DJYM

Kinetic Energy Phone Charger

Final Proposal

OWNERS

Daniel DiMaggio

Yvonne Szabo

Joecarlo S. Manaloto

Michael Santos

San Jose State University
EE 198B Senior Design Project
Fall 2012
Advisor: Dr. Ray Kwok

Table of Contents

I. Introduction

Cellphone usage in the world has increased substantially in an extremely short period of time. As technology has improved, smartphones have quickly become one of the most commonly used products in the world. Battery life is always under scrutiny as a typical battery often times does not last a full day. Society demands a way to charge cellphones without cords and an outlet. There are two main reasons energy harvesters are so attractive. The first is that they can reduce power consumption from the grid which puts people in the mindset that they are helping the environment. The second reason is the convenience of charging without a cord.

Recently the East Coast was devastated by Hurricane Sandy. Many were left out without power for weeks after the initial storm hit, and had continued cloud cover and rain days after. There is no way to charge electronics via wall outlet and solar power would be nearly nonexistent. Kinetic energy harvesting is one way that devices can can be charged. Our group believes that a phone being on a person almost the entire day, harvesting energy from movement provides the best possible solution. It would be most beneficial to develop a smartphone case that harvests kinetic energy and charges a smartphone all as one unit, however, limitations may prove that having the harvester separate while harnessing kinetic power will be most useful.

The goal of this project can be summed up in two parts. The first and most obvious is that it needs to function as claimed. Our research has suggested that the design can reach the desired output. However, our plan is to store the energy harvested in an internal battery and will be available to the user with the flick of a switch. This will allow us to reach the second parameter of being accessible. The product would attach to the phone and the power will be readily accessible.

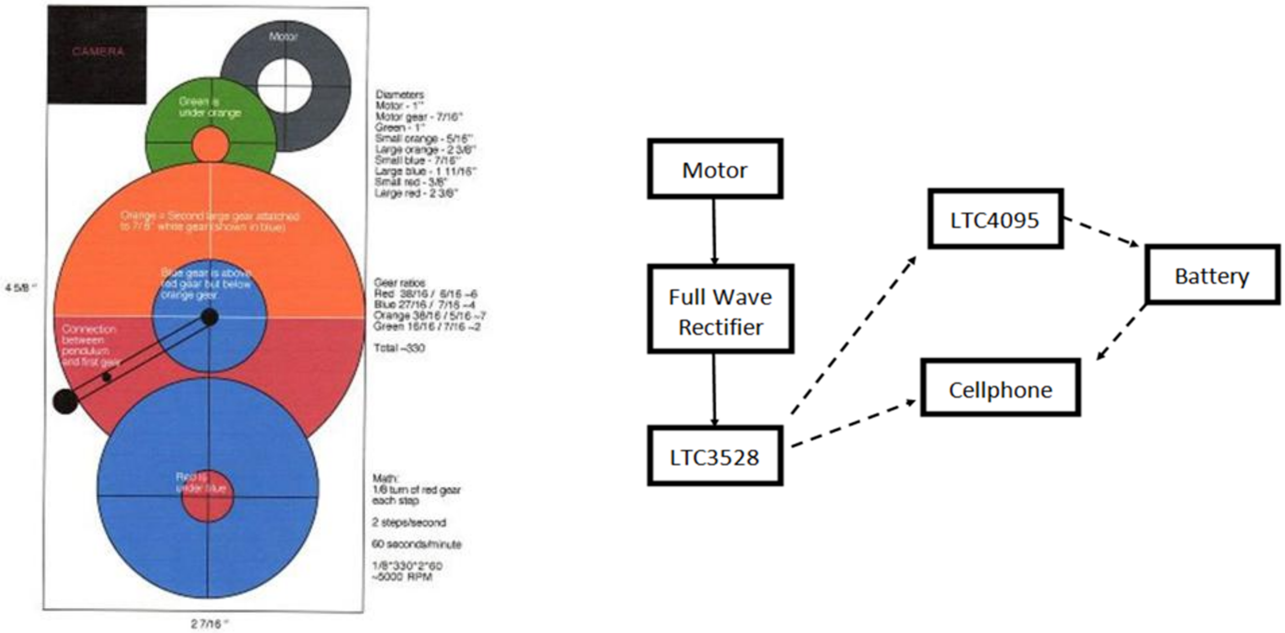
Funding for similar projects such as this one have received large monetary backing especially from the U.S. Department of Defense. Regan Rowe of M2E Power believes that using a design based on a self winding watch in just two hours of movement one would have "enough [power] to charge up one half- to one hour of talk time on your cellular phone." [1] This is advantageous for the military because soldiers often find themselves without power sources and instead must carry extremely large and heavy batteries. Technology such as this could take tens of pounds off the amount of weight soldiers need to carry.

II. Design

This initial ideas that the project was based off were a hand crank flashlight and a self winding watch. In a self winding watch the initial gear in the chain is weighted down. Gravity acts upon the weight constantly pulling it down. When the force from gravity on the weight is greater than the resistance from the other gears, the weight will move all the gears. This principle is used in a similar fashion in this product.

Rather than winding a watch, the gears would instead drive a motor which would store power in a battery or go directly to a cellphone. Since human motion is inconsistent, even if a proper voltage output to charge a phone is achieved, it would likely not stay at that level for a long period of time. This means that the phone would likely show that it is charging for a few seconds, stop, and start again. Therefore it is believed best to store the power in an extra battery similar to how current products do.

The product should be designed to fit as a case for the smartphone. To do so, the number of gears should be kept to a minimum while also maximizing the RPM of the gear driving the motor. Figure 1 below shows an ideal case where space is used efficiently. The gear ratio is calculated by dividing the number of teeth of the two gears, but can be estimated by dividing the diameters.



(a) (b)

Figure 1: Proposed design of gears (input to the motor) and block diagram of project.

The motor used had an output of three volts peak to peak. This output was an AC voltage which meant depending on the direction of spin, the voltage would be positive or negative. The signal would need to be "flipped" up and then made constant with a full wave rectifier and a smoothing capacitor shown in figure 2 below.

Figure 2: Oscilloscope outputs of the motor after the rectifying circuit. The output after the circuit without a smoothing capacitor (left) is 1.87V maximum and 1.15V after the smoothing capacitor (right).

After testing with the motor, the team estimated that it could reasonably expect an output between 0.8V and 1.2V. With this information, the team went to the Linear Technology website to find a chip with low power startup that input a similar voltage and gave a 5V output. The LTC3528 was found and implemented in the design.

To charge a Lithium ion battery, Linear Technology recommended using the LTC4095 to ensure proper input into the battery. The expectation of the team was that consumers would prefer that the power be stored in a battery and accessed with a switch when needed.

III. Mechanical Components

The use of gears is the foundation of the product. The difficulty with the gears was having to ensure that they would function together properly. The first gear that is weighted down needed to be able to rotate 360º. This was crucial to the project because of the fact that many people store their phones in different fashions. For example, some people keep their phones in their front pockets, side pockets, or purses and in those areas the phone may be upside down, right side up, or on its side. Having the full range of motion means that no matter how it's held, it will be able to rotate, including while being held.

The gears needed to be set up in a way in which an extremely small turn of a weighted gear would result in a small gear attached to the motor having enough RPM to get the required output as consistent as possible. The RPM recommended was approximately 1500 so this needed to be worked backwards to the first motor moving approximately 1/8th of a turn twice a second (two steps per second). Figure 1 showed gear ratios estimated to be as high as 7:1 though this could be higher depending on the size of the gears involved. The gears available to the team had a ratio of approximately 5:1. A rotational speed of 1500 RPM works out to 25 revolutions per second which means three gear ratios of approximately 5:1 would be required (25/5/5/5 = 1/5th of a revolution which is approximately equal to 1/4th of a revolution estimated by two steps per second). A fourth gear could be introduced to help achieve the required output when there is less movement or fewer steps per second but this comes at a cost of space and resistance which will require a heavier weight.

The rotation of the motor was something that had to be considered. The direction of rotation determines the direction of current. We know this because of Faraday's Law of Induction, the theory behind which most motors now operate. The team considered that it would be best if the motor always rotated in one direction. A ratchet was considered but it would stop the motor from spinning which would defeat the purpose of what the team wanted to accomplish.

The team decided it was best to just let the motor spin both forwards and backwards. By using a full wave rectifier and a smoothing capacitor (discussed in the following section) a stable output could be achieved. The small gaps in time where the motor hadn't yet changed directions would hardly be noticeable because the capacitor would still have some left over charge from previous motion. This was shown in figure 2, previously.

IV. Electrical Components

The 1N4001, 1A, rectifier diodes were selected to design the full-wave rectifier needed to convert the AC signal from our brushed DC motor to a DC voltage. Other rectifier ICs were first selected for the process for its single chip size when designing the PCB compared to the traditional four diodes. However, it was dismissed since the 1N4001 can provide a low forward voltage drop. After converting the AC signal to a DC voltage, it was important that a large output smoothing capacitor was used to decrease the output noise so that the DC motor would provide a constant input to the LTC3528.

.

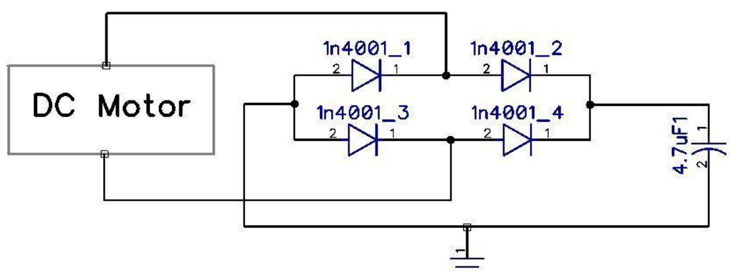


Figure 3: Schematic of a DC motor and full-wave rectifier circuit, with smoothing capacitor.

The two most important ICs used were LTC3528 and the LTC 4095. Both were recommended by application engineers by Linear Technology and were provided free of charge. We were recommended other ICs from other analog companies such as Maxim and National Instruments but we decided to go with the ICs recommended due to the low parameters used to start. The design of the passive components were also sampled and recommended from Linear

Technology datasheets and demo boards. Afterwards, particular components were changed and altered to meet the required expectations for our design.

The LTC3528 is a 3mm x 2mm DFN 1A, 1Mhz Synchronous Step-Up DC/DC Converter. The LTC3528 is the DC booster that allows the expected output of 0.8V to 1.2V from the full-wave rectifier to the desired average of 5V output. The LTC3528 was selected due to its low start-up voltage of 700mV and was proposed due to the fact that the output has an efficiency rating of up to 94%. This is ideal for our design since the motor varies an output voltage of 0.8V to 1.2V.

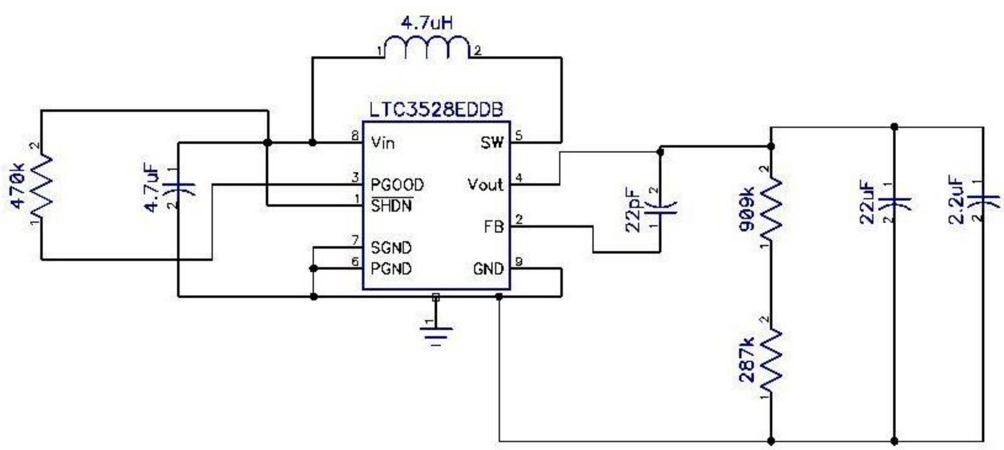


Figure 4: LTC3528 schematic

The LTC4095 is a 2mm x 2mm DFN Standalone USB Li-Ion/Polymer Battery Charger that will provide linear constant-current/constant-voltage. This IC was particularly used because it is strictly designed for lithium-ion batteries and it can provide a high programmable current of up to 950mA. This is well needed since the input from our DC motor varies. An additional feature includes an automatic recharge based upon the use of the output capacitor.

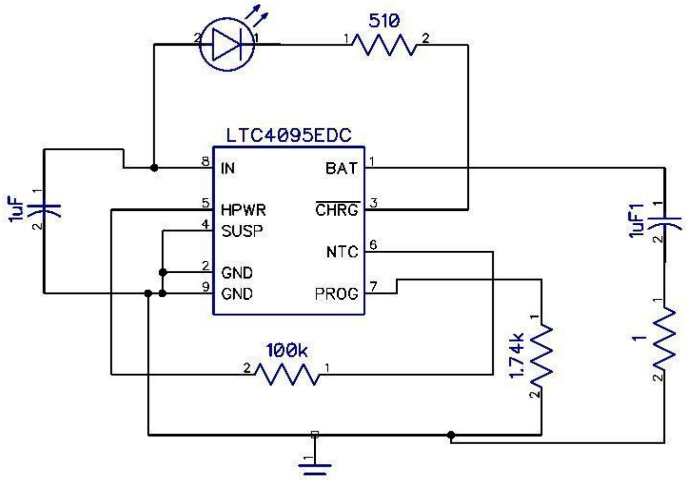


Figure 5: LTC4095 schematic

For demonstrative purposes, a LED tied to a pull-up resistor was used to signify that the LTC4095 is functioning properly and Li-Ion battery is being charged.

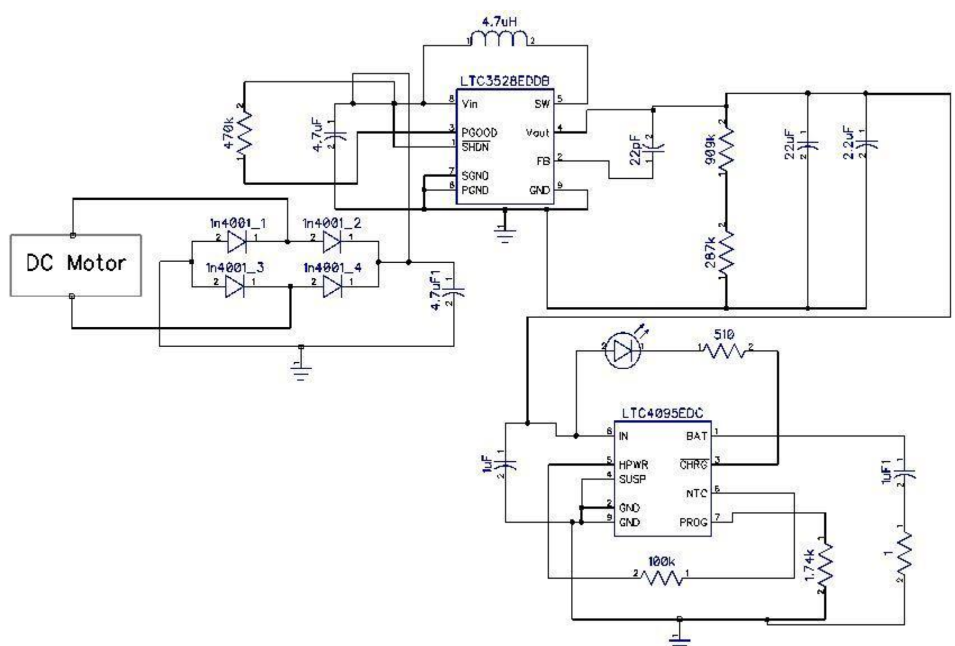


Figure 6: Full circuit diagram from gears to output.

Table 1: Cost estimate for final design. Some had to be bought in multiple quantities, instead of single quantities.

Components Used for Final Design			
Part Number	**Part Description**	**Quantity Purchased**	**Price ($)**
LTC3528	1A, 1MHz Synchronous Step-Up DC/DC Converters in 3mm x 2mm DFN	2	FREE
LTC4095	Standalone USB Li-Ion/Polymer Battery Charger in 2mm x 2mm DFN	2	FREE
USB-A-FH	USB 4-Pin Female Socket Right Angle Connector	5	$3.00
MDN3BL3CSAS	Brushed DC Motor - 2VDC, 1458 RPM, 0.7 ~ 6VDC	5	$8.00
1n4001	Diode - Rectifier - 1A 50V	20	$2.00
287kΩ	1206 SMT Resistor -1%	25	$2.00
470kΩ	1/4W Metal Film Resistor	10	$1.00
909kΩ	1206 SMT Resistor -1%	25	$2.00
100kΩ	0603 SMT Resistor -1%	25	$2.00
1.74kΩ	0402 SMT Resistor - 1%	25	$2.00
510Ω	0805 SMT Resistor - 1%	25	$1.50
1Ω	0603 SMT Resistor -1%	25	$1.50
1µF	0402 10V Capacitor	10	$2.70
1500µF	6.3 SMT Capacitor	2	$1.04
22µF	1206 SMT Capcitor	10	$1.60
2.2µF	1206 SMT Capcitor	10	$2.70
22pF	1206 SMT Capcitor	10	$1.60
4.7µF	1206 SMT Capcitor	10	$3.80
Copper Clad Board	8"x10" Board, MG Chemicals	1	$10.94
007722-84-1	Hydrogen Peroxide	1	$0.89
007722-84-1	Muriatic Acid, Kem-Tek 2X1	1	$10.99
APHB1608ZGSURKC	SMT Green LED	3	$1.00
Plexiglass	Clear Acrylic Sheets	1	$2.00
		Total	$64.26

Note that the table above is the actual cost for the components used for the final design and does not include the components and ICs requested and purchased for initial testing. Prices are generated from local electronic and hardware department vendors. Most of the components detailed in the table were also required to be purchased by a minimum quantity such as 10 or 25.

V. Design Process

After the schematic had been fully designed, the PCB layout would have been designed as well.

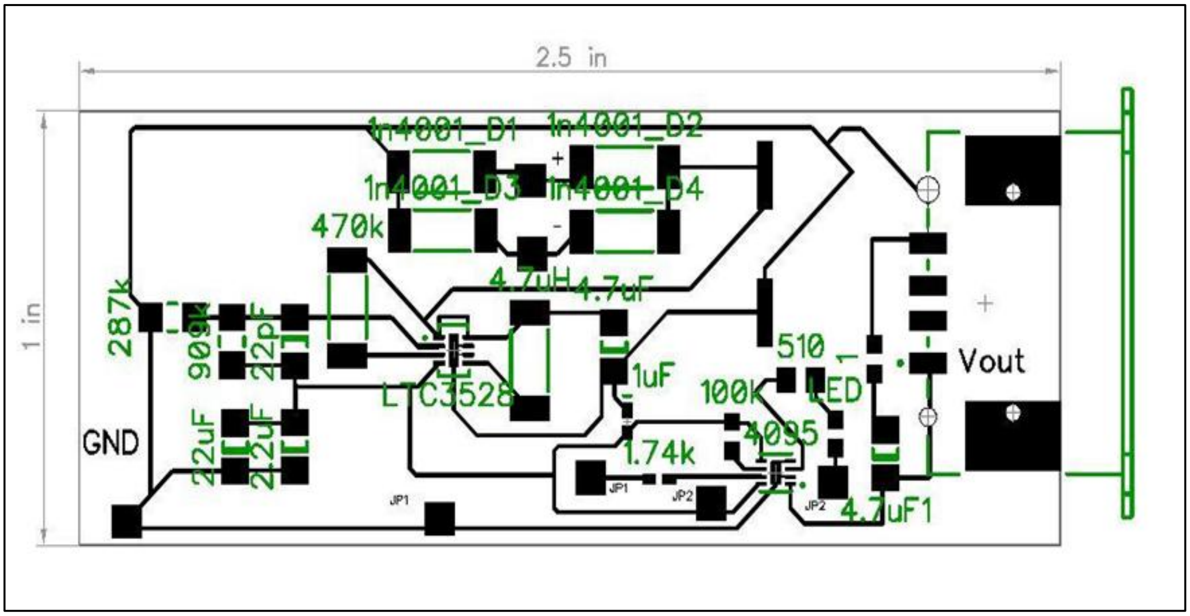
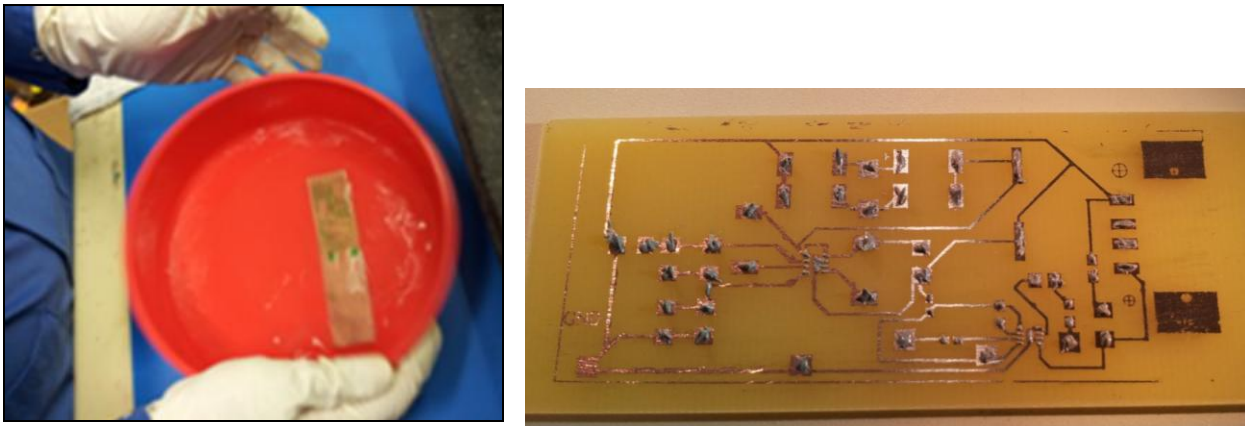


Figure 7: PCB layout

Based upon the size of the prototype case, we were limited to a board that has the following dimensions shown in the figure above. Note that not all parts placed onto the board are surface mount components. The 470kΩ and the 1N4001 diodes are all not surface mount components. The 470kΩ resistor was used so that particular pins can be routed underneath and correctly while still making a single layer board. In addition to the use of the of the non-surface mount resistor, jump pads were also created at GND and Vout.

After the PCB layout, the next process was to create our PCB. In order to take our design on a copper clad board, we used PCB toner transfer paper. Once the ink was successfully ironed onto our copper clad board with green TRF foil, the next step was to etch the copper clad using muriatic acid and hydrogen peroxide. The etching process removes all of the copper on the board except the green foil that has the footprint of the PCB layout file. Once all copper has been removed and the green foil has been successfully been cleaned, only the copper with the PCB layout footprint would be visible.



(a) (b)

Figure 8: (a) Etching the board “at home”. (b) Bare PCB with solder paste.

Once the board had been properly etched, solder paste and components were applied to the appropriate pad locations. After all components were placed, a hotplate was used to reflow the solder and create the solderable joint joining the pad and component together. After the use of the hotplate, a soldering iron was used to solder the diodes, the 470kΩ resistor, the 4.7µH inductor, 1500µF capacitor, and the USB port.

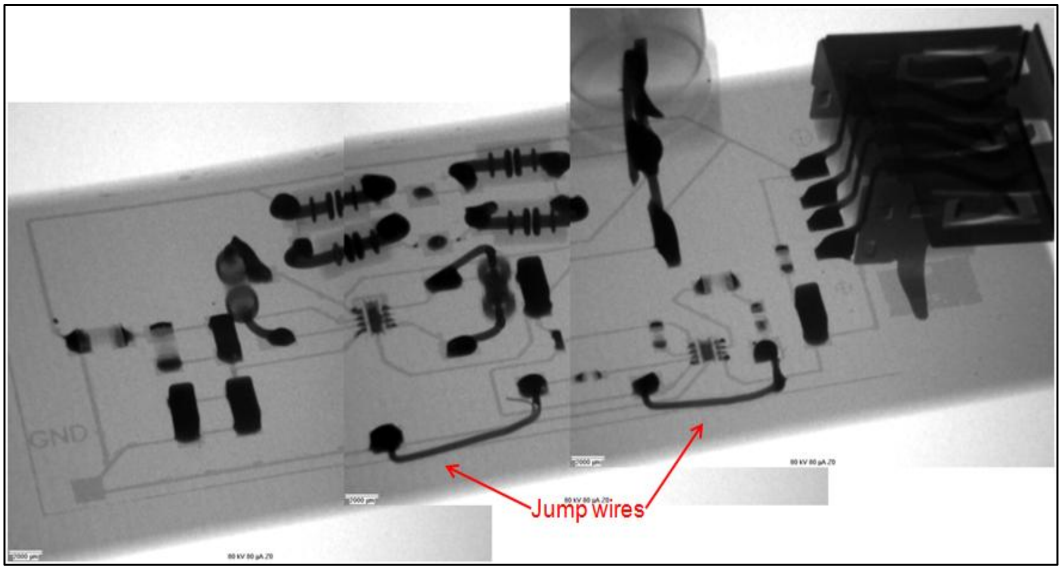


Figure 9: X-ray of PCB. Each part of the board was expected to ensure no shorting had occurred.

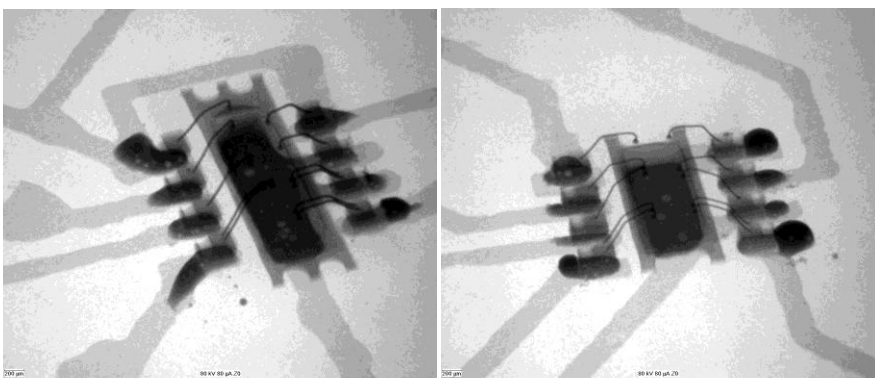
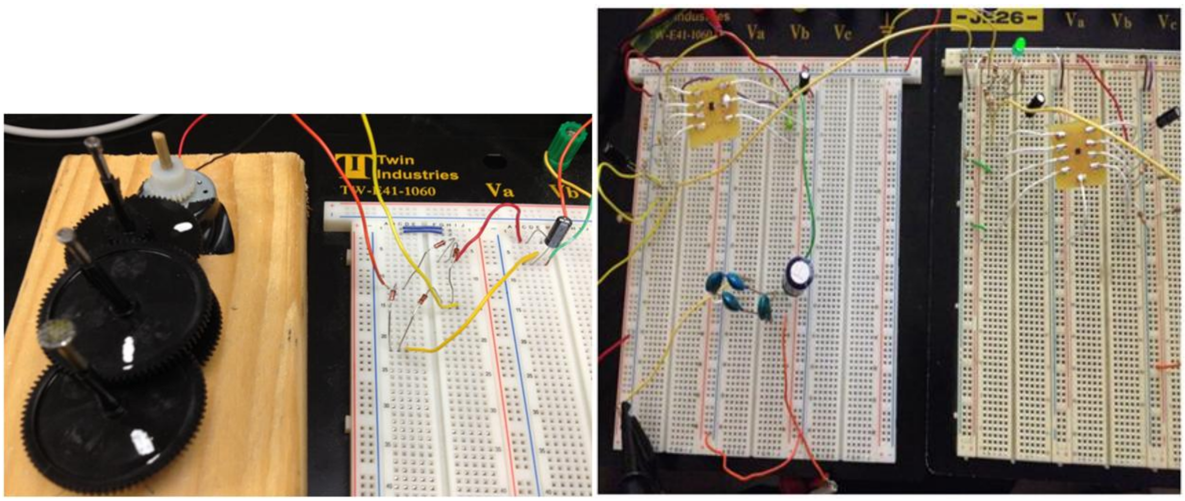

(a) (b)

Figure 10: (a) X-ray of the LTC 3528. (b) X-ray of the LTC4095.

The x-ray was used to ensure each connection was made. During the prototype phase, individual PCB needed to be created for each IC for testing since no schmartboard was purchased for both chips.

VI. Prototype

The first designs for the mechanical side was originally done on Styrofoam and the gears were held in place with toothpicks. The design evolved to the gears on a sturdy wooden block and held in place with nails as pictured in figure 11a. As seen, the four gears were arranged on the wood blocks in a way that would provide proper output with small turns of the initial gear (bottom middle). Based on testing and estimation, three to four gears of similar size would be needed to turn the motor at a high enough RPM to get a useable output.



(a) (b)

Figure 11: (a) First prototype of the gears was made on a wood block and outputs to the motor. (b) first prototype of the electrical components. The LTC3528, on the right outputs 5V. The LTC4095 is on the left.

The electrical part was initially done on breadboards (figure 11b). A schmartboard was created for the LTC3528 and LTC4095 so that they could be tested easily. For simplicity, the circuits were tested with a hand crank. Once the circuits were performing as expected, surface parts were bought and a PCB was made.

The final prototype was then placed in clear plexiglass to show the gears, and only three gears were used in the final design due to difficulties stabilizing the gears. The motor and the PCB were made to fit around the gears. One mistake that was made was that the PCB covers where the camera hole is to be if it was made into an actual case. This can be easily corrected if the nails holding the gears in place went in the other direction which would leave plenty of space below for the PCB board. The case is bigger than it should be as a final product. With proper casing and gears, the product can easily be reduced to half the thickness as the prototype seen in figure 12 below. The gear that came on the motor did not have the proper spacing between teeth and thus a gear was found and attached to the motor so it would work with the gears readily available to the team.

Figure 12: Final prototype of the DJYM. The case is taller than it should be due to the extra neck on the motor gear (can be seen in the one on the top right). The bottom is the final PCB with all components.

The gears are held in place by the heads of the nails and a small wire soldered to the nail. An actual casing would have, most likely, plastic holding the gear and a metal shaft in place. The weight is a marble (the heaviest weight that could be found of a small size) and is taped to the edge of the first gear. If the gears are spun manually, the circuit can indeed charge a phone (figure 13).

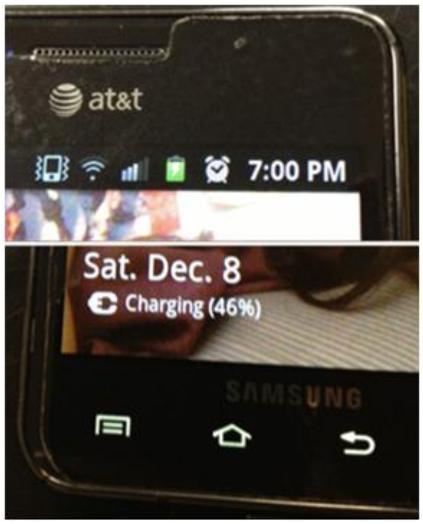


Figure 13: Using only the LTC3528 and manually spinning the gears, the phone can be charged. However, there is just enough power to slow down the depletion of the phone's battery power.

VII. Conclusion

Should the project go forward in the future, several things should be considered first. The most important consideration is getting customer feedback on whether or not they would be interested in carrying a product this size in addition to their phone. If the product is geared towards runners they would likely be more accepting of a larger product that was heavier as it would help their workout. By allowing a heavier weight, the power would be more easily harnessed by the user.

If the charger will be geared towards emergency situations it would also be more acceptable to have the product be heavier as it would likely be a last resort option. The team felt that the product should have a hand crank feature that would allow the user to charge the backup battery initially in an emergency situation. After the initial charge, the user would be able to attach the product to the wrist or ankle until the next charge is needed. This would be incredibly useful in situations where there is no other option to charge a phone.

There are many tradeoffs in the product and striking the right balance will be crucial before further progress can be made. The team felt that the best path forward is to gear the product to emergency situations such as when natural disasters destroy homes. Many people in New York found themselves stranded on the streets with no way to contact family, friends, or local authorities.

Harnessing the kinetic wasted throughout the day is something many feel is a worthwhile idea that should be explored. The power that can be harnessed is not a large amount, but will one day be enough to power a small handheld electronic. Since cellphones have become something nearly every adult in the United States owns and carries with them at all times, it seems to be the most logical device that would benefit from harnessing kinetic energy. Many are trying to find a way to harness kinetic energy, including the military who stands to gain the most from such technology. An article published on the MIT Technology Review discussed military studies that support using a device that “uses the same technical principle that operates a self-winding watch.”[1]

VIII. Acknowledgements

Our team would like to extend our gratitude to the many professors we have encountered in our time as SJSU who gave us the tools and knowledge we needed to attempt this project.

We would like to thank Dr. Ray Kwok for agreeing to work as our advisor for the past year.

We would also like to thank Dr. David Parent who ran an excellent Senior Design class and was available to help when needed.

Finally, we would like to thank Linear Technology and their staff for helping steer us in the direction of the two chips that we used in the project.

IX. References

[1] Baggot, Kate. (2009). *Harnessing Kinetic Power*.
http://www.technologyreview.com/news/409115/harnessing-kinetic-energy/