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Sound Energy Harvesting using Piezoelectric Bimorph Cantilevers for Low-Power Electronics

Siti Nooraya Mohd Tawil[1,2,*], Muhammad Amirudin Abdul Rahman[1], Kamarul `Asyikin Mustafa[1], Kavitanjaliy Viswanathan[1]

[1] Department of Electrical and Electronics Engineering, Faculty of Engineering, National Defence University of Malaysia, Kem, Sungai Besi, 57000 Kuala Lumpur, Malaysia
[2] Centre for Tropicalisation, Defence Research Institute, Universiti Pertahanan Nasional Malaysia (UPNM), Kem Sungai Besi 57000, Kuala Lumpur, Malaysia

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ABSTRACT

This paper presents the utilization of environmental energy as an alternative source for generating micro-energy to power low-consumption electronic devices. A study was carried out, revealing that piezoelectric cantilevers can harvest sound wave energy. This paper focuses specifically on harvesting sound energy, whereby vibrations from sound waves are extracted and converted into electrical energy, which can then be used to power low-power devices. A piezo ceramic bimorph cantilever was employed as an energy harvesting sensor. Two types of circuits were tested to study the output voltage generated by the piezo material. A woofer served as the sound source, enabling the piezo material to vibrate when sound was applied. Different types of music were selected to observe the piezo's ability to generate electrical energy. The sound intensity levels of the output were recorded and analyzed. A prototype was developed and subsequently evaluated for its performance. Two types of circuits, a bridge rectifier circuit and a voltage doubler circuit, were compared to determine which produced the highest output voltage. Power management modules were used to regulate the harvested energy from the piezo device. The results showed that the bridge rectifier circuit produced a higher maximum voltage compared to the voltage-doubler circuit. The highest power successfully harvested in this experiment was 1.3396 mW at a sound intensity of 95 dB.

1. Introduction

Energy Harvesting (EH) is defined as a process of capturing minute amounts of energy from one or more surrounding energy sources, accumulate them and storing this energy for later use [1]. Energy harvesting or energy scavenging is converted into electrical energy and used to operate mobile, remote or off-grid unit like gadgets, Internet of Things (IoT) devices and other similar electronic apparatus [10]. With the recent advances on wireless and Micro-Electro Mechanical

* *Corresponding author.*
E-mail address: nooraya@upnm.edu.my

System (MEMS) technology, energy scavenging became the alternative source of energy to replace conventional batteries [5]. Solar and wind energy had been tapped as a source of renewable energy and being widely used as a replacement for fossil fuels. However, the availability of resources is more dependent on weather, thus another alternative choice is being researched. It is confirmed that sound energy is a largely ignored and readily available all the time [5]. Acoustic sound energy able to be converted into useful electrical energy and use it as a replacement for powering up ultra-low power portable electronics and wireless sensors. Harvesting sound energy may able to replace chemical batteries which raise maintenance, environment issues and size [15]. Besides, utilization of batteries in wireless sensor network is really challenging as it finishes up faster and needs to be replaced frequently. As for the remote or rural areas, the frequent need of change causes higher maintenance cost [3,10].

This paper focuses on the possibility of scavenging energy from sound waves using the piezoelectric bimorph cantilever placed at a surrounding which has high sound intensity level. The creation of energy through sound can translate into creation of electrical energy by the availability of sound pollution. Sound waves are a form of mechanical energy. Using the Thermodynamics law, oscillation of mechanical vibration can be converted into electrical energy [9]. Noise and its influence on people have been studied and analyzed for a period of time. It is classified as unpleasant and annoying which carries serious consequences when the level goes far beyond the permissible limits [6].

Investigation of sound energy becomes a great concern to transform the ambient energy into practical and usable electrical energy. Sound energy is available in some circumstances such as, airports, construction sites, and factory [4. Besides, entertainment sector also contributes to the vast amount of noise production which are mainly from discos, clubs, bar, concerts and musical events, and movie theaters [6]. Efficient ways of harvesting environmental noise into electrical energy are a big challenge since the acoustic energy comes from its low power density. Sound wave energy harvesting is proposed to use a vibration mechanism. The mechanical energy from sound converts into electrical energy using three transduction mechanisms, called electromagnetic, electrostatic and piezoelectric [14]. From research it is summarized that piezoelectric generators are the most reliable mechanism which gives higher output voltage, higher efficiency, and smaller in size [2,3,11]. Based on the study regarding piezoelectric energy harvesting via sound waves, it is known that piezoelectric element, especially Lead-Zirconate-Titanate (PZT) is very suitable in harvesting ambient mechanical energy and converts it into electrical energy [13]. Figure 1 shows how wave energy is harvested into electrical energy via piezoelectric transducer and then supplied to either a storage device or for instant use.

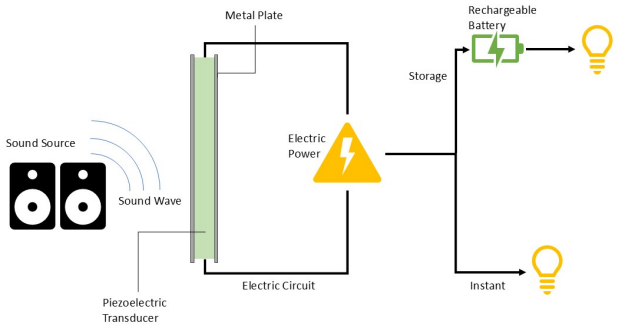

Fig.1. Sound wave energy conversion process

This project focuses on utilizing sound by using piezoelectric materials as an approach of conversion to produce green sustainable electric energy that can be used to power up low power devices.

2. Methodology

2.1 Energy Harvesting System

There are two stages involved in harvesting sound wave energy. Figure 2 shows the project block diagram which explains how sound waves are harvested into electrical energy then used to power up low power devices. The first stage is to develop a sound wave energy converter using piezoelectric bimorph cantilever. This sound wave converter captures the sound waves from the subwoofer and converts it into electricity. Second stage is to design an interface circuit to accumulate the output energy from the piezoelectric as it can be used for low power devices. Sound waves generated from the subwoofer come with sound pressure. Transducer is located near to the port or vent and speaker(driver) so that the sound pressure can hit the piezoelectric. The transducer has the ability to convert the mechanical vibration provided by the sound pressure due to its material properties. Thus, the concept of piezoelectricity, in which mechanical energy is converted into electrical energy, can be realized.

Piezoelectric transducers type Piezoelectric Zinc Titanate (PZT) as in figure 3 is used in this energy harvesting method. PZT has high coupling and high sensitivity which is very useful in generation energy. Ceramic properties inside the piezoelectric transducer have high dielectric constant, high coupling (K_P ≥0.65), and high Curie point which is more suitable to act as a sensor [7].

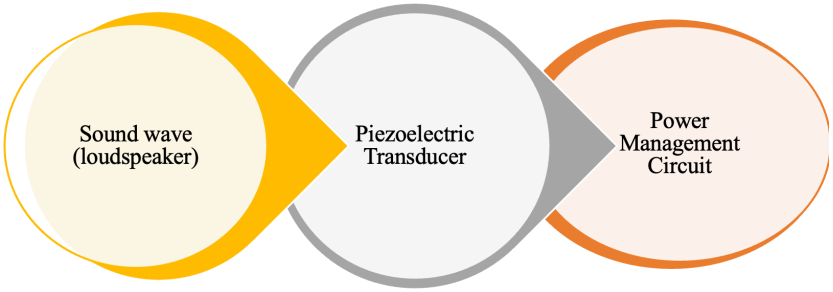

Fig. 2. Project block diagram

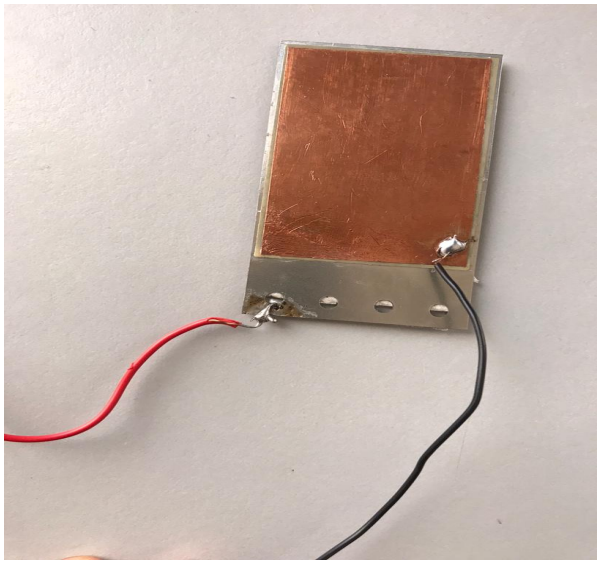

Fig. 3. Piezoelectric transducer

2.2 Power Management System

Power management system as shown in figure 4 is made up of rectifier circuits which are made up of diodes, smoothing capacitors and load. Generated current is obtained from the piezoelectric energy generator which senses the pressure from sound energy act as the energy source for the power management circuit. The generated current is alternating current (AC) thus rectifier circuit will convert it into direct current (DC) and then transferred to the smoothing capacitor.

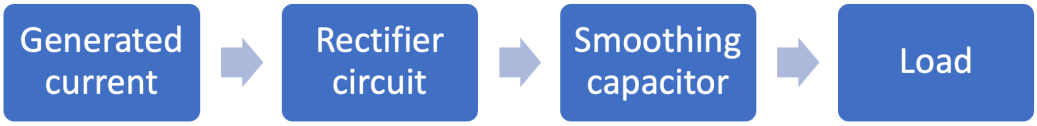

Fig. 4. Power management block diagram

3. Results and Discussion

Figure 5 shows the experimental setup and figure 6 shows the closer look of the piezoelectric module attached to the speaker and its harnessing circuit. The experiment is conducted to determine the output voltage and current based on different types of analysis. In this experiment, a full wave bridge rectifier circuit and voltage-doubler has been used to convert AC voltage generated by the piezoelectric generator to DC voltage.

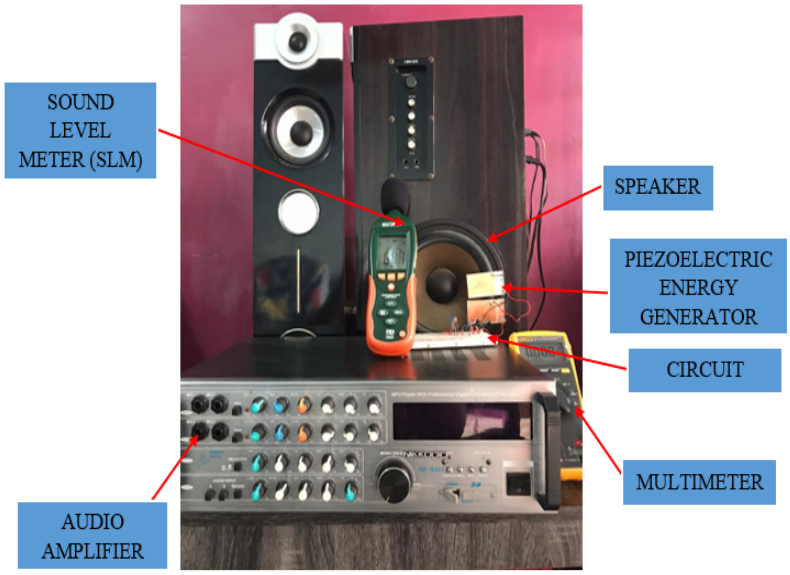

Fig. 5. Power management block diagram

The output from both circuits had been discussed and compared. From the analysis, it is recorded that bridge rectifier circuit produces greater output voltage compared to voltage-doubler circuit. Throughout the experiments, both the quantity of piezoelectric bimorph energy generators and the circuit configurations were varied. The fixed variable is the sound level for the speaker, and the same type of song selected. The sound set to medium for the speaker as this level brings the scope of sound level from 30-100 and song selected has duration of 166 seconds. Bridge rectifier circuits of 2

piezoelectric generator is selected in this experiment as it gives the highest average energy output compared to the other circuit and analysis.

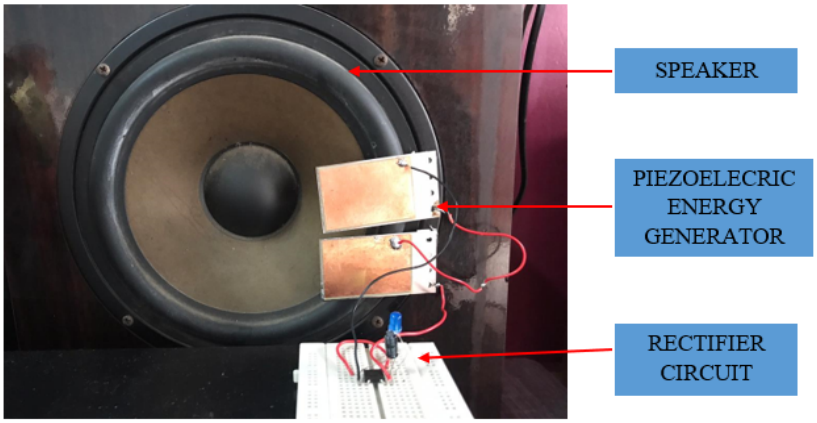

Fig. 6. The piezoelectric modules attached to the speaker

Data in Table 1 and 2 show the type of circuit and number of piezoelectric modules that had been used in this experiment. The maximum voltage and current that can be generated actually depends on the type of piezoelectric material used. The highest scavenged energy is shown at 95 dB and the output started to saturate as it reached 100 dB onwards. This is because of the stiffness of piezoelectric material.

Table 1
Data taken for bridge rectifier circuit on 1 and 2 piezoelectric modules

SLM (dB)	BRIDGE RECTIFIER					
	1 PIEZOELECTRIC MODULE			2 PIEZOELECTRIC MODULES		
	AVERAGE VOLTAGE (V)	AVERAGE CURRENT (mA)	AVERAGE POWER (mW)	AVERAGE VOLTAGE (V)	AVERAGE CURRENT (mA)	AVERAGE POWER (mW)
60	0	0	0	0	0	0
65	0	0	0	0	0	0
70	0	0	0	0	0	0
75	0.122	0.16	0.01952	1.439	0.43	0.61877
80	1.608143	0.221429	0.356089	1.894429	0.49	0.92827
85	1.677286	0.238571	0.400152	2.201	0.502857	1.106788
90	1.743467	0.252667	0.440517	2.352	0.54	1.27008
95	1.937278	0.256111	0.496158	2.37211	0.564722	1.339583
100	1.929451	0.25044	0.483212	2.203231	0.471111	1.037966
105	1.812444	0.23	0.416862	2.093333	0.436667	0.914089

Table 2

Data taken for voltage-doubler circuit on 1 and 2 piezoelectric modules

SLM (dB)	VOLTAGE DOUBLER					
	1 PIEZOELECTRIC MODULE			2 PIEZOELECTRIC MODULES		
	AVERAGE VOLTAGE (V)	AVERAGE CURRENT (mA)	AVERAGE POWER (mW)	AVERAGE VOLTAGE (V)	AVERAGE CURRENT (mA)	AVERAGE POWER (mW)
60	0	0	0	0	0	0
65	0	0	0	0	0	0
70	0	0	0	0	0	0
75	0.098	0.11	0.01078	0.187	0.1	0.0187
80	0.423571	0.18	0.076243	0.583429	0.17	0.099183
85	0.461286	0.225714	0.104119	0.671143	0.177143	0.118888
90	0.555667	0.249333	0.138546	0.717	0.186667	0.13384
95	0.703583	0.250278	0.176091	0.742614	0.2525	0.18751
100	0.697154	0.240769	0.167853	0.742319	0.203516	0.151074
105	0.681556	0.21	0.143127	0.703556	0.198889	0.13993

Generally, the number of bimorph piezoelectric generators used clearly shows an effect on the amount of energy harvested. The voltage, current and power increases as the number of piezoelectric modules increases. The sound levels also play an important role in producing the amount of energy. At certain level the harvested energy started to saturate and deteriorate once the sound level reached 90 dB [8]. From the recorded values of voltages in the tables it shows that piezoelectric generator does not vibrate at their resonant frequency because for each type of analysis the highest increase in voltage produce varies and rectifier circuit able to produce highest output voltage 1.9373 V for 1 piezoelectric module and 2.372V for 2 piezoelectric modules at sound level intensity of 95 dB respectively compared to voltage-doubler circuit. This is due to the ability of the piezoelectric material which could not be able to vibrate at its resonant frequency.

Graph in figure 7 shows the average voltage scavenged on 1 and 2 piezoelectric modules of rectifier and circuit. Based on the graph it clearly shows that bridge rectifier circuit able to produce higher output power compared to the voltage-doubler circuit. This is due to the tendency of vibration of the piezoelectric module is highest at this level which able to produce greater output voltage [3]. Once the sound level tends to increase from 95 dB onwards the output voltage tends to decrease because it will probably damage the piezoelectric transducer.

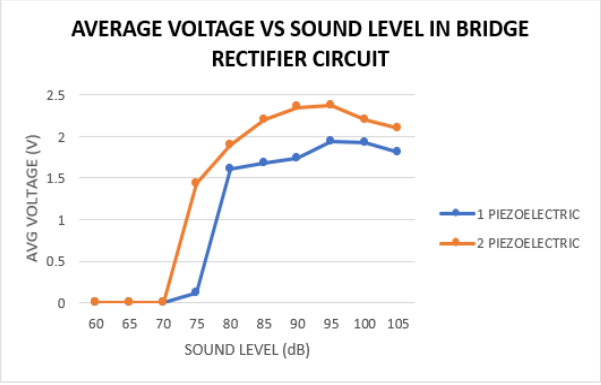

Fig. 7. Graph of average voltage against sound level based on number of piezoelectric modules in bridge rectifier circuit

Series connected piezoelectric modules of 2 units show higher output voltage compared to 1 piezoelectric module in bridge rectifier circuit. The trend line clearly shows an increase in the average voltage as the number of piezoelectric increases when connected in bridge rectifier circuit. The highest voltage produced in bridge rectifier circuit is 2.3721 V with average output power of 1.3396 mW. The analysis is conducted with voltage-doubler circuit. Figure 8 shows the average output voltage on voltage-doubler circuit.

As in Figure 8 the graph shows that the number of 2 piezoelectric modules gives higher output compared to one piezoelectric module in voltage-doubler circuit. The highest average output voltage produced by voltage-doubler circuit is 0.7426 V with average output power of 0.1875 mW at 95 dB of sound intensity level for series connected two piezoelectric modules.

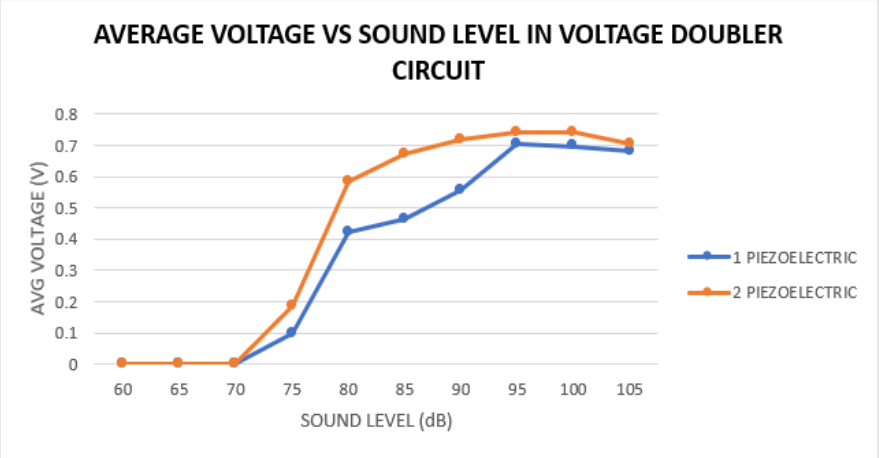

Fig. 8. Graph of average voltage against sound level based on number of piezoelectric modules in voltage-doubler circuit

The relationship between sound intensity level and resulted average voltage obviously shows that the increasing sound intensity level leads to increasing average output voltage. This is where the increasing sound level leads to an increasing vibration force of the piezoelectric energy generator. Therefore, the generated average output voltage increases respectively [3,13]. The series connected piezoelectric modules give the highest voltage value in both rectifier and voltage-doubler circuit as the piezoelectric elements on series collect voltage and current is fixed. Besides, the number of piezoelectric modules also affects the overall average output voltage, which means as the number of piezoelectric modules increases, average output voltage being generated also increases.

Next, another analysis is conducted to compare the ability of circuit in harnessing a greater output with constant number of piezoelectric modules. Based on Table 1 and Table 2, the harnessing circuit is not activated until the sound intensity level reaches 70 dB. This shows that the circuits start to operate when the sound level is more than 75 dB. Figure 9 shows the average output voltage produced by 1 piezoelectric module in rectifier circuit and voltage-doubler circuit. It can be seen that bridge rectifier circuits show a linear increase compared to the voltage-doubler circuit. This is due to the threshold voltage of the diodes being used in the circuit is 0.45 V [3]. When one piezoelectric module is connected to the full-wave rectifier circuit, the average output voltage is 1.9373 V and as for voltage-doubler circuit it clearly shows that 1 stage voltage-doubler circuit produces an average output voltage of 0.7036 V at 95 dB of sound level intensity.

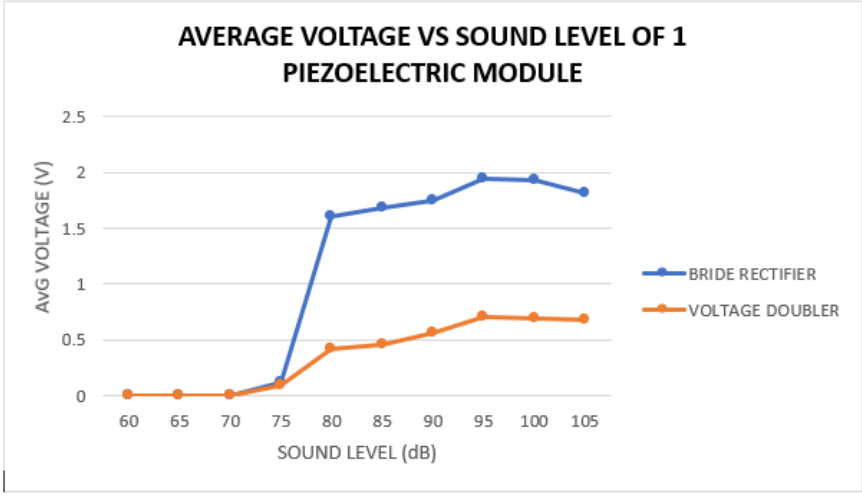

Fig. 9. Graph of average voltage against sound level based on 1 piezoelectric module in both bridge rectifier and voltage-doubler circuit

The highest average output voltage is able to be harnessed at 95dB as the piezoelectric module vibrates and deflects the most at this sound intensity level. The generated voltage does not change too much as the piezoelectric bimorph may have not reached its maximum deflection. Graph in Figure 10 shows the average output current and Figure 11 shows the average output power harnessed from 1 piezoelectric module for each type of circuit.

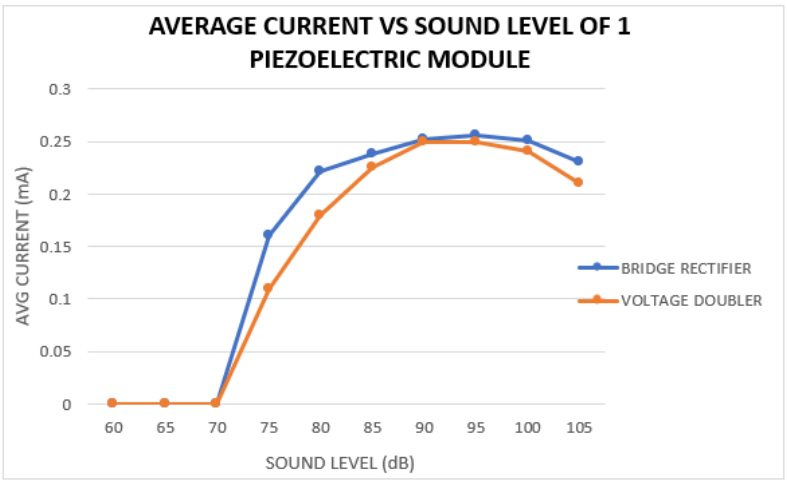

Fig.10. Graph of average current against sound level based on 1 piezoelectric module in both bridge rectifier and voltage-doubler circuit

Since only one piezoelectric module is being used the current produced for both circuits does not differ a lot as the piezoelectric element collects voltage where the current is fixed. From the graph, a slightly lower current is produced at the voltage-doubler circuit is due to the number of capacitors. The circuit parameters do not provide much current. Furthermore, there is a small loss in the diodes and loss in internal resistance in the capacitors. Since charging and discharging happens and this causes the current to be less which makes voltage fluctuation in the output [12].

Figure 11 shows generated power increases when the sound level increases and starts to decline slowly as the intensity level reaches 100 dB. This happens due to the piezoelectric module's performance of not vibrating at its resonant frequency. The highest power generated is from the

rectifier circuit which is 0.4961 mW compared to voltage-doubler circuit which is 0.1761 mW for 1 piezoelectric module at sound intensity of 95 dB. When measuring voltage and current increases, the power also increases as power directly proportional to voltage and current.

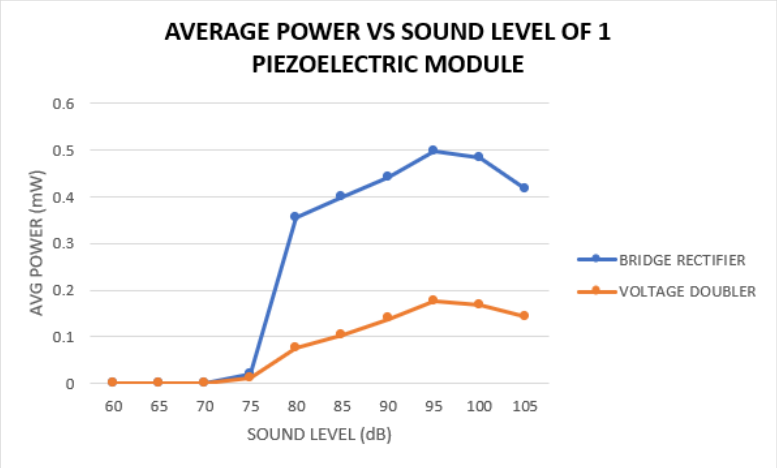

Fig. 11. Graph of average power against sound level based on 1 piezoelectric module in both bridge rectifier and voltage-doubler circuit

Next, the same analysis is conducted using 2 piezoelectric modules for both rectifier and voltage-doubler circuit. Figure 12 shows the graph of average voltage against sound level of 2 piezoelectric modules connected in series. The 2 piezoelectric modules in rectifier circuit produce average output voltage of 2.3721V at 95 dB sound intensity level of generated wave from the woofer speaker.

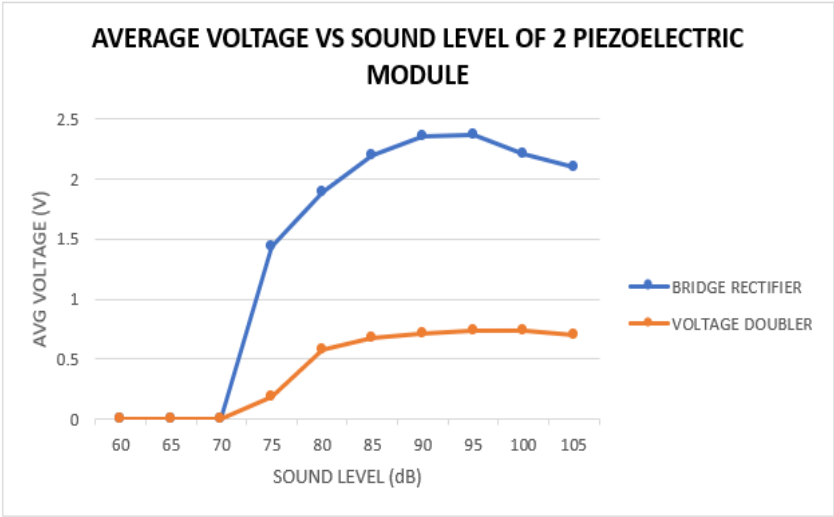

Fig. 12. Graph of average voltage against sound level based on 2 piezoelectric modules in both bridge rectifier and voltage-doubler circuit

From there, it clearly shows that 1 stage voltage-doubler circuit produces an average output voltage of 0.7426 V at 95 dB of sound level intensity. The diodes and capacitors used in this voltage-doubler circuit do not have minimum reverse breakdown voltage rating of at least twice the peak

voltage across them as they are not cascaded to produce a higher output voltage compared to input voltage. Besides, the voltage-doubler circuit supplies low currents to high resistive loads as the voltage starts to drop quickly when load current increases.

Figure 13 shows the graph of average current against sound level of 2 piezoelectric modules. From the graph it can be clearly seen that the bridge rectifier circuit has greater output average current compared to voltage-doubler circuit. The highest recorded current for rectifier circuit is 0.5647 mA whereas voltage-doubler circuit produces current of 0.2525 mA. The decrement of current starts to show up when the intensity level reaches 100 dB onwards as the piezoelectric module starts to not vibrate at its resonant frequency. The highest average current is generated from the harvester circuit is at 95 dB as the piezoelectric modules resonate the most at its frequency [3].

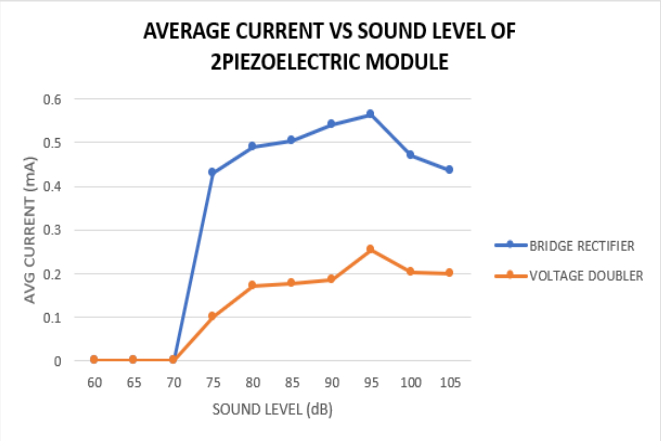

Fig. 13. Graph of average current against sound level based on 2 piezoelectric modules in both bridge rectifier and voltage-doubler circuit

Graph in Figure 14 shows the calculated power generated increases as the sound level increases at certain level and starts to decrease due to the piezoelectric material performance. The highest generated power is produced by a rectifier circuit which is 1.3396 mW. Voltage-doubler circuit generated the highest output power at 95 dB which is 0.1875 mW. When the voltage measured and current increases, the power also increases. Voltage-doubler circuit does not show a drastic increment as compared to rectifier circuits because the energy produced is already used up for the components itself thus, the output energy at the load shows a slow increment as charging takes place at each capacitor.

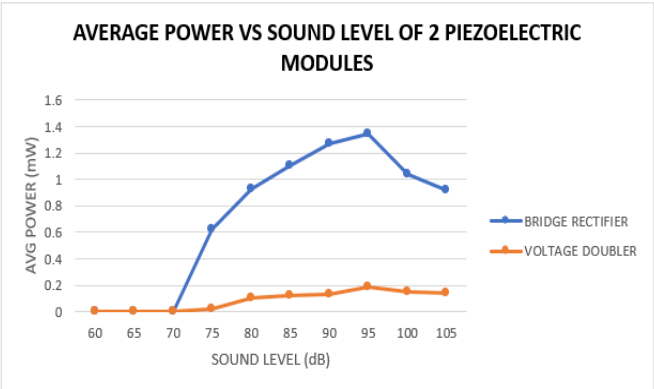

Fig. 14. Graph of average power against sound level based on 2 piezoelectric modules in both bridge rectifier and voltage-doubler circuit

The highest current produced by rectifier circuit is 0.5647 mA which is greater than 0.2525 mA of voltage-doubler circuit. Thus, to light up LED, rectifier circuits are more recommended as the current is high. Less number of LED can be light up in voltage-doubler circuit compared to rectifier circuit. In this experiment a different type of piezoelectric material which is piezoelectric generator is being used. Based on the experiment, this piezoelectric material is also able to produce output energy which can power up low power devices like LED.

4. Conclusions

This paper discusses the development of an energy harvester device using the piezoelectric bimorph cantilever as energy generator. Based on the experiment, the device successfully demonstrated the ability of piezoelectric energy harvesting in environmental wave power generation using subwoofer speakers. The sound intensity level has played a major role in affecting the ability of bimorph to generate power. The output voltage and current also depends on the number of piezoelectric modules. As the number of piezoelectric modules increases, the generated output power also increases. Besides, types of harnessing circuit whether rectifier of voltage-doubler circuit, the efficiency of the circuit to power up low power devices is analyzed. As for the future recommendation, the element of storage also has a good aspect that can be added to this system. Supercapacitors and batteries are energy storage devices for energy harvesting systems. The output voltage and current should be stored and thus the energy stored can be used at any time.

Acknowledgement

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References

[1] Ahmed, Riaz, Fariha Mir, and Sourav Banerjee. "A review on energy harvesting approaches for renewable energies from ambient vibrations and acoustic waves using piezoelectricity." *Smart Materials and Structures* 26, no. 8 (2017): 085031. https://doi.org/10.1088/1361-665X/aa7bfb

[2] Elahi, Hassan, Marco Eugeni, and Paolo Gaudenzi. "A review on mechanisms for piezoelectric-based energy harvesters." *Energies* 11, no. 7 (2018): 1850. https://doi.org/10.3390/en11071850

[3] Fang, Liew Hui, Syed Idris Syed Hassan, Rosemizi Abd Rahim, Muzamir Isa, and Baharuddin bin Ismail. "Exploring piezoelectric for sound wave as energy harvester." *Energy Procedia* 105 (2017): 459-466. https://doi.org/10.1016/j.egypro.2017.03.341

[4] Farghaly, Yasser A., Fahd Abdel Aziz Hemeida, and Sahar Salah. "Noise utilization as an approach for reducing energy consumption in street lighting." *Plos one* 14, no. 7 (2019): e0219373. https://doi.org/10.1371/journal.pone.0219373

[5] Garg, Mehul, Devyani Gera, Aman Bansal, and Arpan Kumar. "Generation of electrical energy from sound energy." In *2015 International Conference on Signal Processing and Communication (ICSC)*, pp. 410-412. IEEE, 2015. https://doi.org/10.1109/ICSPCom.2015.7150687

[6] Hemmat, Walihabib, Atiq Mohammad Hesam, and Hamza Atifnigar. "Exploring noise pollution, causes, effects, and mitigation strategies: a review paper." *European Journal of Theoretical and Applied Sciences* 1, no. 5 (2023): 995-1005. https://doi.org/10.59324/ejtas.2023.1(5).86

[7] Fang, Liew Hui, Syed Idris Syed Hassan, Rosemizi Abd Rahim, Muzamir Isa, and Baharuddin bin Ismail. "Charaterization of differents dimension piezoelectric transducer for sound wave energy harvesting." *Energy Procedia* 105 (2017): 836-843. https://doi.org/10.1016/j.egypro.2017.03.398

[8] Jean, Fandi, Muhammad Umair Khan, Anas Alazzam, and Baker Mohammad. "Advancement in piezoelectric nanogenerators for acoustic energy harvesting." *Microsystems & Nanoengineering* 10, no. 1 (2024): 197. https://doi.org/10.1038/s41378-024-00811-4

[9] Kalyani, Vijay Laxmi, Anjali Piaus, and Preksha Vyas. "Harvesting electrical energy via vibration energy and its applications." *Journal of Management Engineering and Information Technology* 2, no. 4 (2015): 9-14.

[10] Laumann, Felix, Mette Møller Sørensen, Rasmus Felipe Jul Lindemann, Tina Mølholm Hansen, and Torben Tambo. "Energy harvesting through piezoelectricity-technology foresight." *Energy Procedia* 142 (2017): 3062-3068. https://doi.org/10.1016/j.egypro.2017.12.445

[11] Li, Tao, and Pooi See Lee. "Piezoelectric energy harvesting technology: from materials, structures, to applications." *Small Structures* 3, no. 3 (2022): 2100128. https://doi.org/10.1002/sstr.202100128

[12] Liew, Hui Fang, Rosemizi Abd Rahim, Muzamir Isa, Baharuddin Ismail, and Syed Idris Syed Hassan. "Analysis of batteries or supercapacitor as energy storage device for a sound energy harvester system." *IEEJ Transactions on Electrical and Electronic Engineering* 13, no. 12 (2018): 1699-1708. https://doi.org/10.1002/tee.22733

[13] Selim, Kyrillos K., Ayman Haggag, Fathy Z. Amer, Wael A. Rady, and Ahmed M. El-Garhy. "A proposed technique for power extraction from acoustic energy scavenging." *International Journal of Electronics* 105, no. 7 (2018): 1236-1247. https://doi.org/10.1080/00207217.2018.1440425

[14] Wei, Chongfeng, and Xingjian Jing. "A comprehensive review on vibration energy harvesting: Modelling and realization." *Renewable and Sustainable Energy Reviews* 74 (2017): 1-18. https://doi.org/10.1016/j.rser.2017.01.073

[15] Xia, Jintao, Haowei Lu, Gaoru Chen, Dazeng Lin, Wenlong Yang, Chang Liu, Benlin Hu, and Yini Zhao. "High performance piezoelectric nanogenerator by fiber microstructure engineering toward self-powered wireless sensing system." *Nano Energy* 128 (2024): 109901. https://doi.org/10.1016/j.nanoen.2024.109901