Method and Application of Piezoelectric Energy Harvesting as a Mobile Power Source

Research and Design

by

Ryan [redacted]

[redacted]

May 2013

[redacted]

Table of Contents

*This piezoelectric energy harvesting unit was created to meet
the requirements for completion of the Advanced Placement Physics course
at* [redacted]

Special thanks to

Mark [redacted]
Eric [redacted]
Michael [redacted]

Goal

The intent was to create a mobile power source powered by walking, using piezoelectric disks to utilize the piezoelectric effect.

Abstract

A mobile power source was created using piezoelectric disks which utilize the piezoelectric effect. The piezoelectric effect in this particular experiment uses the available mechanical energy of walking. As a user walks, two plates are pressed together which cause rods to impact and physically deform the piezoelectric transducers, therefore creating an electrical output via the piezoelectric effect. This electrical output travels to a load circuit which in this case is 12 LEDs. The output is about 60V and only a few milliamps. Mathematically, the output should be roughly 400V and 100mA, though this was not achieved with the implemented circuitry. The electric output is an AC waveform and is therefore passed through a full-wave bridge rectifier before continuing to the load. The LEDs are all illuminated brightly with a single impact of the piezoelectric transducers.

Introduction

After the AP Physics test, there are a few weeks left of school but the AP Physics curriculum has been completed. As a result, it was decided that student would participate in a research project that demonstrates one or multiple concepts learned throughout the course. Piezoelectric energy harvesting of course involves multiple concepts including simple mechanics, electricity, and a little bit of material science (chemistry). A piezoelectric energy harvester would be built with the idea of creating a mobile power source in the form of a shoe.

This paper is a summary of work and presents informational pieces from research as well as the assembly process and discussion of the unit itself. The beginning of the paper is mostly discussion of piezoelectric theory and functionality. Following are some applications of piezoelectric materials, including some related experiments. The next section of the paper is unique to the unit built for this experiment including material lists and the assembly process, as well as a discussion of the project as a whole. Near the end are some possible future applications of this research and piezoelectric energy harvesting in general. Concluding the paper is a table with download links of both project files and resource files that were used for this research.

Piezoelectric Theory

Introduction to Piezoelectric Functionality

Piezoelectricity translates to "electricity from pressure." The prefix *piezo* in Greek means to press or squeeze. Piezoelectric materials exhibit the piezoelectric effect. This allows a mechanical force to be applied to the material to deform it slightly and the material will produce an output electric power. This is done by rearranging the dipoles of the piezoelectric material. This rearrangement causes a change in the dipole density and therefore a change in the electric field between the dipoles. Because of this change in the electric field, the piezoelectric material produces an output electric power. This is explained visually in *Figure 1* to the right by examining the piezoelectric effect in a Quartz crystal and its atoms of silicon and oxygen.

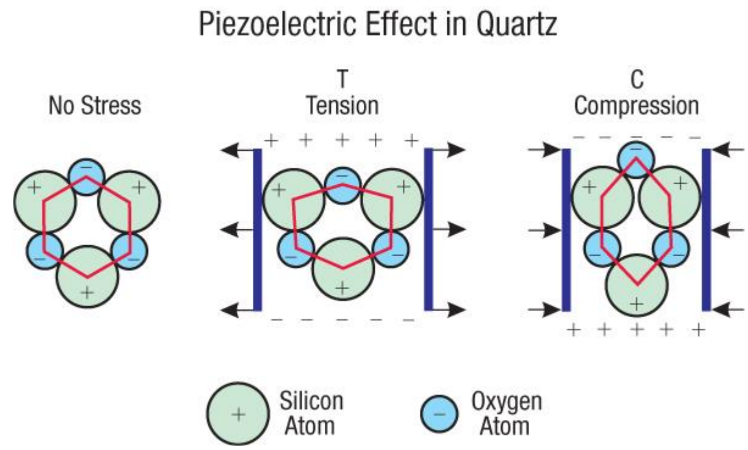

Figure 1 - The piezoelectric effect as observed in Quartz. The movement of the silicon and oxygen atoms due to mechanical stress creates a change in the electric field, producing an electric output.

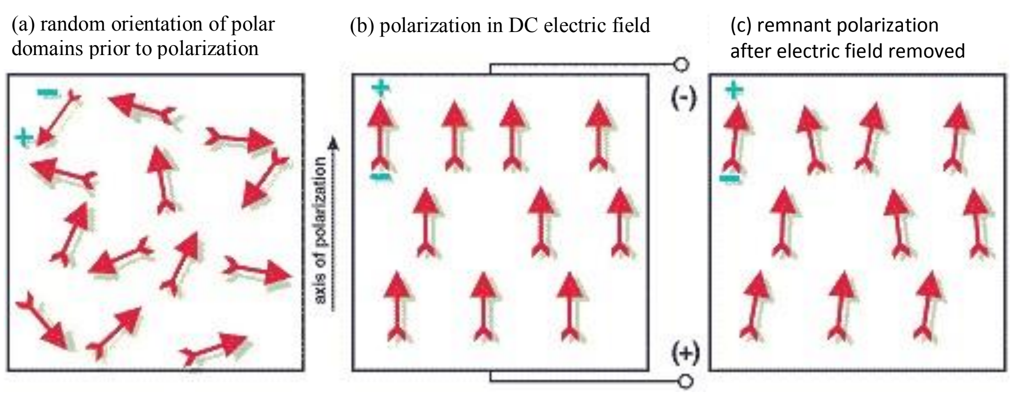

Figure 2 - Polarization of piezoelectric materials.

The Piezoelectric Effect – A Brief History

The piezoelectric effect is the electromechanical relationship that allows certain materials such as crystals and synthetic ceramics to produce an output power due to a mechanical stress as well as produce a mechanical force as a result of an electric input. This concept was first demonstrated by Pierre and Jacques Curie in 1880. These brothers found the mechanical to electrical process of piezoelectricity, but they were unaware of its reversibility (which is discussed further in the next section). This reversibility was found mathematically in 1881, where the Curie brothers quickly confirmed these thermodynamic calculations experimentally.

Reversibility of Processes

One of the reasons piezoelectrics are so interesting is because their functionality can be reversed. Piezoelectric materials can be used in a mechanical to electrical process or the reverse, electrical to mechanical. This is particularly interesting when comparing with other processes as this reversibility is not a possibility. Observe a simple and common object like a space heater for example. Electricity can be used to produce heat, but using the same object, heat cannot be used to produce electricity. Electricity can be passed through piezoelectric materials which will cause a physical deformation of the material. Additionally, mechanical energy can be used to deform the material and therefore produce an output current. This reversibility is one attribute of piezoelectric materials that makes them interestingly unique.

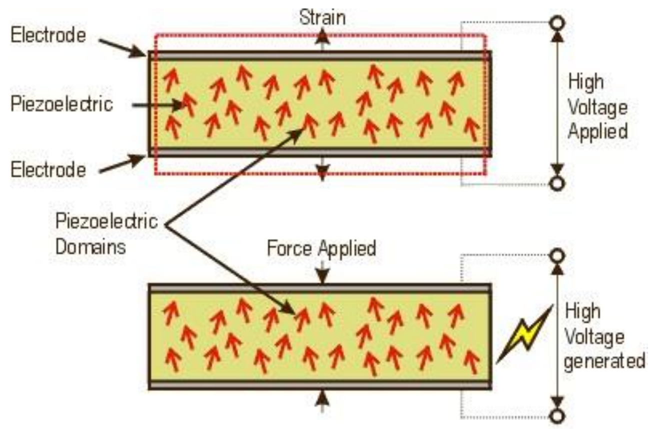

Figure 3 - The piezoelectric effect is a reversible process. Mechanical energy can be applied which will produce an electric output. An electric input can be applied and the piezoelectric material will have a mechanical output.

Common Piezoelectric Materials

There are a wide variety of materials that have piezoelectric properties. Some of these materials are natural, while others are synthetic. The functionality of natural versus synthetic materials is not arguably differentiable as very efficient synthetic materials can be created, matching properties of natural materials.

<u>Natural Materials</u>

The most efficient and effective natural piezoelectric materials are crystals. Specific crystals include quartz, berlinite, which has the same atomic structure as quartz, and topaz. Additionally, sodium, or table salt, is a popular natural piezoelectric material. In fact, a piezoelectric material called Rochelle salt (sodium potassium tartrate tetrahydrate) can be made using sucrose and cream of tartar, along with an extensive process of baking and cooling. Another natural piezoelectric material is bone. There are some very interesting medical texts about this. Lastly, a few other natural materials are wood, silk, and DNA.

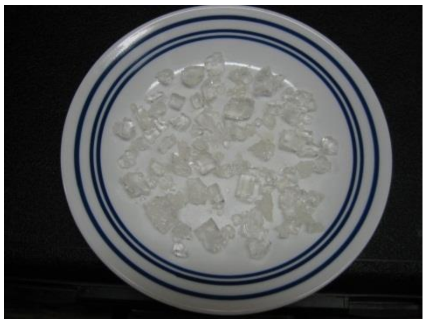

Figure 4 - Rochelle salt crystals.

<u>Synthetic Materials</u>

There are a multitude of synthetic piezoelectric materials. Most of these synthetic materials are ceramics, though there are some synthetic piezoelectric crystals. One of the most popular synthetic piezoelectric ceramics is lead zirconate titanate which is most commonly called PZT. (PZT is the ceramic that is used in this particular piezoelectric energy harvester). Other popular synthetic ceramics are zinc oxide and barium titanate.

Related Work

JR East Railway Corporation

JR East – The East Japan Railway Company had tested piezoelectric energy harvesting in 2008. A floor mat was made with an array of piezoelectric disks, roughly the same product used in this piezoelectric energy harvester. These mats were placed in the automatic ticket readers so that passengers would walk on them when they scanned their train tickets. Roughly 10,000 watt-seconds were produced per day from the installation of these piezoelectric floor mats in only 6 ticket gates. This is not a huge amount of electricity, but if the mats were placed in all ticket gates, could be enough to contribute to the power requirements of the train station such as lighting and power for ticket gates.

Figure 5 - Power generating mats in a JR East railway station.

Sustainable Club – Rotterdam

A dance club called Club Watt in Rotterdam, Netherlands, is the first sustainable dance club of its type. They have installed an energy harvesting floor which contributes to a good portion of the club's electrical needs. The floor does not use piezoelectricity, but a similar method is utilized for the conversion of mechanical energy to electricity. [5]

Common Uses for Piezoelectrics

Buzzers

One of the common uses for piezoelectric disks is the function of a buzzer. The buzzing is caused by running an electric current through the piezoelectric disk which causes it to vibrate at a frequency related to the magnitude of the current. These buzzers can be used as alarms or other alert devices. Additionally, they can be speakers, so music can actually be played using these piezoelectric disks. This is an interesting application when considering the reversibility of the piezoelectric effect. When a certain current is applied to the disk, it vibrates at a certain frequency. For the inverse, if the disk were to vibrate at the same frequency as the previous case, the same current that was applied before would be created by the piezoelectric disk. This is a remarkable aspect of the reversibility of the piezoelectric processes.

Figure 6 - A piezoelectric buzzer.

Sensors

A major use of piezoelectric materials is sensing. The materials are extremely sensitive – a deformation of 0.1% can produce a significant enough current to be measured. Using these devices, sensing very slight movements and vibrations can be done with ease, as the output power is proportional to the physical deformation or the vibrational frequency of the piezoelectric material. Due to this capability, piezoelectric sensors are widely used throughout the manufacturing industry. They are particularly prominent in vibrational testing in the automotive industry, as well as the manufacturing and testing of engines. The image to the right is how most piezoelectric sensors are made and used.

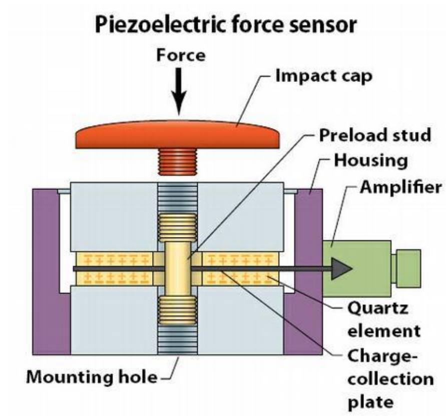

Figure 7 - A common piezoelectric sensor.

Motors

Piezoelectrics can be used as precision motors. In manufacturing, they can be used to move loads very accurate distances. When a certain electric power is applied to the disks, they bend a certain amount. The same concept applies to other forms of the piezoelectric materials, such as film-like strips. When power is applied to these strips, they bend. This bending can be used to lift something a very small and precise distance, or similarly for moving something in a horizontal direction with precision. [1] A method like precision bending can allow extreme accuracy in the manufacturing process.

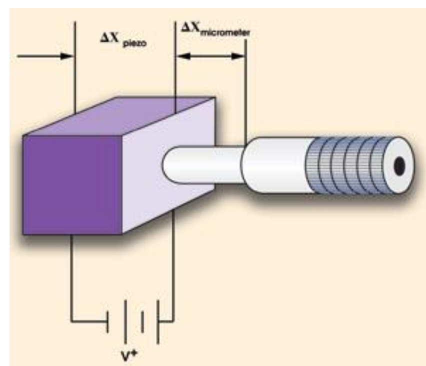

Figure 8 - A piezoelectric motor. When a voltage is applied to the piezoelectric element, it expands some distance X, where it therefore also moves some object a distance X.

Acoustics and Recording

Another common use for piezoelectric materials, specifically the disk form, is a contact microphone for recording. These disks can be placed on the body of an acoustic guitar or other acoustic instrument. When the guitar is played, the vibrations cause the piezoelectric disk to vibrate which is then turned into an electric current. This output can then be read by recording software and translated into sound. This recording method is also commonly used by drummers. The disks are placed on the drum pads and record the vibrations. They can also be used for precision tuning of any acoustic instrument.

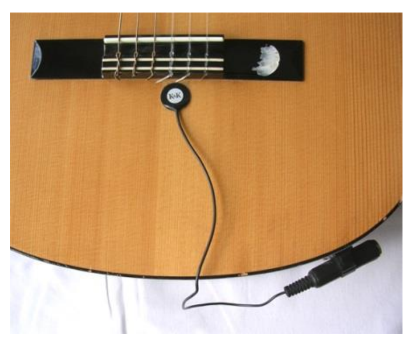

Figure 9 - A piezoelectric contact microphone. These can be used on any acoustic instrument for recording or tuning.

Materials and Tools List

Materials

Item	Seller	Quantity	Link
41mm piezoelectric disks	C.B. Gitty	18	Link
MDF board or other flat wood	Hardware store		
Full-wave bridge rectifier	RadioShack, or build one	1	Link
1/4 inch x 6 inch carriage bolt	Hardware store	4	
1/4 inch hex nut	Hardware store	8	
1/4 inch washer	Hardware store	32	
1/4 inch x 3 inch hex bolt	Hardware store	8	
3/8 inch washer	Hardware store	4	
Screws (must fit in impact rods)	Hardware store	18	
100Ω resistor	Tayda Electronics	1	Link
SPDT switch	Tayda Electronics	1	Link
Compression spring (~40-50lbs each)	Hardware store	4	
LED (optional)	Tayda Electronics		
USB Type A (Female) (optional)	Tayda Electronics	1	Link
Linear Regulator (if using USB)	Tayda Electronics	1	
22-gauge wiring	RadioShack		
3D printed parts		26 pieces	

Tools

- 3-axis CNC Router
- 3D printer
- Soldering iron
- Hot glue gun
- Socket wrench
- Multi-meter
- Alligator clips
- Wire cutter and wire stripper

Software

- AutoCAD 2013
- Multisim 12.0

Assembly Process

1. **Decide what size the unit should be. Draft it in a CAD program, both in 2D and 3D.** When drafting, be sure to know the size of the piezoelectric disks that will be used. Consider spring placement and sizes of springs. The springs that were used in this unit were about 1.5cm in diameter. Think ahead to all aspects of design from disk placement, spring placement, to where guide bolts will be placed and connecting bolts will be placed. Also think about wire management. The wires can sit next to the disks, but it doesn't look neat and clean. It will be helpful to see all of this digitally when it comes to assembling the unit.

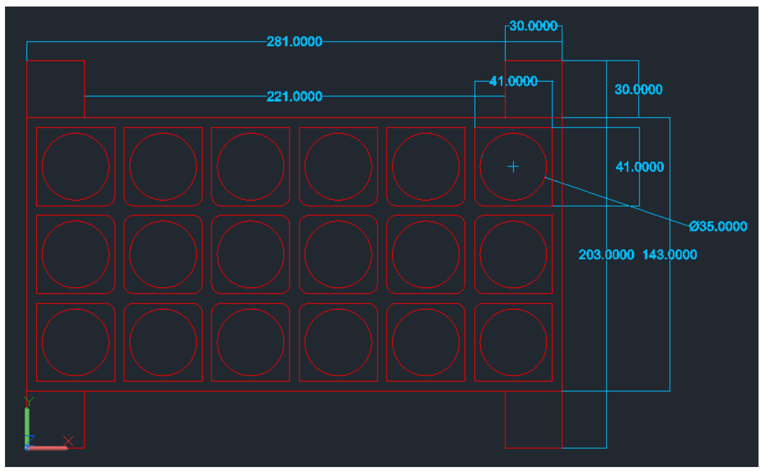

Figure 10 - Base plate drafted in AutoCAD - 2D.

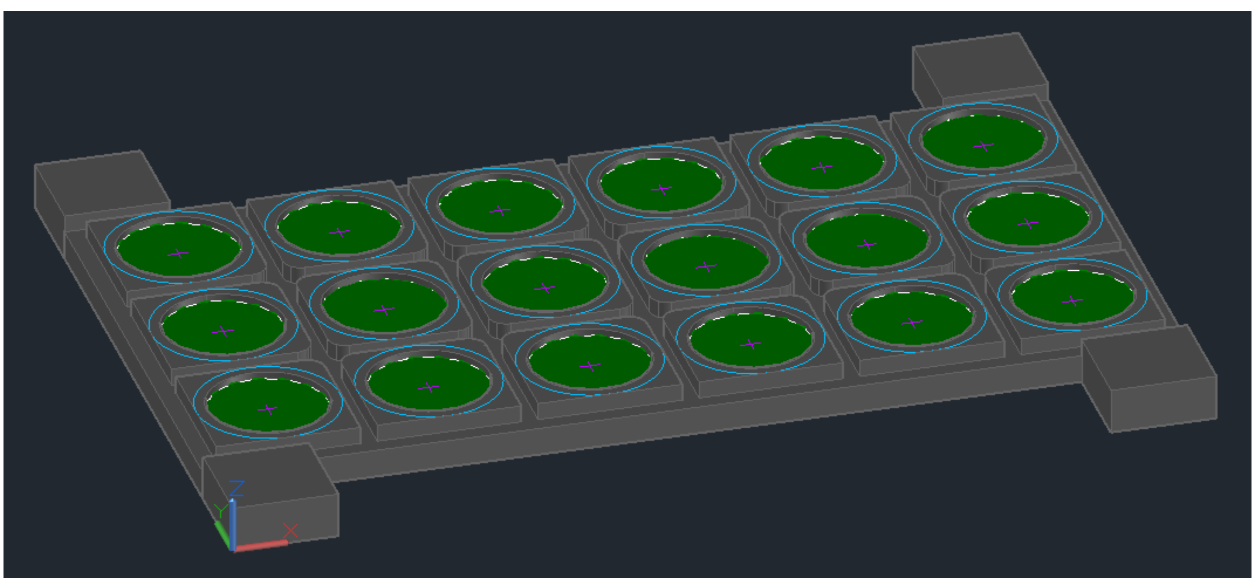

Figure 11 - Base plate drafted in AutoCAD - 3D. Blue circles represent the piezoelectric disks. Purple crosshairs are centers of circles. Green area is 2mm deep. Troughs are 5mm deep.

2. **Draft the stoppers and holders and impact rods.** These will need to be created in a 3D program such as AutoCAD or equivalent, as they need to be made with precision. They will be exported to a 3D printer. One impact rod will be needed for every disk used, and the stoppers and holders will be needed for each spring. The stoppers and holders must be a cup shape and one will be needed for the top plate and one for the bottom plate. The cup shape is used to hold the spring in place. The additional function of these holders is to act as a stopper for the descending top plate so that the impact rods do not deform the piezoelectric disks to their fracturing point. The impact rods were made 1mm longer than the sum of the length of the top and bottom stoppers and holders. This allowed the impact rods to deform the piezoelectric disks 1mm, which is a safe and highly effective deformation distance for the disk elements used in this model.

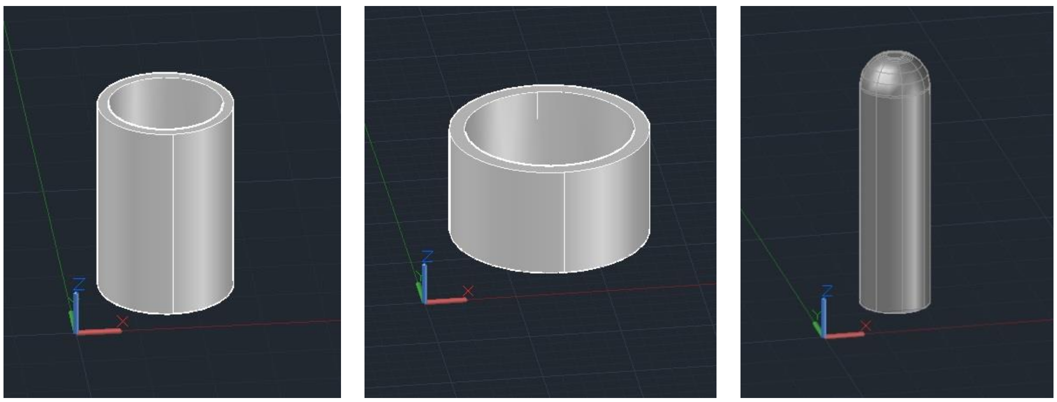

Figure 12 - Left: Base spring holder and stopper. Center: Top spring holder and stopper. Right: Impact rod.

3. **CNC the top and bottom plates.** MDF board was used since it can be purchased flat, while other boards can be slightly warped. The CNC machine requires likely either a .dwg or a .dxf file to be loaded into software to create a tool path. The entire plate was milled – from the details to the actual cutting of the edges. It would be advantageous to have the holes for screws and bolts drilled with the CNC as well, as this would greatly increase the accuracy of the holes. After the boards are cut out, be sure to sand the insides of the troughs and holes if the CNC did not make them very flat. Higher end CNC machines will likely take care of this for you.

4. **Assemble and test the mechanical assembly.** (See Figure 18 on page 15). Attach the spring holders and stoppers to the plates. Holes must be drilled in them first to allow the bolts through. Place one 1/4 inch washer on the 1/4 inch by 3 inch bolt before putting it through the plate. Once through the plate and the cup, place a 3/8 inch washer on the bolt and then another 1/4 inch washer, followed by a nut. Do this for each of the 8 cup bolts. Tighten lightly with a socket wrench. Place a spring in each holder and stopper, then place the top plate on the springs making sure that each spring is sitting in both a bottom and top part of the holders and stoppers. Put two 1/4 inch washers on each of the 1/4 inch by 6 inch carriage bolts. Place the carriage bolts in the corner holes of the top and bottom plates, inserting them up through the bottom plate and then through the top plate. Place two more 1/4 inch washers on the carriage bolt and then a nut on each. Tighten so there is about 1 inch of space between the washers and the end of the carriage bolts.

5. **Attach the impact rods.** The unit will have to be disassembled to do this. Be sure to drill small holes in the impact rods before trying to screw them in. If the holes for the screws were not drilled with the CNC, a printout of the 2D CAD file with circle centers marked will have to be taped to the top plate. This will allow for relatively accurate holes to be drilled manually. Screw in all of the impact rods.

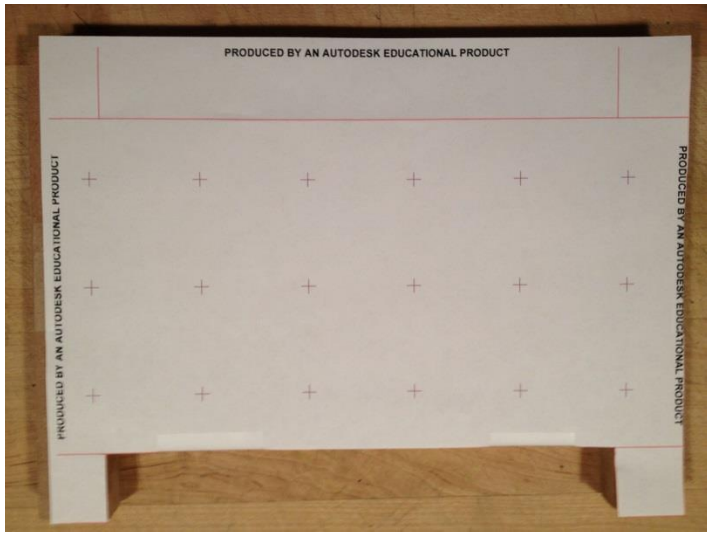

Figure 13 - Printed 2D CAD drawing with circle centers marked. Used for drilling screw holes for the impact rods.

6. **Solder all of the piezoelectric disks in parallel.** It was found to be much easier to solder 3 elements together at a time, leaving 6 groups of disks wired in parallel. Then solder these groups in pairs, leaving three groups of six piezoelectric disks. Lay these three groups out how they will appear on the base plate, and then solder them together. Lastly, solder two longer wires to the end of the disk circuit. These will be the output wires to the load circuit. Note that the leads on the disks are very fragile and will break with too much tugging. Work carefully to avoid a lot of wire stripping and re-soldering.

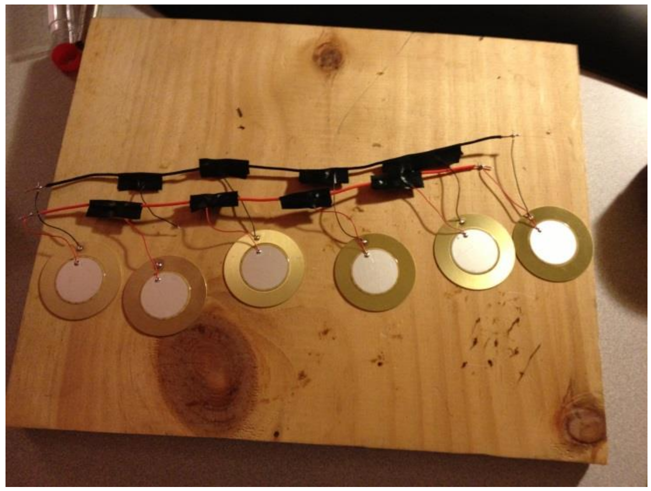

Figure 14 - Solder all the disks in parallel. Apply electrical tape.

7. **Apply electrical tape to the solder joints.** The wires will be very close together in the unit and can move easily. Applying a small strip of electrical tape over each solder joint will ensure isolation and prevent any shorts.

8. **Test the circuit.** Before adhering the disk circuit to the base plate, test the circuit with a multi-meter. Be sure to test each individual disk for an output voltage. Simply tap on them and there should be some voltage. Doing this will ensure that each disk is connected properly in the circuit and that there are no faults in the circuitry.

9. **Hot glue the piezoelectric disks to the base plate.** Apply a small dab of hot glue to four sides of the circles on the base plate. Press the disk down on the hot glue. Repeat for all of the disks. It is easier to start with the middle disks as wires begin to get in the way quickly. Be careful with the wires as well, as they can break off easily – no hard tugs! Use a piece of wire or other means to tie or attach the center circuit wires to the spring holders and stoppers. This will keep them out of the way of the impact rods.

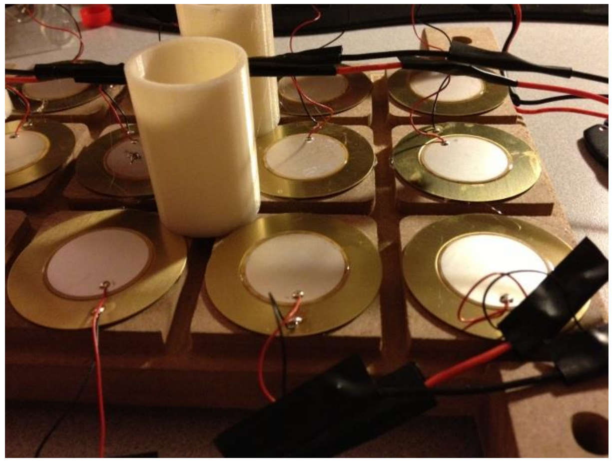

Figure 15 - Hot glue the disks to the base plate.

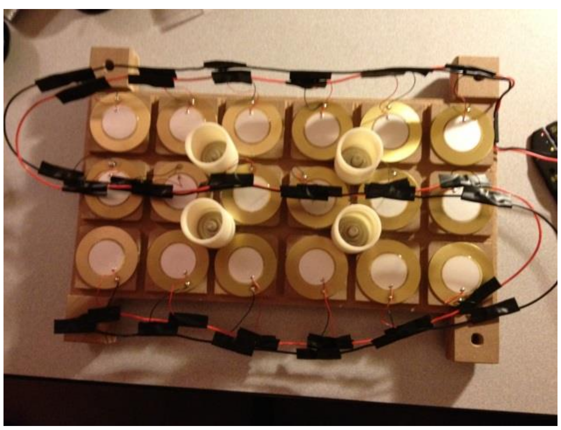

Figure 16 - Circuitry viewed from above.

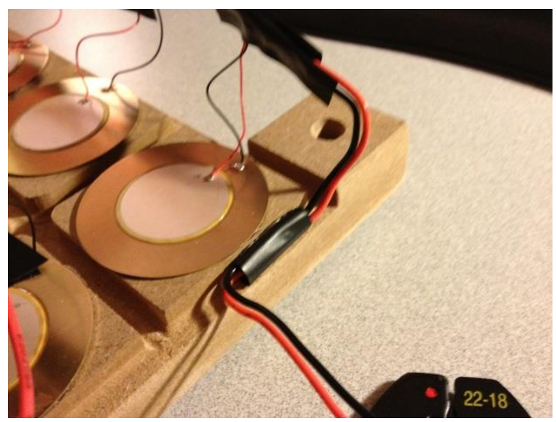

Figure 17 - Output wires.

10. **Assemble the unit and test it.** Put the top plate back on. Connect the output wires to a multi-meter and test the unit. Make sure it slides smoothly and that the wires are not in the way of the impact rods.

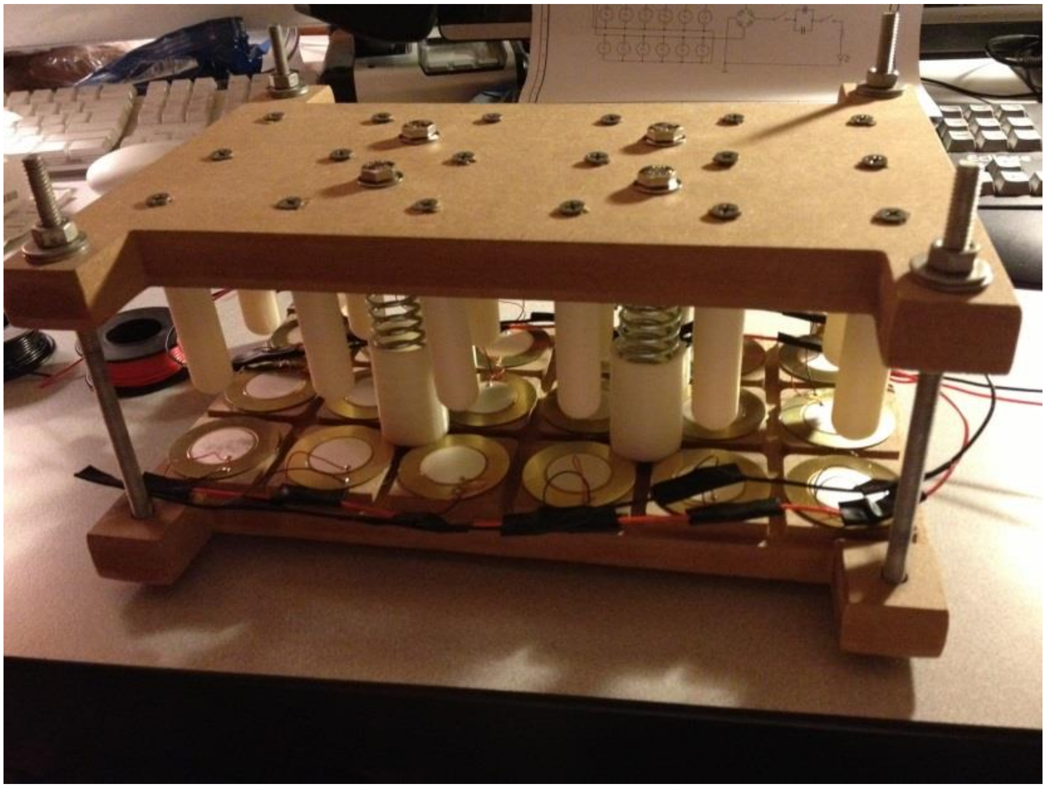

Figure 18 - The final piezoelectric energy harvesting unit.

11. **Build a load circuit.** This can be anything, though LEDs provide a quick and satisfying demonstration of piezoelectric energy harvesting. The load circuit used in this project included 12 LEDs wired in parallel. One of the most important pieces of the load circuit is a full-wave bridge rectifier. A full-wave bridge rectifier flips the negative voltage spike and makes it a positive spike. This will be needed if capacitors are a part of the load circuit. The output power is also doubled when using a full-wave bridge rectifier. A half-wave bridge rectifier would also work, but the power would be half of what a full-wave would provide. Additionally, depending on what the load circuit involves, capacitors could be used for storage or voltage regulation, and linear regulators could be useful for voltage regulation.

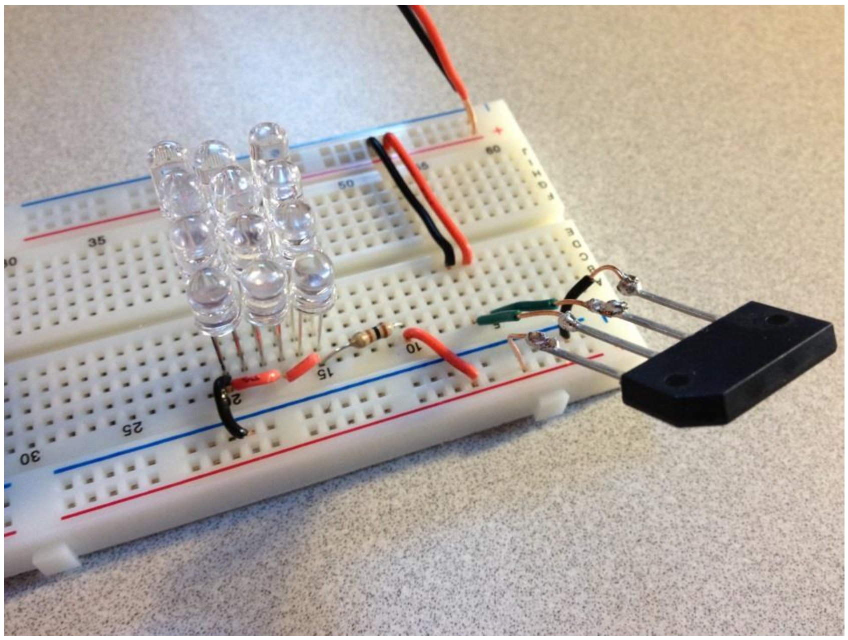

Figure 19 - The load circuit. The ouput wires from the unit are in the top right of the breadboard. The black object is the full-wave bridge rectifier. Resistor is 100ohms, but this will vary depending on your load circuit and the total output from the device. (Use basic electric equations to figure out what resistance to use: P=IV, V=IR, $P=I^2R$…). The LEDs are wired three rows in series, with each containing 5 LEDs in parallel.

Discussion and Conclusion

A mobile power source was created using piezoelectric disks which utilize the piezoelectric effect. The piezoelectric effect in this particular experiment uses the available mechanical energy of walking. As a user takes steps, two plates are compressed together which causes rods on the top plate to impact piezoelectric transducers on the bottom plate. These transducers produce an output in the form of electricity. This output electrical power is wired to a load circuit where it can be used to provide power for any low-power consumption device.

The process began with extensive research on the piezoelectric effect and piezoelectric materials. About two weeks were initially spent researching how piezoelectric materials work and how to obtain them. Many companies were found to produce piezoelectric materials, though most efficient materials are quite expensive. Cheaper materials are much less efficient, but will still work to demonstrate the concept of piezoelectric energy harvesting. Also, it is important to understand how the piezoelectric effect works in order to properly harvest all possible energy from the piezoelectric transducers.

An important understanding of the piezoelectric effect is that these transducers produce an AC waveform. When they are impacted, they produce a negative voltage spike, and when the impacting material is lifted, an equal and opposite (positive) voltage spike is produced. One way to utilize this power effectively is to use a full-wave bridge rectifier. This will take the negative voltages and flip them to be positive. Now the voltage is all positive, but not a smooth DC form. Following this rectification, the current can be put through capacitors or transistors, which will smooth the current to look [on an oscilloscope] more like a DC form.

As for the load circuit, there are many important considerations. It is important to plan ahead as to what the load should be in order to properly design the circuit. For this experiment, the load was simply 12 LEDs wired in parallel. This required only a full-wave bridge rectifier, a 100Ω resistor, and some 22-gauge wiring. The original plan for the load circuit was to have a female USB 2.0 port which would allow the charging of mobile devices, or anything else that can be powered by a USB 2.0 port. A circuit like this is more complicated, involving a transformer, capacitors in parallel, a double-pole, double-throw switch, and a linear regulator to cut output voltage down to 5V for the USB port. It was attempted to put a step-down transformer in the LED load circuit before the rectifier, though one could not be made or found with the required primary to secondary turn ratio. This would allow for voltage to be dropped to roughly 20V and therefore the current would be much greater in the secondary coil than the primary. In a more complicated load circuit involving linear regulators, other rectifiers (including bridge rectifiers), transistors, and other electronic components, it is important to recognize that many of these have significant internal resistances and drops which could greatly affect the output power. An example of this is most linear regulators have a base, or drop-out voltage, where they can no longer effectively regulate voltage once the input into the regulator drops below a certain point. This can be seen by a 5V linear regulator, which has a base voltage of 1.8V. Therefore the regulator can no longer effectively output a smooth DC current without an input of 6.8 volts. Something like this is very important when working with such low power.

The mechanical assembly was a main focus for about three weeks. All elements were drafted multiple times in AutoCAD. These elements include the base plate, the top plate, the impact rods, and the spring holders and stoppers.

The base plate is the most elaborate of all the CAD designs. This is where the 18 piezoelectric transducer disks are held. They are separated by 5mm wide and 5mm deep troughs. These troughs created a grid 3 squares wide by 6 squares long. The troughs were designed for wire management, but for simplicity and due to time constraints, these were not implemented in the design. Inside of each square is a circle with diameter of 35mm and 2mm deep. The 35mm diameter allowed for the piezoelectric disks to sit on an edge. The 2mm depth allows for efficient bending of the disks when impacted by the rods, therefore producing a greater electrical output. The piezoelectric transducers were hot glued into place. In each of the four corners of the base plate extends a 30mm wide by 30mm long box. This box has a hole drilled in the middle of it and is where the bottom and top plates are bolted together. Additionally, the base plate has four locations where spring holders and stoppers are fastened. These cup-shaped, 3D printed parts hold the springs in place. They also act as stoppers so that the top plate cannot be pressed too far down, which would allow the rods to bend the piezoelectric disks too much and cause fracture. (When the disks are fractured, even small cracks are present, the efficiency is greatly reduced. It is important to safely impact and bend the disks otherwise longevity of life will be drastically reduced and they will become inefficient very quickly).

The top plate is much simpler then the base plate. The top plate has the other half of the spring holders and stoppers. Additionally, all of the 3D printed impact rods are attached here. They are screwed in, though in future projects, gluing would work much better. The rods are directly centered above the piezoelectric transducers so that they hit the center during impact which allows for maximum deformation efficiency. The top plate also has 30mm wide by 30mm long boxes extending from the corners which are where the top and bottom plates are bolted together.

Final CAD designs include the spring holders and stoppers and the impact rods. The spring holders and stoppers are designed to hold the springs snugly. The inside diameter of the spring holders is 1mm larger than the diameter of the springs to disallow any horizontal bending or slipping. The walls of the holders are 2mm thick. The stoppers and impact rod designs must be considered together. The impact rods must be 1mm longer than the stoppers to allow proper deformation of the piezoelectric disks. (The disks have material which sticks up roughly 1mm above the brass base plate, so the disks deform a total of roughly 2mm when impacted). These can be designed according to the materials which are available.

An important mechanical consideration is the springs. Compression springs are required for this unit. It is noteworthy that the spring holders and therefore stoppers and impact rods will be designed around the springs used. The springs used in this unit are rated at 44.8 pounds for full compression. Therefore in this unit, 179.2 pounds are required for full compression of all four springs. It is undesirable for the springs to compress fully, hence the stoppers. The weight of the user in this experiment is less than the weight required for full compression. In the situation that user weight did exceed full compression weight, it would not be an issue since stoppers are in place.

The project went very smoothly overall. The mechanical assembly was quite simple once everything was drafted on CAD. The soldering of all 18 piezoelectric transducers was a bit tedious, but needed to be done. As for the most challenging aspect of the project, the load circuit presented the most issues. The first problem was the inability to build or obtain a transformer with the correct primary to secondary turn ratio. This prevented the original load circuit idea to be produced. Also, there were a few problems with charging capacitors. It was determined though that a double-pole double-throw switch could be used to solve this charging issue.

In conclusion, the experiment of a piezoelectric energy harvester as a mobile power source was a great success. Piezoelectric energy harvesting is not, with current piezoelectric transducer efficiency, the solution to the world's energy crisis. It is, however, a method of green energy that can surely contribute to society's everyday energy needs, not to mention their functionality in a multitude of other applications such as sensors and motors.

The total project time, from research to presentation was 6 weeks. At the conclusion of those 6 weeks, a successfully functioning piezoelectric energy harvesting device was used as a mobile power source to brightly illuminate an array of LEDs.

Future Work

Though this project was successful, there are many aspects and building methods that could be changed to make it not only look better, but reduce cost, increase power output, and be easier to produce. All of these changes and notes would be good to take note of if this unit were to be built again.

First, the unit could be much smaller than it is. Making it smaller would allow for the unit to be more compact and therefore neater. Also, it would lessen the window for mechanical errors, such as wobbling and slightly misplaced impact rods. The piezoelectric disks could be stacked on top of each other with dielectrics between each to prevent shorting. With this, the number of piezoelectric disks could be multiplied by two or three using the same surface area base plate, while still efficiently harvesting energy. The area of the unit could also be decreased while using the same number of piezoelectric disks if the stacking method were used. Other higher efficiency and smaller (therefore more expensive as well) piezoelectric materials could be used to create a similar, yet much smaller unit. This unit could be small enough and thin enough to fit in a shoe without being noticeably apparent to the wearer.

Something else that would be done differently if the unit were to be built again would be the manufacturing process. A CNC machine was used to cut out the top and base plates, as well as drill out the details of the base plate. The holes for the bolts and screws to hold the spring holders and stoppers as well as the impact rods were all drilled manually. They could have easily been drilled with the CNC machine and this would have made them much more accurate than a hand drilled hole. This accuracy would increase the efficiency and overall workability of the energy harvesting unit.

Future Applications of Piezoelectric Energy Harvesting

There is surely a future for piezoelectric energy harvesting in the future. With further development of piezoelectric materials, they could become more efficient and prove to be an even more likely means of harvesting green energy for low power applications. In the foreseeable future, it is likely that piezoelectric energy harvesting will be used in two particular areas, roads and public areas.

Roadways

Cars driving on roads provide not only a changing pressure along roadways, but also produce ample vibrations. Piezoelectric elements could be put under roadways in order to harvest energy by utilizing these vibrations and constantly changing pressures. They would likely be most efficient in high traffic areas such as toll booths and the middle of intersections. Highways would also be a great place for piezoelectric energy harvesting since there are thousands of cars and therefore plenty of pressing, squeezing, and vibrations.

Another place for these materials would be on bridges. The piezoelectrics could be matched with the vibrational frequency of the bridge. Also, wind through bridges make them vibrate, and would therefore cause the piezoelectrics to vibrate.

Piezoelectric energy harvesters could be used in these locations to provide power to lower power devices. These could include roadway lighting, traffic lights, the illumination of signs, and other low power applications.

Public Areas

Any high traffic public area would be a great place for piezoelectric elements. All of the pressure from people walking could be used to harvest energy. Sidewalks and hallways could be great for this application. If a hallway were covered with piezoelectric elements, walking alone could light the corridor. Sidewalk piezos could help power lighting or other electronic devices. Doorways could also be a great place since people are funneled through them. Lastly, treadmills would be a very good location for piezoelectric energy harvesting. The impact of people walking on a treadmill at a gym could help light the room or power equipment.

Contact

For questions, comments, resources, or any other inquiries, please feel free to contact Ryan [redacted] via email at the following address:

[redacted]

References

1. Arnone, Dave, Aaron Van Pelt, and Kathy Li Dessau. "Piezoelectric Motors Control Set-and-Hold Semiconductor Applications." *Photonics.com*. Photonics Spectra, Feb. 2003. Web. <http://www.photonics.com/Article.aspx?AID=14986>.

2. "Demonstration Experiment of the “Power-Generating Floor” at Tokyo Station." *JR East*. East Japan Railway Company, 11 Jan. 2008. Web. <http://www.jreast.co.jp/e/development/press/20080111.pdf>.

3. *Diode Tutorial & How to Build an AC to DC Power Supply*. Perf. Afrotechmods. YouTube, 19 Nov. 2010. Web. <http://www.youtube.com/watch?v=cyhzpFqXwdA>.

4. Eduard, Noel. "Modeling and Design of a MEMS Piezoelectric Vibration Energy Harvester." *Caltech Robotics*. Massachusetts Institute of Technology, 20 May 2005. Web. <http://robotics.caltech.edu/~ndutoit/wiki/images/1/1b/MS_thesis.pdf>.

5. "Energy Floors - Home." *Energy Floors*. N.p., n.d. Web. <http://www.sustainabledanceclub.com/>.

6. Gautschi, G (2002). Piezoelectric Sensorics: Force, Strain, Pressure, Acceleration and Acoustic Emission Sensors, Materials and Amplifiers. Springer.

7. "Piezo Film Sensors - Technical Manual." *Images SI*. Images SI Inc., n.d. Web. <http://www.imagesco.com/sensors/piezofilm.pdf>.

8. "Piezo Theory." *Piezo | Piezo Theory | Piezo Transformers*. APC International, n.d. Web. <http://www.americanpiezo.com/knowledge-center/piezo-theory.html>.

9. "Piezoelectric Effect." *Piezoelectricity*. Georgia State University, n.d. Web. 03 June 2013. <http://hyperphysics.phy-astr.gsu.edu/hbase/solids/piezo.html>.

10. Rendl, Christian, Patrick Greindl, Michael Haller, Martin Zirkl, Barbara Stadlober, and Paul Hartmann. "PyzoFlex: Printed Piezoelectric Pressure Sensing Foil." *MI Lab*. N.p., 2012. Web. <http://mi-lab.org/files/2012/10/pyzoflex-final-online.pdf>.

11. Trimarchi, Maria. "Can House Music Solve the Energy Crisis?" *HowStuffWorks*. How Stuff Works, 10 Sept. 2008. Web. <http://science.howstuffworks.com/environmental/green-science/house-music-energy-crisis1.htm>.

12. *Voltage Regulator Tutorial & USB Gadget Charger Circuit*. Perf. Afrotechmods. YouTube, 23 Nov. 2010. Web. <http://www.youtube.com/watch?feature=episodic>.

Files and Downloads

Project Files

File Name	Type	Description	Download Link
Piezo_bottomplate_3D	DWG	Base plate in 3D. File has layers.	Download
Piezo_plates_CNC	DWG	Base plate and top plate for CNC router (2D)	Download
Piezo_plates_CNC	DXF	Plates for CNC in DXF file type	Download
Presentation	PPTX	Powerpoint presentation	Download
Impact_rod	STL	Impact rods (18 printed on 3D printer)	Download
Stoppers_holders_base	DWG	Stoppers and spring holders (base) (CAD file)	Download
Stoppers_holders_base	STL	Stoppers and spring holders (base) (3D printer)	Download
Stoppers_holders_top	DWG	Stoppers and spring holders for top (CAD file)	Download
Stoppers_holders_top	STL	Stoppers and spring holders for top (Printer file)	Download

Resources and Research Files

File Name	Type	Description	Download Link
PyzoFlex	PDF	PyzoFlex - Printed Piezoelectric Pressure Sensing Foil	Download
Images SI Inc	PDF	Piezo Film Sensors - Technical Manual (Images SI Inc.)	Download
MIT	PDF	MIT-Modeling and Design of a MEMS Piezoelectric Vibration Energy Harvester	Download
JR-EAST	PDF	JR-EAST Piezo Floor	Download
APC	PDF	APC International, Ltd. - First Steps Towards Piezoaction	Download
Piezoelectricity wiki	PDF	Wikipedia page on Piezoelectricity	Download

Latest Update: December 2013