ESE 498 Senior Design Report
Supervised by Dr. Robert Morley

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Bicycle Powered Generator for the University Farm

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Submitted in Partial Fulfillment of
the Requirement for the BSEE Degree

Washington University in St. Louis
School of Engineering & Applied Science
Electrical & Systems Engineering Department

Student Statement

We have observed and upheld all codes including the University's Honor System, and have maintained the integrity of this course in the design and implementation of our project.

Bradley Pelz Jeffrey Feiereisen

Abstract

The Burning Kumquat, a student run organic garden on the South 40 of Washington University, is maintained year-round by a growing number of eco-centric students that regularly work long hours during the day and meet at night. To support their endeavors, we took on this design project to provide the group music and nighttime lighting. We have created a user-controlled energy generation system that is free of coal (staying true to the nature of the group) and, unlike traditional renewables, both reliable and consistent. Over the course of the semester, we designed and constructed an entirely unique electric generation system that fuses both form and function into a cost-effective and convenient solution. Using a stationary bicycle to generate electricity and charge a 12 volt battery, we obtain an output power of approximately 60 watts – plenty of power for lights, an amplifier, an iPod charger, and any unforeseen additional loads the student group may attach later. The system provides about 5 hours of fully-loaded use, and requires the equivalent for charging.

Acknowledgments

Thank you to Dr. Robert Morley and Patrick Harkins for their guidance, and the Electrical & Systems Engineering Department, Engineers Without Borders, and the Institute of Electrical and Electronics Engineers for their financial support.

Table of Contents

Table of Figures and Tables

Problem Statement

Our starting point was a permanent magnet DC motor that the Burning Kumquat had removed from a small industrial fan. Our primary goal was to run that particular DC motor (to keep costs low) as a generator and charge a battery capable of powering lights and a music amplifier for about 4-5 hours. The idea of this project was first pitched to the Institute of Electrical and Electronics Engineers (IEEE) and Engineers Without Borders (EWB) by the Burning Kumquat (BK), a student group at Washington University that maintains the University's farm on the South 40. We later decided to take this project on instead for Senior Design with the understanding that our biggest constraint would be time.

The objectives and expectations are fairly clear for a research initiative focused on developing a product, and that is the working product itself. The constraints of this project aside from time are essentially the budget (low as possible) and design specifications as listed below.

One additional side objective, however, is more professional in nature rather than technical: Teamwork/Collaboration. Working in a team effectively where each individual has unique skills to offer after four years of education was another goal as it reflects the environment we expect to work in throughout our careers.

Problem Formulation

In order to design and construct our bicycle power generator, we took a very systematic approach: We based our capabilities off of a generator we had available to us. This meant calculating the required gear ratio needed to achieve required output voltages at reasonable pedaling speeds. From there, we built a structural support for the generator, bike, and extra gears. The circuitry for the charge/discharge controllers, amplifier, and charge indicator were then assembled in parallel. These were then fitted and connected into a secure box with all input connections arranged at the top for convenience and professionalism.

We were able to accomplish our goals for this project by identifying the key steps to get there as described above. The results of our design and construction are detailed in this report and have been verified through simulation and product testing. Through this report, we expect that the reader will be perfectly equipped to replicate the project and obtain the same results.

Project Specifications

Our design will provide all of the following:

- A 12 V_{DC} deep cycle lead acid battery for compatibility, convenience, and cost
- Power for at least 4 hours, without charging, from a full charge
- Capability of powering components directly from generator in case of a dead battery
- Directed and adjustable, low power light source of at least 500 lumens roughly (1/3 the light output of a 100W incandescent light bulb)
- iPod charging capability
- Weather proof or easily moveable for protected storage
- An indicator for the remaining capacity of the battery
- An indicator that the bike is being pedaled fast enough to charge the battery
- A 4-5 watt speaker (or about comparable to computer speakers)
- Expandability to other 12 V_{DC} applications through cigarette socket adaptors

Concept Synthesis

Literature Review

This research endeavor relied most heavily on prior class work and datasheets for our designs. This final result is entirely our own and unique. Though we didn't model our system off of any external resources, other bicycle power generators can be observed and compared in the Mechanical, Aerospace, and Structural Engineering laboratory. A search online would yield other bicycle power generation approaches as well.

Concept Generation

The following page presents a tree diagram of the design options we considered in developing our final product. The ultimate decisions for each consideration have been highlighted and are discussed in greater detail in the engineering analysis.

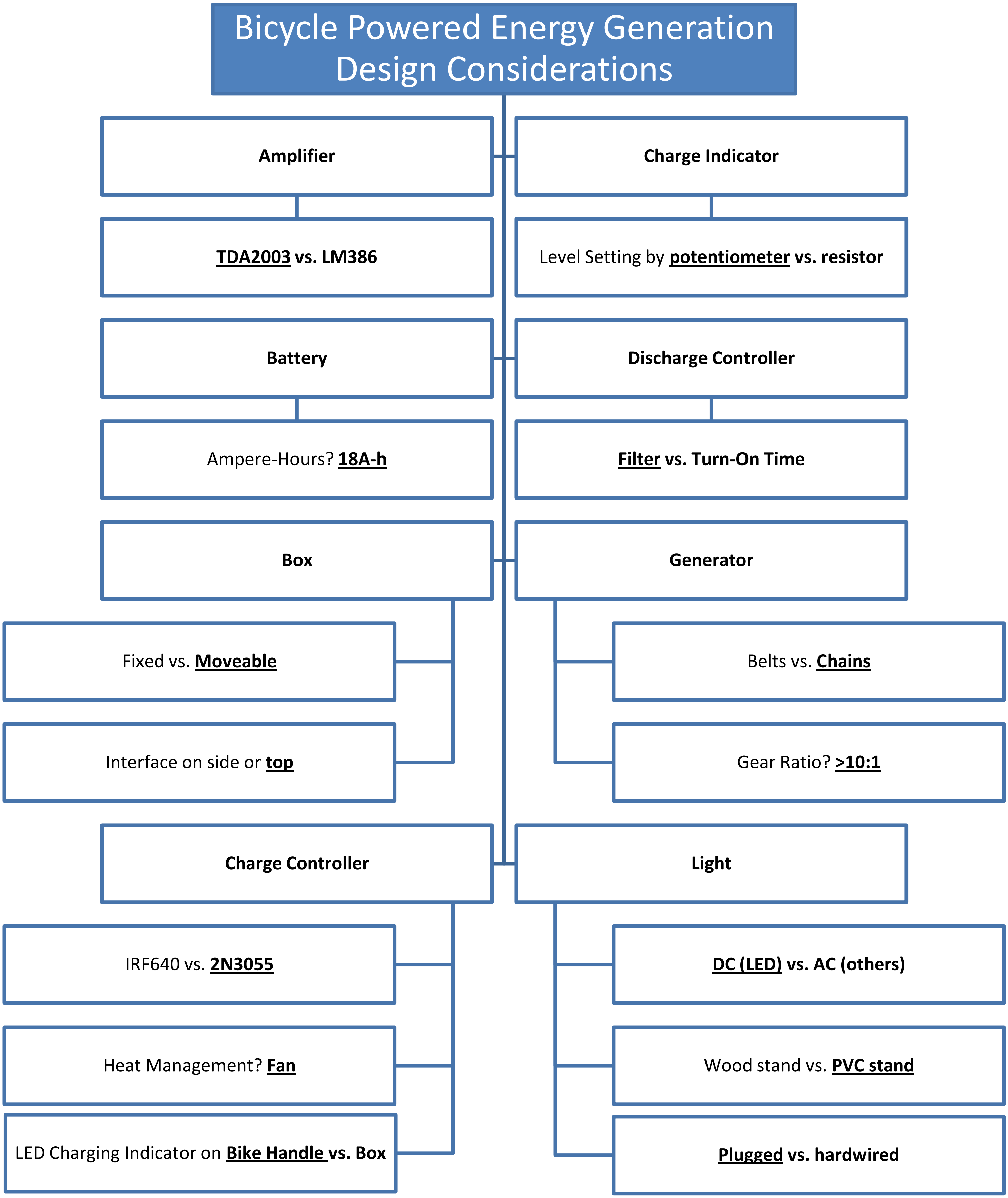

Figure 1 Design Considerations

Concept Reduction

In order to reduce the number of options we have for each part of the system, we generally based decisions on three key, ranked values: specifications, cost, and convenience. In other words, when faced with a decision, we first experimented to see how the options helped meet specifications, then we considered which is cheapest, and finally which would be the more convenient solution.

The following examples go through our design options and provide some of the reasoning behind our decisions:

- **Amplifier**: The LM386 does not provide the output power we need at 1 watt (*specifications*)
- **Battery**: As will be discussed later, 18 A-h meets our requirements (*specifications*)
- **Box**: Moveable makes the system easier to place anywhere (*convenience*)
  Top interface made it easy to access all plugs and switches with the box on the floor (*convenience*)
- **Charge Controller:** IRF640 was exploding because we couldn't keep the gate-to-source voltage low enough (*specifications*)
  2N3055 becomes hot when charging the battery, so a fan was installed for cooling (*specifications*)
  Bike handle indicator is easier to see while pedaling (*convenience*)
- **Charge Indicator:** potentiometer is easier to adjust to desired levels (*convenience*)
- **Discharge Controller:** filter is required at expense of turn-on time for operation (*specifications*)
- **Generator:** Chains provide a better grip with the gears (*convenience*)
  10:1 gear ratio is required with our generator (*specifications*)
- **Light:** DC lighting made connections to battery easier and cheaper(*convenience, cost*)
  PVC pipes are cheaper and lighter (*convenience, cost*)
  Plugs make the system easier to place anywhere (*convenience*)

As is demonstrated above, we struck a balance between each of these three key values as much as possible to identify the best final solution.

Detailed Engineering Analysis and Design Presentation

This section has been split up into the various parts that make up our bicycle powered energy generator. The engineering analysis begins with the generator setup and continues with the bicycle stand setup, battery, charge controller, discharge controller, charge indicator, amplifier, light, and the box.

Generator Setup

The first step in the process was to determine the output capabilities of the permanent magnet DC motor since we were unable to find data sheets for this specific motor. To do this, we ran our DC generator with a DC motor from the electrical energy lab. We built a temporary test rig which is shown below in Figure 2.

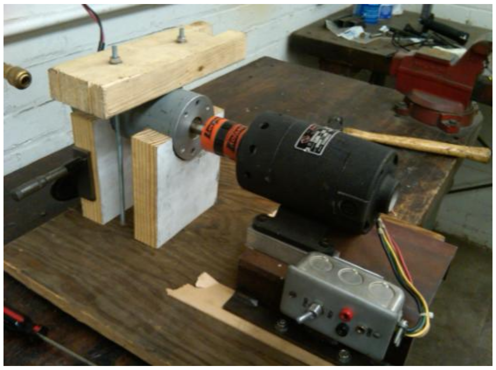

Figure 2 Generator Testing Setup

From these tests, we were able to get the linear voltage speed curve from our generator, and then determine the speed at which we needed to spin the generator to get sufficient output to charge the battery and power our appliances. We estimated that 18 to 20 volts would be sufficient to power the charge controller and provide the 13.5-15 volts necessary to charge the battery. 18V corresponds to roughly 625 RPM. This rotational speed will be critical for determining the gear ratio needed on the bike stand. All the test points are shown in Figure 3 here.

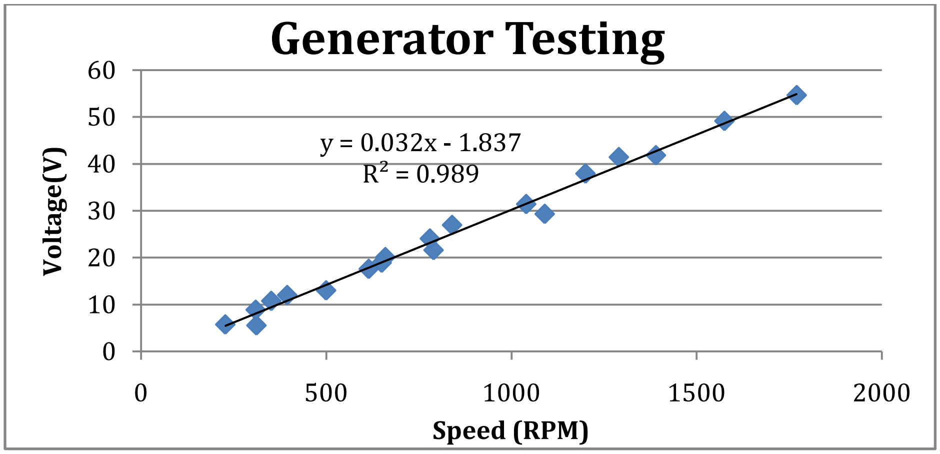

Figure 3 Generator Testing (Voltage vs. Speed)

This graph displays the linear nature of the output of the generator. It also shows that we will need to gear up the rotational speed from the pedals in order to achieve the necessary voltage for charging a 12 V battery.

Bicycle Stand Setup

Having determined the generator output capabilities, we then built a structure to support and mount the generator and bike together. Our primary goal here was to create a compact unit that would not extend beyond the diameter of a wheel. As can be seen in figure 4, the setup we have is tight enough to use an ordinary bike cover in case of bad weather. This was an important consideration because we felt it would be best to have the bike setup remain stationary as much as possible, rather than having users move it indoors for bad weather.

Figure 4 Bicycle stand setup

The bicycle stand setup consists of two parts: (1) the support structure, and (2) the gear design. The support structure has a very simple design in which 2"x4" wood is used to create a stand atop which the bicycle axel is mounted to angle brackets. The stand was made to approximately the same width as from pedal to pedal, thereby providing the necessary stability when climbing on/off and pedaling. The generator sits very snugly in drilled out pieces of plywood. The setup we constructed is extremely durable with minimal undesired movement (e.g. shaking of the generator itself).

The gear design is especially unique. Based on the generator we selected, we needed a gear ratio high enough to spin the generator sufficiently such that it charges the battery. This is due to the following equation:

*Gear Ratio * Pedaling Speed = Speed of the Generator*

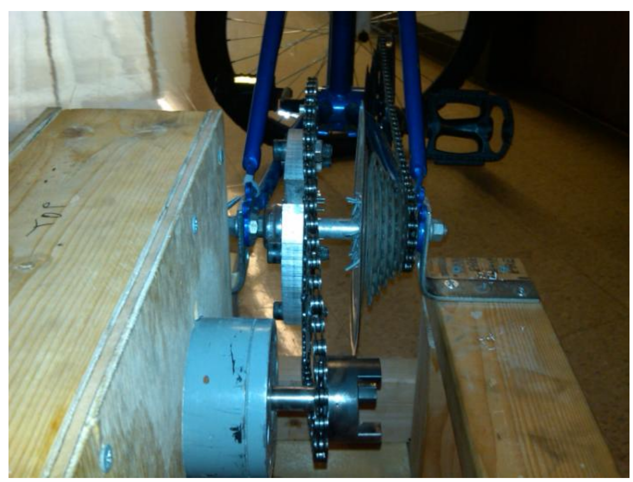

Figure 5 Gear ratio

The battery is charged at about 13.5 volts, which was achievable with our generator given a gear ratio of at least 10:1. To reach this, we have a chain running from the largest 48-tooth gear at the pedals to the smallest on the rear wheel axle, a 14-tooth gear. We then mounted an additional, homemade gear of 52 teeth to the rear axle that is twice the rear cassette's largest gear. A chain then runs from this added gear to a 14-tooth gear at the generator. Our final gear ratio is 12.7:1. As figure 5 shows, the rear cassette was used by cutting off the wheel around it. We also used the original axle from the wheel, thus taking advantage of the pre-installed bearings.

The final addition to the bicycle stand setup is a small skateboard that can just slightly be seen in the figure 4 with two of the wheel's shadows. The skateboard is made of one long sheet of plywood and four pieces of2"x4"s for support. The skateboard is removable and was built to make transportation of the bicycle easier. Referring to figure 5, the skateboard would fit in that middle runway at the bottom between the two wooden supports.

Battery

The battery was selected based on the amount of time we wanted to operate the system at full load. As mentioned in the specifications, we wanted to be able to power the lights and music for about four to five hours. Fulfilling the 12 V_{DC} battery requirement, we found a unit from Universal Battery with 18 Ah. If the battery is discharged to 50% at most, this battery leaves us with 9 Ah. Our load of lighting, music, and an iPod charger uses about 20 watts, but with an alternative appliance connected (e.g. phone), the total power consumed could be estimated at 25 watts. With a 12 V_{DC} battery and a 25 W load, we have about 2 A of current, which gives us about 4.5 hours of use at full load – this is consistent with our design specifications. The exact battery we selected is UB12180 (12V 18Ah).

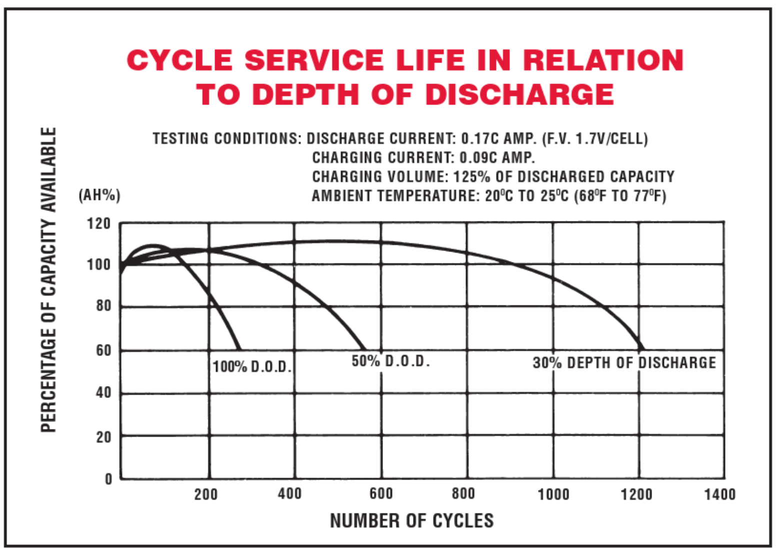

Figure 6 Battery Cycle Service Life

For the purposes of this project, we determined that the discharge controller will kick in at approximately 50% to prevent deep discharge, which happens when the battery is discharged too far resulting in loss of service life. As shown in figure 6, we get nearly 300 cycles with this depth of discharge before we begin to reduce our operating time more significantly.

Charge Controller

The charge controller is the device that controls the voltage out of the generator, which is extremely volatile and can get very large. Looking back at the generator characteristics shown in Figure 3, we can see that the output voltage of the generator varies linearly with the rotational speed. The speed that the user pedals at is difficult to control though, so we designed a switching circuit to maintain the voltage at a constant level. A schematic of the charge controller is shown on the next page in Figure 7.

There are two key features to the charge controller: (1) The heart of the charge controller is the buck chopper which takes the generator output, switches it with a pair of 2N3055 BJT's in Darlington, and then smoothes out the chopped up voltage with D1, L1 and C1, which essentially act as a low pass filter. In a previous design, we had used an IRF640 MOSFET for the buck chopper switching, but this transistor could not handle the gate voltage we were applying, and resulted in punch through of the silica layer and shorting out of the transistor. (2) The second key feature is due to D2. D2 ensures that energy stored in the battery does not travel back to the generator and spin the generator as a motor.

The control of the switching uses a feedback loop and compares the chopper output to a reference voltage created by a LM385 voltage regulator. In this circuit, the LM385 is represented by a Zener diode and has a reference voltage of 2.5 volts. The regulator is protected from the high voltages of the generator by the 510 kilo-ohm resistor. The voltage reference goes to the non-inverting input of the LM339 comparator, while the voltage divided chopper output is fed back to its inverting input. The voltage divider has a trimmer potentiometer so that the output voltage can be set precisely and not be affected by the poor tolerances on the resistors chosen. When the inverting input (buck chopper output) is higher than the non-inverting input (voltage reference), the output of the comparator shorts to ground. This causes the Darlington switch to open and thus reduces the buck chopper output voltage. The power to flip the Darlington switch on comes directly from the generator. Here it is current limited by the 10 kilo ohm resistor. The few milliamps that this resistor limits are enough to allow significant current through the switch and small enough that the LM339 can handle the current.

The thyristor may seem unnecessary, and in fact was not an original part of the circuit, but it serves a very specific purpose. Before the LM339 is powered, its output is shorted to ground. Therefore, without the thyristor, as soon as the generator starts applying its voltage to the input of the chopper, the voltage at the base of the Darlington switch gets shorted straight to ground. That means the Darlington switch never closes, and no power ever gets transferred through the chopper. Thus, by adding the thyristor, no current can be shorted to ground until the comparator has received power as well. Once the comparator and thyristor gate have been powered, the thyristor looks like a short circuit and the chopper operates normally.

The Darlington switch dissipates a lot of power, particularly the 2N3055 labeled 1, in figure 7. In order to prevent the 2N3055 from overheating, we added a heat sink and a fan to blow cool air past the heat sink. We only wanted the fan to run while we were running the chopper, so we attached it to the node on the generator side of D2. This way, the fan cannot be powered by the battery, and every time the generator is powered, power is also delivered to the fan.

In testing our device, we had the luxury of using a multi-meter to determine if we were getting a high enough voltage on the battery to charge it. Thus, we determined, for proper operation, any user would need some way to know that sufficient voltage was being applied to the battery. To do this, we used one of the other three comparators on the LM339 chip to compare the buck chopper output voltage with the reference voltage used on the other comparator. The output of this comparator switches the low side of a green LED that is on the handle bars of the bike. When the operator achieves 13.2 volts, the LED lights up to inform the operator that the bike is being pedaled fast enough.

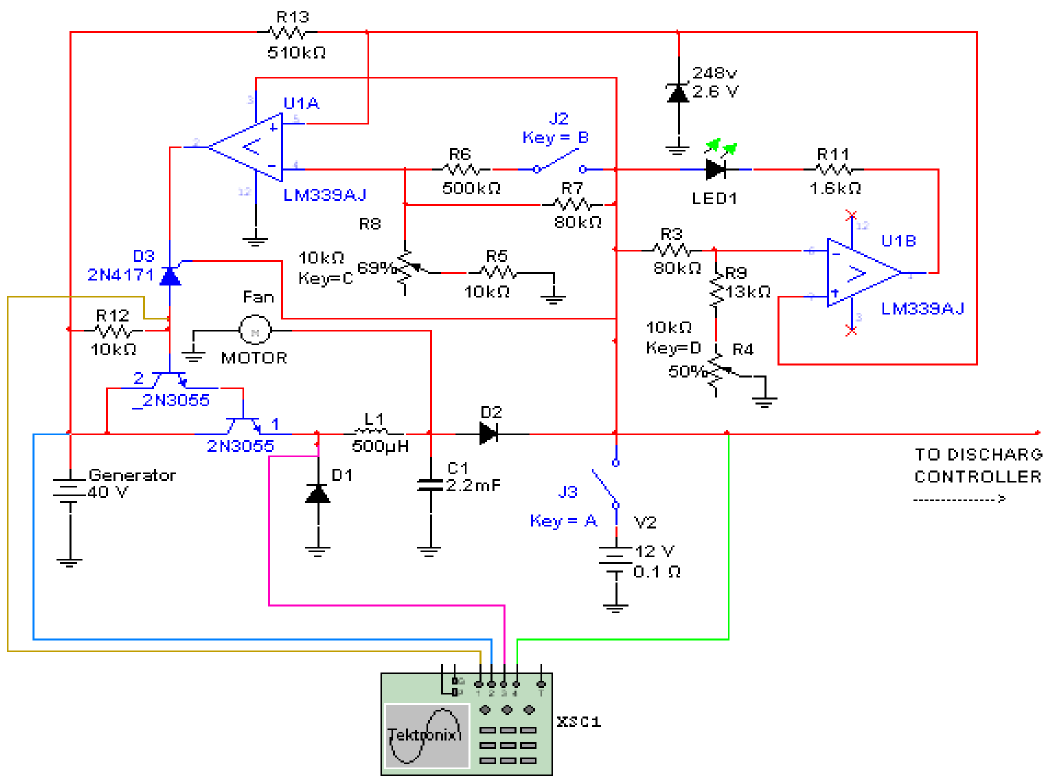

Figure 7 Charge Controller Schematic

We also incorporated the ability to change the output voltage between the battery charging voltage (14.2 V) and 12 V which is suitable for running the loads directly from the bike generator. This switch is J2 in the schematic in Figure 7. J2 simply adds a resistor in parallel with the first resistor in the voltage divider and changes the voltage divider so that a higher percentage of the buck chopper output voltage is seen at the inverting input of the comparator. Since a higher percentage of the voltage is seen at the comparator, the comparator grounds its output more often which results in a lower output voltage of the buck chopper.

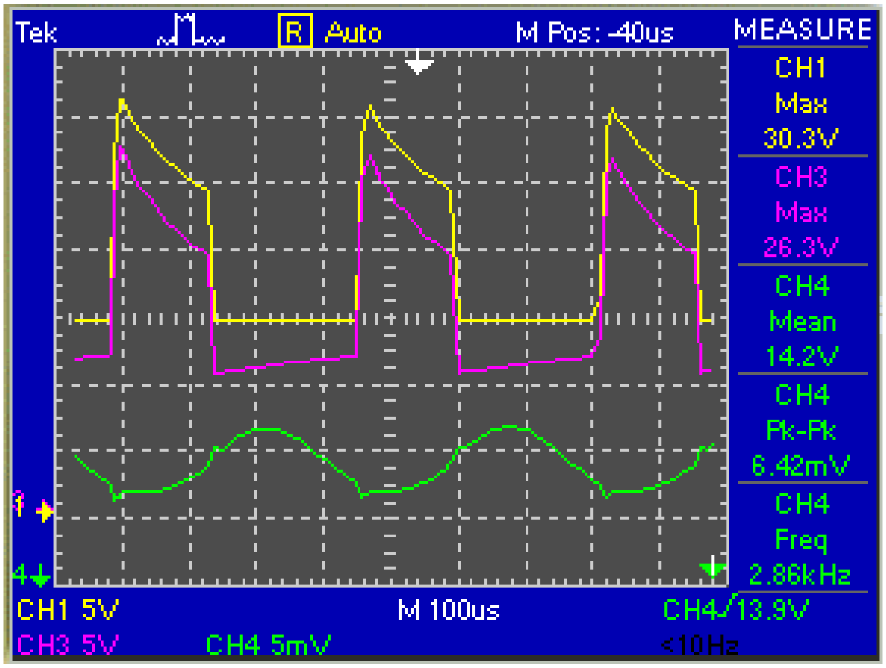

Figure 8 Buck Chopper Simulation Results

Figure 8 above is a simulation of the buck chopper. The graph colors match up to the color of the wires to the oscilloscope in figure 7. Yellow is the base of the Darlington switch, purple is the emitter, and green is the buck chopper output. As you can see, as the buck chopper output (green) begins to dip, the base voltage (yellow) spikes to send more power through the switch. The emitter voltage (magenta) follows the base voltage. Then as the buck chopper output begins to reach a maximum, the base voltage drops as does the emitter voltage. This simiulation show quite a stable output to the chopper. The mean value is 14.2 V with only 6.42 mV peak to peak.

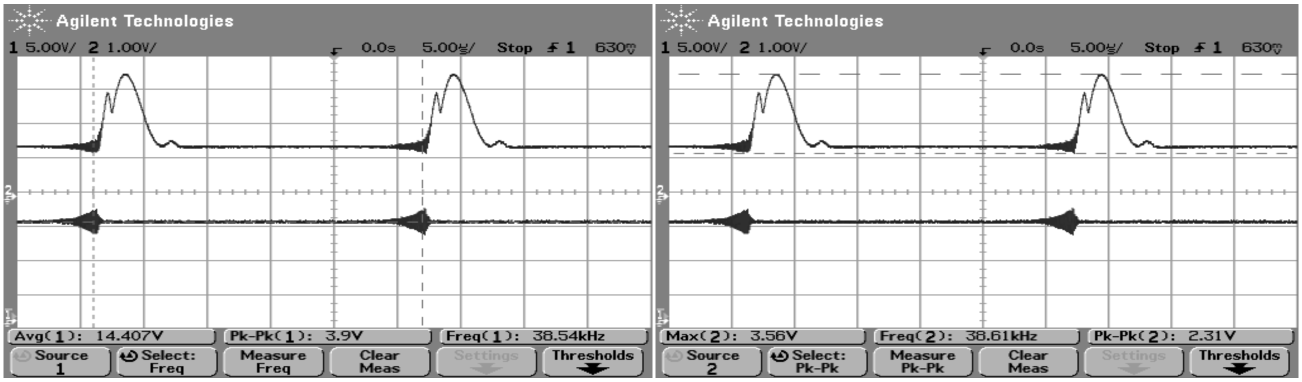

Figure 9A. Buck Chopper Scope (1) B. Buck Chopper Scope (2)

Above in Figure 9A and9B, we show the actual ouput of the buck chopper on channel 1 (lower scope trace) and the base of the Darlington configured switch on channel 2 (upper trace). The buck chopper has higher spikes in reality than in the simulation as shown in the scope captuer the output voltage varies 3.9V peak to peak. However, the variation is localized to the points when the transistors are switching. The actual chopper also oscillates at a much faster frequency.

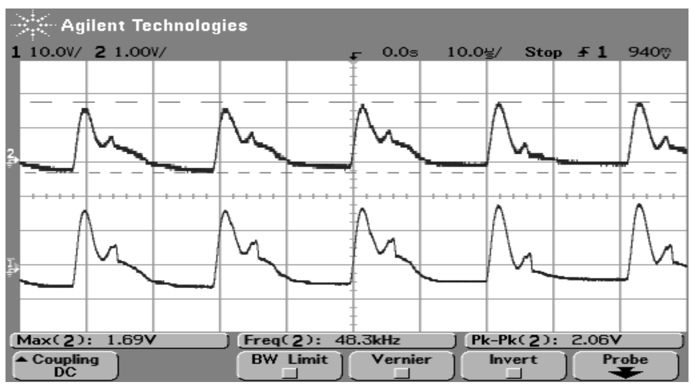

Figure 10 Buck Chopper Scope (3)

In reality, the chopper does not operate quite this effectively because of the variations of the generator voltage at the input. Above, in Figure 10, is a scope capture showing how the voltage coming out of the emitter (channel 1) of the Darlington switch configuration follows the voltage on the base (channel 2).

Discharge Controller

The discharge controller prevents the battery from entering deep discharge and unnecessarily shortening the life of the battery. Initially, we started with a discharge controller that looked like the one in figure 11. Again, we used an LM339 comparator. This comparator takes the voltage divided loaded battery voltage and compares it to a reference voltage using the same technique as the other comparators in this project. We use a trimmer potentiometer so that the cutoff voltage can be adjusted. This is particularly important because after everything is connected, the discharge controller needs to be set to the loaded voltage that corresponds with the open circuit voltage at which we wish to turn off the battery. The actual switching is accomplished by a third 2N3055 BJT transistor which is driven by a 2N3904 BJT in a Darlington configuration.

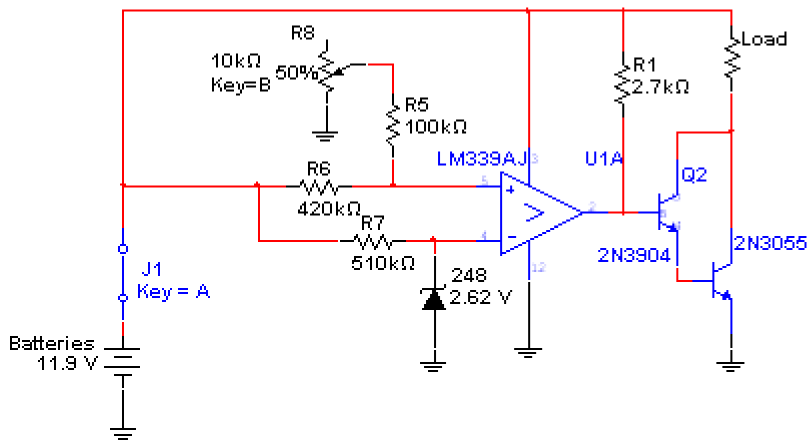

Figure 11 Discharge Controller without Filters

This discharge controller, however, had one major issue. The LED lights cause a lot of noise in the supply voltage. This caused the discharge controller to malfunction, and we no longer had the ability to specify the point at which the discharge controller disconnects the load. To solve this problem, we added filters to remove the noise from the comparator electronics. The resulting circuit is shown below in Figure 12.

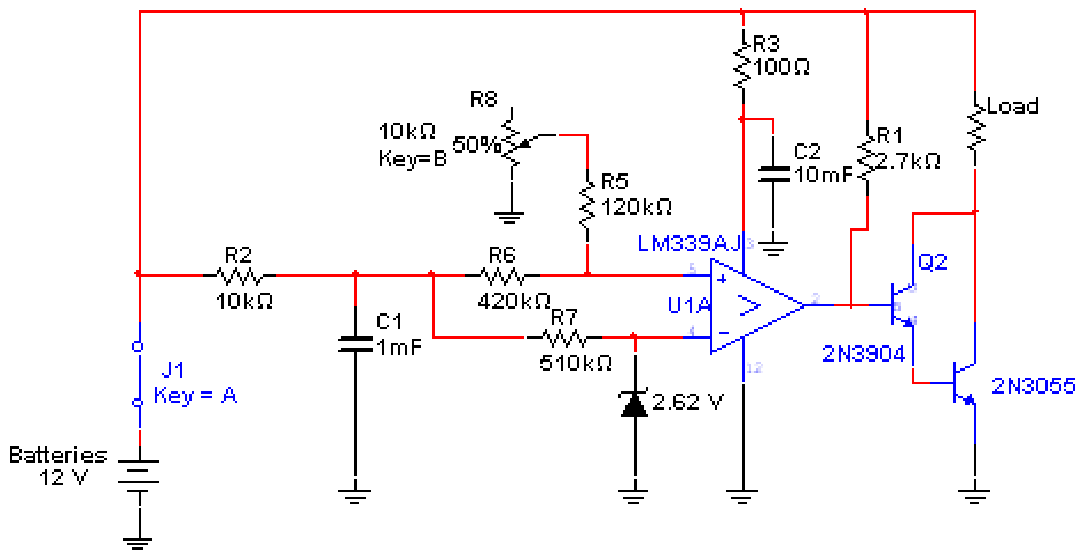

Figure 12 Discharge Controller with Filters

The comparator input filter is show below in figure 13. As is indicated on the graph, this filter attenuates everything above 0.163 Hz by at least 20 dB. This makes this filter incredibly effective at eliminating noise from the discharge controller.

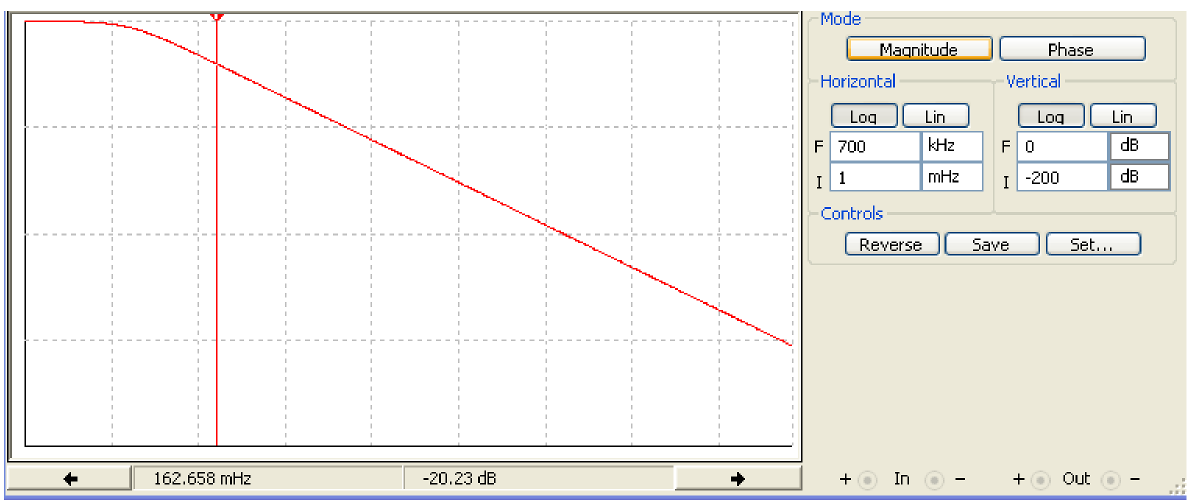

Figure 13 Bode Plot Magnitude of Input Filter

We also filtered the power to the discharge controller comparator (figure 14). This filter does not have a cut off frequency quite as low as the filter shown in Figure 13, but it still effectively filters out the non DC noise. As seen below, the filter at the power input to the comparator attenuates everything above 1.59 Hz at least 20 dB.

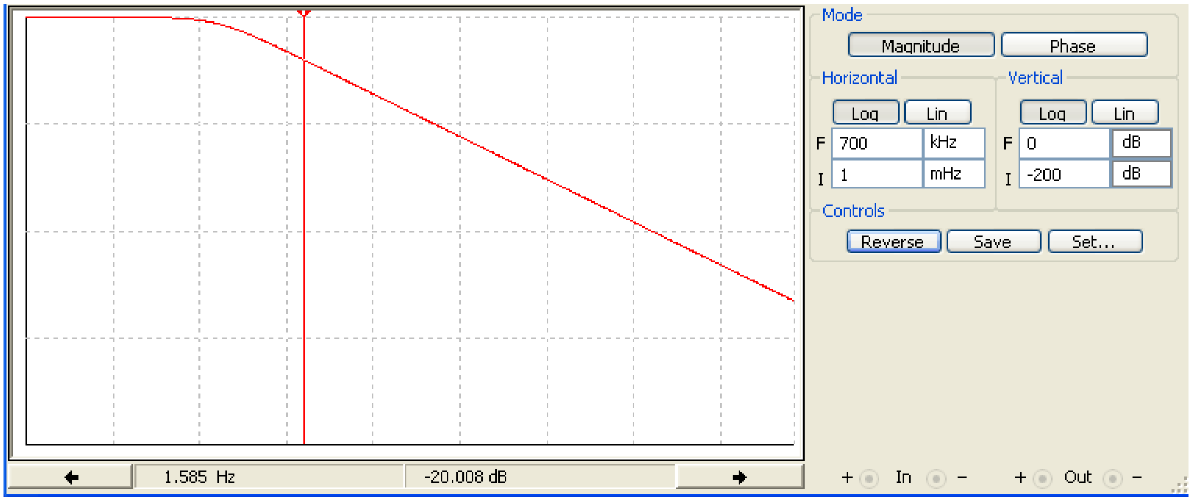

Figure 14 Bode Plot Magnitude of Comparator Power Filter

The one significant drawback of these filters is that if the system is off, you will have to wait approximately 20 seconds for the large capacitors to build up their charge prior to using any of the appliances.

Lastly, as mentioned previously, the discharge controller is set to limit discharging of the battery to a maximum of 50%, which helps ensure a longer battery life and better performance over the course of the battery's life.

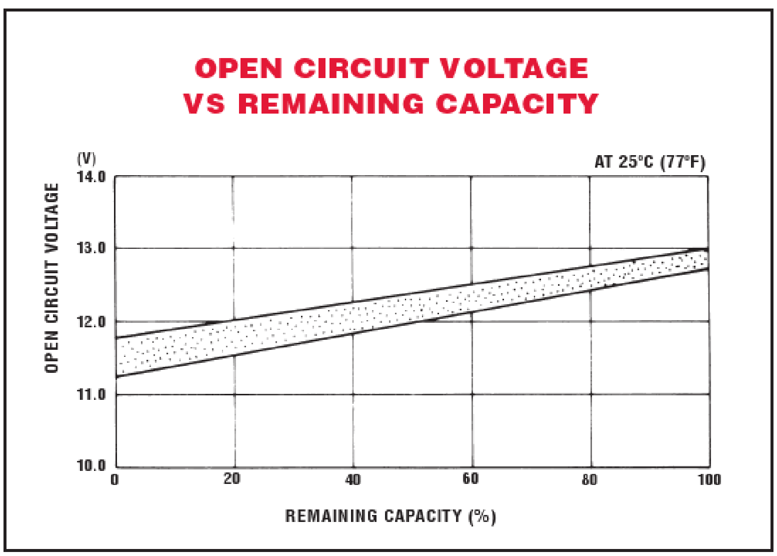

Figure 15 Battery Open Circuit Voltage vs. Remaining Capacity

The above graph in Figure 15 was used to determine the cut off for the discharge controller. The graph shows us that 40-50% of capacity reaming corresponds to approximately 12 V open circuit on the battery.

Using our actual load, we determined that 12 V open circuit resulted in 11.8 V fully loaded. Thus we set our discharge controller to shut the load off if the voltage drops below 11.8 V.

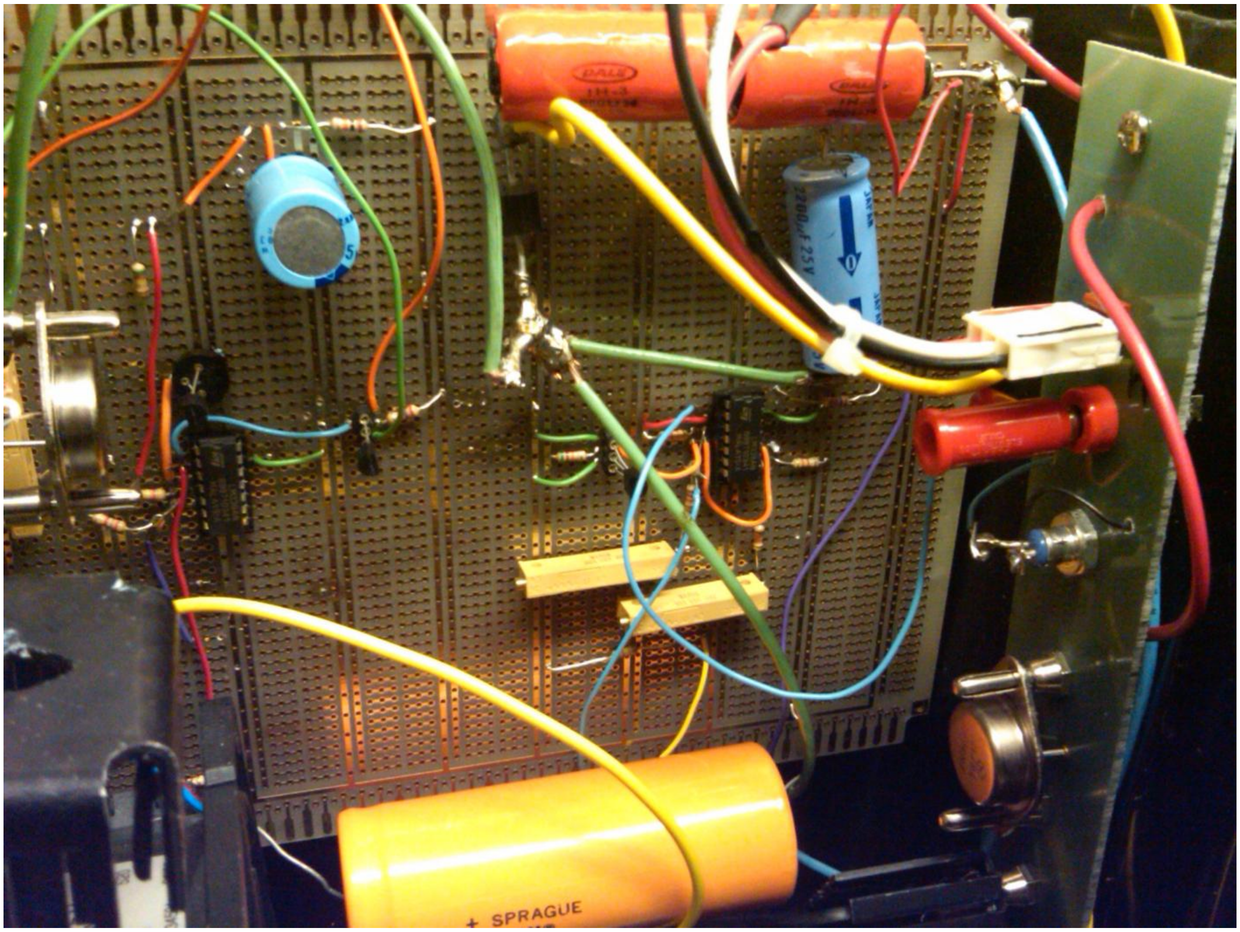

Figure 16 Charge/Discharge Controller

Above is the actual picture of the discharge controller and charge controller circuitry. The discharge controller is on the left side of the board. The left IC is the LM339 comparator used for the discharge controller. The tan trimmer potentiometer to the left (it is barely visible behind the silver transistor) is the potentiometer for the discharge controller. Additionally, the transistor to the left on its own board is the 2n3055 used to disconnect the load from the battery. The big capacitor at the bottom and the blue capacitor to the left are the main components used to filter the inputs to the discharge controller.

On the right is the charge controller. The orange components at the top are the two 250uH inductors. Near the inductors are the two diodes and the capacitor. The IC to the right is the LM339 comparator used for the charge controller. The upper left tan potentiometer is the potentiometer that controls the output voltage of the buck chopper. The lower right potentiometer controls the voltage at which the LED indicator on the handle bars turns on. To the right is a separate board with the two 2N3055 BJT's in Darlington. That board also contains the thyristor. The lower BJT is barely visible and it is the one that switches the majority of the power and has the issues with heat buildup. For this reason, we added the heat sink to the transistor as well as the fan. The fan is barely visible in the lower left corner of the picture (red and blue wires are providing power to the fan).

Charge Indicator

As we began testing, we realized that we were relying on the multi-meter to tell us the remaining capacity of the battery. Recognizing that the Burning Kumquat will not have access to a multi-meter, we installed a method of checking the remaining battery capacity. This is done with a simple set of three LED indicators – green, yellow, and red. Green means full (or nearly full) charge, yellow indicates approximately 75% of the battery capacity remains, and red indicates that the battery is around 50% of capacity and should be charged before it enters deep discharge. Referring back to figure 15, it can be seen that V_{OC} = 12.65 volts corresponds to the nearly full charge for the green LED, V_{OC} = 12.3 volts corresponds to the yellow LED, and V_{OC} = 11.8 is the cut off for the red LED. Figure 17 shows the schematic for our charge controller. We used an LM339 quad comparator chip to compare the open circuit voltage of the battery to a reference voltage attained from an LM385 voltage regulator. In the schematic below, the LM385, which provides a 2.5V reference, is represented by the Zener diode. The reference voltage is connected to the non inverting input of each of the comparators. Each of the inverting inputs is connected to the voltage divided open circuit voltage of the battery. Trimmer potentiometers are included in each of the voltage dividers so that the voltage at which each LED turns on can be adjusted to account for the relatively low tolerance of the resisters used. These potentiometers can be seen in figure 18 as well on the top left with the knobs at their front. The LEDs' turn-on voltages are controlled by these potentiometers in the order red, yellow, and green, respectively.

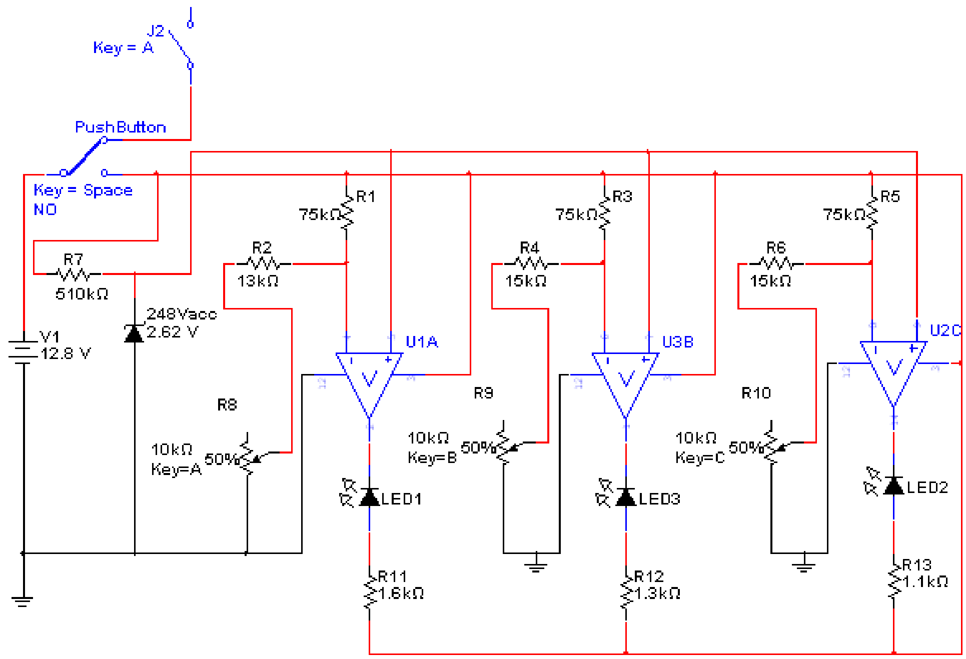

Figure 17 Charge Indicator Schematic

It is important to note that the LM339 comparators output does not go high. Rather, the output switches to ground when the non-inverting input is higher than the inverting input. Thus the LEDs are connected to the high input to the charge controller and grounded to the output of the corresponding comparator. Additionally, there is a current limiting resistor in series with each of the LED's to prevent the 12 volt supply from damaging the LEDs. These resistors do burn up power, but, we are not concerned by this for two reasons: first, the current is extremely small and thus the power is only a fraction of a watt. Secondly, the charge indicator is only on every once in a while and it automatically turns off when the push button returns to its normal position.

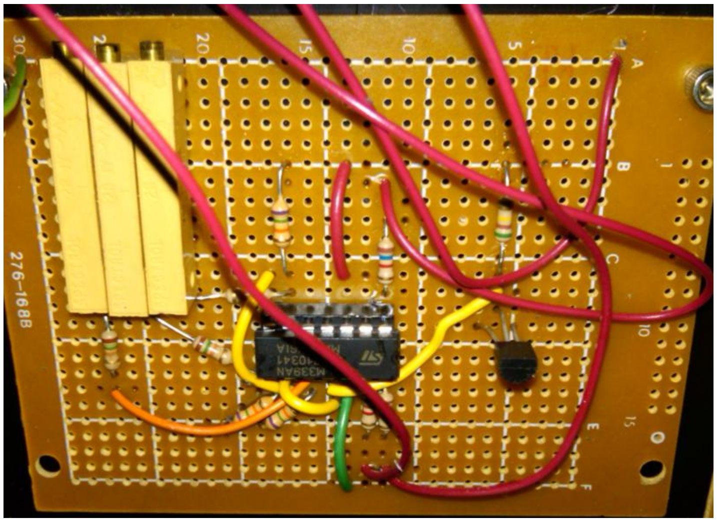

Figure 18 Charge Indicator Circuit

Also, since we mentioned previously that the battery capacity is based off the open circuit voltage, we used a push button in order to ensure that the charge indicator is measuring V_{OC}. This push button is normally closed to the rest of the circuit. However, when the button is pressed, all off the electronics are disconnected, except for the charge indicator. This ensures that we get the most accurate reading of the remaining battery capacity. The only time the charge indicator will not provide an accurate reading is immediately after charging or discharging. This is simply due to the nature of chemical energy storage in batteries. When the battery has been in operation, it needs time for the open circuit voltage to settle to its actual value.

Amplifier

In order to provide the Burning Kumquat with music, we needed to design an amplifying circuit that doesn't consume a lot of power while still being loud enough to spread throughout the farm. The amplifier itself is the most significant component here obviously, so we began by determining the best model to use. The typical LM386 amplifier was our first choice due to its low cost and availability. Unfortunately, we soon discovered that after just 1 watt of output power, there is tremendous harmonic distortion. Considering our design specifications state that the Burning Kumquat are looking for similar power capabilities to that of a computer speaker at 4-5 watts, the LM386 would not suffice with 1 watt. Additionally, the sound gets clipped in the LM386 with voltage levels above 12 volts, which doesn't leave a lot of room for amplification when the input signal varies to ±½-1 volt. As a result, we concluded that the TDA2003 is the best amplifier for the purposes of this project. The TDA2003 can handle a supply voltage of up to 18 volts with a very low power consumption of 4 watts for a 4 Ω speaker. A 4 Ω speaker was used because it was available and free, but it also provides a more powerful sound than speakers with higher impedances (such as the more typical 8 Ω). Also, at 4 watts there is very little distortion with this amplifier.

The schematic of figure 19 shows the design of our amplifier along with the other load appliances – the lights and the iPod charger. Each of the appliances has an on/off function either through a switch or simply by unplugging their cigarette lighter plugs. The rest of the circuit is dedicated to the amplification of the input sound signal, V4. This signal goes through a high pass filter where the input coupling capacitor, C9, blocks DC signal and R1 provides a path for the current to travel. The output of the TDA2003 amplifier, modeled here by an ideal operational amplifier, travels through to the output coupling capacitor, C8. Along the way, the current splits into the voltage divider of R34 and R35, which together set the level of feedback. C10 is blocking DC signals to the differential input in the feedback loop, while R38 is helping set the DC gain. Like C9 and R33, C10 and R37 act like a high pass filter with R37 providing a path for the current to travel through. In the case that there is excessive inductor reactance from the speaker, C11 and R36 have been included to provide a high frequency load. On the supply power side, we have the 12 volts entering the amplifier from the battery and traveling through C12 and C13, two capacitors that help clean the signal by decoupling the power supply and filtering.

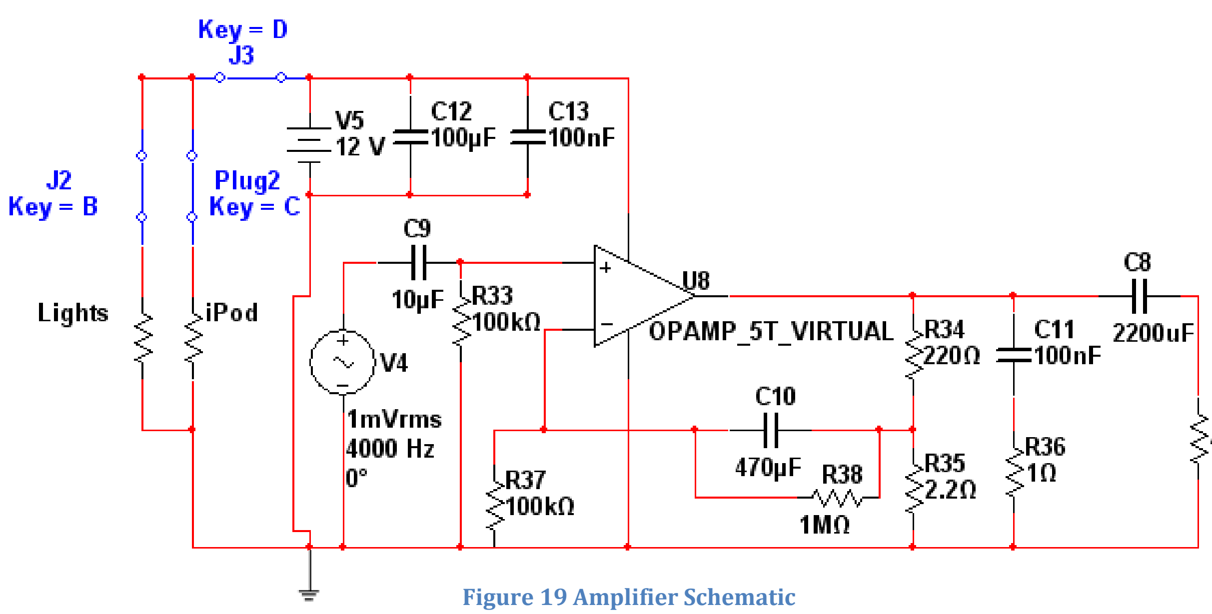

Figure 19 Amplifier Schematic

Figure 20 presents a picture of the actual amplifier circuit in the box. The red line is the input power supply, the thick black line is ground, and the thin black line is the input audio signal. The amplifier is attached to the large heat sink with the white thermal compound and a nut and bolt. The output coupling capacitor, C8, can be seen here as the large blue capacitor. This capacitor needs to be so large in order to filter out any DC that may have been amplified by the TDA2003.

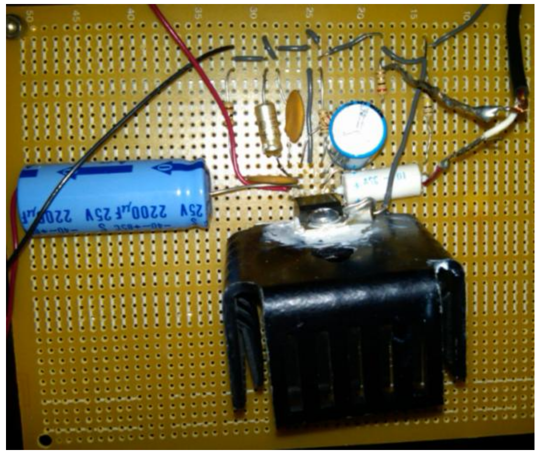

Figure 20 Amplifier Circuit

To test the sound of our amplifier, we used a microphone to measure the frequency response of the speaker. The results are shown in figure 21 in white with the input signal in green. The input signal was an audio file with a frequency sweep from 20 Hz to 20 kHz. While the graph below makes it easy to visualize response, there is quite a bit of error, especially in the 50Hz range. This error is likely attributed to the microphone that was used, which was fairly low-quality. In any case, the speakers seem to respond well to very low frequencies around 100 Hz and between 1 kHz and 10 kHz.

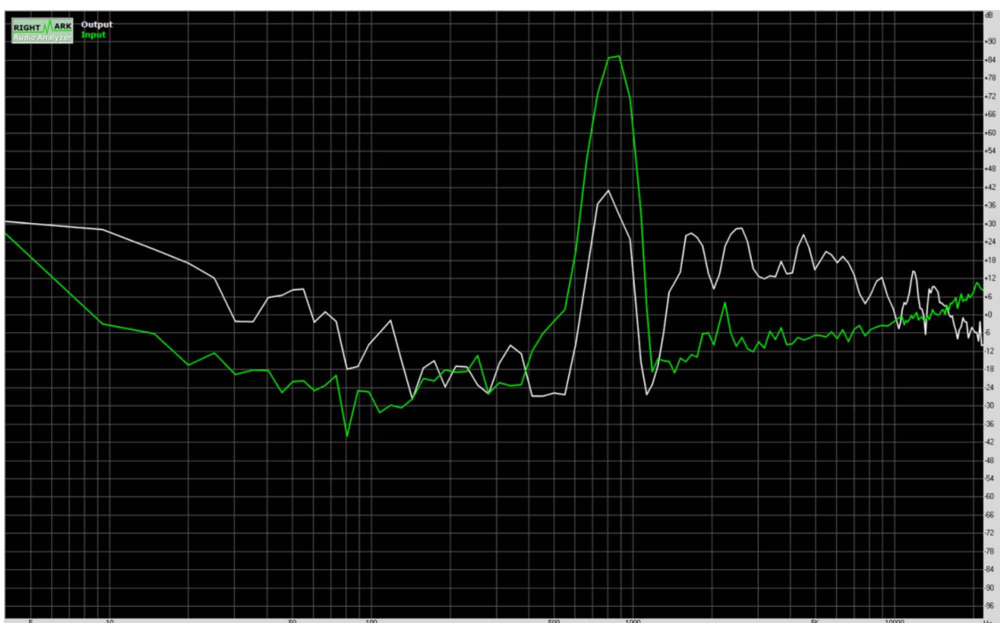

Figure 21 Frequency Response

Additionally, we looked at bode plots of our amplifier simulation to analyze the gain at various frequencies. The log magnitude is shown below from MultiSim. Though the graph doesn't display the axes, the blue line shows a sample point labeled at the bottom. For most of the frequencies we see a frequency gain of 100 at 40dB. The gain begins to decline as the frequency increases however. At around 10 kHz, we see a drastic decline in the gain to 15.

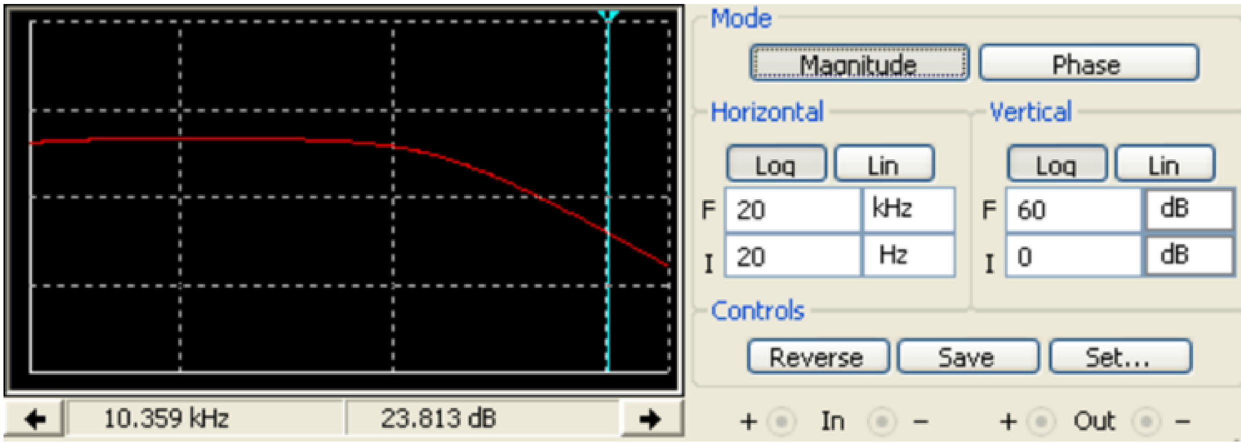

Figure 22 Bode Plot Magnitude (LOG)

The log phase diagram of figure 23 suggests that the amplifier is performing well between 20 Hz and 20 kHz with the phase remaining between -90º and 90º. This is important because our amplification circuit has a feedback loop; if the phase were to approach or reach 180º, we would have noise cancellation. As the graph below shows though, for the frequencies of interest, there is no cancellation.

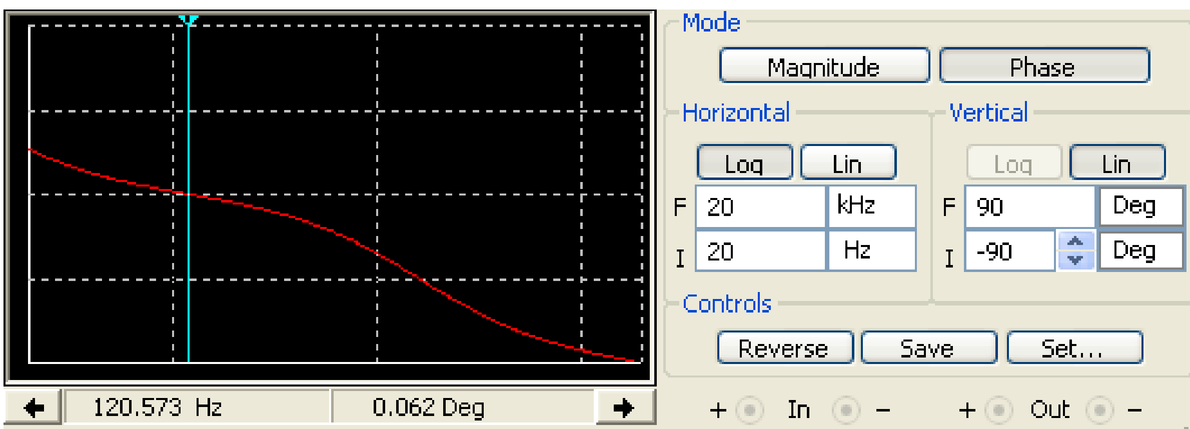

Figure 23 Bode Plot Phase (LOG)

Unfortunately, on a logarithmic scale, it is difficult to see if there is any signal distortion, so we use the linear scale of figure 24 instead.

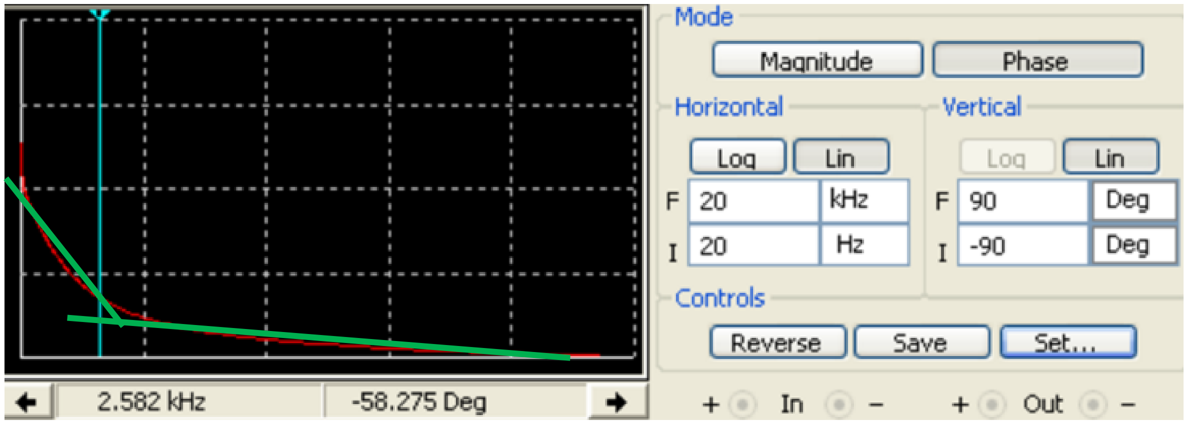

Figure 24 Bode Plot Phase (LIN)

Ideally, the signal would be as close to linear as possible. Our amplifier however shows two fairly distinct curves. The majority of frequencies though lie on the lower line with a slope shift at about 2.5 kHz meaning we have limited distortion for most of our frequencies. There is a slight phase difference between the two slopes as shown in the figure in green.

Light

The lights for the Burning Kumquat were fabricated by considering three aspects: (1) the stand, (2) the specifications, and (3) the light source.

Figure 25 Light Stand

(1) The light stand is made entirely out of PVC piping for its durability, stability, and size. In figure 25, we used pre-fabricated, angled parts to create a tripod out of the PVC. The legs of the tripod are not glued on, so that the Burning Kumquat can disassemble the fixture and make the stand smaller for storage. Since the light stand was not designed to remain outside in bad weather, the size of the unit was largely based on the storage capacity the group has.

(2) As for specifications, the Burning Kumquat wanted to have a light bright enough for them to meet at night in a small group. We determined that a third of the lumens a 100 watt incandescent light provides would fulfill this requirement plenty. This translates roughly to 500 lumens. The group only needs a small amount of light to see one another and only in a focused area.

(3) We decided fairly quickly that we would use LEDs for their compatibility with our circuit and DC functionality. The LED we selected – a Maxxima LED MR16 – suited our needs based on specifications and cost. With a low power consumption of just 4 watts, these LEDs have an output of 120 lumens and a beam angle of 30^{o}. With four of these connected in parallel, we would have the equivalent of an 80 watt incandescent light bulb and only about 9 Ω of resistance. Additionally, these LEDs operate at 12 volts, which fits well with our 12 volt battery.

Figure 26 LED Flexible Fixtures

Unfortunately, the beam angle of 30^{o} that these LEDs provide is not wide enough for the purposes of any group meetings. Considering this, we purchased a lamp with flexible arms that we took off and affixed to our PVC piping as shown in figure 26. The arms provide the group the ability to adjust the beams anyway they would like.

Box

In order to protect all of the circuitry described above, we wanted to house all of it in one convenient and durable box. The box we chose has enough space to fit the various circuit boards and connections, as well as the charge controller fan and battery. The top of the box contains all of the switches and buttons that the Burning Kumquat needs to operate this system, and can also open up to allow for convenient access to the circuitry. The box interior has been arranged such that each of the circuit boards is screwed to the wall for stability and protection. Going clockwise from the top left in figure 28, the circuit boards are for the charge indicator, the amplifier, the charge controller, and the discharge controller. The amplifier continues with a speaker attached to the left of the box behind the battery as seen in figure 27.

Figure 27 Closed Box

Figure 28 Open Box

The thicker wiring is used for lines that carry larger current loads, such as those coming in from the generator and those to the battery. Unless otherwise indicated above, red lines are used for supply voltage and black lines are used for ground. All wires run through drilled holes and troughs in the box to maintain cleanliness and avoid tangling.

Similarly, the top of the box has a plastic cup glued on for the audio cord to coil inside of. This prevents any possible tangling when users of the amplifier push the cord back into the box.

The battery stands loose on the floor of the box for easy removal and is stabilized with a 2"x4" fit to size between the battery and fan. To accommodate the fan we have drilled a pattern of holes into the rear of the box to allow air to flow in.

A description of the exterior design switches and buttons can be found in the user manual at the end of this report. The only feature not mentioned there is our test point. As figure 27 shows, there is a positive and negative test point at the top of the box for convenience. These provide the ability to measure the output voltage of the battery or generator.

Cost Analysis

The following cost analysis takes into consideration the full product lifecycle for this bicycle generator for large-scale deployment. In other words, if this product were to be mass produced, we looked into the change in total production costs including prototyping.

Prototype Costs

We consider our bicycle generator to be the prototype in the case that we would eventually mass produce these. As such, the cost breakdown can be seen in the Bill of Materials in the Appendix, but the total is estimated at approximately $540.87. This cost does not of course account for the time spent on research and development, nor the cost of testing the prototype out on the Farm.

Estimated Unit Cost of Production

If the bicycle generator does move past the prototype and into mass production, the price per unit could be expected to decrease quite a bit. Assuming these are produced 100 at a time, the unit cost could be reduced by about 15-20%. This is an estimate based on some of the electrical components and their DigiKey retail value in different order quantities. Other material used (e.g. the generator) will not see such large reductions, which is why we anticipate the total cost to decrease to within the 12-20% range.

Lifetime Operational Cost

The lifetime cost for the bicycle generator is very low for a number of reasons. Most of the materials used are very efficient and long-lasting. The LEDs for example are expected to last 40,000 hours and with 4 hours of use per day that would last about 4 and a half years. The battery has about 300 cycles in it before it begins to noticeably reduce in charge capacity, so within a year, the battery may have to be replaced. Additionally, the bike chain would have to be oiled occasionally, and the fan may need to be replaced at some point as dust and dirt get into it. With a time constraint of a year, for example, the maintenance cost of the system is about $75 maximum, and this assumes 5 hours of usage every day for the year.

Bill of Materials

The Bill of Materials list is provided in the Appendix of this report. Please note that some of the materials (e.g. generator, bicycle) were obtained at no cost through the University (e.g. various departments or student groups), and so will not be added to the total cost of our project. As such, we have added 50% to our subtotal to provide a rough estimate on the cost for a bicycle powered generator in general.

Hazards and Failure Analysis

The battery should not be charged in a sealed container. Our container is closed, but not sealed, and with the fan bringing fresh air in from outside the box, it should safe for charging. It is important that air flow into the fan is not blocked and that no modifications are made to the box that would potentially cause the box to become a sealed container in which the battery should not be charged.

We have had some problems with the buck chopper switching. If the switching transistor fails, very large transient voltages can be sent into the circuits. We believe that we fixed this problem when we changed out the IRF640 for the 2N3055's in Darlington. However, the failure of the switching transistor can result in damage to any number of different components of the system.

When the battery is no longer good, it must be properly disposed of. Improper disposal of lead acid batteries can be harmful to humans and the environment. It is the user's responsibility to dispose of the battery properly.

Finally, we have exposed moving parts. Whenever the bike is in operation, everyone in the area should be paying attention to avoid getting caught in the moving gears or chains and potential injury.

Conclusions

The bicycle powered generator that we have designed and constructed here represents the culmination of the electrical engineering and business education the University provides. Both of the engineers of this project have significant experience in business and were, thus, able to apply their hands-on technical experience to an actual useable product. The results far exceed our expectations with a power source that could provide ample amounts of energy beyond just lights and music. Using our diverse backgrounds in education, we were able to blend form and function together to create an easy-to-use and unified system here that meets the specifications originally set forth by the Burning Kumquat.

Our generator is capable of outputting about 60 watts total, but with our gear ratio and average human pedaling speeds, we were able to achieve about half of this power output, which is still well over the 20 watt load (16 watts for lighting and 4 watts for the amplifier; the iPod charger uses a minimal amount of power).

As such, we fulfilled the objectives and expectations of this design project by meeting each of the specifications and providing the resources the Burning Kumquat was originally hoping for. Additionally, we successfully remained within our other constraints: the design and construction were completed within the semester, and the cost was kept well within our budget. And, with regard to professional development, we were able to combine both of our skill sets and creativity to fulfill our research expectations and create an operational product. In so doing, we worked collaboratively to effectively walk through the entire product lifecycle.

Suggested design improvements for future reproduction would include overcharging prevention in the charge controller, adding a flywheel before the generator to smooth out torque spikes, stereo amplification, a higher gear ratio, a more powerful generator, and a larger battery among any number of other improvements. Depending on the needs of the user, the overall design could be changed to handle varying loads much more effectively, but the above are the most significant changes.

References

Amplifier, TDA2003

http://www.datasheetcatalog.org/datasheet/stmicroelectronics/1449.pdf

Battery, UB12180

http://www.altestore.com/mmsolar/others/D5745.pdf

Comparator, LM339

http://www.datasheetcatalog.org/datasheet/nationalsemiconductor/DS005706.PDF

LED, Maxxima MR16 Flood Bulb

http://www.lighting.philips.com/us_en/browseliterature/download/p-5992.pdf

Transistor, 2N3055

http://www.datasheetcatalog.org/datasheet/stmicroelectronics/4079.pdf

Transistor, 2N3904

http://www.fairchildsemi.com/ds/2N%2F2N3904.pdf

Voltage Regulator, LM385

http://www.ee.nmt.edu/~thomas/data_sheets/LM385.pdf

Note that the datasheets have been provided at the end of the report.

Appendices

Table 1 Bill of Materials

Type	Value	Quantity	Cost ($)	Descriptions	Source
Amplifier	Tda2003	1	8		Gateway
Audio cord	3.5mm	1	3.6		Amazon
Battery	12V 18A-hr	1	54.9		Battery Web
Bike	18 gears	1	0		University
Bike Chains	1/4"	2	40		Mesa Cycles
Bike Cover	70.75"x42"x42.875"	1	26.94		Amazon
Box	13.5"x10.75"x11.5"	1	9	Black Plastic	Wal-mart
Brackets	L-Brackets	2	2		Home Depot
Capacitor	10000uF	1	0		University
Capacitor	2200uF	2	0		University
Capacitor	1000uF	1	0		University
Capacitor	470uF	1	0		University
Capacitor	100uF	1	0		University
Capacitor	10uF	1	0		University
Capacitor	100nF	2	0		University
Casters		4	10		Gateway
Cigarette Socket	Female	3	15.95		Amazon
Cigarette Socket	Male	2	13.48		Amazon
Comparator	LM339	3	0	14 pin quad	University
DC motor		1	0		University
Diodes	6A	2	0.9		Gateway
Flex Cable Set	Lamp	1	20		Home Depot
Heat Sink		1	0.5		Gateway
Heat Sink		1	0		University
Inductor	250uH	2	0		University
iPod charger	Cigarette socket	1	2.99		Amazon
LED	Green	2	0		University
LED	Yellow	1	0		University
LED	Red	1	0		University
LED sockets	MR11	4	5.52		Amazon
LED spot Lights	MR16	4	75.8		Maxxima
Potentiometer	10k ohm	6	0		University
PVC	10' 1.5"	2	6		Home Depot
PVC	1.5"	4	6	Y fitting	Home Depot
PVC	1.5"	5	4	End Cap	Home Depot
PVC glue and primer		1	6		Home Depot
Resistor	1M ohm	1	0		University

Resistor	510k ohm	3	0		University
Resistor	500k ohm	1	0		University
Resistor	420k ohm	1	0		University
Resistor	120k ohm	1	0		University
Resistor	100k ohm	2	0		University
Resistor	80k ohm	2	0		University
Resistor	75k ohm	3	0		University
Resistor	15k ohm	2	0		University
Resistor	13k ohm	2	0		University
Resistor	10k ohm	3	0		University
Resistor	2.7k ohm	1	0		University
Resistor	1.6k ohm	2	0		University
Resistor	1.3k ohm	1	0		University
Resistor	1.1k ohm	1	0		University
Resistor	220 ohm	1	0		University
Resistor	100 ohm	1	0		University
Resistor	2.2 ohm	1	0		University
Resistor	1 ohm	1	0		University
SCR		1	0		University
Screws	2.25” wood	1	4		Home Depot
Speaker	8 ohm	1	20		Gateway
Sprocket	48 teeth	1	0		University
Sprocket	52 teeth	1	0		University
Sprockets	14 teeth	2	0		University
Switch	SPST	3	9	large	Gateway
Switch	SPST	1	0	small	University
Switch	SPDT	1	3	push button	Gateway
Transistor	2N3055	3	0	BJT	University
Transistor	2N3904	1	0	BJT	University
Vector Boards		3	5		Gateway
Voltage Regulator	LM385	3	0	2.5 V regulator	University
Wood	8' 2x4	2	8		Home Depot
Wood	2"x4"x0.5" plywood	1	0		University

Subtotal	**360.58**
50% General Addition	**180.29**

Total	**540.87**

(Provided separately)

Figure 29 Full Circuit Schematic

User manual

The following guide is formatted based on questions you may have regarding your new Bicycle-Powered Energy Generation (BPEG). Please reference the following picture or the box itself for names of switches, plugs, etc.

Figure 3030 Box Interface

How do I use my appliances?

Any appliance that is connected to this system can run off of the battery or the bicycle directly. To run off of the battery, flip the Battery Connection Switch to the ON position. To run off of the bicycle, flip the Battery Connection Switch to the OFF position, flip the Voltage Level Switch to 12V, and then begin pedaling.

<u>Note 1. When pedaling the bicycle, the box with all input connections must be placed such that there is space from any wall for the fan on the back.</u>

Regardless of whether you are running off of the battery or bicycle:

To listen to music, flip the Speaker Switch to the ON position and connect your music player to the Audio Input Cord, which can be pulled out to a convenient length. Volume is controlled by the mp3 player or iPod.

To use the lights, connect each of the three legs to the main pole and set the stand up where desired while close enough for the plug to reach. Then connect the cigarette plug from the light stand to one of the 12 V_{DC} Supply sockets. Be sure that the Voltage Level Switch is set to 12V and finally flip the switch on the lamppost to ON.

To use the iPod charger, connect the cigarette plug from the charger to one of the 12 V_{DC} Supply sockets.

To power any other compatible appliances, purchase a 12V cigarette lighter charger and connect it to one of the 12 V_{DC} Supply sockets.

The fully charged battery will be capable of providing about 5 hours of power when it is fully loaded.

How do I charge the battery?

To get started, first connect the cigarette plug from the bicycle generator to the Bike Generator Plug and the bicycle light to the Bike Charging Indicator Plug. Flip the Battery Connection Switch to the ON position and be sure to disconnect or turn off all appliances. Be sure the Voltage Level Switch is set to 14V. You are now ready to begin pedaling and charging your battery. When you see the Bike Charging Light Indicator at the right bike handle light up, you have reached a pedaling speed capable of recharging the battery. The battery takes approximately the same amount of time to charge as the amount of time it has been used.

<u>Note 1. When first starting to pedal and charge the battery, the Charging Indicator may be difficult to light up. This is normal and it is important to simply maintain a strong and steady pedaling speed for a few minutes until the charge begins to build up on the battery.</u>

<u>Note 2. When pedaling the bicycle, the box with all input connections must be placed such that there is space from any wall for the fan on the back.</u>

How much charge is on the battery?

To check the charge level of the battery, push the Battery Capacity Indication button. Note that any appliances that are running will be disconnected while the button is pressed down. Be sure to recharge the battery when the charge indicator only lights up red. Note that it take time for the charge on the battery to settle back to its actual value after charging or discharging has taken place. In order to get an accurate reading of the remaining capacity of the battery wait at least 5 minutes from the last time the battery was charged or discharged before checking the capacity

Can I leave the system outside permanently?

No, the only part of the BPEG that can be left outside is the bicycle unit itself with the cover over it. Any water that enters any part of the system could damage it. All parts have been designed such that they can be taken apart and be compactly stored in the Burning Kumquat's shed.

One of the LEDs burned out. Where can I find a replacement?

New LEDs can be purchased here: http://www.maxximastyle.com/Merchant2/merchant.mvc?Screen=PROD&Product_Code=MLB-16450F&Category_Code=MR16. In the case that this particular LED (Maxxima LED MR16) is no longer available, be sure to purchase one with an operating voltage of 12 volts. The original LEDs in the BPEG consumed 4 watts of power, had a light output of 120 lumens, a beam angle of 30 degrees, and a 2-pin base connection. For color matching, they had a cool white color.

The battery does not hold much of a charge anymore. Where can I find a replacement?

New batteries can be purchased here: http://www.batterywholesale.com/battery-store/proddetail.html?prodID=377. In the case that this particular battery (Universal Battery UB12180) is no longer available, be sure to purchase one with an operating voltage of 12 volts. The original battery in the BPEG has a capacity of 18 Ampere-hours (A-h).

Why has pedaling become increasingly difficult over time?

After about a year of regular usage, you may find that pedaling is no longer as smooth. In addition to replacing parts, the BPEG requires routine annual maintenance consisting of oiling the bike chain and realigning all the gears.

The bicycle setup is very heavy. Is there an easy way to transport the system?

Yes, in fact your BPEG comes with a skateboard that fits snugly underneath the rear of the bicycle where the generator rests.

Note 1. The bike generator should never be used with the skateboard in place as the system will not be resting stabled and secured.