

## ORIGINAL ARTICLES

### Analysis of Energy Harvester Generation using Vibration

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#### ABSTRACT

This paper discusses an analysis of harvesting electrical energy from vibration. In this work, two sizes of piezoelectric devices are used as the energy harvester. The piezoelectric devices convert kinetic energy, in the form of vibration, into electrical energy. The electrical energy generated is then passed to a power management circuit that regulates the AC output from the piezoelectric device and stores it in energy storage. When the stored energy reaches a certain level, the power management circuit outputs the DC voltage. In this experiment, the energy harvesters were able to produce a peak-to-peak output voltage ranging from 4.88V and 40.8V, with energy harvester size greatly influencing the amount of harvested energy.

**Key words:** Energy harvester, vibration, piezoelectric, power management

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#### Introduction

Energy is essential to our lives. It is required from lighting up houses to sending astronauts into space. Of the many forms of energy, electrical energy is the most convenient form for the purposes of powering modern electronic devices. This energy can be stored and converted from one form into another.

With the spread of portable and embedded devices, generating and storing electrical energy has become even more critical, because these electronic devices must be able to operate without interruption (Mane, P., 2009). For this reason, researchers are actively looking at various alternative methods to generate this energy. One of the alternatives is to harvest ambient energy.

Several methods exist to harvest electrical energy from the environment. For example, electrical energy can be generated from light, heat and movement using solar cells, thermocouples and piezoelectric materials, respectively. Of these methods, piezoelectric power generators have an advantage over other energy conversion methods since they are simple and can be made small enough to fit inside embedded micro systems (Sunghwan Kim, 2002).

In previous work (Asral Bahari Jambek, 2012), we have analysed the electrical energy generation to power a wireless sensor node using solar, radio frequency and heat. In this work, an investigation will be carried out to analyse electrical energy generation from two piezoelectric devices. The main objective is to understand the factors that affect the voltage and current generation with respect to the harvester sizes and vibration frequency. The harvested energy is stored in an energy reservoir to power embedded devices.

This paper is organized as follows: Section II discusses existing methods of generating electrical energy from vibration. The experiment setup used in this work is then explained in Section III. Section IV discusses the results obtained from the experiments. Finally, Section V concludes the paper.

#### Literature Review:

Several methods exist to harvest energy from vibration, including electromagnetic, electrostatic and piezoelectric methods. However, since the piezoelectric method can produce a higher voltage and power density compared to others, it has been widely used to generate electrical energy through vibration (Erick O. Torres, 2005). This device generates electrical energy by straining an active material, leading to charge separation inside the piezoelectric material. These electrical charges are then used to power electronic devices.

In (Minazara, E., 2007), instead of using a dynamo, the author used a piezoelectric generator to harvest mechanical energy from a bicycle. The electrical energy produced was used to light up an LED lamp. The electrical energy produced was regulated before being supplied to the electronic device. As this paper shows, under a sinusoidal vibration at  $5\text{ms}^{-2}$ , 12.5Hz frequency and optimal resistive load of 100k $\Omega$ , a 3.5mW power can be extracted from the bike's vibration to power up the lamp. In (Dongwon, 2009), the author used piezoelectric material to convert oscillation of mechanical displacement into electrical energy. An energy harvester circuit processed and stored the charge into a rechargeable battery to power up an electronic device.

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In (Andrew Townley, 2009), the author recommends building energy harvesters with an added mass to ensure the cantilever resonates at lower frequencies. This is because lower resonant frequencies can provide the most deflection and produce more energy. Furthermore, the resonant frequency might be lowered by alternating the device geometries to generate more power output. The experiment, using cantilever lengths of 400, 300, 200, and 100  $\mu\text{m}$ , proves that the longest cantilever beam can produce the highest deflection with a higher output voltage.

#### Methodology:

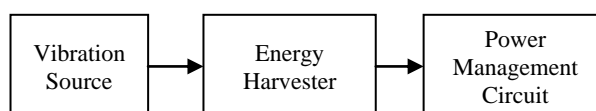
Figure 1 shows the experimental setup used in this work. It consists of three main parts: vibration source, energy harvester and power management circuit. The system works as follows: the energy harvester is attached to the vibration source so that the device vibrates together with the source. It starts to generate electricity once the vibration source begins to vibrate. The energy harvester will then convert vibration into electrical energy and produce an AC voltage. To produce a useable voltage, the AC voltage is rectified and converted into DC voltage using a power management circuit. The output from the power management circuit can be used to power a variety of electronic devices.

In this work, the vibration source is produced using vibration motors. Two different vibration motor were used in this experiment as shown in Table 1. They are motors with diameter of 15mm and 24mm with operated frequency of 83.4Hz and 72.8Hz each (Precision Microdrive, 2012; Precision Microdrive, 2012).

In order to convert the vibration into electrical energy in this experiment, two piezoelectric devices manufactured by Mide (2010) were selected, as shown in Figure 2, on the grounds that the devices can deliver better energy conversion efficiency compared to others piezoelectric devices available on the market [10]. The device characteristics and performance are summarized in Table 2. Each of the devices contains two isolated piezoelectric wafers. They can either be used independently or connected to each other to increase the voltage or current output. Series connection, as shown in Figure 3(a), can produce twice the voltage of a single wafer. On the other hand, parallel connection, as shown in Figure 3(b), can produce two times as much current as a single wafer.

Since the electrical energy generated from the piezoelectric devices is in the form of alternating current (AC), power management is required to convert it into direct current (DC). The power management circuit needs to perform two main functions. Firstly, it stores the electrical energy generated from the piezoelectric device in energy storage. Secondly, it provides a stable DC output when the energy storage has reached a suitable level. In this work, a power management circuit from (Advanced Linear Device, INC, 2011), as shown in Figure 4, was used to perform this function. The device consists of voltage regulator and a capacitor to store the electrical energy. This device can work with instantaneous input voltages ranging from 0V to +/-500V AC or DC, and input currents from 200nA to 400mA.

In this experiment, two types of setting were used. The first setup combines a type A vibration motor, type A piezoelectric devices and the power management circuit. The setup analyses the energy harvested for high frequency vibration using a medium-sized energy harvester. The second setup combines a B vibration motor, type B piezoelectric devices and the power management circuit. The second setup requires a lower vibration frequency, but uses a larger energy harvester.



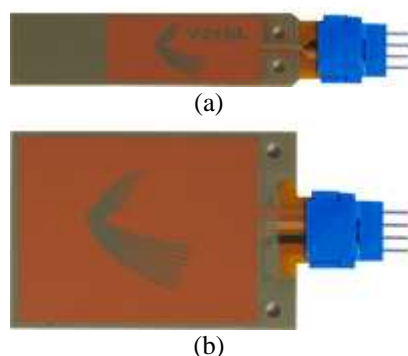
**Fig. 1:** Block diagram of energy harvester system.

**Table 1:** Vibration motor characteristics.

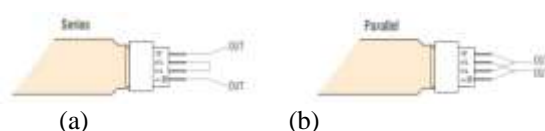
	Type A	Type B
Diameter (mm)	15	24
Frequency (Hz)	83.4	72.8
Vibration amplitude ( $\text{ms}^{-2}$ )	0.4	0.7

**Table 2:** Piezoelectric energy harvesters [10].

	Energy Harvester Type A	Energy Harvester Type B
Model Name	V21BL	V25W
Thickness (in)	0.031	0.024
Device Dimension (in)	0.66 x 3.56	1.5 x 3.19
Maximum deflection (in)	0.18	0.15



**Fig. 2:** Piezoelectric device used in this work (a) type A (b) type B (Mide Engineering Smart Technology, 2010).



**Fig. 3:** Piezoelectric device connection (a) series (b) parallel (Mide Engineering Smart Technology, 2010).



**Fig. 4:** Power management circuit to regulate and store the harvested electrical energy (Advanced Linear Device, INC, 2011).

## Results and Discussion

This section will lay out the results of the energy harvester system, as discussed in Section III. The first setup, harvesting energy from the source, vibrates at a frequency of 83.9Hz. The second setup vibrates at a frequency of 72.8Hz. Figures 5 to 12 show the experiment results, as discussed in Section III. As can be seen in the figure, the series and parallel connections of the first setup give peak-to-peak voltages of 4.88V and 9.4V, respectively. The peak-to-peak currents for the serial and parallel configuration of the first setup are 63.2mA and 32.8mA, respectively. For the second setup, the series and parallel connections give peak-to-peak voltages of 19.0V and 40.8V, respectively. The peak-to-peak currents for the serial and parallel configuration of this setup are 1.07A and 496mA each. Table 3 summarizes this result. The results of the serial and parallel configuration of the first and second setup match with theoretical results, as discussed in Section III.

Figure 13 shows the output voltage of the power management during discharging time. The output of the piezoelectric device is connected to the power management. The power management regulates the AC voltage and stores the charge in the capacitor. Once the capacitor charge has reached a certain level, the power management produces a constant DC output voltage.

The capacitor is first charged fully to 5.0V by the energy harvester. Once it reaches 5.0V, the vibration source is turned off in order to study the time taken for the storage bank to discharge. As can be seen in the graph, without connecting to any load, the energy stored in the capacitor starts to discharge gradually and completes discharging within 1.5 hours. It takes 6 minutes for the voltage to drop from 5.0V to 3.0 V, 8 minutes to drop to 2.5V and 12 minutes to discharge to 1.8V. This shows that the energy has to be used within this time to make sure enough energy is supplied to any electronic devices.

Figure 13 and 14 show the charging time results for the first and second experiment setups, respectively. As is evident in the graph, the first experiment setup takes around 70 minutes to reach 6V, while the second experiment setup takes around 4 minutes to reach the same voltage level. The graph shows that the first setup requires more recharging time compared to the second setup. The second experiment setup can produce more electrical energy compared to the first setup because it has more piezoelectric material compared to the first setup. The next study will investigate the energy harvester's operation under a real load.

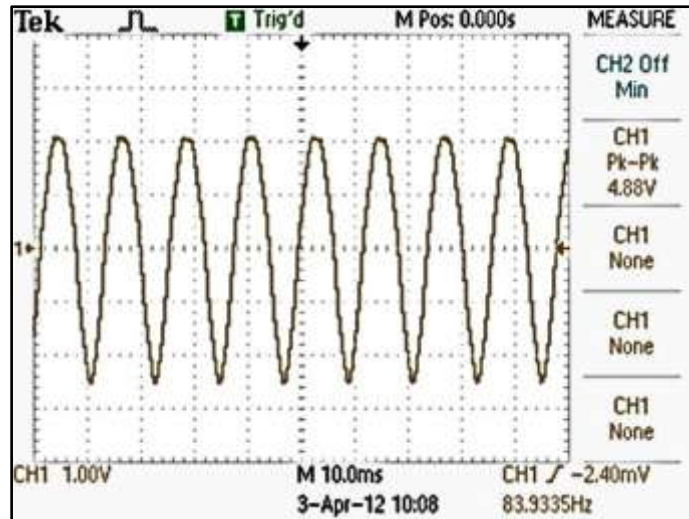


Fig. 5: Parallel connection of V21BL (voltage).

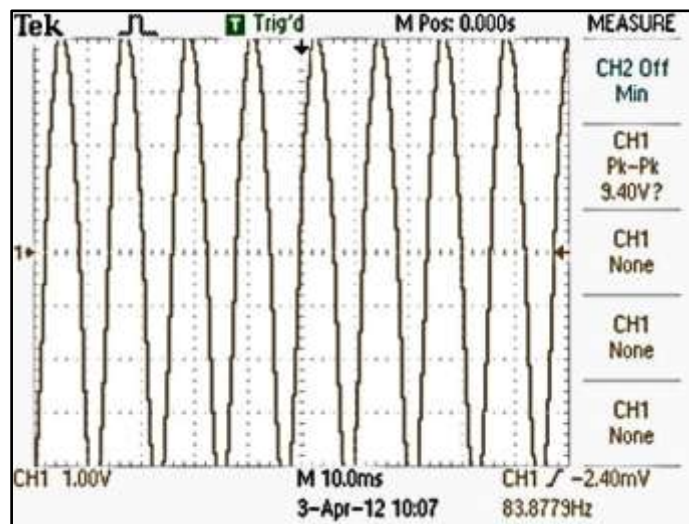


Fig. 6: Series connection of V21BL (voltage).

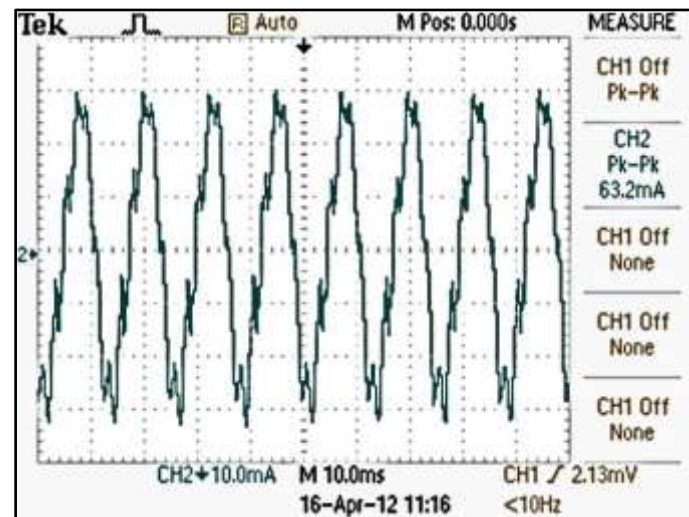


Fig. 7: Parallel connection of V21BL (current).

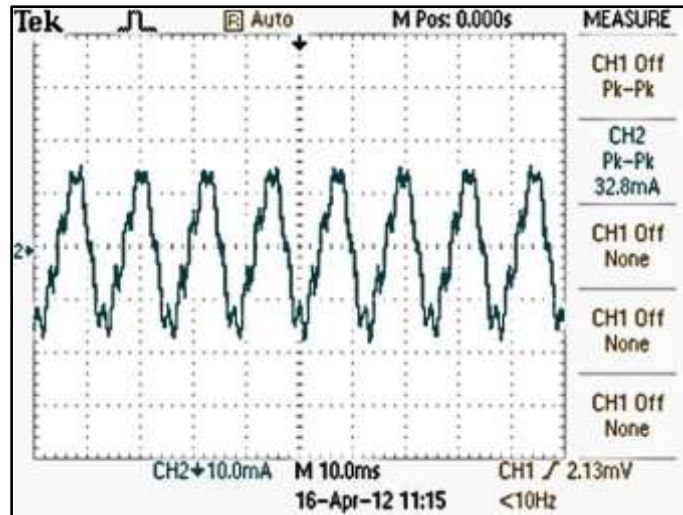


Fig. 8: Series connection of V21BL (current).

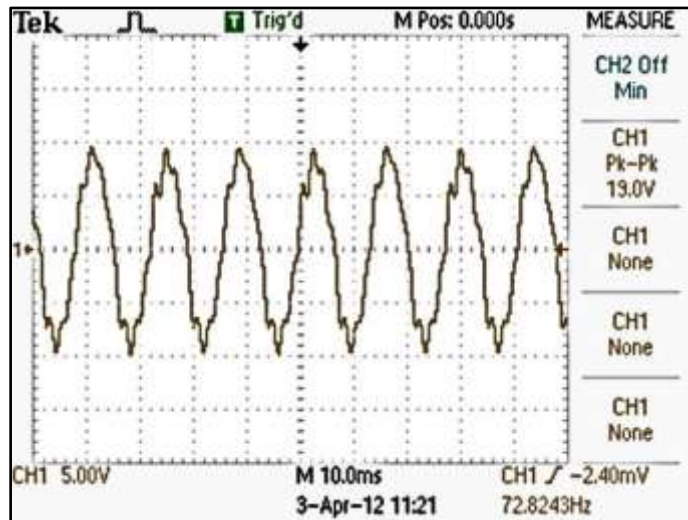


Fig. 9: Parallel connection of V25W (voltage).

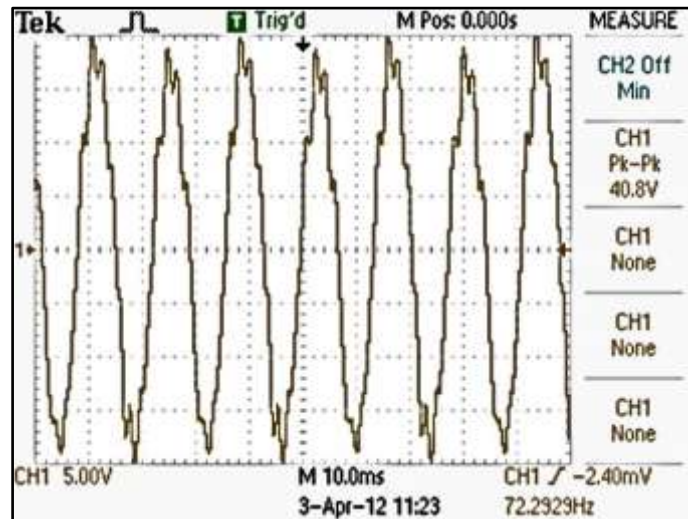


Fig. 10: Series connection of V25W (voltage).

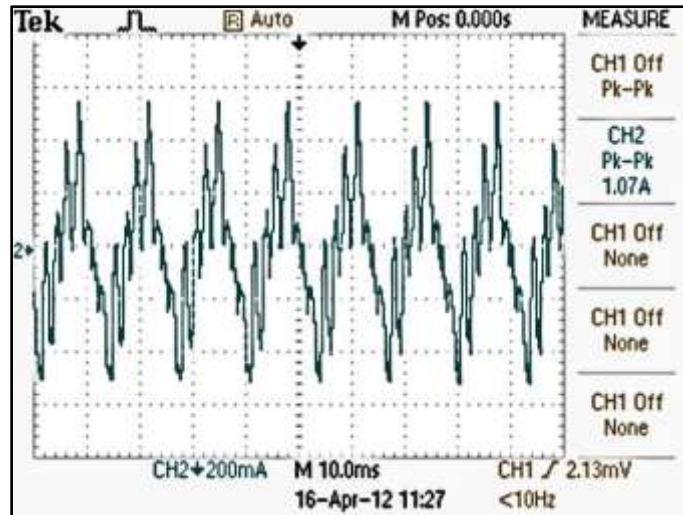


Fig. 11: Parallel connection of V25W (current).

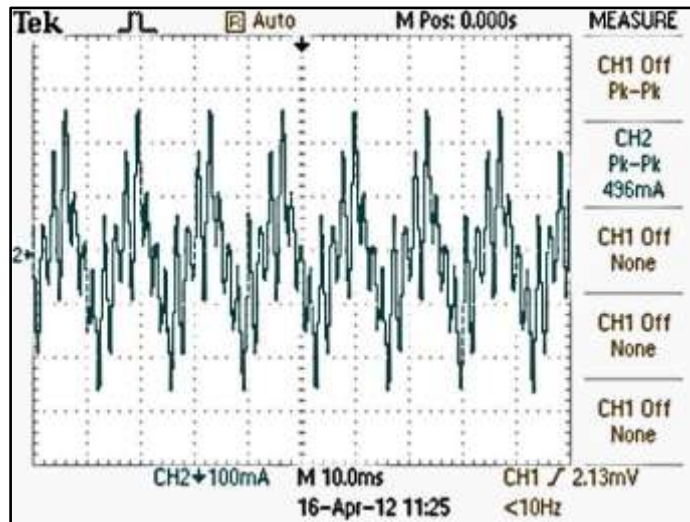


Fig. 12: Series connection of V25W (current).

Table 3: Summary of energy harvested.

	Connection	1 <sup>st</sup> Setup	2 <sup>nd</sup> Setup
Voltage	Series	4.88V	19.0V
	Parallel	9.40V	40.8V
Current	Series	63.2mA	1.07A
	Parallel	32.8mA	496mA

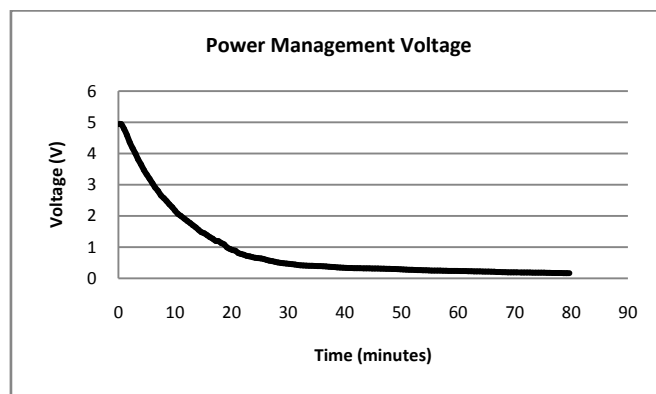
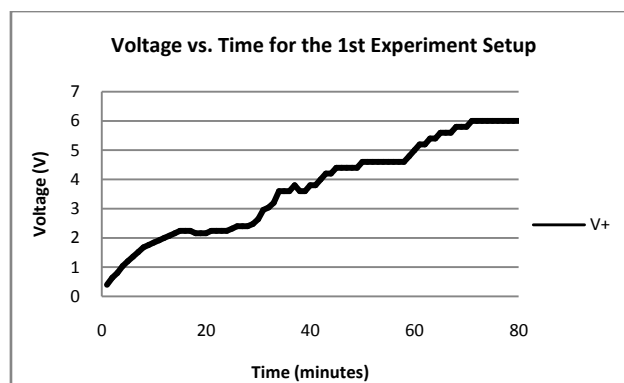
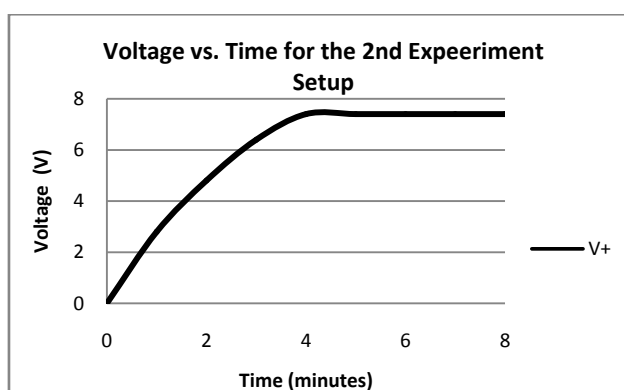


Fig. 13: Voltage versus time (V21BL+EH300).



**Fig. 13:** Output voltage vs. time for the first experiment.



**Fig. 14:** Output voltage vs. time for the second experiment.

#### Conclusion:

This paper discussed an analysis of energy harvesters which generate electricity using vibration. Two types of experiment were performed. The first setup used a medium size energy harvester and operated at a higher frequency, whereas the second setup used a larger energy harvester but operated at a much lower frequency. The experiment shows that the energy harvester can produce a peak-to-peak output voltage of 4.88 V to 40.8V. Furthermore, the second experiment achieved a charging time which was 17 times faster than the first setup. This shows that the size of the energy harvester greatly influences the amount of harvested energy, compared to the frequency applied.

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