

Research Article

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A power source for E-devices based on green energy

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Abstract: Mobile and wearable devices are now the main part of our lives. The power consumed by these devices is usually in the range of μW or mW . Due to the requirement of periodic recharging, this work tries to present an economic renewable energy harvesting source for the process of charging. In this paper, authors exploit a huge amount of energy dissipated daily in the form of loud noise through streets up to 85 dB to generate a sufficient rate of energy to recharge the lithium batteries of wearable and mobile devices (more than 4.01 V). The piezoelectric model 7BB-27-4 was used in this work through a proposed design circuit. Suitable software was used to simulate the design. In comparison to previous research findings, the authors' findings are sufficiently satisfactory.

Keywords: diaphragm; electricity; noise; piezoelectric material; sound energy; sound vibration

1 Introduction

These days, the electricity demand is constantly increasing on this planet and is set to double by 2030, so it is far more

essential for us to discover other alternative methods to produce electric power (Zheng et al. 2023). While we consider some different approaches, we consider solar power, wind power, and hydropower, but we forget “sound energy”. In this century, the most common component we encounter everywhere is noise pollution, a major issue confronting all countries worldwide (Xiao et al. 2023). In terms of the environment, the rapid growth of urban and industrial zones has resulted in massive amounts of hazardous waste. The massive increase in vehicles and residents resulted in a critical assessment of “Noise pollution” (Bhatnagar et al. 2012).

It has evolved into a significant issue for communities. Unwanted noise influences institutional improvement, which directly and indirectly affects human health through social factors, economic procedures, education, and production. The noise has an immediate or indirect effect on corporal health, mental disturbances of daily activity, and permanent or temporary hearing loss, ranging from minor deterioration to hearing loss (Garg et al. 2015). Traffic noise has been identified as a significant source of noise pollution. Trains, buses, motorcycles, heavy planes, and vehicles all contribute to noise pollution (Duan et al. 2023).

Noise can lead to the discovery of any other hidden source of power that could serve as an alternative to non-renewable sources of energy, such as coal, crude oil, and so on, all of which are on the verge of extinction (Jaware et al. 2017).

To produce more vibrations from the amplifier, the piezoelectric quartz crystal is connected directly to the speaker due to the lower sensitivity of the material due to its small size. The sensors are connected in series, and springs are used between each sensor to create more pressure, as shown in Figure 1. These elements convert sound into electrical signals. Still, the converted voltage and current are very low. To enhance the signal, the LM2596S DC to DC Buck Power Converter uses different steps to boost the input signal. It is possible to adjust the output voltage to the level required to charge the battery, which is a low-cost 12V sealed lead acid battery (Chaithanya et al. 2021). The best result this research reached was 2 v at 70–75 dB, and it was enhanced to 3.6 v at the same dB level by using a filter as shown in Table 1. The cost of this system is high compared to the quality of the results.

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Figure 1: The technique used to charge the mobile phone (Chaithanya et al. 2021).

Table 1: Output voltages versus each input sound.

Sound in (dB)	DC V_{Out} without filter (V)	DC V_{Out} with filter (V)
40–45	0.3	0.5
50–55	0.7	0.9
60–65	1	1.6
65–70	1.5	2.8
70–75	2	3.6

Two techniques for extracting electricity from piezoelectric materials were described in Figure 2. The microphone and the PZT were used in the first method to ensure the project's success. If the microphone fails, the PZT can function. When tested on mobile, the project performed admirably. The second method involves applying pressure to a PZT crystal device to charge the phone due to mechanical stress and pressure (Ansari 2017). Table 2 shows that the obtained output voltage in this research from the circuit is limited to a low level (2 V) at 120 dB. The results of this research are considered modest, as the output voltage is small compared to the large level of the input sound.

There are numerous methods for converting sound into electricity. The first method was based on Faradese's law of electromagnetic induction, and it used a diaphragm placed between magnetic poles to convert sound waves into electricity. The second method described how to use modern technology to convert electrical energy into electrical potential by using piezoelectric materials (Gupta, Goel, and Yadav 2014). Figure 3 shows the circuit diagram of the battery charging process used in this research.

The results of this research are modest, as shown in Figure 4. Various control methodologies are used to reduce human exposure to high sound levels. This is based on the oscillation produced by the sound wave, which can then be converted to electricity using a magnetic field. Instead of converting an electrical signal into sound, we will use a loudspeaker (transducer) to convert a sound wave into electrical energy. Other methods for such conversion exist, such as Piezometers and piezoelectric devices, but their efficiency has yet to be found satisfactory (Jaware et al. 2017).

Sound energy can be converted in several ways: the first is to create a device using magnets and a curtain conductor (diagram); the second is to convert sound energy into thermal energy and then into electrical energy; and the third method is to use transducers such as piezoelectric materials



Figure 2: The proposed circuit to generate electricity from sound (Ansari 2017).

Table 2: Results of the experiment used in (Ansari 2017).

Sound level (dB)	Output voltage (V)	Output current (mA)
75	0.7	0.7
80	0.7	0.7
88	0.75	0.8
90	0.8	0.9
95	1	1
100	1.5	1.8
110	0.6	1.9
115	0.55	2
120	2	2

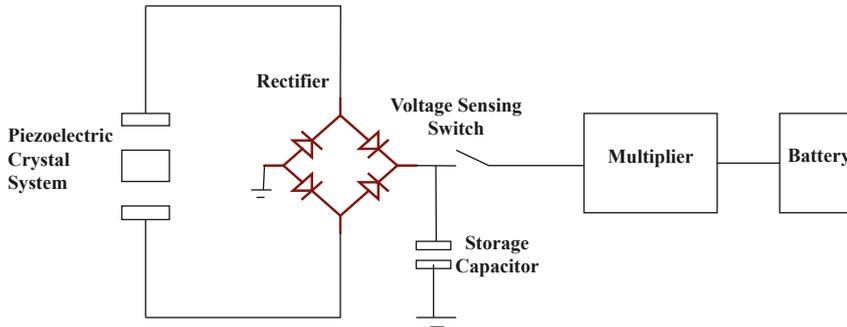


Figure 3: The circuit to charge the battery (Gupta, Goel, and Yadav 2014).

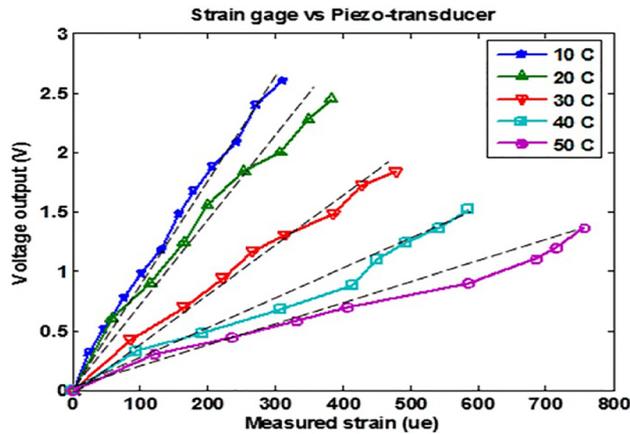


Figure 4: The output voltage due to different strain (Gupta, Goel, and Yadav 2014).

that convert mechanical stress into electrical energy and vice versa (Bhatnagar et al. 2012).

An electromechanical model developed with MATLAB Simulink that was validated by the experimental results of the PVDF and PZT piezoelectric material harvesters was proposed. It was compared to a similar electrical model used in previous research. The electromechanical model proved to be a valuable tool for studying and analysing the behaviour of various piezoelectric materials used in energy harvesting (Kotdawala and Kamat 2018).

The research mentioned earlier, Jaware et al. (2017), Bhatnagar et al. (2012), and Kotdawala and Kamat (2018) is a guide to understanding how to convert sound into electricity in all possible ways.

Various states of piezoelectric transducer mounting on DJ are proposed, and the results to determine the maximum converted power are investigated. Each stage of the proposed technique consists of a piezoelectric transducer followed by a voltage multiplier. In this research, different design methods were applied to improve the output voltage results at the same input sound levels (Selim et al. 2018). The proposed circuit used in this research is shown in Figure 5.

Although the authors guarantee the best result at 1.9 kHz, where the output voltage is 3.9 v using the proposed design, this system suffers from a high overall cost and large scale.

The proposed model used in this research was divided into two parts. Figure 6 shows 18 piezo plates mounted on a thermocol board, which is supported by a wooden board. To support weight, four helical wound springs are attached between the lower and middle wooden plates. A spring was used to connect the middle and upper wooden plates (Deshmukh et al. 2016). The system used in this research is complex and expensive. An efficient method for producing usable electrical energy from available random acoustic energy was proposed in Figure 7. To convert sounds into electrical energy, piezoelectric transducers were used. Multiple piezoelectric transducers generated electrical energy, which was stored in multiple supercapacitors and amplified via adder and voltage multiplier circuits. The electrical energy generated was either used to charge a rechargeable DC battery or stored (Jamal et al. 2013). This research used external power-supplies to operate the power extraction circuit, contradicting the energy harvesting principle. Energy can be generated from unwanted noise pollution. The voltage generated by the amplifier circuit and the sound energy from the amplifier or from the noisy area sensed by the sound sensor The septic boost converter increased this voltage, allowing the battery to provide the required voltage and current for storage as shown in Figure 8 (Viknesh et al. 2018). Due to efficiency concerns, this technology is not currently practicable, but current research in this field makes its future quite promising.

Piezoelectric materials can be used to generate green electrical power that could be used to reduce energy consumption from nonrenewable sources and be used in street lighting. The research was carried out in three bus stations in Alexandria, taking measurements on weekdays and weekends to study the noise emitted and the amount of electrical energy that can be produced using 690 QB220-503YB transducers and used in street lighting (Farghaly,

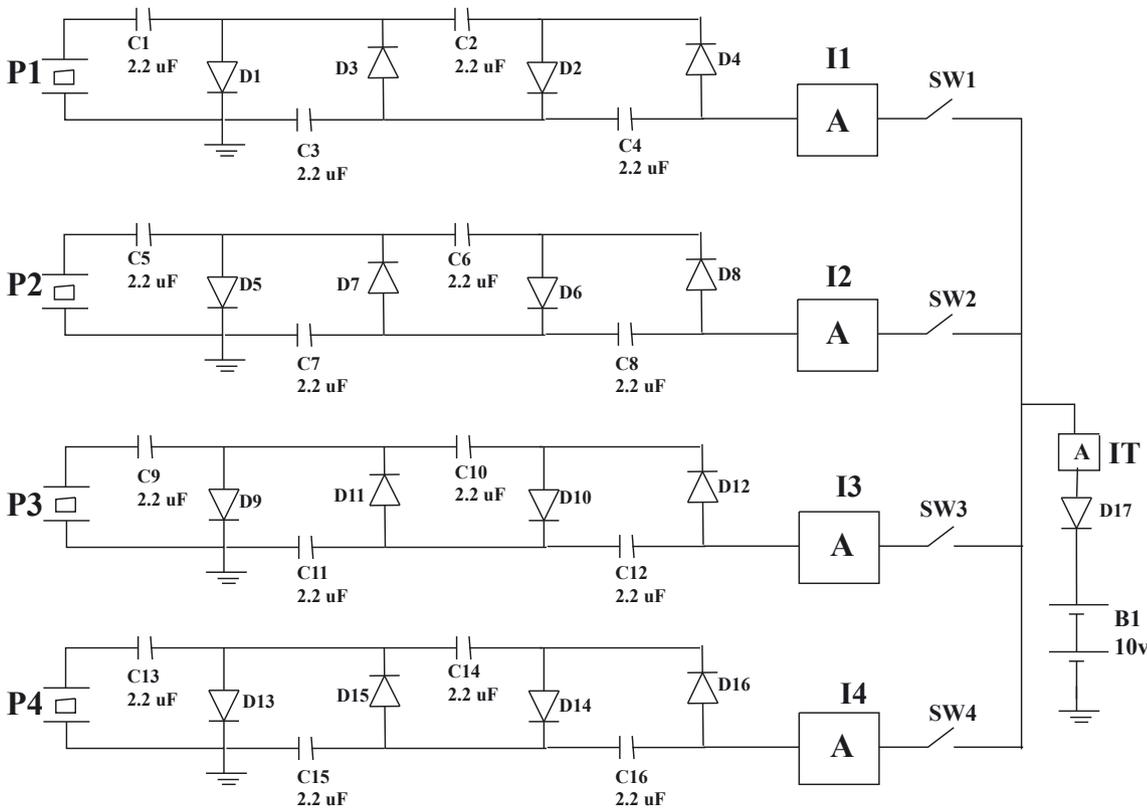


Figure 5: Schematic diagram of the proposed technique (Selim et al. 2018).



Figure 6: The model used to convert sound to electric power (Deshmukh et al. 2016).

Hemeida, and Salah 2019). Figure 9 shows the proposed area to place the piezoelectric transducers at the bus stop at Cleopatra Station. The total cost of the system used in this research is very high compared to the amount of energy produced from it.

The major goals of this study are:

- Generating electrical power using sound energy.
- Utilising the piezoelectric crystal in the development of a sound piezoelectric energy harvesting system.

This article is structured as follows: In Section 2, the nature of sound is described, followed by a piezoelectricity discussion in Section 3. After that, the acoustic energy harvesting system is shown in Section 4, followed by its advantages and disadvantages in Section 5. Then Section 6 discusses the theory and method used in this research in detail. The results are discussed in Section 7. The future work is shown in Section 8. Finally, Section 9 concludes the whole study.

2 Nature of sound

In layman’s terms, sound is the vibration of any substance. The substance could be air, water, wood, or anything else. The only place where sound cannot travel is a vacuum. These substances can produce sound by vibrating or rapidly moving back and forth (Jamal et al. 2013).

Sound waves can be longitudinal or transverse, depending on the direction of vibration of sound particles known as phonons. Phonons are sound particles that provide mechanical power as an output that can be used for conversion following thermodynamic laws (Gupta, Goel, and Yadav 2014).

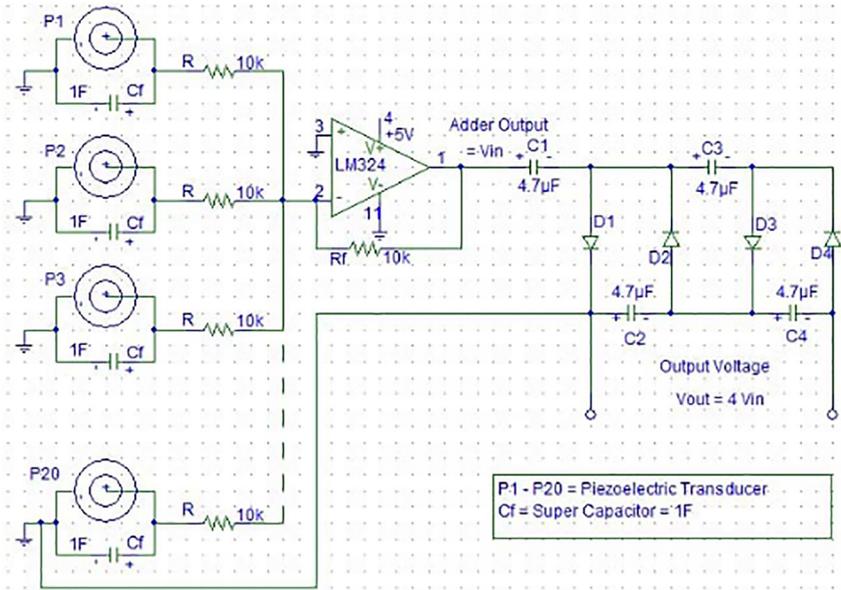


Figure 7: Sound to electricity full circuit (Jamal et al. 2013).



Figure 8: The hardware module used to charge mobile phones (Viknesh et al. 2018).



Figure 9: Cleopatra bus stop station with the proposed model (Farghaly, Hemeida, and Salah 2019).

Sound is transmitted as a longitudinal wave in liquids and gases but can also be transmitted as a transverse wave in solids (Jaware et al. 2017). Human-perceivable sound has frequencies ranging from 20 Hz to 20 kHz. The corresponding wavelengths of sound waves in air at typical temperature and stress range from 17 m to 17 mm (Bejgam et al. 2021).

Sound could be converted into electrical power like mechanical power can be converted into electrical energy using the third law of thermodynamics, which states that mechanical power can be converted into electric power (Jaware et al. 2017).

A transducer is an electronic device that converts one type of power into another, a process known as transduction. Efficiency is defined as the ratio of output energy to input energy. The higher the efficiency, the better the device’s overall performance (Bejgam et al. 2021).

Table 3 depicts various acoustic power sources and the associated sound pressure levels (SPLs). The SPL of vehicles such as cars, trains, power boats, and aircraft ranges from 71.9 to 150 dB over a frequency range of 20 Hz to 20 kHz, just as the SPL of acoustic power ranges from 67 to

78 dB in the vicinity of home appliances. The SPL of acoustic noise in an industrial environment ranges from 87.7 to 136 dB. Furthermore, acoustic power SPL in distinct components of the gas turbine power plant ranges from 100.3 to 114.1 dB over a frequency spectrum of 30 Hz to 8 kHz (Khan et al. 2015).

Sound power can be converted into heat power and then into electrical power, but this is inefficient because the conversion loss is high. In contrast, the other approach shows that piezoelectric materials can generate electricity directly from sound energy, which is defined as crystals that convert mechanical pressure into electricity (Gupta, Goel, and Yadav 2014; Jaware et al. 2017).

Piezoelectric materials respond precisely to vibrations because they have a high energy density and a higher response to vibration (Kotdawala and Kamat 2018).

3 Piezoelectricity

For the conversion of mechanical energy from ambient vibration sources to electrical energy, the best conventional mechanical energy harvesting methods typically rely on piezoelectric materials (Mokhtari et al. 2019).

Table 3: Sound sources and corresponding sound pressure levels (Khan et al. 2015).

Sound source	SPL (dB)	Reference
Turbofan motors	150	Horowitz et al. (2006)
Surrounding cars	90	Jung et al. (2009)
Automobile conditioning system	71.9	Yokoyama and Hashimoto (2010)
Martial aircrafts	115	Ising et al. (1990)
Airbus plane	86	Woods et al. (2011)
Train (200 km/h) moving inside a subway	140	Xiao, Toshiyuki, and Naoya (2012)
Small powered ship	150	Barlett and Wilson (2002)
Hospitals in midday	72	Busch-Vishniac et al. (2005)
Magnetic resonance imaging (MRI) scanner	130.7	Hattori, Fukatsu, and Ishigaki (2007)
Hair dryer	67	Chang, Wu, and Hung (2013)
Juicer machine	76	Chang, Wu, and Hung (2013)
Electrical sweeper	78	Chang, Wu, and Hung (2013)
Grinders	72	Chang, Wu, and Hung (2013)
Printing manufacture	87.7	Grujić et al. (2011)
Textile industry	110	Bedi (2006)
Fiberglass manufacture	101	Pekkarinen (1987)
Glass manufacture	113	Pekkarinen (1987)
Copper tubing manufacture	136	Pekkarinen (1987)
Plastic packing manufacture	112	Pekkarinen (1987)
Aeriform hammers	131.9	Nassiri, Gol-Mohammadi, and Kamali (1992)

The electric power generated by pressure is known as piezoelectricity. This is accomplished by using crystals to convert mechanical power to electric power or vice versa (Bairagi et al. 2023). It is scientifically defined as the appearance of an electrical potential (a voltage) along the sides of a crystal when mechanical pressure is applied to it (Farghaly, Hemeida, and Salah 2019). The linear electro-mechanical interaction between mechanical and electrical states in crystalline substances that lack inversion symmetry is referred to as “The Piezoelectric Effect”. Piezoelectric crystals act as transducers, converting mechanical stress into electrical energy (bt Samaon 2018).

When a crystal is deformed using external pressure, Electric charges appear on crystal surfaces. When the direction of pressure reverses, the polarity of the electric charge reverses, and this is the “direct piezoelectric effect” as shown in Figure 10. It can be seen in the use of gas lighters, and piezoelectric sensors, like acceleration and stress sensors (Panda et al. 2022).

In contrast, the inverse piezoelectric effect occurs when a piezoelectric crystal is placed in an electric field or when charges are applied to its faces by external means, as shown in Figure 11. The crystal’s dimensions change. The direction of the resulting stress is reversed when the direction of the applied electric field is reversed (Tambe et al. 2017). Inverse piezoelectric impact applications include micropositioning actuators and buzzers (Littrell 2010).

Wave filters and ultrasonic power generators are two examples of applications for piezoelectric materials. Ultrasonic imaging appliances are also made with arrays of piezoelectric elements. The connection between electrical power and the mechanism served as the foundation for the evolving conversion technique.

Mechanical energy can be used in novel ways thanks to the use of piezoelectric materials, such as high voltage generation, electronic frequency generation, and other applications. The mechanical power of sound is applied directly to a crystal (or a ceramic) with strong piezoelectric

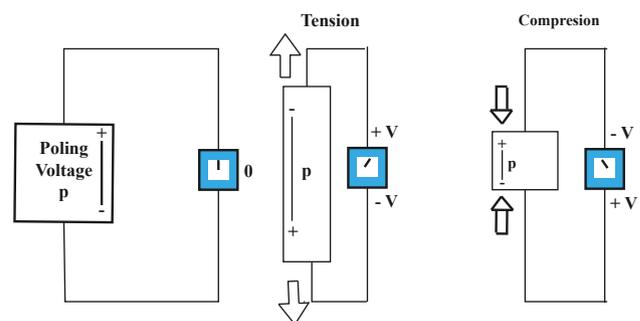


Figure 10: The direct piezoelectric impact (Othman 2017).

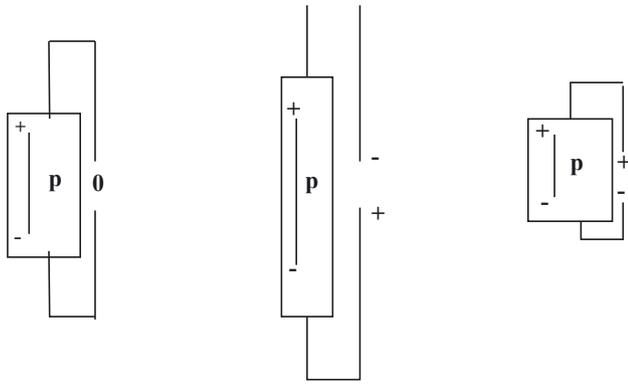


Figure 11: The inverse piezoelectric impact (Bhatnagar et al. 2012).

characteristics, and the crystal generates a small amount of voltage as a result of that mechanical power (sound). As shown in Figure 12, this is referred to as “squeezing” the crystal. When this crystal is released, another small voltage in the opposite polarity can be produced (Gupta, Goel, and Yadav 2014).

A piezoelectric converter is a device that uses piezoelectric material to collect sound waves that are moving nearby. That sound wave will be used to cause a strain in the piezo crystal due to stress caused by its oscillation, which will cause a disturbance in its atoms, resulting in the flow of electric charge on the crystal’s surface, and then sound power will be converted into electric power as the piezoelectric material converts it. As a result, this sound energy could be

converted into usable electric power and applied to a variety of tasks (Jaware et al. 2017).

4 Acoustic energy harvesting

Acoustic Energy Harvesting (AEH) modules are intended to collect sound energy from their surroundings and convert it into usable electric power. As illustrated in Figure 13, such a module is composed of numerous essential blocks. The incident sound wave, also known as the “excitation source,” is where it all begins. A transducer converts the mechanical power transferred into electricity. Finally, a module manages electric power via power electronics and power storage units (Zuo and Tang 2013).

5 AEH advantages and disadvantages

There are numerous reasons to employ and distinguish sound energy harvesting. The following are some examples: AEH provides an escalation path to efficient power recycling and can be used in the event of an energy disaster or any other emergency situation. Furthermore, it lowers electric power prices, making it a low power consumption means (Deshmukh et al. 2016).

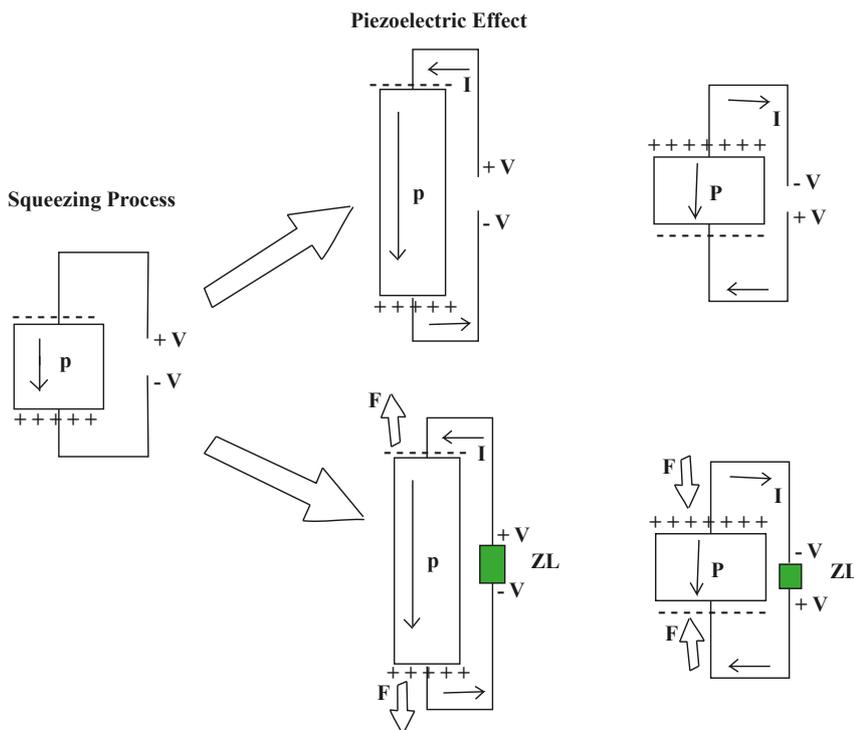


Figure 12: Effects on piezoelectric materials (Gayakawad et al. 2016).

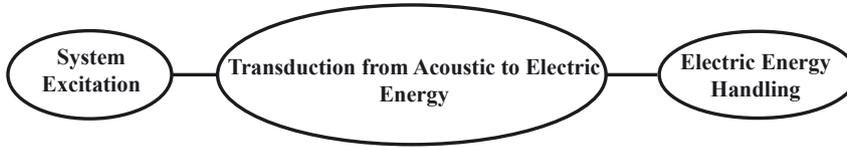


Figure 13: Acoustic energy harvesting block diagram (Salem, Fraña, and Nová 2020).

Despite the majority of these advantages, the AEH system has a few drawbacks, which include its efficiency isn't very good, and it needs to be improved. It will not work in very low decibel environments, and the overall device installation is very expensive (Jaware et al. 2017).

6 Theory and methods

Electrically, a piezoelectric transducer is represented by a voltage source (V_p) connected in series to the capacitance of the piezoelectric plate (C_p).

$$V_p = \frac{g_{33}tF}{A}, \quad (1)$$

where: g_{33} is the piezoelectric material's constant. t is the piezoelectric transducer thickness. F is the force of acoustic energy applied to the piezoelectric transducer. A is the piezoelectric transducer cross-sectional area.

As a result, different piezoelectric transducer connections result in different equivalent capacitances (C_{p-eq}). For our research, we use a series array of four piezoelectric transducers, so the equivalent capacitance (C_{p-eq}) is given as follows:

$$C_{p-eq} = \frac{C_p}{4}, \quad (2)$$

C_p is piezoelectric plate capacitance.

The value of C_p is given by the piezoelectric transducer data sheet directly.

$$C_p = \frac{\epsilon_0 \epsilon_r A}{t}, \quad (3)$$

where: ϵ_0 is the free-space dielectric constant. ϵ_r is the piezoelectric material's dielectric constant. A is the piezoelectric transducer's cross-sectional area. t is the piezoelectric transducer thickness. The work was based on improving an existing circuit by using diodes that had not previously been used for this purpose and avoiding the circuit's flaws.

We use a multistage Villard multiplier circuit as shown in Figure 14 with equivalent values shown in Table 4.

The output voltage (V_o) after n stages:

$$V_o = nV_p, \quad (4)$$

where: n is the number in the Villard doubler circuit.

In our study, the sound source is a Panasonic SBVK30 speaker, and to generate more vibrations, the piezoelectric quartz crystal shown in Figure 15 is connected directly to the speaker because the material's sensitivity is low due to its scale. The sensors are linked in series, and they convert sound into an electric signal. Because the converted voltage and current are extremely low, a multistage Villard rectifier circuit is used to boost the input signal. The sound is measured using the Sound Metre Android app, and the output voltages are measured using a digital millimetre.

According to this study, the circular piezoelectric material used as a transducer has several advantages, including its small size, light weight (3 g), and low cost (approximately 2.09 \$). It is also made of a ceramic material with suitable piezoelectric properties and exceptional performance. Many previous attempts to connect piezoelectric sensors in

Piezoelectric Transducer

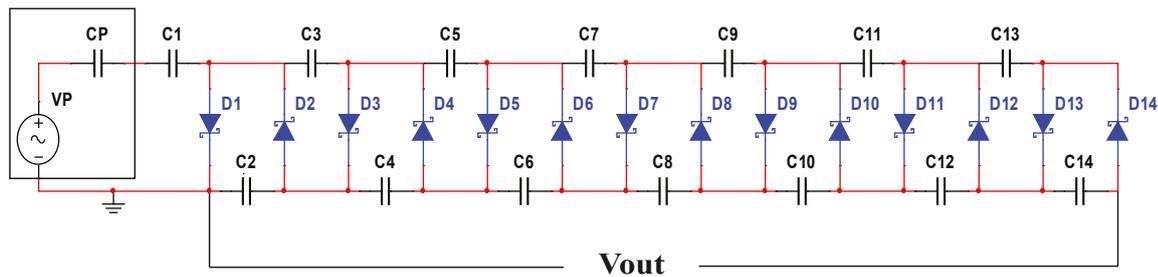


Figure 14: Multistage Villard multiplier circuit.

Table 4: Component used in AEH circuit.

Component name	Label	Value
Stage capacitors	C1 ... C14	22 μ F
Stage diodes	D1 ... D14	1N5817
Piezoelectric capacitor	C_p	20 nF \pm 30 %

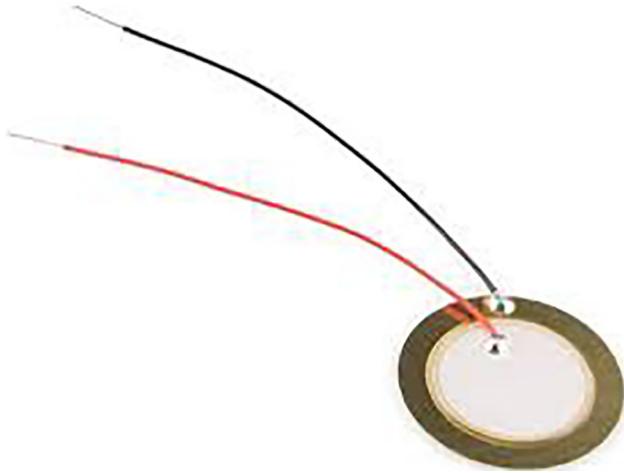


Figure 15: Piezoelectric sensor.

various ways resulted in unsatisfactory results until we arrived at the current form.

7 Results

This section provides extensive simulation results for the circuit in Figure 14 up to 7 stages, with equivalent values shown in Table 4, this circuit is used to collect acoustic waves.

When the piezoelectric sensor detects an input sound, it captures it and converts it into electrical energy, which is then measured and tabulated by the Villard multiplier stage. The higher the intensity or pressure of the sound, the more voltage that can be obtained. A system is set up with all of the necessary components to generate power using sound as an input.

The circuit used in the experiment is shown in Figure 16, and Table 5 shows the tabulation of output voltage to the respective Villard multiplier stage when using four piezoelectric sensors. The experimental results outperform the simulation results, as shown in Figure 17 due to the mathematical calculations used to determine the value of the VP of the piezoelectric sensor equivalent circuit. The VP value

used in the transducer circuit may vary as a result of these calculations.

The figure also shows an increase in output voltage as the number of stages in the voltage multiplier circuit is increased, followed by a decrease in output voltage at the third stage. The value of the circuit's output voltage is experimentally stable after the fifth stage, which is advantageous when using the circuit to charge the battery, whereas in the simulation results, the output voltage continues to increase by increasing the number of stages of the voltage multiplier circuit, then suddenly decreases at the fourth stage.

To improve the results, we increased the number of piezoelectric sensors used in our experiment to 8, and we found a noticeable improvement in the results for the first three stages only, while the results for the other stages did not improve, as shown in Figures 18 and 19. The results of using eight piezoelectric sensors with the Villard circuit are shown in Tables 6 and 7, and it is clear that the practical experiment results are better than the simulation results for the first two stages only, then the simulation results



Figure 16: The proposed circuit.

Table 5: Results in case of using four piezoelectric sensors.

Number of stages	Simulation_V _{Out} (V)	Experiment_V _{Out} (V)
1	1.245	2.2
2	1.921	3
3	2.005	2.45
4	1.518	2
5	0.603	1.903
6	0.296	1.69
7	0.211	1.655

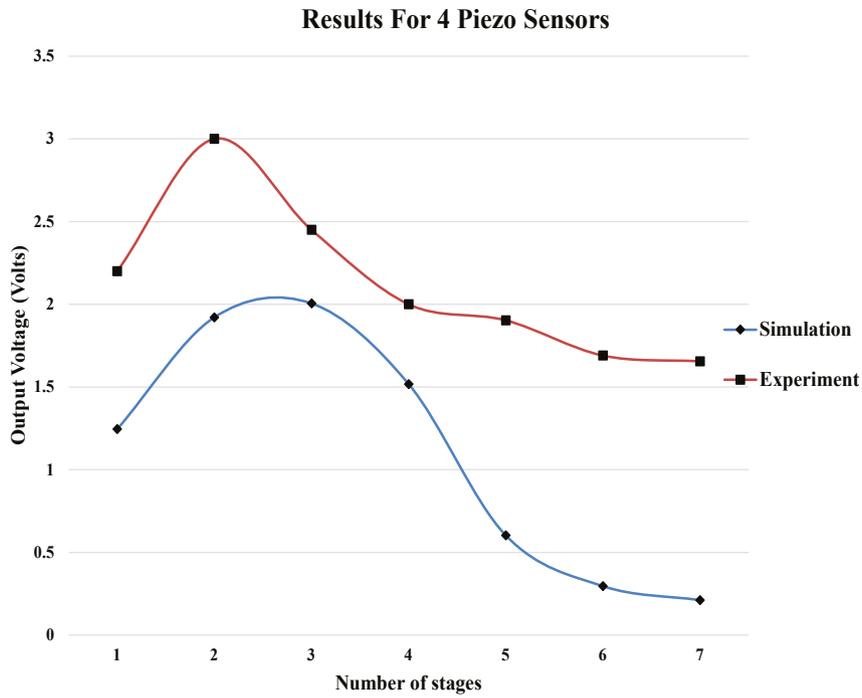


Figure 17: Results in the case of using four piezoelectric sensors.

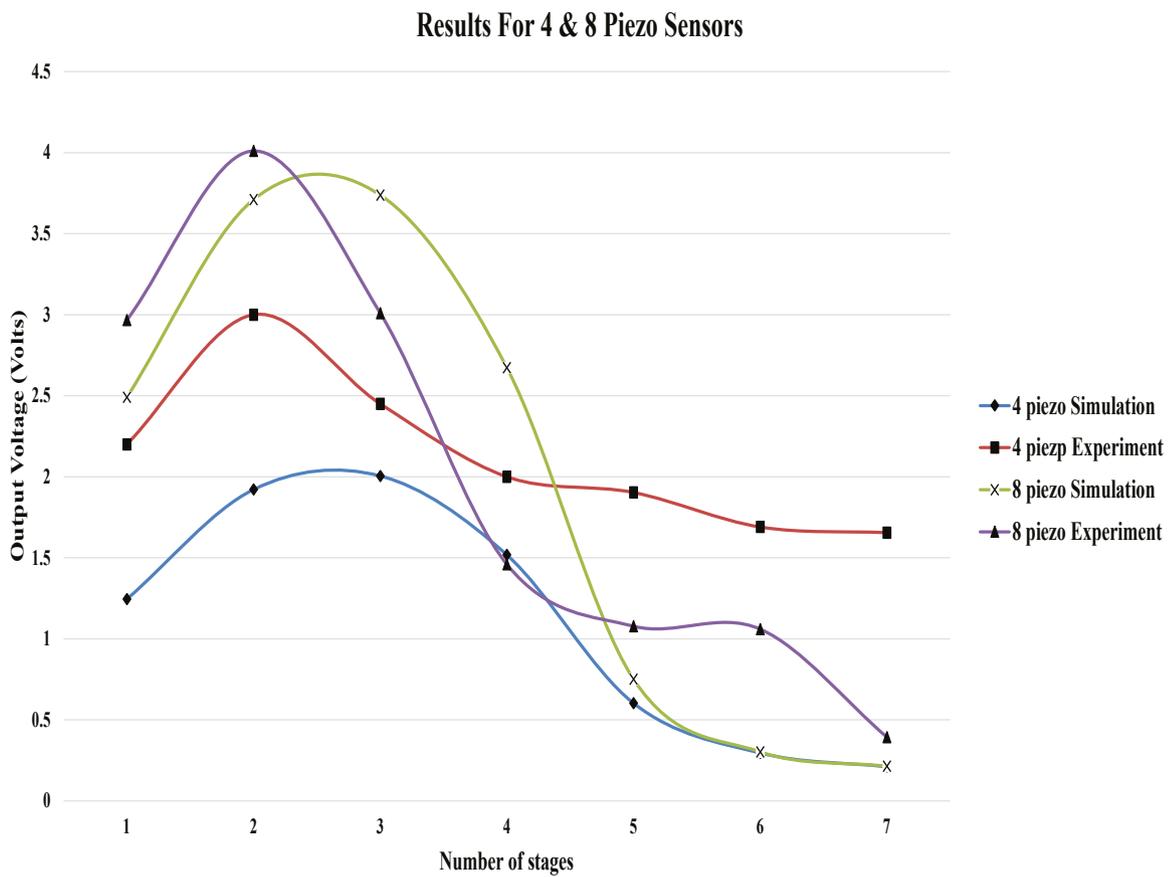


Figure 18: Results in the case of using four, and eight piezoelectric sensors.

Our_work Comparison

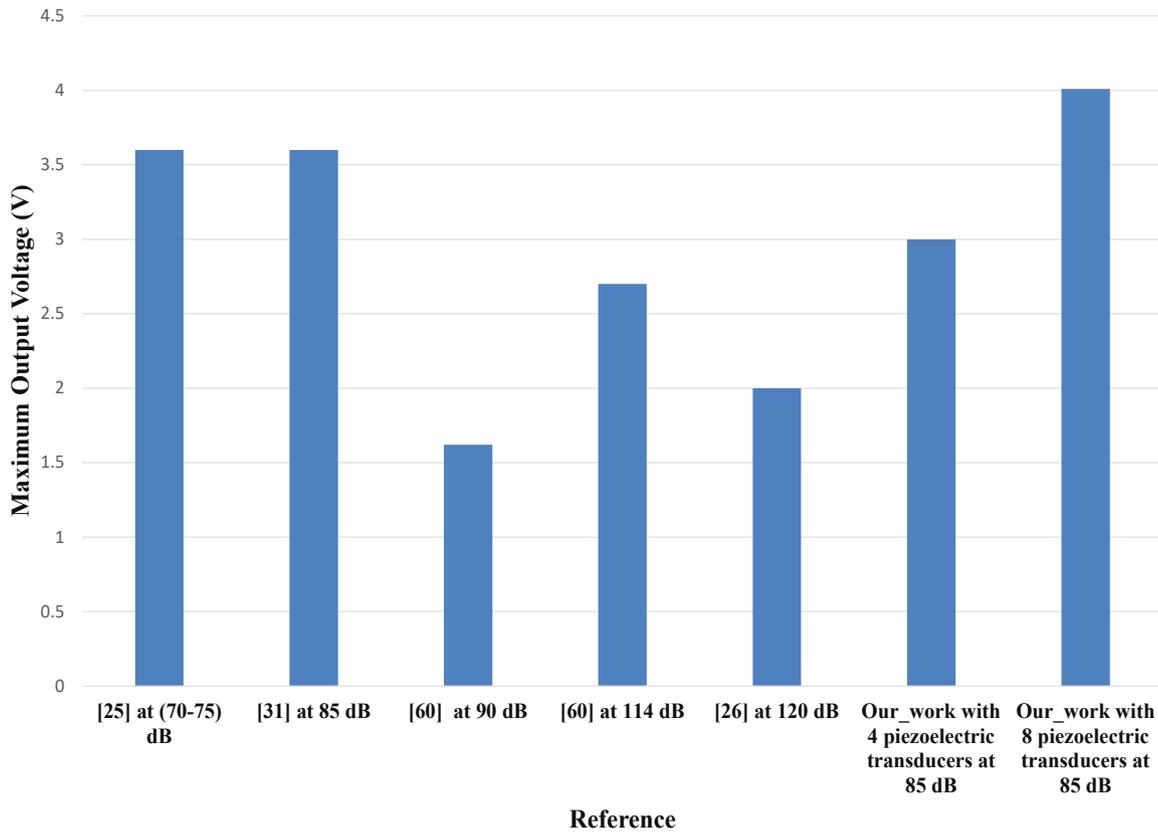


Figure 19: Our work compares with the other studies.

Table 6: Results in case of using eight piezoelectric sensors.

Number of stages	Simulation_V _{Out} (V)	Experiment_V _{Out} (V)
1	2.49	2.967
2	3.71	4.01
3	3.738	3.01
4	2.673	1.46
5	0.751	1.078
6	0.303	1.060
7	0.214	0.394

Table 7: Comparison with the other works.

Reference	Maximum output voltage (V)	Sound level (dB)
Chaithanya et al. (2021)	3.6	70–75
Selim et al. (2018)	3.6	85
Our_work with four piezoelectric transducers	3	85
Our_work with eight piezoelectric transducers	4.01	85
Garg et al. (2015)	1.62 (car horn)	90
Garg et al. (2015)	2.7 (motorbike silencer)	114
Ansari (2017)	2	120

improve for the next two stages, and finally preference returns to the practical experiment results for the final three stages.

Solar energy is the most important and best source of energy harvesting, but its effectiveness is heavily dependent on the amount of time spent in direct sunlight. Wireless waves, due to their low sensitivity, overcome this problem and are considered better than sound energy in this field; however, thousands of piezoelectric sensors must be used to obtain satisfactory results (Shafiq et al. 2022).

8 Future work

The piezoelectric impact concept’s power can be used to meet the needs of various wireless, low-power, self-sufficient systems. This piezoelectric system could be installed beneath railway tracks to generate electricity when a train passes over it. The energy generated by this system may be

significant due to the high force applied by the trains. This system could be used beneath a walkway to generate power every time people walk. This can be used anywhere there is a lot of mechanical pressure and noise in the environment that is being wasted.

9 Conclusions

The world is suffering from a scarcity of nonrenewable energy sources these days, and as a result, the world is concerned about not meeting the world's electricity needs. The best solution is to turn to the renewable resources around us in nature, and sound is one of the most undiscovered of these sources thus far. With a cost of around 31\$, this study presents an effective and less expensive system compared to existing solar energy. Acoustic energy was converted to electrical energy in this experiment by using the Panasonic SB-VK30 amplifier as a noise source and the piezoelectric model 7BB-27-4 as a transducer. We proposed a method that employs a Villard voltage multiplier with an 85 dB sound intensity level and a sound wave frequency of 4 kHz. We obtained satisfactory results using four piezoelectric sensors, which we improved by doubling the number of sensors, and we obtained the highest output voltage of 4.01 V, which is better than previous research results. The converted energy from this study can be used to power small devices such as cell phones.

Research ethics: Not applicable.

Author contributions: Basem M. Elhalawany and M. M. Elsherbini suggest the idea and steps of procedure R.G. Safiq and M. M. Elsherbini wrote the main manuscript text R.G. Safiq for testing and Measurements Noura Ali prepared figures All authors reviewed the manuscript.

Conflict of interest statement: Not applicable.

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