

# [DYNAMIC HUMAN POWER HARVESTING]

---

By

[Eduardo Cano]

[Ignacio Fuente]

[Jeongbin Rew]

Final Report for ECE 445, Senior Design, [Spring 2015]

TA: [Dennis Yuan]

06 May 2015

Project No. 53

## Abstract

This project aims to implement a device that generates electromagnetic field then converts it to a stable DC voltage to be able to charge a Li-ion battery. The electromagnetic field generator will contain a strong magnet inside coiled tube so that when it moves, electromagnetic field is induced. Then this unstable impulse-like signal is put into AC/DC converter to be able to fed into the following boost converter. For AC/DC converter, synchronous rectifier is tried using MOSFETs instead of diodes to minimize voltage drop across, with alternative choice of simple full-bridge diode rectifier. The boost converter uses inductor, capacitor and switching transistor to step up the smaller DC input to higher DC output to charge a battery.

Having each component of the circuit working, future work is still needed to gather all the parts connected so that straight from the electromagnetic field generator, the battery can be charged as desired.

# Contents

|                                                          |    |
|----------------------------------------------------------|----|
| 1. Introduction .....                                    | 1  |
| 2. Design .....                                          | 2  |
| 2.1 Magnetic Generator .....                             | 2  |
| 2.1.1 Magnet .....                                       | 2  |
| 2.1.2 Wire .....                                         | 4  |
| 2.1.3 Spring .....                                       | 4  |
| 2.2 Series Resonance Circuit .....                       | 6  |
| 2.3 Microcontroller .....                                | 8  |
| 2.4 AD/DC Rectifier .....                                | 9  |
| 2.4.1 Full-Bridge Rectifier .....                        | 9  |
| 2.4.2 Synchronous Rectifier .....                        | 10 |
| 2.5 Boost Converter .....                                | 10 |
| 2.5.1 Duty Ratio .....                                   | 11 |
| 2.5.2 Inductance .....                                   | 11 |
| 2.5.3 Capacitance .....                                  | 11 |
| 2.5.4 Actual Values and Calculated Values .....          | 12 |
| 3. Design Verification .....                             | 13 |
| 3.1 Magnetic Generator .....                             | 13 |
| 3.2 Series Resonance Circuit .....                       | 14 |
| 3.3 Full-Bridge Diode Rectifier .....                    | 15 |
| 3.4 Microcontroller .....                                | 16 |
| 3.5 Synchronous Rectifier .....                          | 16 |
| 3.6 Boost Converter .....                                | 17 |
| 4. Costs .....                                           | 18 |
| 4.1 Parts .....                                          | 18 |
| 4.2 Labor .....                                          | 18 |
| 4.3 Total Cost .....                                     | 18 |
| 5. Conclusion .....                                      | 19 |
| 5.1 Accomplishments .....                                | 19 |
| 5.2 Uncertainties .....                                  | 19 |
| 5.3 Ethical Considerations .....                         | 19 |
| 5.4 Future work .....                                    | 19 |
| References .....                                         | 20 |
| Appendix A      Requirement and Verification Table ..... | 21 |

## 1. Introduction

The world is developing faster than ever with new advances in technologies. The downsides of such fast development should not be ignored. The energy consumption needed to power our lives contribute to rampant pollution. Under these circumstances, studies on green energy have been rising and new systems have come into the spotlight. Solar plants are producing power from predicting the Sun's path so that they can maximize the exposure and wind turbines are equipped with system that chases the wind direction. This project aims similar target and tries to apply principles of kinetic power harvesting while introducing the use of digital systems to make a basis for small energy harvesting that is not possible in autonomous systems.

The idea is to implement a device that will convert the kinetic energy to a stable DC voltage. The device is to be portable and eco-friendly so that it will contribute to reduce the pollution and improve scarcity of resource from smaller scales.

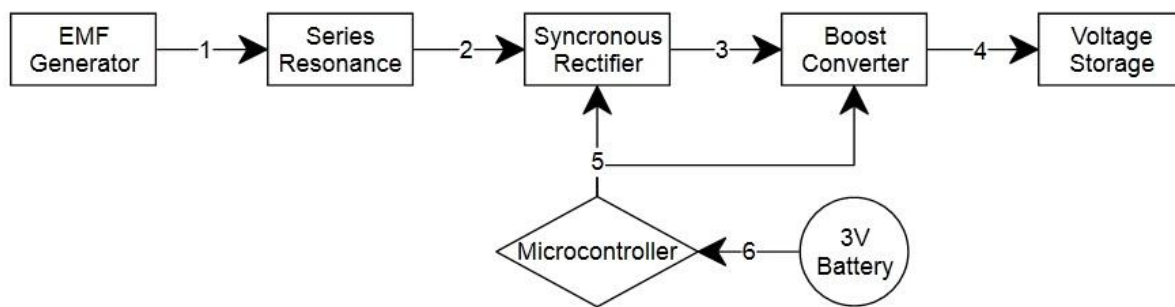


Figure 1 Top Level Block Diagram

Figure1:

1. AC impulse signals
2. Amplified AC signals
3. A stable DC signal
4. Stepped-up DC voltage
5. Pulse Width Modulation signal
6. 3V battery to feed the microcontroller

## 2. Design

### 2.1 Magnetic Generator

According to Faraday's law of Electromagnetic Induction, the voltage induced in a coil is due to a change in the magnetic flux. It can be calculated by the following expression:

$$\varepsilon = -N \frac{\Delta \varphi}{\Delta t} \text{ ll } \varphi = B * A * \cos \theta \rightarrow \varepsilon = \left| -N \frac{\Delta B * A * \cos \theta}{\Delta t} \right|$$

Equation1 : Voltage induced in a coil

Where

$\varepsilon$  : Electromagnetic force induced in the coil [V]

$\varphi$ :Magnetic flux [Wb]

t: Time[s]

N: Number of turns[-]

A: Area of the surface where the magnetic field passes through[m<sup>2</sup>]

B: Intensity of the magnetic field [T]

$\theta$ :Angle between the magnetic field and the area of the surface [°]

Since we want to capture the highest voltage possible, there are two parameters from eq.1 that we can modify: the number of turns around the coil and the magnetic field strength, which depends on the type of magnet used. Next step for the design of this part of the project is to do some research on magnets, copper wire and springs.

#### 2.1.1 Magnet

Neodymium magnets are the strongest magnets available. They can be used for multiple purposes because of their great strength and small size. For this project we wanted a magnet that was simultaneously very strong and easy to carry. We ended up using a D88-N52 disc magnet.

The characteristics that matter for the design are:

Dimensions: ½" dia. x ½" thick

Surface field: 6619 gauss (=0.6619 T)

Therefore, the volume of the magnet is 1.669e-6 m<sup>3</sup>

The magnetic field intensity at any point from a magnetic source can be calculated by:

$$B(r) = \frac{\mu_0 * M * vol}{2 * \pi * r^3}$$

Equation2 : Magnetic Field Intensity

Where

M: Surface magnetic field strength [T]

$\mu_0$  : Magnetic permeability in free space [ $\text{NA}^{-2}$ ]

vol: Volume of magnetic source [ $\text{m}^3$ ]

r: Distance from source [m]

The following picture shows how the magnetic field decreases for our magnet with the distance.

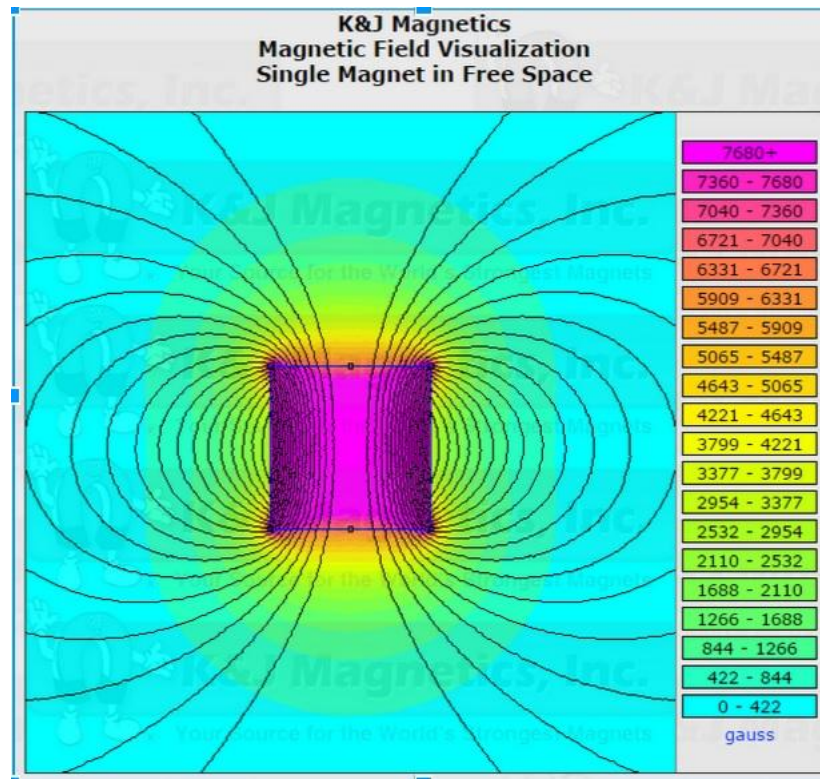


Figure 2 Magnetic field visualization for D88-N52 magnet

Since the design had to be light and easy to carry, we kept the casing as small as possible. Once we had it built, we measured the distance that the magnet travels when we shake it from its steady state and we got that  $r=8\text{cm}$ .

With this value, and knowing that  $M=0.6619T$ , we can calculate the magnetic field in the top and bottom part of the magnetic generator (according to eq.2), that it turns to be  $B(r=8cm)=4.315e-10T$ .

Once that we know the magnet in the top point, it is easy to calculate the difference of magnetic field that will go to eq.1 ( $\Delta B=M-B(r=0.08)$ ).

### 2.1.2 Wire

When choosing the type of wire that we were going to use for the design, we found out that the mid-range of wires available go from 15AWG to 30AWG. We wanted to use one that was easy to manually wind the coil so we decided to build the design with 28AWG magnet wire.

With the wire we could calculate the number of turns  $N$  that we put around the coil dividing the length of the tube (12cm) by the diameter of the wire (0.321mm). The result is that we put 374 turns, much more than the 100 turns that we had assumed for our initial calculations.

### 2.1.3 Spring

The third thing we needed in order to complete the design of the generator was a spring that allowed the movement of the magnet inside the plastic tube. In the beginning, we bought some springs online, but after trying them, we realize that they did not act like expected, because there are many mechanical variables like the air friction that we did not consider for our initial simulations. For this reason, we went to the machine shop and tried with different springs they had in stock until we found one that matched our preferences. The one that we finally used has:

OD(outer diameter): 0.3"

Wire diameter: 0.012"

Once that we had decided and bought the different parts, we were able to calculate the emf expected from (eq.1) Setting the frequency of jogging to 10Hz, we have that the emf expected is 0.702V peak to peak.



Figure 3 Magnetic Generator Design

The figure above shows us the final design of the magnetic generator once built. With the voltage calculated, we wanted to estimate the instantaneous power extracted. The solenoid wire resistance for our 28AWG wire is:

$$R = 212.9 \frac{\Omega}{\text{km}} * 0.022324 \text{ Km} = 4.75 \Omega$$

$$\text{Induced} = \frac{0.702V}{4.75\Omega} = 0.1478A$$

$$P_{\text{out}} = 0.702V * 0.1478A = 0.1W$$

From these calculations, we expect to get 0.1W of power at a maximum voltage of 0.702V and a current of 0.1478A.

## 2.2 Series Resonance Circuit

The purpose of the series resonance circuit (RLC circuit) is to boost the AC voltage that the got from the magnetic generator in order to make it able to go through the rectifier, that requires around 2V to operate.

The alternative to this method is to use a transformer, that once we had finished the project we realized it would have been a pretty much easier option. The explanation of this is that in the lab, it is very difficult to reach the frequency of resonance that the RLC circuit requires to boost the voltage to the level desired.

When designing the RLC circuit, the following equation was employed:

$$f = \frac{1}{\sqrt{4\pi^2 LC}}$$

Equation3 : RLC circuit calculation

At the frequency of resonance, the impedance of the capacitor equals the impedance of the inductor. Thus, the total impedance of the circuit is minimum.

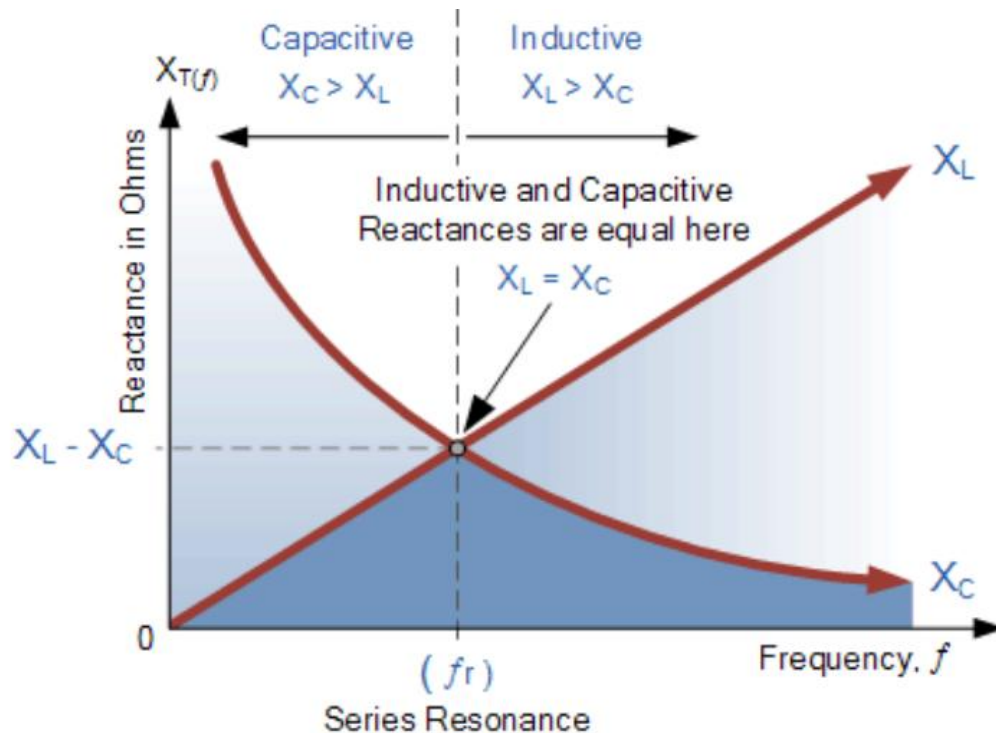


Figure 4 RLC analysis [3]

Approximating the output of the magnetic generator for a pulse signal and assuming that the frequency of that pulse is 500 Hz, we have:

$$L=0.01\text{H}$$

$$C=100\mu\text{F}$$

$$R=1\ \Omega$$

The value of the resistor can be modified. Higher resistors mean lower currents, as we can see in the following picture taken from the same source than the picture above.

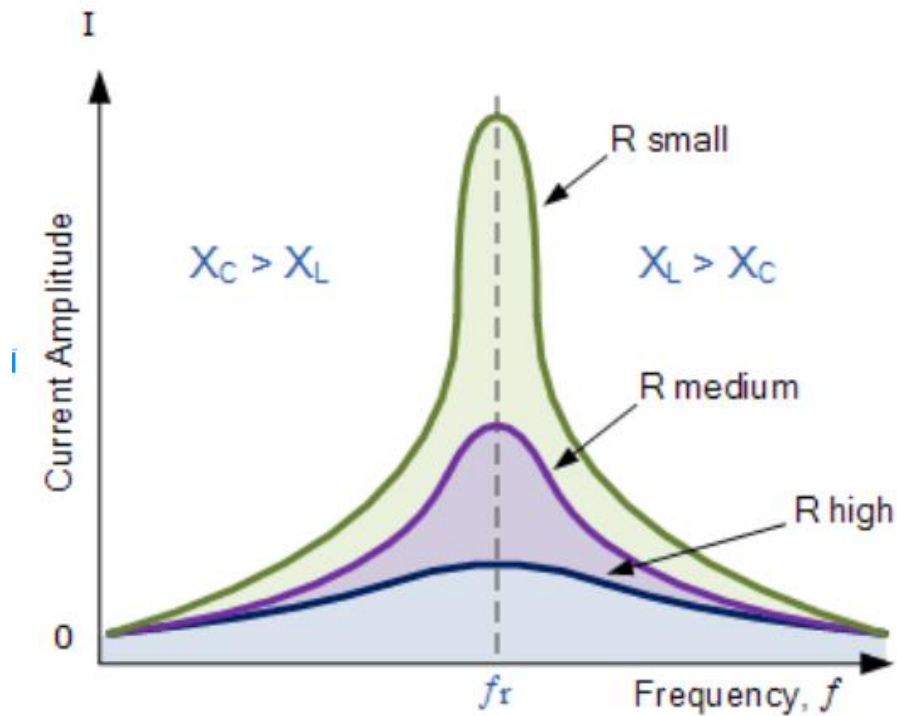


Figure 5 current for different frequencies in a RLC circuit

## 2.3 Microcontroller

The microcontroller we used was the MSP430G2553, part of Texas Instrument's MSP430 low power line and is a line of standalone microcontrollers that can be integrated into a circuit without the use of a Launchpad or arduino.

The goal of our design was to utilize the microcontroller to accurately measure the voltage across the resonant circuit and to open MOSFET gates to allow the appropriately oriented current to pass through, rectifying the input voltage into a DC signal that can be stored onto a rechargeable battery. That said, when searching through microcontrollers the key deciding factors when searching through microcontrollers were the inclusion of an ADC converter, adequate sampling rate, and low power consumption.

One issue with the MSP430 that affected performance was the inability for the ADC's inability to digitalize negative voltages with reference to the chip's ground voltage, making it difficult to measure possibly resonant signals. As a solution, we created a high resistance voltage divider that would offset the input signal by half of the microcontroller's reference voltage of 3.5 Volts. While this worked adequately to offset the AC signal, it was a large source of power loss in the control system. (calculate power loss)

According to our verification page, the limitations for signal sampling and gate control could be a maximum delay of 3 milliseconds. as seen in figure 6, we were able to capture and open gates on average within 2.2 milliseconds.

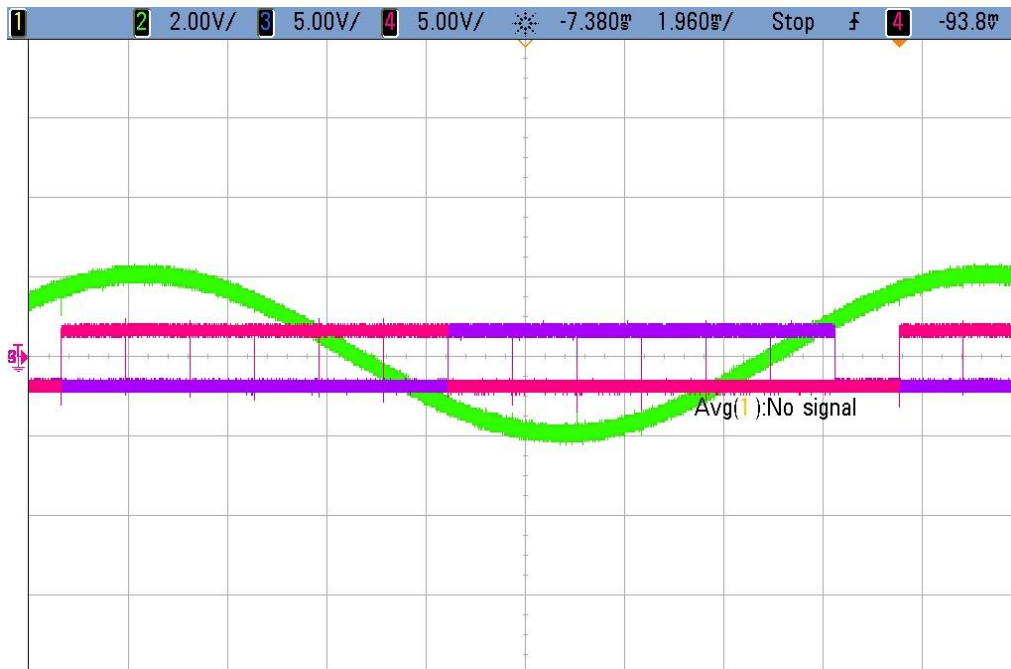


Figure 6 Output signal of microcontroller for MOSFET gate controls

The benefit of using MOSFETs for this system instead of diodes is that there is no minimum voltage that cannot get across the rectifier as long as the difference between gate voltage and source voltage is above voltage threshold. And because the MOSFET gate acts as an open circuit, there is no power loss accumulated from driving the gate voltage other than processing power.

$$I_{DS} = \mu_n C_{ox} \frac{W}{L} \left[ (V_{GS} - V_T) V_{DS} - \frac{V_{DS}^2}{2} \right] (1 + \lambda V_{DS})$$

Equation4 : Current through a transistor

## 2.4 AD/DC Rectifier

Following the series resonance circuit, amplified AC signal is to be converted into stable DC output so that it will be fed into the boost converter. Two kinds of rectifiers are implemented: full-bridge diode rectifier and synchronous rectifier with MOSFETs. A full-bridge diode rectifier is very easy to build and thus functionality is ensured, yet it requires about 1.4V of voltage drop across which is significant since the circuit deals with very small voltage. On the other hand, synchronous rectifier is more complex but has voltage drop of 0.2V which is comparatively lower than that of diodes'.

### 2.4.1 Full-Bridge Rectifier

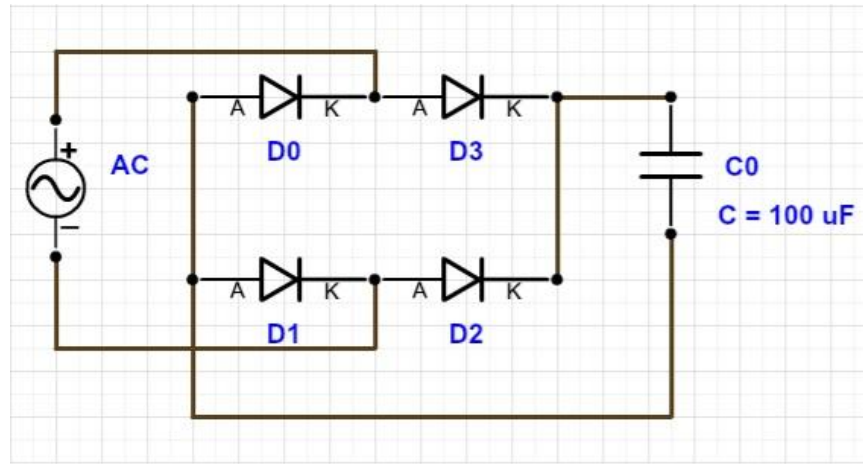


Figure 7 Schematic of Full-Bridge Diode Rectifier

The rectifier converts the AC signal into DC by diodes blocking the negative cycle of the signal and only allowing the positive cycle to the output. For the positive cycle, the signal will be sent to D3 from figure 3, passing the output capacitor C0 and coming back through D1. The negative cycle goes from D2 to the output and coming back through D0. The output capacitor is used to smoothen the output ripple. The signal goes through two diodes to complete a cycle resulting maximum of 2V of voltage drop [1].

### 2.4.2 Synchronous Rectifier

In order to try and capture both halves of an AC input, we decided to use a MOSFET adaptation of a full bridge rectifier.

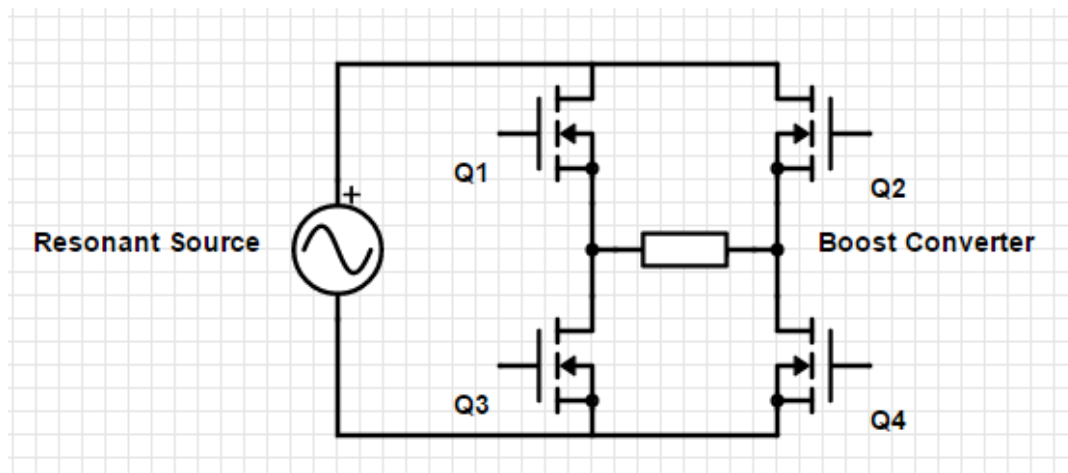


Figure 8 Synchronous Rectifier with MOSFETs

### 2.5 Boost Converter

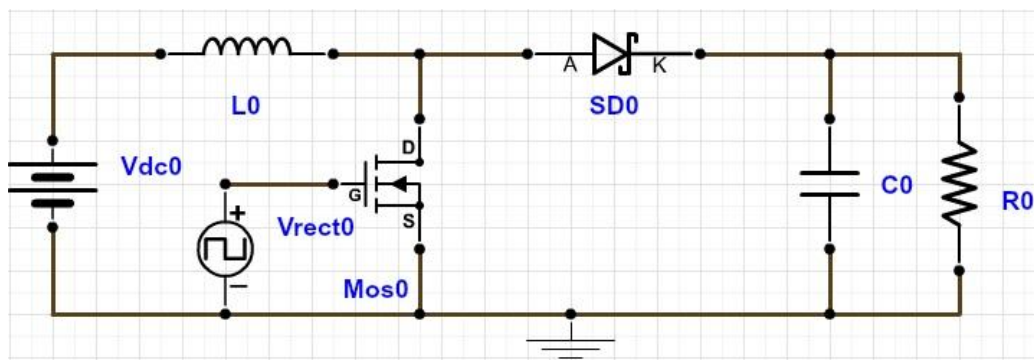


Figure 9 Schematic of Boost Converter

DC output from the rectifier goes into the boost converter to step up the voltage to be able to charge the battery. The boost converter has two phase depending on the state of the switch (a MOSFET transistor in the middle) that is driven by the microcontroller. When Pulse Width Modulation from the microcontroller is allowing the MOSFET to have the current going through it, the inductor on the left loop from the figure 3 will hold the energy from the DC input voltage, depending on its inductance. During this cycle, the diode (SD0 from figure 3) prevents current going reverse direction from the output capacitor. After capturing the energy for right amount of time, which is determined by the duty ratio, the microcontroller opens up the MOSFET and a larger loop (from figure 3,  $V_{dc0}$ ,  $L0$ ,  $SD0$  to output). The output is larger than the input since it will contain both the original input voltage and the energy that has been held by the inductor. Output capacitor is also applied to control the output ripple.

### 2.5.1 Duty Ratio

The duty ratio determines how long the MOSFET is open for so that the current goes through. Its it critical since this will have to be the right amount of time to capture and hold the maximum energy in the inductor so that the circuit will always work in continuous mode. If the duty ratio is too short, the inductor will hold small amount of voltage which will eventually make the output voltage small as well. While the duty ratio is too large, the circuit will go into discontinuous mode in which the current across the inductor constantly hits zero after hitting the maximum point, thus wasting energy while the current is zero. When specific amount of output voltage is desired:

$$D_1 = 1 - \frac{V_{in}}{V_{out}}$$

Equation 5 : Duty ratio of the boost converter []

### 2.5.2 Inductance

Along with the duty ratio, input inductance will also determine whether the circuit will go into discontinuous mode or not. An inductor that is too small will result in discontinuous mode since it will require smaller duty ratio because it can hold smaller energy. The inductance also controls current ripple across the inductor since the inductance is:

$$V_L = L * \frac{di}{dt}$$

Equation 6 : Voltage across inductor []

Larger inductance will reduce the rate of current change in time thus smaller current ripple. The critical inductance that will keep the circuit in the continuous mode and achieve the desired current ripple is:

$$L \geq \frac{V_{in} * \Delta t}{\Delta i}$$

Equation 7 : Critical inductance

Where  $\Delta t = D_1 * T$ .

### 2.5.3 Capacitance

Output capacitor is to achieve desired output voltage. Critical capacitance is:

$$C \geq \frac{i_{out} * D_1 * T}{\Delta V}$$

Equation 8 : Critical capacitance

Where  $i_{out}$  is the approximated output current that can be calculated from power conservation from input side and output side.

### 2.5.4 Actual Values and Calculated Values

Parameters to calculate each component are:

Table 1 Parameters to calculate boost converter components

| Parameter  | Values    |
|------------|-----------|
| $V_{in}$   | 1.3V      |
| $V_{out}$  | 2.5V      |
| $T$        | 1/(60KHz) |
| $\Delta i$ | 0.002A    |
| $\Delta V$ | 0.0025V   |

When implementing real circuit, value of each component changed. Duty ratio was larger than calculated since efficiency of the circuit was to take into account. Since there was voltage drop across the circuit, to achieve desired output, MOSFET had to be open for longer period of time than calculated. Following longer duty ratio, a little larger inductance was used. Varying output capacitor, 100 $\mu$ F was the most suitable choice among available ones: 10 $\mu$ F, 100 $\mu$ F and 15000 $\mu$ F.

Table 2 Values for boost converter component

|                    | Calculated Values | Actual Values |
|--------------------|-------------------|---------------|
| <b>Duty Ratio</b>  | 0.48              | 0.7           |
| <b>Inductance</b>  | 5.2mH             | 10mH          |
| <b>Capacitance</b> | 2.5 $\mu$ F       | 100 $\mu$ F   |

### 3. Design Verification

#### 3.1 Magnetic Generator

Once that we had the solenoid built, we went to the lab and connected the output to the oscilloscope to plot the voltage waveforms obtained. We simulated the movement of walking by manually shaking the generator.

The results we got are shown in the following picture:



Figure 10 Output from Magnetic Generator

We can appreciate that the  $\Delta V$  peak to peak is 1V, a little bit higher than what we had calculated. The explanation of this is that it is very difficult to estimate how fast we have to shake the generator to have a frequency of 10Hz. Since the frequency might have changed, the voltage might vary as well. Our purpose was not to achieve the exact voltage calculated theoretically, but to prove that the generator works and it is able to plot a decent output waveform, so we consider this experiment a success.

### 3.2 Series Resonance Circuit

The series resonance circuit test is to verify that it actually works as a voltage amplifier. Since we knew that it was going to be highly unlikely to achieve the frequency of resonance shaking the generator, we put a pulse waveform with the function generator instead and plotted with the oscilloscope the voltage across the inductor.

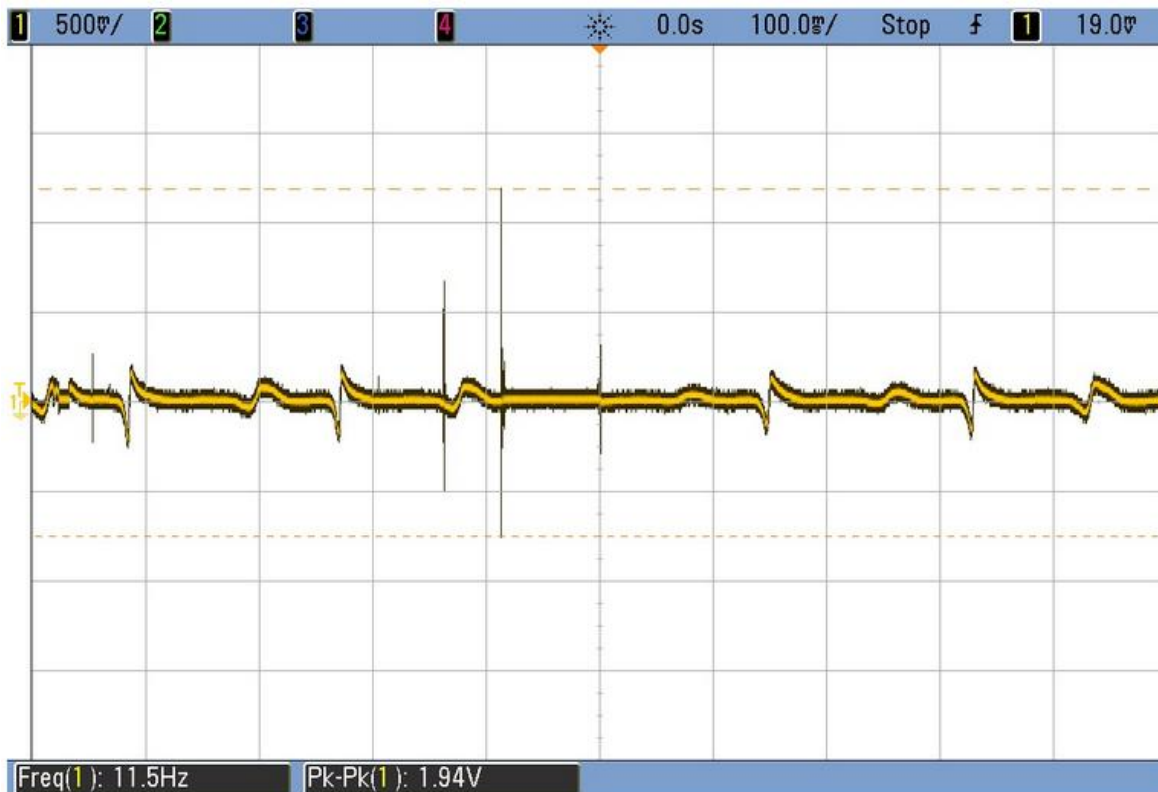


Figure 11 Output from Series Resonance Circuit

The peak to peak output voltage at a frequency of 11.5Hz turns to be 1.94V. This seems to be enough voltage to be rectified into a DC signal, but there are a lot of issues with this plot. For example, we assumed that we were able to capture only the pulse from the output of the magnetic generator and get rid of the rest of the waveform. Not only this, but also we can appreciate from the picture above that we only got one pulse of 1.94V. The rest of the voltage is not high enough to work for a rectifier.

As a consequence, we strongly recommend for future designs to implement this part with a transformer instead of using a RLC circuit. Transformers are definitely bigger and more heavy, but they do not have frequency issues. RLC works great theoretically and with computer simulations, but the problem appears when going to the lab because achieving the frequency of resonance is a task quite difficult.

### 3.3 Full-Bridge Diode Rectifier

Trying to implement the synchronous rectifier with MOSFET rather than the diode rectifier, the main focus was to check the functionality of it, thus the voltage value was not one of the concerns.

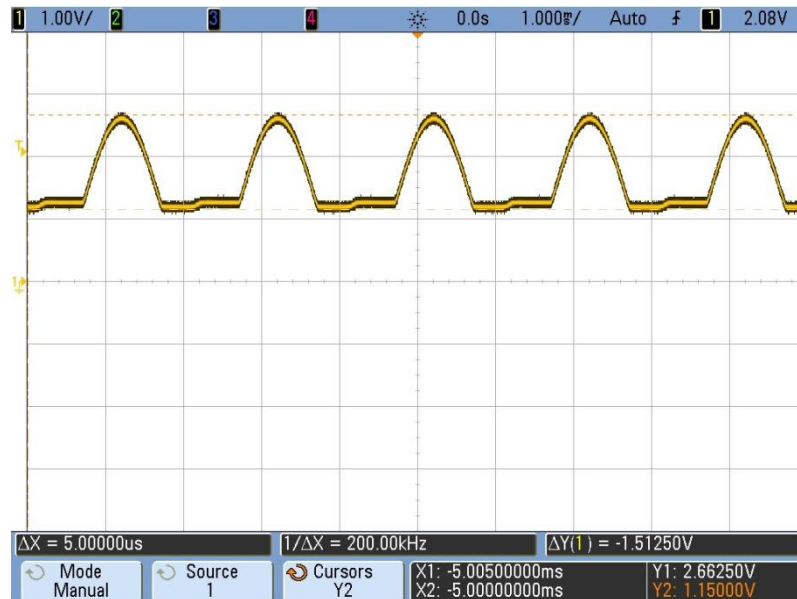


Figure 12 Output from diode rectifier

Figure 10 shows the output from the diode rectifier without the smoothing capacitor at the end. The rectifier correctly cuts out the negative phase of the sine wave input.



Figure 13 Output from diode rectifier with capacitor

By having output 100  $\mu$ F capacitor, output is more stable with less ripple.

### 3.4 Microcontroller

The output of the microcontroller was a bit unstable at moments as visible by the inconsistent sampling of the input signal. Even when under a stable AC input, there was a noticeable delay for the output signals. While it was acceptable by the design's verification, it might have caused problems when integrating with the boost converter system.

This is most likely a failure of the design of the coding and oversight on the natural delay of wires carrying the signals. In this particular case, it was acceptable because of the low frequency of the rectified signal, but would be worthless in higher frequency inputs.

### 3.5 Synchronous Rectifier



Figure 14 Signal across voltage source (yellow) 17 Hz, 600mVPP vs Voltage output of rectifier (green) .25mV DC

Unfortunately, this consolidation of full bridge rectification and a digital system had its issues. While it did rectify the signal, when the rectifier attempted to capture both the positive and negative half of the AC input, there was a severe drop in voltage as compared to simply capturing one side of the AC input. This can possibly be due to the signal delays incremented by the microcontroller.

The reason we did not use our original design for a synchronous rectifier was that the coding design for both the synchronous rectifier and boost converter had autonomous functionality. Meaning, in order to prove each part worked separately, the coding allowed both interrupts to occur within separate independent time cycles with no logic connecting either of their functionality.

With the synchronous rectifier and boost converter acting independently and with no type of storage unit in between the two, the system to capture and boost rectified voltage would have not worked as originally intended.

### 3.6 Boost Converter

Since the circuit was not able to work as a whole, boost converter was tested individually with a DC supply with 2V which is the approximated voltage level from the rectifier.



Figure 15 Output from Boost Converter

Due to noise, ripple shown in the figure 12 is about 1V. The boost converter was able to produce desired voltage to charge a battery which has minimum voltage of 2.5V to charge.

## 4. Costs

The cost of the project is divided into two categories: parts and labor. The parts have been either taken from the ECE building or have been bought online. The labor includes salary of engineers and also the cost of using the equipments available in the laboratory. For the parts used from the ECEB and for the magnetic generator tube, the price is an estimation.

### 4.1 Parts

Table 3 Parts Cost

| Part                    | Manufacturer            | Quantity | Cost Per Unit(\$) | Total Cost (\$) |
|-------------------------|-------------------------|----------|-------------------|-----------------|
| D88-N52 Magnet          | K&J magnetics           | 1        | 3.98              | 3.98            |
| 28AWG Copper Wire       | ECE Store               | 1        | 16.04             | 16.04           |
| 1 Ohm Resistor          | ECE Store               | 5        | 1.07              | 5.35            |
| 0.01H Fixed Inductor    | ECE Store               | 2        | 1.27              | 2.54            |
| 100 $\mu$ F Capacitor   | ECE Store               | 3        | 0.3               | 0.9             |
| Magnetic Generator Tube | ECE Machine Shop        | 1        | 10                | 10              |
| N-MOSFET                | International Rectifier | 5        | 1.13              | 5.65            |
| 1K Ohm Resistor         | ECE Store               | 3        | 1.07              | 3.21            |
| 15000 $\mu$ F           | ECE Store               | 1        | 1.3               | 1.3             |
| Microcontroller         | Texas Instruments       | 1        | 2.8               | 2.8             |
| <b>Total</b>            |                         |          |                   | 51.77           |

### 4.2 Labor

Table 4 Labor Cost

| NAME           | Hourly Rate (\$) | Total Hours Invested (hrs) | Total cost(HourlyRate*HoursInvested*2.5) |
|----------------|------------------|----------------------------|------------------------------------------|
| Eduardo Cano   | 40               | 120                        | 12,000                                   |
| Ignacio Fuente | 40               | 120                        | 12,000                                   |
| Jeongbin rew   | 40               | 120                        | 12,000                                   |
| <b>Total</b>   |                  |                            | 36,000                                   |

### 4.3 Total Cost

Table 5 Total Cost

| Section      | Total (\$) |
|--------------|------------|
| Labor        | 36,000     |
| Parts        | 51.77      |
| <b>Total</b> | 36,051.77  |

## 5. Conclusion

### 5.1 Accomplishments

While we were not able to make the entire project work collectively, our design was able to convert mechanical energy into a small voltage, we were also able to rectify and amplify voltage below the .7 threshold voltage set by full bridge rectifiers in previous projects.

### 5.2 Uncertainties

When the MOSFET full bridge rectifier attempted to capture both the positive and negative half of the AC input, there was a severe drop in voltage as compared to simply capturing one side of the AC input, which output an expected half signal. This can possibly be due to the signal delays incremented by the microcontroller allowing voltage stored to be cancelled out by adding increasingly more negative voltage.

### 5.3 Ethical Considerations

The ethical considerations for this machine are as follows:

- By stating it as a mechanical energy capturing source, we do not want to falsely assure that all mechanical energy is being converted, but that a narrow amount of mechanical movement at a specified frequency can currently be captured.
- By designing the product to be carry-able, we avoided false claims or threat of physical harm by limiting the designs weight and bulk.
- And by labeling our product as eco-friendly, we will not claim that it is a completely self-reliant energy source, but one that tries to capitalize on digital systems to better capture mechanical energy.

### 5.4 Future work

Over the project's course we have considered alternatives that could be used as alternates to our design, but that we could not implement. The first suggestion to use a center tapped transformer in order to rectify the circuit with ground referenced to the center tapped. This would allow for a boosted voltage output, which in turn would cause less loss over resistance, but in turn would increase the bulk of the system.

Another future design implementation would be the inclusion of a tunable capacitor inside of the resonance circuit. While this would mean more complexity and another feedback circuit, controlling the capacitance would allow a tool for fine tuning the resonance frequency. While it is extremely difficult to capture the random pattern from an random outside source in a resonant circuit, a tuning mechanism might expand the range of usable signal frequencies for this circuit.

## References

- [1] Philip T.Krein, *"Elements of Power Electronics" ECE 464 Power Electronics, Fall 2014.*
- [2] P. Sannuti, *"Series and Parallel Resonance" Rutgers University, December 2004.*
- [3] "<http://www.electronics-tutorials.ws/accircuits/series-resonance.html>"
- [4] FAIRCHILD, "BAS40SL Schottky Barrier Diode Datasheet," [online]. [Accessed February 2015]

## Appendix A Requirement and Verification Table

Table 6 System Requirements and Verifications

| Requirement                                                                                                                                                                          | Verification                                                                                                                                                                                                                                                      | Verification status (Y or N) |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| 1. Magnetic Generator<br>a. Having strong enough magnet and wire around the tube so that the generator will produce an EMF                                                           | 1. Magnetic Generator<br>a. Having two wires coming out from at each end of the generator, probing oscilloscope will verify that there is an induced EMF                                                                                                          | Y                            |
| 2. Series Resonance Circuit<br>a. Correct values for resistor, inductor and capacitor to get desired amplification of the AC signal from the generator                               | 2. Series Resonance Circuit<br>a. Measuring input of the circuit with oscilloscope and compare it to the output. Output signal should have larger amplitude                                                                                                       | Y                            |
| 3. Synchronous Rectifier<br>a. Correct switching of transistors so that it captures the positive cycle of the AC signal and convert the negative cycle into positive signals as well | 3. Synchronous Rectifier<br>a. Input a sine wave from the function generator and feed the signal into the rectifier. DC voltage meter to check the output. Also probing oscilloscope to see the shape of the output signal                                        | N                            |
| 4. Microcontroller<br>a. Correctly producing Pulse Width Modulation signal to control MOSFETs                                                                                        | 4. Microcontroller<br>a. Probing oscilloscope to the output of the microcontroller to see the shape of the PWM generated                                                                                                                                          | Y                            |
| 5. Full-Bridge Diode Rectifier<br>a. Correctly converts the AC signal input to DC output, minimize the voltage ripple with output capacitor                                          | 5. Full-Bridge Diode Rectifier<br>a. Feeding the rectifier with function generator with sine wave then probe output with oscilloscope to see the DC output. Take the difference between minimum voltage and the maximum voltage of the output to check the ripple | Y                            |

|                                                                                                                                                         |                                                                                                                                                                                                                                    |   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|
| <p>6. Boost Converter</p> <p>a. Step up the DC input to the desired output voltage level (over 2.5V) with required values of inductor and capacitor</p> | <p>6. Boost Converter</p> <p>a. Feed DC input to the boost converter, control the MOSFET with microcontroller with calculated duty ratio. Measure the output DC voltage</p>                                                        | Y |
| <p>7. Working as a whole</p> <p>a. Integration of the whole circuit from magnetic generator to the voltage storage(battery) at the end</p>              | <p>7. Working as a whole</p> <p>a. Connect each component of the circuit. Generate the AC signal from the magnet and probe the output of the boost converter to see if it's producing desired voltage to charge up the battery</p> | N |