# Piezoelectric Based Energy Harvesting

**Group 3**
**April 29, 2008**

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**I pledge my honor that I have abided by the Stevens Honor System.**

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# I. Abstract

The following report contains official documentation for senior design group 3, piezoelectric based energy harvesting. Contained within this report is a comprehensive design and analysis of a new product: a piezoelectric based energy scavenging floor tile that harvests energy from foot strikes and send wireless signals for building surveillance purposes. The design will utilize ZigBee wireless transmission for communication between the tile and a remote computer. The tile will work in two different ways. During times in which security monitoring is not needed and people will be walking on the floor continuously, the tile will harvest the energy created by the piezoelectric strips. When being used as a security sensor, any step on the tile will create energy that is sent to a microprocessor and the microprocessor will send a short message to the remote computer noting that there was movement in the floor. This report includes the development, implementation, and tests conducted in the design of the prototype of the floor tile. The group was successfully able to harvest enough energy using piezoelectric materials in the floor tile to power a microprocessor and send a signal.

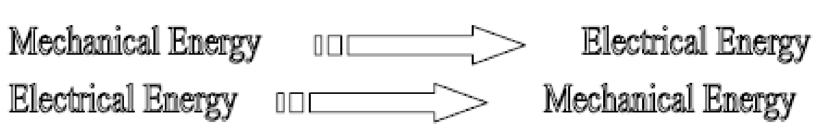
## I.1. Acknowledgement

Traditional ceramic piezoelectric materials are very brittle, and have low electrical energy outputs per unit strain. Materials research and technology improvements have changed the perspective entirely, and the application of piezoelectric to a multitude of new applications is becoming an achievable possibility in light of these technological breakthroughs. Some examples include active smart sporting goods, next generation aircraft, automobiles, motorcycles, wireless sensors, acoustical equipment, sports gear, industrial equipment, infrastructure, apparel and more. A company by the name of Advanced Cerametrics (ACI) in Lambertville, NJ, is a pioneer in this technology breakthrough. They produce a composite material with an aluminum substrate, and PZT piezoelectric fibers spun into the material. ACI's composite materials generate ten times the amount of power from mechanical energy as other flexible forms of piezo materials, and life in the range of millions of cycles. A working relationship with Advanced Cerametrics has already been established, and they will function as a partner, consultant and material supplier for the duration of this project.

# II. Implemented Prototype

### *II.1. Introduction*

Piezoelectric materials create electrical charge when mechanically stressed. The converse effect is also true for these materials, meaning application of an electrical force can cause mechanical movement. The below diagram summarizes this unique material property.



The material properties described above offer three very unique ways to develop a new and exciting commercial application:

1) Signal Generation – electrical energy output of the material in response to strain is proportional, can be used as a sensor

2) Energy Harvesting – trickle charge a battery, capacitor, or other energy storage device from repeated strains and/or oscillation

3) Geometry Manipulation – feed varying voltages into material to create strains/oscillations

Traditional ceramic piezoelectric materials are very brittle, and have low electrical energy outputs per unit strain. Materials research and technology improvements have changed the perspective entirely, and the application of piezoelectrics to a multitude of new applications is becoming an achievable possibility in light of these technological breakthroughs. Some examples include active smart sporting goods, next generation aircraft, automobiles, motorcycles, wireless sensors, acoustical equipment, sports gear, industrial equipment, infrastructure, apparel and more.

A prototype is defined as, “an original type, form, or instance serving as a basis or standard for later stages” and “an original, full-scale, and usually working model of a new product.” The prototype developed by the team uses two of the concepts listed above, signal generation and energy harvesting. The team has created a floor tile design that uses new innovative PZT fibers to collect electricity from a person walking. The harvested energy is used to power a microprocessor and wireless transmitter to detect a step on the tile and transmit a signal to a wireless security monitor, respectively.

The prototype for this project consisted of a floor tile made out of Lexan in which four piezoelectric strips were mounted inside using an adjustable aluminum mounting block, electrical components were mounted to the sidewall of the floor tile, and an actuation bar was mounted so that it was just enough to flick the strips using the actuation system. The electrical components consisted of four rectifiers connected to the positive and negative ends of the piezoelectric strips. The outputs of the rectifiers were connected in parallel to provide power to the energy harvesting module, which stores the energy from the people stepping on the floor tile. The energy harvesting module’s output was connected to a microprocessor, which was supposed to power and send a signal to a wireless transmitter. The wireless transmitter sends a message to a graphical user interface indicating that someone has stepped on the floor tile. However, the implemented prototype that was displayed at the Senior Design Expo consisted everything but the wireless component of the prototype. The group was not able to successfully integrate the wireless transmitter with the electrical circuitry as it will be explained in the sections below.

### *II.2. Prototype Specification*

This section will provide detailed design and functionality specifications of the main components of the project. For reference, a system level diagram (Appendix B) and circuit level diagram (Appendix C) of the prototype have been provided in the appendices. Also, all critical parts used in the prototype are listed in Appendix D.

The first component is the oscillating piezoelectric strip. To increase output voltage, the mechanical group incorporated 4 piezoelectric strips into the final prototype. Our testing results showed an average output of 39 volts from a single strip when deflected. The output from each strip was connected together, passed through individual rectifiers, and entered the energy harvesting PCB in series. Due to using the energy harvesting PCB, impedance matching was no longer a concern. The previous design report specified a resistor being placed in series with the output of the piezoelectric strip. According to our sponsor Advanced Cerametrics, the energy harvesting PCB addresses the impedance matching issue.

The second component is the energy harvesting circuitry. As previous stated the group used an energy harvesting PCB (EH301) developed by ALD. According to the engineers at Advanced Cerametrics, this PCB could harvest enough energy to charge a 1000uF capacitor in only a few flicks of the piezoelectric strip. The group decided to use this PCB after a strong recommendation from Advanced Cerametrics. For implementation, the positive and negative input from the piezoelectric strips was connected to the positive and negative inputs of the bridge rectifier, and then to the PCB. Once adequate energy was provided to charge the 1000uF capacitor to 5.3V, it discharges to the microprocessor through an output pin. The board has four output pins: Output, ground, capacitor voltage, and a pin to discharge the capacitor before it reaches 5.3V. For more information on the energy harvesting PCB, see the datasheet referenced in section (IV).

The third component is the microprocessor. The group used PIC16F877a obtained from the Engineering Design 1 Lab, which has an operating voltage between 3.3 and 5 Volts. Due to the implementation of the energy harvesting PCB, the functional requirements of the microprocessor have changed. Previously, the microprocessor was to be powered in sleep mode all night using the energy stored during the day from a large capacitor. If the tile was stepped on, an interrupt would be triggered waking the microprocessor. Once awake, the microprocessor would power the ZigBee transmitter and send a USART signal to the ZigBee device for transmission. The updated configuration no longer requires the microprocessor to be powered in sleep mode. The microprocessor is now powered from the output discharge of the capacitor in the energy harvesting circuitry. Power and a USART signal are then provided to the ZigBee transmitter. This program runs in a loop until the capacitor is drained beyond the necessary level to power the microprocessor. For more information on the microprocessor, see the datasheet referenced in section (IV).

The fourth and final component to the project is the ZigBee transmitter. The functionality of the ZigBee transmitter has changed slightly. It is no longer powered in sleep mode from the microprocessor. It is simply powered to 3.3 volts from the microprocessor when the tile is stepped. At that time, the transmitter receives a USART signal from the microprocessor and it transmits a warning signal to a receiver terminal. The power supplied from the microprocessor is 5 volts. This is reduced to 3.3 volts using a voltage divider where R1 = 3K and R2 = 5K.

### Test Procedures

The most critical test in our project was testing the energy harvesting circuitry. The test setup required one piezoelectric strip, a bridge rectifier, and the energy harvesting device from ALD. The positive and negative outputs of the strip are connected to the positive and negative input of the bridge rectifier, and then the energy harvesting PCB. A multimeter is connected to the output of the capacitor on the PCB (positive lead) and ground of the PCB (negative lead). The strip is then flicked until the capacitor reaches 5.3 volts and discharges to 3.2 volts. The level of voltage increase is noted as the capacitor charges after each flick. After the discharge, the process is then repeated and the amount of flicks is recorded again. This test was most significant, because it enabled us to determine the output energy available to power the microprocessor.

The microprocessor was tested to verify the USART signal was being sent properly. To do this, the microprocessor was powered with a power supply, and the programmed output pin was connected to an oscilloscope. The oscilloscope was then adjusted to adequately view the signal. This test was crucial to determine of the proper USART signal was being sent to the ZigBee Transmitter. Also, to determine of the pins were set correctly, a resistor was placed in series with an LED running to ground. This was a simple test to verify the outputs.

The test for the ZigBee transmitter is the least complex. The ZigBee is powered with a power supply to 3.3 volts. The microprocessor sends the USART signal, and the output at the receiver terminal is watched. If a packet is received, the transmission was successful.

## *II.3. Prototype Performance and Evaluation*

The capabilities of the final design did not vary too much from our planned outcomes. Our final prototype was able to charge a 5.3 volt capacitor from 3.1 volts to 5.2 volts in approximately 20 steps on the tile. To test this, the energy harvester's V+ pin, which measures the voltage on the capacitor, was measured using a voltmeter. While stepping on the tile, we were able to observe an average charge of 100mV per step. The microprocessor was programmed to turn on an LED, and when it turns on, it would denote exactly when the harvester reached 5.2 volts. Figure B (Appendix E) shows the breadboard circuit and the LED connected to the microprocessor. As explained earlier, the harvester charges a capacitor and when the internal logic recognizes that the capacitor reaches 5.2 volts, it begins to output the voltage. Using a rectifier for each strip, the group was successfully able to store energy using the piezoelectric output. The rectifiers and harvester circuit are shown in Figure A (Appendix E), on the pc board in the tile. The team was also able to show that the LED stayed lit for approximately 3 seconds, giving plenty of time for it to send numerous ZigBee messages. Ideally, the microprocessor would have been programmed to output one message to me transmitted then immediately go back into sleep mode. This would save the energy on the capacitor to last throughout the night.

To simulate the voltage we would receive from the piezoelectric strips, we set a function generator to 25 Hz and 7 volts peak to peak. We would apply this voltage to the positive and negative inputs of the harvester circuit to verify that it was working correctly. We would also use this test procedure to test our own energy harvesting circuit that was made up of a one farad capacitor.

The team was unable to successfully transmit a ZigBee signal because of microprocessor difficulties. After looking at the UART output pin on an oscilloscope, the oscillator was deemed to slow at 45Hz for the ZigBee to read it as a UART signal. The team first thought the PIC was outputting square waves, but the square waves turned out to be UART signals that were significantly slowed down. The resistor and capacitor of the RC oscillator were swapped to create a higher clock frequency but it must have made the PIC unstable as the output of the UART became only noise. As a last minute idea, the ZigBee transmitter was programmed to output random messages when it turns on instead of using the input from the PIC's UART. This worked when it was powered with an independent power supply, but when powered by the PIC, it would not turn on. There was difficulty in finding a ground for the ZigBee, as the grounds were somehow shorting and only supplying 1.9 volts of the 3.3 necessary volts to the transmitter.

In testing the ZigBee, a GUI was designed so when the receiver received any packets of data from the transmitter, it would change to a red screen with "WARNING" written across it as seen in Figure D (Appendix E). We used this as an easy way to distinguish if the receiver was receiving any data whatsoever. The transmitter was supplied 3.3V from a power supply and had the UART output of the PIC to the Din pin. Using this configuration, we would troubleshoot the UART signal to try and understand why it would not work correctly. An LED was also connected to the ON pin to show the status of the transmitter as on or off, and another LED connected to the transmitter that would be lit of the transmitter was communicating with the receiver. The receiver was connected to a laptop via the supplied Maxstream board. This board was also helpful in troubleshooting as it had various status LEDs that would show if it was receiving any data.

The only operating limitations were regarding the use of the tile. When stepping on the tile, it should simulate real world operation. So, after a step, the piezo strips should be allowed to stop vibrating before the tile is allowed to be stepped on again. Stepping on the tile repeatedly, or before the strips stop vibrating, will not get the most voltage from the tile or could stop the piezo strip from vibrating altogether. Also, the tile should be stepped on evenly so the tile remains level and each of the strips is actuated evenly.

In all, the group was able to harvest energy in a new application. The ZigBee worked independently of the microprocessor, but was unable to be successfully implemented into the design. Throughout the project, the team had trouble integrating all the pieces of the project together when they worked independently of each other.

### *II.4. Financial Budget*

Working with a budget of roughly $250, the financial budget below is the actual costs of the team's expenses throughout the semester. All expenses cover what it will cost to harvest the energy from the piezoelectric application designed by the mechanical engineering team. As noted below, the team went over the budget by roughly $28. This could have been prevented since the team bought parts that were not used at all.

## Project Expenses

| Item | Vendor | Price | Quantity | Total |
|---|---|---|---|---|
| Energy Harvesting Module | Mouser Electronics | $49.53 | 2 | $125.41 |
| Resistors | Mouser Electronics | $0.50 | 8 | $10.00 |
| Power Transformer | Digikey | $12.45 | 1 | $20.72 |
| Inverter Voltage | Digikey | $5.60 | 1 | $5.60 |
| Protoboard | Marlin P. Jones & Assoc. | $3.00 | 1 | $3.00 |
| Capacitors | Marlin P. Jones & Assoc. | $0.45 | 8 | $3.60 |
| Protoboard w/ bus strips | Marlin P. Jones & Assoc. | $3.21 | 1 | $3.21 |
| Shrink tubing | Marlin P. Jones & Assoc. | $0.24 | 5 | $1.20 |
| LED's - Green | Marlin P. Jones & Assoc. | $0.12 | 100 | $12.00 |
| Xbee Socket | Sparkfun Electronics | $1.25 | 1 | $9.10 |
| Xbee Breakout board | Sparkfun Electronics | $2.95 | 1 | $9.55 |
| Xbee Headers | Sparkfun Electronics | $2.50 | 1 | $2.50 |
| Breadboard | Digikey | $53.23 | 8 | $53.23 |
| Full Bridge Rectifier | Radioshack | $9.81 | 4 | $9.81 |
| Rosin | Radioshack | $5.52 | 1 | $5.52 |
| Brochure Copies | Stevens Print Shop | $0.12 | 30 | $3.48 |
| | | **TOTAL** | | $277.93 |

* Total Prices include tax and shipping costs

Based on the final prototype the team has concluded the following parts list necessary to completely build a working prototype of the energy harvesting module.

## Parts List

| Item | Vendor | Price | Quantity | Total |
|---|---|---|---|---|
| Piezoelectric Strips [1] | Advanced Cerametrics | $60.00 | 4 | $240.00 |
| Bridge Rectifiers [2] | Mouser | $1.59 | 4 | $6.36 |
| Bread Board [3] | DigiKey | $24.60 | 1 | $24.60 |
| Protoboard [4] | Marlin P. Jones & Assoc. | $22.95 | 1 | $22.95 |
| Energy Harvesting Module [5] | Mouser | $49.83 | 1 | $49.83 |
| PIC16F877a Microcontroller [6] | MCPros | $6.14 | 1 | $6.14 |
| 3K Resistor [7] | Radioshack | $0.99 | 1 | $0.99 |
| 5K Resistor [8] | Radioshack | $0.99 | 1 | $0.99 |
| ZigBee Module [9] | Digi MaxStream | $21.00 | 2 | $42.00 |
| Computer Terminal | Personal Cost | $0.00 | 1 | $0.00 |
| Miscellaneous | | $5.00 | 1 | $5.00 |
| | | **TOTAL** | | $398.36 |

### *II.5. Project Schedule*

By looking at the Gantt Chart (Appendix A), one can see that the team spent 122 days working on the project. Consider that each day the team worked on the project two hours (give or take), brings the total to 244 hours. With the final month to Senior Design day, the team also spent numerous hours in the lab trying to get functionality to the piezoelectric harvesting device. The team spent on average 3 days a week and roughly 3 hours a day in the lab. With this, the final month alone leading to Senior Design Day, the team spent over 30 hours working in the lab. Combine this number with the previous total gives the total man-hours expended on the project to be over 270 hours.

Parts not working, wrong parts ordered, and simply not having the system work the way it is expected to work contributed to the various tasks the team underwent to accomplish a working prototype. Due to the various obstacles that the team had to go through trying to get the project to work, further delays to the project timeline was inevitable. Delays ranged from two days to as much as a week.

## III. Conclusion

The piezoelectric based energy scavenging floor tile that harvests energy from foot strikes was implemented almost to the full extent as stated in the interim report this semester. The designed prototype for this project consisted of a floor tile made out of Lexan in which four piezoelectric strips were mounted inside using an adjustable aluminum mounting block, electrical components were mounted to the sidewall of the floor tile, and an actuation bar was mounted so that it was just enough to flick the strips using the actuation system. The electrical components consisted of four rectifiers connected to the four piezoelectric strips. The outputs of the rectifiers were connected in parallel to provide power to the energy harvesting module, which stored the energy from the people stepping on the floor tile. The stored energy was then used to power a microprocessor pin high lighting up an LED, which indicated that the floor tile generated enough energy to power a microprocessor to potentially send a wireless signal.

The project was completed based on the principle of proving a concept. This was to show that piezoelectric material when combined efficiently with the right mechanical and electrical components can power a self-sustained surveillance system. For this project, performance, cost, and commercial applicability were not taken into account to the full extent. The functionality and performance of the prototype can greatly improve by using low powered diodes and circuitry and creating mechanical ways of fine tuning the piezo strips to vibrate at the most efficient frequencies. The cost of the product itself would have to be analyzed taking into account the market demand and how price varies when manufacturing mass quantities as opposed to making a single prototype. For future development, the floor tile should be created with cost efficient parts such that it is an attraction in the market of security devices for high traffic areas.

Based on the results obtained, the project was a technical success in terms of effectively getting individual parts of the piezo based floor tile working. The group was successful in creating and understanding how an energy harvesting circuitry, programming a microprocessor, and sending point to point wireless signals. In addition to this, the group was able to integrate the piezoelectric strips with the harvesting circuitry and with the microprocessor by using the energy harvesting circuitry as a power source to the microprocessor. In terms of combining all parts of the project, the group was disappointed that all parts were not integrated as planned. However, the hands on work of trying to integrate the all the parts proved to be a significant learning experience.

## IV. References


Datasheet for PIC16F877A:
http://ww1.microchip.com/downloads/en/DeviceDoc/30292c.pdf

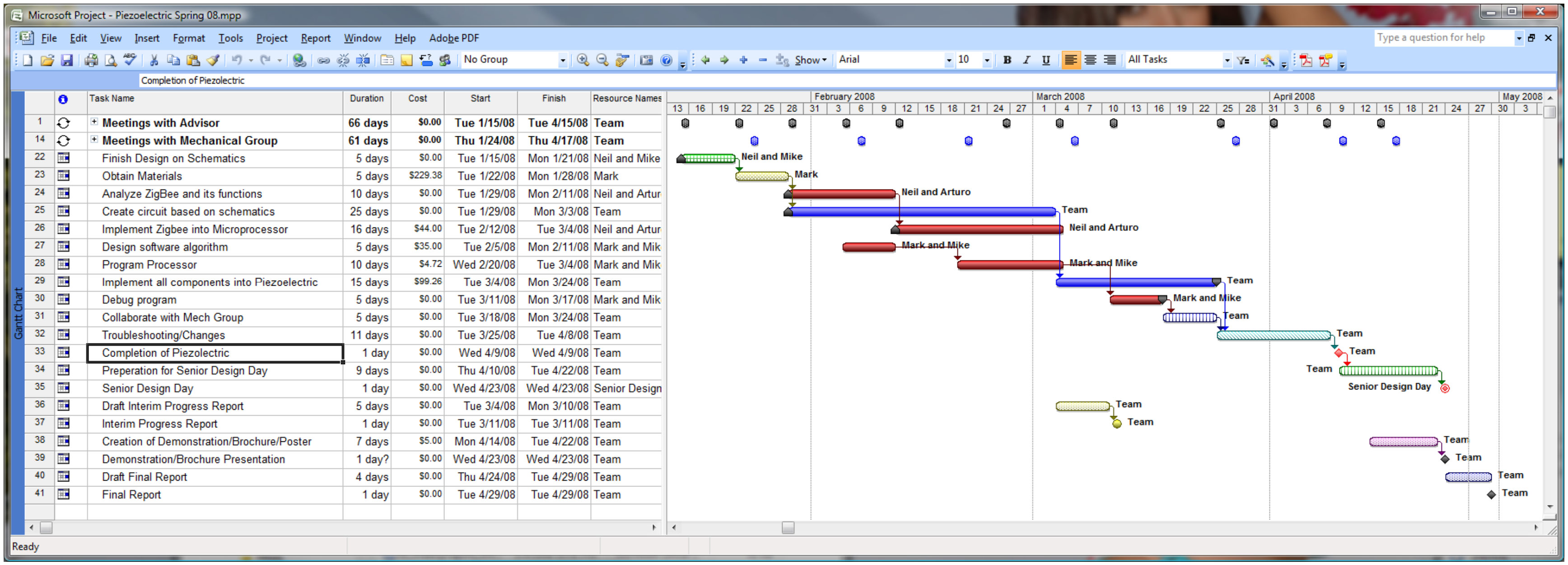
Datasheet for EH301:
http://www.aldinc.com/pdf/EH300ds.pdf

Brochure for EH301:
http://www.aldinc.com/pdf/EH300Brochure.pdf

Parts List Reference:
[1] http://www.advancedcerametrics.com/pages/energy_harvesting_components/
[2] http://www.radioshack.com/product/index.jsp?productId=2062581&cp
[3] http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail?name=923252-ND
[4] http://www.mpja.com/prodinfo.asp?number=4447+TE
[5] http://www.mouser.com/Search/ProductDetail.aspx?qs=NoieiqYAh1CVRGGWkRFRmg%3d%3d
[6] http://microcontrollershop.com/product_info.php?cPath=112_184&products_id=992
[7] http://www.radioshack.com/product/index.jsp?productId=2062324&cp
[8] http://www.radioshack.com/product/index.jsp?productId=2062324&cp
[9] http://www.digi.com/products/wireless/zigbee-mesh/xbee-series2-module.jsp

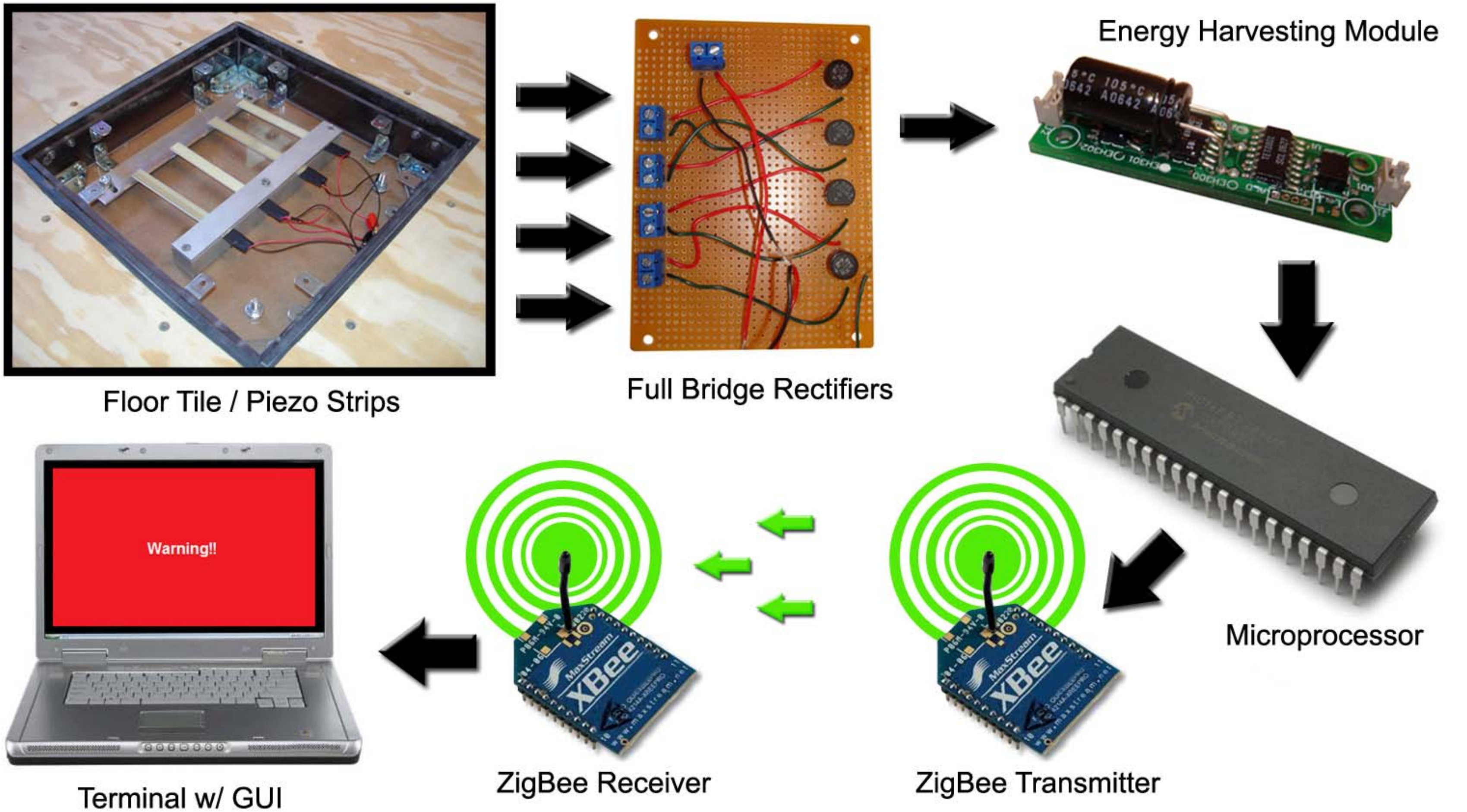
# V. Appendices

## *Appendix A: Gant Chart*

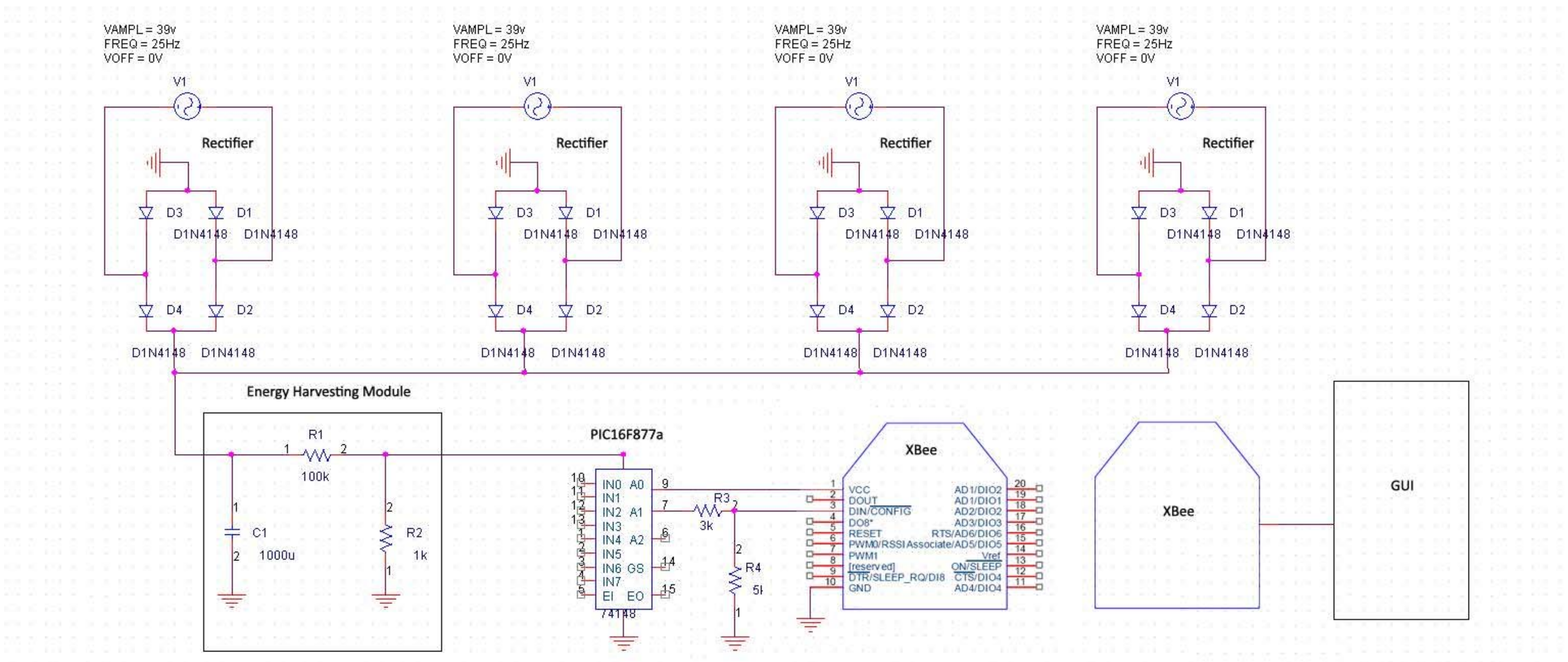


| | Task Name | Duration | Cost | Start | Finish | Resource Names |
|---|---|---|---|---|---|---|
| 1 | **Meetings with Advisor** | **66 days** | **$0.00** | **Tue 1/15/08** | **Tue 4/15/08** | **Team** |
| 14 | **Meetings with Mechanical Group** | **61 days** | **$0.00** | **Thu 1/24/08** | **Thu 4/17/08** | **Team** |
| 22 | Finish Design on Schematics | 5 days | $0.00 | Tue 1/15/08 | Mon 1/21/08 | Neil and Mike |
| 23 | Obtain Materials | 5 days | $229.38 | Tue 1/22/08 | Mon 1/28/08 | Mark |
| 24 | Analyze ZigBee and its functions | 10 days | $0.00 | Tue 1/29/08 | Mon 2/11/08 | Neil and Artur |
| 25 | Create circuit based on schematics | 25 days | $0.00 | Tue 1/29/08 | Mon 3/3/08 | Team |
| 26 | Implement Zigbee into Microprocessor | 16 days | $44.00 | Tue 2/12/08 | Tue 3/4/08 | Neil and Artur |
| 27 | Design software algorithm | 5 days | $35.00 | Tue 2/5/08 | Mon 2/11/08 | Mark and Mik |
| 28 | Program Processor | 10 days | $4.72 | Wed 2/20/08 | Tue 3/4/08 | Mark and Mik |
| 29 | Implement all components into Piezoelectric | 15 days | $99.26 | Tue 3/4/08 | Mon 3/24/08 | Team |
| 30 | Debug program | 5 days | $0.00 | Tue 3/11/08 | Mon 3/17/08 | Mark and Mik |
| 31 | Collaborate with Mech Group | 5 days | $0.00 | Tue 3/18/08 | Mon 3/24/08 | Team |
| 32 | Troubleshooting/Changes | 11 days | $0.00 | Tue 3/25/08 | Tue 4/8/08 | Team |
| 33 | Completion of Piezolectric | 1 day | $0.00 | Wed 4/9/08 | Wed 4/9/08 | Team |
| 34 | Preperation for Senior Design Day | 9 days | $0.00 | Thu 4/10/08 | Tue 4/22/08 | Team |
| 35 | Senior Design Day | 1 day | $0.00 | Wed 4/23/08 | Wed 4/23/08 | Senior Design |
| 36 | Draft Interim Progress Report | 5 days | $0.00 | Tue 3/4/08 | Mon 3/10/08 | Team |
| 37 | Interim Progress Report | 1 day | $0.00 | Tue 3/11/08 | Tue 3/11/08 | Team |
| 38 | Creation of Demonstration/Brochure/Poster | 7 days | $5.00 | Mon 4/14/08 | Tue 4/22/08 | Team |
| 39 | Demonstration/Brochure Presentation | 1 day? | $0.00 | Wed 4/23/08 | Wed 4/23/08 | Team |
| 40 | Draft Final Report | 4 days | $0.00 | Thu 4/24/08 | Tue 4/29/08 | Team |
| 41 | Final Report | 1 day | $0.00 | Tue 4/29/08 | Tue 4/29/08 | Team |

***Appendix B: Flow Chart***



## *Appendix C: Circuit Diagram*



## *Appendix D: Parts List*

### Part's List for Prototype

- (4) Piezoelectric Strips from Advanced Cerametrics, Inc.
- (4) Bridge Rectifiers
- Breadboard
- Protoboard
- Energy Harvesting Module from ALD, Inc. (EH301)
- PIC16F877a
- 3K Resistor
- 5K Resistor
- ZigBee Transmitter
- ZigBee Receiver
- Computer Terminal to Connect Receiver
- (5 ft.) Wire

## *Appendix E: Pictures from Senior Design Expo*

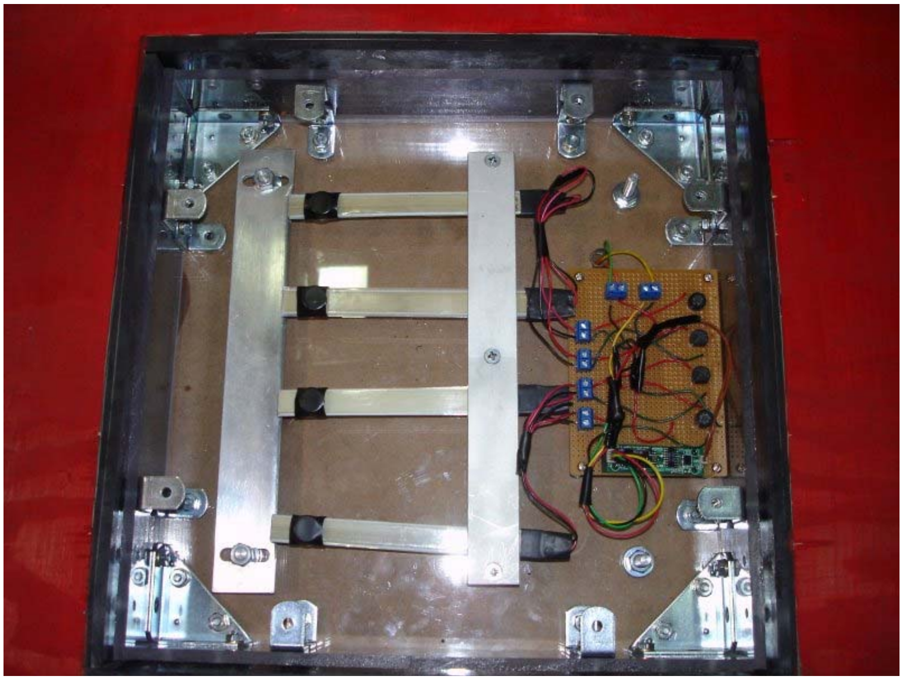


***Figure A***

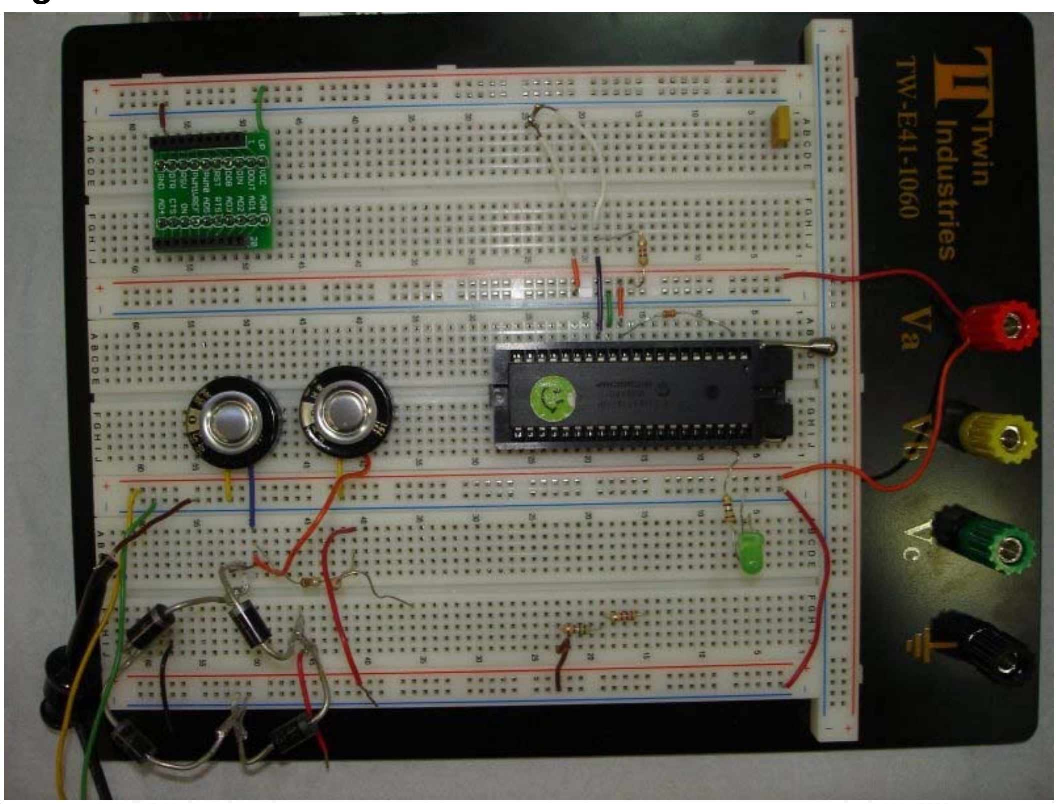



***Figure B***

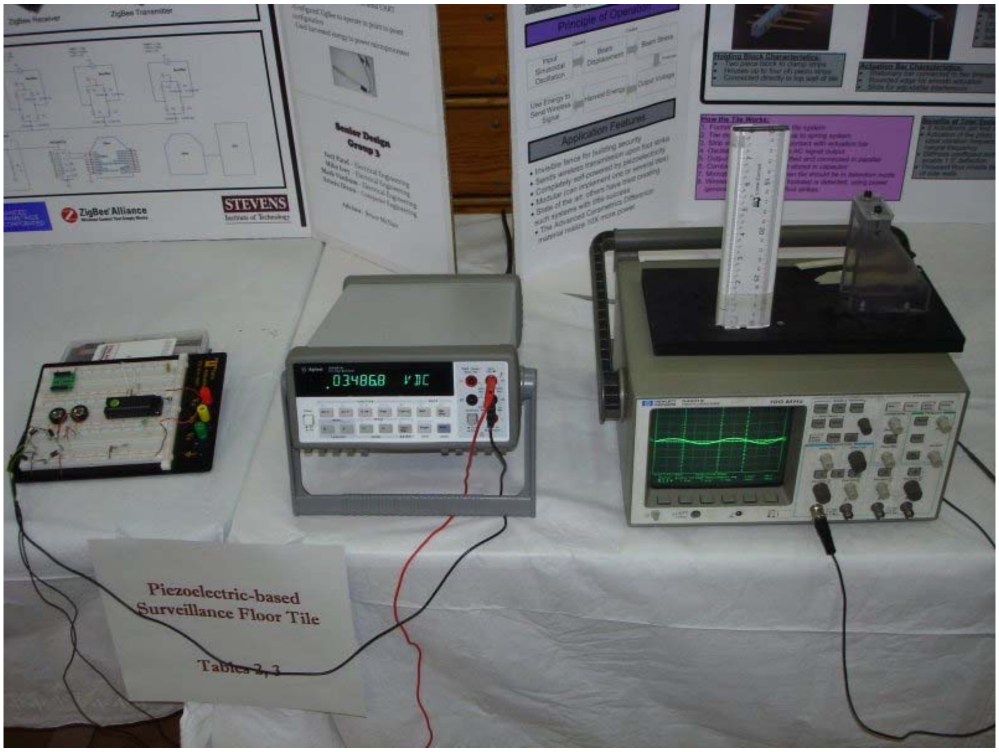



***Figure C***


***Figure D***