



# Energy Harvesting from Sound Waves Using Piezoelectric Crystals

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## ABSTRACT:

It is not possible to continue our way of life without energy. Renewable energy sources are very important in creating clean, cheap and sustainable energy.

The sound waves from the noise pollution of our everyday lives are constantly wasted. Thanks to the setup I built in order to collect the ambient noise, I was able to achieve 5 V of minimal but useful energy at an average of 80 dB. The setup that I have built is completely environmental because it produces no waste and requires no activation energy. It transforms the sound waves in the environment into electrical energy using piezoelectric crystals and is also able to store the energy.

To convert the energy carried by sound waves to electrical energy through the use of piezoelectric crystals and increasing the voltage values using an amplifier circuit. Hence, producing energy where the decibel of sound is high (classrooms, highways, subway roads, etc.)

In this project low current and voltage producing piezoelectric crystals were connected in a parallel circuit which contained a capacitor. Due to the existence of the capacitor the values for the current and the voltage have increased. The primary goal of producing usable energy from ambient noise has been achieved and enough energy to charge a phone that works with 1 ampere and 5 volt has been produced.

As the sound waves are in the environment 24/7, it does not require sunlight or a certain wind speed unlike the solar plants or the wind turbines. It is able to produce an electric current and voltage even at low volumes of sound. As the amount of the setup is increased the energy that is produced also increases so any equipment or battery that works with electricity can be used with it. This way clean energy can be produced without too much of a cost.

**Key Words:** Piezoelectricity, Sound volume, Renewable energy

## Introduction

### Piezoelectricity:

Piezoelectricity is using special crystals to convert mechanical energy into electrical energy. These special crystals become conductors when they are compressed. The crystal do not have a symmetrical lattice structure but they retain their neutrality. When they are compressed the unique lattice structure changes and the crystal gains a net charge. This can be used to convert sound energy into electrical energy. Sound waves are pressure waves which can rock and compress the crystal. They are also used in quartz watches as a tiny motor. (Woodford, C.) (Johnson Electric Company) (Mends, F.)

### Condenser Microphones:

Condenser microphones are used as studio or choir microphones. They can detect low and high sound frequency equally. They can detect dynamic sound sources in a better way. They are used especially for detecting volume levels below 60dB. This is their noise floor. Due to their low noise floor and a wide frequency range, they can pick up ambient noise well. They are much more sensitive than dynamic microphones. They are used for transforming acoustic energy into electrical energy. These types of microphones are made up of two plates that are close to one another. The plates are charged with voltage. The plate that detects the sound waves is called the diaphragm and the movement of the diaphragm changes the length between the two plates. This change in distance causes a potential difference and this difference causes an electrical current. However, the current is too small to be of use, so an external power source is needed to increase the power of the current. (Reasons to Use a Condenser Microphone)

### Piezoelectric Transducers:

Piezoelectric crystals convert physical quantities into electric signals through piezoelectric crystals. The voltage that is produces by the crystals can be easily measured. (Electrical4U)

## Formula of Electrical Power:

Current forms with the movement of the electrons. In the section of the conductor, which has to be perpendicular to the motion of the electrons, the amount of electrical charge that passes per unit time is the electrical current and it is denoted with the symbol I. If the amount of charge that passes during the differential amount of dt is dq, then the current can be found by using the formula  $I = dq \cdot dt$ . However, if the current is constant, dt and dq can be replaced with a constant t and a constant q. The formula can be rewritten as:  $I = q \cdot t$ . The unit of q is coulomb but in practical use this unit is not sufficient. Because of this reason Q, or ampere-hour, is used. The formula for Q can be written as  $Q = I \cdot t$ . It is important to note that t has to be measured in hours.

In order for the electrons to move in between two points, there needs to exist a potential difference between the points in question. Along with a potential difference, a force must be applied to the electrons. According to Coulomb's Law: a charge of +q applies the force F on a charge of +1C. This force can be shown by the formula:

$$F = \frac{q_1}{4\pi\epsilon_0 R^2}$$

F can be shown with the formula:

$$dW = F \cdot dL \cdot \cos(\alpha) = \frac{q_1}{4\pi\epsilon_0 R^2} \cdot dL \cdot \cos(\alpha)$$

However, the length of  $dL \cdot \cos(\alpha) = Ah$  is the projection of AA' in the direction of F and it is a differential quantity. When point O is the center of a circle and OA is the radius; point C which lies in the direction of F, can be considered to be at the same point as the projection h. According to this assumption,  $dL \cdot \cos(\alpha)$  can be rewritten as:  $Ah = AC = OC - OA$ . This equation can be further rewritten as:  $dL \cdot \cos(\alpha) = (R + dR) - R = dR$ . If this statement is used in the equation of work, then the formula becomes:

$$dW = dR \cdot \frac{q_1}{4\pi\epsilon_0 R^2}$$

As shown in the figure above, when a charge of +1C moves from A to B in an arbitrary motion, the work done can be found by taking the integral of  $dW$  according to the change of  $R$  from  $R_A$  to  $R_B$ . The formula of this can be shown as:

$$W = \int_{R_B}^{R_A} \frac{q_1}{4\pi\epsilon_0 R^2} = \frac{q_1}{4\pi\epsilon_0 (R_A - R_B)}$$

According to this formula, it can be deduced that the work is dependent on the distance between  $R_A$  and  $R_B$  instead of the line of motion.

Some of the potential energy between the charge of +q and the charge of +1 is lost as the unit charge moves from point A to point B. This will lead to a difference of potential energy between the two points and this can be shown with the equation below:

$$W = \frac{q}{4\pi\epsilon_0 R_A} - \frac{q}{4\pi\epsilon_0 R_B}$$

If the potential energies are represented with  $U_A$  and  $U_B$  respectively, the work done can be show with the following equation:  $W = U_A - U_B$ .

The potential energy of a charge q is

$$\frac{q}{4\pi\epsilon_0 R^2}$$

However, this statement is derived by the integration of

$$-dR \cdot \frac{q}{4\pi\epsilon_0 R^2}$$

and since indefinite integrals are in question an integration constant,  $K$ , must be added to the statement. But due to the fact that the potential difference between two points is in question, the  $K$  constant becomes negligible.

When the derivative of the potential energies, which are denoted with  $U$ , are taken and the

$$dR \cdot \frac{q}{4\pi\epsilon_0 R^2}$$

relationship is considered the equation of

$$dU = -dR \cdot \frac{q}{4\pi\epsilon_0 R^2} = -dW$$

can be found.

In order to find the work done by the unit charge between points A and B, the equation of

$$W_{AB} = dW = U_A U_B - dU$$

must be calculated. If the charge which does the work has the charge of  $Q$  instead of +1, the work done will be  $Q$  times as large. Thus, the work done can be expressed by

$$W = Q(U_A - U_B)$$

If a charged system is left on its own, the electrostatic forces will move in their own directions and do positive work. In this case, in order for the work done to be positive, the coefficients of  $Q$  and  $(U_A - U_B)$  must have the same signs.

Since the ground is considered to be a sizeable conductor, the potential energy is the same at all points. In this case, the constant potential energy of the ground can be considered as zero and the other potential energies can be evaluated according to this zero. If the work done by a charge of 1 coulomb, when moving in between two points, is equal to 1 joule; then the potential difference of these two points must be 1 volt. This can be deduced from the work formula.

In the expression of the work done, the difference of  $(U_A - U_B)$  is usually denoted with  $U$ . Hence, the work formula can be expressed as

$$W_{joule} = Q_{coulomb} U_{volt}$$

Since the potential difference the charge of q experiences is  $U$ , and since

$$Q = I \cdot t$$

the work can be expressed as

$$W = U \cdot Q = U \cdot I \cdot t.$$

The formula for power is

$$P = W \cdot t.$$

If the expression for work is substituted in this formula, it will be rewritten as

$$P = U \cdot I \cdot t \cdot t = U \cdot I$$

(Ergeneli, A. (1972))

**Method:**

The Equipment Used to Setup a Lab Experiment and Data Collection:

- Piezoelectric ceramic circuit element 25 mm.
- LM 358 integrated circuit element
- 100 nf capacitor
- 1k, 3k, 9k, 10k, 100k, resistors
- Decibel meter (Frequency range: 31.5Hz – 8kHz Measuring Stage: 30dB ~ 120 dB)
- Multimeter (Voltage, Resistance, Continuity, Capacitance)
- Source of Sound (Vernier LabQuest 2 – 100-2000Hz)
- Computer for recording data
- 3D Printer and filament
- Extension clamp: used for positioning the circuit elements
- 100cm ruler: used to measure the distance between the circuit elements

The method has been split into two parts: setup and data collection:

1. Setup

- The circuit shown below is established with the circuit elements
- Wire connection is established through piezoelectric crystals.
- Piezoelectric crystals are connected in a parallel circuit.
- Parallel connected piezoelectric crystals are connected to the capacitor.
- A hexagonal echo box for amplifying sound is printed using the 3D printer.
- Piezoelectric crystals are fixed inside the box.
- A multimeter is connected to the other end of the capacitor.
- Sound waves of different frequencies and decibels are sent into the echo box and measurements are made.

**Data Collection:**

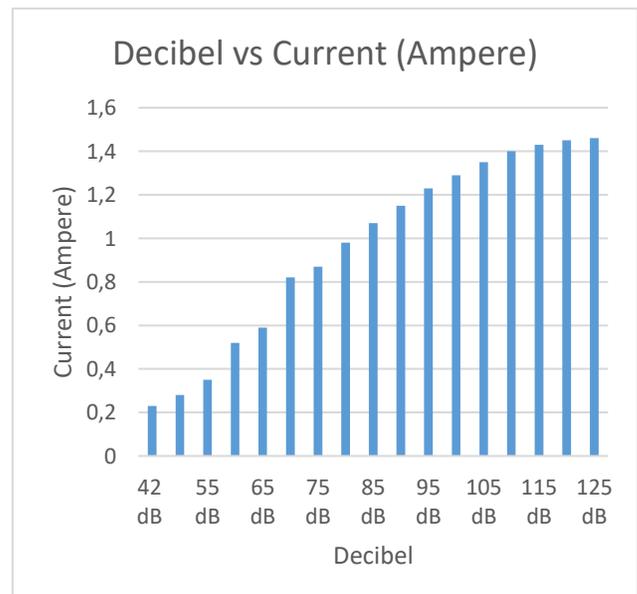
Sound waves of different frequencies and decibels were sent onto the piezoelectric crystals and the voltage with the current was measured.

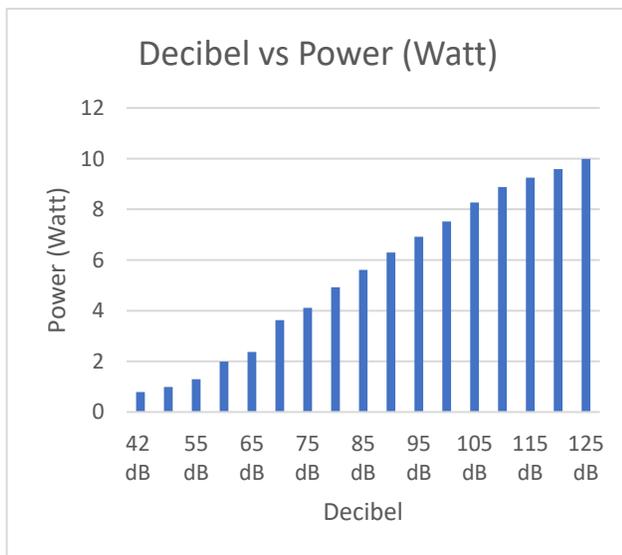
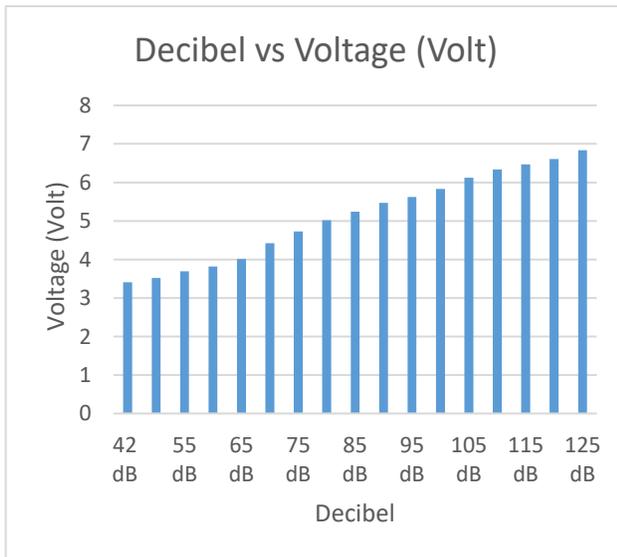
All the collected data is in the table shown in the findings section.

The experiment was carried out in a closed lab environment. Since the lab itself was located underground, it was isolated from potential outside sound waves. The decibel of the environment under normal conditions were measured to be 42-45 dB. By minimizing all the factors that could have caused an error in the measurements, the working area was standardized for every experiment.

The Collection of Data:

	Current Produced (Ampere)	Voltage Produced (Volt)	Power (Watt)
42 dB	0,23	3,41	0,7843
50 dB	0,28	3,52	0,9856
55 dB	0,35	3,69	1,2915
60 dB	0,52	3,82	1,9864
65 dB	0,59	4,01	2,3659
70 dB	0,82	4,42	3,6244
75 dB	0,87	4,73	4,1151
80 dB	0,98	5,02	4,9196
85 dB	1,07	5,24	5,6068
90 dB	1,15	5,47	6,2905
95 dB	1,23	5,62	6,9126
100 dB	1,29	5,83	7,5207
105 dB	1,35	6,12	8,2620
110 dB	1,40	6,34	8,8760
115 dB	1,43	6,47	9,2521
120 dB	1,45	6,61	9,5845
125 dB	1,46	6,84	9,9864





## Results and Discussion

The results of our experiment can be summarized as follows:

1. A change in decibel directly affects the current and voltage produced by the piezoelectric materials.
2. An increase in decibel has also caused an increase in the values for voltage and current.
3. The direct proportion between the decibel and the power increases the usability of energy created in areas where the decibel is measured to be high.
4. The values for voltage and current have become usable in the everyday volume of 60 to 90 dB. These values are enough for charging a phone that works with 1

ampere and 5 volt. These values show that charging reusable batteries is possible.

In this project low current and voltage producing piezoelectric crystals were connected in a parallel circuit which contained a capacitor. Due to the existence of the capacitor the values for the current and the voltage have increased. The primary goal of producing usable energy from ambient noise has been achieved and enough energy to charge a phone that works with 1 ampere and 5 volt has been produced.

By increasing the amount of circuits and circuit elements contained within the hexagonal echo box, it is possible to obtain usable energy from environments where there are constant sources of sound waves. These environments include but are not limited to: classrooms, train tracks, highways, airports, etc.

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