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The Battery Charging Hand-Powered Washing Machine "Project UWash"

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ABSTRACT

KENNEDY, CATHERINE A battery charging hand powered washing machine: Project UWash. Department of Electrical and Computer Engineering, June 2015.

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Project UWash consists of converting the mechanical energy that goes into hand washing laundry into usable electricity. Our proof-of-concept system is composed of: an energy source (salad spinner), an energy harvester (AC generator), a regulating circuit (voltage regulator), a storage component (lithium ion batteries), and an application (charging an iPhone and USB based LED flashlight). The goal is to fully charge the LED flashlight after a one hour use and charge an iPhone to at least 50% after a 6 hour use. We were able to fully charge the flashlight in about 15 minutes but were only able to charge an iPhone to 41% after 8 hours of cranking with the AC generator. With the final UWash product we were able to power the flashlight for one and a half hours after a 15 minute use.

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1. Introduction

In many third world countries electricity and water are not easily accessible to the majority of the population. About 1.5 billion people, about one fifth of the world's population, have no access to electricity, and only a billion more only have an unreliable supply. [1] Washing laundry in a third world country usually consists of walking to the closest water source, collecting water, and bringing it back home in order to wash and dry clothes by hand. This is a chore that can consume 6 hours of a persons' day for 3 to 5 days a week. Typical washers use around 45 gallons of water or more to wash one full load of water, which is not possible for a person living in certain areas of third world countries. [2]

This project, the battery charging hand-powered washing machine, called the UWash, will be designed for those with the least income living in the poorest nations who do not have easy access to water or electricity. The UWash is designed to take a physically laborious task that people in third world countries are already doing and provide a way to convert their work into usable electricity. The goal of this project is to construct a hand-powered washer that can be successfully implemented in an energy harvesting system for use in a third world country. Specifically, the UWash will charge rechargeable batteries to be used to provide energy in a bottom-up way, through a low-energy light-emitting diode flashlight, which may be more sustainable and produce fewer carbon emissions than centralized schemes, including toxic kerosene lamps. The UWash will convert mechanical energy provided by a salad spinner into electrical energy with the use of a DC motor generator. The output voltage of the generator will be regulated in order to charge a commercial USB based power bank equipped with lithium ion batteries. The output of the charger can then be used to charge an iPhone or portable LED flashlight through a USB cable.

This paper focuses on first defining the background of this project explicitly, and then detailing the design requirements, alternatives, and final the preliminary proposed design of the energy harvesting system. We break down the background into discussing the context and history of energy harvesting systems including the discussion of past work completed related to energy harvesting. This section also focuses on describing the most important issues for this topic in terms of the goals of the project as well as the effects on society. The next section of the paper focuses on the design requirements, which includes the specifications and requirements for the project. After, we look into design alternatives, in which we discuss the justifications for our overall approach and chosen parts. Lastly we finish by discussing the preliminary proposed design project, the UWash.

2.1 BACKGROUND

Admirably, many projects designed to harvest energy in third world countries are already being distributed to various people in need of these products. Though the development of a new energy harvesting system may be challenging, a permeating desire and responsibility still remains to design one. In order to see where our project fits into the picture, we must first understand the basic need for the UWash as well as the basic components of energy harvesting systems.

In the past there have been previous efforts to bring electricity to third world countries as well as to create devices to make washing laundry a simpler and less exhausting task. My project seeks to combine these two efforts into one: making a washing machine that can provide a person with electricity.

1.1a Past Efforts to Make Laundry Washing Easier

In many third world countries laundry is washed by hauling water from far places in order to wash the clothes by hand. The washer was required to walk miles in order to collect the water and take it home by the bucket load before washing their clothes one at a time. Currently, a project designed by Alec Cabunoc and Ji A You, of the Art Center College of Design in Los Angeles, called the pedal-powered GiraDora washer was designed for people in third world countries. Their project consisted of a pedal-powered washer that is a plastic tub tall enough to sit on and requires no electricity to work. The model was based on sink plungers and salad spinners. The design works by a person sitting on the tub and repeatedly pressing down on the pedal with their foot. The machine agitates, cleans and rinses out the clothes. After the clothes are clean a stopcock in the base is opened and the pedal works again. At this point the washer becomes a spin drier and the clothes can be hung to complete drying in a reasonable time. The washer cost only $40 dollars, which is within a reasonable budget to mass-produce [3].

Another design by German-based DesignAffairs Studio called Swirl, is an eco-friendly electricity-free innovative concept for easy laundering on the go. [4] The swirl is a colorful ball that lets people fill it up with dirty clothes, water and soap and then the rotational motion of playing soccer does all of the work. The positive aspect of this project is that it combines work with fun which could make doing laundry an enjoyable chore to a person living in a third world country [4]. Before we talk about previous work done in the energy harvesting research field, it is useful to know the basics behind how these types of systems work.

1.1b Energy Harvesting

Mechanical energy harvesting systems that convert mechanical energy into usable electrical energy represent promising emerging technology to achieve autonomous, self-renewable, and maintenance-free operation of wireless electronic devices and systems. Energy harvesting systems consist of three main components: the energy harvester that converts mechanical energy into electrical energy, an energy harvesting interface circuit that conditions and regulates the energy, and an energy storage element that stores the intermittent harvested energy.

1.1c Faraday's Law

Many energy-harvesting systems use Faraday's law of electromagnetic induction in order to power electrical motors, generators, electrical transformers, and inductors. Faraday's first law states that any change in the magnetic field of a coil of wire will cause an electromotive force (emf) to be induced in the coil. The emf induced is called the induced emf and if the conductor circuit is closed, the current will circulate through the circuit. This current is called the induced current. Figure 1 shows the experimental setup of Faraday's law. There are various ways to change the magnetic field. The first way is to move a magnet towards or away from the coil. The second method is to move the coil into or out of the magnetic field. The third way is to change the area of the coil place in the magnetic field. The last method is to rotate the coil relative to the magnet.

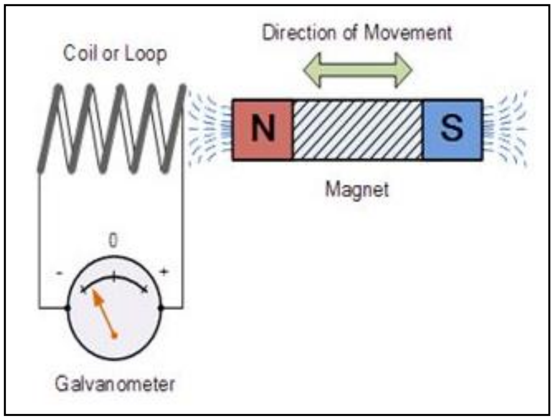

Figure 1 – Experimental setup of Faraday's law

Faradays' second law states that the magnitude of the emf induced in the coil is equal to the rate of change of flux that linkages with the coil. The product of the number of turns in the coil and the flux associated with the coil is equal to the flux linkage of the coil. Faraday's law is the main component of the energy harvester that the UWash will implement. [5]

1.1d Bio-engineering Energy Harvesting

Romero's article, "Body Motion for Powering Biomedical Devices", looked into energy harvesting in order to power portable electronic devices. Their design consisted of an axial flux generator powered by human motion. The generator consisted of a gear-shaped planar coil and a multipole NdFeB permanent magnet rings along with an attached eccentric weight. The device is able to generate energy through electromagnetic induction on the planar coil when it undergoes a changing magnetic flux as a result of the generator oscillations produced via body motions.

Their 1.5 cm^3 prototype was able to generate 3.9 μW of power while walking with the generator placed laterally on a person's ankle.

This article looked into an available power, which is an important question that would be raised about my project. How much power is available through hand washing your own laundry? The article noted that power generation from energy harvesters is proportional to the proof mass (m), the acceleration (a) squared, and the quality factor (Q), and inversely proportional to the driving frequency (ω) for a system where the driving frequency matches its resonant frequency: $P = (1/2)*m*(a^2/\omega)*Q$. The researchers estimated that the human motion could produce 1mW/cm^3 of power from walking, which was enough power to energize low-power applications by charging batteries.

The generator created by the researchers uses the motion conversion mechanism for body movements found in automatic self-winding wristwatches, which consists of rotations or oscillations due to the unbalanced proof mass. The generator also incorporates the approach of axial flux generators used in small-scale wind turbines, which consists of multiple pole-pair arrangements of permanent magnet (PM) coil. The rotor of the generator is composed of two rings with multiple pole-pairs of NdFeB permanent magnets and an eccentric mass. The stator is composed of several stacked layers of a gear-shaped planar coil fabricated using thin-film technology. Use of the gear-shaped planar coil allows for simplification of the wiring of the two electrical connections per layer. The diagram of the prototype is seen below in Figure 2.

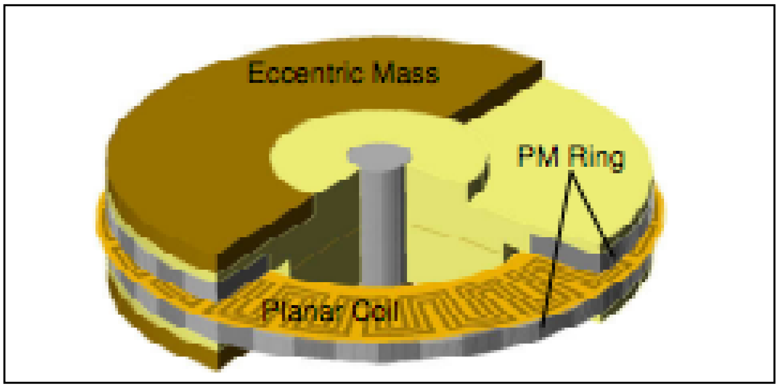

Figure 2 – Schematic of the axial flux generator

Body movement creates the driving force needed to move the rotor eccentric mass. After the mass has been interacted with, it oscillates like a pendulum. The variations of magnetic field due to the rotor oscillations induce a voltage on the planar coil. The AC voltage is then rectified into a DC signal and is stored in a capacitor or a rechargeable battery. [7]

Rao and fellow researchers looked at a fully functional, self-sufficient body-worn energy harvesting system for passively capturing energy from human motion, with the long-term goal of supplying power to portable electronic devices. The system converted the induced AC voltage to a DC voltage and then boosted and regulated the DC voltage in order to charge a lithium ion battery. The harvester structure was made in two symmetric hemispheres using a Nylon plastic material that was 3D printed. The two halves formed a spherical cavity with a permanent magnet ball on the inside. Both halves were then wrapped with 1400 turns of a 34 AWG copper wire. Figure 3 shows this set up of the energy harvester.

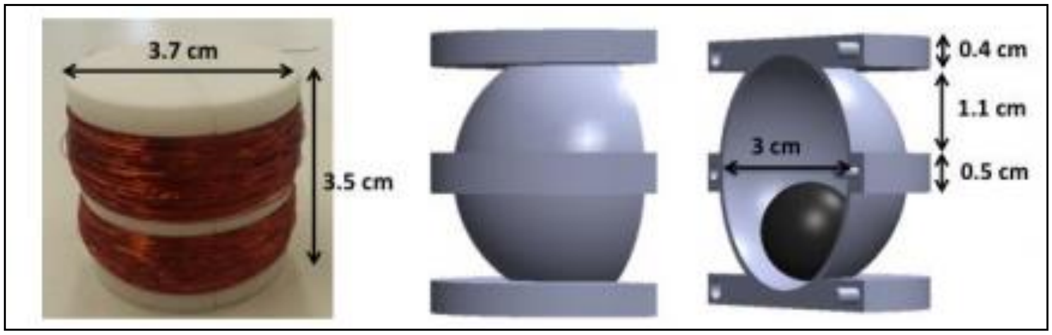

Figure 3 – Photograph (left) and 3-D schematic (right) of the energy harvester

As the person walks the motion of the magnet ball induces a time-varying magnetic flux in the coils, which generated a voltage. Connecting an electrical load allows current to flow through the coil, converting mechanical energy into electrical energy. The researchers conditioned the pseudo-random output voltage of the harvester by an input-powered energy harvesting circuit, which is powered by a time-varying voltage. Figure 4 shows a diagram of the circuit.

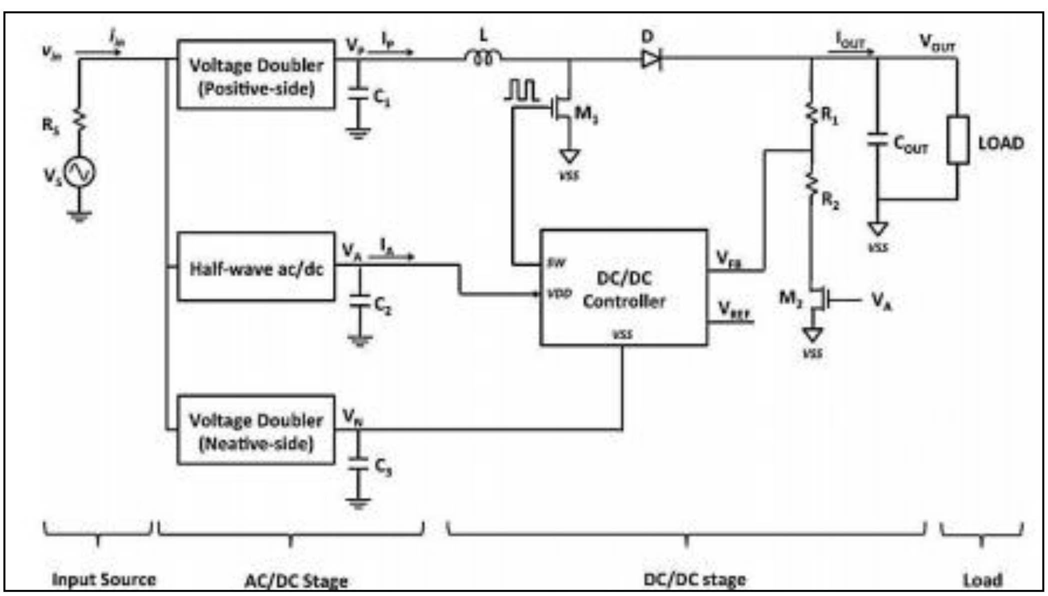

Figure 4 – Energy harvesting interface circuit

Researchers found that their system successfully scavenged and converted mechanical energy from ordinary human motion into electrical energy for charging a battery. [8]

1.1e Energy Harvesting Efforts in Third World Countries

A design project implemented in a third world country that incorporates electromagnetic energy harvesting is the Soccket soccer ball. The Soccket was designed by two Harvard graduates, Jessica Mathews and Julia Silverman. The Soccket is a soccer ball that has a small generator inside and stores energy by harvesting the kinetic energy. The Soccket was designed to replace kerosene lights in developing third world countries by converting an everyday pleasure into electricity. The small generator inside the Soccket can be used to turn on a small LED lamp for 3 hours after 30 minutes of play. The Soccket has a 6-watt output and is just two ounces heavier than a standard soccer ball. As a person plays with the Soccket, a pendulum harnesses the kinetic energy that comes from the movement by turning a generator connected to a rechargeable battery. Uncharted Play, the company started by the Harvard undergraduates, has had three versions of the soccer ball. The first design could be inflated and deflated but the major problem was that it did not last very long. The second design was too heavy compared to standard soccer ball. The third design wasn't that heavy and had a fist-sized gyroscope inside. The cost of a standard Soccket and lamp is $99. [6] My project design idea is a combination of the hand powered washer and the Sockket. Combining the kinetic energy generated by hand washing laundry and the energy harvesting aspect of the Sockket resulted in a unique design that would allow for people in third world countries to have access to electricity.

1.1f Ethics

The UWash will be a part of an ecological friendly household system. Washing laundry in a third world country usually consists of walking to the closest water source, collecting water, and bringing it back home in order to wash and dry clothes by hand. The UWash has the potential to make the lives of people in these countries much easier and provide a way to save water and electricity for others as well. This project would be a green energy conversion system, which would be beneficial to both the user and to the environment. Because the UWash converts mechanical energy into electrical it is not relying on an external electrical power source which is desirable for people living in third world countries.

This project would also have a social impact. Ideally the UWash would be for a family, so one per given household. Because there are a limited number of water sources in low-income third world countries, washing laundry becomes a social chore. Many people gather around the water source to wash their laundry. The UWash would play a role in this weekly task, further contributing to communication between family members.

An important safety concern in the design of UWash is the water coming into contact with the electrical components of the UWash. To keep the user safe, the electrical components will be isolated from the water that will go into the UWash in order to ensure the user is not in any danger of electrocuting themselves.

There are certain ethical related questions we have considered for the UWash. One of these questions is if the UWash was a success, how would we take it from production to an actual third world country village. The UWash would need funding in order to be mass produced and shipped to different countries as well as media support to raise enough money to do this. The UWash would also need to be cost effective enough in order for funding to be able to support the cost of multiple UWash machines. We have also considered the fact that UWash components could break after use, which would lead to the need for repair. The materials needed to repair the UWash would need to be accessible to the people owning a UWash. There are also some environmental concerns associated with the lithium ion batteries we are using as our storage element. There are limitations on lithium ion batteries when it comes to temperature, which could cause the batteries to fail or even leak if exposed to much heat. If these batteries needed to be replaced, where would the people properly dispose of them as to not cause any environmental problems? We have also considered how difficult it may become to turn the handle of the UWash if it is filled with an excessive amount of clothes or water. We would not want a person to become physically injured after using the UWash. If the UWash were to be mass produced and sent to people in need of it in third world countries it would be beneficial to have some sort of isolated testing group in order to detect any possible malfunctions we have not already considered. These are a few of the endless number of questions that are associated with UWash ethics.

2. Design Requirements

In this section, we describe the specifications and requirements for our hand powered battery charging washing machine. This will give a clearer understanding as to what requirements the individual components of the system must satisfy. This section will also help us in order to classify what, in our perspective, a successful project entails, which will allow us to easily identify when the final objective has been reached.

2.1 BEHAVIORAL OBJECTIVES

The main behavioral objective of the system is to convert mechanical energy into electrical energy. The UWash must consist of the following components: a washer that provides a source of mechanical energy, an energy harvester, an energy regulator, a storage component, and an application. Figure 5 below shows a simple block diagram of the desired UWash system.

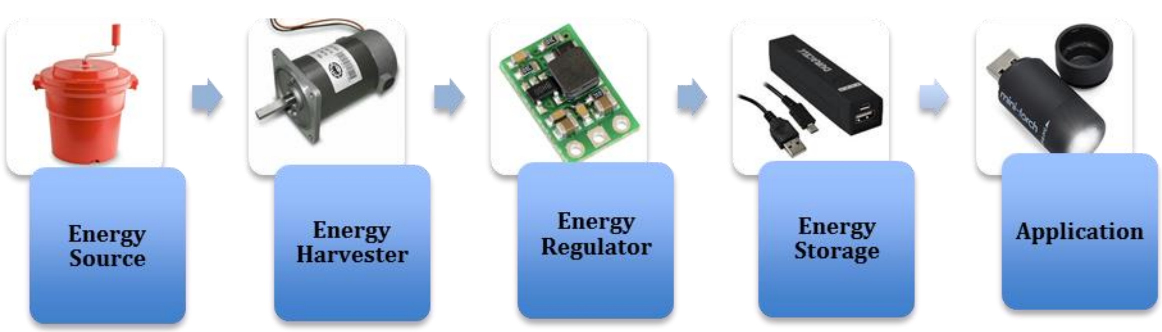

Figure 5 – Block diagram of the desired UWash system

2.1a Washing Machine

One of the main goals of the UWash is to be able to wash at least 5 pounds of soiled clothing. Therefore a washer device will be needed that is able to wash clothes. Members of third world countries need a washer that they will be able carry to the nearest water source, so the washer will need to weigh less than 5 pounds unfilled. The washer can't be too heavy because it would be ideal for a younger family member to also be able to lift the washer.

The basic idea is that a person that needs to wash a load of laundry should be able to carry the UWash to the location of the nearest water source to wash their laundry there, or they can leave the UWash at home and bring the water from the nearest water source back home to the UWash. Next, after both the soiled clothing and water has been placed in the UWash along with some form of detergent, the person can use the UWash to clean their clothes. The dirty water in the UWash should also be able to be drained out of a spout in the bottom if the water gets too dark. Afterwards, the UWash should be able to be refilled with clean water in order to continue washing the laundry.

The washer must also use rotational motion in order to wash the clothes so that an energy harvester can harvest the mechanical rotational motion. We also want to choose a washer that could eventually be remade from cheaper materials in order to reduce the cost of the overall system to make it more affordable for members of third world countries.

2.1b Energy Harvester Generator

The second component of the UWash is the energy harvester generator. The energy harvester aspect of the UWash needs to be able to convert mechanical motion into electrical energy. The energy harvester should be small enough to be able to attach to the washer. The energy harvester must also be able to generate enough electricity in order to be stored in a 5V USB charger/power bank. It is desired for the energy harvester to be able to produce at least 0.5 Wh of energy after a one-hour use so that after 1 hour a small LED flashlight could be fully charged and after a 6 hour use an iPhone can be 50% charged.

2.1c Energy Regulation

The third component of the energy harvesting system is energy regulation. Since we would like to store energy in a 5V USB power bank, the voltage output of the generator must be regulated. The energy regulator must be able to output DC voltage. Therefore if the energy harvester outputs AC voltage the regulator should be able to convert it into DC voltage. The voltage regulator must be able to step up or step down a voltage to 5 Volts for the 5V USB power bank. The voltage regulator must also be able to easily connect to the energy harvester. This component should also be small enough to fit easily onto the UWash washer component.

2.1d Energy Storage

The fourth component of the energy harvesting system is the energy storage component. The UWash should be able to store enough energy to charge a small rechargeable USB LED flashlight (0.3Wh) and an iPhone battery (5.45 Wh). Therefore our power bank needs to be able to both be charged by 5V and charge 5V devices. The energy storage component should also be small enough to fit on the washer.

2.1e Application

The fifth component of the UWash is the application. Since a USB rechargeable micro flashlight and Apple iPhone USB Data and Charge Cable are the two devices we want to power with the UWash. The UWash must be able to charge a flashlight so people in third world countries can have access to light when the sun goes down. These batteries are typically rated at 0.3 Wh, so the UWash must at least generate this many watt-hours of energy. The UWash must also be able to charge an iPhone because products similar to the UWash, like the Sockket, are able to charge up these devices most commonly found in first world countries. Therefore in order to charge these two devices we need exactly 5 V. A typical iPhone battery can hold a charge of 5.45 watt-hours, so the UWash should also be able generate 5.45 watt hours of energy.

2.2 PERFORMANCE OBJECTIVES

Ideally, we would like to have the electromagnetic energy harvester in the UWash have a maximum power transfer to the electrical load close to 100%. The output of small electromagnetic energy harvesters requires regulating in order to generate an output voltage that falls within the allowable operating range of the load electronics. Even after rectification and boosting, an electromagnetic energy harvester still only has a maximum power transfer to the electrical load of about 50% of the power flowing into the device. In order to achieve the maximum potential power of an energy harvester, the power conditioning system of the UWash must provide the optimum load for the generator for the specific input and output conditions. [15]

The UWash must also be easy enough for an average person to rotate the handle. Assuming the average person using the UWash spins the handle of the salad spinner 30 rotations per minute, and the iPhone draws about 5 Watts of power (charger rated 5V at 1A), using the equation Power = torque X rotational speed = current X voltage, we can see the torque needed to charge the iPhone is about 1.2 foot pounds, which seems achievable for an average person to generate.

We can model the voltage regulator, power bank, and application devices as a variable resistor. If the devices are completely discharged this modeled variable resistor will draw the most current from the generator meaning a person will have to spin the handle with more force or faster to achieve the same power output. If the application devices are 50% charged then they will draw less current and it will be easier to rotate the generator and handle of the UWash. With this in mind, the UWash handle should never be "too hard" to spin. So all of the chosen components of the UWash should ensure a user is able to easily wash their clothes without too much resistance.

The UWash is a success if it can fully charge a rechargeable USB flashlight after a 1-hour use (about 1 wash) and if it can charge an iPhone to at least 50% over a 6-hour use (about 6 washes). It is assumed the user would be washing and spinning the handle of the UWash at about 30 RPM, which we will consider an average speed. We also assume one wash will take about 1 hour of a persons time. This measure of success is discussed in more detail in section 4.2 "System Analysis". A chart of the overall goal of the UWash and the design requirements of each component can be seen below in Figure 6.

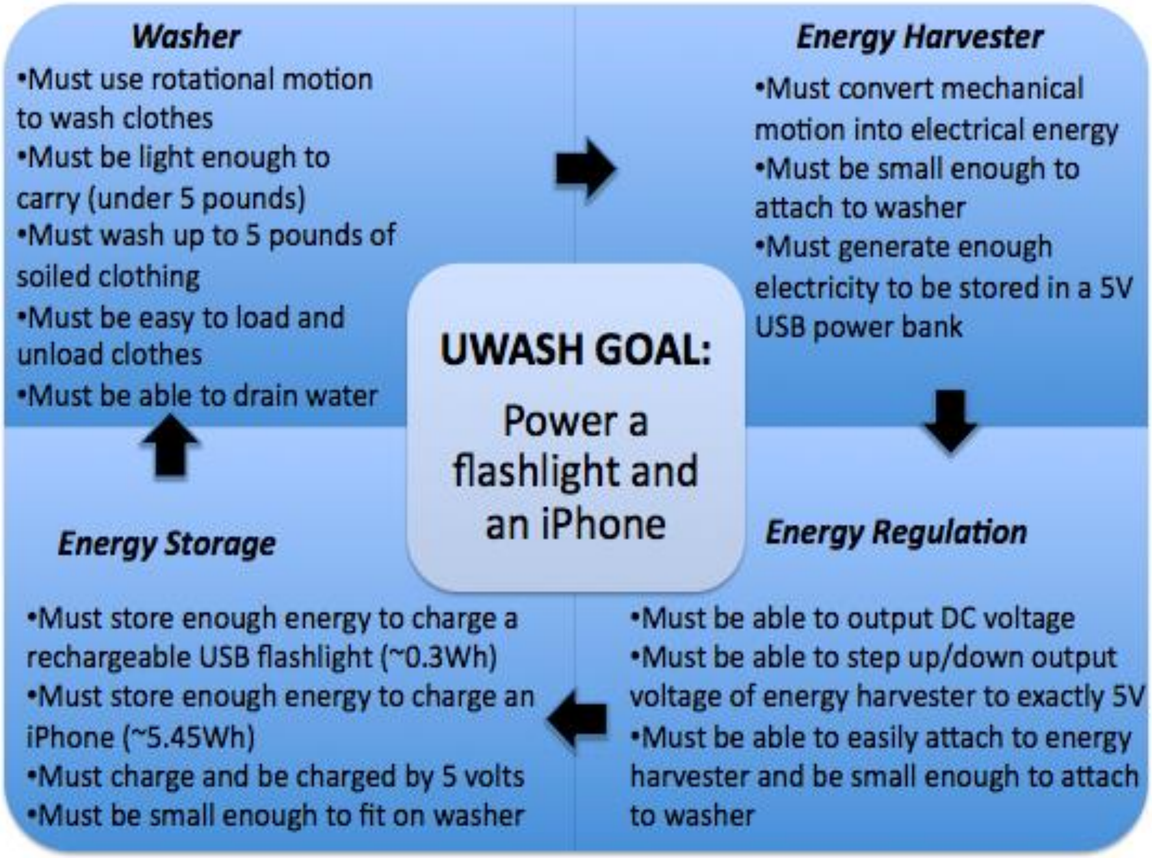

Figure 6 – Chart of the design requirements and UWash goal

At this point we will begin detailing design alternatives for the UWash by looking at the individual alternatives for each component of the UWash system.

3. Design Alternatives

The UWash will consist of the following components: a washer, energy harvester, interface circuit, storage component, and device applications. In this section we will discuss the alternative design choices for each component in order to justify the final design choice made for the UWash.

3.1 COMPONENT ALTERNATIVES

3.1a Washer Alternatives

There were a few choices for the washer component of the UWash. There are a couple of commercially available washing components, including the Wonderwash, which is a hand-powered portable washer that can clean clothes in 1 to 2 minutes. The cost of the Wonderwash is $42.95 The Wonderwash weighs about 6 pounds and is compact in size making it ideal for anyone who frequently washed small loads of laundry. [16] The Wonderwash does not operate using a gear system.

Another design alternative for the washer component was a foot powered washing machine called the GiraDora Washer. This washer requires no electricity and costs about $40. The washer was created in mind for people in developing countries that lack electricity and the funds to buy expensive machines. The product developed is a combination washer and spin-dryer powered by a spring loaded foot pedal. While the design of this washer is practical, it does not utilize a rotational motion to wash clothes. [3]

3.1b Energy Harvester Alternatives

There are important pros and cons to weigh in choosing an energy harvester for the UWash. Solar energy has several advantages and disadvantages. Solar energy is renewable, abundant, sustainable, environmentally friendly, widely available, and reduces electricity costs. However solar energy harvesting can also be expensive, intermittent since access to sunlight is limited at certain times during the day, energy storage is expensive, certain solar cells require materials that are expensive and rare in nature, and it requires space to derive power. [17]

3.1b-1 Bike Dynamos

Bike dynamos are electromagnetic energy harvesters because they convert mechanical energy into electrical energy. There are two main types: hub and bottle. Both of these bike generators are used to power bicycle lights. Unlike actual dynamos that output DC power, hub and bottle dynamos output AC power. Bottle dynamos are easy to add to an existing bike wheel and are generally cost effective. However, bottle dynamos are prone to slipping in wet conditions because the roller on the bottle dynamo can slip against the surface of a tire, which will reduce the total amount of electricity generated. [18] Bike dynamos also typically create more drag than hub dynamos, add wear to the side of the tire and make a lot of noise when in operation. Hub dynamos are built into the hub of a bicycle wheel, requiring more installation than bottle dynamos. Hub dynamos are generally about 70% efficient, compared to bottle dynamos with about a 40% efficiency rating. [19] Both bottle and hub dynamos operate at 6 Volts at 3 Watts.

3.1b-2 AC Motors

Electric motors can be categorized into two types: alternating current (AC) electric motors and direct current (DC) electric motors. The term motor refers to the energy flow, electrical to mechanical. Motors can act as generators if used in reverse, meaning the energy flows from mechanical to electrical. DC motors usually characterize a continual and standard current flow. AC motors tend to work well for hard systems that need a lot of up front power. DC motors do not perform that well at producing power over extended periods of time.

AC electric motors are categorized into two types: synchronous AC motors and induction AC motors. The synchronous AC motor starts rotating when a sub-multiple of the supply frequency hits. The rotor magnetic field is the result of the slip ring current or the result of a permanent magnet. Synchronous motors are divided into two major types depending on how the rotor is magnetized: non-excited and direct current excited. Non-excited motors fall into three types: reluctance motors, hysteresis motors, and permanent magnet motors. [28] The permanent magnet synchronous generator (PMG) is one where the excitation field is provided by a permanent magnet instead of a coil. Synchronous corresponds to the fact that the rotor and magnetic field rotates at the same speed. PMG are commonly used in wind turbine generators. They have several advantages such as being small in size, low in cost, and have a quick response to varying speed. PMG generators are also very efficient and simple in structure. The advantage of using permanent magnets are the following: they do not require an additional DC supply for the excitation circuit, PMG avoid the use of slip rings making them simpler and maintenance free, and condensers are not required for maintaining the power factor in synchronous generators as is required in induction generators. [26] PWM generators are commonly used in hand crank flashlights because they are capable of producing more current to charge the built in battery pack the flashlights come with as well as powering the built in LED’s well. [27] These types of generators are highly efficient (up to 97%) and reliable because there is no need for external excitation and conductor losses are removed from the rotor. [29]

Induction motors work on the principle of induction where an electro-magnetic field (emf) is induced in to the rotor conductors when the rotating magnetic field of the stator cuts the stationary rotor conductors. There are two types of induction motors based on the construction: squirrel cage induction motor and slip ring induction motors. Because induction motors are simple and rugged in construction they are robust and can operate in any environmental condition. These motors are also cheaper in cost and maintenance free due to the absence of brushes, commutators, and slip rings. The induction asynchronous AC motor turns a little slower than the standard supply frequency. The magnetic field on the rotor works with the help of the induced current. AC induction motors have long life expectancies compared to DC motors, making them desirable for use as generators. [12]. Induction motors vary in efficiency from 85% to 97%. [30]

3.1b-3 DC Motors

DC motors are categorized into brush motors and brushless motors. A brushed DC motor is composed of a rotating set of wound wire coils, called an armature, which acts as an electromagnet with two poles. A mechanical rotary switch called a commutator reverses the direction of the electric current that flows through the armature so that the poles of the electromagnet push and pull against the permanent magnets on the outside of the motor. As the poles of the armature pass the poles of the permanent magnets, the commutator reverses the polarity of the armature electromagnet. During the instant of switching polarity inertia keeps the motor rotating in the correct direction [9]. Brushed DC motors are about 75%-80% efficient. [10] The DC brush electric motor is the most common type of motor used because they are easy to construct, very cost effective, and available in a variety of sizes.

The tradeoff for the brush DC motors is that the carbon brushes used to transfer electrical current to the rotating part wear over time and eventually result in the failure of the electric motor. These motors are also less efficient than brushless DC motors and are electrically noisy [10].

A DC brushless motor uses a permanent magnet external rotor, three phases of driving coils, one or more Hall effect devices to sense the position of the rotor, as well as the associated drive electronics. The coils in a brushless DC motor are activated by the drive electronics as cued by the signals from the Hall effect sensors. Brushless motors are typically 85-90% efficient. [23] Brushless DC motors also eliminate the problem due to the brushes that DC brush motors have. However, these motors are also more expensive and require complicated drive electronics in order to operate. Brushless motors can be driven to much higher RPM limits than brush DC motors and usually have a lower inertia [11]. The brushless DC motor also dissipates heat more efficiently because the stator windings are thermally connected to the outside of the motor case. These motors also require lower maintenance than brush motors because there is no need to replace the brushes.

Table 1 below shows all of the options for energy harvesters discussed above: hub dynamos, bottle dynamos, DC motors, and AC motors.

ELECTROMAGNETIC ENERGY HARVESTERS				
Type:	Hub Dynamo	Bottle Dynamo	DC Motor	AC Motor
Visual:				
Output Voltage:	AC Voltage	AC Voltage	DC Voltage	AC Voltage
Product Ratings:	6V, 3W	6V, 3W	Varies with part	Varies with part
Efficiency:	72%	40%	75 - 80%	85 - 97%
Pros:	• Doesn't wear out as fast as bottle dynamos do	• Cheaper and smaller than hub dynamos	• Cheap & available in a variety of sizes	• Low maintenance & long life spans
Cons:	• Requires special attachment	• Noisy, slip in wet conditions	• Brushes wear out over time	• Can be more expensive and produce more audible noise than DC motors.

Table 1 – Electromagnetic energy harvester comparison

3.1c Interface Circuit Alternatives

In order to understand the type of interface circuit the UWash system needs it is important to review the basics behind battery charging systems in order to see the interface circuit's role in the system. A battery charger system is the system used to draw energy from a utility grid, store it in a battery, and release it to power a device. Designers of these circuits try to maximize the energy efficiency of their devices in order to ensure long operation times between charging. It is not possible to charge a battery by directly plugging it into a standard wall outlet, therefore a series of power conversion steps needs to be performed in order to change the high AC voltage from the power outlet into the appropriate amount of low DC voltage that the battery can use. Battery charging circuits work by first reducing the voltage form the utility level to the lower voltage at which the batteries can operate, second by rectifying the AC electricity into DC electricity, and thirdly by regulating the low-voltage DC current into the battery. Figure 7 below shows a block schematic of a battery charging system.

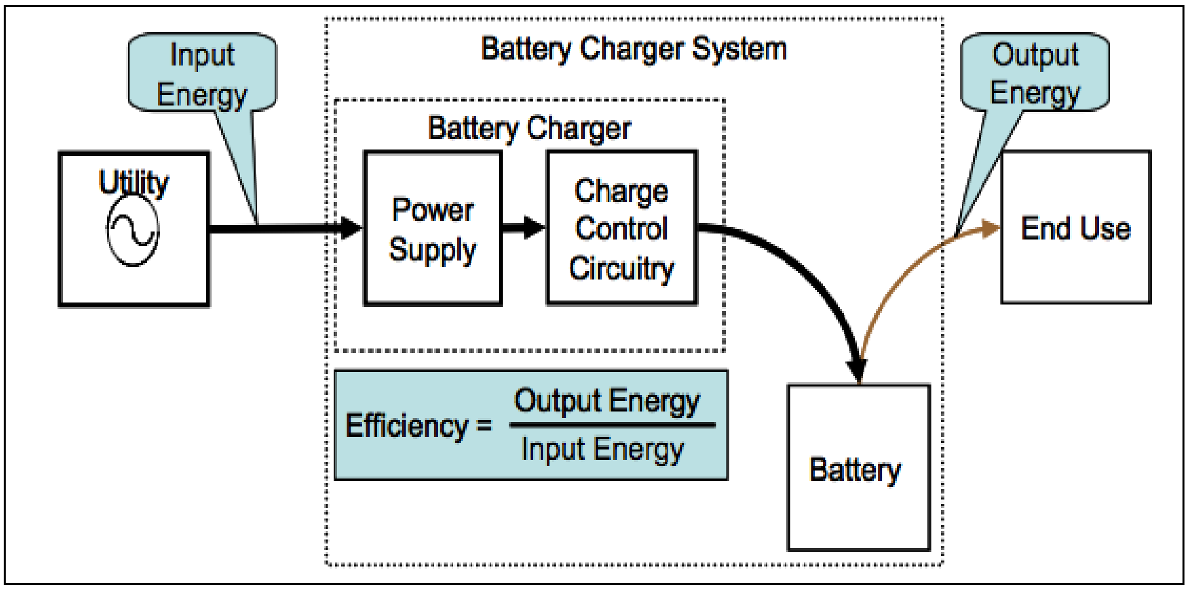

Figure 7 – Block schematic showing the general configuration of a multi-piece battery charger system with a discrete power supply and charge control circuitry. The efficiency calculation is made over a 24-hour charge and maintenance period and a 0.2 C discharge for the battery.

Battery chargers can operate in three modes. In active mode the battery is being charged from a discharged state. It is during this state in which battery chargers draw the most current form the outlet. In maintenance charge mode the battery state is being maintained at a fully charged state. A battery charger usually draws less power in this mode than in active charge mode. [13]

The role of the interface circuit in the UWash system is energy regulation. The interface circuit must regulate the output of the energy harvester. The interface circuit must be capable of converting any voltage produced by the energy harvester to exactly 5 Volts. The type of interface circuit needed depends on the output voltage of the energy harvester. If the energy harvester produces AC voltage like the bottle and hub dynamos, then a rectifier will be needed in order to convert the AC voltage to DC voltage. In addition to the rectifier, a DC-to-DC converter will be needed in order to convert the DC output of the rectifier to exactly 5 V. If the output of the energy harvester is DC then only a DC-to-DC converter will be needed. There are a few options for DC to DC converters including a step up converter, step down converter, or both a step up and step down converter.

3.1d Energy Storage Alternatives

There are various types of rechargeable batteries that can store electrical energy. Depending on the chemicals involved and the overall design, a battery behaves differently when being used and charged.

Lithium ion batteries are low maintenance, can provide high current to applications, are lightweight, and also have improved safety circuitry to prevent overcharge in turn preventing electrolyte leakage. [14] Alkaline rechargeable batteries have a long shelf life and are available in household sizes. They lose their charge gradually, giving the user plenty of warning that it's time to change or recharge. The downside of these batteries is that they don't fully recharge, so that battery capacity shrinks rapidly with each charge cycle. Nickel cadmium batteries are rechargeable, however they are hazardous when disposed of. These batteries also have low capacity and will not properly recharge if they are not completely drained. [20]

3.1e Application Device Alternatives

Since the devices that need to be charged are a portable flashlight and an iPhone we will look into flashlights an iPhone chargers that can be charged via a 5V USB port. The Apple iPhone USB Data and Charge Cable is capable of plugging into an iPhone and charging it through a standard USB port. Since 5 Volt USB cables to charge iPhones are pretty standard there aren't many alternatives besides choosing cables to charge specific types of iPhones like the 5s or the iPhone 6. There are many brands of rechargeable USB flashlights that can satisfy the application design requirement. One such option is a rechargeable micro flashlight made by Minitorch that consists of a white LED rated from 8000 to 12000 microcandella. This USB flashlight is able to fully charge in 2 hours and is capable of providing 2+ hours of light after a full charge. The battery used in this device is a lithium ion battery rated at 300mAh at 1V or (0.3Wh). Another option is a mini USB rechargeable 20-Lumen LED flashlight by FASTTECH. This flashlight claims to have 150 minutes of working time after charging for 15-20 minutes. [22]

4. Preliminary Proposed Design

4.1 CHOSEN COMPONENTS

The project we have developed, the UWash, is a battery charging hand powered washing machine. The components of the energy harvesting system we have chosen specifically satisfy the design requirements listed in section 2.

4.1a Washer Choice

The mechanical energy source of the UWash will come from the rotational motion of a salad spinner. We chose to use a five-gallon salad spinner purchased from KaTom because it is light enough to carry, capable of washing a small load of laundry, has a built in drainage system, operates based on rotational motion, and has a built in gear system. The salad spinner lid size and ultimate capacity influenced the rest of the components we chose to use for the UWash system. Figures 8 and 9 below show the exterior and interior, respectively, of the hand powered washer, originally a salad spinner, that will be used to create the UWash. [21]

Figure 8 – Exterior of the hand-powered washer (salad spinner).

Figure 9 – Interior of the hand-powered washer (salad spinner).

The salad spinner we ordered has a built in gear train that we will utilize to generate electricity with our motor energy harvester. A picture of the gear train is seen below in Figure 10.

Figure 10 – Salad Spinner with built in gear train.

The top 2 gears have a 2.5:1 gear ratio. We plan on 3D printing a gear to fit the energy harvester we purchased to increase the ratio even more to obtain the maximum amount of RPM's. We will design our gear ratio based on the assumption that the average UWasher is going to spin the handle at about 30 RPM's. It is ideal for final gear ratio, if we are utilizing the 2 top gears that come with the salad spinner, to be at least 3:1.

4.1b Energy Harvester Choice

We purchased three types of energy harvesters with the intention of performing tests on each to see if it would be the most suitable choice for the UWash. We purchased a bottle dynamo, a DC motor, and a hand crank flashlight generator.

We purchased a Busch & Muller Dymotec 6 light travel dynamo for our bottle dynamo. We chose this bottle dynamo because it was cost effective and operated based on rotational motion. This specific bottle dynamo is 40% efficient and is rated 6V at 3W. This bottle dynamo is also designed to withstand extreme weather conditions, which would be useful for the third world country application of the UWash. This bottle dynamo is gentle to the tire, self-cleaning and provides maximum traction paired with optimum contact pressure. [32] Figure 11 below shows a picture of the bottle dynamo.

Figure 11 – Busch & Muller Dymotec 6 light travel dynamo

We purchased a 19:1 metal gear motor from Pololu Robotics & Electronics. We purchased this motor because it was cheap, can operate as a generator, and contained a built in gear system that we could utilize. This 2.05" × 1.45" × 1.45"gearmotor is a powerful brushed DC motor with 18.75:1 metal gearbox intended for operation at 12 V. The units have a 0.61"-long, 6 mm-diameter D-shaped output shaft. Some key specifications include that at 12 V: 500 RPM and 300 mA free-run, 84 oz-in (5 kg-cm) and 5 A stall. [33] Figure 12 below shows a picture of the DC motor.

Figure 12 – 19:1 DC Metal Gear Motor

We purchased a Dorcy LED Dynamo Flashlight. The self-powered, renewable energy technology requires no recharging of batteries. The fold out hand crank winds up and charges the flashlight conveniently and quickly. The flashlight also dual functions as a 3-bulb LED flashlight and a 5-bulb LED blinking flashlight. One minute of cranking results in about 3 to 6 minutes of light if the light is completely dead. The battery inside the dynamo is a lithium ion 2032 3.6V coin cell that is charged by the crank. The generator inside the flashlight is driven by a gear train discussed more in section 4.4 of this report. The generator is a small permanent magnet brushless AC generator rated 8-9V. [34] Figure 13 below shows a picture of the hand crank flashlight.

Figure 13 – Hand Crank Flashlight Generator

We ultimately ended up choosing both the DC motor and the permanent magnet AC generator for the energy harvester for the UWash. After creating gears for both, in order to mechanically connect the energy harvesters to the salad spinner, we will decide which one produces the most watt-hours in one hour and is the most efficient. We chose to decide between these two generators because they are both cost effective, highly efficient, and proved to be able to generate 0.5 Watts of power after an hour or mechanical rotation, which is the ultimate measure of success for the UWash energy harvester. We chose these two generators after analyzing the data from a bottle dynamo, DC motor, and permanent magnet AC generator. These results are seen in section 4.4 of this report titled “Preliminary Experiments”.

4.1c Energy Regulator Choice

In order to deliver exactly 5 Volts to the storage component we chose a 5V step up/step down switch mode voltage regulator. We choose to use a switch mode voltage regulator for our energy regulator because it is 80% efficient compared to linear regulators which can be have half of the efficiency. The step-up/step-down regulator from Pololu we chose produces a fixed 5 V output from input voltages between 2.9 V and 30 V while allowing a typical output current of up to 2 A when the input voltage is close to the output voltage. The part also offers efficiencies of 80% to 90%. Its ability to convert both higher and lower input voltages makes it useful for applications where the power supply voltage can vary greatly, as with batteries that start above but discharge below the regulated voltage. [24] The output of the voltage regulator will be connected to the storage component, the Duracell power bank, via a USB A Female Solder Connector. Figure 14 shows a picture of the voltage regulator.

Figure 14 – Switch mode Voltage Regulator

4.1d Energy Storage Choice

The chosen storage component of the UWash system was a Duracell power bank. We chose this storage component because it can charge and be charged by a 5V USB port and because the total storage capacity is enough to fully charge both of our application devices. This device contains a lithium ion battery rated 2600mAh at 3.7 Volts, or 9.62 Wh. 9.62Wh of storage means our chosen power bank can hold more than 5.45Wh and 0.3Wh, which are the energy storage capacities of the iPhone battery and LED flashlight battery respectively. This power bank has 4 LED's that light up one after another to indicate that it is charging. The 4 different LED's will light up after the power bank has been charging for a certain amount of time. Table 2 below shows the percent charged values that correspond to the different LED's on the power bank. Figure 15 shows a picture of the Duracell power bank.

LED	Percent of Battery Charged (%)
4	80 – 100
3	60 – 80
2	40 - 60
1	20 - 40
1 (flashing)	< 20
0	0

Table 2 – Power bank indicator translation

Figure 15 – 5V USB charger and power bank

4.1e Application Choice

We chose the flashlight seen in Figure 13 for the portable flashlight because it is charged by a 5V USB port, is light in weight, and can provide a lot of light after being fully charged The flashlight is rated 300mAh at 1V, or 0.3 Wh. After a full charge the flashlight can provide 2 plus hours of light. [25] A picture of the flashlight is seen in Figure 16 below.

Figure 16 – Rechargeable micro LED flashlight

We chose to charge an iPhone because the Sockket soccer ball can charge both a portable flashlight and iPhone and we thought it would be good to have the UWash be comparable in abilities. Choosing to charge an iPhone is also a good comparison to a flashlight because of the different needs of people in third world countries versus first world countries. An iPhone battery is rated at 1140 mAh at 5V, or 5.45 Wh. Figure 17 shows a picture of the USB cable needed to charge an iPhone.

Figure 17– Apple iPhone USB data and charge cable

4.2 SYSTEM ANALYSIS

An important equation for our UWash system is the power equation: power = torque x rotational speed = current x voltage. The voltage regulator, power bank storage component, and application devices can all be modeled as a variable resistor in the UWash system. In a perfect world the voltage across this "variable resistor" part of the system is constant at 5 Volts. Therefore, if voltage is constant the thing that is changing in our system is current. The current drawn from the generator all depends on how charged our application devices are. The salad spinner handle will be the hardest to rotate when the generator is drawing the most current. The generator will draw the most current when the application device, iPhone for example, is at 0 percent charge. The generator will draw half that amount of current when the iPhone is at 50% charge. Therefore, when the generator is drawing the most current the UWasher will have to either rotate the handle with more force or spin the handle faster to maintain the same power as if the iPhone was drawing less current.

Another big question for our UWash system is the following: How long will it take to charge the LED flashlight and iPhone? As a worst-case scenario, we will base our data off the specifications of a 40% efficient bottle dynamo [31]. Since bottle dynamos are made for bike riders the information provided for power output is based on the speed of the biker in kilometers per hour (km/hr). We are able to convert the speed into rotations per minute (RPM) taking into account the 8.5-inch radius of the salad spinner lid. A speed of 2.5 km/hr and 8.5 inch spinning radius of the salad washer handle corresponds to a RPM of 30.72. Taking into account the 3:1 gear ratio of the salad spinner we expect to generate at least 90 RPM. Based on this RPM the bottle dynamo should be able to output about 0.5 Watts of power. This means that rotating the handle of the UWash at about 30 RPM for one hour can generate about 0.5 Watts of energy. In order to fully charge the power bank, which can hold up to 9.62 Wh, a person would have to do a 1 hour wash at 30 RPM about 19 times (9.62Wh / 0.5Wh = 19.24 washes). To fully charge the 0.3 Wh micro flashlight a person would have to do a 1 hour wash at 30 RPM about 1 time (0.3 Wh / 0.5Wh = 0.6 washes). To fully charge the 5.45 iPhone battery a person would have to do a 1 hour wash at 30 RPM about 11 times (5.45 Wh / 0.5Wh = 10.9 washes). To charge the 5.45 iPhone battery to 50% a person would have to do a 1 hour wash at 30 RPM about 6 times { (5.45/2) Wh / 0.5Wh = 5.45 washes }. The UWash is a success if it can fully charge the micro flashlight after a 1-hour use and if it can charge an iPhone to at least 50% over a 6-hour use.

4.3 COST OBJECTIVES

Because the UWash is created with the purpose of helping members of third world countries, it is vital for all of the components used to be relatively low cost and readily available.

The UWash system consists of 4 main components:

- a hand powered washer
- an energy harvester generator
- an energy regulator
- an energy storage component.

The cost objectives for this project are derived from comparisons to readily available hand-powered washers, salad spinners and other designed energy harvesting circuits. All of the components that will be used in the UWash system can be found in Table 3 below.

Stage	**Part**	**Purpose**	**Price**
Salad Spinner:	5 Gallon Plastic Salad Spinner/Dryer	Serves as the hand powered washer	$ 100
Energy Harvesters:	19:1 Metal Gear motor	Converts rotational mechanical energy into AC voltage.	$ 25
	Bottle Dynamo	Converts rotational mechanical energy into DC voltage.	$ 25
	Hand Crank Flashlight with	Converts rotational mechanical energy into AC voltage.	$ 14

	brushless AC motor		
Voltage Regulation:	5V step up/step down regulator	Steps the voltage up/down to exactly 5 Volts for the USB charging devices	$ 5
Energy Storage:	Duracell Power Bank	Charges and is charged through 5 V USB port.	$ 30
Application Devices:	USB Rechargeable Micro Flashlight	Provide light to a UWash user	$ 5
	Apple IPhone USB Cable	Charge an Apple IPhone	-----
Miscellaneous Parts:	USB female solder connecter	Connects output of voltage regulator to storage component	$ 1
Total Price:			$ 205

Table 3 – List of components for the UWash

4.4 PRELIMINARY EXPERIMENTS

An important component of the UWash is the energy harvester. The energy harvester chosen must be able to output, at the minimum, 0.5 Wh of energy, assuming the user is spinning the salad spinner handle at an average speed (30 RPM). It is important that we pick an energy harvester that is efficient and can output enough power to able to be stored in our power bank and later able to charge our flashlight and iPhone. The three types of energy harvesters we considered include the following: a bottle dynamo, a brush DC motor, and a permanent magnet brushless AC generator. For a preliminary test we decided to use a prototype board to set up a circuit consisting of the energy harvester, the 5V voltage regulator, and varying load resistances. We used the following load resistances for the energy harvester tests: 10 Ω, 50 Ω, 100 Ω, 1 kΩ, 10 kΩ, 100 kΩ, and a 200 kΩ. We chose these values for our load resistances because the UWash needs to deliver at least 0.5 Wh of energy to the load after one hour of use. Therefore, since $P = V^2/R$, and the regulator output is 5 V, to get 0.5 W we need at least a 50 Ω load resistance. We look at resistances above and below 50 ohms to analyze the performance of the energy harvesters.

So, as stated previously the input to the energy harvester is a mechanical rotational motion, which will induce a voltage output from each energy harvester. As part of each test we measured the following: the input voltage to the regulator, the output voltage of the regulator, the input current to the regulator, and the current through the load resistor. From these measurements we were able to calculate the input power to the regulator, the output power across the load and the efficiency of the energy harvester for various loads. Figure 15 below shows a general flow chart of the circuit we used to test each energy harvester.

Figure 18 – Energy harvester circuit flowchart

In order to test the bottle dynamo, which outputs AC voltage, we needed to first convert the output into DC voltage so that it could be regulated by our 5V step up/step down voltage regulator. In order to do this we first made a rectifier consisting of four n4148 diodes and a 470 μF smoothing capacitor. We then connected the output of the rectifier to the voltage regulator. The output of the regulator was connected to various load resistors. In order to generate voltage out of the bottle dynamo the cap was hand spun as fast as possible. The circuit test for the bottle dynamo showed that the energy harvester could only output 5.12 Volts at load resistances at or above 100 kΩ. At 200 kΩ the bottle dynamo was able to output about 100 mW of power at 10.7% efficiency. The data obtained from the bottle dynamo can be seen below in Table 4. The input voltage refers to the voltage into the regulator. The output voltage refers to the voltage out of the regulator. The input current is the current going into the regulator. The load current is the current through the load.

Resistance Load RL (Ω)	Input Voltage Vout (V)	Output Voltage Vout (V)	Input Current Iin (mA)	Load Current IL (mA)	Input Power PL (mW)	Output Load Power PL (mW)	Efficiency %
10	3.2	1.84	12	2.2	38.4	4	10.4
50	3.2	2	16	4	51.2	8	15.6
100	3.04	2.4	20	2	60.8	4.8	7.9
1 k	3.52	2.6	6	0.6	21.12	1.56	7.4
10 k	3.04	4.8	3	0.4	9.12	1.92	21
100 k	3.6	5.12	0.9	0.05	3.24	0.256	7.9
200 k	3.04	5.12	0.4	0.025	1.2	0.128	10.7

Table 4 – Preliminary bottle dynamo data

There was no need to use a rectifier for the brush DC motor because the motor already outputs DC voltage. So for the DC motor test all we had to do was connect the output of the motor to the voltage regulator, then to various load resistances. In order to generate voltage from the motor we attached a handle that spins the shaft of the motor. The

DC motor we purchased already has a built in gear system with a ratio of 19:1. The circuit test for the brushless DC motor showed that the energy harvester could only output 5.1 Volts at load resistances at or above 50 Ω. At 50 Ω the DC motor was able to output 510 mW of power at 89% efficiency. The data obtained from the DC motor can be seen below in Table 5.

Resistance Load RL (Ω)	Input Voltage Vout (V)	Output Voltage Vout (V)	Input Current Iin (mA)	Load Current IL (mA)	Input Power PL (mW)	Output Load Power PL (mW)	Efficiency %
10	3.4	3.3	88	40	299	132	44
50	3.8	5.1	150	100	570	510	89
100	4.4	5.03	75	50	330	252	76
1 k	4.6	5.03	9	5.04	41	25	61
10 k	5.3	5.03	5	0.59	27	3	11

Table 5 – Preliminary DC motor data

The permanent magnet AC generator we used was from a hand crank flashlight. The flashlight has its own gear train that drives the motor. After taking the flashlight a part I was able to see that there are 3 sets of motors that make the gear train each with a gear ratio of 40:12, making the total gear ratio about 37:1. Because the permanent magnet brushless AC generator outputs AC voltage we used the same rectifier we used for the bottle dynamo test in this circuit. So, we connected the output of the AC generator to the rectifier. Then the output of the rectifier was connected to the input of the voltage regulator. The output of the voltage regulator was then connected to various load resistances. In order to generate voltage from the AC generator we attached a handle that spins the shaft of the motor. The circuit test for the permanent magnet brushless AC generator showed that the energy harvester could only output 5.01 Volts at load resistances at or above 50 Ω. At 50

Ω the AC generator was able to output 501 mW of power at 70.4% efficiency. The data obtained from the AC generator can be seen below in Table 6.

Resistance Load RL (Ω)	Input Voltage Vout (V)	Output Voltage Vout (V)	Input Current Iin (mA)	Load Current IL (mA)	Input Power PL (mW)	Output Load Power PL (mW)	Efficiency %
10	2.8	2.6	400	300	1120	780	70
50	12	5.01	59.4	100	712	501	70.4
100	13	5.019	54.5	50	709	251	35
1 k	15	5.019	5.6	5	84	25	30
10 k	16	5.019	1.322	0.65	21	3.3	16
100 k	17	5.019	0.834	0.19	14	0.95	7.3
200 k	16	5.019	0.767	0.16	12	0.8	6.7

Table 6 – Preliminary AC generator data

A summary of the data collected from the energy harvesters is seen below in Table 7. Table 7 identifies the load that produces an output voltage of 5 Volts and the highest efficiency.

Energy Harvester:	Bottle Dynamo	Brush DC Motor	Permanent Magnet AC Generator
Load:	100 kΩ	50 Ω	50 Ω
Power across load:	100 mW	510 mW	501 mW
Efficiency:	10.7 %	89.0 %	70.4 %

Table 7– Preliminary energy harvester data

Based on the results the brush DC motor and permanent magnet AC generator were the most efficient and produced similar power ratings across the load resistors. However, it is important to remember that a different gear ratio was used to drive the two generators. The gear ratio that drives the AC generator is 37:1 versus the gear ratio that drives the DC motor, which is 19:1. We expect the power output and efficiency of the DC motor to increase if we increased the gear ratio to 37:1.

Since both the DC motor and AC generator were more efficient than the bottle dynamo, the choice of energy harvester must be between these two energy harvesters. Because the UWash also must incorporate the salad spinner we will have to mechanically connect the energy harvester to the salad spinner. Both the DC motor and AC generator will require at least one gear to be made in order to allow the rotational motion of the salad spinner to be converted into electrical energy by the energy harvester. Because the mechanical gear will change the data we obtained for the DC motor and AC generator I believe it will be worth it to make a gear for both the DC motor and the AC generator and see which generator will perform better.

4.5 SCHEDULE BREAKDOWN

The weekly break down of how the UWash will be completed is seen below in Table 8. Winter term we will assemble and test the final functioning UWash.

WEEK	GOAL
1	➢ Test salad spinner washing capabilities
2	➢ Test the chosen motor with storage element.
3	➢ Test the storage element with charging applications.
4	➢ Design way to fit motor, charging circuit, and storage component on salad spinner
5	➢ Create and order any parts needed to mechanically fit components on salad spinner
6	➢ Work on altering washer to incorporate motor with gear
7	➢ Connect motor generator storage element and test how well the system works with the salad spinner
8	➢ Test UWash and make changes as needed to design.
9	➢ Test UWash while actually washing laundry ➢ Make changes to ensure user safety
10	➢ Collect final test data and construct user manual and final report

Table 8 – Weekly breakdown of the completion of the UWash

5. Final Design and Implementation

5.1 GENERATOR EXPERIMENTS

In order to choose between the AC generator from the hand crank flashlight and the 19:1 DC gear motor we performed a series of tests in order to see which generator was the most efficient and compatible with the rest of the UWash system.

5.1a AC Generator Experiment Set Up

To test the AC generator in the hand crank we disassembled the flashlight, took out the LED's and the charging circuit inside, and replaced it with our own regulation circuit seen below in Figure 19. A picture of the hand crank flashlight is also seen below in Figure 20. The crank of the AC generator was able to turn on average about 120 RPM, taking into account the 94.6:1 gear ratio, the generator spun at about 11,352 RPM.

Figure 19 – AC Generator Regulating Circuit Block Diagram

Figure 20 – Hand crank flashlight

This circuit is composed of five parts. First there is an AC generator, outputting AC voltage. Next, the full bridge rectifier converts the AC voltage to DC. The smoothing capacitor gets rid of any ripple voltage present in the output of the bridge rectifier. The voltage regulator then takes the DC output voltage of the capacitor and steps it up or down to about 5 Volts to be stored in the final component, the power bank.

5.1b DC Generator Experiment Set Up

In order to regulate the output of our 19:1 DC gear motor we connected the output of the generator to the 5V step up / step down voltage regulator. The output of the voltage regulator was then connected to the power bank. This flow is seen below in Figure 21.

Figure 21 – DC generator regulating circuit block diagram

We used a second DC motor and spring shaft in order to drive our 19:1 DC gear motor. Figure 22 below shows a picture of the DC motor set up. The shaft of the DC generator was able to turn on average about 180 RPM, taking into account the 19:1 gear ratio, the generator spun at about 3,420 RPM.

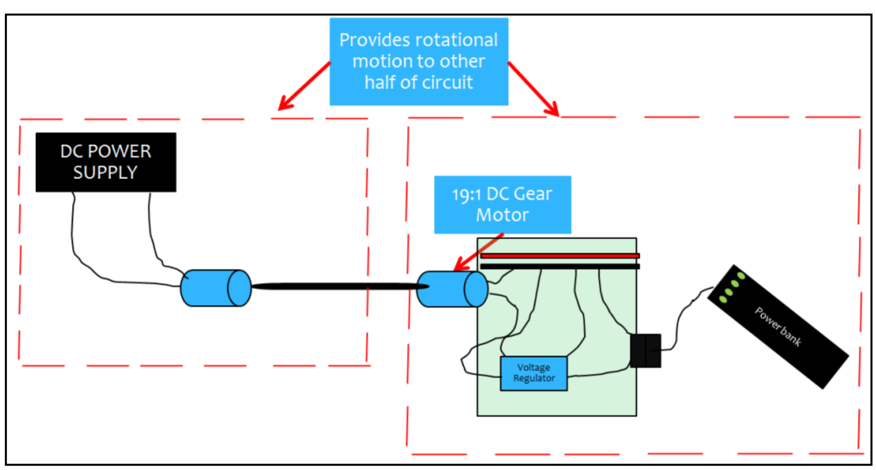

Figure 22 – Method used to drive DC generator

It is noteworthy to notice there is a huge difference (greater than a factor of three) between the RPM the DC generator spins at versus the RPM the AC generator spins at. This difference will affect the performance results for the AC generator and the DC generator.

5.1c Generator Results

In order to test both the AC and DC motors we looked specifically at the power going into the voltage regulator and the power going into the load (the power bank). In order to calculate power we first found the voltage, with respect to ground, in the lead attached to the input of voltage regulator (Vin) using the multimeter. Next we used a 0.08 Ω power resistor and the multimeter to find the current going into the voltage regulator input (Iin). Therefore, to find the power into (Pin) the regulator we multiplied the Vin x Iin. To find the power into our power bank load we performed the same process as before, except the measurements were taken from the output lead of our voltage regulator instead of the input lead.

Figure 23 below is a graph of the voltage with reference to ground before the regulator versus the average percent battery charge of the power bank for the AC generator and DC generator tests. The average percent batter charge is based on the data sheet for the power bank seen in Table 2. The table indicated that one lit LED corresponded to the power bank being charged between 20 and 40 percent, indicating an average charge of 30 percent. The second LED lights up when the power bank is between 40 to 60 percent charged, the third LED for 60 to 80 percent charged and the last LED will light up between 80 and 100 percent charged. The graph shows us that the average voltage before the regulator is always greater for the DC generator. When the power bank is between 20 and 30 percent charged the voltage before the regulator for the AC generator is 2.85 V, versus the DC motor which is 3.05 V.

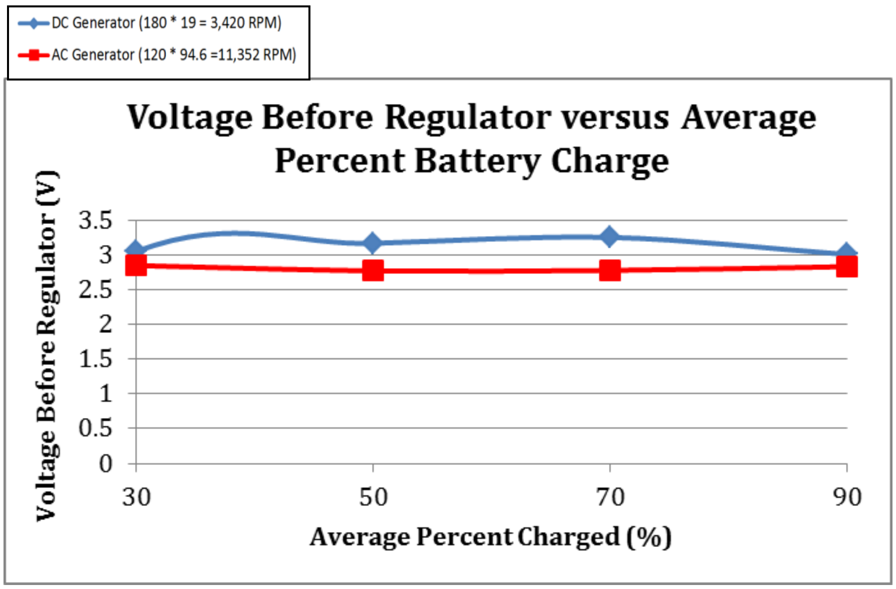

Figure 23 – Voltage before regulator vs. average percent battery charge

Figure 24 below shows the input current versus average percent battery charge of the power bank. The graph shows us that the average input current is always greater for the AC generator. When the power bank is between 20 and 40 percent charged the input current to the AC generator is 449.375 mA versus 259.375 mA for the DC generator.

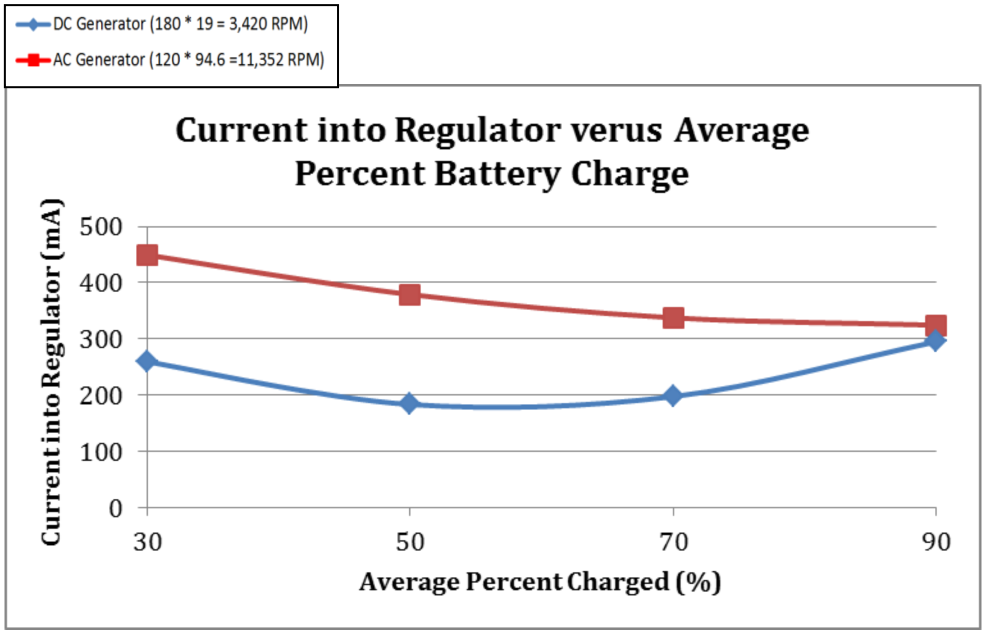

Figure 24 – Current into regulator vs. average percent battery charge

Figure 25 below shows the input power versus average percent battery charge of the power bank. The graph shows us that the average input power is always greater for the AC generator. When the power bank is between 20 and 40 percent charged the input current to the AC generator is 1278.472 mW versus 791.09 mW for the DC generator.

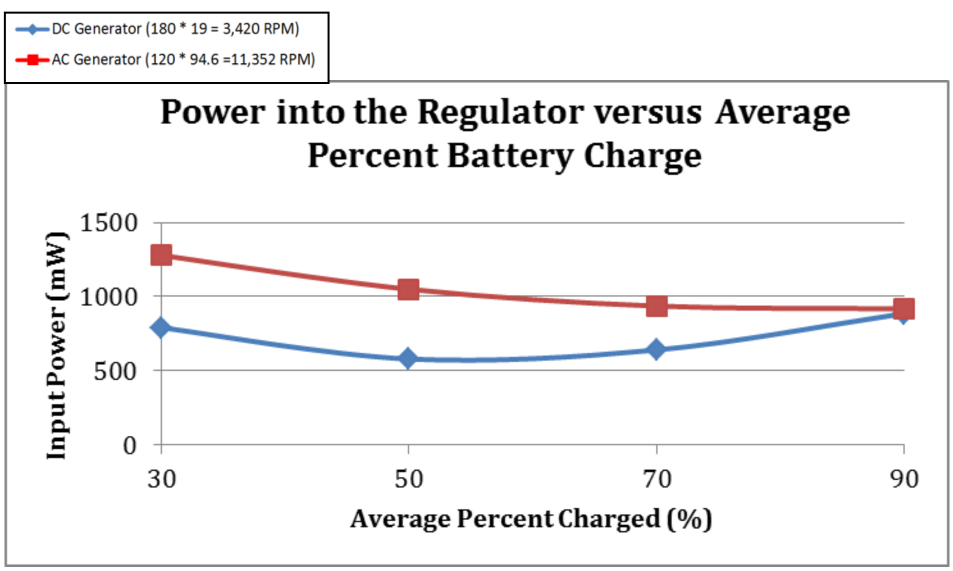

Figure 25 – Input power vs. average percent battery charge

Figure 26 below shows the load voltage versus average percent battery charge of the power bank. The graph shows us that the average load voltage is always greater for the AC generator. When the power bank is between 20 and 40 percent charged the input current to the AC generator is 4.06 V versus 3.895 V for the DC generator.

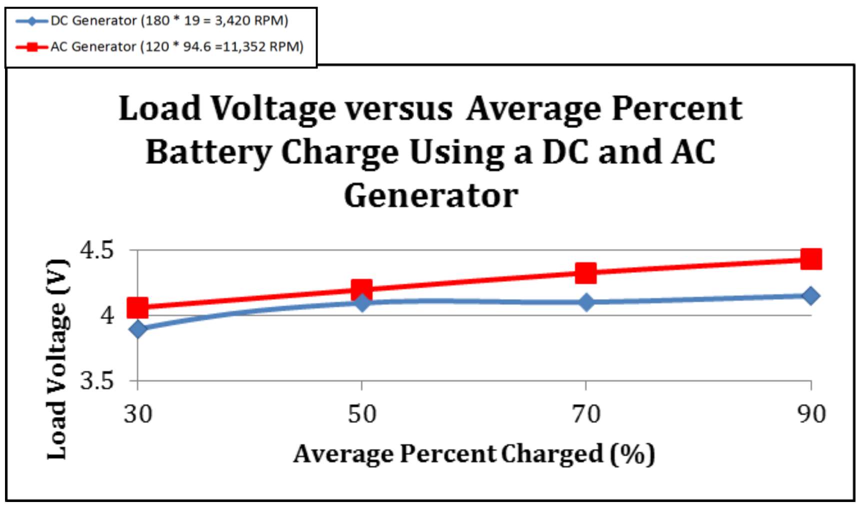

Figure 26 – Load voltage vs. average percent battery charge

Figure 27 below shows the current going into the load versus average percent battery charge of the power bank. The graph shows us that the average load current is always greater for the AC generator. When the power bank is between 20 and 40 percent charged the input current to the AC generator is 230 mA versus 151.75 mA for the DC generator.

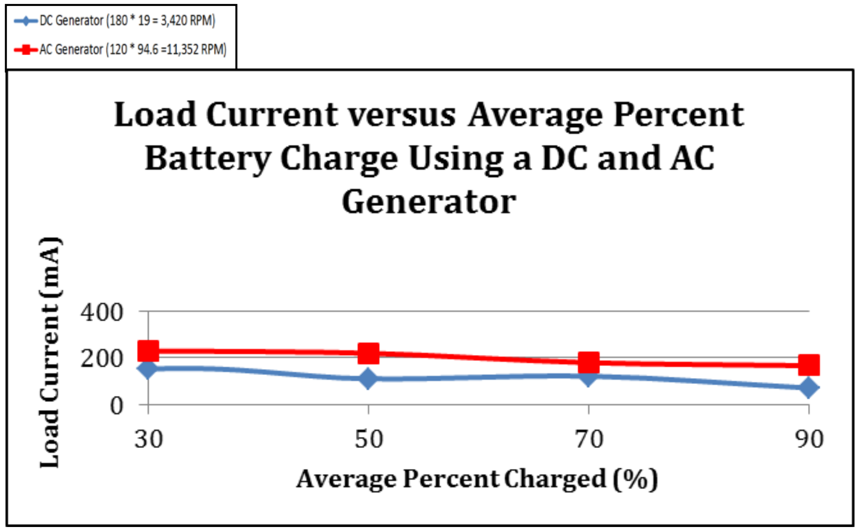

Figure 27 – Load current versus average percent battery charge

Figure 28 below shows the current going into the load versus average percent battery charge of the power bank. The graph shows us that the average load current is always greater for the AC generator. When the power bank is between 20 and 40 percent charged the input current to the AC generator is 933.8 mW versus 605.483 mW for the DC generator.

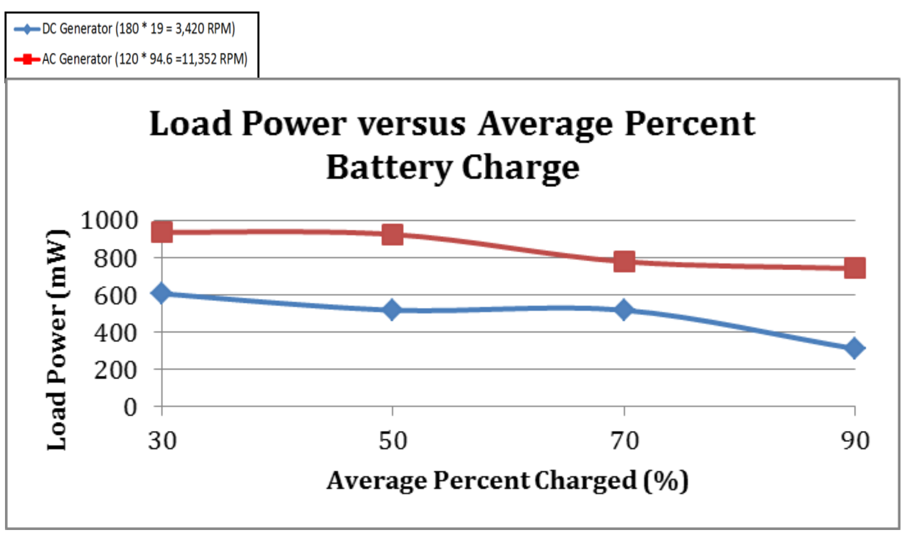

Figure 28 – Load power versus average percent battery charge

Figure 29 below shows the electrical efficiency versus average percent battery charge of the power bank. Electrical efficiency is defined as power out (load power) divided by power into the regulator. The graph shows us that the average electrical efficiency is relatively similar for the AC and DC generators expect for when the power bank is almost 100% charged. When the power bank is between 20 and 40 percent charged the AC generator efficiency is 73.04 percent, versus 76.54 percent for the DC generator. When the power bank is between 80 and 100 percent charged the AC generator efficiency is 80.62 percent, versus 35.08 percent for the DC generator.

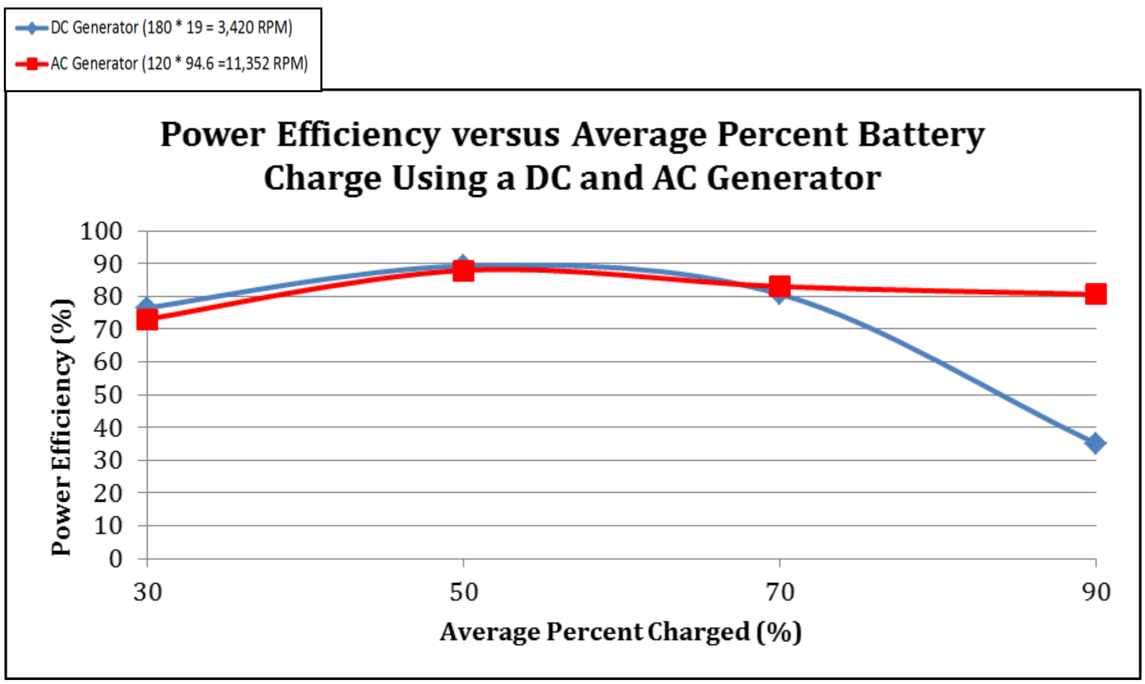

Figure 29 – Electrical efficiency versus average percent battery charge

After doing some preliminary charging with the AC generator for about 1 hour we were able to get one of the LED indicators on the power bank to light up, however after two hours of charging via the DC generator we were not able to get any indicator LED's to light up. Based on all of the results we found we chose to move forward with the AC generator rather than the DC generator. We chose the AC generator because on average the power delivered to the load was always greater than the power delivered to the load by the DC generator. Because we are charging via a 5 V USB port we wanted to choose the generator that produces a load voltage closest to 5 V. We also needed to choose the generator that produces the most electrical power. The AC generator satisfies both of these needs as is seen in the figures above.

It is noteworthy to mention that while performing these teste we found that there was some error caused by using the multitier to calculate current into and out of the voltage regulator. This error may contribute to the significant difference in electrical efficiency between the DC and AC motor when the power bank is almost 100 % charged.

5.1d AC Hand Crank Charging Results

After measuring the power in and out of the regulator we used the AC generator attached to the hand crank to see how long it would take to get the power bank LED indicators to light up. As seen in Table 9 below it took about 15 minutes to get the first LED to light up, meaning 15 minutes to get the power bank charged between 20 and 40 percent. It takes about 7 hours and 45 minutes to charge the power bank between 80 and 90 percent. Table 9 below shows all of the results we obtained for charging the power bank.

Power Bank Percent Charged (%)	AC Motor
20 – 40	15 min.
40 – 60	2 hours 15 min.
60 – 80	4 hours 35 min.
80 – 100	7 hours 45 min.

Table 9 – Time to charge power bank with AC generator using hand crank

After charging the power bank to between 80 and 100 percent we wanted to see how long the power bank could power our small LED flashlight for. After 7 hours and 45 minutes of charging our flashlight was able to stay on for about 16 hours. After only 15 minutes of charging by hand we were able to get the flashlight to stay on for about 2 hours. Earlier in our report we talked about how a fully charged LED can provide about 2 hours of light. The first half of our initial goal for the UWash was to be able to fully charge the LED flashlight after 1 hour of charging. Based on our results for powering the LED flashlight the final UWash system is definitely capable of accomplishing this goal. Table 10 below shows the results we obtained for powering the flashlight using the charged power bank.

Power Bank Percent Charged (%)	Duration of time flashlight stays on for (hours)
20 – 40	2
40 – 60	5
60 – 80	10+
80 – 100	16+

Table 10 – Length of time power bank can power flashlight for

After charging the power bank a second time to between 80 and 100 percent we wanted to see how much our power bank could increase the charge of a fully dead iPhone to. After about 7 hours and 45 minutes of charging we were able to increase the charge of our iPhone to about 41 percent. After only 15 minutes of charging by hand we were only able to charge our iPhone to 5 percent. The second half of our goal for the complete UWash system was to be able to increase the charge of a dead iPhone to at least 50 percent after a 6 hour use. Based on these results the final UWash system is not capable of charging an iPhone to 50 percent after a 6 hour use because after almost an 8 hour use the hand crank AC generator could only increase the charge of a dead iPhone to 41 percent. Table 11 below shows the results we obtained for charging an iPhone 5S using the charged power bank.

Power Bank Percent Charged (%)	Percent increase in iPhone Charge (%)
20 – 40	5
40 – 60	11
60 – 80	26
80 – 100	41

Table 11 – Percent charge power bank can increase a 0 percent initially charged iPhone to

5.1e Simulated AC and DC Circuits

We used Multisim to simulate the AC and DC testing circuits. The regulator used in both simulations seen in Figures 30 and 31 below is a linear voltage regulator which contributes to errors in our simulation because we chose to implement a switch mode voltage regulator in our actual system. In addition to this error, it is not accurate to simulate a generator with a constant DC or AC source. The results verified that the AC generator would produce the output that would most efficiently charge the USB based power bank.

5.1e-1 AC Generator Simulation

In order to obtain the value for the magnitude of the AC generator we looked at the open circuit voltage of the AC generator, which is about 16 Volts, added 1.4 Volts to take into account two diodes in the full bridge rectifier (now 17.4V), then converted to VRMS making the final open circuit voltage 12.3 Vrms. To estimate the value of the frequency we used the formula:

*Frequency = { (# of Poles of AC Generator) * (Speed of Shaft in RPM) } / 120*
*Frequency = (2 * 11,352) / 120 = **189.2 Hz***

These values are seen below in Figure 30. The value for the load resistance (RL) was chosen based on preliminary results we collected. In these preliminary tests we attached load resistances of various values to the output of the voltage regulator. The load voltage that most closely matched the load voltage we found after connecting the power bank was 50 ohms. Therefore, we chose to use 50 ohms to model the load resistance of the power bank. In order to calculate the value of the source resistance (Rs) we looked at the data we obtained when the load (power bank) was connected to the AC generator. Specifically, we looked at the load voltage and input current into the voltage regulator. The output voltage was about 4.06 Volts. Adding 0.7 Volts to the load voltage, due to the 0.7 diode drop, we obtained the voltage just after the source resistance. Using ohms law we have the following: Rs= 17 V – 4.76 V / 450 mA = 28 Ω. The load voltage for the AC generator was very similar to the load voltage we obtained using the oscilloscope, which was just about 5 Volts.

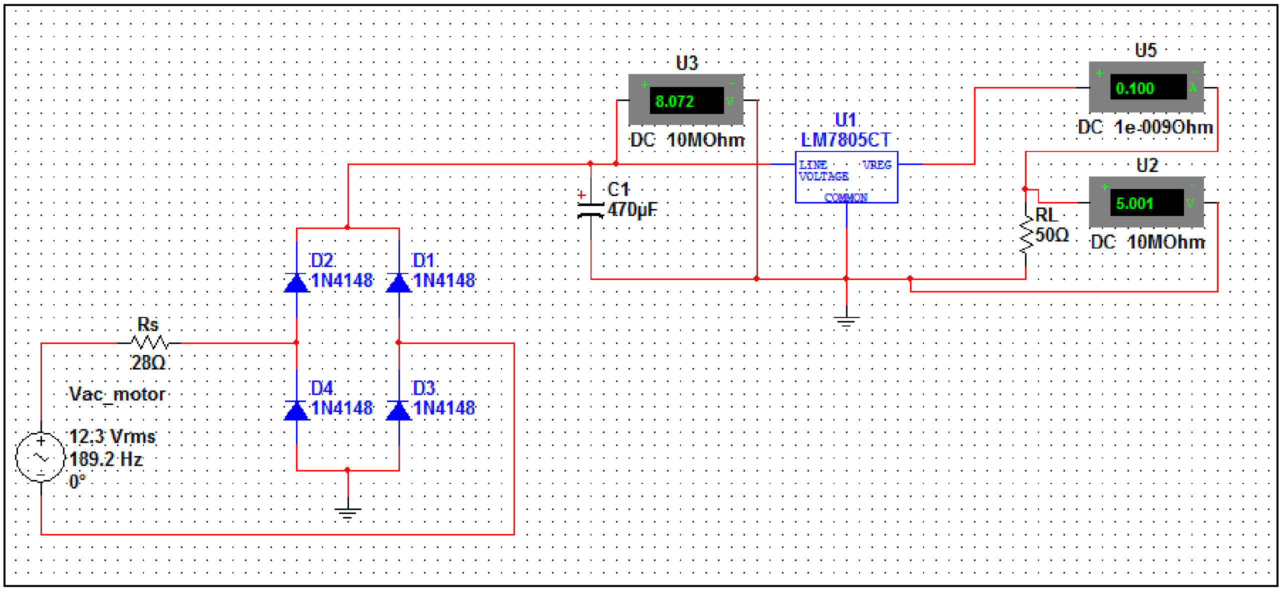

Figure 30 – Multisim simulation of AC generator charging circuit

5.1e-2 DC Generator Simulation

In order to obtain the value for the magnitude of the DC generator we looked at the open circuit voltage of the DC generator, which is about 4.9 Volts. These values are seen below in Figure 31. The value for the load resistance was also chosen based on the preliminary results we collected in which we attached load resistances of various values to the output of the voltage regulator. The load voltage that most closely matched the load voltage we found after connecting the power bank was 30 ohms. Therefore we chose to use 30 ohms to model the load resistance of the power bank. In order to calculate the value of the source resistance (Rs) we also looked at the data we obtained when the load (power bank) was connected to the DC generator. Specifically, we looked at the load voltage and input current into the voltage regulator. The output load voltage was about 3.99 Volts. So, using ohms law we have the following: Rs = 4.9V – 3.99 V / 259.38 mA= 3.5 Ω. The value for the load voltage we obtained was much lower than that for the AC generator simulation and also in practice using the millimeter. This difference helps explain why after 15 minutes of charging with the AC generator we are able to get one of the LED indicators on the power bank to light up, but after 2 hours we couldn't get any indicators to light up for the DC generator.

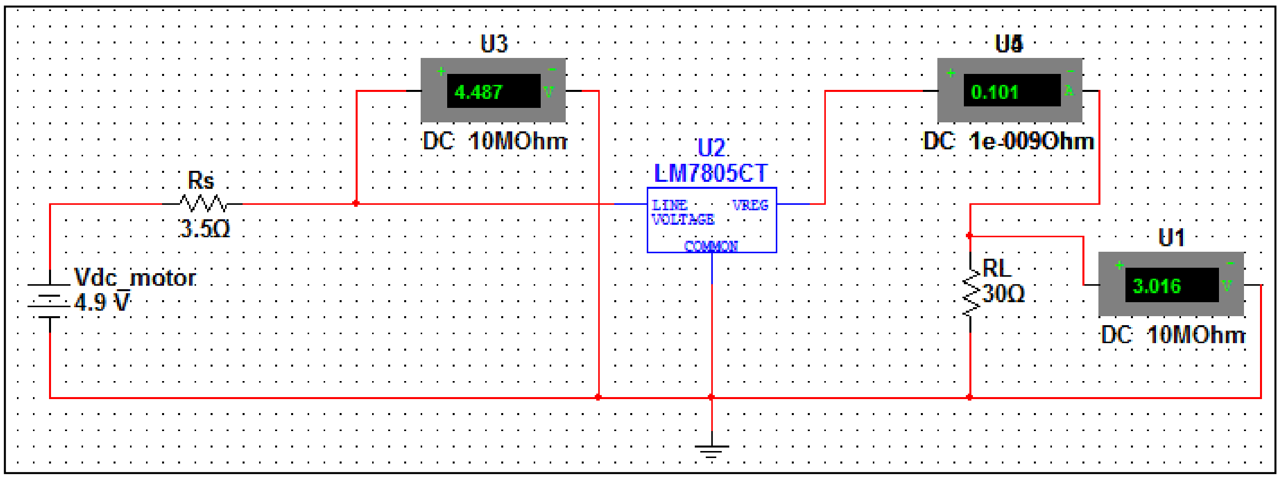

Figure 31 – Multisim simulation of DC generator charging circuit

5.2 FINAL DESIGN

The final UWash system design is composed of five main components. There is the energy source (rotational motion from a salad spinner), the energy harvester (AC generator from a hand crank flashlight), a regulating interface circuit (full bridge rectifier, smoothing capacitor, and a 5 V step up/step down switch mode voltage regulator), a storage component (rechargeable lithium ion batteries), and the application (a small LED micro USB flashlight and an iPhone). Figure 32 below shows a picture of the final UWash system design. The basic idea of the system is that as you turn the UWash handle you wash clothes and create electrical energy via the energy harvester, which is then regulated, stored and ready to be used for application.

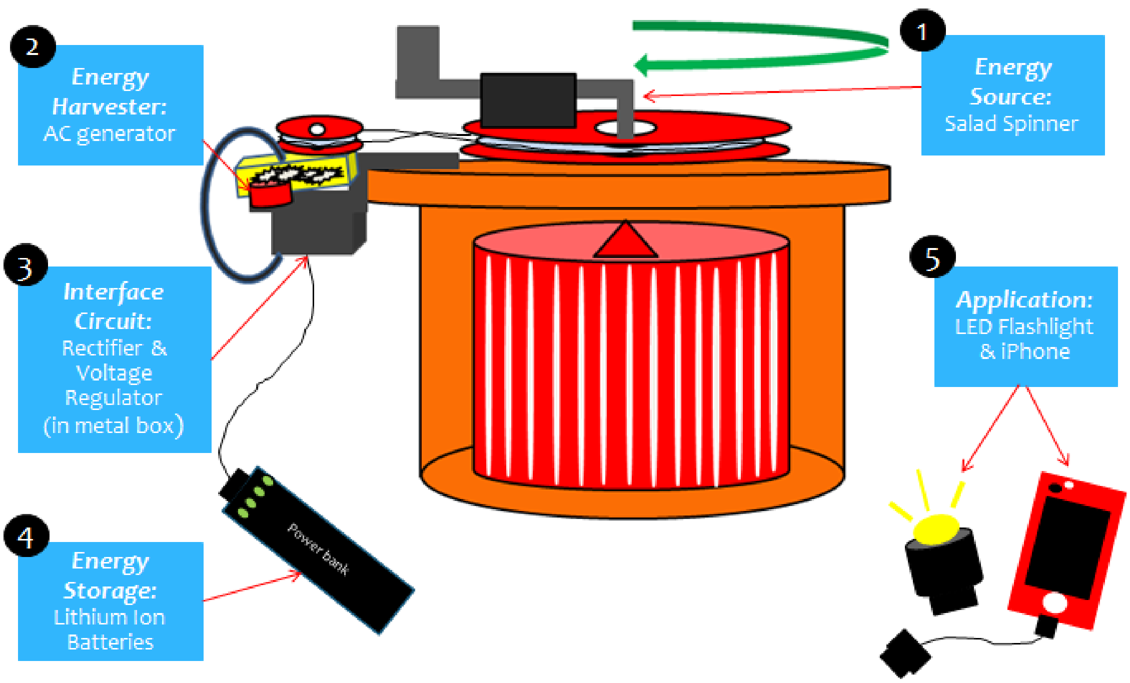

Figure 32 – Final UWash System Design

5.2a Energy Source

The energy source of the UWash comes from the rotational motion of a 5 gallon salad spinner. The salad spinner basically consists of a lid, an outer bucket, and an inner bucket. The lid attaches to a 0.1m long handle that spins the inner bucket via a gear system. The salad spinner can hold a maximum of 4 gallons of water to wash clothes with. Putting too much water in the salad spinner causes water to splash from the inside and also makes turning the handle too difficult. The rotational motion of the salad spinner is the mechanical energy that is later converted to electrical energy via our chosen energy harvester.

To utilize the rotational motion of the salad spinner we created a 5.2:1 pulley system that attaches to both the salad spinner lid and energy harvester component. Both pulleys were created using three pieces of wood glued together using poxy glue. The three pieces of wood were cut precisely using a laser in the mechanical engineering department.

The large pulley attached to the salad spinner seen below in Figure 33 is 7.75 inches in diameter. This is the driver pulley in the UWash system. This pulley was sliced in half first in order to be able to fit onto the handle of the salad spinner. In order to get this pulley to spin with the rotational motion of the handle we created a part in Solid Works that attaches the handle to the pulley via screws. This part was created in the machine shop.

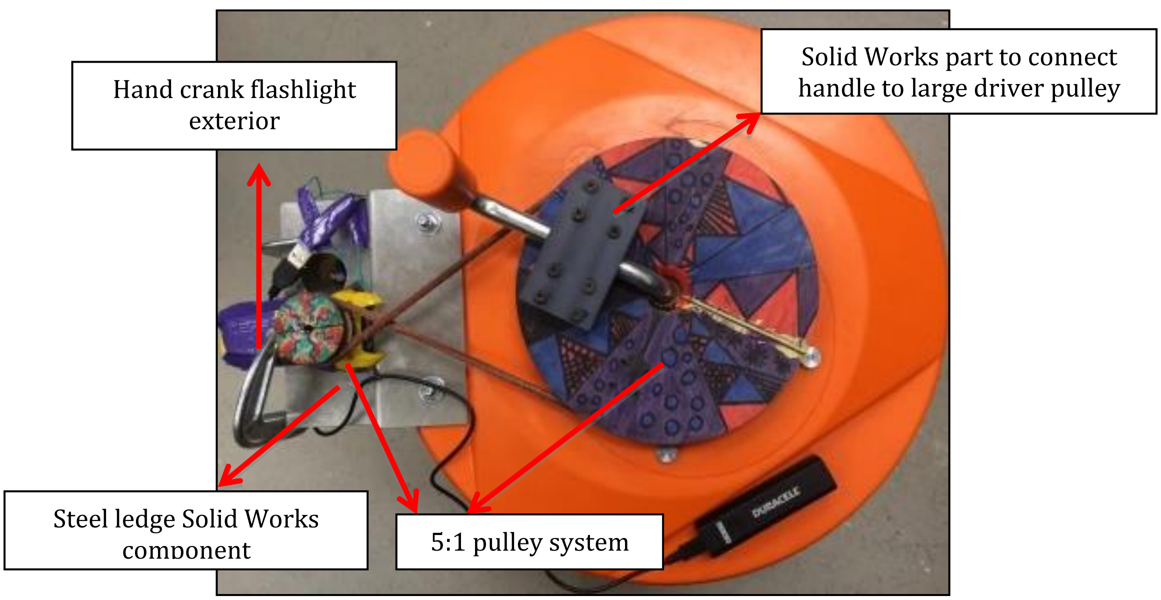

Figure 33 – UWash pulley system

The smaller driven pulley seen below in Figure 34 is the component that drives the energy harvester.

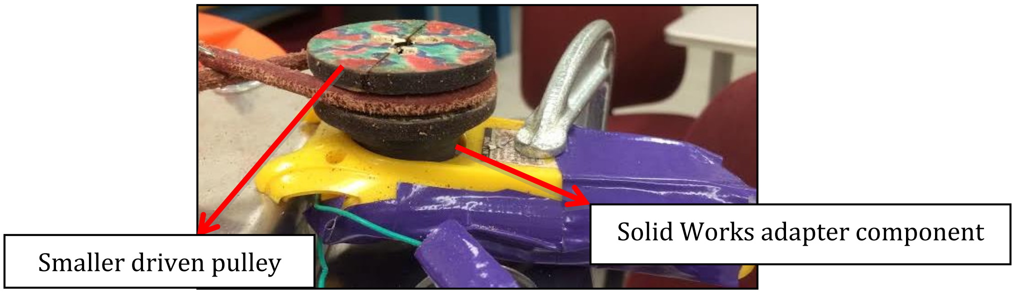

Figure 34 – Energy harvester pulley

This driven pulley is 1.5 inches in diameter and attaches to the first gear in the flashlights' gear train seen in Figure 35. In order to attach this pulley to the first gear in the hand crank flashlight we created a component in Solid Works that acts as an adapter between the pulley and the first gear. This adapter component was created in the machine shop.

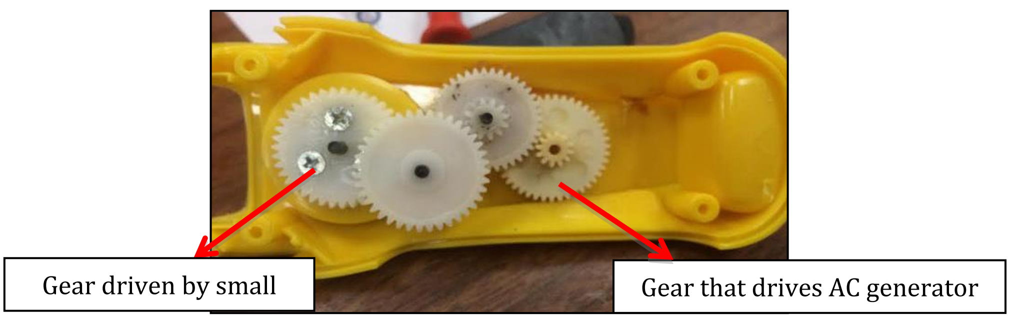

Figure 35 – Gear train in hand crank flashlight

The belt we used for our pulley system is made of leather and makes a figure 8 between the two pulleys. This design is not ideal because the figure 8 design creates friction between the two crossing components of the leather belt. However, we chose this design because it was the only way the leather belt seemed to create enough traction with the smaller driven pulley in order to get our system working. The general concept for the pulley system is the following: as the larger pulley turns, the smaller pulley turns, which in turn spins the gear train in the hand crank, which finally spins the shaft of the AC generator.

To hold the hand crank component (which contains the gear train and AC generator) we created a steel part in Solid Works to attach to the salad spinner. This part acts as a ledge so that the hand crank flashlight exterior can rest on it. This component was created in the machine shop. We used C-clamps to hold the hand crank component to the steel ledge component. The steel component is attached to the lid of the salad spinner via two screws and bolts.

5.2b Energy Harvester

The final energy harvester choice for the UWash was an AC generator from a hand crank flashlight seen below in Figure 36. This AC generator is rated at 8.2 to 9 Volts. We tested this AC generator as well as a 19:1 DC gear motor in order to see which harvester was the most efficient and compatible with the rest of the UWash system. The results are seen in section 6.1.

Figure 36 – AC generator in hand crank flashlight

The shaft of this AC generator is rotated by the gear train seen in the hand crank flashlight we dismembered seen in Figure 35. The gear train ratio in the hand crank flashlight is 94.6:1. If a person rotates the handle of the UWash at about 24 RPM, taking into account the 5:1 pulley system, the driven pulley that rotates the gear train in the hand crank flashlight rotates at about 120 RPM, and the actual shaft on the AC generator rotates at about 11,352 RPM.

5.2c Regulating Interface Circuit

The final energy harvesting interface regulation circuit included a rectifier, smoothing capacitor, and a switch mode voltage rectifier. The output voltage of our AC generator needed to be converted to 5 Volts DC in order to efficiently charge our chosen power bank, which charges via a 5V USB port. We used a full bridge rectifier composed of four 1N4148 diodes to rectify the AC voltage. Next, the output of the bridge rectifier needed to be smoothed out in order to eliminate any ripples and make the output a true DC voltage. We used a 470 µF smoothing capacitor for this component. The output of the smoothing capacitor was then connected to the 5V step up/step down voltage regulator chosen earlier in the project that can take a voltage between 2 and 30V and step it up or down to about 5V with 80% efficiency. The final DC voltage regulated output could then be connected to our power bank.

In order to conceal these electrical components from the water that is placed inside the UWash we put the circuit board inside an enclosure that sits under the steel ledge component discussed earlier.

5.2d Energy Storage

In order to connect the output energy of the regulating interface circuit to the energy storing power bank we needed to purchase a USB A female solder connector. We connected the output of our switch mode voltage regulator to the female USB solder connector, which then allowed us to simply plug in the male USB connector that comes with our power bank. The power bank can hold a maximum of 9.62 Watt hours of energy.

5.2e Application

The application of the UWash is the small LED rechargeable micro flashlight and an iPhone. The flashlight can hold 0.3 Watt hours of energy and can provide about two hours of light after a full charge. An iPhone can hold about 5.45 Watt hours of energy. Both of these devices can be charged via a USB port. In order to charge the LED flashlight you just have to unplug the power bank from the regulating circuit component and plug the USB port of the flashlight into the power bank. In order to charge your iPhone all you have to do is unplug the power bank as before and plug your iPhone charger into the power bank.

6. Performance Estimates and Results

6.1 TESTING RESULTS

After the final UWash was assembled we performed two basic exhaustive tests to see if the charging results measured up to the charging results we found using the AC generator hand crank test in section 5.1. Rotating the handle of the UWash for 15 minutes with four gallons of water, 5 soiled shirts, and soap to use as detergent, provides the LED flashlight with enough charge to stay on for about 1 hour. Rotating the handle of the

UWash for 15 minutes with nothing inside results in the LED flashlight staying charged for about 1 and a half hours. These results are seen in Table 12 below.

Laundry & Water Inside UWash?	Duration of time flashlight stays on for (hours) after 15 minute UWash use
YES	1
NO	1.5

Table 12 – Final testing results

There is a significant difference between how difficult it is to spin the handle of the UWash with versus without clothes and water. It is much harder to spin the handle when the UWash is filled with clothes, water, and detergent than it is when the UWash is empty. This explains why with no clothes and water inside the UWash we were able to power the flashlight for about half an hour longer. The number of RPM's a person can easily spin the handle at when there are clothes and water inside the UWash is smaller than the number of RPM's a person can spin the handle at with nothing inside.

6.2 MECHANICAL TO ELECTRICAL CONVERSION EFFICIENCY

In order to find the mechanical to electrical conversions efficiency of the UWash we must multiply the mechanical efficiency by the electrical efficiency. The mechanical efficiency is the mechanical power out of the generator divided by the mechanical power into the generator. The electrical efficiency is the electrical power delivered to the load (power bank) divided by the electrical power into the system (power coming out of the generator). Because the mechanical power out of the generator is the same as the electrical power into the system, the mechanical to electrical conversion efficiency becomes equal to the power delivered to the load divided by the mechanical power into the system. The mechanical power into the system is equal to the torque multiplied by angular speed. Torque is equal to force times distance. We estimate the force on the 0.1 m long salad spinner handle to be about 5 Newtons. The angular speed of the AC motor is equal to 2 π x RPM / 60. The AC generator handle rotates about 120 times, so the angular speed is about 12.6 radians/sec. After multiplying the torque times the angular speed we get a value of 6.3 Watts. We used the data we obtained for the electrical power out (power into the load) to obtain the values seen below in Table 13.

Average (%) Battery Charge	Mechanical : Electrical Conversion Efficiency (%)
30	14.8
50	14.6
70	12.3
90	11.8

Table 13 – Mechanical to Electrical Conversion Efficiency

7. Production Schedule

I break the production schedule down into 8 week periods as seen in Table 14. The first week was spent doing preliminary tests with the DC and AC generators to see how different load sizes influenced the output of the AC and DC generators. The results found in this week are seen in section 4.4.

Week two consisted of constructing the pulley system as well as designing the Solid Works part to make the pulley attached to the handle of the salad spinner to spin with the rotational motion of the salad spinner.

During week three we performed tests on the DC and AC generators in order to decide which one to implement in the UWash system. After obtaining data we analyzed it and created plots to better visualize it using Microsoft Excel. During this week we also used Multisim to simulate our DC and AC generator charging circuits in order to see how the results obtained compared the data we measured in testing.

Week four was spent using the AC generator charging circuit to charge the power bank to see how long it takes to fully charge as well as how long the power bank can power the flashlight with that charge. During this week we also began designing the pulley system that attaches to the Hand crank flashlight to spin the AC generator.

In week five we charged the power bank fully once more in order to see how much a hand charged power bank could increase the charge of a completely dead iPhone to.

Week 6 consisted of constructing the actual pulley to attach to the hand crank flashlight component as well as designing the Solid Works part to act as the adapter to hold the pulley to the actual hand crank flashlight. During this week we also tested the AC generator to see how clockwise and counter clockwise rotations affected the load voltage.

During week seven we designed the steel component to attach to the lid of the salad spinner. It is during this week in which the final UWash system was also assembled which consists of the pulley system and chosen AC generator.

Week eight consisted of testing the final UWash system to see how the performance compared to earlier tests done with just the hand crank and AC generator.

Week	Description of Production
1	• Performed preliminary tests on DC and AC motor with varying load sizes
2	• Constructed half of UWash pulley system (pulley attached to handle of salad spinner). • Designed one solid works part to be used to stabilize handle to pulley.
3	• Performed tests on DC and AC motor using the power bank as the load. • Analyzed DC and AC motor data and created scatter plots to visualize data. • Simulated AC and DC testing circuits using Multisim.
4	• Charged power bank to 100 % then drained it to see how long it can power flashlight for. • Began to design pulley system to spin AC generator
5	• Charged power bank to 100 then drained it to see how long it can power an IPhone for.
6	• Constructed half of UWash pulley system (pulley attached to hand crank for AC generator). • Designed one solid works part to be used to stabilize pulley to hand crank. • Tested AC generator with various RPM speeds.
7	• Created solid works part to attach a hand crank AC generator component to the side of the salad spinner. • Assembled final UWash pulley system.
8	• Tested final UWash system using water, dirty laundry and detergent.

Table 14 – Production Schedule

There are several recommendations that could be made in scheduling and planning of Project UWash. I would spend more time in 498 working on the mechanical side of the UWash so that more time in 499 could be better spent with the electrical testing. I would also spend at least two weeks doing final UWash testing, which means that the final project should have been assembled earlier in the term.

8. Cost Analysis

Because the UWash was designed to be implemented in a third world country it was necessary to purchase components that were cost effective compared to others in the market. In our original estimations seen in Table 15 we calculated that the total cost of the UWash system would be $ 205. The final cost of the UWash system seen in Table XX was actually $ 181.89, a difference of about 23 dollars. The most expensive component of the UWash taking up about 55 percent of the entire UWash cost was the salad spinner component.

Component	***Cost***
Salad Spinner	$ 100.93
Hand Crank Flashlight	$ 9.90
DC Motor	$ 24.95
Voltage Regulator	$ 14.95
Female USB Solder Connecter	$ 1.17
Power Bank	$ 29.99
Total:	**$ 181.89**

Table 15 – Cost analysis [35] –[40]

9. User's Manual

Project UWash was made for people who can lift at least up to 15 pounds in weight. The user manual consists of five main steps summarized below in Figure 37. The first step consists of filling your UWash with about half a pound of clothing and then taking it to the nearest water source. The UWash is capable of holding 4 gallons of water to wash laundry with safely. This step also consists of filling your UWash to the fill line inside with four gallons of water and the appropriate amount of detergent.

Now on to Step number 2. After filling your UWash with water and laundry, firmly grip your hands on the lid of the UWash and use your two feet grip the outside of the UWash. Turn the handle of the UWash clockwise or counter clock wise for about 15 minutes.

After 15 minutes continue on to step number three which consists of opening the lid of the UWash to see how dirty the laundry inside is. If the laundry inside is soiled, proceed to dump out the water inside and replace it with fresh water and detergent from the water source.

Step four consists of repeating steps 1 through 3 until the clothes inside the UWash are completely clean. Once your clothes are clean you can take them out to hang dry.

Step five occurs after all of your laundry has been cleaned. This step entails de-plugging the power bank from the UWash, then using it to charge the LED flashlight or an iPhone.

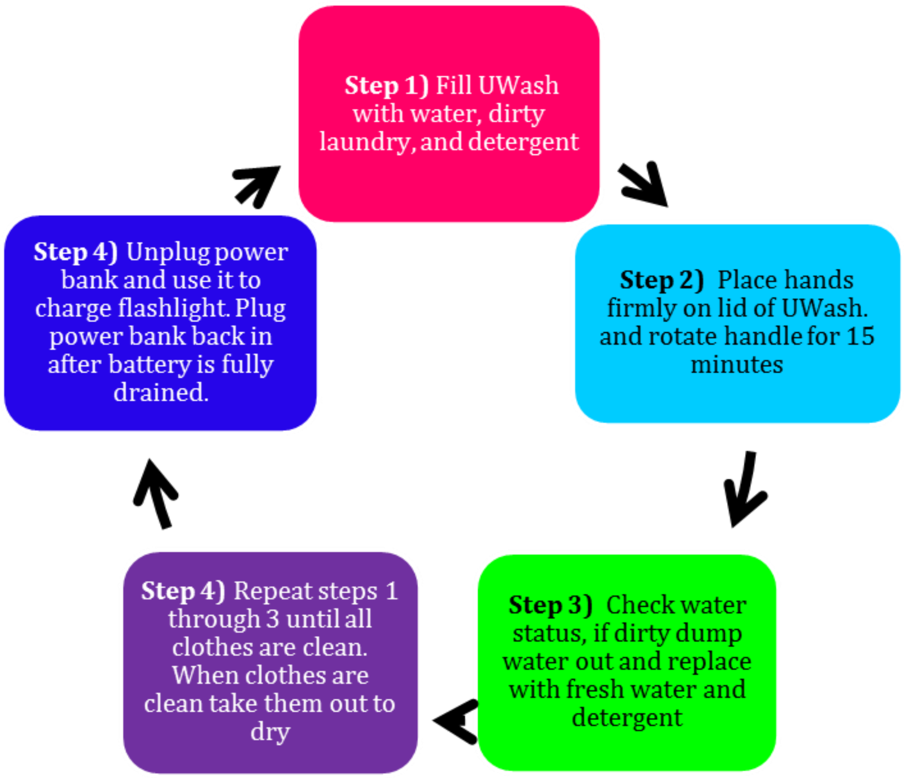

Figure 37 – UWash User Manual

10. Discussion, Conclusions, and Recommendations

Project UWash has greatly enhanced my personal views of issues faced by many members of third world countries. Many people living on our planet do not have luxuries like we have in America including electricity and access to fresh water supplies. The UWash was designed to utilize the mechanical efforts used by people in third world countries to wash their laundry and harvest it into usable electricity.

The initial goal for the UWash was to be able to charge the small LED flashlight fully after a one hour use and to be able to charge an iPhone to at least 50% after a 6 hour use. The fully charged LED flashlight can proved about 2 hours of light. After final testing the UWash is definitely capable of charging the flashlight fully after a one hour use since it was able to charge the flashlight to about 50% after a 15 minute use, providing about 1 hour of light. After the charging tests seen in section 5.1d we knew that the UWash is not capable of charging an iPhone to at least 60% after a 6 hour use because it took about 8 hours to get an iPhone charged to just 41%.

One important question we have considered for the UWash is how effective a salad spinner is as a washing machine. For a prototype the salad spinner was effective enough to get the soil out of the garments, however more testing should be done to test different types and amount of garments to see what the limitations of using a salad spinner as a washer are. We have also considered that the speed the UWash rotates the AC generator at may be too great for the generator to handle. However, this question could only be answered over a long period of UWash, but it is a pertinent question we have considered. In the future I would like to replace the current pulley system with a chain and sprocket system to reduce slippage that the pulley system comes with . I would also like to test other AC generators to see if another yields better charging results and a higher overall electrical efficiency. To make the UWash system more stable I would also replace the old hand crank flashlight exterior with a personally designed one so that it can be screwed to the salad spinner rather than held with C-clamps.

Overall this project has helped me learned how to take what once was just an idea, and effectively research, design, construct, and test a working prototype. I have gained such a variety of knowledge from completing this project. I have learned about third world countries, washing machines, energy sources, energy harvesters, charging circuits, storage elements, iPhones, USB charging, Solid Works, circuit simulations, and pulley designing.

In a way, my project was able to combine knowledge acquired from all three engineering department courses: electrical, bioengineering, and mechanical engineering. I am extremely thankful for the opportunity I have received and the knowledge I have gained through the completion of Project UWash.

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12. Appendices

12.1 DATA SHEETS

The data sheets for the salad spinner, diodes, capacitor, voltage regulator, DC generator, power bank and flashlight are included in this section.

12.1a Salad Spinner

Dynamic SD92 Description

SKU: 048-SD92

Standard Features and Benefits

- Replaces Chef Master 90005
- 5-gal. capacity - holds up to 8 heads of lettuce
- Manual spinner
- Outlet with hose for excess water to drain
- Hermetic gear system to help keep food from getting in gear area
- Overall Dimensions: 17-in. W x 17-in. D x 21-in. H

Manual salad spinner; dries up to 6-8 heads of lettuce; 5 gallon capacity; dries produce in minutes; 17" length x 17" width x 17" heigh

***The warranty will not be honored for residential or non-commercial use of any Commercial Equipment.**

12.1b Diodes

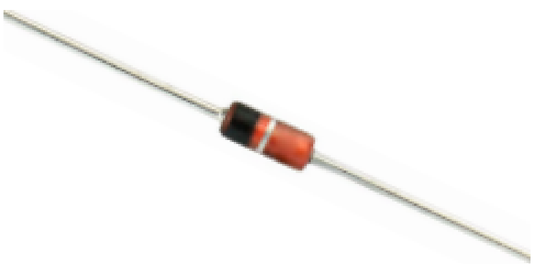
VISHAY.

www.vishay.com

1N4148

Vishay Semiconductors

Small Signal Fast Switching Diodes



FEATURES

- Silicon epitaxial planar diode
- Electrically equivalent diodes: 1N4148 - 1N914
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

RoHS COMPLIANT

HALOGEN FREE

APPLICATIONS

- Extreme fast switches

MECHANICAL DATA

Case: DO-35

Weight: approx. 105 mg

Cathode band color: black

Packaging codes/options:

TR/10K per 13" reel (52 mm tape), 50K/box

TAP/10K per ammopack (52 mm tape), 50K/box

PARTS TABLE

PART	ORDERING CODE	TYPE MARKING	INTERNAL CONSTRUCTION	REMARKS
1N4148	1N4148-TAP or 1N4148TR	V4148	Single diode	Tape and reel/ammopack

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
Repetitive peak reverse voltage		V_{RRM}	100	V
Reverse voltage		V_R	75	V
Peak forward surge current	t_p = 1 µs	I_{FSM}	2	A
Repetitive peak forward current		I_{FRM}	500	mA
Forward continuous current		I_F	300	mA
Average forward current	V_R = 0	$I_{F(AV)}$	150	mA
Power dissipation	l = 4 mm, T_L = 45 °C	P_{tot}	440	mW
	l = 4 mm, $T_L \leq$ 25 °C	P_{tot}	500	mW

THERMAL CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
Thermal resistance junction to ambient air	l = 4 mm, T_L = constant	R_{thJA}	350	K/W
Junction temperature		T_j	175	°C
Storage temperature range		T_{stg}	- 65 to + 150	°C

ELECTRICAL CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)

PARAMETER	TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
Forward voltage	I_F = 10 mA	V_F			1	V
Reverse current	V_R = 20 V	I_R			25	nA
	V_R = 20 V, T_j = 150 °C	I_R			50	μA
	V_R = 75 V	I_R			5	μA
Breakdown voltage	I_R = 100 μA, t_p/T = 0.01, t_p = 0.3 ms	$V_{(BR)}$	100			V
Diode capacitance	V_R = 0 V, f = 1 MHz, V_{HF} = 50 mV	C_D			4	pF
Rectification effiency	V_{HF} = 2 V, f = 100 MHz	η_r	45			%
Reverse recovery time	I_F = I_R = 10 mA, i_R = 1 mA	t_{rr}			8	ns
	I_F = 10 mA, V_R = 6 V, i_R = 0.1 x I_R, R_L = 100 Ω	t_{rr}			4	ns

TYPICAL CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)

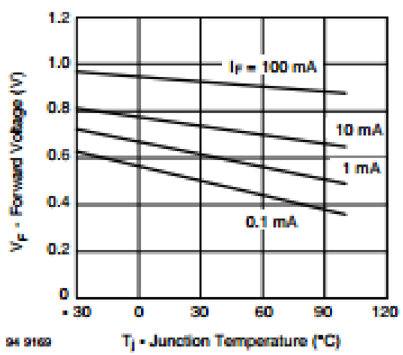


Fig. 1 - Forward Voltage vs. Junction Temperature

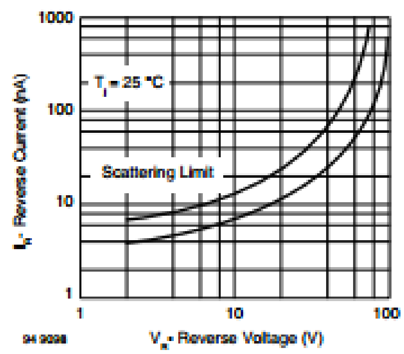


Fig. 3 - Reverse Current vs. Reverse Voltage

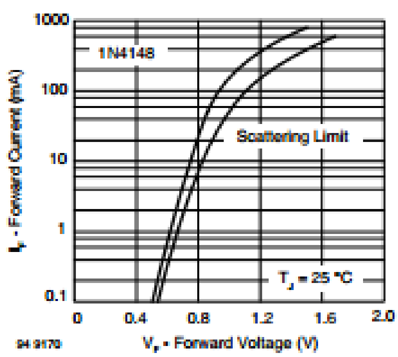
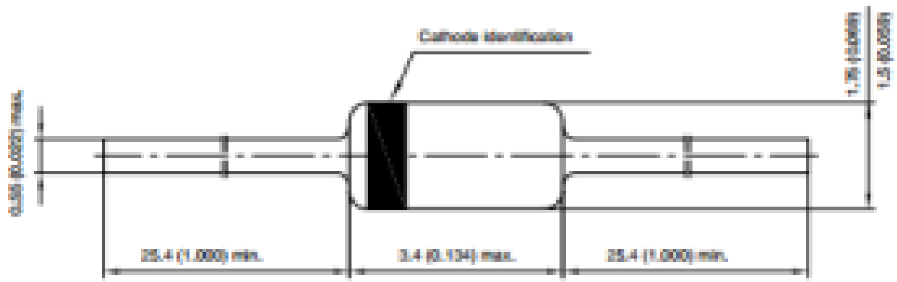


Fig. 2 - Forward Current vs. Forward Voltage

PACKAGE DIMENSIONS in millimeters (inches): **DO-35_02**



Document no.: 6.560-5004.12-4
Created - Date: 17. March 2008
21145

12.1c Capacitor

Electrolytic Capacitors

multicomp

LPR Series

Features:

- Material : Aluminium.
- Large size snap-In.
- LPR series large size capacitors with the specially designed terminals have "self-standing" and can be directly soldered to printed circuit boards without holders.
- They are easily to fixing to printed circuit boards due to the specially designed terminals.

Specification Table

No.	Item	Performance	
1	Operating Temperature Range	-40 to +85°C	-25 to +85°C
2	Rated Working Voltage Range	16 - 100 V dc	250 - 400 V dc
3	Nominal Capacitance Range	470 - 68,000 µF	47 - 2,700 µF
4	Capacitance Tolerance	±20% (at +20°C, 120 Hz)	
5	Leakage Current	I = 0.02 CV or 3,000 (µA) Max. Whichever is greater after 3 mins. I : Leakage Current (µA) C : Rated Capacitance (µF) V : Working Voltage (v)	
6	Dissipation Factor (tan δ) (120 Hz / +20°C)	See table below. Less than the value under table	
7	Characteristics at Low Temperature (Stability at 120 Hz)	Impedance Ratio at 100 Hz Z -25°C / Z 20°C : 3 Max. Z -40°C / Z 20°C : 12 Max.	

W V / µF	16	25 - 35	50 - 63	100	250	400
47 - 330	-	-	-	-	0.15	0.2
470 - 3,300	0.25	0.2	0.2	0.2		
4,700 - 6,800	0.35	0.3	0.3	0.25	-	-
10,000 - 22,000	0.4	0.35		-	-	-
27,000 - 47,000	0.45	0.4	0.35	-	-	-
56,000 - 68,000	0.5	0.45	-	-	-	-

Less than the value under table

Electrolytic Capacitors

LPR Series

multicomp

Case Size Table and Permissible Ripple Current (Case Size : ØD × L (mm))

Maximum Ripple Current : A (rms)

W V	Capacitors (µF)	Case Size	R C
100 (125)	2,700	30 × 36	3
	3,300	25 × 50	3.39
		30 × 41	3.27
	3,900	30 × 46	3.5
		35 × 37	3.3
	4,700	30 × 51	3.7
		35 × 42	3.5
	5,600	35 × 47	3.9
	6,800	35 × 50	4.85
	8,200	35 × 60	5.3
	10,000	35 × 70	5.49
		40 × 60	
250 (300)	120	20 × 30	0.9
		22 × 25	0.75
	150	20 × 30	1
		22 × 25	0.97
	180	22 × 26	1.1
	220	22 × 30	1.35
		25 × 25	1.09
	270	22 × 31	1.11
		25 × 25	1.05
	330	22 × 40	1.58
		25 × 31	1.42
	390	22 × 41	2
		25 × 36	1.85
	470	22 × 46	2.08
		25 × 41	1.93
	560	25 × 45	2.29
		30 × 36	2.22
	680	25 × 50	2.68
		30 × 40	2.46
	820	30 × 45	3.11
		35 × 40	2.83

12.1d Voltage Regulator

Electronics » Regulators and Power Supplies » Step-Up/Step-Down Voltage Regulators »

Pololu 5V Step-Up/Step-Down Voltage Regulator S18V20F5

Pololu item #: 2574 199 in stock

Price break	Unit price (US$)
1	**14.95**
5	13.46
25	12.33
100	11.21

Quantity: 1 Add to cart

backorders allowed Add to wish list

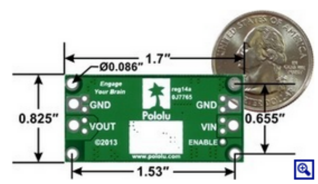
This powerful step-up/step-down regulator efficiently produces a fixed **5 V** output from input voltages between 3 V and 30 V while allowing a typical output current of up to 2 A when the input voltage is close to the output voltage and offering typical efficiencies of 80% to 90%. Its ability to convert both higher and lower input voltages makes it useful for applications where the power supply voltage can vary greatly, as with batteries that start above but discharge below the regulated voltage.

Select options: 5 V Go

Compare all products in Step-Up/Step-Down Voltage Regulators or S18V20x Step-Up/Step-Down Voltage Regulators.

Description **Specs (8)** **Pictures (12)** Resources (0) FAQs (0) On the blog (0)

Overview



These step-up/step-down regulators take an input voltage from 3 V to 30 V and increase or decrease it as necessary to produce a fixed 5 V, 6 V, 9 V, or 12 V output, depending on the version. They are switching regulators (also called switched-mode power supplies (SMPS) or DC-to-DC converters) with a single-ended primary-inductor converter (SEPIC) topology, and they have a typical efficiency between 80% and 90%. The available output current is a function of the input voltage, output voltage, and efficiency (see the *Typical Efficiency and Output Current* section below), but it will be around 2 A when the input voltage is close to the output voltage.

The S18V20x regulator family consists of the four fixed-output versions mentioned above along with two adjustable-output versions: the S18V20ALV offers an output range of 4 V to 12 V and the S18V20AHV offers an output range of 9 V to 30 V. The different versions of the board all look very similar, so the bottom silkscreen includes a blank space where you can add your own distinguishing marks or labels. This product page applies to all four fixed-output versions of the S18V20x family.

The flexibility in input voltage offered by these regulators is especially well-suited for battery-powered applications in which the battery voltage begins above the desired output voltage and drops below the target as the battery discharges. Without the typical restriction on the battery voltage staying above the required voltage throughout its life, new battery packs and form factors can be considered. For example:

- A 4-cell battery holder, which might have a 6 V output with fresh alkalines or a 4.0 V output with partially discharged NiMH cells, can be used with the 5V version of this regulator to power a 5 V circuit.
- A disposable 9 V battery powering a 5V circuit can be discharged to under 3 V instead of cutting out at 6 V, as with typical linear or step-down regulators.
- The 6V version of this regulator can be used to enable a wide range of power supply options for a hobby servo project.

The no-load quiescent will typically be between 1 mA and 5 mA for all possible combinations of input and output voltages (e.g. the quiescent current of the 12 V version is approximately 4 mA with 3 V in, 1.5 mA with 12 V in, and 1 mA with 30 V in). The ENABLE pin can be used to put the board in a low-power state that reduces the quiescent current to between 10 and 20 µA per volt on VIN (e.g. approximately 30 µA with 3 V in and 500 µA with 30 V in).

This regulator has built-in reverse-voltage protection, over-current protection, thermal shutdown (which typically activates at 165°C), and an under-voltage lockout that causes the regulator to turn off when the input voltage is below 2.5 V (typical).

For similarly powerful boost-only regulators, consider our U3V50x regulator family, which are typically more appropriate if you know that your input voltage will always be lower than your output voltage.

Features

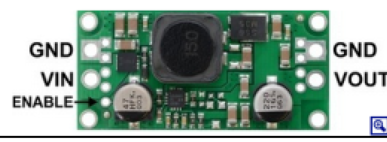
- Input voltage: 2.9 V to 32 V[1]
- Fixed 5 V, 6 V, 9 V, or 12 V output with 4% accuracy
- Typical maximum continuous output current: 2 A (when input voltage is close to the output voltage; the *Typical Efficiency and Output Current* section below shows how the achievable continuous output current depends on input and output voltages)
- Integrated reverse-voltage protection (up to 30 V), over-current protection, over-temperature shutoff, and under-voltage lockout
- Typical efficiency of 80% to 90%, depending on input voltage, output voltage, and load
- Four 0.086″ mounting holes for #2 or M2 screws
- Compact size: 1.7″ × 0.825″ × 0.38″ (43 × 21 × 10 mm)
- Smaller holes for 0.1″ header pins and larger holes for terminal blocks offer several options for connecting to the board

[1] 32 V is the absolute maximum operating voltage; the recommended maximum operating voltage is 30 V, which is the limit of the reverse voltage protection.

Using the regulator

Connections

This step-up/step-down regulator has four connections: input voltage (VIN), ground (GND), and output voltage (VOUT), and ENABLE.



The input voltage, VIN, should be between 2.9 V and 32 V. Lower input voltages can cause the regulator to shut down or behave erratically; higher input voltages can destroy the regulator, so you should ensure that noise on the input is not excessive. 32 V should be treated as the absolute maximum input voltage. Our recommended maximum operating voltage is 30 V, which is the limit of the reverse voltage protection.

The regulator is enabled by default: a 100 kΩ pull-up resistor on the board connects the ENABLE pin to reverse-protected VIN. The ENABLE pin can be driven low (under 0.7 V) to put the board into a low-power state. The quiescent current draw in this sleep mode is dominated by the current in the pull-up resistor from ENABLE to VIN and by the reverse-voltage protection circuit, which will draw between 10 µA and 20 µA per volt on VIN when ENABLE is held low (e.g. approximately 30 µA with 3 V in and 500 µA with 30 V in). If you do not need this feature, you should leave the ENABLE pin disconnected. Note that the SEPIC topology has an inherent capacitor from input to output; therefore, the output is not completely disconnected from the input even when the regulator is shut down.

Pololu fixed step-up/step-down voltage regulator S18V20Fx with included optional terminal blocks and header pins.

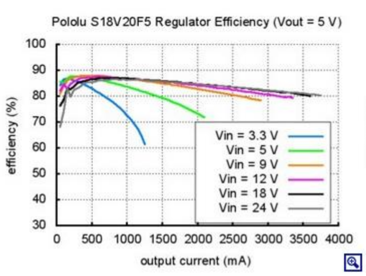
Pololu fixed step-up/step-down voltage regulator S18V20Fx, assembed with included terminal blocks.

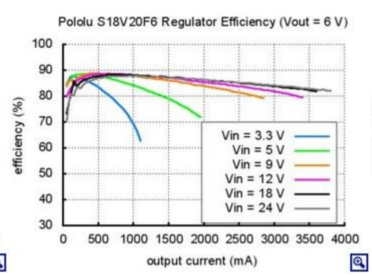
The connections are labeled on the back side of the PCB, and the board offers several options for making electrical connections. You can solder the included 2-pin 5mm-pitch terminal blocks to the two pairs of larger holes on the ends of the board. Alternatively, if you want to use this regulator with a solderless breadboard, 0.1″-pitch connectors, or other prototyping arrangements that use a 0.1″grid, you can solder pieces of the included 9×1 straight male header strip to the 0.1″-spaced smaller holes (each large through-hole has a corresponding pair of these smaller holes). For the most compact installation, you can solder wires directly to the board.

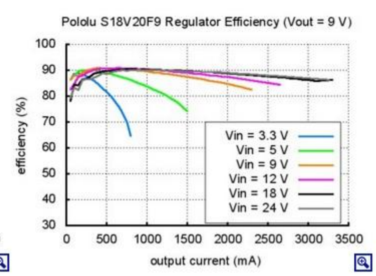
The board has four 0.086″ mounting holes intended for #2 or M2 screws. In applications where mounting screws are not used and wires are soldered directly to the board, the insulated part of the wires can be passed through the mounting holes for strain relief. The picture above shows an example of this with 20 AWG wire, which was close to the limit of what would fit through the mounting holes.

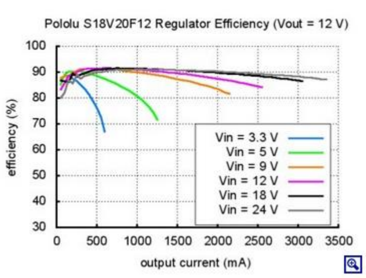
Typical efficiency and output current

The efficiency of a voltage regulator, defined as (Power out)/(Power in), is an important measure of its performance, especially when battery life or heat are concerns. As shown in the graphs below, these switching regulators have an efficiency of 80% to 90% for most combinations of input voltage, output voltage, and load.



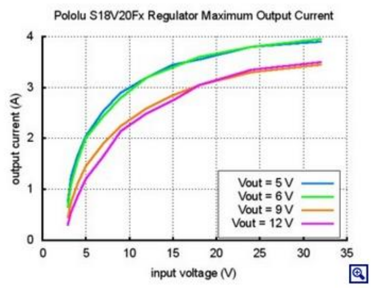






We manufacture these boards in-house at our Las Vegas facility, which gives us the flexibility to make batches of regulators with customized components to better meet the needs of your project. For example, if you have an application where the input voltage will always be below 20 V and efficiency is very important, we can make these regulators a bit more efficient at high loads by replacing the 30V reverse voltage protection MOSFET with a 20V one. We can also customize the set output voltage. If you are interested in customization and want at least a few dozen units, please contact us.

The maximum achievable output current of the board varies with the input voltage but also depends on other factors, including the ambient temperature, air flow, and heat sinking. The graphs below show output currents at which this voltage regulator's over-temperature protection typically kicks in after a few seconds. These currents represent the limit of the regulator's capability and cannot be sustained for long periods, so the continuous currents that the regulator can provide are typically several hundred milliamps lower.



During normal operation, this product can get hot enough to burn you. Take care when handling this product or other components connected to it.

Dimensions

Size:	0.825" × 1.7" × 0.38"[1]
Weight:	7.5 g[2]

General specifications

Minimum operating voltage:	2.9 V
Maximum operating voltage:	32 V[3]
Maximum output current:	2 A[4]
Output voltage:	5 V
Reverse voltage protection?:	Y[5]
Maximum quiescent current:	5 mA[6]

12.1e DC Generator

Motors and Gearboxes » Pololu Metal Gearmotors » 37D mm Gearmotors »

19:1 Metal Gearmotor 37Dx52L mm

Pololu item #: 1102 **0** in stock

Price break	Unit price (US$)
1	**24.95**
10	21.20
50	18.66

Quantity: 1 Backorder

backorders allowed Add to wish list

This 2.05" × 1.45" × 1.45"gearmotor is a powerful brushed DC motor with **18.75:1** metal gearbox intended for operation at 12 V. These units have a 0.61"-long, 6 mm-diameter D-shaped output shaft. This gearmotor is also available with an integrated encoder.

Key specs at **12 V**: 500 RPM and 300 mA free-run, 84 oz-in (5 kg-cm) and 5 A stall.

Overview

This powerful brushed DC gearmotor is available in six different gear ratios. Versions with an integrated quadrature encoder are also available, including just the motor and encoder portion by itself (no gearbox).

Gear Ratio	No-Load Speed @ 12 V	Stall Torque @ 12 V	Stall Current @ 12 V	With Encoder	Without Encoder
1:1	11,000 RPM	5 oz-in	5 A	motor without gearbox	
19:1	500 RPM	84 oz-in	5 A	37Dx52L mm	37Dx52L mm
30:1	350 RPM	110 oz-in	5 A	37Dx52L mm	37Dx52L mm
50:1	200 RPM	170 oz-in	5 A	37Dx54L mm	37Dx54L mm
70:1	150 RPM	200 oz-in	5 A	37Dx54L mm	37Dx54L mm
100:1	100 RPM	220 oz-in	5 A	37Dx57L mm	37Dx57L mm
131:1	80 RPM	250 oz-in	5 A	37Dx57L mm	37Dx57L mm

These motors are intended for use at 12 V, though in general, these kinds of motors can run at voltages above and below the nominal voltage (they can begin rotating at voltages as low as 1 V). Lower voltages might not be practical, and higher voltages could start negatively affecting the life of the motor.

Details for item #1102

Exact gear ratio: $\frac{25 \times 30 \times 30}{10 \times 10 \times 12} = \mathbf{18.75:1}$

Dimensions

Size:	37D x 52L mm
Weight:	6.7 oz
Shaft diameter:	6 mm

General specifications

Gear ratio:	19:1
Free-run speed @ 6V:	256 rpm[1]
Free-run current @ 6V:	250 mA[1]
Stall current @ 6V:	2500 mA[1]
Stall torque @ 6V:	42 oz·in[1]
Free-run speed @ 12V:	500 rpm
Free-run current @ 12V:	300 mA
Stall current @ 12V:	5000 mA
Stall torque @ 12V:	84 oz·in

12.1f Power bank

Duracell® Portable Power Bank With 2600mAh Battery, Black

★★★★★ 6 Reviews Item # 408067 OfficeMax # 24907291

Charge your mobile devices on the go, with no outlet needed

- Power bank utilizes an internal battery to store a charge from any standard wall outlet.
- Charge and sync cables included.

Item #	408067
Manufacturer #	PRO509
battery type	lithium-ion
battery capacity	2600 mAh
average charging time	2.5 hours
automatic shut-off	yes
charger type	USB
warranty length	1-year limited
brand name	Duracell
manufacturer	ESI
model name	PRO509
postconsumer recycled content	0%
total recycled content	0%
wattage	9.62 watts

12.1g LED Flashlight

A TINY LIGHT TO GUIDE YOUR WAY

We often wonder where we'll be when the news of the zombie outbreak hits. Will we be at home on a weekend with our families or at work with our colleagues? As much as we love our families, we think our chances of survival are better at ThinkGeek HQ. We're collectively the most zombie-savvy and we're pretty heavily armed... with Airsoft pellets and Nerf... oh dear.

Convenient!

Got a blackout at the office? Zombies are on the way and you need to be ready? No problem! Just unplug your mini flashlight from your computer and you'll be ready to fight your way to secure the doors before the zombies break in. Tiny flashlight gives 2+ hours of light after a 1.5 hour charge. Slip it into your pocket before you go out to fight the darkness.

Product Specifications

- Tiny flashlight that charges via USB
- Perfect for blackouts at the office!
- White LED is 8000-12,000 mcd
- Made of durable ABS plastic, black
- Charges fully via USB cable (included) in 1.5 to 2 hours
- Light lasts 2+ hours before a recharge is needed
- Battery: Lithium-ion battery recharged via USB
- Dimensions: 0.87" diameter x 2.05" long