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Power 2π - Mobile Bicycle Generator



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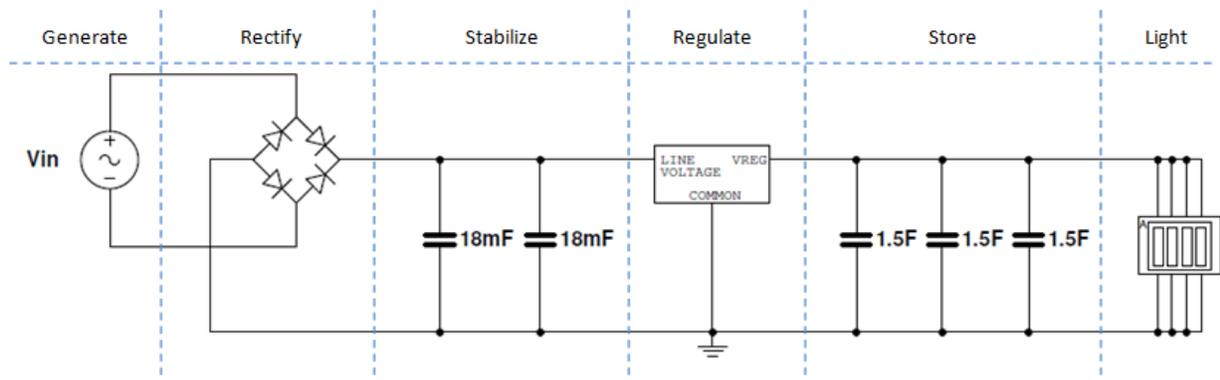
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Introduction:

Power 2π is a mobile bicycle generator which directly employs Faraday's Law in order to power a safety light. Strong neodymium magnets on each wheel spoke pass by an iron-core solenoid, generating electromotive force (EMF) and inducing current. The resulting power is then rectified, regulated and stored before being fed into an LED bicycle light.

As an increasing amount of people adopt a more active and healthful lifestyle, the bicycle has become an important vehicle for both commute and recreation. At night, most riders use a simple battery powered light to avoid collisions and possible injury. Battery cells however, inevitably wear out and must be replaced, and some contain corrosive chemicals, which if not disposed of properly can end up in a landfill, creating an environmental hazard.

Power 2PI aims to create a sustainable, no-maintenance, eco-friendly design with nearly unlimited charge-recharge capabilities. This project's main focus was to shed light on current alternative energy solutions and to explore the need for further research in green technology.

The solenoid is comprised of 200ft of 30AWG magnet wire wound around a soft iron core. A full bridge rectifier converts the generator's AC input to a positive DC signal, effectively adding the positive and negative components. Two 18mF capacitors in parallel average out the rectifier's output to provide the regulator with a stable input. A SWADJ3 step-down adjustable switching regulator sets its output to a constant voltage. Three 1.5F supercapacitors in parallel are used to store power not dissipated by the bicycle light. During longer bike rides, this stored energy can be used to sustain the light when the bike is temporarily slowed or stopped, such as at intersections.

Power 2π demonstrates an ecofriendly way to generate, rectify, regulate, store and ultimately utilize electrical energy for safety applications. The project aims to make electrical engineering concepts more accessible to the general public and to foster discussion of new ideas in the field.

Discussion of Alternative Energy:

The importance of alternative energy seems to be at an all-time high in life today. With threats of pollution, global warming, and environmental catastrophe lurking at the front doorstep, humanity continues to search for alternatives. Over the past few decades people have seen huge advancements in the areas of solar power, wind energy, geothermal energy, among others, which has helped to push society in a better direction. Although it provides a step towards solving the energy crisis, one of the major issues is the funding needed for further research and advancements. Recently, people have seen gas prices soar, making it difficult to fill up their gas tanks, and they demand change. Advancements in alternative energy, though expensive now, could end up saving money in the future. Breakthroughs in this area are essential providing people the change that they have been searching for.

Project Design:

Generate:

What is Faraday's Law?

Faraday's Law, derived from Maxwell's equations, states that "any change in the magnetic environment of a coil of wire will cause a voltage (emf) to be induced in the coil".

$$\text{Voltage generated} = -N \frac{\Delta(BA)}{\Delta t}$$

The induced electromotive force in any closed circuit is equal to the negative of the time rate of change of the magnetic flux through the circuit. The magnetic field can be altered in a number of ways, including moving or spinning a magnet and coil in relation to one another. Inductors, transformers, certain types of motors, and generators all function based on this concept.



How does Power 2PI employ Faraday's Law?

Power 2PI's generator is comprised of a stationary solenoid and a series of rare-earth, neodymium magnets. The mechanical energy exerted by pedaling the bicycle is converted to electrical energy. As each set of magnets, affixed to the spokes of the wheel, passes the solenoid, the magnetic field about the solenoid is altered repeatedly. Electromotive force is generated and the presence of a load allows current to flow. A series of voltage spikes, corresponding with the moments when a magnet passes the solenoid, is produced. As can be seen in figure 1, the signal has a positive and negative component.

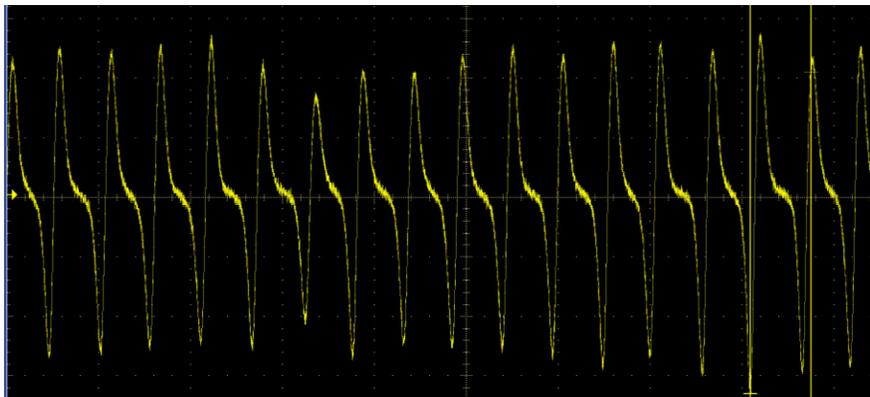


Figure 1- A typical generated signal

The positive spike is the electrical energy produced by the magnet approaching the solenoid. Voltage is zero when the magnetic field is at its peak (the solenoid is directly aligned with the center of the magnet). It then becomes negative as the magnetic field decreases (the magnet is moving away from the solenoid).

Solenoid Design

The generator's solenoid is constructed with 200ft of 30AWG magnet wire wound around a soft iron core. Magnet wire is made of copper and has a very thin insulating coating which makes tight turns and coils achievable. The insulation on normal copper wire is much thicker and can result in more loss and a lower achievable number of turns. During the designing of the solenoid, a high inductance coupled with a low internal resistance was desired. The following equations were pivotal in determining how to balance these two competing effects.

$$L = \frac{N^2 \mu A}{l}$$

N = number of turns
 μ = permeability
 A = cross section of solenoid
 l = length of coil

$$R = \frac{\rho L}{A}$$

ρ = resistivity
 L = length of wire
 A = cross section of solenoid

www.calctool.org

Figure 2 shows the calculated data for the inductance of several different solenoids. Each solenoid is characterized by thickness and length of wire. Lengths were converted to meters, permeability is given in H/m and inductance (L) is given in Henrys.

	Assorted length/gauge spool w/Iron core						L
	l(of wire)	N	μ	r (of coil)	A	l	
22Gauge, 40ft	12.192	611.155	1.26E-06	0.003175	3.17E-05	0.0254	0.000587
26Gauge, 75ft	22.86	1145.916	1.26E-06	0.003175	3.17E-05	0.0254	0.002063
30Gauge, 200ft	60.96	3055.775	1.26E-06	0.003175	3.17E-05	0.0254	0.01467

Figure 2- Inductance data for multiple solenoids

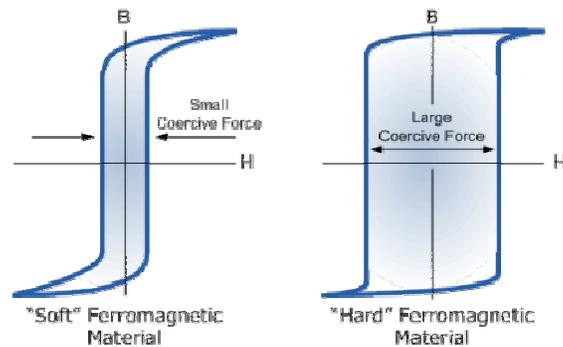
Figure 3 shows calculated data for the internal resistance of the same solenoids as above. Internal resistance is an important factor to consider since a high value will, by Ohm's law, result in a significantly lower achievable current.

	L	ρ	r(of wire)	A	R (OHM)
22Gauge, 40ft	12.192	1.68E-08	0.000321	3.24E-07	6.32E-01
26Gauge, 75ft	22.86	1.68E-08	0.000202	1.28E-07	3.00E+00
30Gauge, 200ft	60.96	1.68E-08	0.000127	5.07E-08	2.02E+01

Figure 3- Internal resistance data for multiple solenoids

The 30AWG, 200ft solenoid was chosen to be used in the final generator design. As can be seen, this coil produces the best balance of high inductance and low internal resistance.

In these calculations, the permeability of air ($1.26E-6$ H/m) is used as a baseline. In the final design, however, a soft iron core (pern www.electronics-tutorials.ws) The iron core helps to concentrate the magnetic field lines throughout the solenoid, strengthening the relative magnetic force shared between the solenoid and the magnets. Soft iron is preferable to other materials since its magnetic hysteresis loop is one of the least dramatic. This means that a soft iron core can undergo many magnetic field changes with little consequence. It will not become saturated or remain magnetized after the field initially influencing it is removed.



The measured inductance of the 30Gauge, 200ft solenoid is approximately 40mH, compared to the 15mH calculated value. This difference can be attributed to the use of the soft-iron core. Ideally the measured value should be higher, in the range of Henrys, however this inductance can be affected by the shape of the core, the spaces between windings of the solenoid itself, and eddy currents present in the core during use.

Design and Placement of Magnets

Power 2PI's final design employs a series of rare earth, neodymium magnets epoxied regularly around the wheel's rim. Rare earth magnets are extremely strong, permanent magnets constructed from alloyed metals. The combination of lanthanide rare-earth metals (high magnetism which is only exhibited at low Curie temperatures) and transition metals (with abnormally high Curie temperatures) allows the material's magnetic properties to be exhibited at room temperature.



In this design, 18 sets of 4 small disc-shaped magnets were equidistantly attached around the spokes of the bicycle wheel. Increasing the total number of magnets increases the amount of power generated at the cost of causing a weight imbalance in the wheel and overall design appearance. 4 stacked neodymium magnets provides an optimal stack height where the top of the magnets do not protrude beyond the bicycle tire. This allows the solenoid to be placed close enough to the top magnets of the ring without danger of brushing against any other part of the wheel.

Rectify:

What is a Full Bridge Rectifier?

A full bridge rectifier consists of four diodes assembled in a closed loop formation that allows one to achieve a desired output for certain applications (Figure 4). One of the main applications of a full bridge rectifier is that it can be used to convert an AC input signal into a DC output signal. During the positive half-cycle (Figure 5) current will flow through diode D1, then it will come out of node 1 (positive terminal of the load), and it will continue flowing through diode D4 and then out of node 3. As the current flows through diodes D1 and D4, a positive half-wave signal is generated. During the negative half-cycle (Figure 6), current flows through diode D3, then, out of node 1 (positive terminal of the load), and finally, it flows through diode D2 and out of node 2. When the current begins to flow through diodes D3 and D2, the negative half-wave becomes rectified and it becomes a positive half-wave.

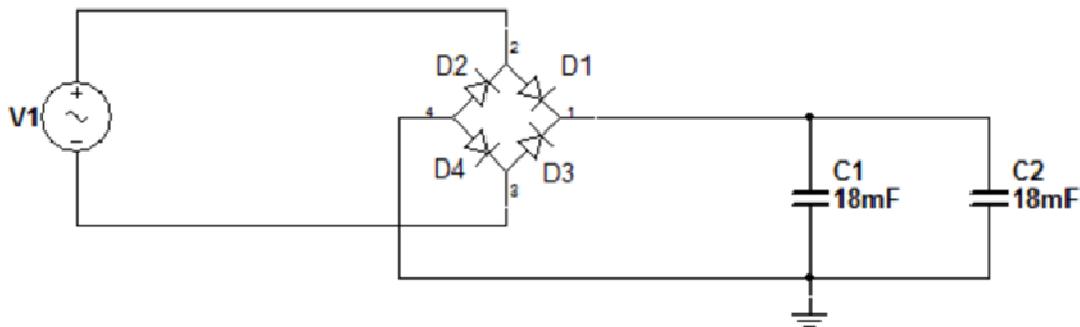


Figure 4- Full bridge rectifier

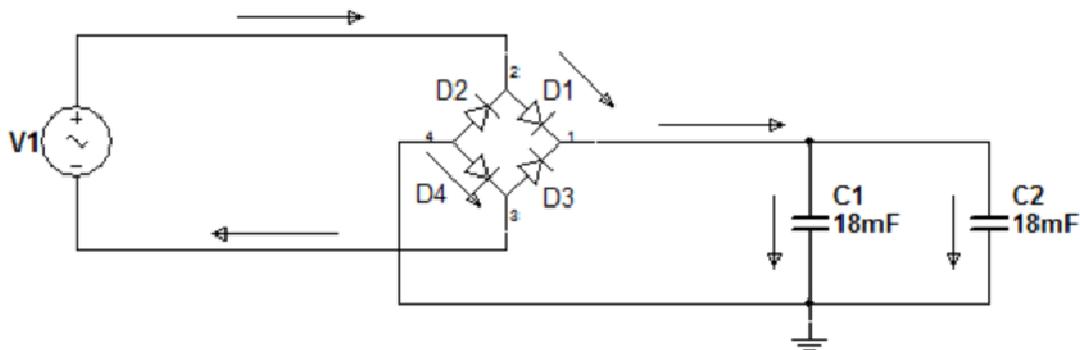


Figure 5- Positive Cycle

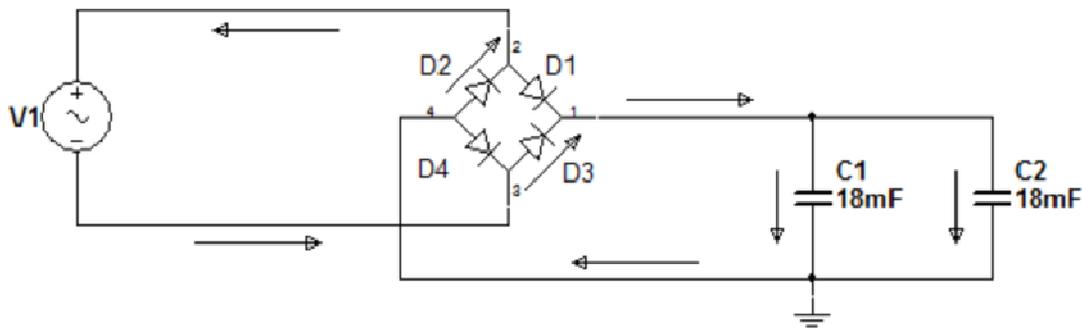


Figure 6- Negative Cycle

Implementation of the Full Bridge Rectifier

The full bridge rectifier is one of the most important configurations in the design of this mobile bicycle generator. It allows us to convert from AC to DC, which is vital because the light that is being powered requires a DC input power supply to turn on.

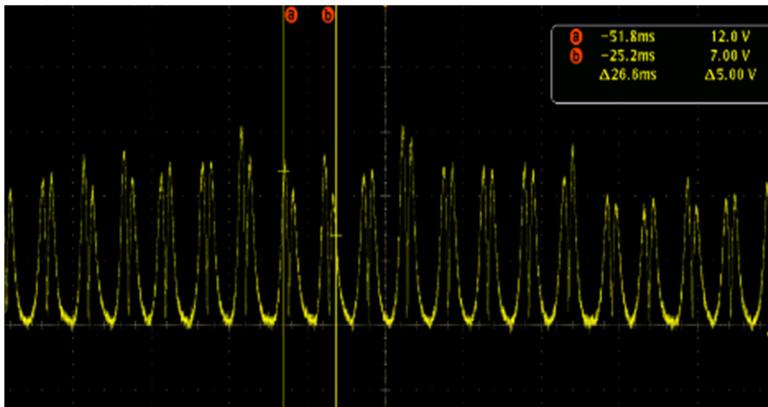


Figure 7- Rectified Input

The diodes used in the design of the generator are Schottky SR102 diodes, as opposed to regular diodes. A major benefit that came from using Schottky diodes, is that they have a lower forward voltage drop than regular diodes. The Schottky SR102 diode has a voltage drop of 0.55V, whereas a regular diode can have a voltage drop that ranges from about 0.6V to about 1.5V. This is a major advantage because less power is lost due to the small voltage drop, which will directly increase our efficiency. Unlike an actual semiconductor pn-junction diode, a Schottky diode is made up of an n-type substrate, which comes into contact with a metal. In a Schottky barrier diode, electrons will diffuse from the n-type substrate to the metal contact; note that, as the electrons diffuse from semiconductor to metal, they leave holes, so with respect to the metal, the semiconductor is now more positive than the metal, creating a small forward voltage drop across both junctions.

Figure 7 depicts the rectified input signal that was produced using four neodymium rare-earth magnets per spoke. As can be seen, during the negative-half cycle, the negative waveform flips and becomes positive due to the direction the current is flowing, as discussed above.

During this test run, the RMS voltage was measured to be approximately 5.93V, with a max peak voltage of approximately 16.2V. The RMS voltage can be found using the following formula

$$V_{rms} = \sqrt{\frac{1}{T} \int_0^T V^2(t) dt}$$

where, T is the period in seconds and V(t) is the instantaneous voltage that changes with respect to time. From Figure 7, the period of one wave cycle is approximately 32ms, and the period for 18 wave cycles is roughly 368ms. Also, the delay time between each waveform is less than 8ms; this is a good thing because it shows that the output of the rectifier does not really stay at 0V for long.

The RMS voltage is desired because it represents the effective voltage that is seen at the output of the load of the rectifier. Note that speed plays a deciding factor in the type of RMS value that is generated in the output of the rectifier because ultimately, the faster the wheel of the bicycle spins, the larger input signal will be, which directly results to a larger output RMS value.

Another issue with this DC signal is the oscillation of the waveform that is produced. Stabilizing capacitors will be needed to filter out this waveform to a more desirable DC power supply that can be fed into the switching regulator. Note that an input of roughly 5.4V is required to turn on the switching regulator, so this means that the RMS voltage seen at the output of the rectifier needs to be at least 5.4V

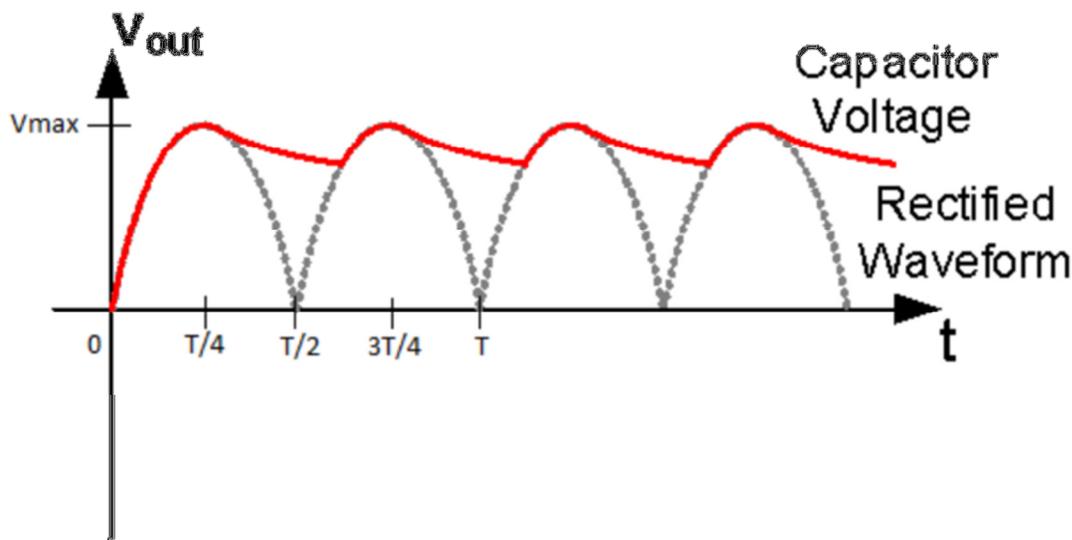
Stabilize:

How do capacitors stabilize a signal?

Capacitors are devices that can store charge in an electric field. The voltage through a capacitor cannot change instantaneously, and is shown in the following equation:

$$v_c(t) = \frac{1}{C} \int_0^T i_c(t) dt + v_c(0^+)$$

V_c is the voltage seen across the capacitor at some time t . $i_C(t)$, is the instantaneous current flowing through the capacitor at time t , and $v_C(0^+)$ is the initial voltage that is stored through each capacitor at the beginning of each wave cycle.



The image above shows how adding a capacitor to the load of a full wave rectifier can affect the output signal of the rectifier. Note that the gray dotted line depicts the rectified output without a capacitive load; this rectified waveform has a large variation in instantaneous values, which is not desired. Using a capacitor in the load of the full bridge rectifier, the output waveform can be smoothed into a more stable DC signal, as portrayed by the red line.

The above image supports the fact that voltage through a capacitor does not change instantly. From time 0 to $T/4$, the capacitor charges up (exponentially) to V_{max} , however, the time it takes to discharge (exponentially) is longer due to the large time constant (RC), where R is the resistance in the wires, diodes, and other elements in the circuit, and C is the capacitance. The output voltage, seen across the capacitor, never reaches 0V because as the capacitor starts to discharge, the input voltage will rise and the capacitor will start charging up again.

Why is it important to stabilize the signal?

Stabilizing the signal after rectification is important in providing a smoother signal that can be applied to the input of the voltage regulator. Ideally, the signal fed into the regulator should be constant and free of sudden oscillations. Having a capacitive load offers this capability, as can be shown in Figure 6. The Power 2PI design utilizes two 18mF stabilizing capacitors, each of which have a 16V rating.

The regulator will take in an unregulated DC input and will regulate the output to the desired voltage. A regulator requires that the input voltage be about 1V or 2V above the required output voltage. The main reason a capacitor is needed in the load of the rectifier is because the variation of the capacitive peak voltage that occurs (Fig 8), is very small compared to that of a non-capacitive load. A small ripple means that the input going into the regulator will not vary much from peak-to-peak, so the necessary voltage will not fall below the desired input needed to turn on the regulator.

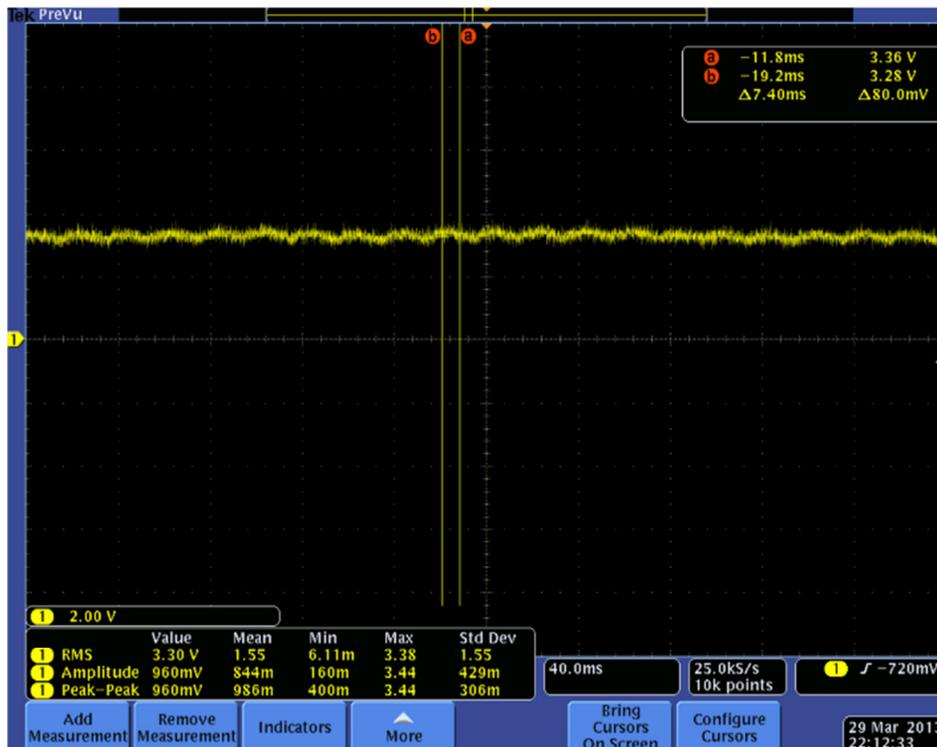


Figure 8- Rectified and Stabilized Voltage

Regulate:*Why use a regulator?*

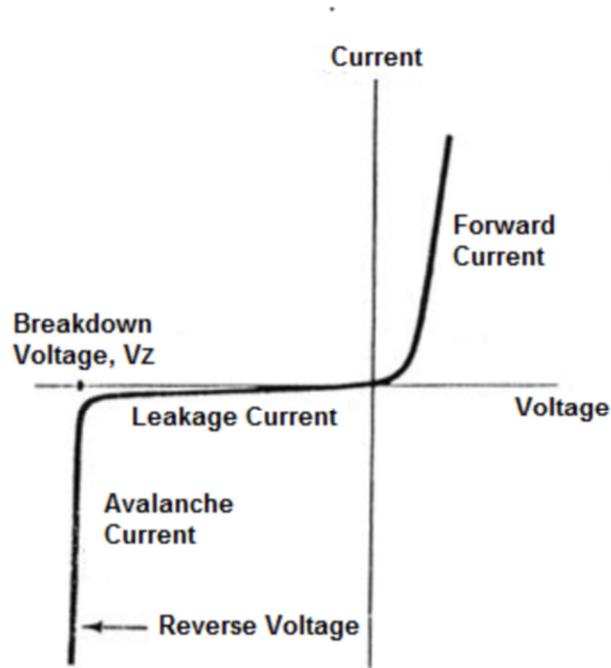
The regulator phase deals with the DC end of the circuit. It takes in and puts out a direct current signal, stepping down the variable voltage from the rectifying circuit to a consistent three volt overall circuit output. It should be noted that the 3 volt output was defined by the group as an optimal value for the selected LED bicycle light. At a 3V output, the LED brightness is strong, but not blinding and can be maintained on the constant “ON” mode by the average cyclist at around 12mph.

The purpose of the regulator in the circuit is to keep the voltage that the load experiences at a constant value. This keeps the light at a constant brightness. Without the regulator, riding faster would produce a brighter light and riding slower would result in a dimmer light. This component ensures that even at high speeds, such as riding down a hill, the load will not be subjected to more voltage than it can safely handle.

The team contemplated and tested two regulator styles, linear and switching. The linear regulator was simplistic and straightforward. It was able to maintain the voltage at a level designed by the team through the utilization of a zener diode.

The Linear Regulator

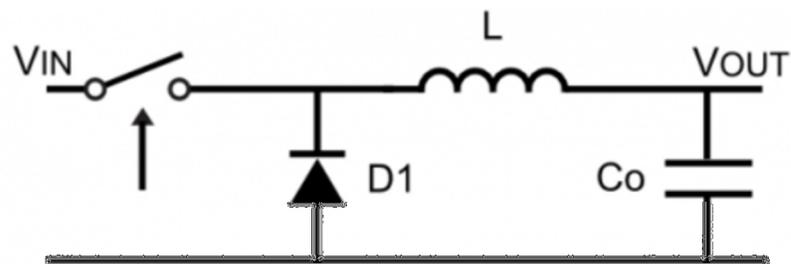
The voltage zener diodes break down at is a model specific value. The zener diodes used in testing were 3.3V. In the forward bias, zeners operate as a normal diode would; having roughly the standard 0.7 volt drop across it when turned on. However in a reverse bias situation, this type of diode allows current to flow through a path of minimal resistance once the potential drop across it is over or equal to the model’s known reverse breakdown. This means that the voltage will stay relatively the same across this diode (regulator) for a given change in reverse breakdown current. The image on the next page is a graphical depiction of this phenomenon , where V_z marks this reverse bias breakdown voltage.



The problem with this style regulator was it was not efficient enough to enable use in the group's overall circuit. By allowing enormous amounts of current to flow through in a zener reverse bias situation, too much power was being lost to even attempt to achieve the ultimate goal of lighting a bicycle light. The solution was to use the other regulator design, a switching regulator.

The Switching Regulator

Switching regulators use transistors turning on and off at a high speed to alter a DC input to produce a different voltage DC output. As discovered in testing the generator and rectifier combination, the group found that the regulation necessary was to be from a higher DC voltage to a lower DC value. Using a collective power electronics knowledge base, the team decided that the regulator design would essentially be that of a Buck Converter. The figure below shows a basic Buck arrangement where the high speed switching transistor is represented as a simple switch for simplicity.



Current through an inductor is formulated by the equation

$$I_L = \frac{1}{L} \int_{t_0}^{t+to} V_L dt.$$

By applying this equation to a Buck Converter we are left with the equations

$$I_L = \frac{1}{L}(V_{in} - V_{out}) * DT + IC$$

when the switch is closed and

$$I_L = -\frac{V_{out}}{L}(1 - D) * T + IC$$

when the switch is open, where D is the duty cycle, T is the chosen variable of integration, and IC is the initial current.

Switching regulators work by altering the duty cycle of the switching transistor, which will from now on be referred to as the switch. This duty cycle, in layman's terms, is a percentage representation of how long the switch is turned on (Duty Cycle = Output Voltage/Input Voltage). The longer the switch is on, the closer the output voltage will get to the input voltage. The Buck can be said to operate in two modes, mode one where the switch is closed and mode two where the switch is open. While in mode one, the inductor charges and in mode two, it begins to discharge. By operating in this fashion, the output is able to be continuously fed by a voltage lower than the input, stabilized and buffered by a capacitor, 'Co' in Figure 8. This method of regulation, called pulse width modulation (the input is "pulsed" at intervals dependent on duty cycle) is more efficient than the linear regulation. It does not dump current as the voltage rises above what is desired, instead it shuts down the feed, 'Vin' in Figure 8. The stabilization spurring from the capacitor 'Co' is imperative to understand as it is the potential that the LED light will see. Using the equation for voltage across a capacitor

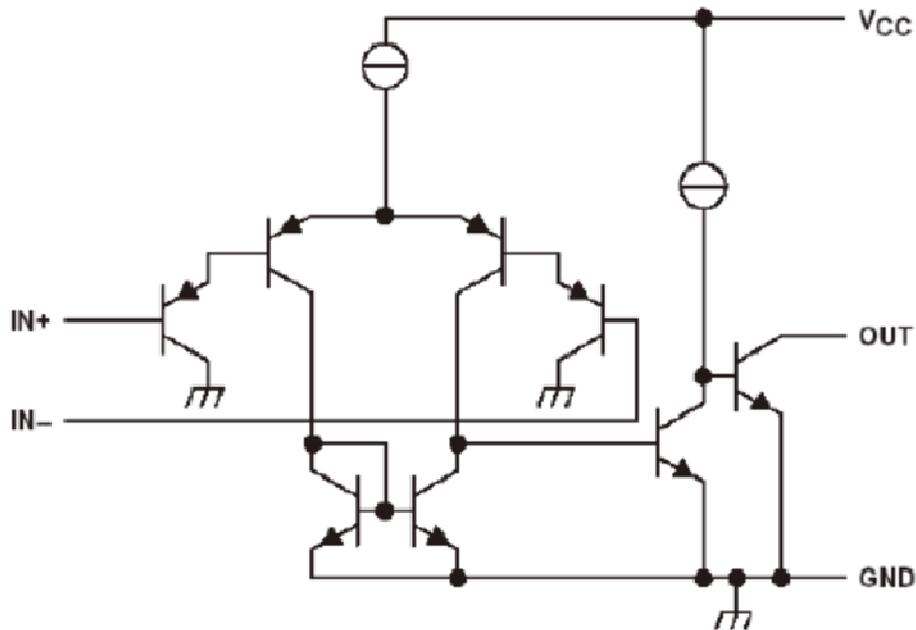
$$V_C = \frac{1}{C} \int_{t_0}^{t+to} I_C dt$$

the ripple of the capacitor 'Co' voltage (the output voltage) can be

$$\Delta V_C = \frac{V_{out}}{8LCf^2}$$

as derived in Power Electronic Circuits' by Issa Batarseh. It should be noted that L is inductance, C is capacitance, and f in this instance stands for switching frequency. Interestingly, as switching frequency increases, the ripple of the regulated output voltage decreases.

Once the group decided to take the switching regulator route, the team experimented with the idea of a simple comparator circuit. Comparators take two inputs, a reference voltage and a regulated voltage, and based on which voltage is higher, the circuit outputs a high or low signal. This output is then used to continuously adjust the duty cycle of the switch to ultimately keep the converter's output constant. This is an example of a feedback loop. The figure on the next page shows a simple comparator circuit.



<http://encon.fke.utm.my/nikd/latest/sloa067.pdf>

Choosing the Regulator

Due to lack of time, designing an efficient and working comparator was not feasible. A switching regulator design was attempted with the aid of an Arduino microcontroller to act as a pulse width modulating comparator, but the microcontroller required a 9V input, which could not be supplied without using an outside voltage source. Instead the team purchased a SWADJ 3A voltage regulator. The SWADJ 3A system was chosen as it was marketed to have an average efficiency of 90%, was able to handle the wide range of input voltages the generator would subject it to, and could be adjusted to different output voltages. The adjustable output voltage enabled testing of the light, with a normal operating voltage of 4.5 volts, at various potentials to see which would provide sufficient light while still consuming less energy than was being generated as to keep the light lit.

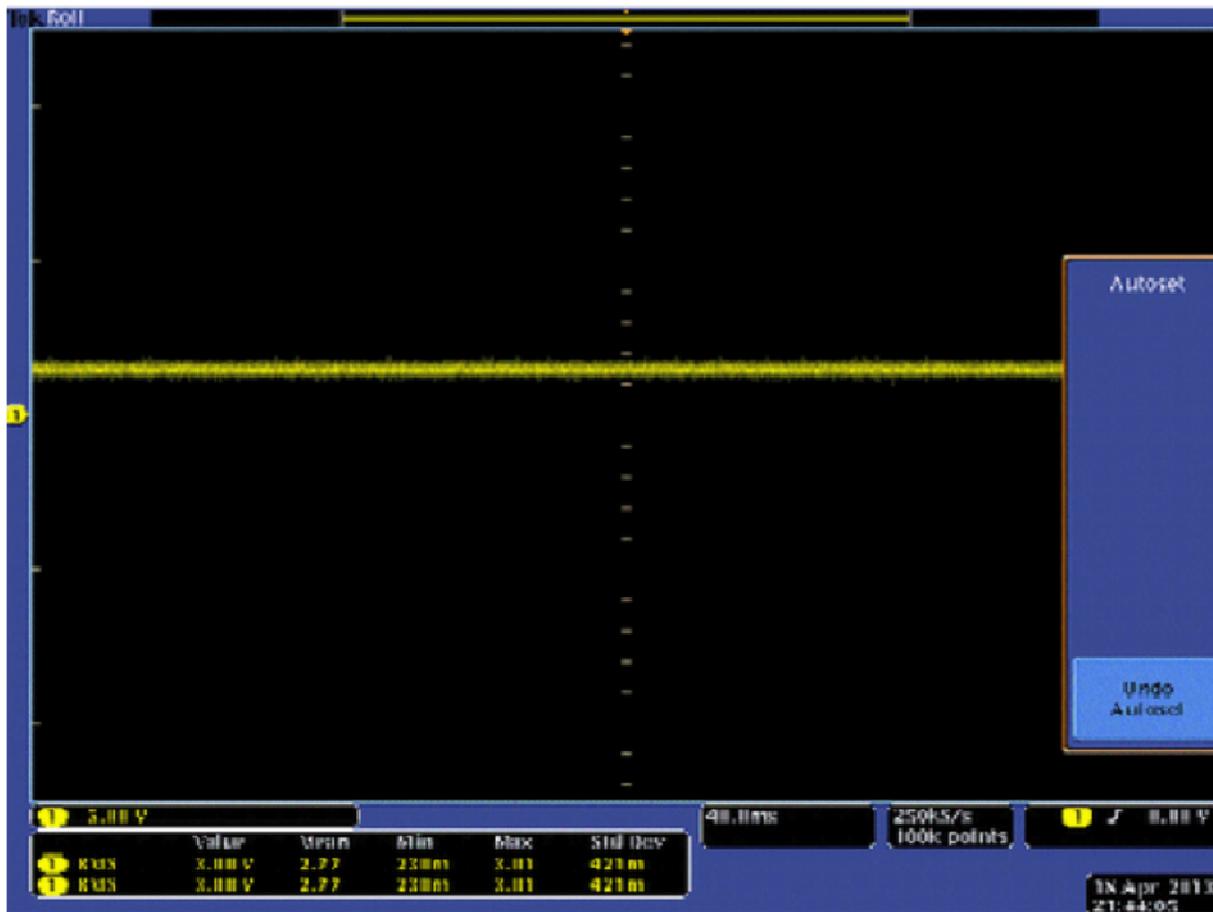
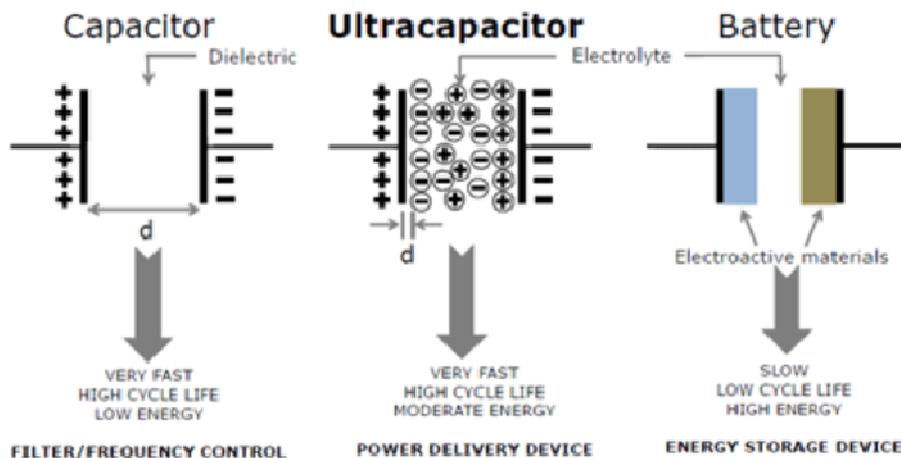


Figure 9- Regulated Voltage

It should be noted that the team tested a regulated output voltage of 2.8 volts and 3 volts. The idea was to give a lower power option for a more casual or slower rider. It was found that when set to 2.8 volts on the output side the light did turn on more quickly at a low speed than did the 3 volt setting. However, the time saved (in the seconds range) was not worth the tradeoff of having a somewhat dimmer safety light.

Store:*What is a Super Capacitor?*

Supercapacitors, also known as ultracapacitors or double layered capacitors, are capacitors capable of having a very high capacitance. Capacitors store energy utilizing a static charge over an electrochemical reaction, such as used in batteries. It is analogous to the buildup of static electricity when walking on a carpet and releasing the energy through contact.



<http://www.gizmag.com/graphene-supercapacitor/21925/>

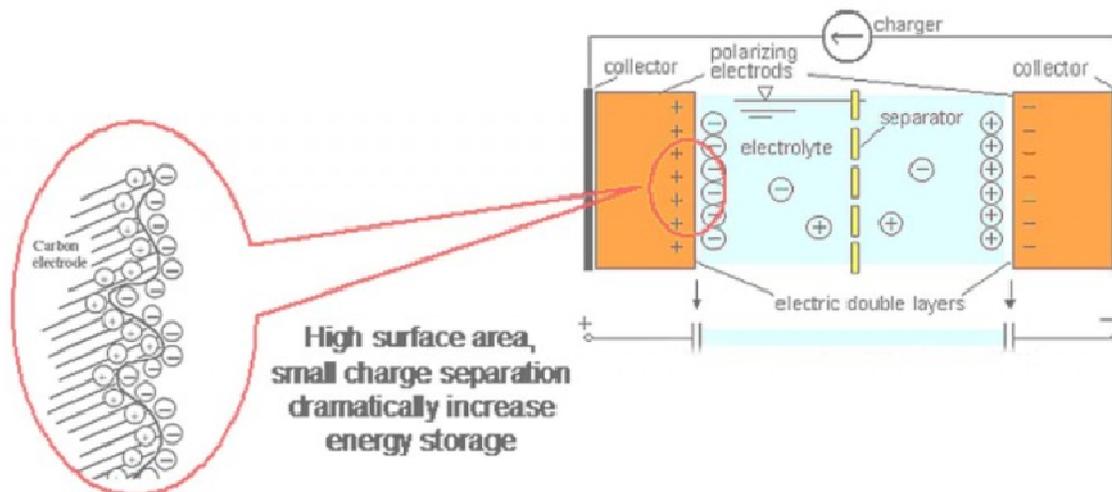
In batteries, ions are actually inserted into the atomic structure of an electrode, whereas in a supercapacitor the ions simply cling onto the electrodes. This act of storing energy without chemical reaction allows the supercapacitors to charge and discharge much more quickly. It also reduces wear and tear, resulting in a longer lifetime. Supercapacitors last for 10 to 15 years, whereas batteries only last for 5 to 10 years. Also using batteries would be detrimental to our motive of reducing the use of harmful substances and reducing the carbon print.

Supercapacitors do not release harmful chemicals like lithium ion batteries. They also have a much lower internal resistance than a battery.

Both capacitors and supercapacitors employ the act of charge separation, however in capacitors this separation is limited by film in the middle whereas in supercapacitors the difference between ions is so small it is measured in nanometers. This is important because the shorter the separation distance the larger the size of the electric field. A larger field converts into more energy storage capacity.

Another reason why supercapacitors can store more energy is because they contain activated carbon which helps the ions to cling onto the surface. Supercapacitors have two metal plates just like capacitors but their plates are coated with a sponge like, porous material known as activated carbon. One of the plates is positive and the other negative. During charging, the ions from the electrolyte accumulate at the surface of the carbon plates.

In capacitors only one layer of charge is accumulated while on a supercapacitor there are two layers of charge coating the electrolyte surface. Surface area of these plates makes a huge difference when it comes to holding electric charge.



<http://ev.sae.org/article/9236/>

How does Power 2π use Supercapacitors?

Initially, 18mF capacitors were used for storage. Since they are not supercapacitors they did not hold a lot of power, but they did charge faster because their capacitance was very low relative to the supercapacitors. Also tested with one supercapacitor in the stabilize stage and two supercapacitors in the storage stage. This resulted in the stabilizing supercapacitor to stabilize it to a lower voltage and hence causing the regulator to turn on at a later time. Since the voltage rating of the supercapacitors is 5.5V and the regulator starts regulating at 5.4V, it would make it a futile setup. Tested many different combinations and concluded to use two capacitors in series after the rectifier and 3 supercapacitors at the end to store the energy. The storage capacitors are rated at 5.5v and take about 5 minutes to completely charge up when riding at an average speed of 10 mph. If a rider rides at a higher speed it would take a shorter time to get fully charged.

The option of having 3 super capacitors in series, resulting in a total capacitance of a massive 4.5 F was picked to help store more power for a longer time. With 3 supercapacitors in the storage level of the circuit, when fully charged, the light can be kept on for approximately 1 minute 30 seconds to 2 minutes. This time was determined to be ample for someone riding a bicycle to stop at a traffic light, stop sign or simply for a break and sip of water.

Light:*Comparison of Light Types*

Choosing a light to meet power needs played a crucial role in the project. Greater power draw results in longer turn-on times for the regulator and shorter durations of power storage. Environmental impact of the chosen light was also taken into consideration.

		
Life Span	50,000 hours	8,000 hours
Watts of electricity used	6-8 Watts	13-15 Watts
Watts needed to produce 450 Lumens	4-5 Watts	9-13 Watts
Durability	Very Durable- can handle bumping and jolting	Not Durable- made of glass that can break easily
Sensitivity to Humidity	No	Yes
Temperature Sensitivity	None	May not work under 10 degrees Fahrenheit and over 120 degrees Fahrenheit
Harmful Substances	None	Mercury- Very toxic to your health and environment

Taking the factors into consideration, LED was the obvious choice.

How does an LED work?

When current flows into an LED, electrons from the current flow into the semiconductor material, which contains spaces that would be occupied by the electrons. When these spaces are filled, energy is released in the form of photons is emitted.

Choosing the Bicycle Light

LED systems which took more than 3 AA or AAA batteries were screened out, since each battery provides 1.5V. Modes of operation for several LED systems were tested and recorded in the chart below. Readings were taken at high operation levels, normal operation and the lowest possible level of operation. It is important to note the power each light consumes in the lowest mode of operation. This shows the moments when the light will turn on and off.

Type of Light	Mode of operation	Voltage (Volts)	Current (milliAmperes)	Power (milliWatts)
Bell Spyder (1 Red LED)	High	3	25	75
	Normal	2.3	10.5	24.15
	Lowest	1.65	0.97	1.6
Schwinn (3 Red LED)	High	3	95	285
	Normal	2.4	28	67.2
	Lowest	1.72	0.52	0.89
Schwinn (4 White LED)	High	4.5	93	418
	Normal	3.5	39.5	138.3
	Lowest	2.5	0.23	0.575

The light ultimately used for the project was the Schwinn (4 White LED) light. In normal operation, it requires 418mW of power. A combination of a front light and a back light could be used, but the operation of a front light for a longer period, instead of both lights for a shorter period seemed like a better option. The Schwinn front light at its normal operation was seen as too bright and might be blinding to the oncoming traffic. The regulator could be calibrated to regulate to 3V, hence the light only gets 3V which is bright enough to be seen while giving on-time. The light also has a strobe function, allowing for lower power consumption and greater opportunity for the supercapacitors to charge.

Results:

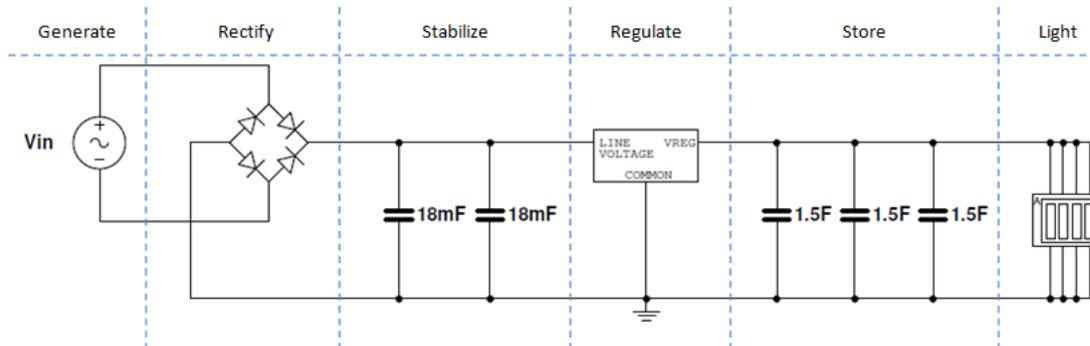


Figure 10- Final Circuit Design

The immediate result of this design is a working generator and associated rectifying, regulating and storage circuitry. Figure 10 shows the finalized circuit diagram.

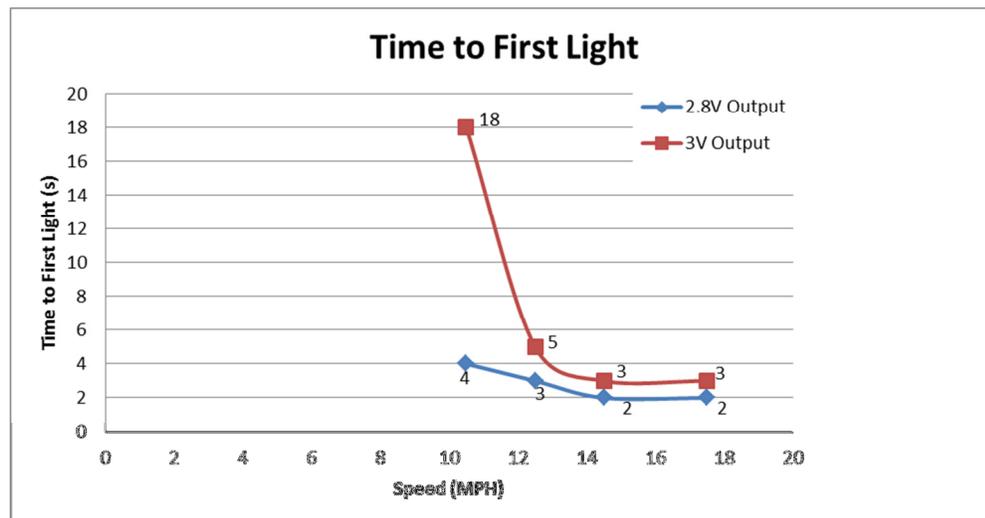


Figure 11- Time to first light

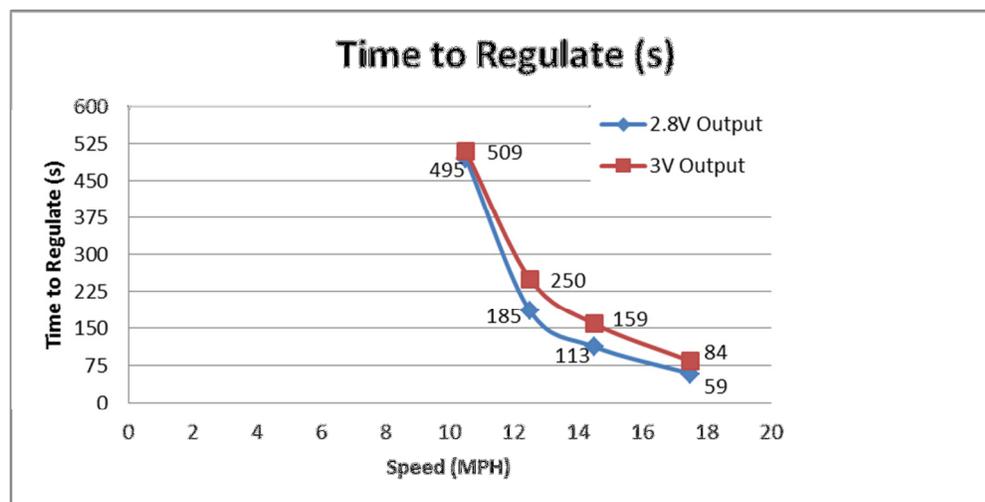


Figure 12- Time to regulate

The time the light takes to turn on (figure 11) is dependent on both speed of the bicycle and the voltage the regulator is adjusted to. The initial generated light has a blinking behavior, which stabilizes to an unwavering beam (figure 12) as more power is generated and available to the regulator and light. This behavior allows the cyclist to be able to use the light quickly, without requiring a long charge-period. Excess power is stored in the supercapacitors. When the bicycle is briefly stopped, at an intersection for example, this excess power can be drawn on to keep the light powered and the rider safe.

Efficiency:

The overall efficiency of the Power 2PI design is approximately 48%. Efficiency is given by

$$\text{Efficiency} = P_{out}/P_{in}$$

The average speed used in the efficiency calculations was 10.5mph. The input power of the generator was found by multiplying the voltage by the current flowing through it. The voltage of the generator is about 6.6V (figure below) and the current flowing through it is about 0.3A, giving an input power of 1.98W. To determine the output power, each supercapacitor is listed as having an internal resistance of 30 Ω or less, and the internal resistance of the LED load system was found to be 176.5 Ω . Thus, the load resistance is found to be: $(30\ \Omega \parallel 30\ \Omega \parallel 30\ \Omega \parallel 176.5\ \Omega) = 9.46\ \Omega$. With an output voltage regulated to 3V DC, the output power is the output voltage squared divided by the load resistance, which is .951W.

$$P_{out} = (V_{out})^2/R_{load}$$

As a result, the overall efficiency of the circuit comes out to be 48%.

Losses can be attributed to the combination of a significant voltage drop across the full bridge rectifier, internal resistances in each device and the listed 10% efficiency loss through the regulator.

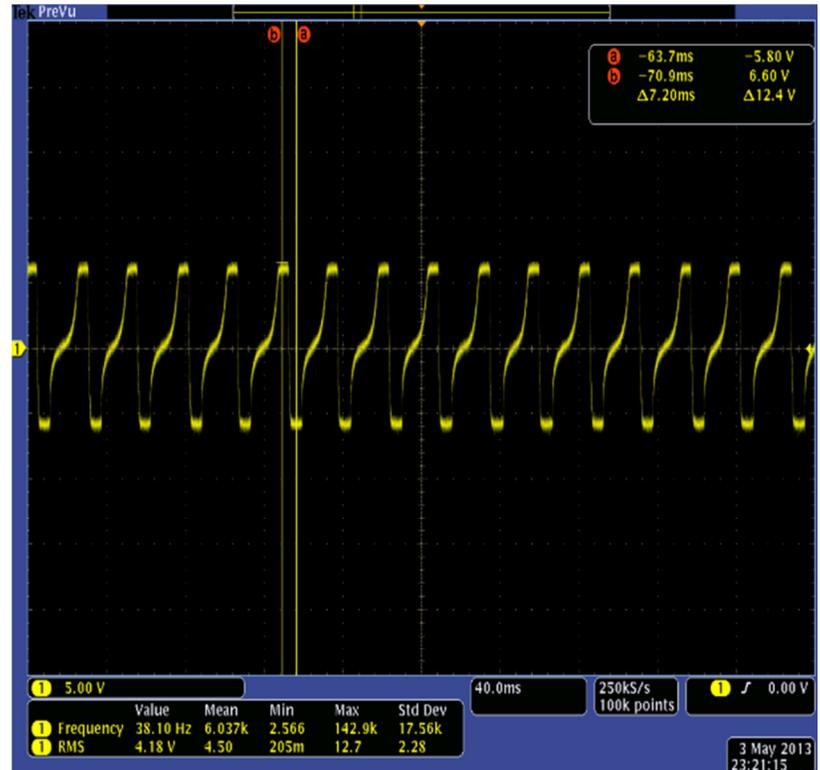


Figure 13- Generator input signal 10.5mph

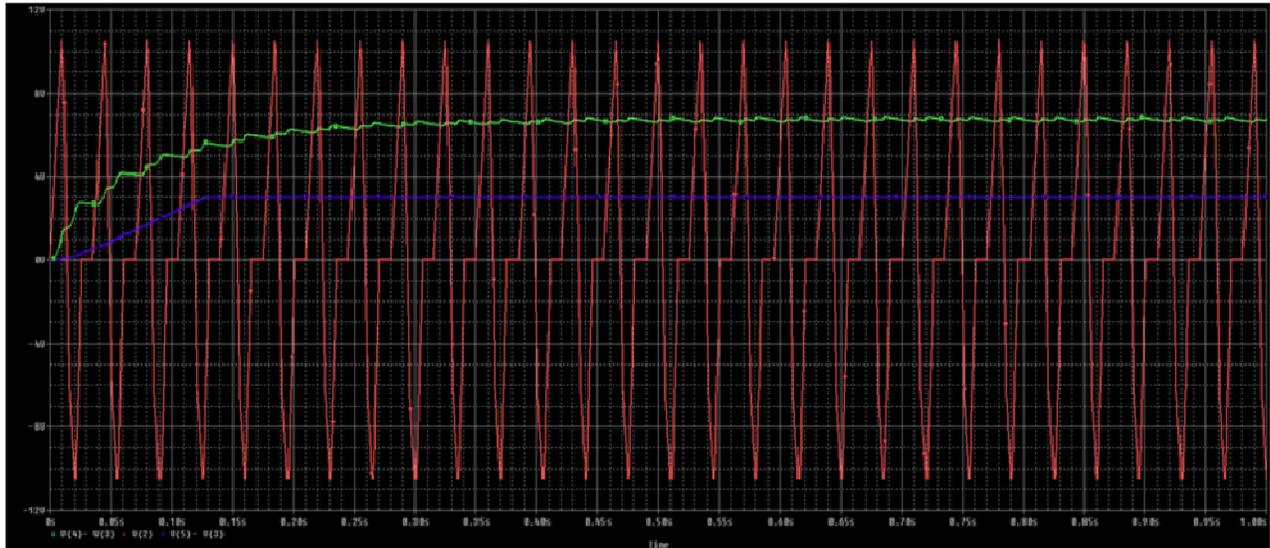
PSPICE simulations:

Figure 14- Red: generator input, Green: rectified w/capacitor, Blue: regulated voltage

*Generator (Red)

V1 1 0 PULSE(0 10.5 0 .01 .005 .001 .035)

V2 2 1 PULSE(0 -10.5 .01 .01 .005 .001 .035)

*Rectifier (Green)

RL 4 3 1K

CL 4 3 1000u

D1 3 2 D1N4148

D2 2 4 D1N4148

D3 3 0 D1N4148

D4 0 4 D1N4148

*Regulator (Purple) R1

4 5 1k

*R2 5 3 1K

C2 5 3 100u

DZ 3 5 BZX84_C3V0

.model D1N4148 D (IS=0.1PA, RS=16 CJO=2PF TT=12N BV=100 IBV=0.1PA)

.MODEL BZX84_C3V0 D (

+ IS = 1.001e-09

+ RS = 0.3552

+ CJO = 1e-12

+ VJ = 0.75

+ TT = 5e-09

+ M = 0.3333

+ BV = 3

+ IBV = 0.005

+ N = 1.11

+ EG = 1.11

+ XTI = 3

+ KF = 0

+ AF= 1

+ FC = 0.06503

+ TNOM = 27

+)

.TRAN .001 1

.PLOT TRAN V(2)

.PRINT TRAN V(2)

.PROBE

.END

Testing Apparatus:

It was apparent early on in the design phase of the project that a way to test the theoretical and simulated models was going to be necessary. The group carefully progressed through the test phase; beginning with the generation stage then progressing through the rectification, regulation, and storing elements of the circuit. Over the course of the semester, multiple testing setups were utilized.

To simulate a bicycle being ridden without taking up too much space in the lab, team members designed a double sided support out of angled aluminum to suspend a single bike tire. This tire was then spun by hand to mimic a person riding. The speed consistency of the person spinning the tire was evaluated constantly using a cyclometer to ensure our ten mile per hour goal was the speed being tested. Using this arrangement it was then possible to evaluate what type of waveforms were being generated using an oscilloscope. From there, with the aid of a protoboard, the full-bridge rectifier was investigated again with the oscilloscope. Lastly the voltage regulator was tested and tuned to a three volt output using a digital volt meter. Only once all components were tested individually was the circuit put together and soldered onto a board. It was at this stage in the engineering process that this stand originally designed to hold a simple tire was adapted to suspend the back wheel of the entire bicycle complete with the rider.

Cost Analysis:

The largest expenditure involved in this design was the rare-earth, neodymium magnets epoxied around the wheel. 18 sets of 4 magnets were utilized in the final design. From Home Depot, each magnet cost \$1.42, giving a total of \$102.24 for the magnets alone. Other costs included the 30AWG magnet wire (about \$3.00; package of three spools was \$8.99), the soft iron rod (about \$8.00; two rods were \$16.42), 3 supercapacitors (\$4.45 each), the SWADJ regulator (\$25.00), the bike headlamp (about \$10.00, set was \$16.01) and the bicycle bag (\$15.00). The final product ultimately cost about \$177, not counting the materials bought for testing or other project purposes. Additionally, the group had access to lab materials such as wire, solder, diodes and capacitors, along with items already owned by members, including epoxy, circuit boards, electrical tape, building materials (for stand), and bicycle. Taking into account these additional materials, the total cost for the team's generator, circuitry and LED kit (bicycle not included) can be estimated to be around \$200.

Future Directions and Applications:

One important focus of this project was to shed light on current alternative energy solutions and to explore the need for further research in green technology. It is something interactive and fun that can be understood on a very basic level even for those with no prior electrical engineering experience. It is meant to generate interest and excitement concerning the field of alternative energy.

Future research could involve more experimentation with solenoid design or placement of the magnets and solenoid in relation to each other. Currently, a generator called the bottle dynamo exists where instead of magnets passing by a solenoid as in Power 2PI's design, a magnet revolves in place beside the stationary coils. Other situations could also be explored. If multiple solenoids were added to the circuit, or both wheels fitted with magnets, a larger power could be generated, providing more room for expansion. Research could also be done to improve the efficiency of the circuitry so that more of the generated power could be utilized by the load.

Originally, the team's intention for the generator was to charge a phone or other USB powered device. However, it was found that the generated current was not high enough to feasibly accomplish this within the given time. Future applications could involve the use of alternative loads, instead of the LED bicycle light. Bicycling is becoming an increasingly commonplace mode of transportation and recreation. The energy exerted by the rider can also be harvested to power personal electronics.

Beyond the bicycle, there is a rapidly expanding field of passive energy harvesting. This includes solar, wind, vibration, kinetic and many other types of energy. These energies can all be utilized and are a much more eco-friendly alternatives than fossil fuels or oil.

Conclusion:

By the end of the semester, a working generator, along with circuitry to rectify, stabilize, regulate, store, and ultimately use the generated power was designed and constructed. The generator features a different placement of components than other commercially available bicycle generators such as the hub or bottle dynamo. The rectifier uses Schottky diodes while the regulator employs pulse width modulation for greater efficiency. Supercapacitors are explored as a viable substitute for batteries in this application.

Ultimately, the project served as a great learning experience for all involved members. The team had the opportunity to revisit important principles of physics, basic electronics, power electronics, and physical electronics. Additionally, it was necessary to learn the basics of soldering, and to become very comfortable performing circuit simulations and using lab equipment.

The experience and skills acquired by team members over the course of the semester will be integral in future endeavors. The technical skill, ability to work cohesively with a team, and dedication to a long-term project are important in both acquiring and holding a job in the engineering field. Additionally, the project served to reinforce principles learned in previously taken courses, providing a more solid base for either further research or higher learning.

Division of Activities:

Built initial cardboard prototype wheel for testing (NK)
 Built Wheel apparatus for simulation and testing purposes. (PF, MM)
 Made calculations for internal resistance and inductance. (PF, NK)
 Researched into different aspects of the project. (PF, NK, SK, MM)
 Updating faculty advisor weekly. (PF, NK, SK)
 Looking into designing the rectifier. (PF, NK, SK, MM)
 Simulations with Multisim/PSPICE. (PF, NK, MM)
 Winding of solenoid (PF, NK, SK, MM)
 Measuring the internal resistance. (PF, NK, SK)
 Testing every week to see what can be improved (PF, NK, SK, MM)
 Testing for feasibility of project. (PF, NK, SK, MM)
 Worked on writing Capstone Midterm report. (PF, NK, SK, MM)
 Went shopping to obtain required materials for testing. (PF, NK, SK, MM)
 Cut the soft iron core. (PF)
 Met with Sumati to discuss solenoid. (PF)
 Work on designing the regulator. (PF, NK, SK, MM)
 Work on designing the rectifier. (PF, NK, SK, MM)
 Performing calculations for the rectifier and the regulator. (PF, NK, SK, MM)
 Meeting with Dr. Hanafi to discuss the regulator. (PF, NK)
 Testing and simulating new rectifier and regulator designs . (PF, NK, SK, MM)
 Obtaining bicycle (NK)
 Documenting progress. (PF, NK, SK, MM)
 Research on LED bike lights. (PF, NK, SK, MM)
 Epoxy magnets to spokes of primary bike wheel (PF, MM)
 Glue stacks of 4 magnets together (NK, SK)
 Epoxy solenoid to rear bike fork. (PF, NK, SK, MM)
 Build optional stationary bike stand (PF, MM)
 Wiring the bicycle (PF, NK, SK, MM)
 Design Poster Board (NK, SK)
 Research about supercapacitors. (SK)
 Arduino Microcontroller feedback regulation system trials (PF, NK, SK, MM)
 Soldering Final Circuit Board (NK, MM)
 Powerpoint slides (PF, MM)
 Final Report Compilation (NK)
 Project Timeline (PF, SK)
 Rutgers Day Presentation (PF, NK, MM)
 Poster Day Presentation (PF, NK, SK)
 Final report write up (PF, NK, SK, MM)

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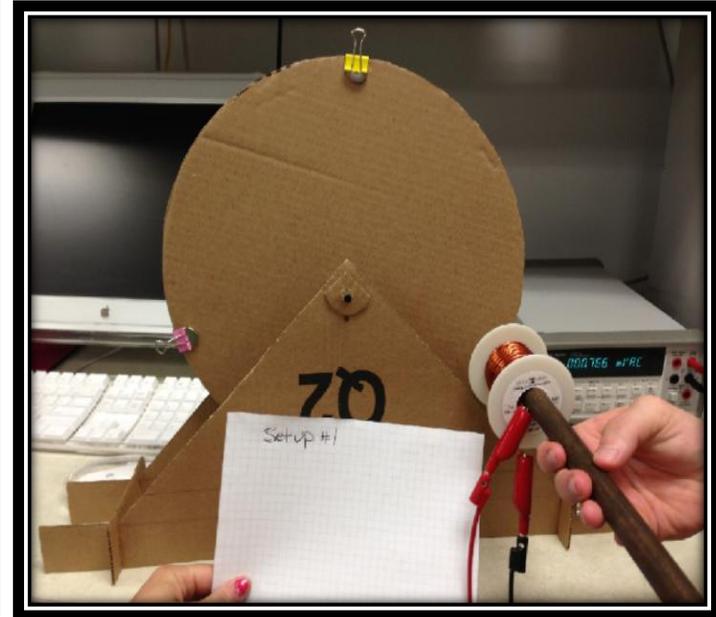
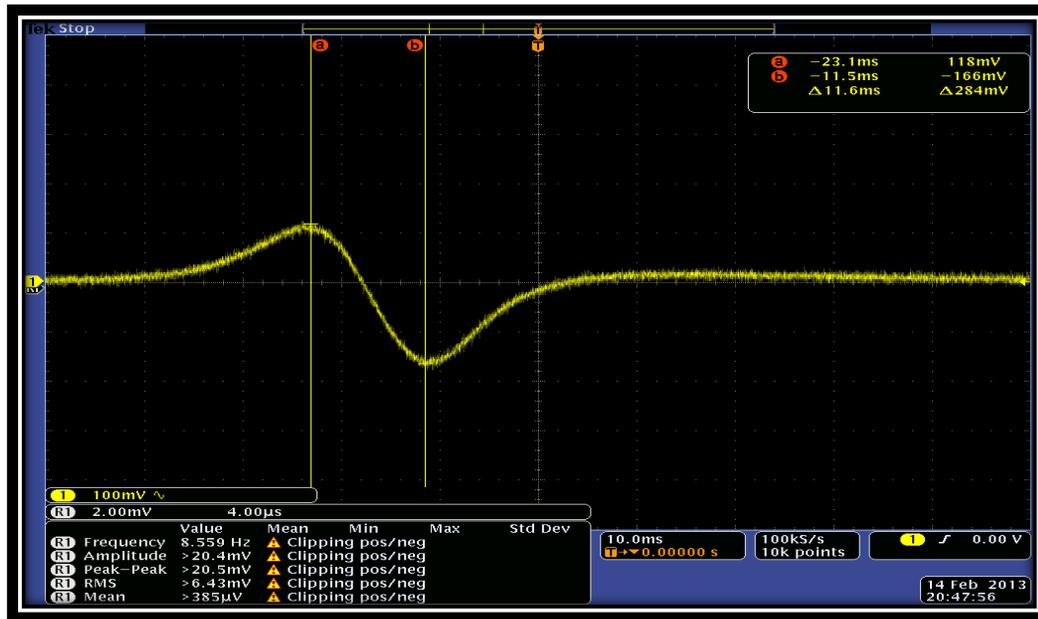
<http://encon.fke.utm.my/nikd/latest/sloa067.pdf>

Timeline

2/14/2013

Designed cardboard wheel for initial lab testing

Using 1 Magnet - peak voltage = 0.118V



2/16/2013

Magnets taped to inner spokes on temporary bike.

As # increases, magnets are stacked on top of each other (green solenoid w/steel core was used)

This data was taken with magnets fixed to the center of each spoke, closer to the axle of the wheel.



# Neodymium Magnets	Vmax (V)
1	0.368
2	0.508
3	1.02
4	1.52
5	2.16
6	3.26
18 (3 groups of 6 magnets)	6.28
18 Using large coil+iron rod	0.354

Note: 13-14mph (speedometer reading) necessary to generate 5-6.5V
6.68 V @faster speed



2/18/2013

Designed the testing apparatus for lab experimental testing purposes

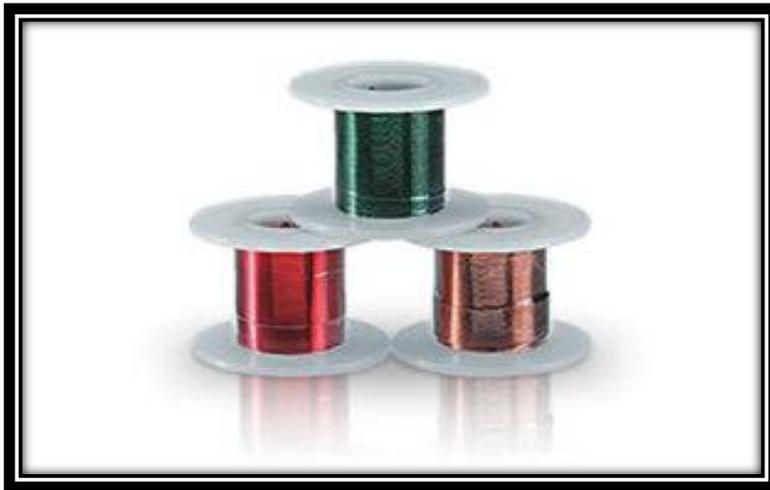
This apparatus is made of an aluminum base with angled aluminum brackets.



3/5/2013

Test with Assorted gauges from Radio Shack and measure the internal resistance

Theoretical Data			
Gauge (AWG)	Length	Inductance	Internal Resistance
22	40ft	.587mH	0.632 Ω
26	75ft	2.063mH	3 Ω
30	200ft	14.67mH	20.2 Ω



http://i.ebayimg.com/t/Radio-Shack-Assorted-Enamel-Coated-Magnet-Wire-Coil-Electromagnet-Brand-NEW-/00/s/MjM1WDM0NQ==/qR,!hIFBbKEvoOiBQh+FqEgyg~~60_35.JPG

<http://www.cencophysics.com/soft-iron-rod/p/IG0038157>

3/7/2013

Wound the final solenoid that will be used for the design - (30 Gauge Magnet Wire, 200 ft long)

Solenoid Testing

Max Voltage Achieved 4.36V-6.8V (7.44 at high speed)

200ft-30Gauge redsolenoid on iron rod

So Internal resistance is probably 22 OHM by voltage divider properties (Half of 0 OHM voltage)

Average Spin	Spin1	Spin2	Spin3	Spin4	Spin5
Vout with No Load	4V	4.16	4.72	4.48	3.92
Vout with 22Ω Load	2.24V	2V	2.48V	X	X
Vout with 75Ω Load	3.84V	X	X	X	X
Vout with 100Ω Load	4V	X	X	X	X
Vout with 150kΩ Load	4.64V	X	X	X	X

Speed	Average	Fast
Voltage with 3 Magnets	2.6V	3.84V

3/7/2013

Rearranged magnets to the perimeter of the wheel for greater angular velocity

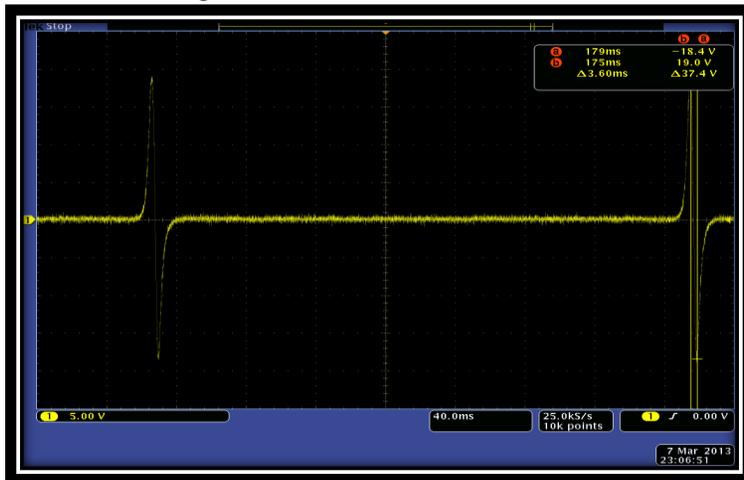
	Average	Fast
Voltage with 6 Magnets	13.6V	19V
Voltage with 3 Magnets	11.6V	12.6V

Verified internal resistance ~22 OHM

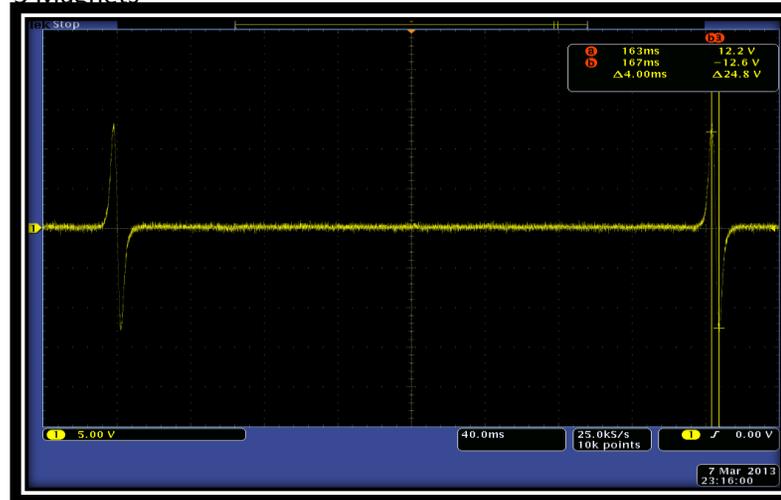
Average Spin	spin1	spin2	spin3
Vout with No Load	9.6V	10V	9V
Vout with 22Ω Load	4.8V	X	X
Vout with 100Ω Load	8.8V	X	X

This data was achieved using the testing apparatus . It was recorded when the magnets were attached near the perimeter

6 Magnets



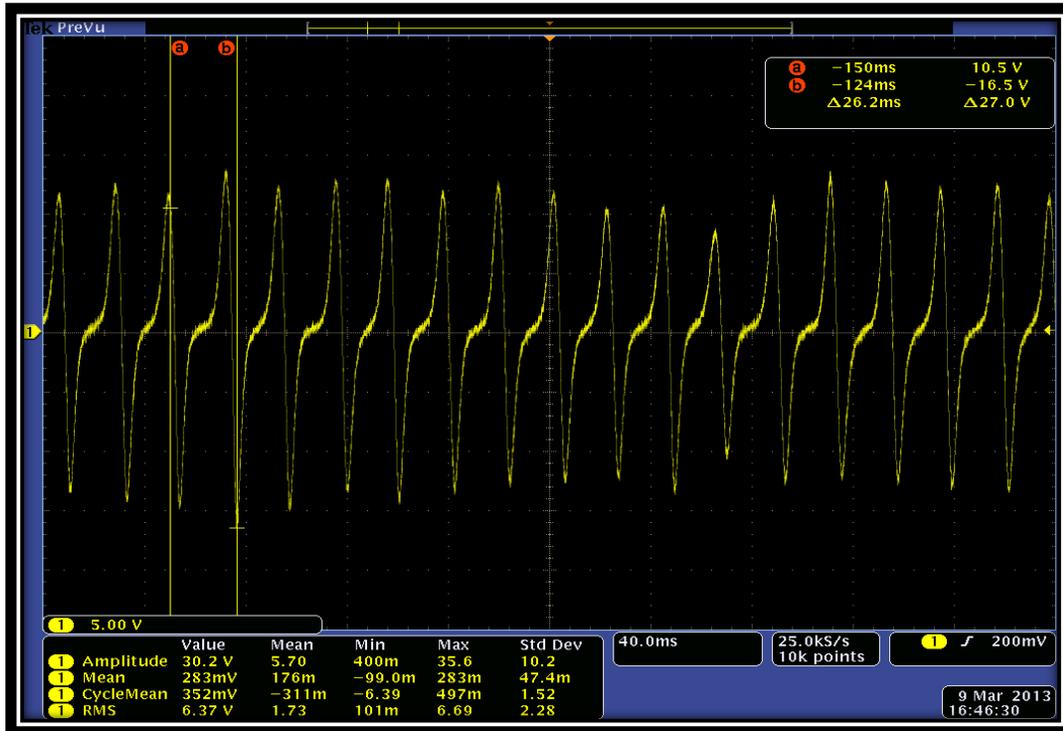
3 Magnets



3/9/2013

Tested with 3 sets of magnets on 18 spokes.

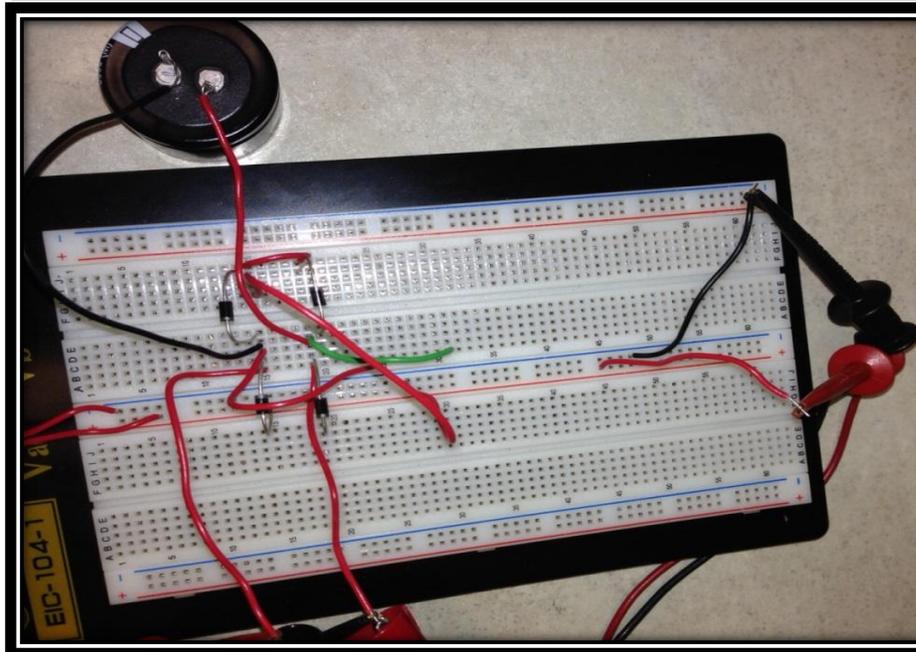
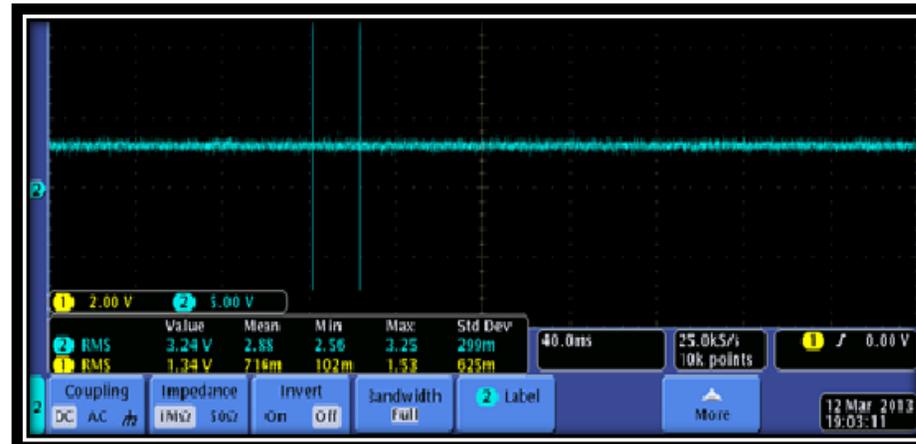
*Note: Time delay between waveforms is well below 40ms; $V_{rms} = 6.37V$ and the peak voltage is a magnitude of 16.5V.



3/12/2013

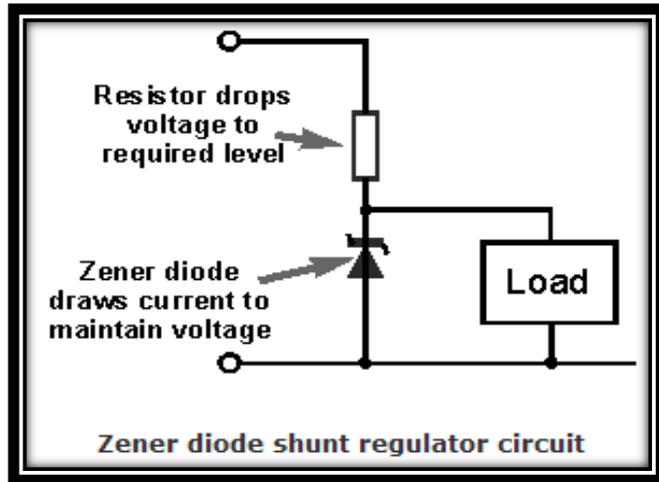
Tested the rectifier with an 18mF capacitor in the load to stabilize the output signal.

*Note: Only issue is the ripple effect when you zoom in, so need a regulator.



3/29/2013

Obtained 4.5 V and 3 V zener diodes to test the efficiency of the linear regulator.
0.2mA current was measured along with a power output of 0.62mW.



4/6/2013

Tested the operating points of different light systems.



Model A--Bell Spyder (Red, 1LED)
Normal Operation = 3 V @ 25mA
75mW
Lowest Operation = 1.65 V @
0.97mA
1.6mW
Low Mid Operation = 2.3 V @
10.5mA



Model B--Schwinn (Red, 3LED)
Normal Operation = 3 V @ 95mA
285mW
Lowest Operation = 1.72V @ 0.52mA
0.89mW
Low Mid Operation = 2.4V @ 28mA
67.2mW



Model C--Schwinn (White, 4LED)
Normal Operation = 4.5 V @ 93mA
418mW
Lowest Operation = 2.5 V @ 0.23mA
0.575mW
Low Mid Operation = 3.5 V @ 39.5mA
138.3mW

4/12/2013

Tested the adjustable step down regulator.



4 Magnets @ 10 to 11mph
(00:06:30) fully charged at 5.4V, not
oscillating, but regulator comes on
and off, stays on for 00:01:25 after
wheel is stopped.
3 supercaps were used in parallel at
the output, with 2 normal 18mF
capacitors after the rectifier.

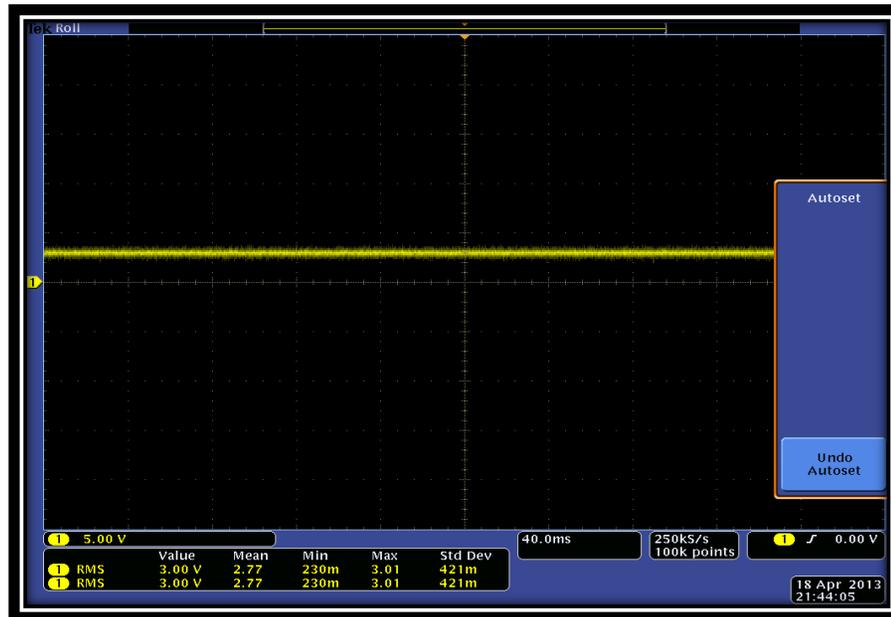
4/18/2013

Tested the brightness of the light and how long it would take for it to turn on when the regulator was set to 2.8V and 3.0V - (4 Magnets per spoke).

3 Supercaps (1.5F each with a 5.5V rating):

10-11mph, 3 supercap - 4s to blink, 8:15 min to 2.8V(regulated)
12-13mph, 3 supercap- 3 s to blink, 3:05min to 2.8V(regulated)
14-15mph, 3 supercap- 2 s to blink, 1:53 min to 2.8V (regulated)
17-18mph, 3 supercap- 2 s to blink, 0:58 min to 2.8V (regulated)

10-11mph, 3 supercap- 18s to blink, 8:29min to 3V(regulated)
12-13mph, 3 supercap- 5s to blink, 4:10min to 3V(regulated)
14-15mph, 3 supercap- 3s to blink, 2:39min to 3V(regulated)
17-18mph, 3 supercap- 3s to blink, 1:24min to 3V(regulated)

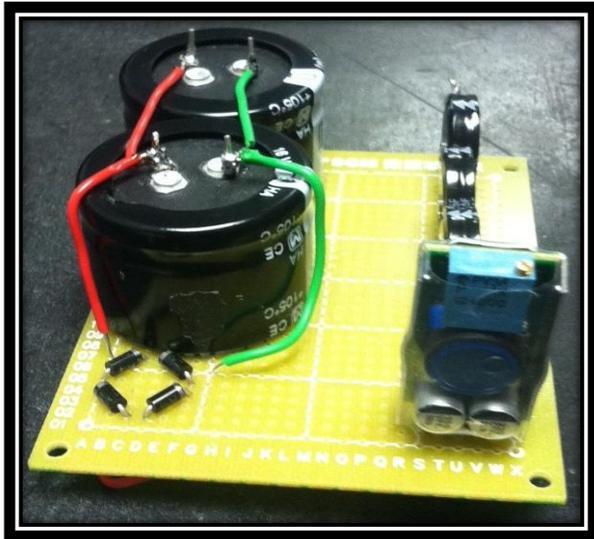


4/19/2013

Started to assemble components of the final design



Epoxied magnets to spokes and solenoid to bike frame



Soldered components

4/23/2013

Designed the stand and created the poster for poster day

