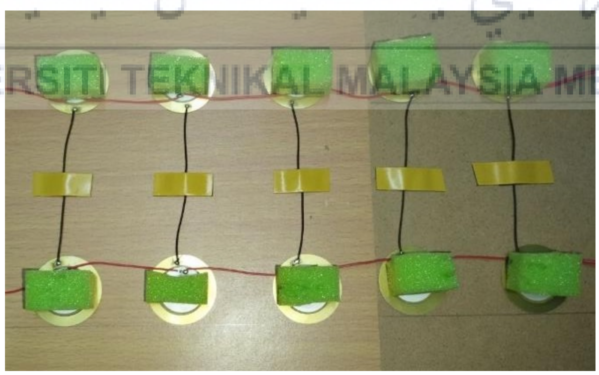

Figure 4.8 10 pieces of 27mm diameter PZT

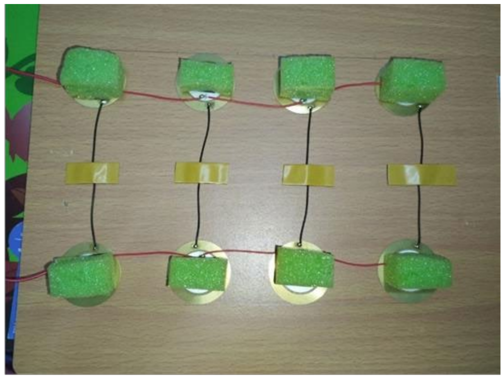

Figure 4.9 8 pieces of 35mm diameter PZT

4.4.2 Data Measurement between different quantity of piezoelectric with different diamater

The reading of the multimeter was recorded of each different diameter of piezoelectric in Table 4.3 and Table 4.4.

Table 4.3 Data collection of the 10 pieces of 27mm diameter

Load (kg)	Voltage (V)
0.5	0.9
1.0	1.20
1.5	1.80
2.0	2.4
2.5	2.6
3.0	3

From this data, the pressure response starts from 0.5 kg until the maximum of 3.0 kg. Here, the data shows that with the increasing load given to the piezo plate, the measured voltage at the multimeter also increases. The highest measured voltage at 10 pieces of 27 mm in diameter is 3V.

Table 4.4 Data collection of the 8 pieces of 35mm diameter

Load (kg)	Voltage (V)
0.5	1.25
1.0	1.60
1.5	2.17
2.0	3.77
2.5	4.20
3.0	4.88

Next, the experiment continued with the different quantity and diameter, which is 8 pieces of 35mm. From this data, the load starts from 0.5 kg until the maximum of 3.0 kg. Here, the data shows that with the increasing load given to the piezo plate, the measured voltage at the multimeter also increases. The highest measured voltage at 8 pieces of 35 mm in diameter is 4.88 V.

4.4.3 Performance analysis between different quantity with different diameter of piezoelectric

The pressure response against output voltage graph is depicted in Figure 4.10 below, which is based on data gathered from Tables 4.3 and 4.4. The voltage produced with a diameter of 27mm(10 pieces) has a minimum output voltage of 0.9V and a maximum output voltage of 3.0V, as shown by the graph. On the other hand, the output voltage range for a 35mm diameter (8 pieces) is 1.2V at the least and 4.0V at the highest. It is show that the quantity of piezo is related with diameter. As the diameter of piezoelectric 0f 35mm is larger than 27mm, the active area is larger.

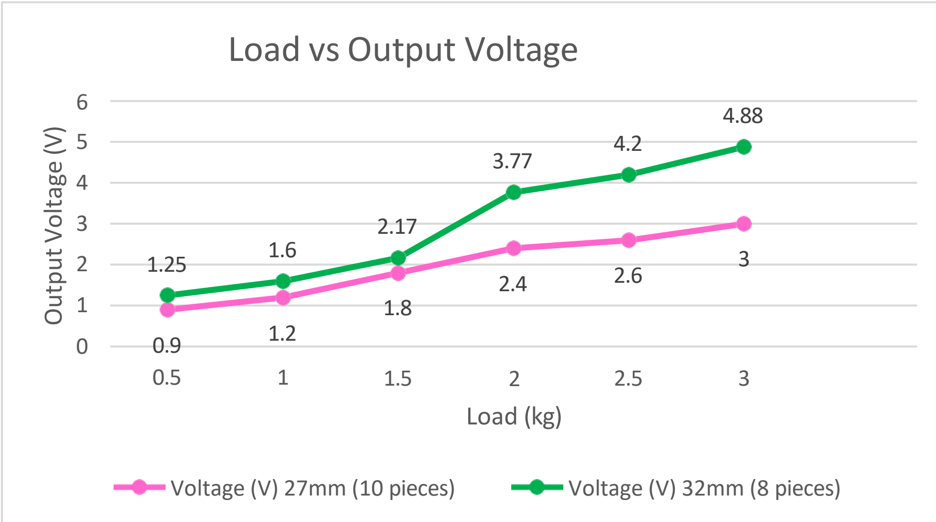

Figure 4.10 Graph of load against output voltage for different quantity with different diameter of piezoelectric

4.4.4 The reading of voltage at multimeter

The example of reading the voltage of a multimeter is shown in Figures 4.11 and 4.12. From this, the data shows that the reading of the multimeter at 2.5kg is 4.20 V, while at 3.0 kg it is 4.88 V. The multimeter is connected directly to the output of the piezoelectric plate.

Figure 4.11 The multimeter reading of 2.5kg

Figure 4.12 The multimeter reading of 3.0kg

4.5 Discussion

The two distinct piezoelectric sizes included in the investigation are 27 mm and 35 mm. Because the output voltage from the harvesting is more steady than it is from the other connection, the two different diameters are connected in series and parallel. In addition, the output voltage is high but the output current is low if the piezoelectric is connected in series. In the meantime, the output voltage is low but the output current is large when compared to the piezoelectric connected in parallel. Because series parallel combination produces good output voltage and output current, it is the appropriate connection to obtain better output voltage. Additionally, as the pressure applied to the piezoelectric changes depending on the diameter, the harvesting will provide varying outputs overall. According to my calculations, the piezoelectric with a 35mm diameter harvests greater output because of its larger diameter, which increases the potential pressure that can be applied to it. Apart from that, the amount of PZT piezoelectric usage is the subject of the second analysis included in this research. In order to guarantee continuous output, the battery has to be charged by the piezoelectric harvesting process and steady pressure applied to the piezoelectric. Additionally, the non-stable output voltage and output current that are obtained from piezoelectric devices result in a resonant frequency. Unfortunately, in this project, the connection for rectification and display matrix was unsuccessful. This is because the connection for the systems is not enough to generate voltage from piezoelectric for matrix led displays. Hence, the voltage dropping to 0V after initially increasing with pressure may indicate that the material has reached its polarisation saturation or has experienced other non-linear effects. These non-linear behaviours can sometimes cause the piezoelectric material to show a drop in output voltage when a threshold pressure is reached.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

This section generally discusses the conclusion and recommendation for the future work to enlarge the limitations for futher study.

5.1 Conclusion

The series-parallel piezoelectric transducer circuitry's performance evaluation, in summary, the diameter and the quatity relate for output voltage. The circuit design's deliberate blending of series and parallel layouts has a synergistic effect that enhances overall performance. It is clear from methodical testing and analysis that this strategy successfully overcomes the intrinsic drawbacks of traditional piezoelectric transducers, enabling greater output voltages. Unfortunately, for the connection for rectification and display matrix was unsuccessful. This is because the connection for the systems is not enough to generate voltage from piezoelectric for matrix led displays. But, for the study of series-parallel connection for greater output is done. The optimised circuit design shows promise for wider applications in a number of domains, including energy harvesting, sensing, and actuation, in addition to optimising energy harvesting efficiency. The development of piezoelectric transducer technology will require ongoing study and improvement in series-parallel topologies. This will open the door to more effective and adaptable electronic systems.

5.2 Recommendations

To enhance the output voltage performance of a series-parallel piezoelectric transducer circuit, it is crucial to implement a comprehensive set of performance measures.

a) Consider optimizing the circuit topology by strategically configuring the series and parallel connections to maximize energy harvesting efficiency.

b) Utilize advanced signal conditioning techniques such as impedance matching to minimize power losses and enhance voltage transfer.

c) Employing an effective feedback control system can further improve performance by dynamically adjusting parameters based on the operating conditions.

d) Regular monitoring and iterative adjustments based on empirical data will be essential for ongoing improvement and fine-tuning of the system.

5.3 Project Potential

Every project have project potential. For the project on the performance measurement of series-parallel piezoelectric transducer circuitry for improving output voltage has several potential practical applications and commercialization opportunities. Here are some possibilities:

a) Wireless sensor networks might make use of this technology because of its improved voltage output. Self-sufficient power sources are frequently needed for these networks in rural and difficult-to-reach areas. This circuitry may aid in the creation of effective and long-lasting power solutions for these kinds of networks.

b) Utilising sensors, structural health monitoring systems evaluate the state of bridges, buildings, and other structures. By converting the vibrations or motions of the structure into electrical energy, the idea may help build self-powered sensors for use in situations like these, where the monitoring system would be provided with electricity.

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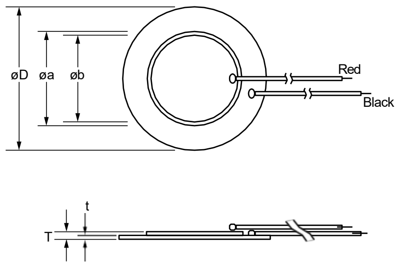
Piezoelectric Sound Components

Piezoelectric Diaphragms

■ Features
1. Clear sound
2. Ultra thin and lightweight
3. No contacts: therefore, no noise and highly reliable
4. Low power consumption for voltage type

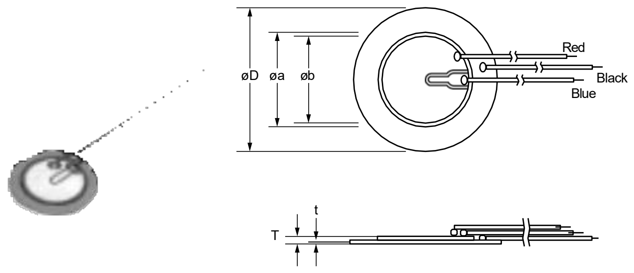


■ Applications

Clocks/Calculators/Digital camera/Various alarms (Burglar alarms, etc.)

External Drive Type

Part Number	Resonant Frequency (kHz)	Resonant Impedance (ohm)	Capacitance (nF)	Plate Size dia. D (mm)	Element Size dia. a (mm)	Electrode Size dia. b (mm)	Thickness T (mm)	Plate Thickness t (mm)	Plate Material
7BB-12-9	9.0 ±1.0kHz	1000 max.	8.0 ±30% [1kHz]	12.0	9.0	8.0	0.22	0.10	Brass
7BB-15-6	6.0 ±1.0kHz	800 max.	10.0 ±30% [1kHz]	15.0	10.0	9.0	0.22	0.10	Brass
7BB-20-3	3.6 ±0.6kHz	500 max.	20.0 ±30% [1kHz]	20.0	14.0	12.8	0.22	0.10	Brass
7BB-20-6	6.3 ±0.6kHz	350 max.	10.0 ±30% [1kHz]	20.0	14.0	12.8	0.42	0.20	Brass
7BB-20-6L0	6.3 ±0.6kHz	1000 max.	10.0 ±30% [1kHz]	20.0	14.0	12.8	0.42	0.20	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-27-4	4.6 ±0.5kHz	200 max.	20.0 ±30% [1kHz]	27.0	19.7	18.2	0.54	0.30	Brass
7BB-27-4L0	4.6 ±0.5kHz	300 max.	20.0 ±30% [1kHz]	27.0	19.7	18.2	0.54	0.30	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-35-3	2.8 ±0.5kHz	200 max.	30.0 ±30% [1kHz]	35.0	25.0	23.0	0.53	0.30	Brass
7BB-35-3L0	2.8 ±0.5kHz	200 max.	30.0 ±30% [1kHz]	35.0	25.0	23.0	0.53	0.30	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-41-2	2.2 ±0.3kHz	250 max.	30.0 ±30% [1kHz]	41.0	25.0	23.0	0.63	0.40	Brass
7BB-41-2L0	2.2 ±0.3kHz	300 max.	30.0 ±30% [1kHz]	41.0	25.0	23.0	0.63	0.40	Brass (with Lead Wire: AWG32 Length 50mm)
7NB-31R2-1	1.3 ±0.5kHz	300 max.	40.0 ±30% [120Hz]	31.2	19.7	18.2	0.22	0.10	Nickel Alloy



Self Drive Type

Part Number	Resonant Frequency (kHz)	Resonant Impedance (ohm)	Capacitance (nF)	Plate Size dia. D (mm)	Element Size dia. a (mm)	Electrode Size dia. b (mm)	Thickness T (mm)	Plate Thickness t (mm)	Plate Material
7BB-20-6C	6.3 ±0.6kHz	500 max.	8.5 ±30% [1kHz]	20.0	14.0	12.8	0.42	0.20	Brass
7BB-20-6CL0	6.3 ±0.6kHz	800 max.	8.5 ±30% [1kHz]	20.0	14.0	12.8	0.42	0.20	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-27-4C	4.6 ±0.5kHz	200 max.	18.0 ±30% [1kHz]	27.0	19.7	18.2	0.54	0.30	Brass
7BB-27-4CL0	4.6 ±0.5kHz	350 max.	18.0 ±30% [1kHz]	27.0	19.7	18.2	0.54	0.30	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-35-3C	2.8 ±0.5kHz	200 max.	26.0 ±30% [1kHz]	35.0	25.0	23.0	0.53	0.30	Brass
7BB-35-3CL0	2.8 ±0.5kHz	200 max.	26.0 ±30% [1kHz]	35.0	25.0	23.0	0.53	0.30	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-41-2C	2.2 ±0.3kHz	250 max.	24.0 ±30% [1kHz]	41.0	25.0	23.0	0.63	0.40	Brass
7BB-41-2CL0	2.2 ±0.3kHz	350 max.	24.0 ±30% [1kHz]	41.0	25.0	23.0	0.63	0.40	Brass (with Lead Wire: AWG32 Length 50mm)
7SB-34R7-3C	3.1 ±0.3kHz	150 max.	24.0 ±30% [1kHz]	34.7	25.0	23.4	0.50	0.25	Stainless

■ Node Diameter

Part Number	Node Diameter (mm)
7BB-20-6C	ϕ13.5
7BB-27-4C	ϕ17.5
7BB-35-3C	ϕ22.5
7BB-41-2C	ϕ26.5

• Sound diaphragms without feedback electrode also have the same node diameters.

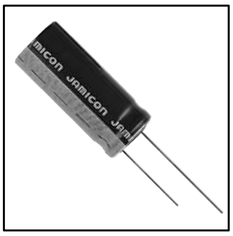
RADIAL TYPE

TK Series

Wide Temperature Range

SM ← → TM

JAMICON®



- High temperature 105°C and high reliability

SPECIFICATION

Item	Characteristic		
Operation Temperature Range	-55 ~ +105°C	-40 ~ +105°C	-25 ~ +105°C
Rated Working Voltage	6.3 ~ 100VDC	160 ~ 400VDC	450VDC
Capacitance Tolerance (120Hz 20°C)	±20%(M)		

Leakage Current (20°C)

6.3~100 VDC I *0.01CV or 4 (μA)	160~450 VDC I *0.03CV +40 (μA)max

*Whichever is greater after 3 minutes
I : Leakage Current(μA) C : Rated Capacitance(μF) V : Working Voltage(V)

Surge Voltage (20°C)

W.V.	6.3	10	16	25	35	50	63	100	160	200	250	350	400	450
S.V.	8	13	20	32	44	63	79	125	200	250	300	400	450	500

Dissipation Factor (tan d) (120Hz 20°C)

Add 0.02 per 1000 μF for more than 1000 μF

W.V.	6.3	10	16	25	35	50	63	100	160	200	250	350	400	450
tan d	0.24	0.20	0.17	0.15	0.12	0.10	0.10	0.08	0.15	0.15	0.15	0.20	0.20	0.20

Low Temperature Stability

Impedance ratio at 120Hz

Rated Voltage (V)	6.3	10	16	25	35~100	160~250	350~400	450
-25°C / +20°C	4	3	2	2	2	3	6	15
-40°C / +20°C	10	8	6	4	3	4	10	—

Load Life

After 2000 hours application of W.V. at +105°C, the capacitor shall meet the following limits.

Capacitance Change	*±25% of initial value for 6.3~16 W.V., *±20% of initial value for 25~450 W.V.
Dissipation Factor	*200% of initial specified value
Leakage current	*initial specified value

Shelf Life

At +105°C no voltage application after 1000 hours the capacitor shall meet the limits for load life characteristics. (with voltage treatment)

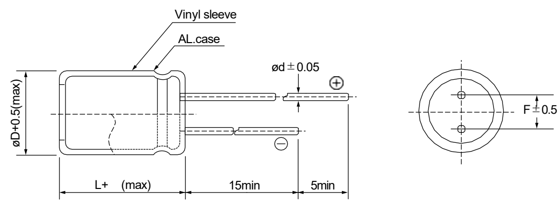
DIMENSIONS (mm)

fD	5	6.3	8	10	12.5	16	18	20	22	25
F	2.0	2.5	3.5	5.0	5.0	7.5	7.5	10.0	10.0	12.5
d	0.5	0.5	0.6	0.6	0.6	0.8	0.8	0.8	1.0	1.0
a	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.0

RIPPLE CURRENT COEFFICIENTS

Temperature(°C)	65	85	105
Multiplier	1.75	1.40	1.00

Frequency(Hz)	60	120	1k	]10k
W.V.	Multiplier			
6.3~25V	0.85	1.00	1.10	1.20
35~100V	0.80	1.00	1.15	1.25
160~250V	0.75	1.00	1.25	1.40
350~450V	0.70	1.00	1.30	1.80



CASE SIZE & MAX RIPPLE CURRENT

Case size : D x L (mm)

Max ripple current : mA(rms) 105 °C 120Hz

μF	Code \ V(Code) Item	6.3 (0J)		10 (1A)		16 (1C)	
		DxL	R.C.	DxL	R.C.	DxL	R.C.
47	470				→	5x11	75
100	101	5x11	95	5x11	100	5x11	110
220	221	5x11	140	5x11	150	6.3x11	190
330	331	6.3x11	200	6.3x11	210	8x11.5	270
470	471	6.3x11	230	6.3x11	260	8x11.5	320
1000	102	8x11.5	400	10x12.5	460	10x16	550
2200	222	10x16	660	10x20	790	12.5x20	910
3300	332	10x20	860	12.5x20	990	12.5x25	1170
4700	472	12.5x20	1040	12.5x25	1230	16x25	1310
6800	682	12.5x25	1300	16x25	1390	16x31.5	1620
10000	103	16x25	1450	16x35.5	1780	18x35.5	1970
15000	153	16x35.5	1860	18x35.5	2060	20x40	2210
22000	223	18x40	2250	20x40	2460	22x50	2940
33000	333	22x50	2950	22x50	3020	25x50	3300

All blank voltage on sleeve marking is the same voltage as" → "point to.

μF	Code \ V(Code) Item	25 (1E)		35 (1V)		50 (1H)	
		DxL	R.C.	DxL	R.C.	DxL	R.C.
0.1	0R1				→	5x11	5
0.22	R22				→	5x11	7
0.33	R33				→	5x11	8
0.47	R47				→	5x11	10
1	010				→	5x11	15
2.2	2R2				→	5x11	22
3.3	3R3				→	5x11	27
4.7	4R7				→	5x11	32
10	100	5x11	38	5x11	42	5x11	46
22	220	5x11	55	5x11	65	5x11	70
33	330	5x11	70	5x11	75	5x11	85
47	470	5x11	80	5x11	90	6.3x11	110
100	101	6.3x11	140	6.3x11	150	8x11.5	190
220	221	8x11.5	240	8x11.5	260	10x12.5	300
330	331	8x11.5	290	10x12.5	340	10x16	410
470	471	10x12.5	360	10x16	450	10x20	540
1000	102	10x20	650	12.5x20	770	12.5x25	930
2200	222	12.5x25	1060	16x25	1180	16x35.5	1480
3300	332	16x25	1240	16x35.5	1570	18x35.5	1790
4700	472	16x31.5	1520	18x35.5	1840		
6800	682	18x35.5	1890				
10000	103	20x40	2270				
15000	153	22x50	2840				
22000	223	25x50	3210				

CASE SIZE & MAX RIPPLE CURRENT

Case size : D x L (mm)

Max ripple current : mA(rms) 105°C 120Hz

μF	Code	63 (1J) DxL	63 (1J) R.C.	100 (2A) DxL	100 (2A) R.C.
0.1	0R1		→	5x11	5
0.22	R22		→	5x11	8
0.33	R33		→	5x11	9
0.47	R47		→	5x11	11
1	010		→	5x11	16
2.2	2R2		→	5x11	24
3.3	3R3		→	5x11	30
4.7	4R7		→	5x11	35
10	100	5x11	46	6.3x11	55
22	220	5x11	70	6.3x11	85
33	330	6.3x11	95	8x11.5	120
47	470	6.3x11	110	10x12.5	160
100	101	10x12.5	200	10x20	280
220	221	10x16	340	12.5x25	490
330	331	10x20	460	12.5x25	600
470	471	12.5x20	580	16x25	720
1000	102	16x25	940	18x40	1380
2200	222			22x50	2260

All blank voltage on sleeve marking is the same voltage as" → "point to.

μF	Code	160 (2C) DxL	160 (2C) R.C.	200 (2D) DxL	200 (2D) R.C.	250 (2E) DxL	250 (2E) R.C.
0.47	R47	6.3x11	9	6.3x11	10	6.3x11	11
1	010	6.3x11	14	6.3x11	15	6.3x11	16
2.2	2R2	6.3x11	20	6.3x11	22	6.3x11	24
3.3	3R3	6.3x11	25	6.3x11	26	8x11.5	34
4.7	4R7	6.3x11	29	8x11.5	37	8x11.5	40
10	100	8x11.5	50	10x12.5	55	10x16	70
22	220	10x16	85	10x20	100	12.5x20	120
33	330	10x20	120	12.5x20	130	12.5x20	150
47	470	12.5x20	150	12.5x20	160	12.5x25	190
100	101	12.5x25	240	16x25	260	16x31.5	310
220	221	16x35.5	420	18x40	510		
330	331	18x40	580				
470	471	22x40	770				
1000	102	25x50	1330				

μF	Code	350 (2V) DxL	350 (2V) R.C.	400 (2G) DxL	400 (2G) R.C.	450 (2W) DxL	450 (2W) R.C.
0.47	R47	8x11.5	11	8x11.5	11	10x12.5	11
1	010	8x11.5	16	8x11.5	16	10x12.5	17
2.2	2R2	8x11.5	24	10x12.5	26	10x20	30
3.3	3R3	10x12.5	30	10x12.5	31	12.5x20	40
4.7	4R7	10x12.5	36	10x16	42	12.5x20	47
10	100	10x20	65	12.5x20	70	16x25	75
22	220	12.5x25	110	12.5x25	120	16x31.5	130
33	330	16x25	140	16x31.5	160	18x35.5	170
47	470	16x35.5	190	18x35.5	210		
100	101	18x40	320	20x40	350		
220	221	22x50	580				