PIEZOELECTRIC STORING CIRCUIT DESIGN

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ABSTRACT

Vibration energy is a wasted energy that can be captured from the surrounding of us for beneficial purpose. The aim of this project is to create a piezoelectric storing circuit designed for event trigger application that harvest energy from ambient vibration sources. A super capacitor is used as the storage element for the energy transformed from mechanical vibration to electrical. A bridge rectifying and filter circuit is used to convert the piezoelectric AC voltage to DC voltage before being stored. As we know, energy harvesting devices are self generated and self powered that normally used for activating low power electronic components which have low electrical power consumption. This project uses the vibration energy, which is in the form of mechanical energy that needs to be transformed into the useful electrical energy using piezoelectric device. Besides that, in this project, the circuit used for the application is designed and analyzed for its charging and discharging performance using a range of difference storing elements. A series of experiments are carried out to verify simulation and theoretical calculation. The setup for the experiment is done in laboratory with dynamic shaker as the source of vibration to test the piezoelectric and the storing circuit. Alternate blinking LEDs will be used to indicate the functional ability of piezoelectric storing circuit as the output result of the project. As a conclusion, this project demonstrates a self-powered sustainable electronic system for long lasting low power electronic operation.

ABSTRAK

Tenaga getaran tenaga yang terbiar dan sia-sia boleh didapati dan diperoleh dari persekitaran kita untuk tujuan berfaedah. Tujuan projek ini adalah untuk merekabentuk satu litar penyimpan tenaga hasilan oleh piezoelektrik tuaian dari sumber getaran persekitaran untuk aplikasi berdasarkan peristiwa. Satu "supe-kapasitor" digunakan sebagai elemen simpanan tenaga untuk tenaga yang berubah dari getaran mekanikal kepada elektrik. Litar jejambat penerus dan litar penapis digunakan untuk menukarkan voltan AC piezoelektrik kepada voltan DC sebelum disimpan. Seperti yang kita tahu, alat penuaian tenaga boleh menjana kuasa sendiri yang biasanya digunakan untuk mengaktifkan komponen elektronik yang berkuasa rendah. Justeru, projek ini menggunakan tenaga getaran, yang pada mulanya dalam bentuk tenaga mekanikal dan diubah kepada tenaga elektrik yang berguna dengan menggunakan peranti piezoelektrik. Selain itu, dalam projek ini, litar yang digunakan untuk aplikasi yang direka telah dianalisis prestasinya dalam mengecas dan menyahcas dengan menggunakan nilai kapasitor yang berbeza. Satu siri eksperimen dijalankan untuk mengesahkan simulasi dan pengiraan berdasarkan teori. Persediaan untuk eksperimen yang dilakukan di makmal dengan dinamik penggoncang sebagai sumber getaran untuk menguji piezoelektrik dan litar penyimpan. LED berkelip selang seli digunakan untuk mengesahkan kebolehgunaan litar penyimpan piezoelektrik yang dijadikan sebagai output projek ini. Kesimpulannya, projek ini menunjukkan satu penjanaan kuasa sistem elektronik berkuasa rendah yang mampan dan dapat beroperasi berterusan.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays, energy harvesting technologies have rapidly changed follow with the advancement technology as well as they dramatically change our life with green technology and environmental friendly. Many low power electronic applications using energy harvesting system power are applied and now invented as self powered electronic systems and to enhance the overall efficiency and reliability of any system. Thus, piezoelectric storing circuit design is produced for event trigger and self-generated application. It can be commercialized in wireless monitoring machine system, wireless sensor network or hazards warning system. Energies from ambient sources that are common to our surrounding are vibration, thermal, solar, wind, and others are potential energy which can be harvested. These free and unlimited energy sources can be captured, accumulated, stored and used them after converting it into electrical energy form [1]. These energies harvested from environment are in the range of a few mill-watts up to a few watts which can power-up low power electronic integrated circuit (IC) and components that used in many application such as that used as home appliance, automobile, medical, military and others. In short, ambient sources are for applications which require low power consumption. Piezoelectric is

essentially a transducer device which can perform energy conversion from kinetic or mechanical energy into electrical energy

Since energy harvesting is popular among many researchers, the various inventions and applications that related to energy harvesting are created to apply the theoretical. For example, the handheld electronic devices using solar panel or piezoelectric devices, remote wireless sensors using solar panel or RF energy from antenna, remote wireless actuators using thermal energy and others have been created for low cost and more convenient. Energy harvesting sources are usually used to power up electronic applications or devices, which is used in very small amount of power or low-energy needed. Thus, the applications for nowadays have been changed to a more sustainable, resource efficient and low carbon economy. This is because, to protect the earth and to ensure that industrial, climate, energy, environmental and other relevant policies provide consistency, coherence and certainty and create the right conditions for innovation [2].

Then, piezoelectric storing circuit design is proposed as a final year project in order to decrease the cost and for long lasting operability as well as to show the harvested energy can be stored and then will be used such battery-less and event trigger application. Piezoelectric is a transducer that converts mechanical energy to usable electrical energy especially for vibration, which is one of the energy harvesting sources. Any environmental vibrations energy is mechanical energy which is suitable to convert it into electrical energy using piezoelectric for reuse the lost energy that normally occur around most machines and biological systems. The instance of piezoelectric storing circuit design can be applied in the event trigger application or battery charger. A battery charger is a device used to put energy into a cell or rechargeable battery by forcing an electric current through it. Lead-acid battery chargers typically have two tasks to accomplish. The first is to restore capacity, often as quickly as practical. The second is to maintain capacity by compensating for self discharge. In both instances optimum operation requires accurate sensing of battery voltage [3].

Piezoelectric is a small volume devices and simple technology that has been popular among most researchers. It have some advantages which are no external

voltage source, compact of configuration, compatible with micro electromechanical system (MEMS) and high coupling in single crystals with less energy losses. Then, electrical energy that produces from piezoelectric is usually an alternative current mode with an instantaneous peak voltage which is proportional to the level of vibration. In order to create piezoelectric storing circuit design, rectifier is needed for converting the AC power into DC power and other required components in circuit are also needed to fulfil the requirement for harvested energy applications. Therefore, for long lasting operability, super capacitor or rechargeable battery are required to work together with the piezoelectric device as an energy storage element, which is then used to power up the small electronic systems with low power consumption to be operated automatically.

1.2 **Problem Statement**

Piezoelectric is a device that capable to generate a voltage when a corresponding mechanical stress is applied. The piezoelectric materials are usually fabricated in the form of a cantilever structure. Electrical energy is produced when the cantilever operates in bending mode at resonant frequency [4]. Hence, there are some problems while handling the energy harvesting and some external problem that need energy harvesting to be used, have been stated by following below:

a) The power that produced from piezoelectric is in an AC power which is unregulated and relatively low output voltage [5]. However, in order to use in circuit application such as for low power electronic components, DC power is required.
b) The average harvested power from piezoelectric is too small [6] due to the high internal impedance restricts the amount of output current that can be driven by the piezoelectric source to the micro-amp range [5].
c) Piezoelectric used to harvest energy from ambient vibrations will produce inconsistent and random output voltage. The output voltage can be greater than the rating of some sensitive components, which may destroy the

components. Therefore the voltage generated from piezoelectric, which proportional to the mechanical stress, should be regulated before being used to power-up electronic devices [7].

d) On the other hand, the use of traditional battery in the low power electronic components is has a limited power or lifespan [8]and expose easily to the pollution due to the chemical use in the battery.

The above problems are addressed in this project by considering several aspects in order to start the piezoelectric storing circuit design. Hence, the first thing to do is by identifying the way to transform AC power to DC power. So, rectifier circuits that are suitable for power conversion with a piezoelectric source will be used [5]. Generally, a bridge rectifier is used as an ac-dc rectifier that has own advantages.

Next, some storage elements are used to store and accumulated the harvested energy for intermittent use since the average power is too little. The use of capacitors as a way to store energy has been considered due to the past research on the power energy harvesting [9] as well as can overcome the problem of traditional battery that as limited power. Then, the protection circuit will be used since inconsistent applied voltage. Therefore, the piezoelectric harvesting circuits for circuit application designs were studied.

1.3 **Objectives**

There are some objectives of this final year project that need to be achieved due to the following aspects below:

a) To design and analyze of piezoelectric energy harvesting storing circuit
b) To construct and demonstrate the application of the piezoelectric storing circuit

1.4 Scope of Project

Since there are many issues about piezoelectric as energy harvesting device, so, this project just focus on the following properties below:

a) This project emphasizes on the piezoelectric storing circuit design with maximum input frequency of 300Hz.
b) Piezoelectric material off-the shelf is used in this project and the size of piezoelectric device that is used is 0.51mm T x 31.8 mm W x 63.5 mm L.
c) Output voltage from piezoelectric device is produced up to 3V.
d) Low power electronic components in the range 10mW and 30mW produced from piezoelectric material will be applied to power up low power electronic applications.

1.5 Report Outline

In this thesis, there are five chapters involved to describe the project of piezoelectric storing circuit design in detail. First and foremost, it is Chapter 1. This chapter will discuss briefly about the project introduction that consist of objectives, problems statements, scopes of project and report outline in order to conduct the project. Next, the thesis is continued with Chapter 2. This chapter contains the literature review on the past research and some theoretical concepts applied in this project. Then, Chapter 3 focus on the methodology used in order to complete this project of piezoelectric storing circuit design. In this chapter, there is flow chart to explain the procedures of designing the piezoelectric storing circuit. Then, circuit design and simulation are discussed. Next, the detail description about experimental setup is discussed too. In Chapter 4, results consist of two parts which are theoretical and simulation and experimental results. Several comparisons include the theoretical, simulation and experimental setup will be discussed in this chapter too. Last but not least, a summary of project about piezoelectric storing circuit design is discussed as well as the conclusion and recommendation is provided for future work in the Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

The market sale of low power electronics and wireless technology increase gradually year by year. Nowadays, electronic technologies are being familiar with an embedded system that consist of software and hardware component as well as user friendly especially for intelligent building, home automation, autonomous vehicle and health monitoring. Hence, the embedded system also have been environmental friendly in order to provide green, clean and renewable electrical energy sources with ambient energy sources or wasted energies. Most of the low powered electronics devices rely on the batteries as a power sources to power up the devices. However, the powers of batteries are limited. In short, energy harvesting can overcome the issue of limited lifespan of batteries and the pollutions [10]. Thus, it will reduce the cost and avoid the chemical waste that might harm environment.

In order to improve the performance of the application that can self power and self generate by using the energy harvesting in which can use anytime and everywhere, the piezoelectric circuit design is introduced for sustainable development. So, vibration based energy is the most significant energy that most popular among researchers as energy harvesting over the last decade as well as can

convert the ambient waste energy into the useful electrical energy. This is according to one of the researchers, to realize the need for power storage circuitry, who speculated the use of piezoelectric materials for harvesting numerous sources of energy around the body, including limb and finger motion [11]. Moreover, there are three basics vibration-to-electric energy conversion mechanism, which are the electromagnetic, electrostatic and piezoelectric transductions [12].

Hence, the piezoelectric transduction has received greatest attention in order to generate electricity from vibrations. Therefore, the vibration based energy can be used in powering up the electronic devices with small amount power. For example, according to the project of piezoelectric generator harvesting bike vibrations energy to portable devices, it has stated that energy harvest from vibration has produced low power with 3.5 mW to power LED-lamp of bicycle. The vibration that has been captured while riding the bicycle was at $5ms^{-2}$ and 12.5Hz. Moreover, power that has been transformed by using piezoelectric generator is sufficient to recharge a battery, or to power up the low consumption devices [13].

However, energy-harvesting system designs will address the power uncertainty; so, it will be overcome by incorporating an energy storage element of some kind in the power-management circuitry. In fact, energy storage is essential for dealing the ambient sources especially with piezoelectric converters in applications that do not have strictly periodic movement in converting the mechanical power to electrical power. Having energy storage as part of the important circuitry, therefore, direct application of the piezo-film as a power source is not practical. It is unavoidable to use a storage device to collect the weak power output for future usage.

2.2 Energy Harvesting

Harvesting of waste energy for powering small electronic components such as the wireless sensor network used in monitoring application become popular in

recent years. There are many applications of wireless sensor network that offer an attractive solution such as environmental monitoring, safety, security and military applications, animal tracking and control, built environment and health [14, 15]. So, with energy harvesting, it can enable once device or application be a self powered electronic components as well as can save the cost, low maintenance and reduce the chemical waste resulting from the use and replacement of conventional batteries. Hence, there are a number of general definitions of the term energy harvesting. According to Kompis and Sureka [16], energy harvesting is a means of powering wireless sensor nodes by converting many low grade ambient energy sources such as environmental vibrations, human power, thermal sources, solar power, wind energy and their conversion into useable electrical energy.

So, energy harvesting devices are created to enable the electronic application operates over a wide range of operating conditions and for long term with high reliability especially use in low power wireless electronic devices, such as to activate the programmable integrated circuit (PIC) that can be commercialized. According to the Figure 1, it shows the energy harvesting system with power management at wireless sensor node. Normally, wireless sensor mesh network consist of the radio frequency, piezoelectric, solar power and wind energy that always keep small. It is embedded in build to power up and the battery be a supplement is must sustain with ambient energy or environment sources since in order to replace the battery every time is too difficult. Moreover, ambient energy will be used as well as could be charged and stored the energy for a long time and act as event trigger to produce one signal after discharging.

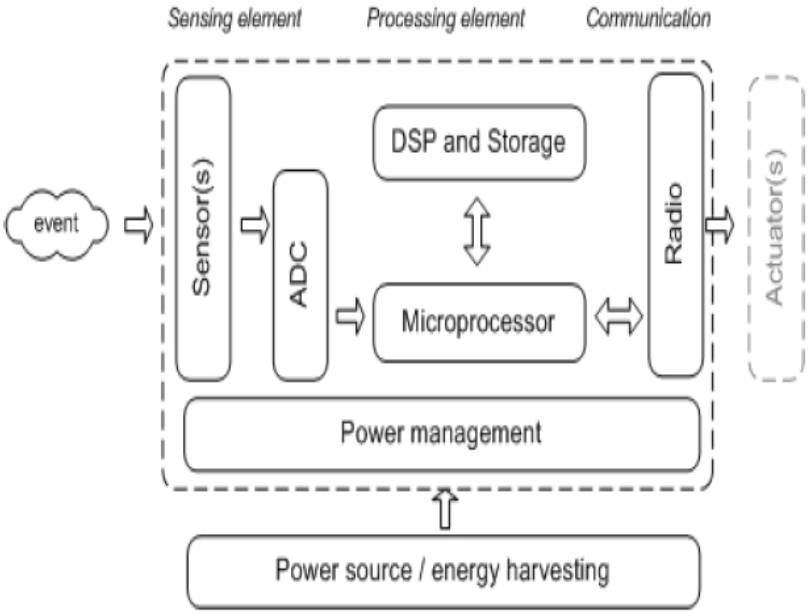

Figure 1: Wireless Sensor Node with Energy Harvesting System [16]

Besides, energy harvesting is the process by which energy readily available from the environment such as solar, vibration, heat, and others is captured and converted into usable electrical energy [17]. So, this energy normally produce in low power signal in which the small maximum power, cannot power our home or power our car, but small power signal, power sensor in car or home or any low power of electronic portable devices. Thus, according to the research on the piezoelectric, solar and thermal energy harvesting for hybrid low-power generator systems with thin film batteries, it has stated that the ambient sources such heat, solar, and vibration can be captured and transformed as well as can be stored in applying the process of charging. Hence, the duration of charging for each ambient source has been shown in Table 1below [18].

Table 1**:** Extrapolated data for estimating the full charging duration of 1mA h

	Thermal	**Solar**	**Vibration**
Input	Temperature difference: 31°C	Irradiance: 223 Wm^{-2}	Base acceleration: 0.5g at 56.4Hz
Dimensions	30.5mm x33mm x 4.1mm (excluding the sink)	93mm x 25mm x 0.178mm (single layer)	93mm x 25mm x 1.5mm (cantilevered volume)

Volume	4.13 cm^3	0.414 cm^3	3.49 cm^3
Duration of charging	40 min 1mAH	20 min 1mAH	8hour 1mAH

On the other hand, the energy provided by an energy harvesting source depends on how long source is in operation. Generally, energy harvesting suffers from low, variable and unpredictable of available power. The harvester, because of its unlimited energy supply and deficiency in power, can be used as a lifetime extended for a primary battery. Vibration energy harvesting and indoor photovoltaic, yield power levels may appear respectively of mV in typical operating condition. Advantages of energy harvesting is power levels may appear respectively small. Besides, it is normally used in long life primary batteries because the operation of harvesting elements over a number of year. Moreover, there is ability to monitor more closely the amount of energy being used by a system. So, several task power management for in energy harvesting power supplies includes by matching energy harvesting transducer voltage level, by regulating of supply as well as to generate a constant voltage independent of source or load variations and last but not least, the rechargeable battery and the capacitor with high capacitance are required as a storage units [16].

As a result, an energy harvesting system has two key elements include electricity-producing energy converters, and power-management blocks that condition and sometimes store the electrical power for application use. Energy converters can utilize radiant, mechanical, or thermal energy as their source to produce electrical currents and voltages. Converters for each energy type are now available, with more in active development. According to industry analysis IDTechEx, more than 200 organizations in 22 countries are actively involved in energy-harvesting development [19]. For instance, the silicon-based photovoltaic (PV) cell is by far the most well-known and widely available energy converter, harvesting radiant energy in the form of ambient visible light. Then, mechanical energy converters use electromagnetic (EM) or piezoelectric (PZE) effects to turn

movement into electricity. Waste heat can also be a source of power for electronic devices by leveraging the Seebeck effect to produce an electrical current from thermal energy flowing through the generator. Hence, each of these thermal, mechanical, and radiant energy converter approaches to generating system power comes with significant design challenges. Thus, the need arises for the second key element of an energy-harvesting system: the power-management block. The details of this block can vary widely, depending on the type of energy converter in use [19]. Typical output power for real-world energy-harvesting technology is listed in Table 2.

Table 2**:** Characteristics of Typical Energy Harvester

Energy Source	**Characteristics**	**Efficiency**	**Harvested Power**
Light	Outdoor Indoor	10-25%	100mW/cm^2 100µW/cm^2
Thermal	Human Industrial	~0.1% ~3%	60µW/cm^2 10mW/cm^2
Vibration	~Hz-human ~kHz-machine	25~50%	4µW/cm^2 800µW/cm^2
Radio Frequency (RF)	GSM 900MHz WiFi 2.4GHz	~50%	0.1µW/cm^2 0.001µW/cm^2

2.3 Vibration-Based Energy Harvesting

Vibration is one of the energy harvesting, that available in various environments as an alternative form of waste energy. Hence, it is mechanical energy source and normally available at micro and nano-scale kinetic energy such as structures of buildings and bridges, industrial plant equipment, moving structures like automobiles and aeroplanes, household goods and others. Human and animal bodies also are considered as vibration harvesting [20]. Moreover, mechanical energy sources have their own frequency like human movements frequency is about less than 10 Hz while machinery vibrations are typically over 30 Hz [2]. For example, it is shown as in Figure 2 with three different spectra computed from vibrations taken from a car hood in motion, an operating microwave oven and a running train floor.