ELECTRICAL ENGINEERING DEPARTMENT
California Polytechnic State University

EE 462

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"Piezoelectric Powered LED Street Reflector"

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By

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Abstract

In many areas of Washington, it rains for a majority of the year. During rainy weather it becomes difficult to see street lanes and dividers, causing hazardous road conditions. The Piezoelectric Powered LED Street Reflector solves this problem. The PPL Street Reflector modifies a street reflector with LED lights. These lights help drivers clearly see where dividers and street lines are in non-ideal weather conditions, such as rain, fog, and snow. The PPL Street Reflector capabilities include harvesting energy through the Piezoelectric Effect, creating a self-sustaining device with minimal maintenance.

I: Introduction

Traditional street reflectors such as Botts' dots, delineators, cat's eyes and road studs, are used to specify street lanes. The issue with traditional street reflectors is that they cannot be clearly seen during bad weather conditions. During bad weather conditions such as rain, it becomes hard to see these reflectors due to light refraction. To resolve this issue there is a need for a street reflector that can be seen in such conditions. Creating a street reflector that integrates a bright LED that can allow drivers to see them during such conditions can do this. The powering of this LED will need to be done in a non-traditional way given the growing environmental concerns to save energy. This has been occurring due to the awareness to preserves extinguishable natural resources and also because it is increasingly becoming an advantage to have self-powered devices. Having systems that can be self-sustainable and efficient are a necessity. Once such non-traditional energy source is Piezoelectric energy harvesting. Piezoelectric devices combined with the advancement of energy harvesting technology presents a practical option for delivering power to small-scale devices that operate in environments with a high potential for Energy Harvesting. Traveling cars present this high potential for Energy Harvesting.

The focus of this project is to develop a street reflector that integrates a LED and powers said LED by a piezoelectric energy harvesting system. The operation of this system in a typical application is that in the occurrence of an event that produces sufficient vibrations from motor vehicles in the environments, the system will derive power from said vibrations, and use the power to activate an LED and then deactivate the LED. This system can have applications in various parts of the world where bad weather conditions are common, such as the State of Washington.

II: Background

Piezoelectricity stems form the Greek word “piezo” for pressure and the word “electric” for electricity. Pierre and Jacques Curie first discovered the Piezoelectric Effect in 1880. The Piezoelectric Effect is the effect of crystals acquiring a charge from being compressed, twisted or distorted. This effect provides a useful transducer effect between electrical and mechanical oscillations. The first discovery of this effect was seen in tourmaline, quartz and Rochelle salt. Other ceramics such as lead-zirconate-titanate(PZT), barium titanate($BaTiO_3$), lead zirconate($PbZrO_3$), and lead titanate($PbTiO_2$) also exhibit the Piezoelectric Effect. This technology, however, was not popularized until the 1940’s with the development of sonar technology. Today the most commonly used piezoelectric ceramic is lead-zirconate-titanate(PZT) due to a high electromechanical coupling ability.

III: Requirements and Specifications

Customer Needs Statement
The development and use of the PPL Street Reflector saves lives, protects cars and saves money. Drivers during dangerous weather conditions poise a higher risk of crashing. The PPL reflector decreases this risk through street lane illumination allowing safer driving during dangerous conditions. Decreasing accidents also decreases insurance claims saving people money and car damage.

TABLE I
PPL STREET REFLECTOR REQUIREMENTS AND SPECIFICATIONS

Marketing Requirements	Engineering Specifications	Justification
2,3	Harvest energy through Piezoelectric Effect.	Traveling cars harvests needed energy
5	Have light sensor to increase LED life span.	Using a light sensor will keep LED off when use is not necessary.
5	Circuit components must maintain ROHS compliance.	Allows for safe disposal of components in respect of decreasing harmful long-term environmental impacts from the EHFEM project.
1	Produces visible light at a minimum distance of 50 ft.	Drivers can see 5ft reflectors approximately 50ft away. 10ft spacing between reflectors.
4	Withstands 40 tons of pressure.	5-axle trailer's legal maximum weight in the United States.

Marketing Requirements
1. Clearly visible from 50 feet away.
2. Harvest energy reliable sources.
3. Withstand extreme pressure.
4. Easily implemented.
5. Ability for LED to be ON or OFF

The requirements and specifications table format derives from [1], Chapter 3.

TABLE II
PPL STREET REFLECTOR DELIVERABLES

Delivery Date	Deliverable Description
2/20/14	Design Review
5/31/14	EE464 Demo Device
5/31/14	ABET Senior Project Analysis
5/31/14	Senior Project Expo Poster
6/8/14	EE464 Report

[1] R. Ford and C. Coulston, *Design for Electrical and Computer Engineers*, McGraw-Hill, 2007, p. 37
[2] *IEEE Std 1233, 1998 Edition*, p. 4 (10/36), DOI: 10.1109/IEEESTD.1998.88826

III: Design

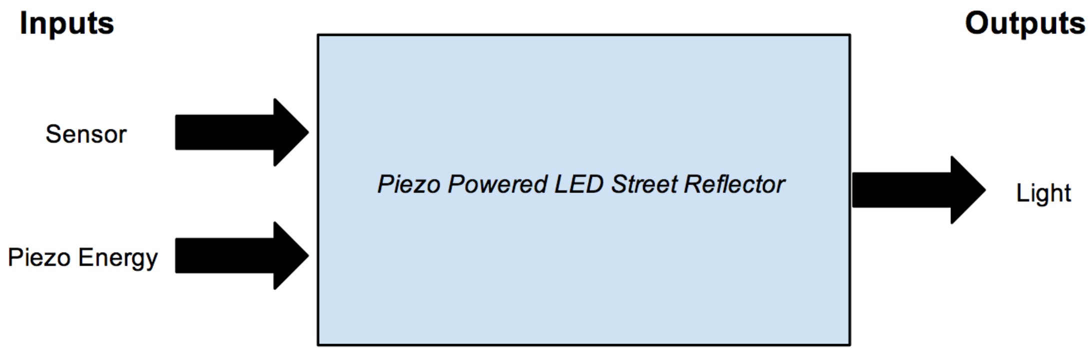

Figure 1: Level 0 Block diagram for Piezoelectric Powered LED Street Reflector

The system design involves the use of two inputs and one output. The two inputs are sensor and Piezoelectric energy. The Level 0 block diagram of the system is shown in **Figure 1** above. The sensor controls when the functionality of the LED when Piezoelectric Energy is present. The Level 1 Block Diagram is shown in **Figure 2** below giving a more detailed description of the overall system design.

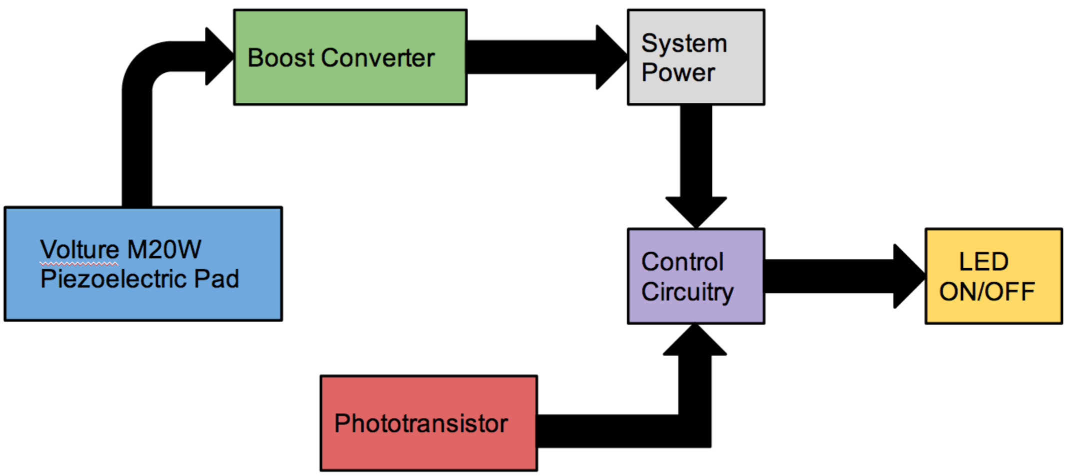

Figure 2: Level 1 Block diagram for Piezoelectric Powered LED Street Reflector

The Mide Volture V20W Piezoelectric Energy Harvester is used as the piezoelectric energy source. "Volture™ vibration energy harvesters convert otherwise wasted energy from mechanical vibrations into usable electrical energy. The Volture™ accomplishes this by utilizing normally brittle piezoelectric materials. The Mide Volture™ energy harvester is unique amongst other piezo based energy harvesters because it incorporates Mide's patented piezoelectric transducer packaging technology. Through a proprietary manufacturing process, the Volture™ packages piezoelectric materials in a protective skin with pre-attached electrical leads, producing a robust component with no soldered wires. The Volture's™ protective skin also provides electrical insulation and defense against humidity and harsh contaminants" [11]. A diagram of Mide's patented piezoelectric transducer packaging technology is shown in **Figure 3** below. Mide integrates two electrically isolated piezo wafers in each Volture™

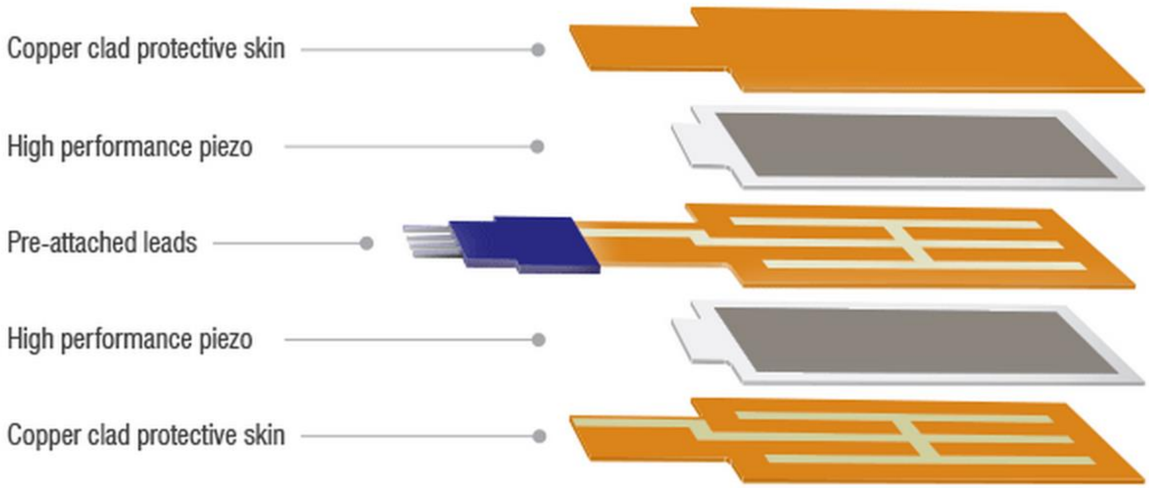

Figure 3: Mide's patented piezoelectric transducer packaging technology [11].

Piezoelectric Energy Harvester. The two wafers can be used either independently, bridged in series configuration for increased voltage, or bridged in parallel configuration for increased current output. For the current system the Mide Volture V20W Piezoelectric Energy Harvester was used in a bridged series configuration for increased voltage. **Table III** shows the open circuit voltages expected given different variable in the series configuration.

TABLE III
MIDE VOLTURE™ V20W RELATION BETWEEN TIP MASSS AND OPEN CIRCUIT VOLTAGES [11]

Tip Mass (gram)	Fn (Hz)	Amplitude (g)	Open Circuit Voltage*
0	180	0.25	4.7
0	180	0.375	6.5
0	180	0.5	7.7
0	180	1	12.8
2.4	130	0.25	6.7
2.4	130	0.375	9
2.4	130	0.5	11
2.4	130	1	18
7.8	95	0.25	8.3
7.8	95	0.375	11.8
7.8	95	0.5	16.4
7.8	95	1	23.1
15.6	75	0.25	13.3
15.6	75	0.375	19
15.6	75	0.5	22.6
15.6	75	1	34.7

* piezo wafers connected in series

The collected energy from the Mide Volture V20W Piezoelectric Energy Harvester will be connected to the Demo Circuit 1459B-A from Linear Technology. The board incorporates the boost converter and system power stages found in **Figure 2.** "Demonstration Circuit 1459B is an energy harvesting power supply featuring the LTC3588-1. The LTC3588 integrates a low-loss full-wave bridge with a high efficiency buck converter to form a complete energy harvesting solution optimized for high output impedance energy sources such as piezoelectric transducers. An ultralow quiescent current under voltage lockout mode with a wide hysteresis window allows charge to accumulate on an input capacitor until the buck converter can efficiently transfer a portion of the stored charge to the output" [12]. **Figure 4** and **Figure 5** show the circuit diagram and board layout for the Demo Circuit 1459B-A. **Table IV** refers to the jumper settings that decide output voltage on V_{out}. For system, jumpers will both be set to high for an output voltage of 3.6V.

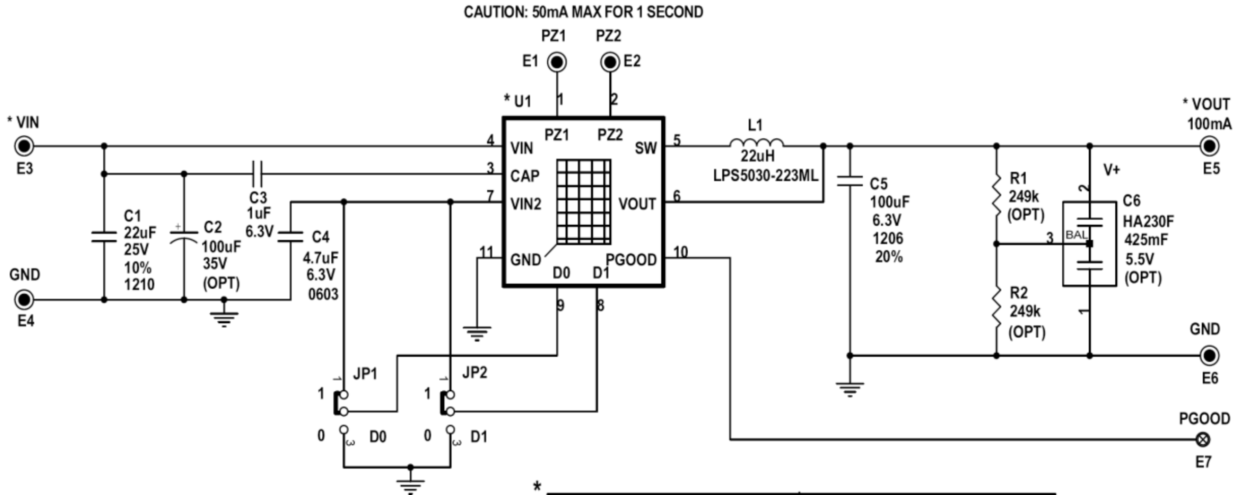

Figure 4: LT Demo Board 1459B-A Circuit Diagram [13]

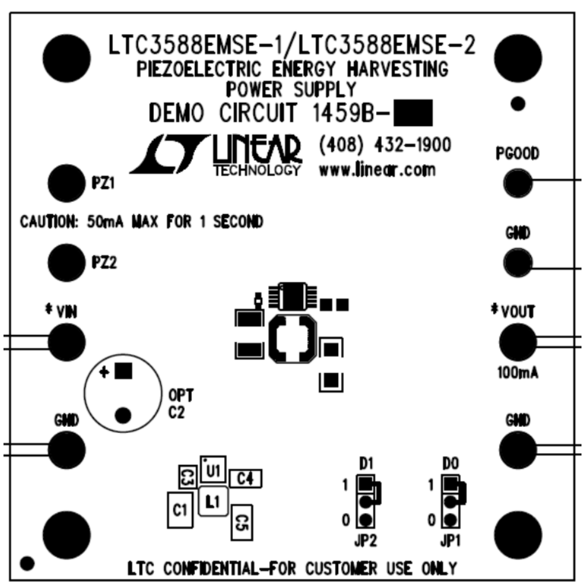

Figure 5: LT Demo Board 1459B-A Layout [13]

TABLE IV
DEMO BOARD 1459B-A JUMPER SETTINGS [13]

ASSEMBLY	U1	* VIN	* VOUT			
DC1459B-A	LTC3588EMSE-1	2.6V-20V	1.8V	2.5V	3.3V	3.6V
DC1459B-B	LTC3588EMSE-2	14V-20V	3.45V	4.1V	4.5V	5.0V
JUMPER SETTINGS		D1	0	0	1	1
		D0	0	1	0	1

The output voltage V_{out} was connected to the control circuitry pictured in **Figure 6.** The control circuitry consists of an LTR-4206E phototransistor, 1KΩ resistor, and a 2N3904 transistor. The control circuitry was used to control when the LED is ON and when it is OFF.

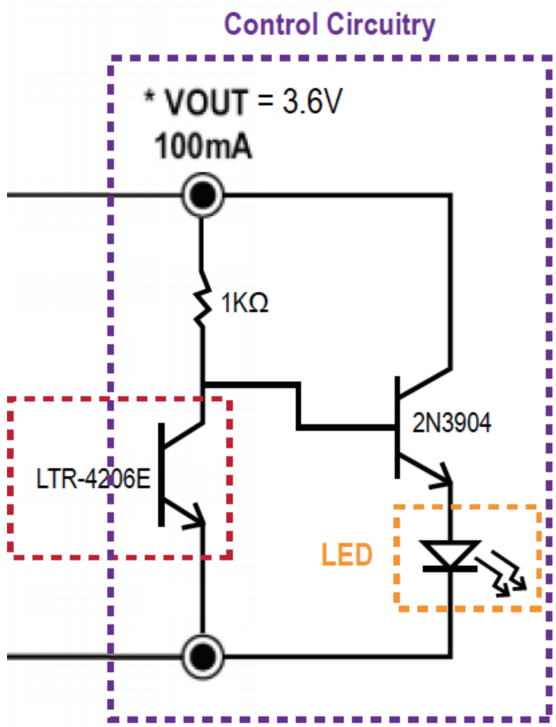

Figure 6: Control Circuitry Design

The LTR-4206E is a phototransistor in a 3mm black package, the black package blocks visible light, so it is only sensitive to infrared light, sunlight and incandescent lights. The 2N3904 transistor is a general purpose NPN transistor with a useful dynamic range that extends to 100mA as a switch. Using the three components describe above an LED was connected between the 2N3904 emitter and ground.

When light falls on the LTR-4206E phototransistor it begins to conduct up to 1.5mA, this in turn pulls down the voltage at the lower side of the resistor by 1.5V, thus turning off the 2N3904 transistor which will not allow voltage to reach the LED keeping it turned off. When it is dark, the 2N3904 transistor's saturation voltage is reached and 15mA is conducted through the LED turning it ON when acceptable vibrational energy is present. The complete system circuit diagram can be seen in **Figure 7**. In this diagram each component of the Level 1 block diagram in **Figure 2** is outline and labeled. All circuitry is designed and constructed to fit in a K-Lite KT-201-2 W/W/R ABS Pavement Marker and will be discussed in section **IV: Construction**.

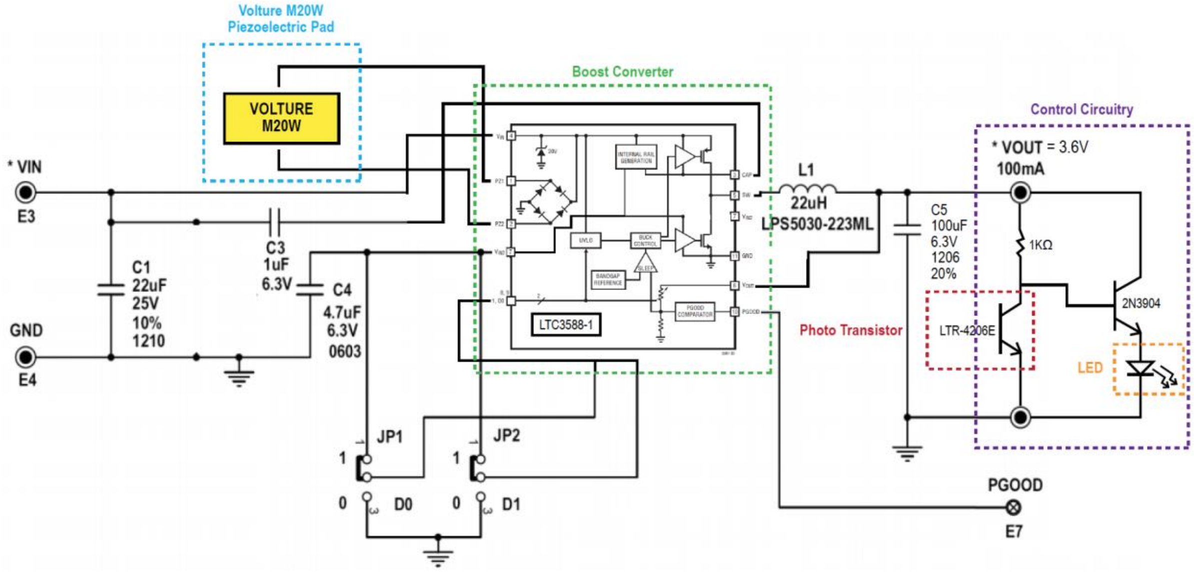

Figure 7: Level 2 Block Diagram (Complete Circuit diagram).

IV: Construction

Construction of the Piezoelectric Powered LED street reflector is reflected in the following descriptions and subsequent images. **Figure 8** shows all components used in the construction of the Piezoelectric Powered LED Street Reflector and **Table V** lists all components.

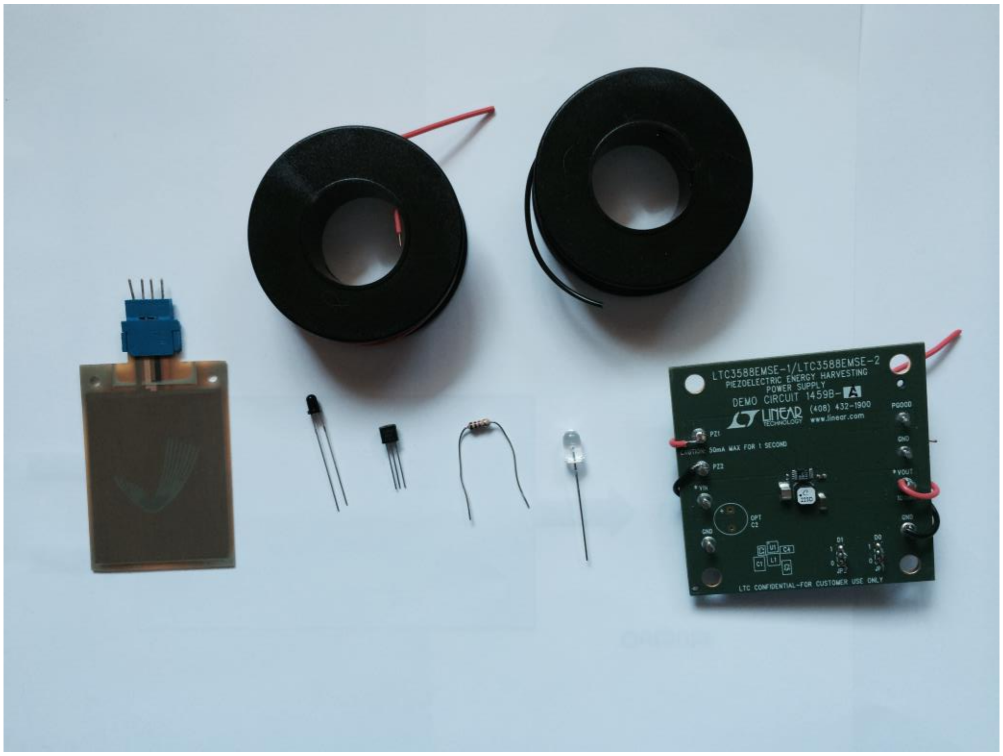

Figure 8: Needed Components

TABLE V
COMPONENT LIST

QUANTITY	COMPONENT
1	LTR-4602E Phototransistor
1	2N3904 NPN Transistor
1	6.2 cd LED
1	K-Lite KT-201-2 W/W/R ABS Pavement Marker
1	LT 1459 Demo Circuit 1459B-A
1	1/4” LED Plastic Holder
1	Mide Volture^{TM} V20W Piezoelectric Energy Harvester
1	1KΩ Resistor
1.5ft	Wire

STEP 1: Bridge the two piezoelectric wafers in series.

Using the Mide Volture™ V20W Piezoelectric Energy Harvester datasheet, bridge Pin 2 and Pin 3 as seen in **Figure 9. Figure 10** also shows how this step was done.

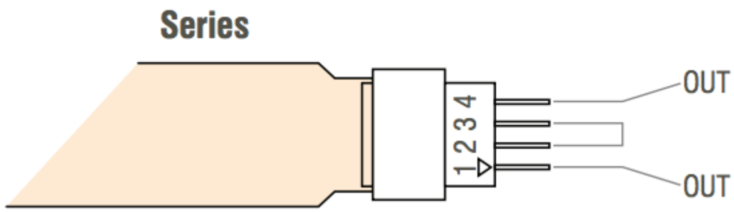

Figure 9: Mide's Instruction for connecting outputs in series

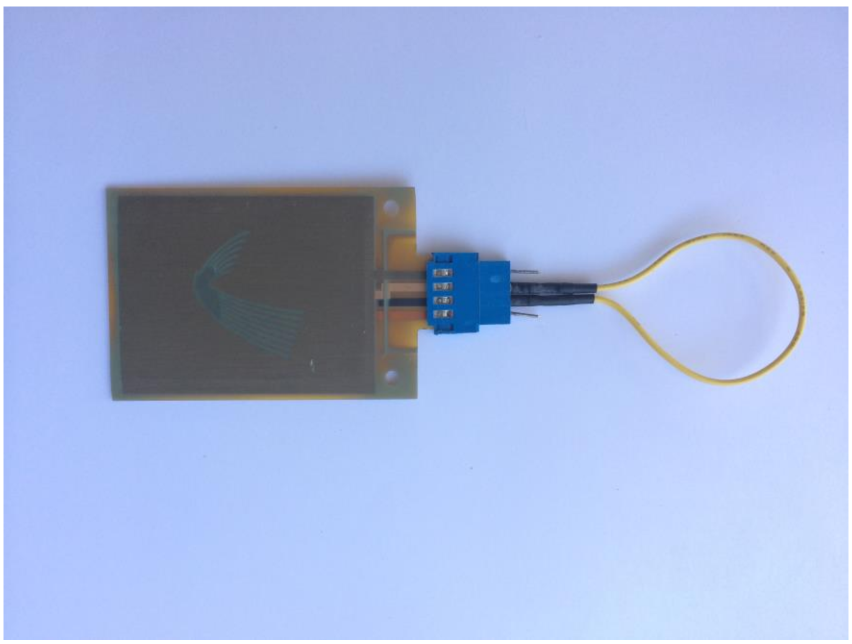

Figure 10: Bridging Two Piezoelectric Wafers in Series

STEP 2: Demo Board 1459B-A Preparation.

Leads were soldered to the Demo Circuit 1459B-A as seen in **Figure 11.** To comply with IEEE standards red wire was used for PZ1 and V_{out}, and black wire was used for PZ2 and GND. Each wire is approximately 3" in length and 22 gauge in diameter.

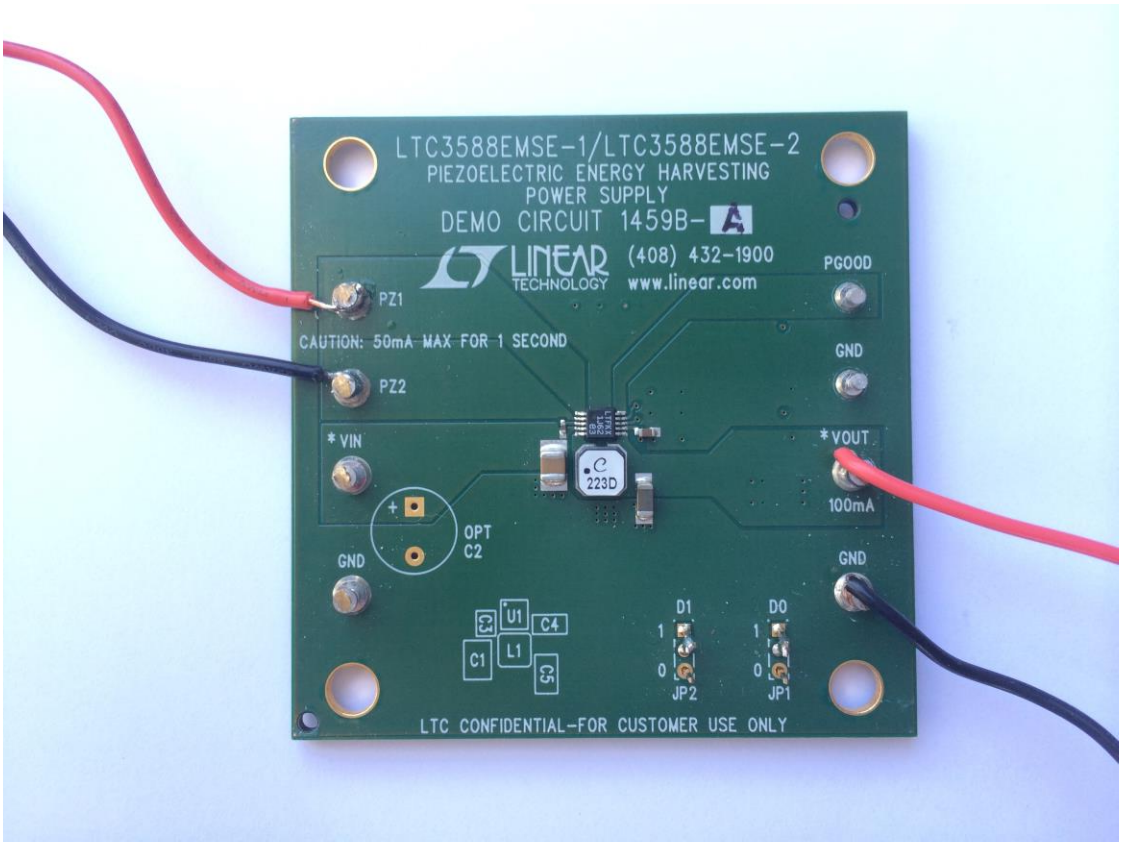

Figure 11: Demo Board 1459B-A after leads have been soldered on.

STEP 3: Construction of Control Circuitry.

Using the circuit depicted in **Figure 6** and the components listed in **Table VI** the control circuitry was constructed**.** A resistor was soldered between the Base and Collector pins of the 2N3904 transistor and is shown in **Figure 12.**

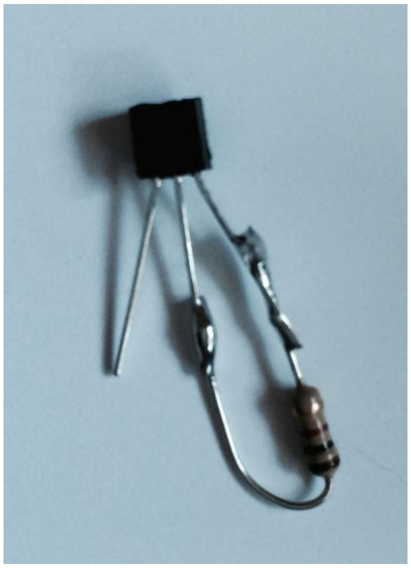

Figure 12: Resistor and 2N3904 transistor soldered together.

Next the LTR-4206E Phototransistor Collector was soldered to the Base of the 2N3904 transistor using a 2” strip of 22 gauge red wire. This is shown in **Figure 13.**

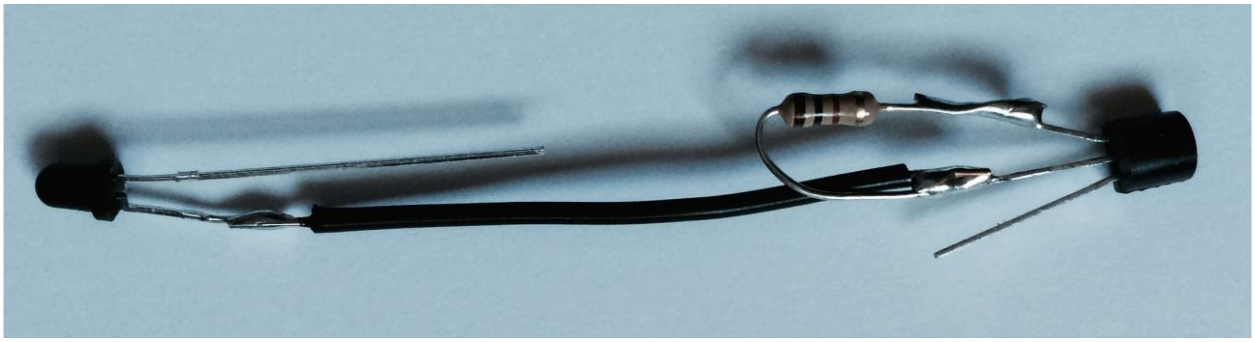

Figure 13: LTR-4206E Phototransistor Emitter soldered to Base of 2N3904 Transistor

Next the positive lead of the LED is soldered to the Emitter lead of the 2N3904 transistor using a 2” strip of 22 gauge black wire. This is shown in **Figure 14.**

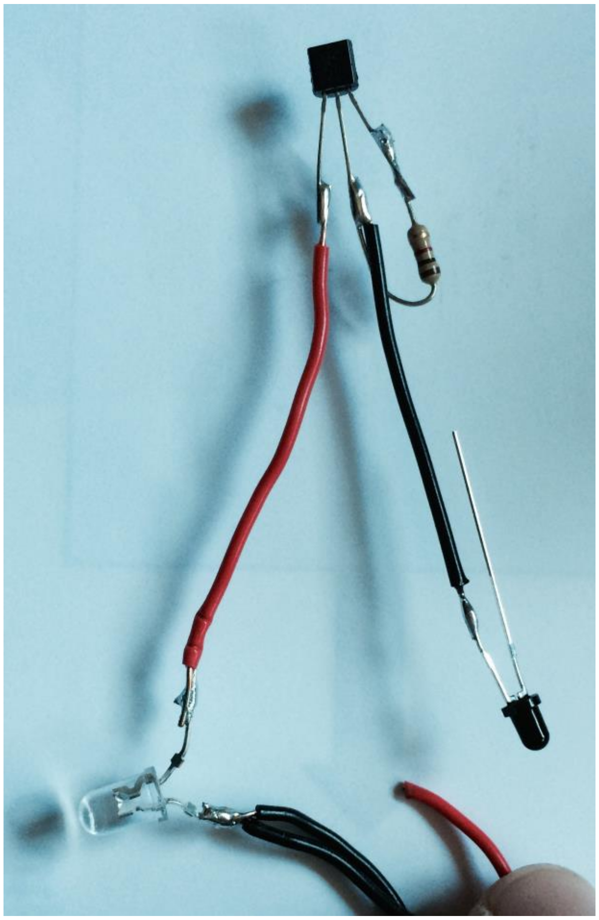

Figure 14: Positive Lead of LED soldered to Emitter of 2N3904 transistor.

The final step in construction of the control circuitry was to solder together the negative lead of the LED to the Emitter of the LTR-4206E phototransistor using 2” of 22 gauge black wire. This is shown in **Figure 15.**

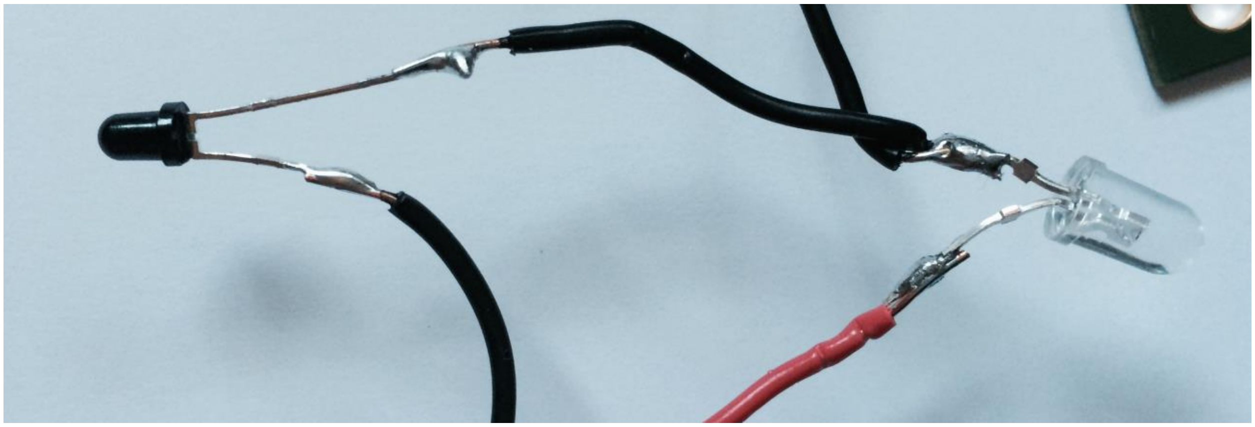

Figure 15: Negative lead of LED soldered to Emitter of LTR-4206E Phototransistor

STEP 4: Connecting Control Circuitry to Demo Circuit 1459B-A.

The 3" black lead soldered to the GND pin on the Demo Board 1459B-A was soldered to the negative lead of the LED. This is shown in **Figure 16.**

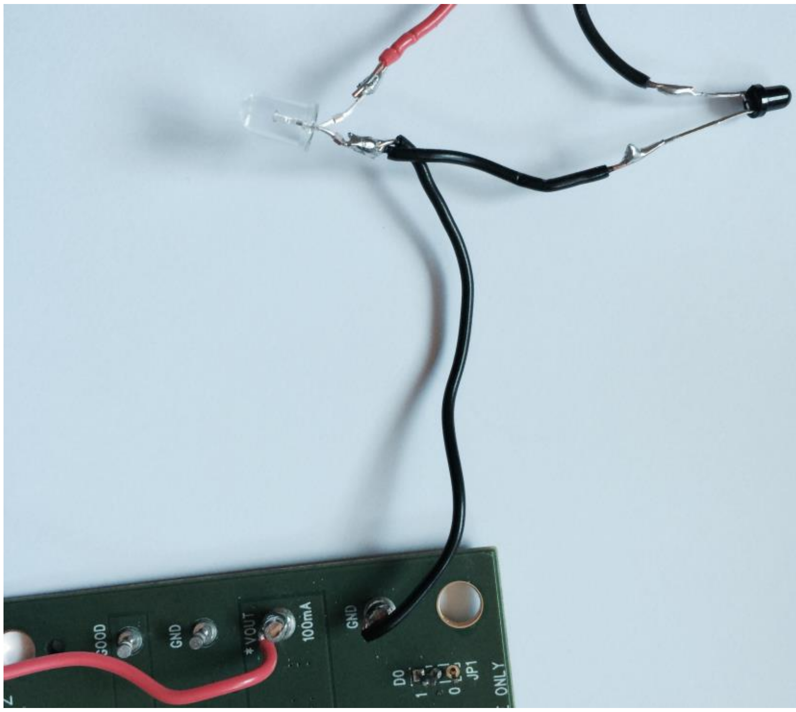

Figure 16: Connected GND of Demo Board 1459B-A to Control Circuitry

The 3" red lead soldered to the V_{out} pin on the Demo Board 1459B-A was soldered to the Collector of the 2N3904 transistor. This is shown in **Figure 17.**

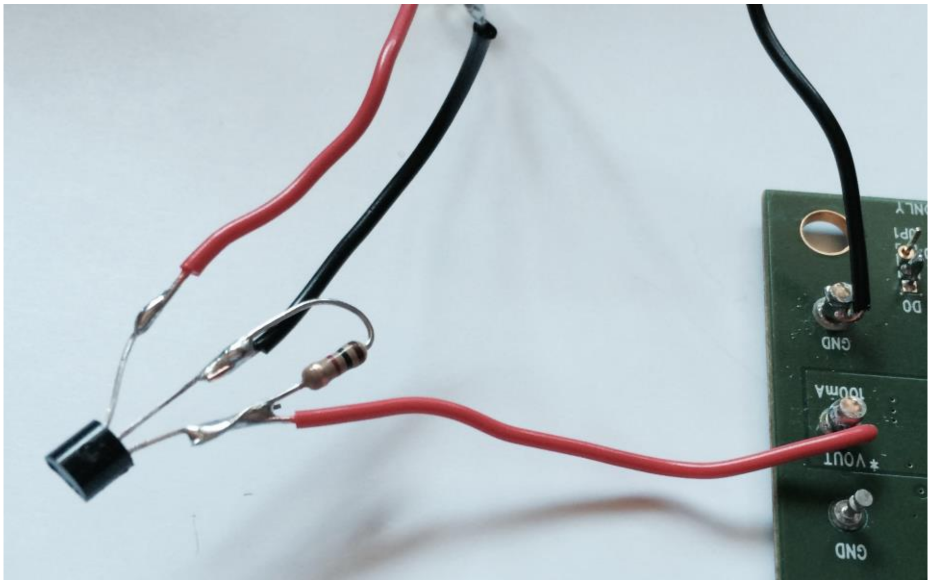

Figure 17: Connected V_{out} of Demo Board 1459B-A to Control Circuitry

STEP 4: Connecting Mide Volture™ V20W Piezoelectric Energy Harvester to Demo Circuit 1459B-A.

Using **Figure 18** as a guide the 3” red lead on the PZ1 pin of the Demo Circuit 1459B-A was soldered to Pin 4 of the Mide Volture™ V20W Piezoelectric Energy Harvester. This is shown in **Figure 19.**

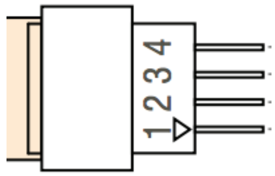

Figure 18: Pin layout for Mide Volture™ V20W Piezoelectric Energy Harvester.

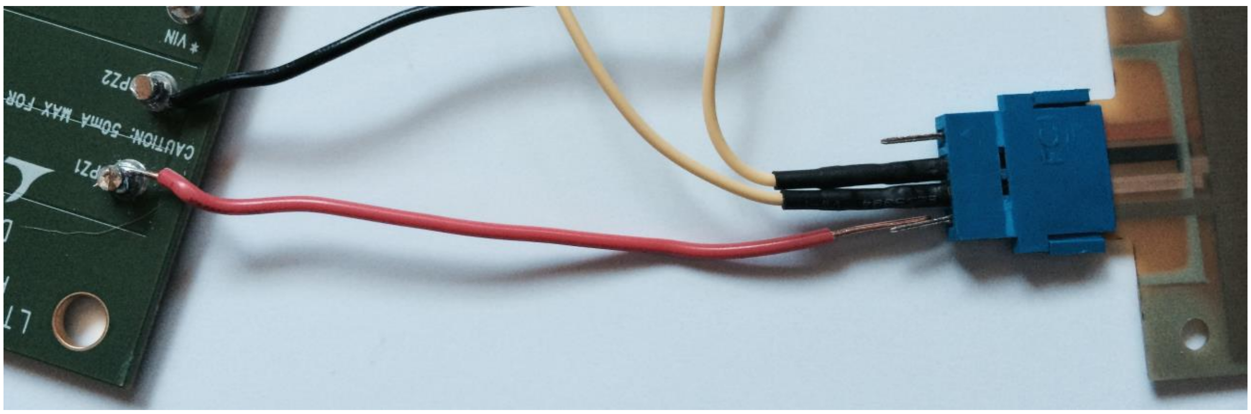

Figure 19: Connected PZ1 of Demo Circuit 1459B-A to Pin 4 of Mide Volture™ V20W Piezoelectric Energy Harvester

Using **Figure 18** as a guide the 3” black lead on the PZ2 pin of the Demo Circuit 1459B-A was soldered to Pin 1 of the Mide Volture™ V20W Piezoelectric Energy Harvester. This is shown in **Figure 20.**

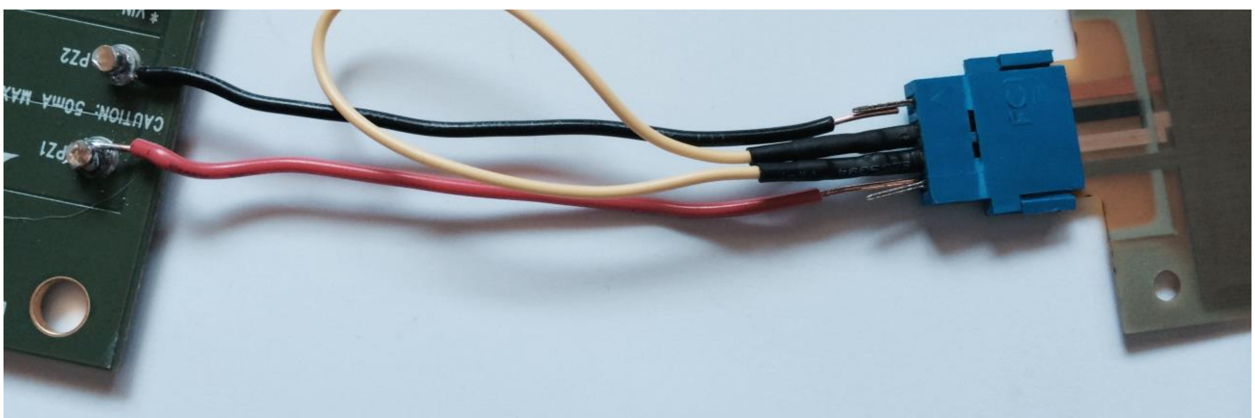

Figure 20: Connected PZ2 of Demo Circuit 1459B-A to Pin 1 of Mide Volture™ V20W Piezoelectric Energy Harvester

STEP 5: Preparation of K-Lite KT-201-2 W/W/R ABS Pavement Marker.

Using a Dremel and Grout cutting bit a 2 9/16" x 2 11/16" square at a depth of ¼" was carved out of the K-Lite KT-201-2 W/W/R ABS Pavement Marker. Before and after images are shown in **Figure 21** and **Figure 22.**

Figure 21: K-Lite KT-201-2 W/W/R ABS Pavement Marker Before.

Figure 22: K-Lite KT-201-2 W/W/R ABS Pavement Marker After.

Using a Dremel and Grout cutting bit a 1 5/8” rectangle at a depth of 1/16” starting 1 3/16” from the edge of the reflective side was carved out of the K-Lite KT-201-2 W/W/R ABS Pavement Marker. This is shown in **Figure 23.**

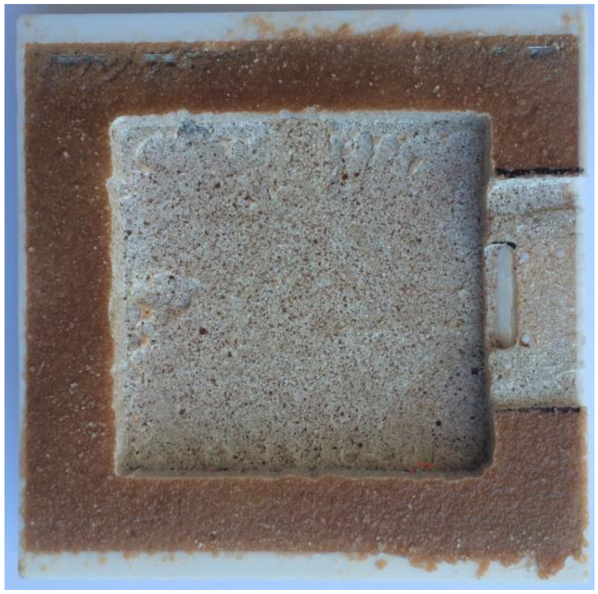

Figure 23: K-Lite KT-201-2 W/W/R ABS Pavement Marker After 1 5/8” Rectangle cut out.

Using a drill and a ¼” drill bit a hole was drilled 2” in and ¾” up in the middle of the silver reflective surface of the K-Lite KT-201-2 W/W/R ABS Pavement Marker at the same angle as the reflective surface, and a ¼” Plastic LED holder is placed in hole. This is shown in **Figure 24.**

Figure 24: ¼” hole drilled on Silver reflective side of K-Lite KT-201-2 W/W/R ABS Pavement Marker.

Using a drill and a 1/8” drill bit a hole was drill 3/16” form the top of the silver reflective surface of the K-Lite KT-201-2 W/W/R ABS Pavement Marker. This is shown in **Figure 25.**

Figure 25: 3/16” form the top of the silver reflective surface of the K-Lite KT-201-2 W/W/R ABS Pavement Marker

Using a drill and a ¼” drill bit a hole was ¼” deep using the 1/8” hole as a pilot hole from the backside of K-Lite KT-201-2 W/W/R ABS Pavement Marker. This is shown in **Figure 26.**

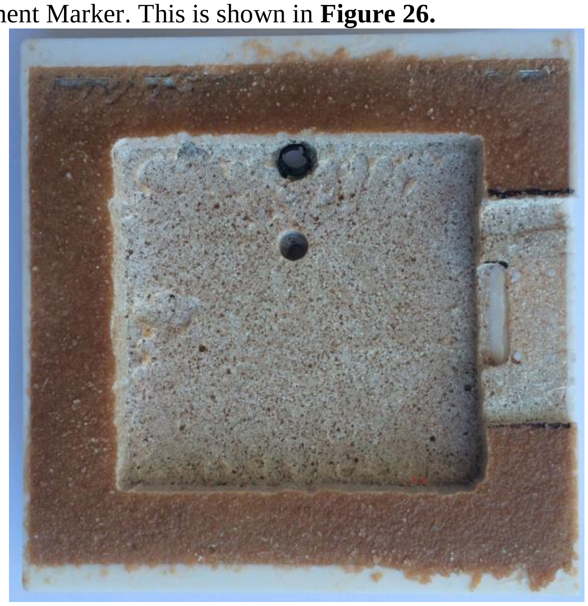

Figure 26: ¼” hole drilled ¼” deep using the 1/8” hole as a pilot hole from the backside of K-Lite KT-201-2 W/W/R ABS Pavement Marker

STEP 6: Integrating circuit into K-Lite KT-201-2 W/W/R ABS Pavement Marker.

LED is placed in LED holder and LTR-4206E Phototransistor is placed in ¼" hole. Demo Circuit 1459B-A was placed in 2 9/16" x 2 11/16" square. The Mide Volture^{TM} V20W Piezoelectric Energy Harvester was place in 1 5/8" rectangle. This is shown in **Figure 27.**

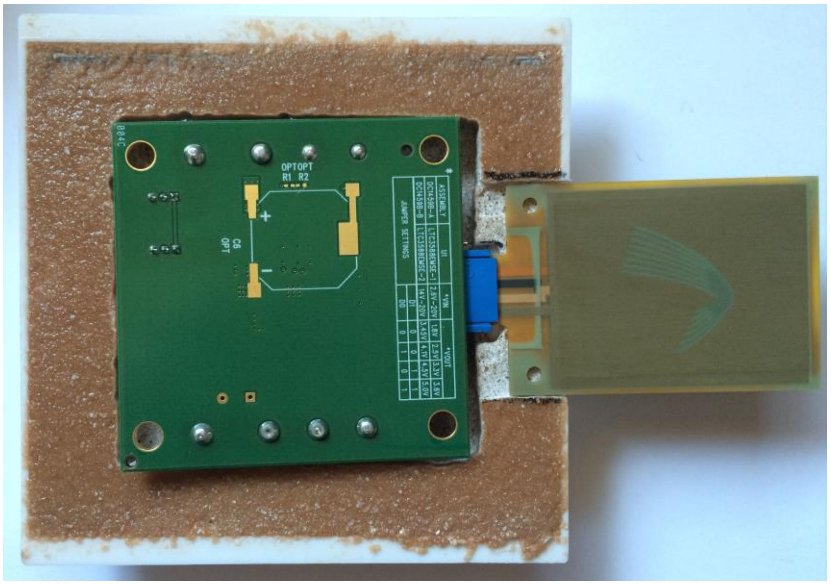

Figure 27: All components arranged properly.

For demonstration purposes the final system is held in using a 4" x 4" piece of acrylic. This is shown in **Figure 28.**

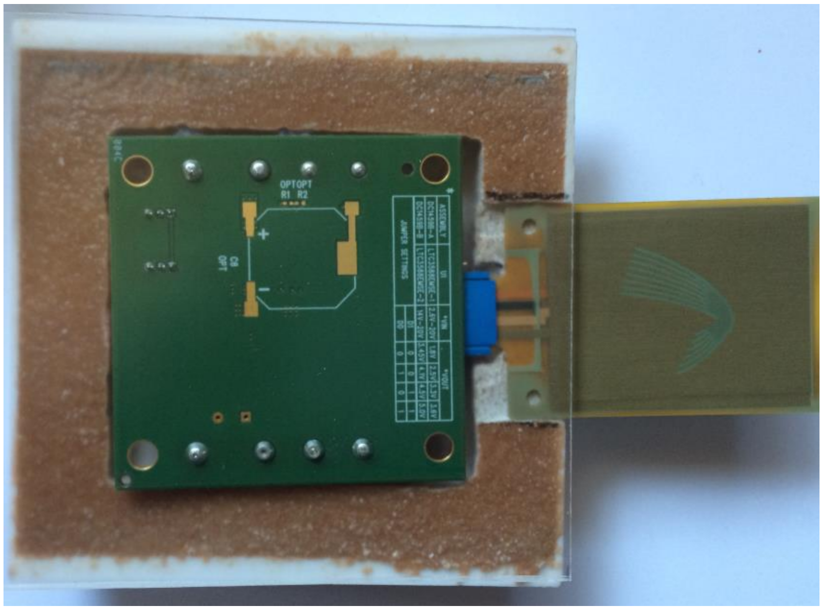

Figure 28: 4" x 4" acrylic holding in components.

Finished product is shown in **Figure 29.**

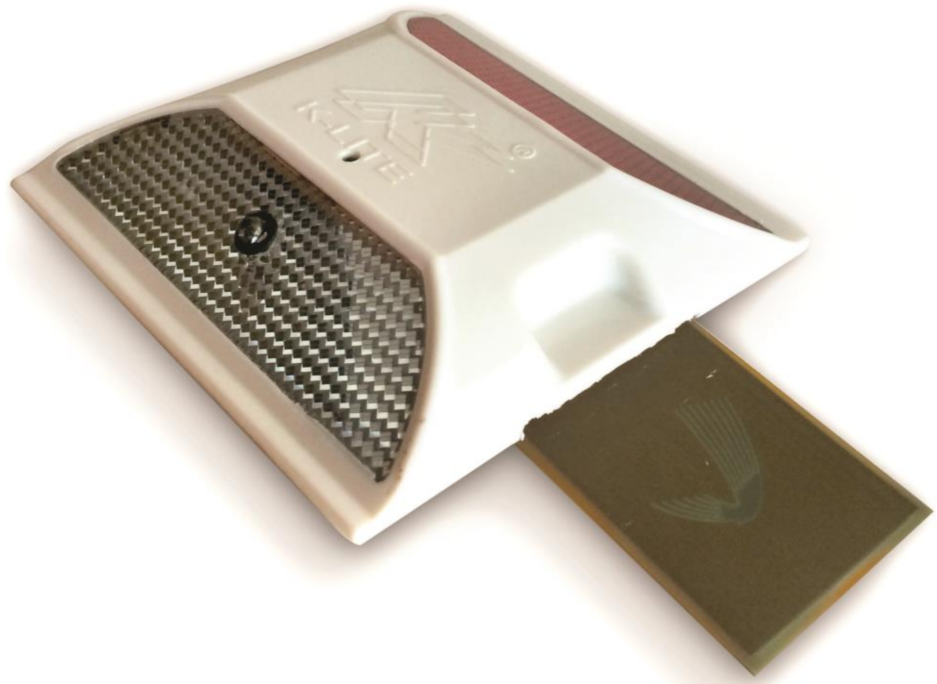

Figure 29: Finish Product

VI: Testing and Results

Circuit Testing

Testing was done by examining output waves using an Agilent InfiniiVision Series Oscilloscope to ensure that sufficient voltage were being produced to power the LED. Note that the LED used has a forward voltage of 2.7V. Also note that all oscilloscope testing was done in a darkened room to obtain results when entire circuit is operating.

The first examination point was the output of the Mide Volture^{TM} V20W Piezoelectric Energy Harvester without being connected to a load to verify functionality. The results are shown in **Figure 30.**

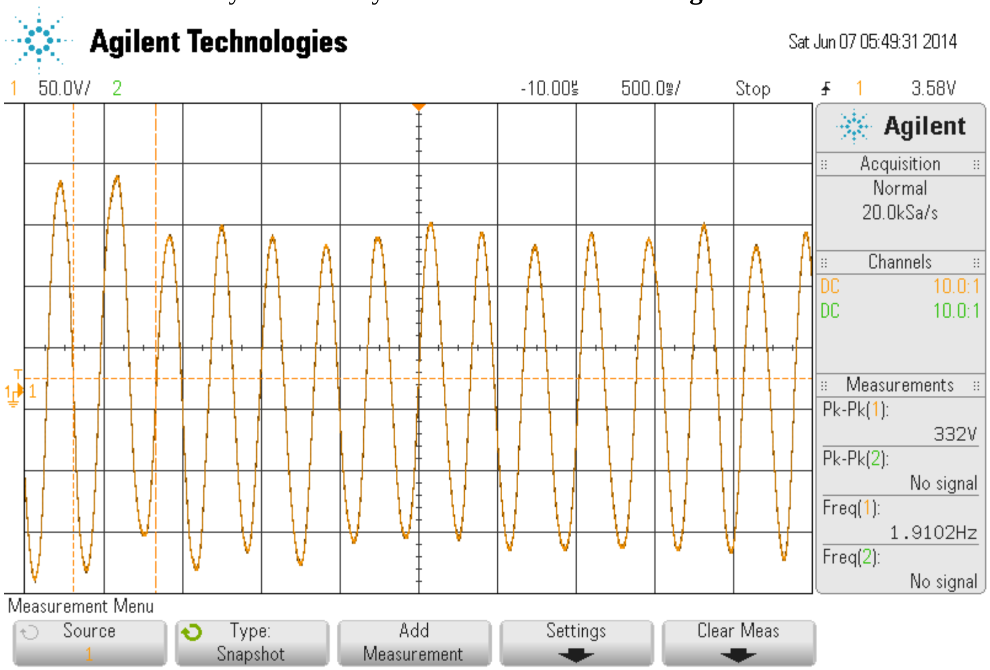

Figure 30: Oscilloscope Capture of Output of Mide Volture^{TM} V20W Piezoelectric Energy Harvester.

The results show that the voltage out of the Mide Volture^{TM} V20W Piezoelectric Energy Harvester varies depending on tip displacement as describe in datasheet and **Table III**. Since the Mide Volture^{TM} V20W Piezoelectric Energy Harvester is first displaced it outputs a positive voltage and as it returns to its original state it outputs an identical negative voltage creating an AC voltage giving the sine wave seen in **Figure 30**.

The next point of data collection was across the PZ1 and PZ2 pins of the Demo Circuit LTR-1459B-A when the Mide Volture^{TM} V20W Piezoelectric Energy Harvester was connected. Results are shown in **Figure 31.**

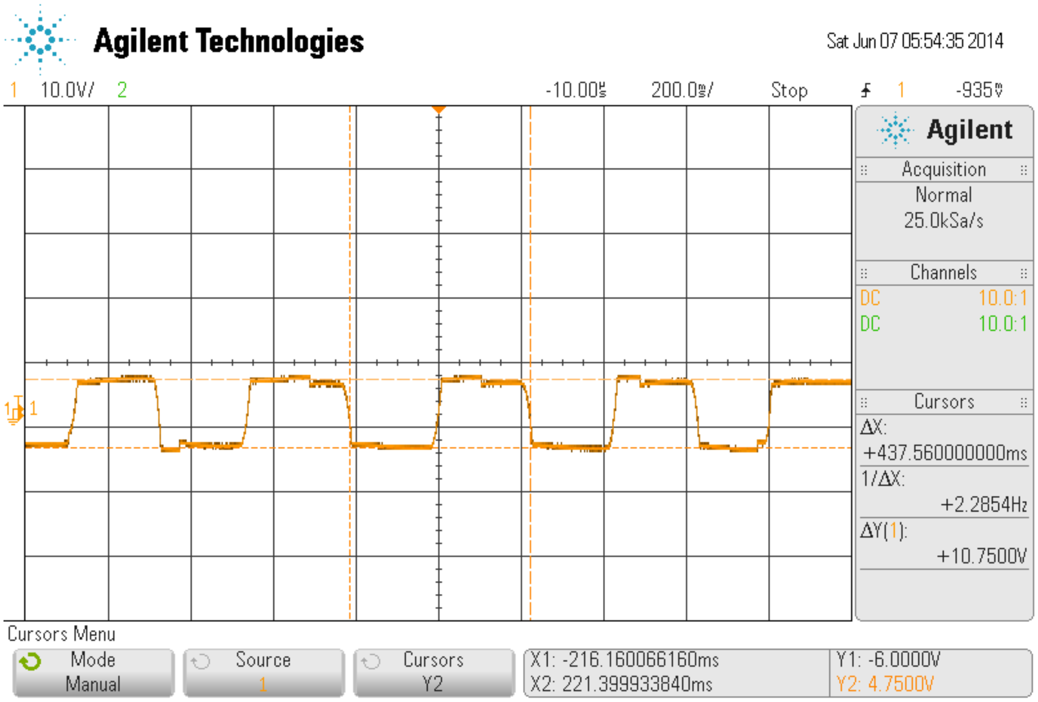

Figure 31: Oscilloscope Capture across PZ1 and PZ2.

Results show that a sufficient amount of voltage is coming across PZ1 and PZ2 to enable the buck converter on the Demo Circuit 1459B-A board allowing for an output voltage on V_{out} to be regulated by jumper 0 and jumper 1. The jumpers are both set to high. This corresponds to V_{out} = 3.4V-3.7V.

Figure 32 shows the resulting output wave across V_{out} and GND pins.

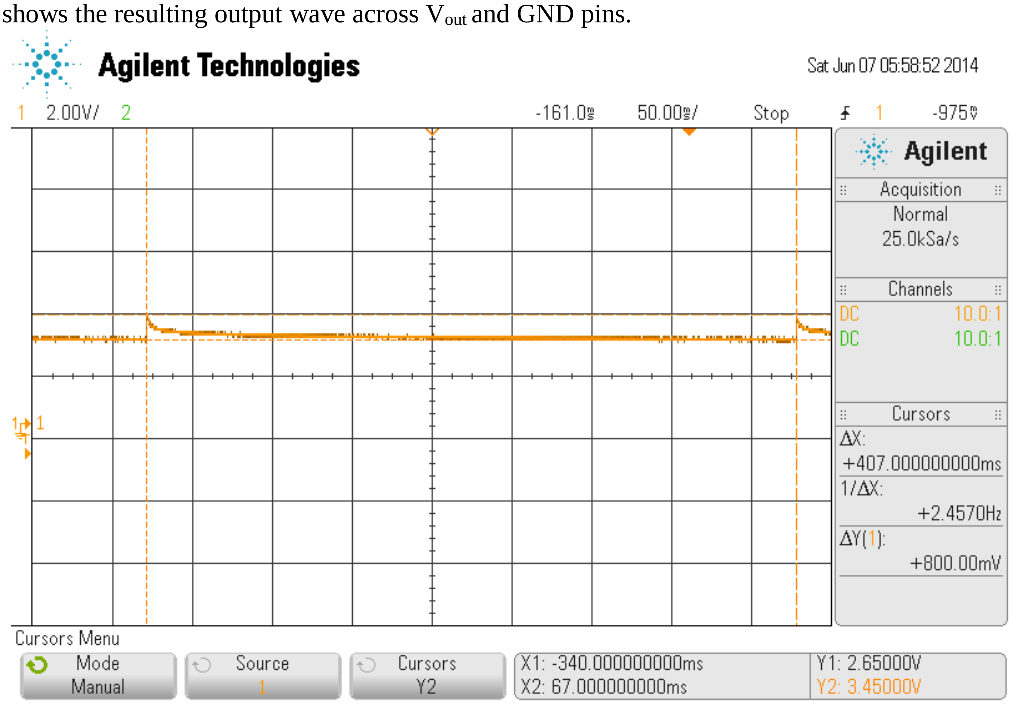

Figure 32: Oscilloscope Capture across V_{out} and GND

According to the scope capture in **Figure 32,** V_{out} is resting at 2.6V and spiked to 3.45V when there is displacement on the Mide Volture™ V20W Piezoelectric Energy Harvester. There is only one spike per displacement since the output voltage is DC and the voltage produced by the Mide Volture™ V20W Piezoelectric Energy Harvester when returning to its original location is neglected. These results show that at this point there is sufficient voltage to power the LED and that the voltage is being properly regulated base on the aforementioned jumper settings.

The next data collection point was at the base of the 2N3904 transistor. Results are shown in **Figure 33.**

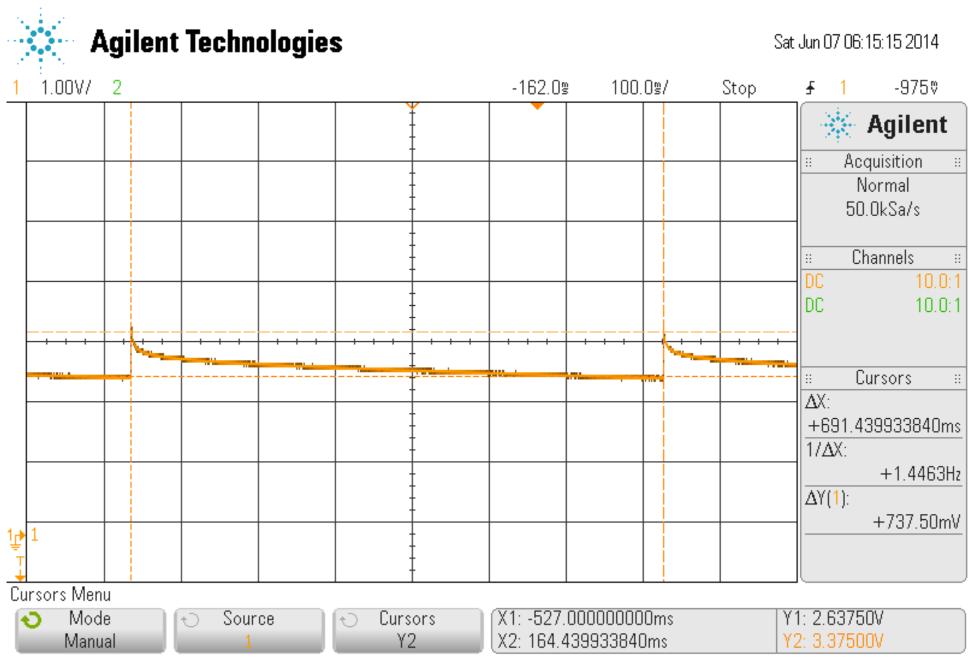

Figure 33: Oscilloscope Capture across 2N3904 Base and GND

Results in **Figure 33** are similar to the results seen in **Figure 32.** This is expected since the only device separating these two locations is a 1kΩ resistor. **Figure 33** also shows that there is a sufficient voltage (3.375V) to trigger flow through the transistor and power the LED.

The final point of data collection was that of the positive lead of the LED to verify that there is sufficient voltage to turn on the LED. Results are shown in **Figure 34.**

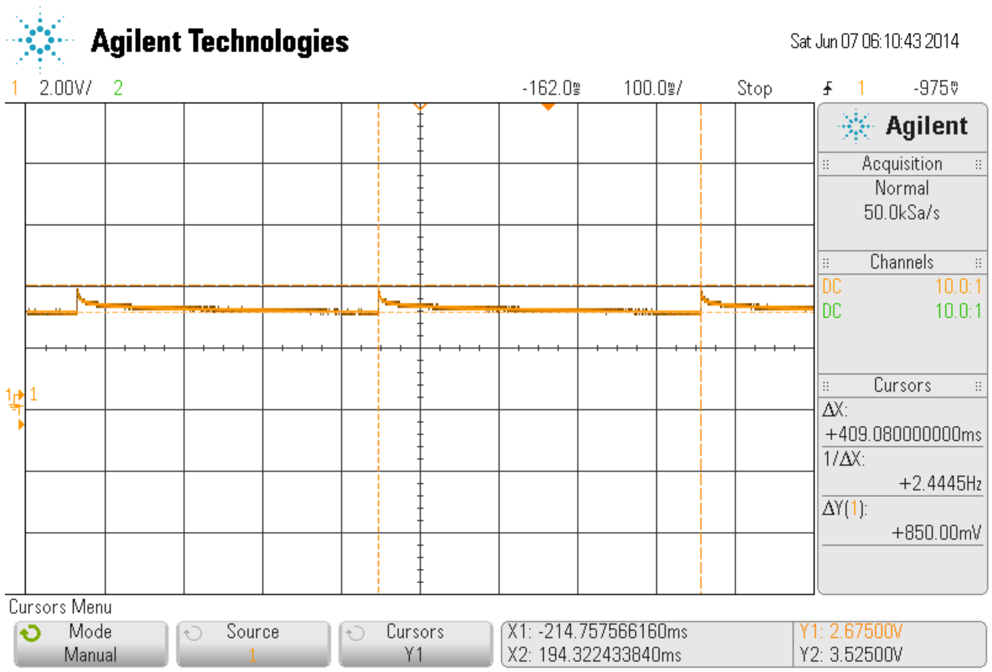

Figure 34: Oscilloscope Capture across LED.

Results of **Figure 34** shows that at the point when the Mide Volture™ V20W Piezoelectric Energy Harvester is displaced the voltage spikes from 2.675V-3.525V. Once the threshold voltage of 2.7V was surpassed the LED turned on. This was also visually verified.

Engineering Specification Testing:

Engineering Specification 1: Harvest energy through the Piezoelectric Effect**.**

Using the Mide Volture™ V20W Piezoelectric Energy Harvester combined with the Demo Circuit 1459B-A piezoelectric energy was harvested from the Piezoelectric Effect. This is verified in **Figure 30**, **Figure 31** and **Figure 32. Figure 30** indicates that the Mide Volture™ V20W Piezoelectric Energy Harvester produces a harvestable voltage. **Figure 31** indicates that this voltage is visible on the input nodes. **Figure 32** indicates that this voltage is harvested into a stable output voltage.

Engineering Specification 2: Have light sensor to increase LED life span.

The control circuitry was designed to disable the LED when there is sufficient light present, and to enable the LED when there is not a sufficient amount of light present. To verify this capability the system was taken outdoors on a bright day. When in daylight the LED does not turn on and the voltage across the LED is 0.0V. When the system is taken into a darkened room there is insufficient infrared light the LED turns ON. This voltage can be seen in **Figure 34.**

Engineering Specification 3: Circuit components must maintain ROHS compliance.

All circuit component purchased are ROHS compliant.

Engineering Specification 4: Produces visible light at a minimum distance of 50 ft.

To verify this specification the system was taken outside at night. The Mide Volture^{TM} V20W Piezoelectric Energy Harvester was then displaced. During this time an associate stood 50 ft. away to observe the light. The photo seen in **Figure 35** shows the results. Further testing resulted in visible light up to 200ft.

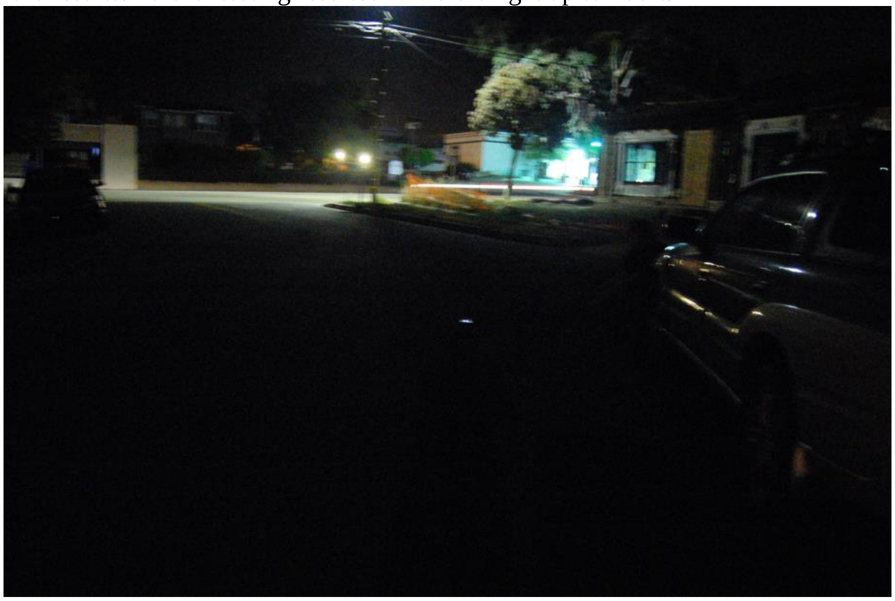

Figure 35: Photo of Piezoelectric Powered LED Street Reflector at 50ft.

Engineering Specification 5: Withstands 40 tons of pressure.

In the current prototype state of the system it cannot withstand 40 tons of pressure. This is due to the LED not being inset into the reflector. To do so requires a custom molded street reflector that did no fit into the prepared budget for the project.

VII. Conclusion and Recommendations

Conclusion

In conclusion, the development of the Piezoelectric Powered Street Reflector proved success for four of the five Engineering Specifications. The PPL Street Reflector was successful in harvesting energy using the Piezoelectric Effect through the use of the Mide Volture^{TM} V20W Piezoelectric Energy Harvester combined with the Demo Circuit 1459B-A.This is verified in **Figure 30**, **Figure 31** and **Figure 32** in **VI: Testing and Results. Figure 30** indicates that the Mide Volture^{TM} V20W Piezoelectric Energy Harvester produces a harvestable voltage. **Figure 31** indicates that this voltage is visible on the input nodes. **Figure 32** indicates that this voltage is harvested into a stable output voltage. The PPL Street Reflector was successful in integrating a light sensor to increase the life span of the LED using the control circuitry seen in **Figure 6** in **III: Design**. The PPL Street Reflector was successful in creating a circuit that is ROHS compliant by using all ROHS compliant components. The PPL Street Reflector was successful at producing visible light at a minimum of 50ft as shown in **Figure 35** in **VI: Testing and Results**. The PPL Street Reflector was not successful in withstanding 40 tons of pressure. In the current prototype state of the system it cannot withstand 40 tons of pressure. This is due to the LED not being inset into the reflector. To do so requires a custom molded street reflector that did no fit into the prepared budget for the project.

Recommendations

To further advance the development of this project a higher budget would be needed. This budget would allow for a custom molded street reflector out of Aluminum alloy eliminating the need for the timely process of modifying a current reflector design. This would also allow for all components to sit properly in a protective environment to fulfill the Engineering Specification calling for the reflector to be able to withstand 40 tons of pressure. Other advancements in the design would be to integrate multiple piezoelectric pads on both sides of the reflector to power more LED’s. A battery management system would also be integrated to store harvested energy when the control circuitry disables the LED’s from being illuminated. This would allow for a continuous illumination of the LED rather than only being illuminated when the piezoelectric pad is displaced.

After the completion of all the suggested advancements, some reflectors would need to be modified for data collections. These reflectors would be implemented on highways in Washington for data collection to see if the project would be a feasible solution for the issue presented.

VIII: Bibliography

[1] Khaligh, O. Onar , Energy harvesting: solar, wind, and ocean energy conversion system, 1st ed., Boca Raton: CRC Press, 2010.

[2] D. Wright, "Circuits for harvesting energy from piezoelectric devices," Patent No. 8 253 307, August 28, 2012.

[3] G. Ottman, H. Hofmann, A. Bhatt, "Adaptive piezoelectric energy harvesting circuit for wireless remote power supply, " Power Electronics, Vol. 17, no. 5, 669-676, 202.

[4] G. Ottman, G. Lesieutre, H. Hofmann, "Optimized piezoelectric energy harvesting circuit using step-down converter in discontinuous conduction mode," Power Electronics, Vol. 18, no. 2, 696-703, 2003.

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[8] S. Anton, H. Sodano, "A review of power harvesting using piezoelectric materials (2003-2006), "Smart Materials and Structures, Vol. 16, no. 3, 21, 2007.

[9] S. Roundy, P. Wright, "A piezoelectric vibration based generator for wireless electronics, "Smart Materials and Structures, Vol. 13, no. 5, 2004.

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[11] Mide Technology Corporation, "Volture™ Piezoelectric Energy Harvesters," Volture™ Piezoelectric Energy Harvesters Product Datasheet, Medford, MA: Mide Technology Corporation 2013.

[12] Linear Technology, "Demo circuit 1459B quick start guide LTC3588EMSE-1 LTC3588EMSE-2 piezoelectric energy harvesting power supply," Demo circuit 1459B Product Datasheet, Milipitas, CA: Linear Technology 2010.

[13] Lite-On Electronics, Inc., "LTR-4206E data sheet," LTR-4206E Product Datasheet, Taipei, Taiwan: Lite-On Electronics, Inc. 2013.

[14] Fairchild Semiconductors Corporation, "2N3904 / MMBT3904 / PZT3904 NPN general purpose amplifier," 2N3904 Product Datasheet, San Jose, CA: Fairchild Semiconductors Corporation 2011.

APPENDIX A — ANALYSIS OF SENIOR PROJECT DESIGN

Please provide the following information regarding your Senior Project and submit to your advisor along with your final report. Attach additional sheets, for your response to the questions below.

Project Title:PSPL Street Reflector

Student's Name: Collin Douglass Student's Signature:

Advisor's Name: Art MacCarley Advisor's Initials: Date: June 7, 2014

• 1. Summary of Functional Requirements

The PPL Street Reflector provides visible dividers on roads. It allows for safe driving during bad weather conditions. It harnesses energy through piezoelectronics. It is self-sustaining from energy harvested from cars driving over or near the energy harvest piezoelectric pad. It will only come on when there is insuffiecient light to see reflective surface of street reflector.

• 2. Primary Constraints

One challenge with creating the PPL Street Reflector is the amount of energy that can be harvested from a single car on the road, and will this energy be enough to power the LED. The main challenge that remains is how far will the light be visible during bad weather conditions. After the complettion of the PPL Street Reflector these challenges were able to be overcome. A single car possesses enough mechanical energy to produces a visible light of more than 100ft.

The most difficult portion in the creation of the PPL Street Reflector was the development of the casing. To create a custom mold required a larger order then was pratical for a prototype build and proved to be out of the allowed budget for this project. This lead to the use of modifying an existing street reflector design produced by K-Lite USA.

• 3. Economic

Some economic factors to be considered include how much will implementation cost be for the Washington State Government. is this cost feasible for their current budget for highway maintenance?

Implementation of this project will also cut insurance cost for customers were accidents are prevented. The PPL Street Reflector will also affect the Natural Capital for it will be a self-sustaining energy device that is ROHS compliant.

Costs for the project will accrue in the implementation stage and benefits will accrue at the completion of the project.

Original estimated costs can be seen in the **Table I**.

TABLE I
PPL Street Reflector Cost Estimate

Item	Cost Estimate
Piezoelectric energy harvesting Pad	$100
LT Piezo Energy Harvesting Board	$200
Street reflector	$5
Misc. parts	$25
Labor Cost	100hrs @ $10 = $1,000
Total	$1,330

Actual final cost of component parts can be seen in **Table II.**

TABLE II
COSTS

QUANTITY	COMPONENT	COST
1	LTR-4602E Phototransistor	$0.123
1	2N3904 NPN Transistor	$0.33
1	6.2 cd LED	$1.89
1	K-Lite KT-201-2 W/W/R ABS Pavement Marker	$3.87
1	LT 1459 Demo Circuit 1459B-A	$227.39
1	1/4" LED Plastic Holder	$0.50
1	Mide Volture™ V20W Piezoelectric Energy Harvester	$99.79
1	1KΩ Resistor	$0.50
96	Labor Hours	$960

Total Cost: $1300.39

The project will essentially earn no money since it will be a government funded implementation process, However, those who benefit will be the drivers in the state of Washington. This project will emerge once prototype is completed and funding has been provide. Once implemented the product will last the duration of the life span of the LED and maintenance is minimal since the PPL street reflector will be self-sustaining. Other maintenance would be on a case to case basis.

Original estimated development time can be seen in **Chart 1** and actual development can be seen in Chart 2.

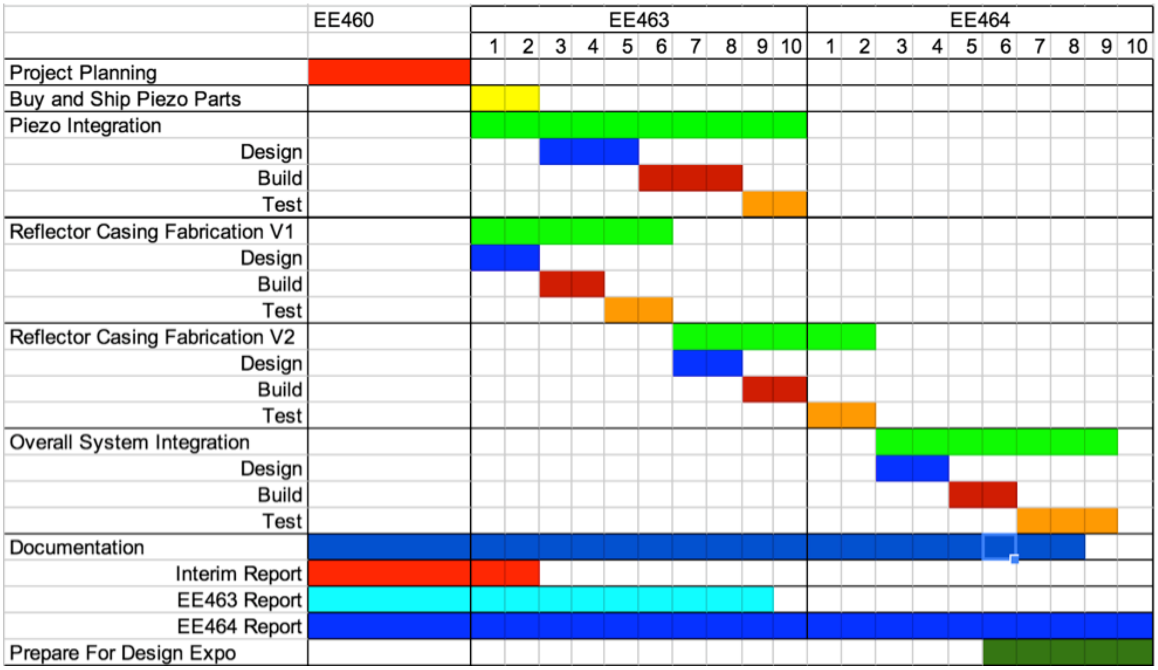

Chart 1: Projected Gannt Chart for PPL Street Reflector

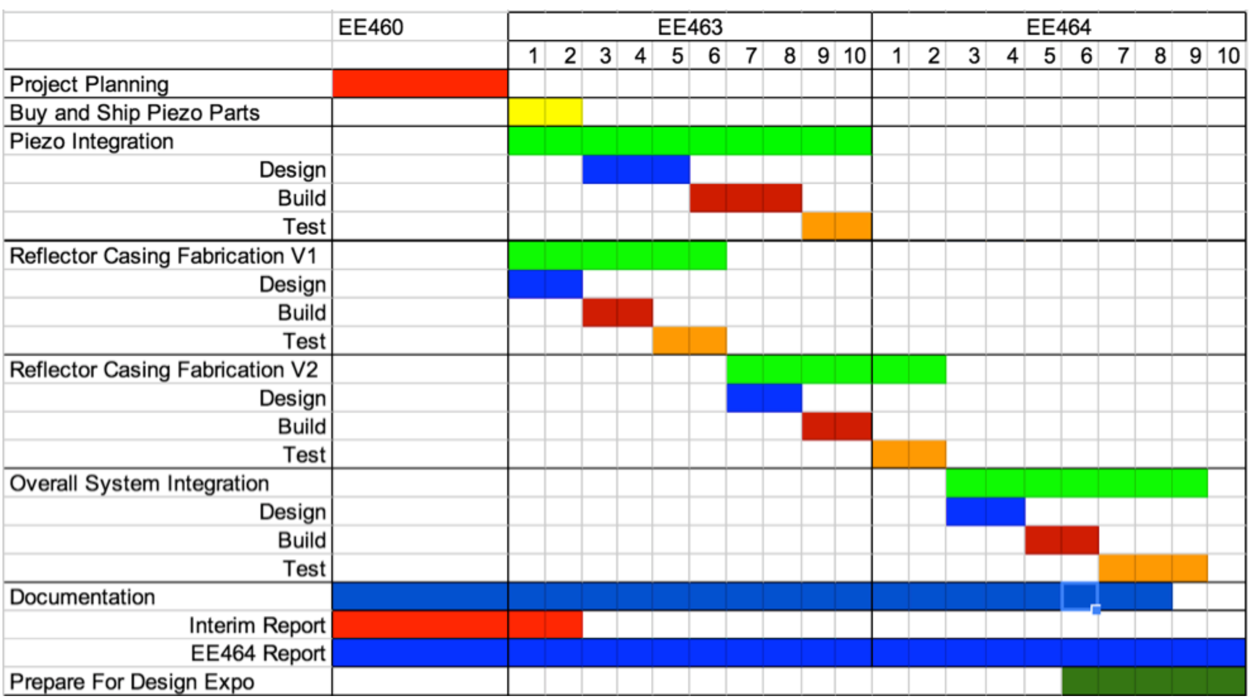

Chart 1: Actual Gannt Chart for PPL Street Reflector

After the completion of the PPL Street Reflector it will be modified to be a data collection device to be implemented on a highway. The data collected during this process will give further insight into the feasablility of the PPL Street Reflector.

• 4. If manufactured on a commercial basis:

Estimated number of devices sold per year would be around 500,000. This would change depending on how many miles of road will be implemented with the PPL Street Reflector. The manufacturing cost for each device at this stage is around $340 and is subject to change with technological advances. This cost for one PPL at 100% mark up would be $680 and would total to a profit of $170,195,000.

• 5. Environmental

The environmental impacts of my project are that is will continue progress to natural resource based technology. However some negative impacts include that it could create more carbon dioxide into the environment from increased travel during bad weather conditions.

• 6. Manufacturability

Issues with the manufacturing of the device is the hands on manufacturing process. However, initial product can be redesigned to be more easily manufactured in a factory setting.

• 7. Sustainability

The PPL Street Reflector runs off of renewable energy allowing for a self-sustaining device. It can also be upgraded to have a larger piezoelectric pad to cover wider roads and create a larger energy harvesting area. This can be done in conjunction with Mide technologies who makes custom piezoelectric pads. An issue that will be presented with this upgrade will be the quality and efficiency of the device which will have to be addressed as upgrades are made.

• 8. Ethical

The ethical framework used during the creation and implementation of the PPL Street reflector are The Common Good Approach and the Utilitarian Aprroach. The Common Good Approach describes that life in a community is a good in itself and our actions should contribute to that life. The Utilitarian Approach is an approach that provides the most good or does the least harm, or, to put it another way, produces the greatest balance of good over harm. Decreasing accidents and bettering the community's way of life weigh upon both approaches through completion of the PPL Street Reflector.

• 9. Health and Safety

Safety concerns of the current design include the inhalation of solder fumes and dust from the tightly inherent potting compound that is grinded out of the K-Lite KT-201-2 W/W/R ABS Pavement Marker, but the device itself is created to create safer driving practices lowering safety concerns while driving during bad weather conditions.

• 10. Social and Political

A political issue that arises from this project is government budgets allocated for streets and highway renewal and maintenances. The budget that is allocated for a design such as the PPL Street Reflector will also dictate whom it will impact based on the areas were the reflector is needed. In implemented areas, the drivers in that area will be impacted and be an indirect stakeholders. The political representatives in these areas will be the direct stakeholders in getting the funding needed. Both indirect and direct stakeholders will benefit equally in better protecting the safety of themselves and others on the road. One concern that arises is where does the funding for the project come from, and what other areas could the funding of this project have gone to.

• 11. Development

As development of the PPL street reflector has progressed I have gain a greater knowledge of piezoelectric power sources and how to harness said energy.

Literature Research

[1] Khaligh, O. Onar , Energy harvesting: solar, wind, and ocean energy conversion system, 1st ed., Boca Raton: CRC Press, 2010.

[2] D. Wright, “Circuits for harvesting energy from piezoelectric devices,” Patent No. 8 253 307, August 28, 2012.

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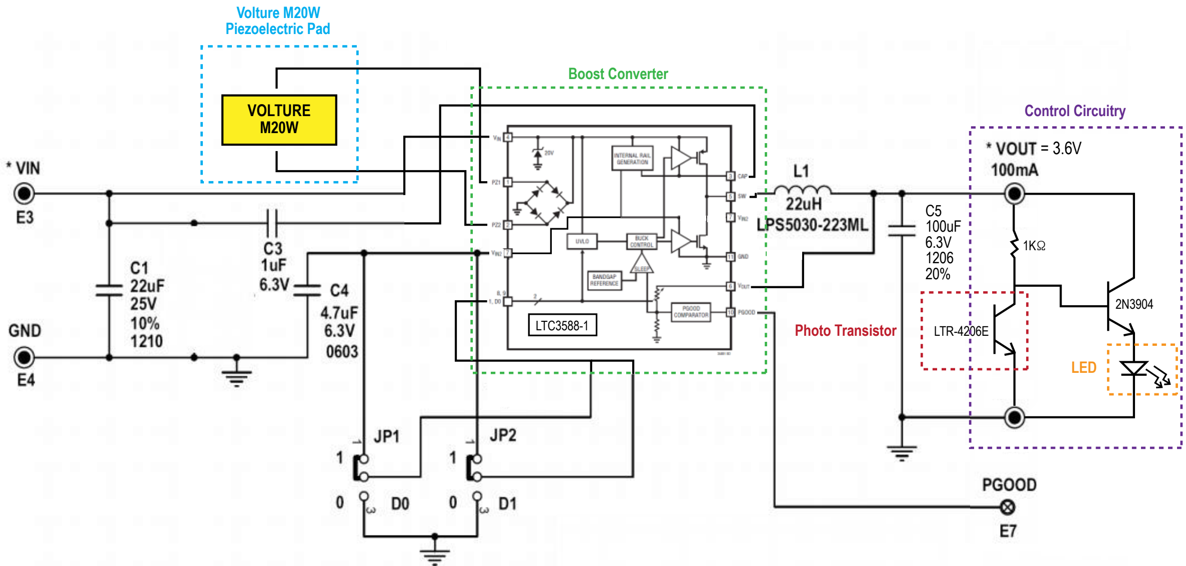
[14] Fairchild Semiconductors Corporation, “2N3904 / MMBT3904 / PZT3904 NPN general purpose amplifier,” 2N3904 Product Datasheet, San Jose, CA: Fairchild Semiconductors Corporation 2011.

APPENDIX B — SCHEMATIC



APPENDIX C — PARTS LIST, COST, TIME SCHEDULE

TABLE I
PARTS LIST

QUANTITY	COMPONENT
1	LTR-4602E Phototransistor
1	2N3904 NPN Transistor
1	6.2 cd LED
1	K-Lite KT-201-2 W/W/R ABS Pavement Marker
1	LT 1459 Demo Circuit 1459B-A
1	1/4” LED Plastic Holder
1	Mide Volture™ V20W Piezoelectric Energy Harvester
1	1KΩ Resistor

TABLE II
COSTS

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1	LT 1459 Demo Circuit 1459B-A	$227.39
1	1/4” LED Plastic Holder	$0.50
1	Mide Volture™ V20W Piezoelectric Energy Harvester	$99.79
1	1KΩ Resistor	$0.50

Total Cost: $340.39

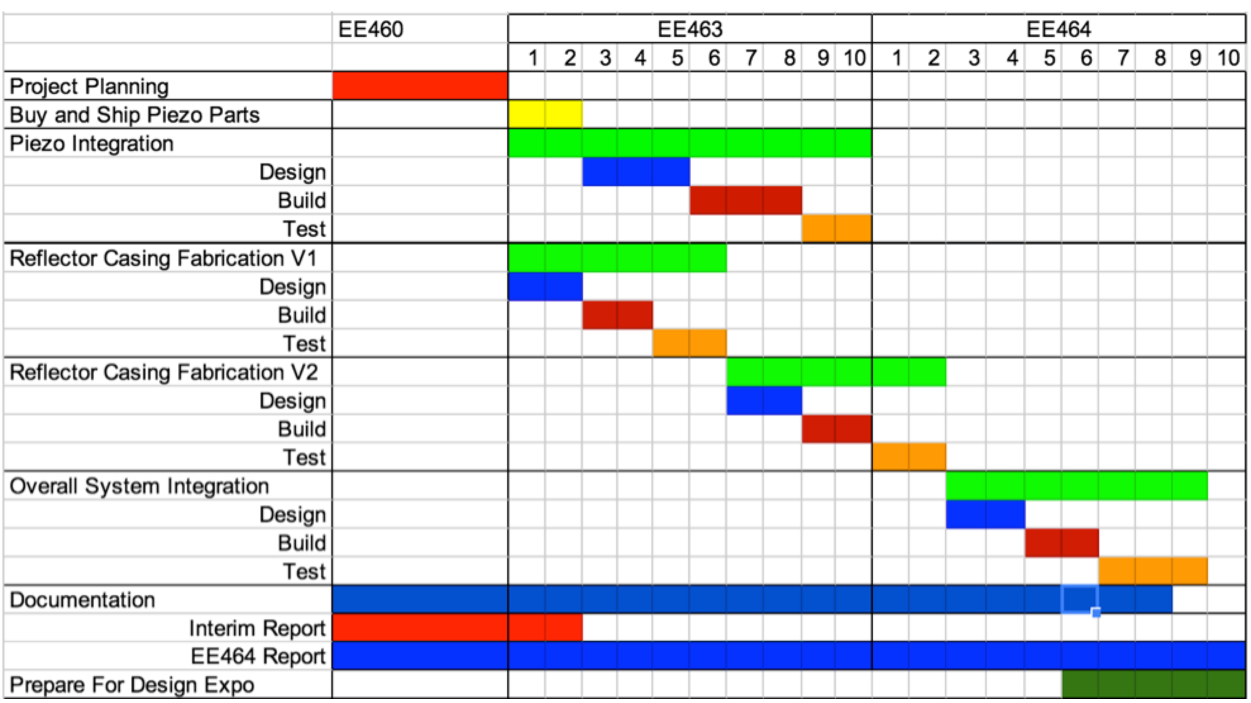

Chart 1: Time Schedule Gantt Chart