UNIVERSITY OF CENTRAL FLORIDA

Senior Design Project
Portable Solar Power Supply

Submitted to:
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EEL 4914
Senior Design II

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1.0 Summary

In today's society, many products are being developed to be portable and efficient. Also, many current portable products are being redesigned to be more portable while improving efficiency. As more products become more portable, the demand for portable power increases.

Due to the more apparent limitations of fossil fuels, solar energy is becoming more popular as the renewable energy source that could change the future. It is available in abundance and its usage does not harm the environment with greenhouse gas emissions.

Developing a portable device that could capture this solar energy and supply it when needed is an invaluable solution to keeping up with the demand of portable devices. Also, a portable device that could provide power for non-portable devices that could be handy when used outdoors is of great significance. Examples of non-portable devices that can be handy when used outdoors are an electric fan, a projector to watch movies, a computer printer, and a microwave oven for people who want to heat up their food quickly.

The applications a portable solar power supply is very broad. It can be used to supplement a mobile home's fuel powered portable generator. It can be used to provide power to devices while camping outdoors. Examples of devices used while camping outdoors that will utilize a portable solar charger are: a flashlight light with a rechargeable battery, a radio, a television, and also the battery of the vehicle that is used for transportation.

The group's goal concerning supplying the demand for portable power is to develop a portable solar power supply device. The main idea of the groups' project is to develop a portable device that can capture solar energy efficiently and provide AC and DC power to support a wide range of devices.

The components that of this project that will be researched and developed by the group will have maximum power point tracking, solar tracking, and light weight can be carried around by the average individual, simple, user-friendly features, and the ability to charge multiple devices simultaneously.

2.0 Project Definition

2.1 Motivation

In today's society and continuing into the future, many appliances and devices are becoming smaller and more portable. Portability is a great thing provided that there is a portable power source that can provide sufficient power. Most portable devices run on batteries and also have a power supply for attachment to any 120/240 volt, 60/50Hz power outlet. The convenience of finding a power outlet can be a problem in certain situations when a portable device or appliance is low on power. For example, when

camping outdoors or even while fishing, chances of finding a power outlet can be very low. This can be helpful for convenience or at times in case of emergencies. It is not everywhere you can stop on the side of the road and charge your cell phone because your battery died on your vehicle, but the sun has a better probability of being there. Creating a portable power supply that can generate sufficient power for portable appliances and devices while it charges itself portably, is a complete and pure portable system independent of power outlets. Due to the more apparent limitations of fossil fuels, solar energy is becoming more popular as the renewable energy source that could change the future. It is available in abundance and its usage does not harm the environment with greenhouse gas emissions. From an ethical and moral point of view the group will try to save the worlds resources by relying on natural renewable energy versus using harmful fossil fuels. As current engineering students, we see that one of the best resources to use for energy is the sun. Here in Florida and many other states, there is no worry about not having any sunlight. By creating this project it would not only be a convenience or safety device, but in addition will help save the use of electricity at home.

The group members are personally motivated to implement and design this project after so many years of studying engineering concepts. This project will be able to give the group a chance to utilize all of their knowledge and skills learned at the university and elsewhere. The group has a genuine interest in building the solar portable power supply. Successfully creating and designing this project will be a motivation to being future engineers.

2.2 Goals and Objectives

Now that we have found a thought-provoking and thrilling project, there are many goals that the group will need to achieve. Portability and efficiency are a big focus in our project. There are multiple designs and ways of creating a portable solar panel. The group decided to differentiate our project from others by doing extensive research to familiarize what has been created. This led us to create specific goals that we put together after carefully analyzing our project. The goals are listed below:

- To create a portable power generation system that is easy to carry by an average individual
- To develop a portable system that can charge most portable appliances (AC and DC)
- The portable power supply must look user-friendly and be simple to use
- The portable power system must be able to charge more than one device simultaneously
- The charge ability of this device must be equivalent to the charging ability of any indoor power outlet
- This device must have a reasonable charging rate
- This device should be able to reduce electricity bills because many portable devices that are charged at home can be charged from this portable power supply

Now that we have explained our goals, the group came up with particular objectives. The objectives will describe numbers and specifics the group wants the solar power supply to obtain and achieve. The objectives are listed below:

- To convert 12 V DC to 120 V AC
- Capable of supplying 5 V DC for USB outputs
- The weight of the product should not exceed 20 lbs.
- The efficiency (Input power from solar panel to output power from outlet devices) should be at least 90 percent
- Maximum Power point tracking that will output the cells and apply the proper resistance (load) to obtain maximum power
- Horizontal rotation for solar panel mount

2.3 Functionality

This portable device charger is a pure portable device; it will not be recharged from a power outlet. The device charge is basically a briefcase with internal components, a solar panel attached to one of its larger sides, power outlets, and LCD screen. Most of the components that make up this device charger will be inside a briefcase. The power outlets on this device charger, the LCD screen, and the solar panel are the only external components. This device can charge up to four devices simultaneously. The portable solar power supply will be able to provide both DC and AC power to support portable DC and AC devices. This device comes with an LCD display that can measure voltage received from sunlight, measures the voltage in the battery of the device, and also notifies the user when the battery is charging. The maintenance of this device charger is very simple and can be performed by most individuals. Only the battery inside the charger needs to be replaced after number a years.

2.4 Tasks and Responsibilities

In order to get this project started, the group decided to split the project up into sections. The sections that were selected are the following, Solar Panel, Microcontroller adjusting position of PV, Charge Regulator, Microcontroller charging the battery, DC Regulator, DC/AC Regulator, and AC Regulator. Figure 2.4-1 below shows the initial block diagram that each individual group member chose to encounter.

Power from Solar Panel
- Amos
- David
- Peter

Microcontroller (MPPT)
- Peter

LCD Display
- Peter

Charge Regulator
- Peter

12 V Lead Acid Battery
- Amos

AC/DC Inverter
- Amos

DC/DC Converter
- David

Solar Panel Mount
- Amos
- David
- Peter

Microcontroller and Motor (Solar Tracking)
- David
- Peter
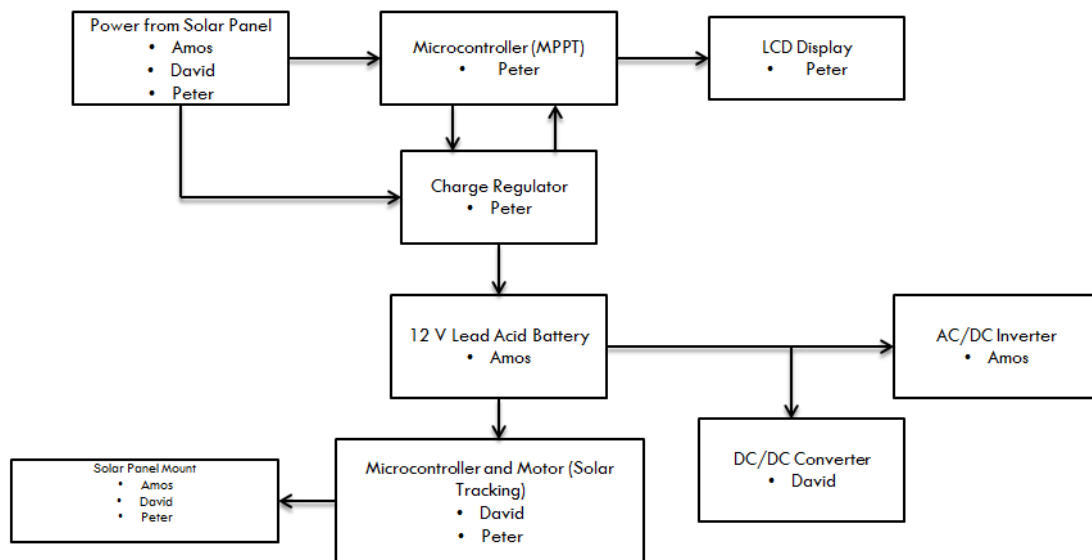
Figure 2.4-1: Function Block Diagram

The group came up with the responsibilities by what their interests in the project were. Each member chose their section, which luckily everyone had different desires in topics. Some group members decided to work together to help the project by having diverse styles of researching on particulars. Every team member had a responsibility to keep the team updated with an email on what they had worked on. Throughout the summer, we started to evaluate the full responsibilities and roles of each member. The group decided to all work on programming and the microcontrollers. The group had some minor changes, but this did help the research method work.

> **David**: DC/DC converter, DC Regulator, frame mounting, panel sensor, programming, microcontroller.

> **Peter**: LCD display, Charge Regulator, programming, microcontroller, Servo Motor

> **Amos**: Battery, AC/DC inverter, solar panels, AC Regulator, microcontroller

The group found a stable foundation of what each member was going to research. Researching the devices was one big part of their role, but also had to make sure certain terms were in line. Specific terms were agreed by all members, which are listed below.

1. Keeping the budget in mind while researching
2. Document and cite all research precisely
3. Weekly updates
4. Meeting twice a week in class or lab
5. Paper done by deadline: August 3, 2012
6. Easily reached

7. Following the laws of ethics

These guidelines and terms helped the group keep a motive for a good and organized senior design report. The group is now at the end of the semester, and each individual has achieved their tasks. The team as a group will have the responsibility to meet up a month before the project is due to start organizing the final paper. In addition to their specific parts, they will all work on the design, build, and testing sections of the final report.

2.5 Project Budget and Financing

The group had to now come up with the budget that is attractive to the group members and the near future customers that are willing to purchase. The group decided that a range from $600 to $800 would be in good consideration as of right now. This price range was prepared in the first two weeks of choosing the project. Not having the full knowledge or the present pricing of each device, may lead the group to be under or over calculating the prices. Once the group has done at least a full month of research, the accuracy of the price range will be on point. Table 2.5-1 displays some of the products and estimates that the group has come up with according to the price range mentioned above.

Parts	Price
Solar Panel	$175
Solar Panel Mount	$75
DC Motor	$30
Battery	$150
DC/AC Inverter	$25
DC/DC Converter	$10
Microcontroller	$70
AC Output	$10
DC Output	$15
AC Output	$5
Case	$20
LCD Display	$20
Total:	**$605**

Table 2.5-1: Budget and Financing

2.6 Project Milestone

Throughout the summer, the group is going to emphasize most of the focus on research. The group is going to search many reference sources in order to have the basic ideas of each component of the function block diagram. Searching is an imperative for any project. We have established that biweekly everyone shall need to provide an update and complete evolution and process of his work, so we can be on the same page and working with the same pace. The list of research is listed below:

Summer

- Research on new and improved solar panels
- All classes, functions, procedures, and methods for programming
- Design Dc/Ac Inverter
- Research the inputs and outputs of all regulators
- Design microcontroller
- Research all components needed to design the solar power supply. (Regulators)
- Final schematics of all components connected
- Order all parts chosen for our final design

The group decided to have a schedule for each part of the project. This was thought to be a good idea because the project would be done at a timely manner. The group held each one accountable to making sure their part was done according to the schedule. Each member held up to their responsibilities at a timely manner, which helped the report with organization. The schedule for the summer is shown in figure 2.6-1 below:

Task Name	Start	End	14-May	21-May	28-May	4-Jun	11-Jun	18-Jun	25-Jun	2-Jul	9-Jul	16-Jul
Initial Team Org.												
Choose Team Members	5/14	5/22										
Project Ideas	5/22	5/29										
Project Chosen	5/29	5/29										
Assigned Parts	6/5	6/5										
Research Topics												
Solar Panel	6/7	6/10		■								
DC/DC	6/12	7/14		■	■	■	■	■	■	■	■	
DC/AC	6/12	7/5		■	■	■	■	■	■	■		
Micro-controller	6/8	6/19				■	■	■				
LCD Display	6/13	6/18					■	■				
Charger Controller	6/13	6/20					■					
Battery	6/21	6/24						■	■			

Solar Panel Mount	7/10	7/14										🟧	🟧
Maximum Power Point Tracking	7/10	7/14										🟩	🟩
Legend													
🟦	David												
🟩	Peter												
🟪	Amos												
🟧	David /Peter												

Figure 2.6-1: Summer 2012 Schedule

Once the summer is over and all the research has been completed, the group will start the building process in the fall. Each member ordered their parts through the manufacture, so when the semester starts the parts will be starting to arrive. This will help speed up the process of testing, just in case the group runs into any type of issues. The team members decided to meet once through the break between semesters, to produce a schedule that will help the overall project with organization. The group will meet three times a week totaling 10 hours. The group will start to build each component individually, doing extensive testing and analyzing making sure the theoretically values match. By early November, the group will have all the components connected and ready for overall testing and design. The procedure outline is listed below:

Fall

- Build Design
- Make sure all components are working as planned
- Test design
- Observe our tested results
- Make adjustments if needed
- If adjustments are need make sure it fits the goals and specifications
- Prepare Presentation

3.0 Specifications and Requirements

The group has made a list of specifications that are good guidelines for the design to work properly. Each component of the design will have its own specific specifications that were given by the particular group member or members working on that device. Table 3.1-1 below shows the listed specifications and requirements for each device.

LCD Display	❖ 16*2 character ❖ Dot-matrix ❖ Backlit ❖ Low-power consumption
Battery	❖ 12 volt, 35Ah ❖ Must last for at least 2 hours with 2 dc devices charging simultaneously ❖ Must be able to last for at least 30 minutes while supplying a 120 volt AC voltage
Servo-motor	❖ Must be able to position the solar panel for maximum power point tracking ❖ Should not consume more than 5% of battery power to function ❖ Giant scale with metal gears ❖ Dual ball-bearing ❖ Water and dust resistant case ❖ Torque: 200oz/in at 6 volts ❖ Transit time: 0.28sec/60 degrees
Microcontrollers	❖ One to control the position of the solar panel ❖ One to control charging the battery ❖ Low power consumption
DC/AC inverter	❖ Very low power consumption ❖ Converts a 12 volt DC current into a 120 volt, 60Hz, pure sine wave voltage
DC/DC converter	❖ LT1912 -36V, 2A 500K Hz Step-Down Switching Regulator ❖ Must be able to provide a constant 5 volt dc output until the 12 volt battery reaches 4 volts

Table 3.1-1: Specifications and Requirements

4.0 Research

4.1 Solar Panels

4.1.1 Definition

One easy way to explain how a solar panel works is, first they harness solar energy in individual solar cells. Then they transfer the energy it captures into an inverter, where it

can be converted into usable electricity. When the sun shines on a solar photovoltaic cell, particles of the light are absorbed by a type of silicon (monocrystalline, polycrystalline, amorphous...etc.), transferring the energy from the light into the silicon. Electrons will then flow through the solar cell; the cells are designed so that these electrons all flow in one direction, which create a current. The electricity will then be created by the solar panel into DC current. Solar panels will continue to increase as the market will turn to solar energy. Now that society has been doing extensive research on solar cells, they have found three popular types of solar panels. The three main types of solar panels are Monocrystalline, Polycrystalline, and Thin-Film. The solar panels are differentiated by the type of materials they are made from; all three will have pros and cons. The three different types of panels will be explained below in section 4.1.2.

4.1.2 Types

Monocrystalline Silicon Solar Panels

The monocrystalline silicon panels are the most efficient out of the three. With this type of silicon panel you do not need as many panels to generate the same amount of electricity. This type of panel will be very useful when you are dealing with a smaller surface area. Monocrystalline panels are slightly more efficient than polycrystalline, plus they don't usually cost more. The monocrystalline is of the highest grade of silicon purity, solar panels made of it are the most efficient. The efficiency rate usually ends up between 12-19%. They also seem to last the longest and the majority of the manufactures put a 25 year warranty on them. They tend to perform better then polycrystalline solar panels at lower light and lower temperature conditions. The monocrystalline are still the most expensive of the three. A very important fact states, as the temperature increases, the electrical conversion rates goes down. Table 4.1.2-1 below shows the specifications of a monocrystalline silicon 30 W solar panel.

Manufacturer	Nature Power
Product name	30 Watt Solar Panel
Product Type	Monocrystalline Photovoltaic Solar Panel
Voltage	12 Volts DC
Maximum	Up to 30 Watts (power) Up to 1.74 Amps (current)
Transform efficiency	18-20%
Weight(each)	6.6 lbs.

Table 4.1.2-1: Monocrystalline Silicon 30 W Solar Panel Specifications

Polycrystalline Silicon Solar Panels

The polycrystalline silicon panel does not contain as much silicon as the monocrystalline panels. This makes the panels a little less efficient than the monocrystalline panels. The polycrystalline panels are made up of a bunch of small cells put together versus one large cell. Polycrystalline solar panels have higher heat tolerance than those made of monocrystalline silicon. The temperatures affect performance of a solar panel and can also reduce its lifetime. The polycrystalline tend to perform better than the

monocrystalline at high temperatures. Since the silicon of the polycrystalline panels are not as pure as the monocrystalline, the monocrystalline silicon panels still have high efficiency rates. The polycrystalline requires covering a larger surface to output the same electrical power as you would with a solar panel made of monocrystalline silicon. The table 4.1.2-2 below shows the specifications of a polycrystalline silicon 30 W solar panel.

Manufacturer	Blue Carbon
Product name	30 Watt Solar Panel
Product Type	Polycrystalline Photovoltaic Solar Panel
Voltage	12 Volts DC
Maximum	Up to 30 Watts (power) Up to 1.74 Amps (current)
Transform efficiency	17-19%

Table 4.1.2-2: Polycrystalline Silicon 30 W Solar Panel Specifications

Thin-Film Solar Panels

The thin-film solar panels use thin, lightweight layers of a photovoltaic material (amorphous). They are less expensive than the other types of solar panels and are better able to work in hot weather. The primary advantage of the thin-filmed panels is in their low manufacturing costs and versatility. Amorphous silicon and similar semiconductors do not depend on the long, expensive process of creating silicon cells, than can be produced much quicker. The problem with the thin-filmed panels is they are not efficient. We would need a handful more silicon than the other panels. The table 4.1.2-3 below shows the specifications of thin-film (amorphous) silicon 30W solar panel.

Manufacturer	Blue Carbon
Product name	20 Watt Solar Panel
Product Type	Amorphous Photovoltaic Solar Panel
Voltage	12 Volts DC
Maximum	Up to 20 Watts (power) Up to 1.2 Amps (current)

Table 4.1.2-3: Thin-Film 30 W Solar Panel Specifications

4.1.3 Solar Sensors

In order for the solar powered tracking device to work, the group needs to figure out a way to sense light from the sun. The term photodiode is more commonly used, rather than solar sensor. Photodiodes are PN junction diodes that are designed to harness the photoelectric effect. The photodiode is a versatile solid state device that has many applications. Photodiodes are used as light detectors, power sources, and light emitters. Photovoltaic operation occurs when the photodiode is used as a power source. This is done by allowing photons to hit the pn junction. In addition, the energy is then passed into an electron that is flowing its way across the junction, which then creates a current. This device that was explained above is a solar cell, which is an example of a photo diode.

Now that you have a brief understanding of what a photodiode is and what its applications are we are going to explain photo resistors. Photo resistors are found in many useful low cost photo sensitive elements. Photo resistors are also known as LDR. LDR are components that are used as a photoconductor between two contacts. LDR are in many electronic circuit designs because of the price, rugged features and the simplicity of the structure. The properties can vary widely upon the type of material that is used. It can be made of a semiconductor like silicon. Silicon in the dark has fewer electrons that are on the move so conductivity is lower. The benefits of this type of resistor are they allow less power to be used in light. The figure 4.1.3-1 below shows an example of a light sensor circuit:
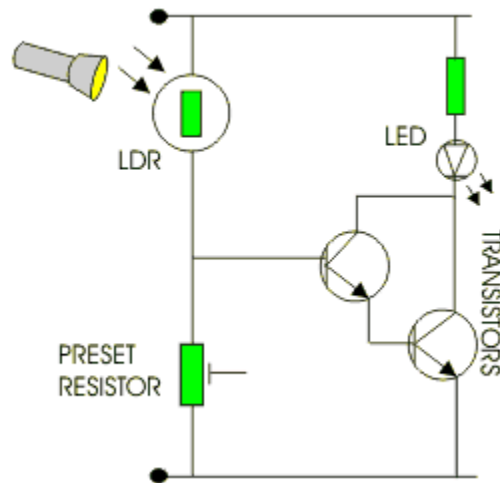
Figure 4.1.3-1: Light Sensor Circuit Pending permission from V. Ryan

A basic understanding of the figure 4.1.3-1 is when the light is hitting the light detection resistor at a low light level the resistance of the light dependent resistor is high. This will help prevent current from flowing to the base of the transistors. The LED will not light. If the light will shine heavily on the light dependent resistor the resistance will fall and the current will then flow into the base of the first transistor and the second transistor. Then the LED will light up.

4.2 Charge Controllers and Regulator

4.2.1 Hardware Design Options
Below in Figure 4.2.1-1 is the first hardware design that the group will consider for implementing the charge controller and regulator.

11
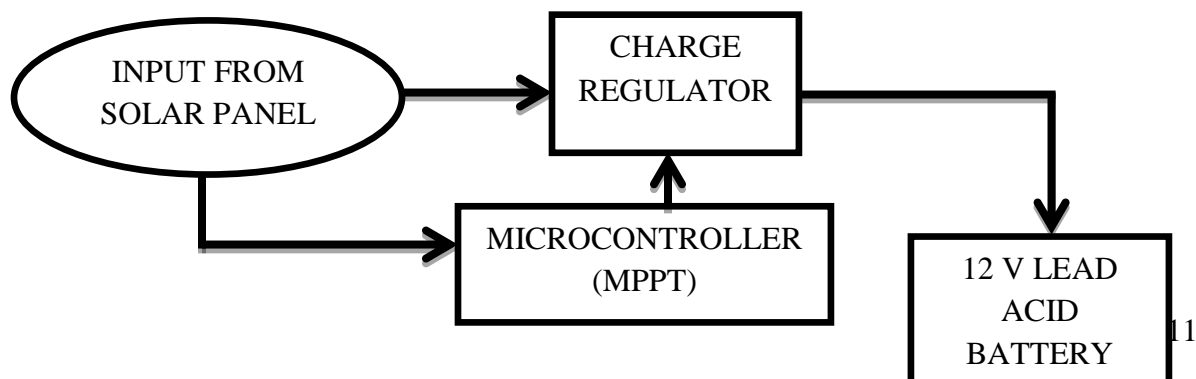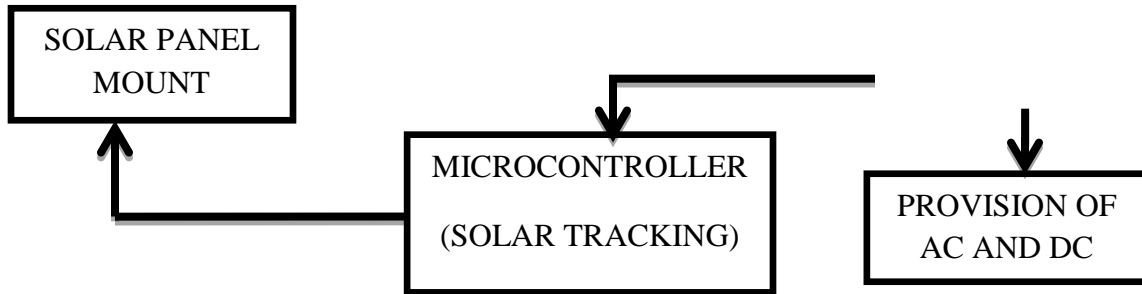
Figure 4.2.1-1: Block Diagram for Hardware Functionality of Charge Controller and Regulator with Solar Tracking Capability

In the block diagram in Figure 4.2.1-1 above, solar tracking is included into the hardware functionality to further increase the amount of power that can be extracted from the solar panel into the battery. This hardware configuration will provide an improvement to the MPPT. MPPT is discussed in section 4.2.1.2. This hardware implementation is more complicated and more expensive than the hardware implementation in Figure 4.2.1-2 below, but provides better performance.

The second hardware implementation for consideration is illustrated in Figure 4.2.1-2 below. It is very similar to the hardware implantation illustrated in Figure4.2.1-1 with only a minor modification.
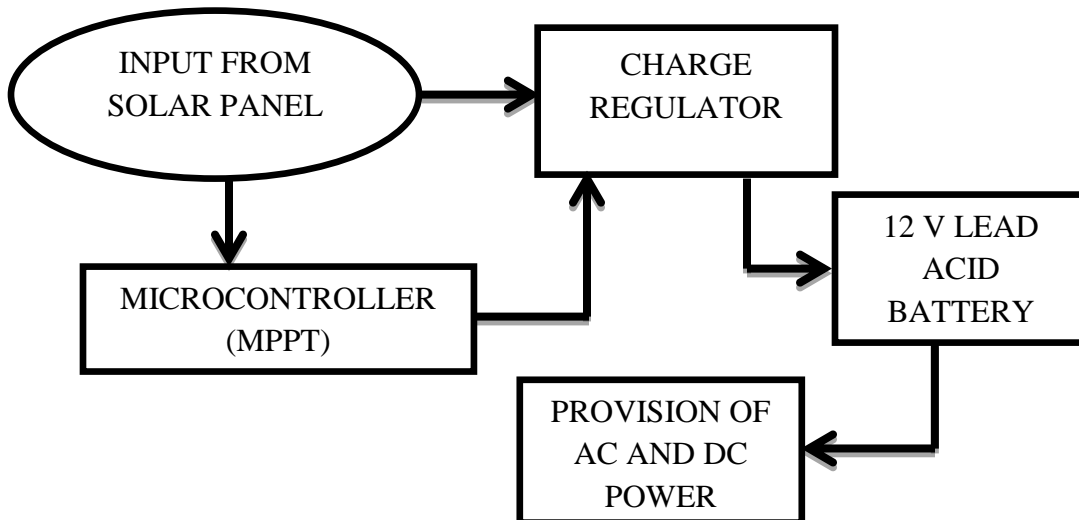
Figure 4.2.1-2: Block Diagram for Hardware Functionality of without Solar Tracking Option.

Looking at Figure 4.2.1-2 above, it can be seen that it is almost identical to Figure 4.2.1-1 above. The only reason they are not the same is due to the fact that Figure 4.2.1-2 excludes solar tracking. It is understood that MPPT and solar tracking are two different techniques used to increase power delivered into the battery. It is ideal to have both techniques implemented into the hardware but, the cost for both techniques and the time to build and test both can be a limitation for the group.

If the group has to choose between MPPT and solar tracking, MPPT will be chosen. MPPT is has a higher priority over solar tracking because of the situation when solar tracking practically has no significance if the solar panel is connected directed to the battery. As long as the panel is receiving a higher voltage than the battery, the battery will step the panel's voltage to down match its voltage. Therefore, the extra voltage from the solar panel would not be extracted and delivered into the battery. To further understand why MPPT is the wiser choice, please see section 4.2.1.2 which is the section on MPPT.

A third option for a hardware implementation is illustrated in Figure 4.2.1-3 below. This option includes an AC/DC battery charger for charging the battery of the device from any 120 volt, 60Hz socket.
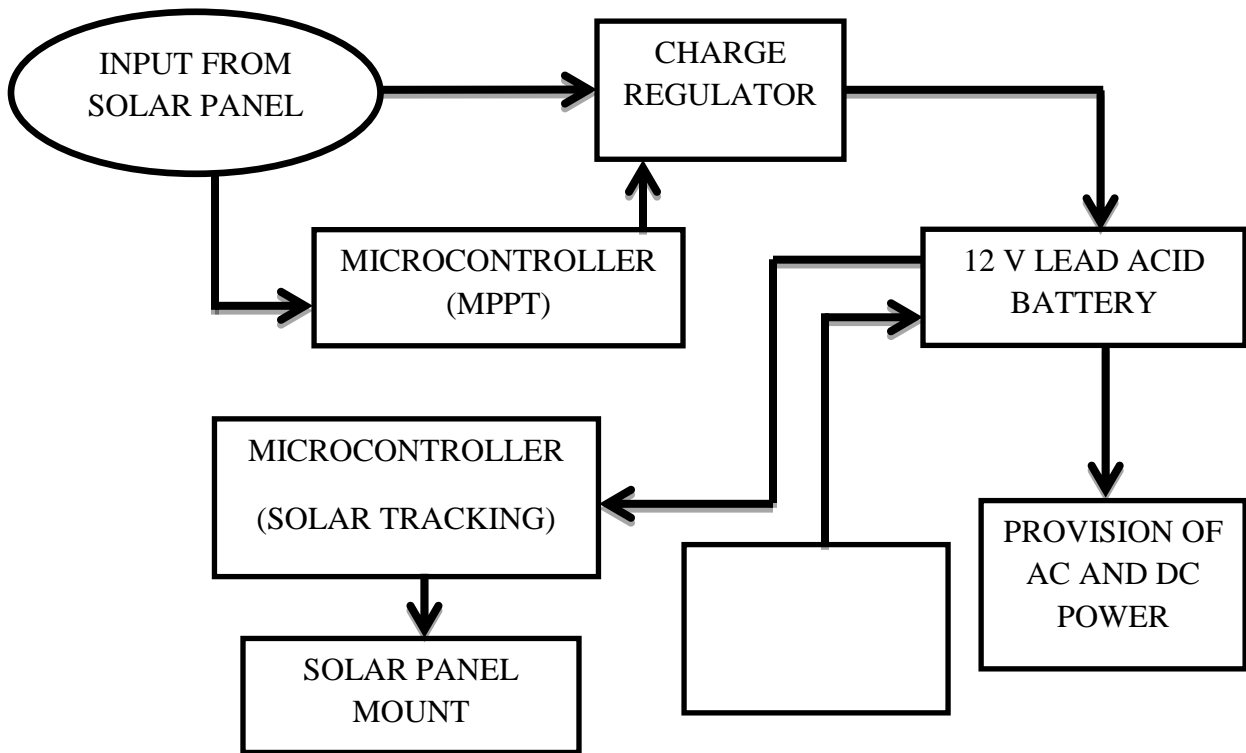
Figure 4.2.1-3: Block Diagram for the Functionality of the charge controller with battery charging capabilities from an AC wall outlet.

Including the capability of the portable solar charger to be charged from an AC wall outlet is a very useful idea. The device can be charged before it is taken outdoors. So if a user of this device needs power to perform a task, or get a job done, the user does not have to wait for the device to charge from the sun before using it. If the user has to wait for the sun to charge the battery before using the device, then, the user will have to place the device in an area that has favorable sunlight. This means that the user's job or task that requires power to be accomplished will have to be put on hold until the battery is charged to a level for favorable operation. Because sunlight intensity can fluctuate, and also at times not be available, it can be unpredictable on the time needed to charge the battery from solar energy.

The solar tracker can be excluded from the block diagram in Figure 4.2.1-3 like the block diagram in Figure 4.2.1-2. It can be excluded for the same reason that it was excluded in Figure 4.2.1-2.

It is critical that the efficiency and performance of the parts in Figures 4.2.1-1 to 4.2.1-3 are optimized. If the components in the Figures do not perform properly and have low efficiency levels, then it degrades the projects usefulness as a whole. To further justify this, consider the AC and DC outputs that will provide power for applications. If the components that take the power from the battery and provide DC output power (DC/DC converter) is not efficient or functions improperly, there is still a good chance the components that take the power from the battery and provide AC power (DC/AC inverter) will perform properly with high efficiency and vice versa.

4.2.1.1 Regulator Hardware Design Options

There were many design options that were taken into consideration for designing the hardware for the charge regulator circuit. Efficiency, complexity, and circuit schematic design space were three key points for the group while designing the charge regulator circuit. The charge regulator was expected to have an efficiency of at least 90 percent. The circuit was designed to have a very low level of complexity as possible. In other words, the design of the circuit was to be as efficient as possible. Reduced complexity means the space required to build the circuit will also be reduced. The three key points above increases the portability solar charger. Increased portability is a major goal of this project.

The main purpose of the charge regulator is to regulate the power coming in from the solar panel and to output 12V dc with approximately 2 A of current for the 12V battery. The charge regulator prevents the battery from being charged above and below its recommended charge rate. If the battery is charge above or below its charge rate range, the battery can be damaged and the lifetime can be greatly reduced. This portable solar charger cannot function without the 12V battery.

The technique chosen to achieve charge regulation was to implement a buck-boost regulator circuit. A buck-boost regulator circuit is designed to provide a required output voltage regardless of the input voltage fluctuating above or below the output voltage. The buck-boost regulator circuit can perform this task very well within a specified input voltage range.

Below in Figure 4.2.1.1-1 is the schematic of the first hardware design implementation option for a charge regulator circuit.
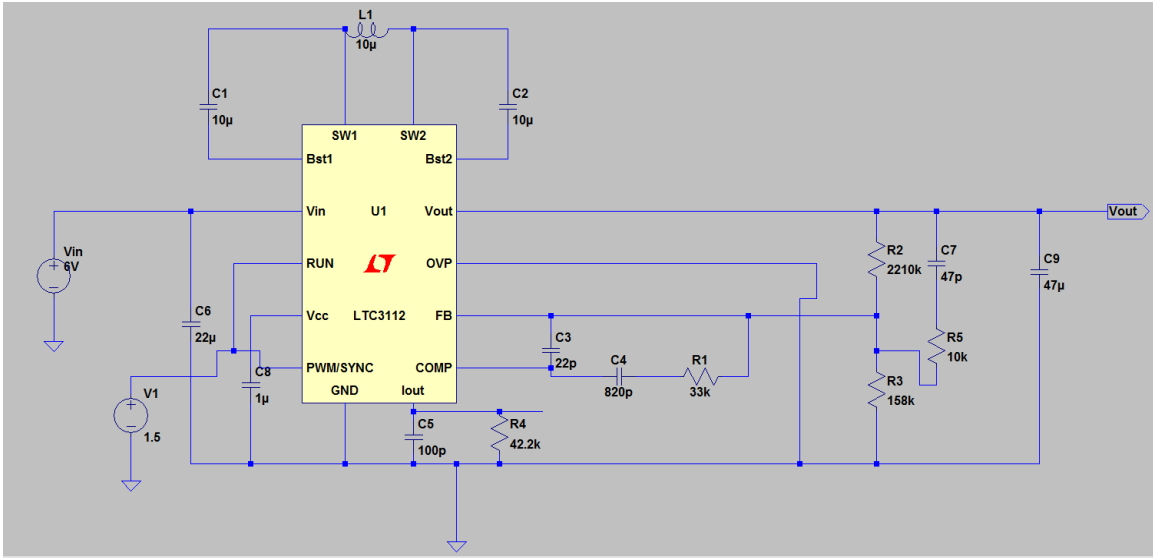
Figure 4.2.1.1-1: Buck-Boost Regulator circuit that outputs a regulated 12V from a wide input supply voltage range

The buck-boost regulator circuit in Figure 4.2.1.1-1 above is designed to accept an input voltage rage from 4.5V to 15V DC. This circuit is designed to output 12V DC with 1A for an input voltage greater than 5V and less than 9V, and 12V DC with 2A for an input voltage greater than 9V.

Below in Figure 4.2.1.1-2 is an illustration of the performance of the charge regulator circuit given in Figure 4.2.1.1-1. This data was obtained from the datasheet of the LTC3112 chip.
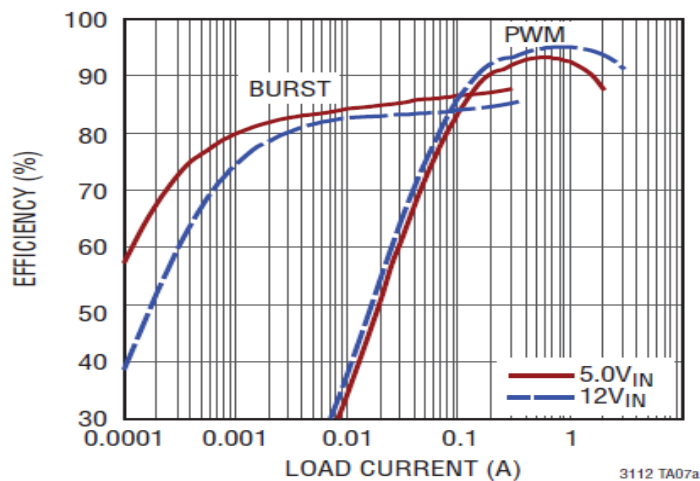
Figure 4.2.1.1-2: The efficiency of the circuit that is illustrated in Figure 4.2.1.1-1. Printed with permission from Linear Technology

Another circuit configuration for the charge regulator circuit is illustrated in Figure 4.2.1.1-3 below.

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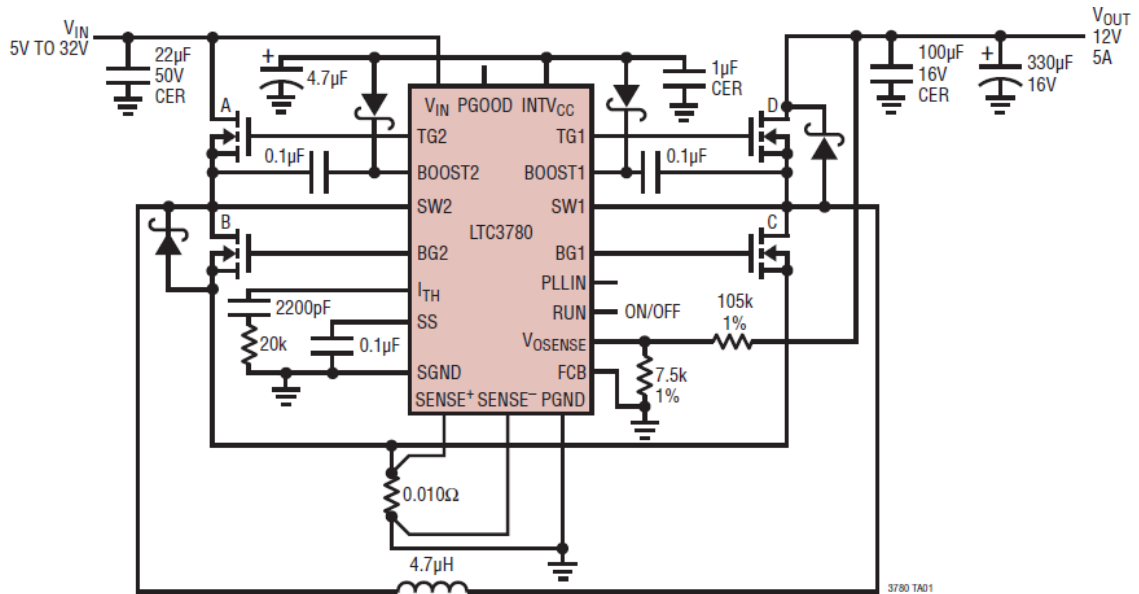
Figure 4.2.1.1-3: Another Buck-Boost Regulator Circuit with 12V Regulated Output Voltage. Reprinted with permission from Linear Technology

The LTC3780 chip in Figure 4.2.1.1-3 has a wider input voltage range than the LTC3112 chip from the previous charge regulator circuit. The wider input voltage range makes this circuit more flexible to input voltages received from the solar panel. This circuit will make the portable solar charger less restricted to certain levels of sunlight while still having normal operation. This circuit will function properly with an input voltage range from 5 volts to 32 volts. On the other hand, the LTC3112 charge regulator circuit in Figure 4.2.1.1-1 will function properly only within the range of 4.5 volts to 15 volts. Another major advantage of using this regulator circuit is that it can output a larger current when compared to the previous regulator circuit. This circuit can output a maximum power of 12 volts at 5 amperes while the previous regulator circuit can output a maximum power of 12 volts at 2 amperes. In other words, this circuit is capable of transferring more power to the battery than the previous circuit.

The complexity of the circuit illustrated in Figure 4.2.1.1-3 is of the same level to the circuit in Figure 4.2.1.1-1

4.2.1.2 Maximum Power Point Tracking (MPPT)
The amount of electrical power generated by a photovoltaic system is dependent on several conditions. Such conditions are solar irradiance (solar energy per unit area of the solar panel's surface), temperature, and cloud coverage. The maximum power point occurs where the current and voltage at which a solar module can generate the maximum power. The maximum power point location is not known in advance. Below in Figure 4.2.1.2-1 is a graphical illustration of the current and voltage point where the maximum power point is located. There is also a power versus voltage graph with respect to the current versus voltage graph.

16
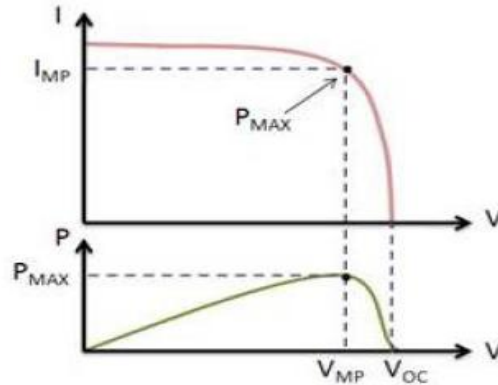
Figure 4.2.1.2-1: Illustration of maximum power point – The current and voltage at which a solar module generate the maximum power. Reprinted with permission from National Instruments

Maximum power point tracking performs modifications to the electrical operating point of a solar energy system thus, enabling it to generate the maximum amount of power. This involves finding the current or voltage of the solar panel at which maximum power can be generated. The electrical efficiency of a solar system is improved with maximum power point tracking.

Using a descriptive example of how maximum power point tracking works, consider a 12V battery and an 18 volt rated solar panel. When the solar panel is being used to charge the battery, assuming that the solar panel is operating at 18 volts, the battery will reduce the operating voltage of the solar panel to its own voltage of 12 volts. This means that there is potential to acquire more power from the solar panel charging system it the solar panel continues to operate at 18 volts while charging the 12 volt battery.

To obtain the efficiency of the MPPT, the 18 volts of the solar panel needs to be stepped down to the 12 volts of the battery. A DC/DC (buck regulator) converter (electronic circuit) is responsible for performing this task. It is the foundation for MPPT. The buck regulator converter modifies the solar panel's higher voltage and lower current to the lower voltage and higher current required to charge the battery. The buck regulator is considered to be a loss-less device (less some small real-world inefficiencies), so it is safe to say it outputs the same power as the input, but at a different voltage and current. In a power supply, simple feedback is used to set the DC/DC converter to a fixed output voltage. This is done by controlling the ratio of the input voltage to the output voltage. In the solar panel example, the ratio would be 18 volts /volts or 3/2.

There are many algorithms to perform MPPT. Some important factors that will be considered when selecting a technique to perform MPPT are: sensors used, ability of an algorithm to detect multiple maxima, cost, and convergence speed.

For a large scaled application, the number of sensors used can affect complexity and accuracy. Often, more sensors are used for more precise MPPT. The MMPT technique plays a major role in determining the number and type of sensors to be used.

It is normal to have variations in the irradiance levels at different points on a solar panel's surface. This creates multiple local maxima in one system. The efficiency and complexity of an algorithm will determine if the true maximum power point or a local maximum power point was calculated. In the latter case, the maximum electrical power is not obtained from the solar panel.

The number of sensors as well as the type of hardware used to monitor and control the electrical tracking system affects its implementation cost. The type of algorithm that will be used significantly determines the resources needed to set up this application.

To have a high-performance MPPT system, the time taken to converge to the required operating voltage or current should be small. Depending on the required speed to do this operation and the tracking system requirements, the system has to accordingly maintain the load at the maximum power point.

4.2.1.3 Microcontroller

The first microcontroller that the group will consider for implementing into this project is the MSP 430. Below in Figures 4.2.1.3-1 is an illustration of this microcontroller.
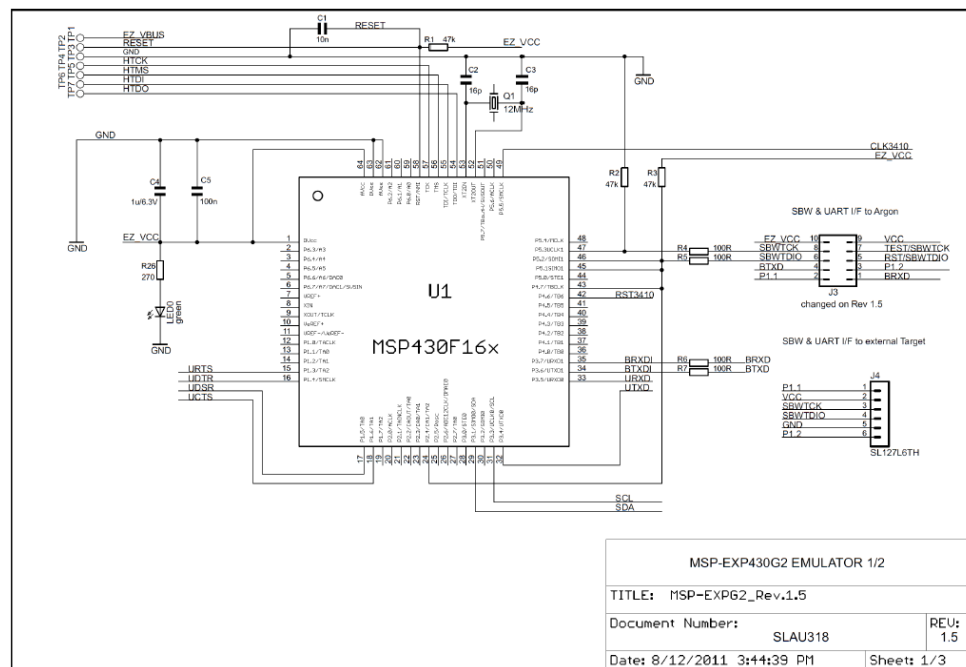
Figure 4.2.1.3-1 (a): Schematic of MSP-EXP430G2 Emulator. Part 1/2. Courtesy Texas Instruments.
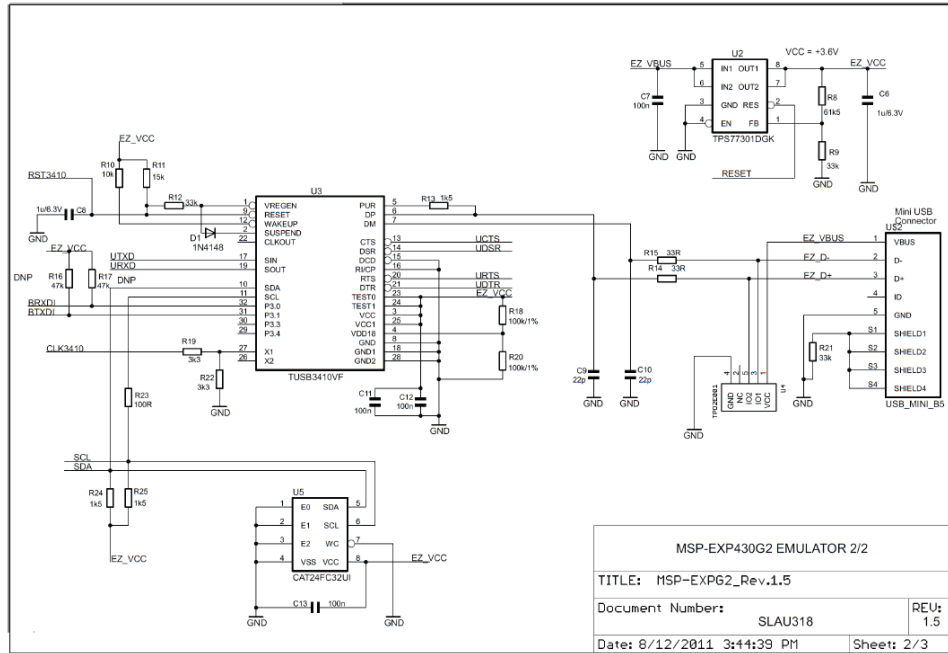
Figure 4.2.1.3-1 (b): Schematic of MSP-EXP430G2 Emulator, Part 2/2. Courtesy Texas Instruments.
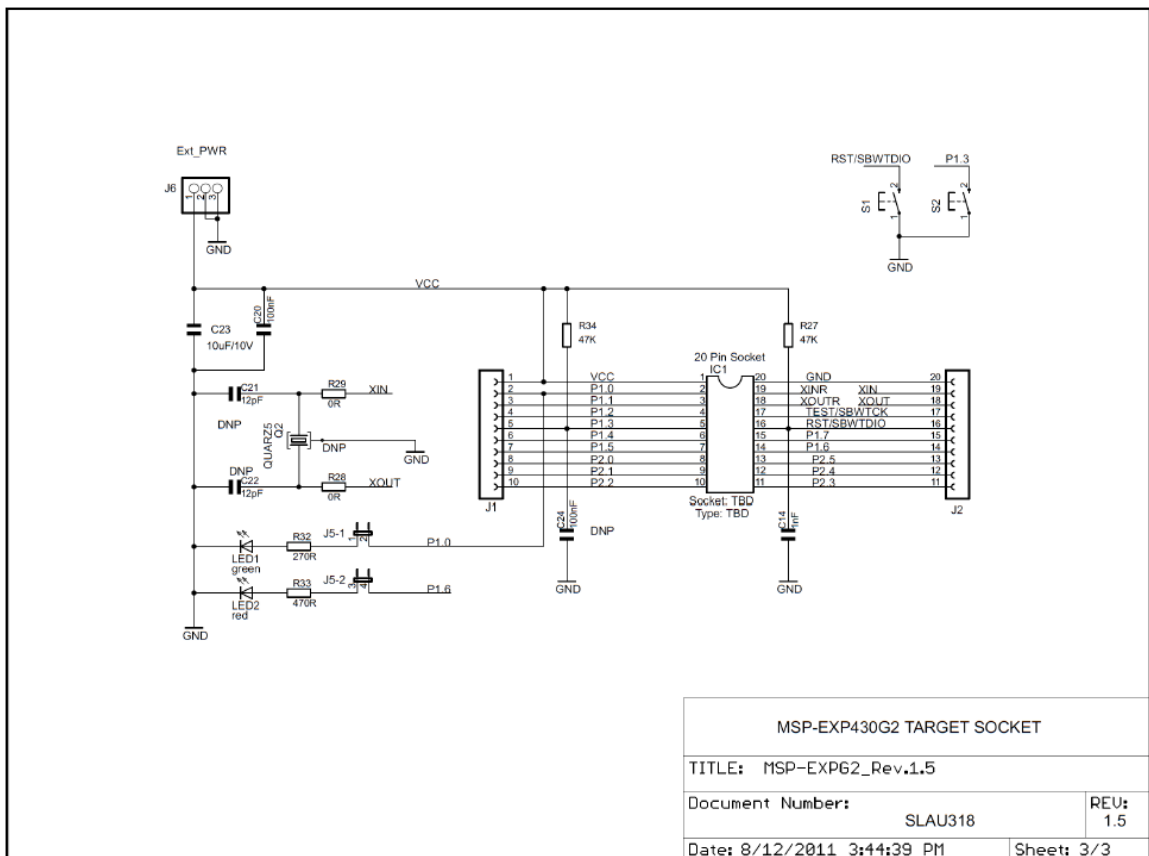
Figure 4.2.1.3-1 (c): Schematic of MSP-EXP430G2 Target Socket. Courtesy Texas Instruments.

The MSP430 microcontroller in Figure 4.2.1.3-1 provides 16-bit performance, up to 16 MHz operation and ultra-low power consumption. This microcontroller is also very inexpensive. The MSP430 Value Line device in Figure 4.2.1.3-1 has a 14 and 20- pin DIP target socket. When the MSP40 device is programmed, the LaunchPad can be used as the complete stand-alone system, or the MSP430 device can be unplugged and inserted into a custom PCB or breadboard.

Another microcontroller that will be considered for implementation into this portable solar charger is based on the open source hardware platform of the Arduino Duemilanove. This open source hardware platform is illustrated in Figure 4.2.1.3-2 below.
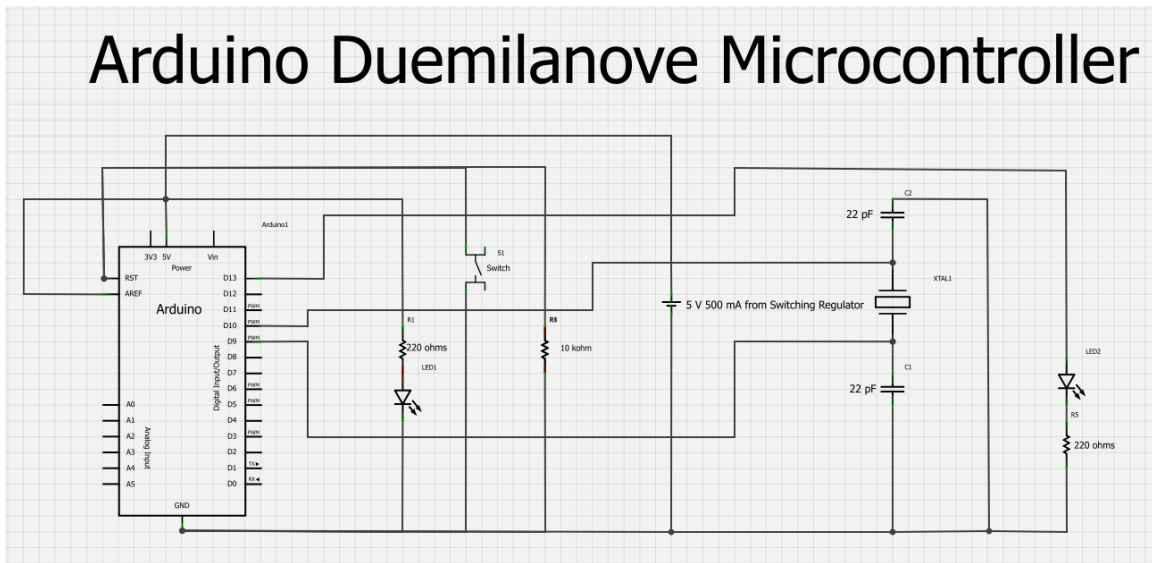
Figure 4.2.1.3-2: Open source hardware platform of the Arduino Duemilanove.

If the open source hardware platform of the Arduino Duemilanove is used to build a microcontroller for this project, then, additional costs will have to be spent to have a company manufacture the PCB and also stamp the chips that need to be attached to the PCB. This means that it would be more expensive to use the Aduino Duemilanove open source hardware platform as a means to implement a microcontroller for this project. This microcontroller operates at a clock speed of 16 MHz like the MSP430.

Another schematic designed to perform Maximum Power Point Tracking is illustrated below in Figure 4.2.1.3-3
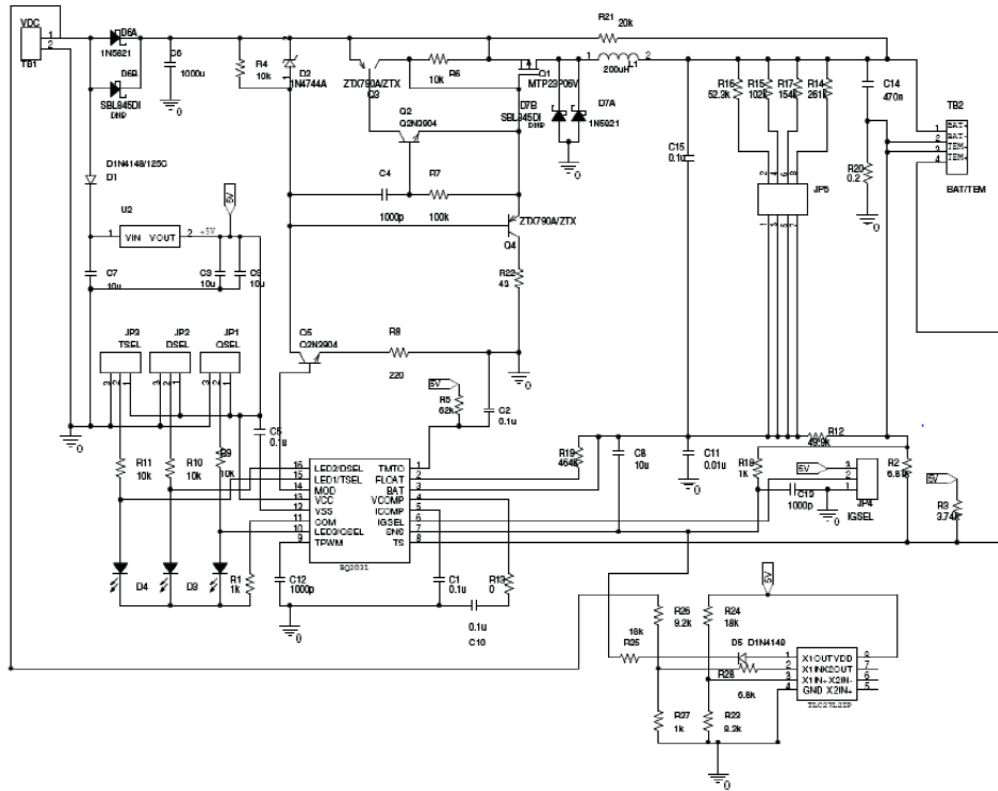
Figure 4.2.1.3-3 Schematic of MPPT-Based Charger Using bq2031. Courtesy Texas Instruments.

The schematic of Figure 4.2.1.3-3 is based on a board, DV2031S2, with an extra current control loop added to implement the MPPT using the operational amplifier TLC27L2. The bq2031 provides a maximum current of 1 A. The extra current control loop will be added to reduce the charge current as the sunlight reduces and to maintain panel voltage around the maximum power point voltage. The bandwidth of TLC27L2 is much less than the switching frequency of bq2031. Therefore, the extra current loop that the circuit displays remains stable. This alternative is the more expensive route since we would have to purchase the board directly from the distributer.

Protoshield

The ProtoShield will be used by the group if the Arduino microcontroller is used for MPPT. The charge regulator will be built on the ProtoShield. The ProtoShield is designed to facilitate prototyping. It provides an easy connection between a breadboard and an Arduino. The ProtoShield provides the Arduino with easy access to a prototyping area, two general LEDs, access to a BlueSMiRF socket, a general use push button, and most

important of all, the Arduino reset button. Also, the option of sticking a mini, self-adhesive breadboard onto the ProtoShield is available. The ProtoShield is designed to sit on top of the Arduino, extending the functionality of the Arduino platform. Below in Figure 4.2.1.3-4 is an illustration of the ProtoShield schematic diagram
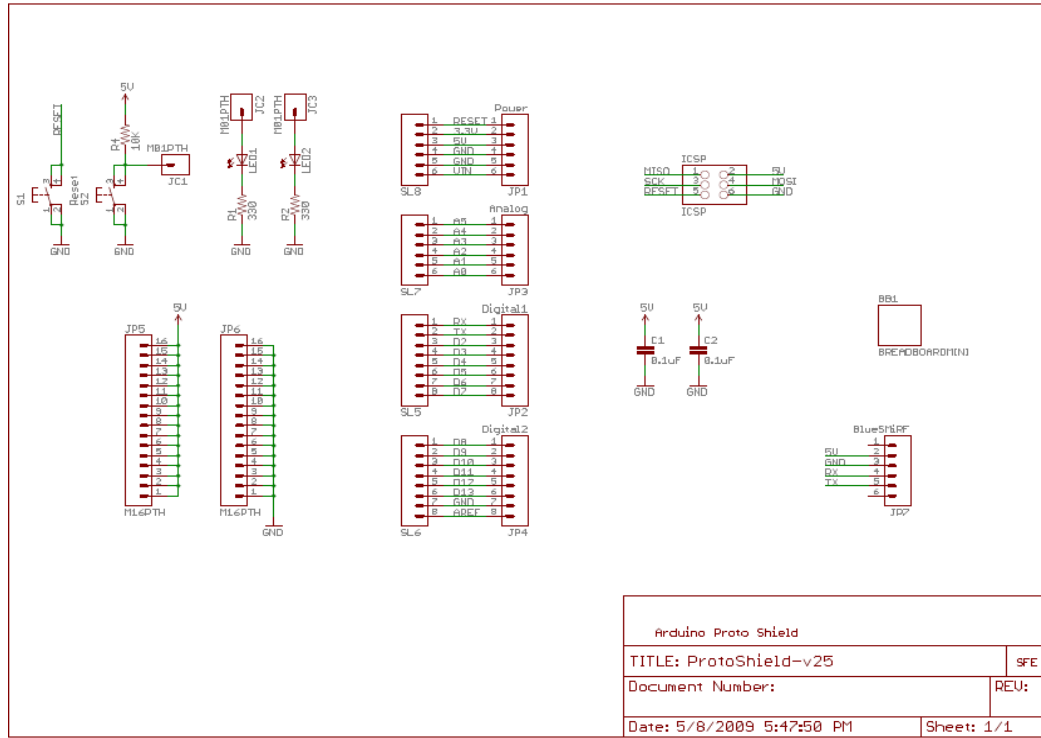
Figure 4.2.1.3-4: ProtoShield schematic Diagram. Reprinted with permission from SparkFun Electronics.

4.2.2 Software

4.2.2.1 Introduction

Software is required to optimize charging the battery. In other words, software plays a major role in the efficiency of the portable solar power supply. Choosing an efficient software algorithm and an efficient code is necessary for the software that would be implemented on the microcontroller to be efficient.

4.2.2.2 Types of Algorithms

Perturb and Observe

A popular and effective MPPT algorithm is the 'Perturb and Observe' algorithm. This algorithm modifies the operating voltage or current of the photovoltaic panel until maximum power can be obtained from it. For example, if increasing the voltage to a cell

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increases the power output of a cell, the system increases the operating voltage until the output power begins to decrease. Once this occurs, the voltage is reduced to get back to the maximum power point output value. This process will continue until the maximum power point is reached. Hence, the output power value oscillates around a maximum power value until it stabilizes. The 'Perturb and observe' is the most commonly used MPPT algorithm because of its ease of implementation. Below in Figure 4.2.2.2-1 is as Flowchart illustrating the 'perturb and observe MPPT tracking algorithm.

```
                          ┌─────────────┐
                          │    Start    │
                          └─────────────┘

┌──────────────────┐                    ┌──────────────────┐
│ Increase Operating│                   │ Decrease Operating│
│      Voltage      │                   │      Voltage      │
└──────────────────┘                    └──────────────────┘
              Yes
   No                          Is P_K > P_{K-1}?              No

              Yes
                   Is P_K > P_{K-1}?
```
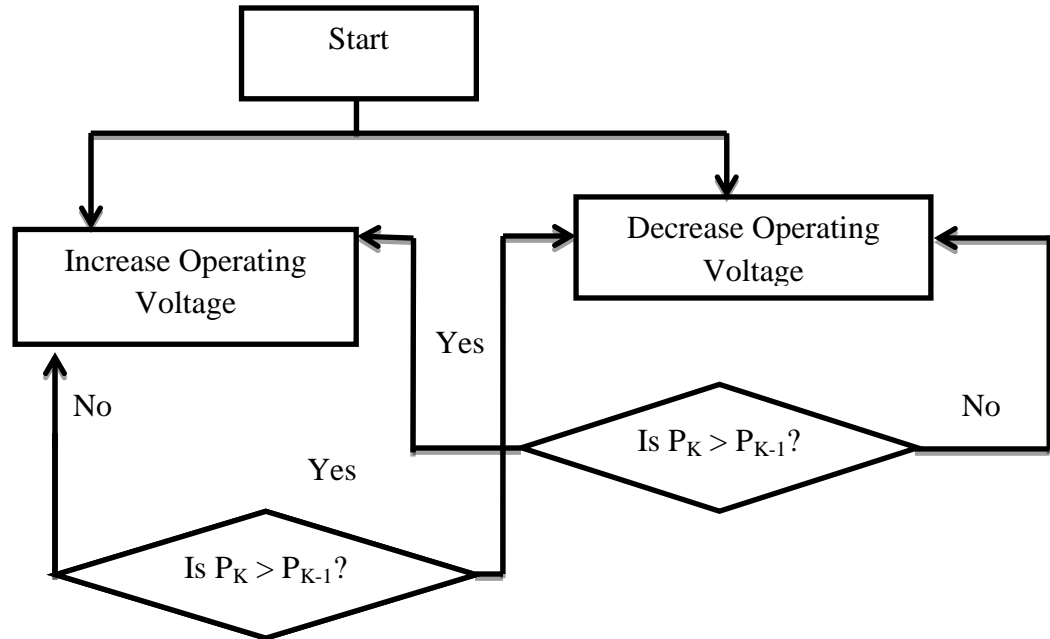
P_K = Current power value

P_{K-1} = Previously acquired power value

Figure 4.2.2.2-1: Flowchart for a the Perturb and observe Tacking System

A major disadvantage of the perturb and observe algorithm is that the obtained power oscillates around a maximum power point in steady state operation. Also, it is possible for this algorithm to track in the wrong direction when the irradiance levels are varying rapidly.

Incremental Conductance

Another MPPT algorithm that the group will consider is the incremental conductance algorithm. This technique is based on the fact that the slope of the power-voltage curve is zero at the maximum power point (MPP). At the left of the maximum power point, the slope of the power-voltage curve is positive, and it is negative at the right of the maximum power point. The concept of the slope of the power-voltage curve with respect to the maximum power point is further explained with the equations below.

$$\frac{dP}{dV} = 0 \quad \text{at MPP}$$

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$$\frac{dP}{dV} > 0 \qquad \text{left of MPP}$$

$$\frac{dP}{dV} < 0 \qquad \text{right of MPP}$$

As power (P) = IV,

$$\frac{dP}{dV} - \frac{d(IV)}{dV} - I + V * \left(\frac{dI}{dV}\right) = I + V * (\frac{\Delta I}{\Delta V})$$

The MPP can be obtained by doing a comparison of the instantaneous conductance (I/V) to the incremental conductance (ΔI/ΔV). When the MPP is obtained, the solar module maintains this power point unless a change in ΔI occurs. Normally this happens when there is a change in the MPP and in the ambient conditions. If this happens, the algorithm will modify the operating voltage until the new MPP is obtained.

Below in Figure 4.2.2.2-2 illustrates a flowchart for an incremental conductance tracking system.
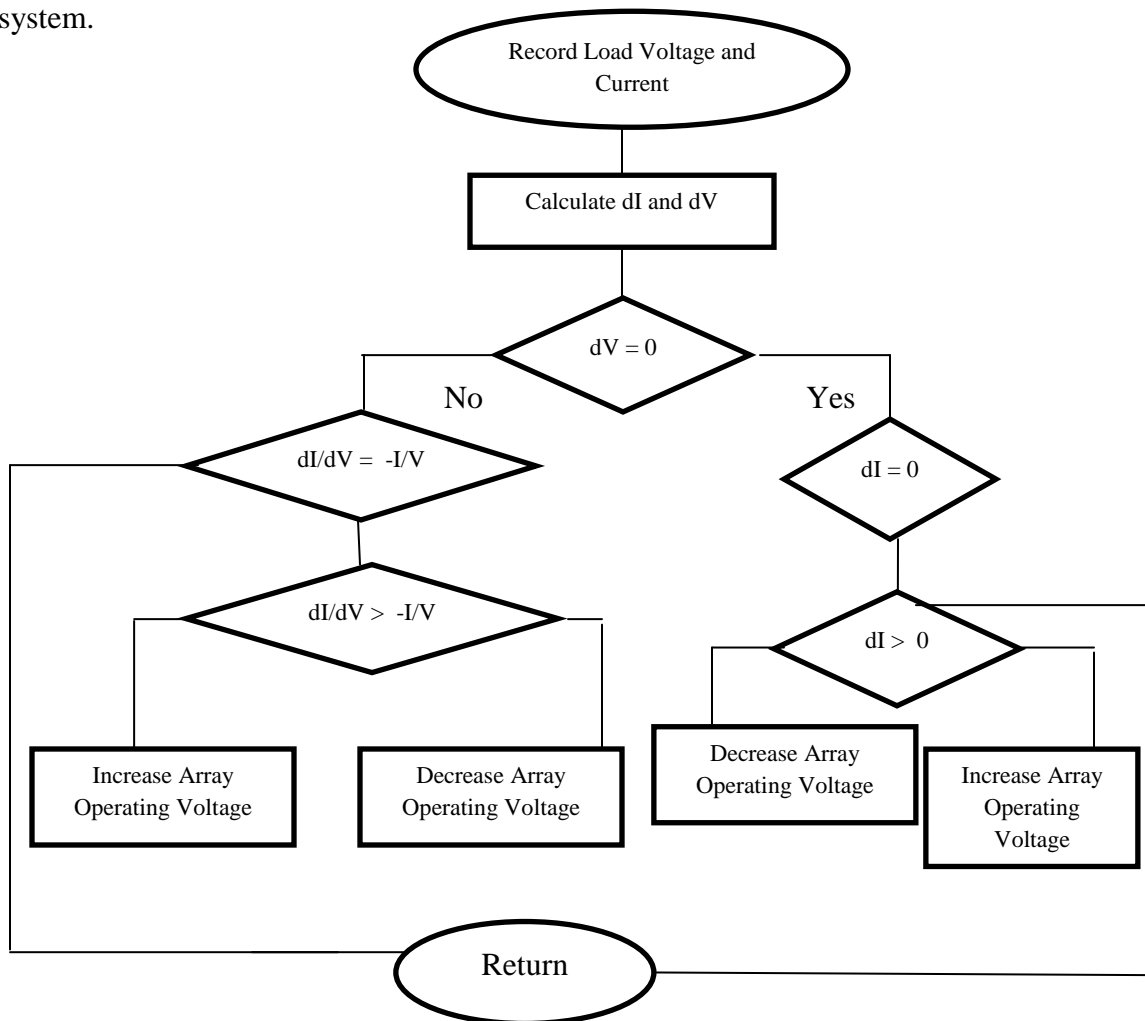
Figure 4.2.2.2-2: Flowchart for an Incremental Conductance Tracking System

The incremental conductance algorithm has an advantage over the perturb and observe algorithm because it can determine when the MPP has arrived without oscillating around this value. It can also perform MPPT during rapidly increasing and decreasing irradiance conditions with more accuracy than the perturb and observe method.

Constant Voltage

Constant Voltage is another algorithm that is used for maximum power point tracking. The method consists of, an interruption in the power that is being delivered and the open circuit with zero current is measured. The controller will then resume operation with the voltage controlled at a fixed ratio of the open circuit voltage. The open circuit voltage is approximately constant, the equation below will demonstrate.

$$\frac{V_{MPP}}{V_{OC}} \cong K < 1$$

The maximum power point tracking will calculate the operating point using equation (2) and the value for K, and adjusts the arrays voltage until the calculated maxim power point voltage is reached. These steps will reiterate to track the position of the maximum power point .Equations (1,2, and 3) are to graph the curves using the I-V relationship for a photovoltaic cell. Figure 4.2.2.2-3 will show the constant voltage algorithm flowchart.

$$I = I_L - I_{OS} * (e^{\frac{q}{Ak_BT}\{V+IR\}} - 1) \qquad \text{Equation (1)}$$

$$I_{OS} = I_{OR} \left(\frac{T}{T_R}\right) e^{\left[\frac{qE_G}{Ak_B}\left(\frac{1}{T_R} - \frac{1}{T}\right)\right]} \qquad \text{Equation (2)}$$

$$I_L = \left(\frac{G}{1000}\right) [I_{SC} + K_{T'I}(T - T_R) \qquad \text{Equation (3)}$$
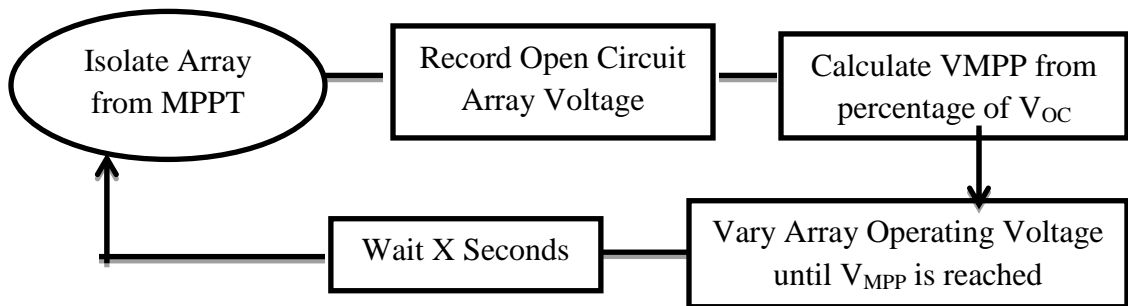
Figure 4.2.2.2-3 Constant Voltage Algorithm Flowchart

This algorithm is very simple, but the difficult portion of this algorithm is choosing the value of K. For this algorithm individual panels are not efficient enough for good power point tracking. The constant reference voltage is considered as the maximum power point voltage. The data for this algorithm differentiates with geographical locations and has to be processed differently. The constant voltage method does not require any input. When the solar panel is in low insulation conditions, this algorithm is more effective than the other two explained early.

After analyzing all of the maximum power point algorithms we found that the perturb-and-observe and the incremental conductance algorithms have almost the same overall efficiencies. Although in most cases and examples, the incremental conductance usually has slightly better efficiency. However, both of the perturb-and-observe and the incremental conductance algorithms can have efficiencies well in excess of 97% when they are properly used. The advantage of using the perturb-and-observe is the simplicity of the algorithm. The perturb-and-observe can be easily implemented with simple analog circuitry or a low cost microcontroller. The incremental conductance algorithm requires differentiation and division circuitry and a complex decision making process. Therefore, this results in having a more complex microcontroller with more memory. Studies show that on the basis of maximum power point tracking efficiency the perturb-and-observe method is the most commonly used algorithm in converters.

4.2.3 Solar Tracking

4.2.3.1 Introduction
There are several variables that can affect the amount of solar energy that can be harnessed such as the sun's position and atmospheric conditions. A solar tracker can increase the amount of energy delivered into a solar powered system. There are two types of solar tracking systems. They are single-axis tracking and two-axis tracking. A single axis-tracking system follows the azimuth of the sun and can increase the efficiency of the solar system up to 26 percent. A two-axis tracking system tracks the elevation of the sun along with the azimuth. A two-axis tracking system can increase the efficiency of a solar system up to 32 percent.

There are two benefits of solar tracking. As mentioned in the previous paragraph, it maximizes the amount of energy that a solar energy collector device can capture from the sun. The other benefit is that it distributes the solar flux evenly on a solar collector's surface, therefore increasing the longevity of the system.

A solar tracking system can be either active of passive. Active tracking signifies that a light-intensity sensor provides solar irradiance feedback for the system to optimize the position of the solar collector. A passive tracking system uses the predetermined known path of the sun to control the direction of the solar collector. Astronomers have provided algorithms that determine the position of the sun based on date, time, and their location on the earth. These algorithms are designed to consider the rotation of the earth and the revolution around the sun (seasonal changes) for different longitudes and latitudes. They are also capable of providing the azimuth and elevation of the sun.

4.2.3.2 Components of Solar Tracking
The main components for solar tracking system are listed and explained below:

Solar Tracking Algorithm

A solar tracking algorithm will calculate the azimuth and elevation of the sun and will provides data to the solar panel about the direction it should be facing. It can either calculate the sun's position using real-time light-intensity readings or using predetermined knowledge of the sun's movement.

Motion Control System

For this part of the solar tracking system, a motor is driven to rotate the solar panel while an encoder is used to read the current position of the panel. These components are used to ensure that the panel is facing the desired azimuth and elevation.

Power Quality Monitoring System

Monitoring the current, voltage, and power generated by a solar cell is important to monitor efficiency and system health. The current and voltage readings can be used to perform maximum power point tracking (see section 4.2.1.2)

Ambient Condition Sensing System

Ambient conditions affect the operating point and efficiency of solar power collection, therefore, it is necessary to acquire and log readings from sensors that measure light intensity (solar radiance), temperature, humidity, etc. Pyranometers that read light intensity are needed if this value will be used directly in the sun tracking algorithm.

4.2.3.3 Hardware Design
Below in Figure 4.2.3.3-1 is the schematic design of the circuit that the group will use for the solar tracker.
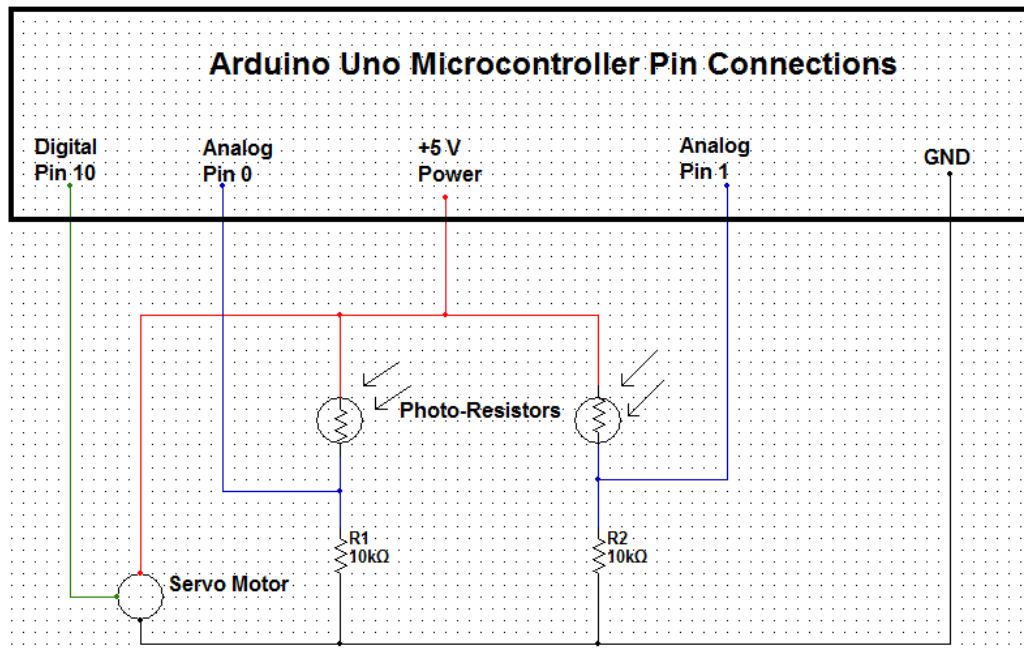
Figure 4.2.3.3-1 Circuit Schematic Diagram for Solar Tracker

The photoresistors in Figure 4.2.3.3-2 are required to be at an offset from each other. This angle facilitates the direction finding capability. Below in Figure 4.2.3.3-2 is an illustration of the photoresistors.
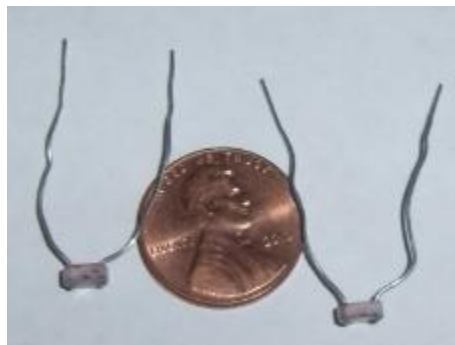
Figure 4.2.3.3-2: Photoresistors used for Solar Tracking

4.2.3.4 Setup and Testing

The circuit schematic Diagram for the solar tracker in Figure 4.2.3.3-1 would be connected to an Arduino microcontroller that the group will build. Both the solar tracker and the Arduino will be built onto a prototype board.

The values read from each photoresistor into the Arduino microcontroller is compared and then the microcontroller decides whether or not the position of the solar panel needs to be adjusted. For instance, if the left photoresistor inputs a higher value than the right,

then this means that there is more sunlight striking the left photoresistor. The goal of solar tracking is to move the solar panel into a direction that optimizes the amount of sunlight that can strike the surface of the solar panel. Therefore, the microcontroller will detect that the left photoresistor has a higher value after the performing the comparison. Then it will make the servo motor rotate the solar panel in the direction of the left photoresistor until both the left and right photoresistors are at the same value.

4.2.4   LCD Display

4.2.4.1 Purpose in Project
An LCD display is essential for monitoring the functionality of the portable solar power supply. The voltage, current, and power, of the battery and solar panel needs to be monitored to ensure that the solar panel is charging the battery in the most effective way and that battery is being charged properly. A two line dot matrix LCD display is sufficient for displaying the items that needs to be monitored from the previous sentence. It would be difficult to know what is happening internally with the portable solar charger without an LCD display.

4.2.4.2 Description
Below in Figure 4.2.4.2-1 shows how an LCD display that is compatible with a Hitachi HD44780 driver should be connected to an Arduino microcontroller.
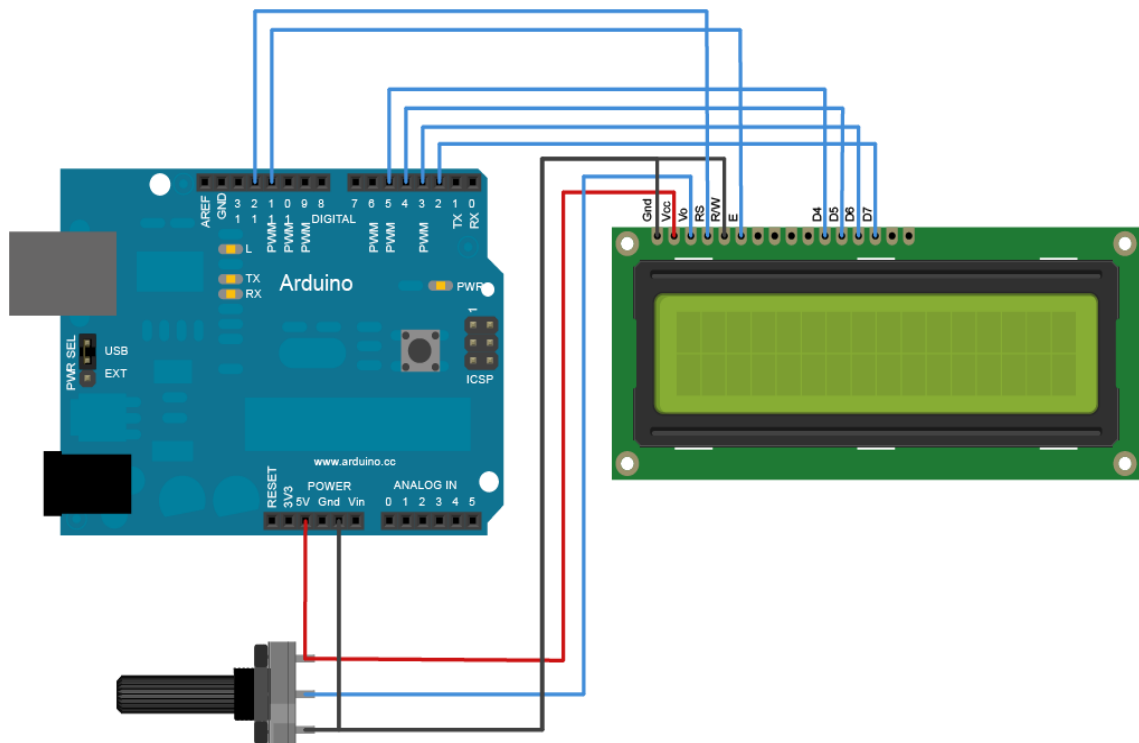
There is a *LiquidCrystal* library that makes it possible to control LCD displays that are compatible with the Hitachi HD44780 driver. These LCD displays are usually identified by their 16-pin interface.

The LCDs have a parallel interface; the microcontroller has to manipulate several interface pins at once to control the display. The LCD interface pins consists of the following pins in table 4.2.4.2-1 below:

Pin	Description
Register Select (RS:	A register select pin that controls where in the LDC's memory that data would be written to. Either the data register or an instruction register can be selected. The data register holds what goes on the screen. An instruction register is where the LCD's controller would look for instructions on what to do next.
Read/Write (R/W):	A read/write pin selects reading mode or writing mode
Enable:	An enable pin enables writing to the registers.
8 Data (D0 – D7):	The states of these pins (high or low) are the bits that are written to a register when writing, or the values that are read when reading.
Display Contrast pin (V_0):	This is a pin that is used to control the display contrast.
Power Supply (+5V and Gnd):	These pins are used to power the LCD.
LED Backlight (BKlt+ and BKlt-):	These pins are used to turn on and off the LED backlight.

Table 4.2.4.2-1: 16-Pin Interface Names and Descriptions

The process of controlling the display involves putting the data that form the image that is desired to be displayed into the data registers, then putting instructions in the instruction register. The *LiquidCrystal* Library simplifies this task, so the low-level instructions do not need to be known.

The Hitachi-compatible LCDs can be controlled in two modes: 4-bit or 8-bit. The 4-bit mode requires seven I/O pins from the Arduino, while the 8-bit mode requires 11 pins. For displaying text on the screen, almost everything can be done in 4-bit mode.

4.2.4.3 Specifications
Hardware Required

Arduino Board

LCD Screen (compatible with Hitachi HD44780 driver)

10k potentiometer

Breadboard

Hook-up wire

The Circuit

To wire the LED screen to the Arduino microcontroller, connect the pins as listed in Table 4.2.4.3-1 below.

LCD Pins	Arduino Microcontroller Pins
RS	digital 12
Enable	digital 11
D4	digital 5
D5	digital 4
D6	digital 3
D7	digital 2

Table 4.2.4.3-1: List of the pin connections from the LCD to the Arduino Microcontroller

Also, wire a 10k potentiometer to +5V and GND, with its wiper (output) to LCD screens Vo (pin 3).

4.2.4.4 LCD Controller/Driver
Introduction

The Hitachi HD44780U dot-matrix liquid crystal display controller and driver LSI displays alphanumerics, Japanese kana characters, and symbols. It can be configured to drive a dot-matrix liquid crystal display that is controlled by 4-bit or   8-bit microprocessors. Due to the fact that all the all the functions such as display RAM, character generator, and liquid crystal driver, required for driving a dot-matrix liquid display are internally provided on one chip, a minimal system can be interface with this controller/driver.

A single HD44780U can display up to one 8-character line or two 8-character lines.

The HD44780U has pin function compatibility with the HD44780S making it possible to easily replace an LCD II with an HD44780U. The HD44780U character generator ROM is extended to generate 208 5*8 dot character fonts and 32 5*10 dot character fonts for a total of 240 different character fonts.

The low power supply (2.7V to 5.5V) of the HD44780U is suitable for any portable battery-driven product requiring low power dissipation.

Features

Below in the table 4.2.4.4-1 is the list of specifications of the Hitachi HD44780U dot-matrix liquid crystal display controller and driver.

Item	Description
5*8 and 5*10 dot matrix possible	
Low power operation support	2.7 to5.5V
Wide range of liquid crystal display driver power	3.0 to 11V
Liquid crystal drive waveform	A (One line frequency AC waveform
Corresponds to high speed MPU bus interface	2 MHz (when V_{CC} =5 V)
4-bit or 8-bit MPU interface enabled	
80*8-bit display RAM (80 characters max.)	
9,920-bit character generator ROM for a total of 240 character fonts	208 character fonts (5*8 dot) 32 character fonts (5*10 dot)
64*8 bit character generator RAM	8 character fonts (5*8 dot) 4 character fonts (5*10 dot)
16-commom*40-segment liquid crystal display driver	
Programmable duty cycles	1/8 for one line of 5*8 dots with cursor 1/11 for one line of 5*10 dots with cursor 1/16 for two lines of 5*8 dots with cursor
Wide range of instruction functions	Display clear, cursor home, display on/off, cursor on/off, display character blink, cursor shift, and display shift.
Pin function compatibility with HD44780S	
Automatic reset circuit that initializes the controller/driver after power on.	
Internal oscillator with external resistors	
Low power consumption	

Table 4.2.4.4-1: Features of the Hitachi HD4470U Controller and Driver

4.2.4.5 Compatible LCD Displays

LCD Display

<u>Description</u>

An LCD display that meets the requirements of the Hitachi HD44780 driver is the SSC2F20 20*2 STN LCD with LED Backlight. This LCD display is a 20 character by 2 line blue HD44780 Super Twisted Nematic (STN) with built-in HD44780 equivalent

controller (also known as alphanumeric displays) . The interfacing is simplified with 4-bit or 8-bit communications.

Below in Figure 4.2.4.5-1 is a block diagram for the SSC2F20 LCD display.
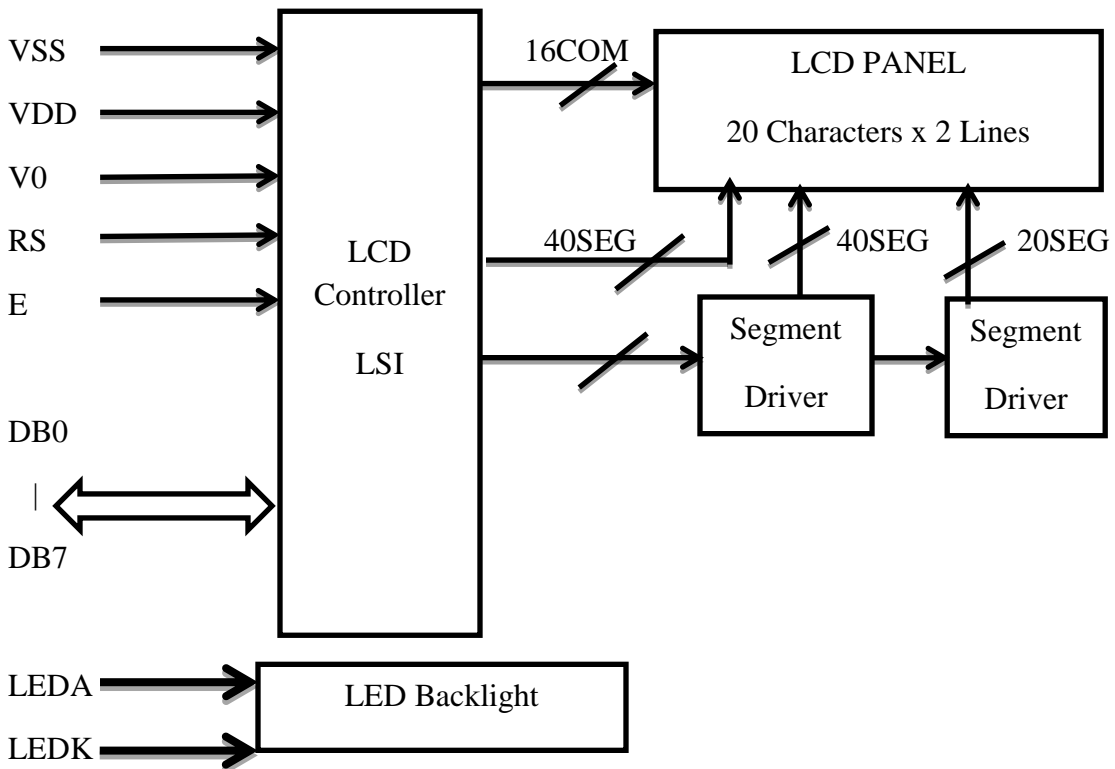
Figure 4.2.4.5-1: Block Diagram of SSC2F20 LCD Display.

A schematic illustration of the power supply circuit is illustrated below in Figure 4.2.4.5-2 below.
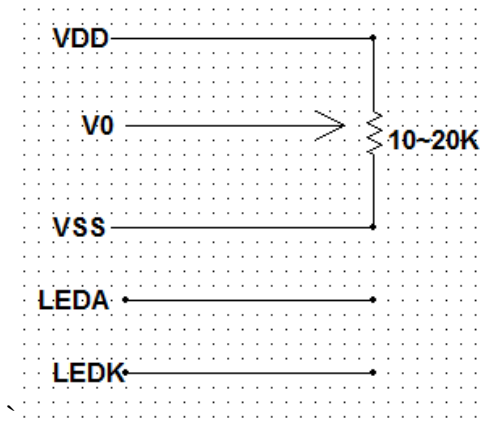
Figure 4.2.4.5-2: Schematic of Power Supply Circuit

The specifications of this LCD display are described in Tables 4.2.4.5 (a-d) below.

Mechanical Data

Item	Nominal Dimensions	Unit
Module Size (W*H*T)	116.0*36.0*13.0	mm
Viewing Area (W*H)	83.5*18.4	mm
Character Size (W*H)	3.25*5.39	mm
Dot Size (W*H)	0.61*0.63	mm

Table 4.2.4.5 (a.): LCD Mechanical Data

Pin Connections

Pin	Symbol	Level	Functions
1	VSS	----	GND (0V)
2	VDD	----	Supply Voltage for Logic (+5V)
3	V0	----	Power supply for LCD
4	RS	H/L	H: Data; L: instruction Code
5	R/W	H/L	H: Read; L: Write
6	E	H/L	Enable Signal
7	DB0	H/L	Data Bus Line
8	DB1	H/L	
9	DB2	H/L	
10	DB3	H/L	
11	DB4	H/L	
12	DB5	H/L	
13	DB6	H/L	
14	DB7	H/L	
15	LEDA	----	Backlight Power (+5V)
16	LEDB	----	Backlight Power (0V)

Table 4.2.4.5 (b.): LCD Pin Connections

Item	Symbol	Min	Type	Max	Unit
Input High Voltage	V_{IH}	2.2	----	VDD	V
Input Low Voltage	V_{IL}	0	----	0.6	V
Output High Voltage	V_{OH}	2.4	----	VDD	V
Output Low Voltage	V_{OL}	0	----	0.4	V

Table 4.2.4.5 (c.): LCD Electrical Characteristics

Absolute Maximum Ratings

Item	Symbol	Min	Type	Max	Unit
Operating Voltage	VDD	4.5	5.0	5.5	V
Operating Current	IDD	1.2	1.6	2.0	mA
LED Voltage	V_{LED}	4.5	5.0	5.5	V
LED Current	I_{LED}	77	120	180	mA
Operating Temp.	T_{opr}	-20	----	+70	deg. C
Storage Temp.	T_{sto}	-30	----	+80	deg. C

Table 4.2.4.5 (d.): LCD Absolute Maximum Ratings

4.3 Battery

4.3.1 Introduction
The battery is a very essential component for our portable solar power supply to work. If another component malfunctions, there is still a good chance that the portable power supply will work. It is critical that a high quality battery is implemented into the design of this project.

4.3.2 Battery Requirements
The four factors that will be considered for choosing a battery are: (1) Capacity, (2) Size, (3) Cost, and (4) Weight. The most the team is willing to pay for a battery within this capacity range is approximately $80.00. The battery for the project needs to be as light as possible to increase the portability of this solar charger. The weight range of this battery needs to be within 15 pounds to 25 pounds. The size of this battery needs to be within 8 inches*6inches*6inches.

4.3.3 Types
Nickel Cadmium Battery

The NiCad rechargeable batteries were one of the earlier rechargeable batteries. However, now they are almost impossible to find. This battery uses nickel oxide in the cathode and cadmium in the anode, while potassium hydroxide as its electrolyte. They may be stored either charged or discharged. These batteries have a lower capacity than both Ni-MH and Alkaline rechargeable batteries. They typically have about 10 to 20 of the capacity of alkaline of the same size. Most common devices used today, if powered by the NiCad could maybe run for only one tenth to one fifth of what the alkaline battery could do. Not to mention, this type of battery contains toxic metals that require

hazardous waste disposal. This type of battery has initial potential of 1.2 V, in comparison to the alkaline battery having an initial potential of 1.5V.

The biggest disadvantage of this battery is that it suffers from memory effect. Memory effect is when the batteries come weaker with continued use, this tends to happen when the actual battery has seen light use and they do not respond well to any future charging.

Type	Secondary
Chemical Reaction	(Charged = Discharged) $2NiOOH + Cd + 2H_2O = 2Ni(OH)_2 + Cd(OH)_2$
Usage Temperature	Good for constant temperature usage. Very low temperature conditions can affect the batteries performance; very high temperature conditions cause the batteries to self-discharge much more rapidly.
Recommended Devices	Scanners, Remote controls (including the Remote controls for RC cars), Portable radios, and Devices which use the battery for backup (answering Machines, clock/radios)
Initial Voltage	1.2 volts or 7.2 volts
Capacity	The capacity of NiMH batteries is higher than that of Ni-Cd. They generally provide up to 30% longer service life.
Discharge Rate	The NiCad discharge curve is flat; it will deliver 1.25 volts throughout most of the discharge time.
Recharge Life	500-700 cycles
Storage	Ni-Cd batteries self-discharge about 1% per day in storage. Since these batteries contain cadmium, they must be recycled; they cannot be simply thrown away.

Table 4.3.3-1: NiCad Batteries Characteristics

Rechargeable Alkaline Battery

The rechargeable alkaline batteries are most commonly known when batteries come into one's mind. These types of battery are most commonly used because they are in your standard AA and AAA batteries. Alkaline batteries have very long shelf lives. These batteries do not suffer from the memory effects that other batteries may suffer from. For example, NiCad batteries suffer from memory effect. The rechargeable alkaline battery has a higher standard voltage that the standard alkaline battery. The lifetime of alkaline rechargeable battery is almost up to 30 times greater than the non-rechargeable kind. Non-rechargeable batteries could usually cost around 3 to 6 dollars for a pack of six, while the rechargeable cost around 20 dollars with the charging kit included. You could see the benefit of having the rechargeable over the non-rechargeable batteries. The alkaline battery that is made to be recharged is made out of alkaline manganese. These batteries are more not rated highly in most of the technical reports researched. Even

though these batteries are usually rechargeable for up to a maximum of 100 times, they do not recharge times as the other rechargeable batteries.

A great benefit from this battery is it does not self-discharge. The NiCad battery shows a big disadvantage in this area. NiCad is a type of battery that does self-discharge. The rate of the self-discharge in the NiCad battery is almost about 2% per week. In addition, if the temperatures were to raise high than room temperature this could make these rates increase. The disadvantage of the alkaline rechargeable is the fact that they are lower capacity than the Ni-MH. The alkaline rechargeable are not seen as fully rechargeable because each time the battery takes a charge the battery will lose a portion of its capacity. The Ni-MH rechargeable battery can offer almost ten more charge cycles than the alkaline rechargeable battery.

Type	Primary
Chemical Reaction	$2Zn + 3MnO_2 \xrightarrow{KOH} 2ZnO + MN_3O_4$
Usage Temperature	-20º F to 130º F (-28º C to 54º C). Good range of operating temperatures
Recommended Devices	Scanners, Remote controls (including the remote controls for RC Cars), Portable radios, and any device using the battery for backup (answering machines, clock/radios)
Initial Voltage	1.5 volts or 9.0 volts.
Capacity	Alkaline batteries do not have a standard capacity rating; see the Capacity heading for a full explanation.
Discharge Rate	Sloping. Products with a high current drain are particularly hard on batteries; the higher the current drain is, the steeper the discharge slope will be.
Recharge Life	100 cycles
Storage	Loses 5% of performance per year.

Table 4.3.3-2: Alkaline Batteries Characteristics

Nickel-Metal Hydride Battery

The Ni-MH battery has grown and been popular in the past few decades. In the mid-1990s the Ni-MH batteries reach the common home. You will commonly see this battery in TV remotes, handheld GPS units, flashlights, and many more devices. The nickel-metal battery is very similar to the NiCad battery but with a higher capacity and no super toxic components.

Some advantages to this battery are that it has a high energy density. It has a flat discharge characteristic, has a wide operating temperature range, plus has a rapid charge. The battery could charge possibly in about an hour. The battery is a much safer battery than the high lithium ion battery in case of any accident or abuse due to active chemicals. This is very important to know, particularly in high power and automotive applications.

Some disadvantages to this battery are the fact that it has lower current then the NiCad battery. Therefore, the high current applications like cordless power told and electric cars

continued to uses the NiCad battery. The battery has high self-discharge rate, and battery will start to deteriorate during long time storage. The cell voltage ranges only about 1.2 V which implies that the cells are required to make high voltage batteries, compared to lithium ion batteries that have three times the cell voltage and a much higher energy density. Table 4.3.3-3 below shows the characteristics of the NiCad battery.

Type	Secondary
Chemical Reaction	$NiOOH + (M)H = Ni(OH)_2 + (M)$ where (M) is the specific metal alloy.
Usage Temperature	Good in constant temperature situations. Low temperature conditions can affect the batteries performance. Usable for all discharge rates: high, medium and low. Commonly used in high-discharge devices such as: Digital Cameras, RC cars, Portable Power Tools, Heavy-use
Recommended Devices	Flashlights, CB Walkie-Talkies, FRS radios, Portable Televisions, Handheld Video Games, Portable Audio Systems (Boom boxes), CD Players, MP3 Players, Appliances, Shavers and Toothbrushes
Initial Voltage	1.2 volts or 7.2 volts
Capacity	The capacity of NiMH batteries is higher than that of Ni-Cd. They generally provide up to 30% longer service life.
Discharge Rate	Flat
Recharge Life	300 - 400 cycles
Storage	NiMH batteries self-discharge about 4% per day in storage. NiMH batteries can be recycled by dropping them off at any of our over 7,200 stores nationwide.

Table 4.3.3-3: Ni-MH Batteries Characteristics

The Figure 4.3.3-1 below shows a comparison discharge voltage charge between two types of batteries. The alkaline battery and Ni-MH battery. The chart shows that the alkaline initial voltage is a t 1.5 compared to 1.2 V the Ni-MH starts at. The Ni-MH battery has more of a steady discharge, whereas the alkaline has a much steeper slope.
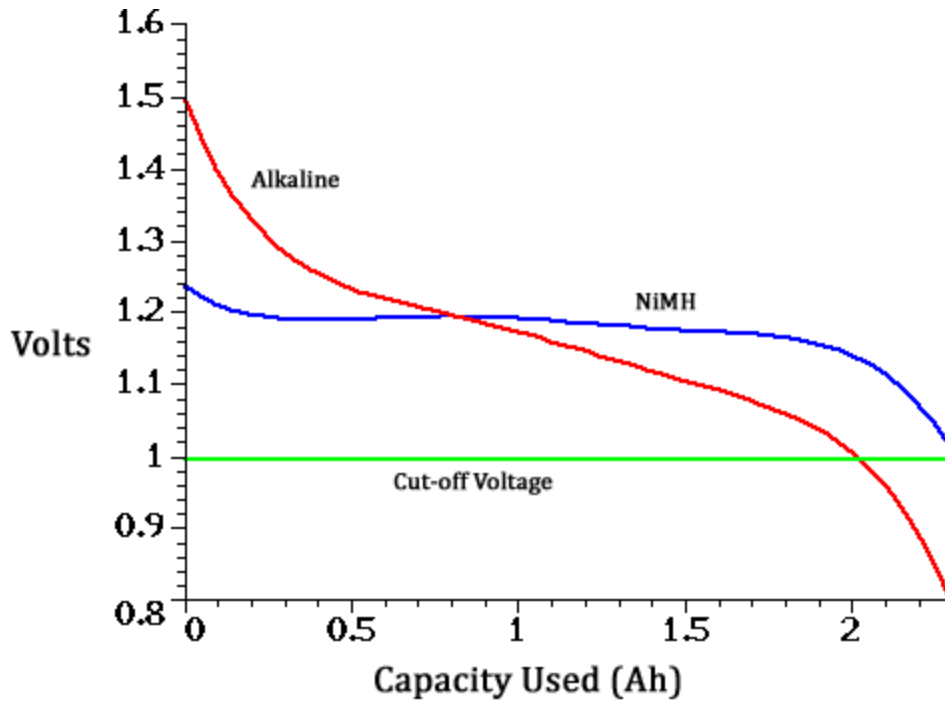
Figure 4.3.3-1: Comparison Discharge Voltage Chart. Reprinted with permission from Stefav Jovic

Lithium Ion Battery

Most portable devices today run of lithium ion batteries. For example, digital cameras, cell phones, camcorders, laptops, iPod's and many more devices. These are one of the most popular batteries because by weight they are one of the most energetic rechargeable batteries available.

Some of the advantages of the lithium ion batteries are why they are used in almost the common electronic devices. They are lighter than any of the other rechargeable batteries that are the same size. The electrodes of the battery are made of light weight carbon and lithium. These batteries can store a lot of energy in its atomic bonds, since lithium is a highly reactive element. For example, a lithium ion battery can store up to 150 watt-hours of electricity in one kilogram of battery, where as a NIHM battery pack can store 100 watt-hours per kilogram. A lead acid batter can store around 25 watt-hours per kilogram. If you look at the differences between the watt-hours, the lithium ion is a great choice in this category. The lithium ion batteries also hold their charge while only losing 5 percent of it charge per month. Compared to the NIMH battery has a 20 percent loss of charge per month. This type of battery has no memory effect, they can handle hundreds of charge and discharge cycles.

The lithium ion battery also has disadvantages. The lithium ion battery will start to degrade as soon as they are sent out of the warehouse. This makes the battery life of only two to three years from when they are made. They need an on board computer to manage the battery, which is why the cost of them are higher. In just recent news, they have

discovered that the lithium ions batteries have the ability to burst into flames. This is not a common issue where it would happen every time you purchased a pack, but around two or three packs out of every million sold. The table 4.3.3-4 below shows the characteristics of the lithium ion battery.

Type	Secondary
Chemical Reaction	Varies, depending on electrolyte.
Usage Temperature	4º F to 140º F (-20º C to 60º C)
Recommended Devices	Cellular telephones, mobile computing devices.
Initial Voltage	3.6 volts and 7.2 volts
Capacity	Capacity Varies (generally up to twice the capacity of a Ni-Cd cellular battery)
Discharge Rate	Flat
Recharge Life	300 - 400 cycles
Storage	Loses less than 0.1% per month.

Table 4.3.3-4: Lithium Ion Batteries Characteristics

Lead Acid Battery

The lead-acid battery was invented in 1859 by French physicist Gaston Plant, being one of the oldest rechargeable batteries. They use a chemical reaction of lead, lead oxide and sulfuric acid to produce voltage. Voltages range from 10-14v DC and are commonly used in vehicles and older battery applications like golf carts and motorized wheelchairs. The battery has a nominal cell voltage of about 2.1 V. It has the second lowest energy to weight ratio, the nickel-iron battery being on top. One of the most important characteristic of a battery is the lifetime, the maintenance required, and the depth of the discharge. The Lead acid batteries typically have a energy efficiency of 70% and a coulombic efficiency of a 85%. The battery is almost 2 to 4 times less expensive than the NiCad batteries. The lead-acid battery can also retain nearly their full charge for about two months when they are unattached to a charger. The system of a lead-acid battery averages voltage during discharge, energy output, and the capacity delivered is dependent upon the discharge current.

The advantages of a lead-acid batteries are numerous. They have very low cost, as well as, being very reliable since they have been under development for over 140 years. The battery is tolerant to abuse and tolerant to overcharging. It can deliver very high voltage and can be left on trickle or float charge for prolonged periods. This product is also the world's most recycled product, with a wide range of sizes and capacities available in the market. The battery has disadvantages, one of them being that they are typically heavy and bulky. The battery could also overheat during charging, and it is not really suitable for fast charging. The battery will usually last longer with partial discharges and the charging methods should be in consideration with the constant voltage followed by a float chart. The table 4.3.3-5 below shows the characteristics of the lead-acid battery.

Type	Secondary
Chemical Reaction	(Charged = Discharged) $PbO_2 + SO_4 + 4H = PbSO_4 + 2H_2O$
Usage Temperature	-85º F to 149º F (-65º C to 65º C)

Recommended Devices	Camcorders, alarm systems, cellular telephones, and deer feeders.
Initial Voltage	Varies
Capacity	Varies
Discharge Rate	Flat
Recharge Life	-40º F to 149º F (-65º C to 65º C)
Storage	No more than six months, varies by temperature (longer at non-freezing low temperatures, shorter at high temperatures).

Table 4.3.3-5: Lead Acid Batteries Characteristics

The team's goal is to purchase a 12V lead acid battery that has a capacity range between 20Ahr and 40Ahr. When compared to all of the other gel batteries of the same capacity, the lead acid battery are the best priced. One of the batteries we found is a sealed lead acid battery that falls within the 4 factors the team will use to for considering a battering. This battery is manufactured and distributed by Powerizer. Below in Table 4.3.1-6 is a list of the Powerizer battery performance specifications:

Nominal Voltage(V)		12 volts(6cells in series)
Nominal Capacity (AH)		
• 20 hour rate F.V (1.75V/cell) (1000mA to 10.50volts)		20.0A.H.
• 10 hour rate F.V.(1.75V/cell) (1900mA to 10.50volts)		19.0A.H.
• 5 hour rate F.V.(1.75V/cell) (3400mA to 10.50volts)		17.0A.H.
• 1 hour rate F.V.(1.55V/cell) (1200mA to 9.30volts)		12.0A.H.
Approximate Weight		6350g(14.00lbs)
Terminal		
• Standard		Type B1
• Optional		Type T2, l1
Internal Resistance (Fully Charged Battery)		<11mΩ
Maximum Discharge Current For 5 sec.(A)		300A
Maximum Charge Current(A)		6A
Ambient Temperature		
• Charge		0 C(32 F)~40 C(104 F)
• Discharge		-20 C(-4 F)~50 C(122 F)
• Storage		-20 C(-4 F)~40 C(104 F)
Vibration Test:		
Frequency: 16.7Hz		
Amplitude: 4mm		
Vibrate the battery horizontally or vertically for 60 minutes. The battery has no abnormality.		
Case		ABS
Dimension(mm/inch)		
• Length	±1.5mm	181/7.13
• Width	±1.5mm	76/2.99
• Container Height	±1.5mm	166/6.54
• Total Height	±1.5mm	

Application	UPS, Fishing Lights, Emergency Lights, Lawn Mowers, Video Camcorders

Table 4.3.3-6: Performance Specification data of the battery

A battery in consideration that meets the group's requirements for this project is manufactured by Battery Mart. This battery has a capacity of 28Ah, which is 8 Ah more than the battery manufactured and distributed by Powerizer.

This battery is supposed to have a long shelf life. It has a low self-discharge rate so when the battery is fully charged; it will stay charged for a longer period of time as compared to batteries without a long shelf. The dimensions of this battery meet the dimensions requirements by the group. This battery has a length of 6 and ½ inches, a width of 4 and 15/16 inches, and a height of 6 and 7/8 inches. It has a weight of 22 pounds. The specifications of this battery are listed in the table 4.3.1-7 below:

BM Part #	SLA-12V28
Voltage	12 Volt
Capacity	28 ah
Type	Sealed Lead Acid Battery
Warranty	1 Year
Shipping Weight	22.00 pounds
Length	6 1/2"
Width	4 15/16"
Height	6 7/8"

Table 4.3.1-7: Specifications for the 12V 28ah battery

Another sealed lead acid battery that the group will consider implementing into the solar charger, again a battery that is sold by Battery Mart. This battery has a capacity of 35Ah. This battery is supposed to have a long shelf life and a low self-discharge rate like the battery explained above that was also being sold by Battery Mart. The dimensions of this battery meet the dimension requirements required by the group. This battery has a length of 7 and 5/8 inches, a width of 5 and 1/8 inches and a height of 7 and 3/16 inches including the terminals. It has a weight of 29 pounds. The specifications of this battery are listed in the table 4.3.1-8 below:

BM Part #	SLA-12V35
Voltage	12 Volt
Capacity	35 ah
Type	AGM Sealed Lead Acid Battery
Warranty	1 Year
Shipping Weight	29.00 pounds
Length	7 5/8"
Width	5 1/8"
Height	7 3/16"

Table 4.3.1-8: Specifications for the 12V 35ah battery

4.4 DC/AC Inverter

We focus this section of the report on the DC/AC Power Inverter, its characteristics, its configuration as well as its operation, and at the end we come up with the requirements for the design and specifications on the type of inverter we have to build in our project. Basically, power inverter or inverter is a very useful electrical device which converts DC voltage into AC voltage depending on the desired output need. If you want to boost the DC voltage read across a battery or a solar panel into AC voltage, the best way to do so is to use a Power Inverter. Such is the main purpose of this section, using a Power inverter we would elevate a particular 12 DC volts from a solar panel and converts it into 120 AC volts. The realization of this specific purpose could achieve using a variety of inverters, some with more efficiency than others and also more expensive. Our goal is to create and build such an efficient device with the least cost of money possible that also presents more features and better performance.

4.4.1 Types Of Inverters:

We can identify three (3) main types among the DC/AC inverters in today's market: Square Wave, Modified Square Wave, and Pure Sine Wave.

1. Square wave

Square wave inverters were the first ones among the inverters to be developed. These inverters are not very efficient and are most of the time very dangerous for electronic devices. They produce a square wave

2. Modified Square wave

Modified square wave inverters are the most common and used in the market today. In fact, they present an output that is better adequate than the square wave inverters. They also develop better efficiency. Their applications vary in a large amount of electronic devices, for example, computers, refrigerators… Their output is almost similar to the square wave; however, there is a slight difference on the wave that makes it similar in a certain way to the sine wave output.

3. Pure Sine Wave

Pure sine wave inverters constitute the best ever developed among the inverters. With a sine wave output nearly perfect, pure sine wave inverters are required for devices with a sensitive calibration. Also, there assure that the correct power is running through the loads. They represent the range of most precise inverters, and are applicable in most of electronic devices that require digital wave form. Comparing to the other types of inverters, pure sine wave units are more efficient and project more advantages than either modified square wave inverters or square wave itself. The following Figure.

There are a lot of different types of inverters, but three of them are among the most used in the market. This table shows the difference between these three inverters.

Specifications	Square wave	Modified square	Pure sine wave
Efficiency	Very low	Average	Good
Applications	Limited electronic devices	Large amount of electronic devices	All including devices with sensitive calibration
Prices	Cheap	Normal prices	Expensive

Table 4.4.1-1: Inverters Comparison Table

The table above resumes the research on the specifications for the different types of inverters considered. It also gives us a better view on which one presents more quality and is more suitable for use in our project.

4.4.2 Inverter Configuration System:

In fact, most inverters follow and perform two main functions in order to realize what they are meant to do. Some configurations of inverters realize the conversion from the incoming low voltage DC into low voltage AC first, and then the result low AC voltage converted is stepping up into the desired output by using a step up transformer. Such configuration is based on two processes: the converting step through a simple converting circuit and the elevating with a transformer added to that circuit. The following configuration is shown below (Fig. 4.4.2-1):
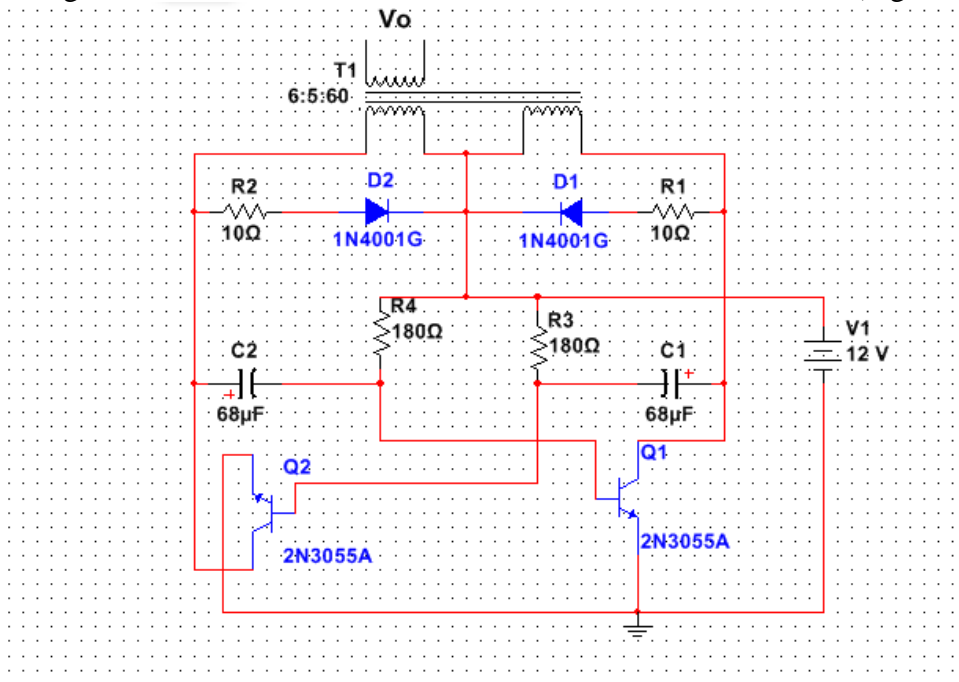
Figure 4.4.2-1: Basic Component Circuit Diagram

As stated above, this configuration takes in considerations some basics steps to complete the process of inverting DC into AC, and as a result the output run only a square wave

which is not so efficient and does not present either the characteristics and specifications of our design.

Modern inverters, however, configure in a way that they use a basic circuit diagram that converts the low DC voltage into a high DC voltage first, and then converts the high DC into a desired AC output voltage. This process is carrying out through some different components that constitute the inverter configuration system itself. Among these components we can illustrate:

1. A DC to DC converter or a simple microcontroller that takes the low input DC and converts it into a high DC out.
2. An H-bridge inverter which is nothing but a very efficient electronic circuit that converts the incoming high DC voltage from the DC to DC converter or Microcontroller into the desired AC output voltage using a couple of high power MOSFETs which act like electronic switches.
3. A Pulse Width Modulator (PWM) which is a special circuit that control and regulate the output AC voltage resulted from the H-bridge inverter. Usually, the PWM uses simple method by comparing a fixed frequency and magnitude triangular carrier with the AC waveform desired.
4. A digital filter which is most often used to correct and reconfigure the output at any desired frequency. Depending on the response we have, low pass, high pass, and band pass behavior with a specific frequency, an active filter can be used to reduce the attenuations of the signal and sharp the edge at cutoff frequency.

The following figures (Fig. 4.4.2-2 & 4.4.2-3) show some examples for modern inverters configurations. The block diagrams are as follow:
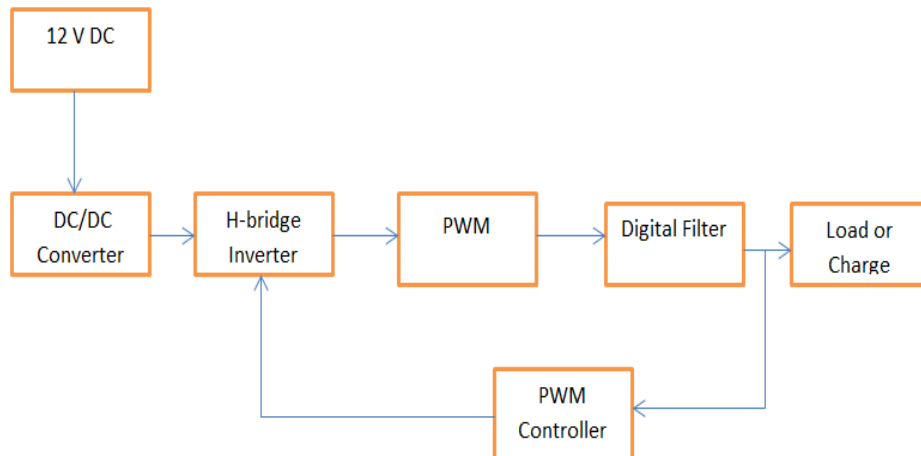
Figure 4.4.2-2: Basic Components Diagram with DC/DC Converter
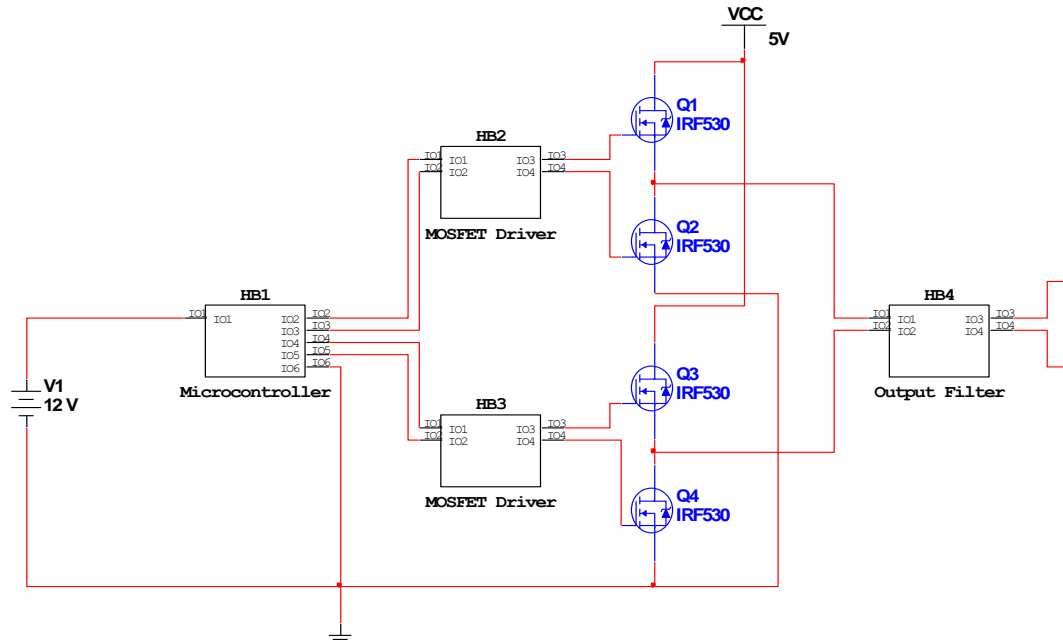
Figure 4.4.2-3: Basic Components Diagram with Microcontroller. Reprinted with permission from WPI

4.4.3 Pure Sine Wave Inverters:

The following sub-section will discuss on Pure or True Sine wave Inverters.
As we made it clear since the very beginning, our goal is to build elements of circuit that provide the maximum efficiency possible with less noise and attenuations. Therefore, we want to build an inverter from which the electrical output power is similar to the output outlets that we have in the house, which is highly reliable and does not produce the electrical noise interference and also reduce the attenuations. We realize then, with its adequate sine wave output, Pure or True Sine Wave Inverter can fully assure that sensitive loads will be correctly powered, with no interference. Indeed, the inverter we have chosen to build for this project is a Pure or True Sine Wave Inverter.

Pure or True Sine Wave Inverters come in many shapes, sizes, and prices. They are among the most expensive inverters in the market today. However, our main focus is will not on prices since we will have to build the inverter from scratch. In fact, our focus is on using and comparing some similar related references designs and at the end we can come up with the best solution that fits perfectly our established goal.

Since we want our project to be small and portable, we assume that our Inverter including all the inside component should not exceed ten (10) pounds (Lbs.). In order to do so, we have to go by the reference circuit that requires less equipment and components but that provide at the meantime better efficiency.

The first reference design we will consider is the Full-bridge or H-bridge Inverter with transformer whose equivalent circuit is shown as follow:
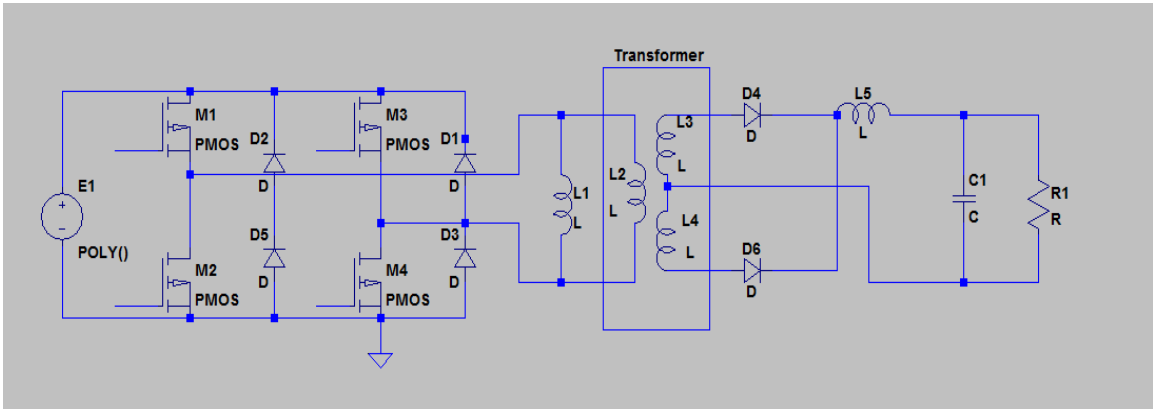
Figure 4.4.3-1: H-bridge Inverter with Transformer

In this circuit, the DC voltage being provided by the DC supply goes to the H-bridge converter that performs the DC to AC conversion using MOSFETs as electronic switches. Then, through a step-up transformer elevate the AC output voltage in an adequate level to the load. We also used a filter type LCL that reduces the noises and attenuations from the output point of the load.

We are going to describe, briefly, in the following lines each and every element that constitutes the H-bridge Inverter circuit diagram.

1. H-bridge or Full bridge converter
   By using Transistors MOSFETS switches, this element of the circuit converts DC voltage into AC producing the pulses and allowing access to the system. This converter is also control by the Pulse Width Modulator that sets the output sine wave.
2. Transformer and Filter
   The transformer allows us to control and set the AC output voltage into the desired one. Since, we expect to read 120 VRMS to the load, the transformer should be chosen in a way that it complies with the criteria of the design. From the output of the transformer, the filter is connected in order to reduce the attenuations at the load.

Now, we will consider another reference design that implements the Pure Sine Wave Inverter. It is shown in the following figure:
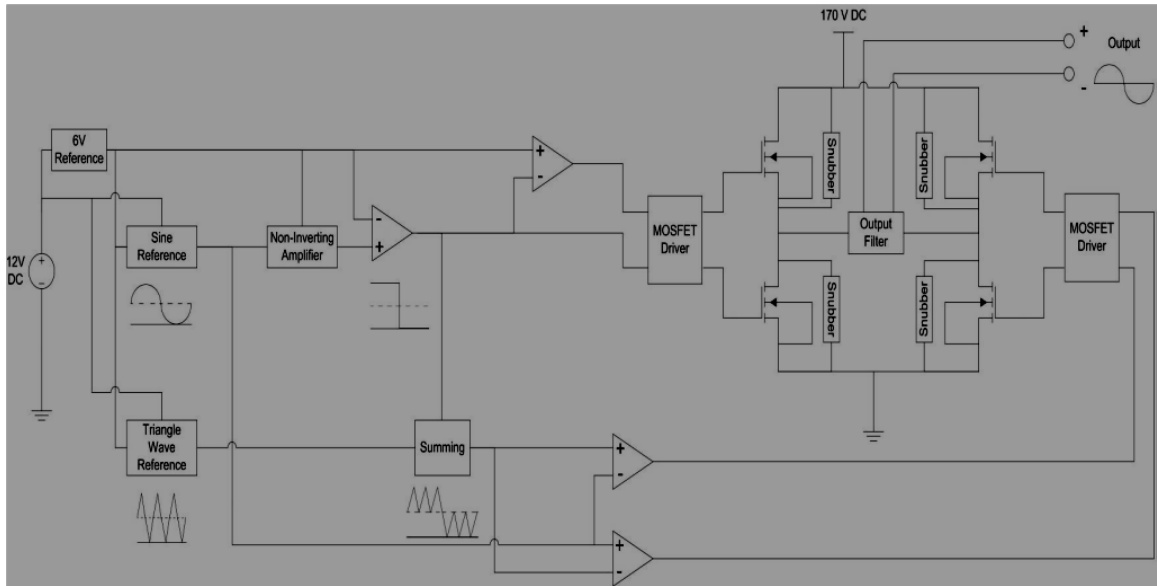
Figure 4.4.3-2: Pure Sine Wave Inverter Block Diagram. Reprinted with permission from WPI

As we have seen in the previous reference design, this diagram has many similarities to the previous design for the major components. The difference resides on that, for this particular design, the use of a Budda oscillator simplifies the circuit and makes it easy implement. With the use of that oscillator, we are no longer need to use a transformer. The block diagram below shows the varying parts of the project for this particular reference design. An analog circuitry compounded of op-amps, transistors, and other electronic components that drive low DC voltage into high DC voltage through the H-bridge converter. From that point, the circuit follows the path to the low pass filter and later shows the result as a sine wave output to the load.

We can also use a different circuit to implement the DC to DC converter alternatively to the Budda Oscillator. Such circuit is known as DC to DC boost converter and takes the 12 V DC from the input and converts it into a high DC voltage like 120 V. And then, it goes to the input of the Full-bridge Inverter that converts the 120 V DC into 120 V AC. This particular circuit is shown in the following figure (Fig. 4.4.3-3):
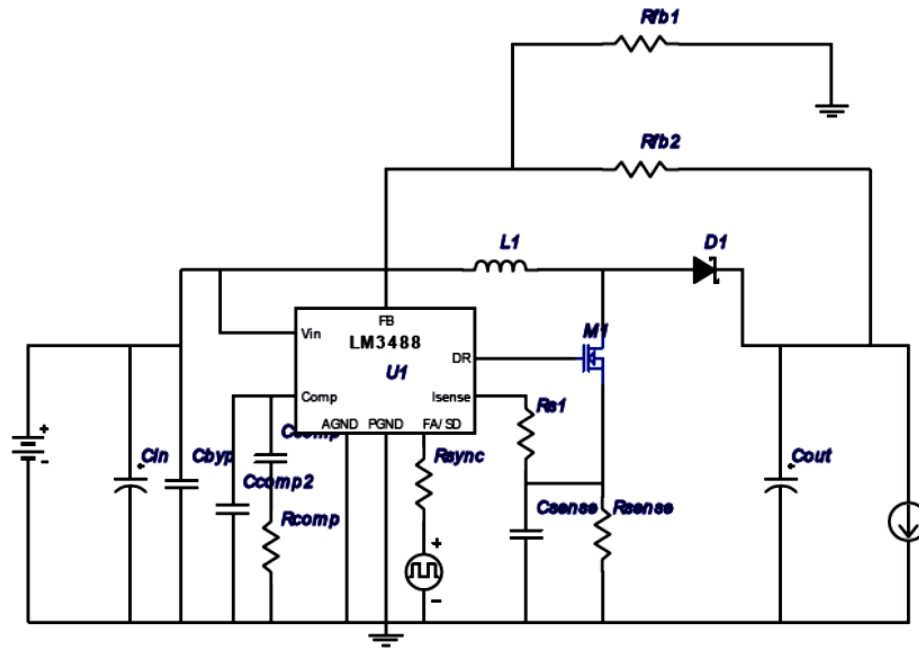
Figure 4.4.3-3: 12V DC to 120V DC Converter. Reprinted with permission from Texas Instrument

Since modern inverters use Power MOSFETs as to convert DC voltage into AC, it becomes also more convenient and easier to implement other circuit in order to come up with other solution for better and more efficient Inverter. The figure below (Fig. 4.4.3-4) is just an example of a total different circuit that we can combine with the H-bridge converter without the implementation of a transformer to perform the same job of inverting 12V DC into 120V AC, but now with better efficiency.

Another similar reference design for the Pure Sine Wave Inverter is shown in the following figure (Fig. 4.4.3-4):
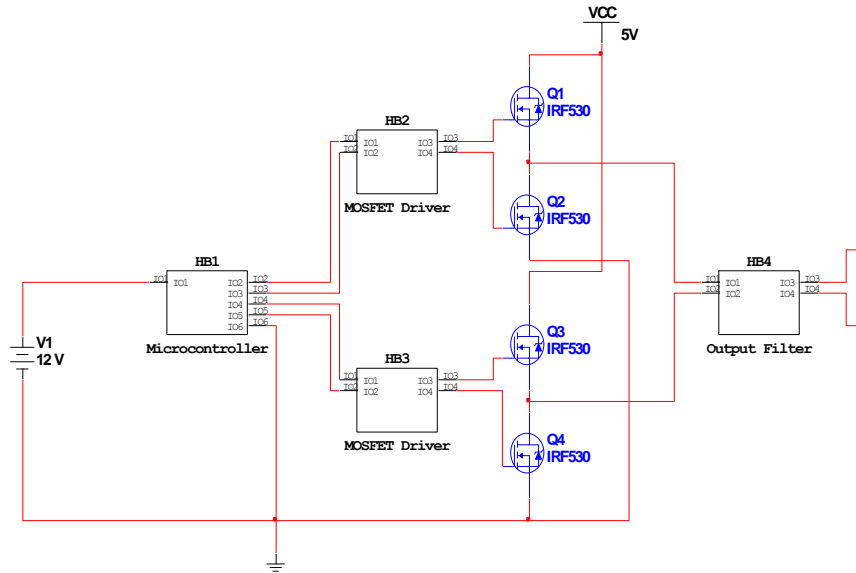
Figure 4.4.3-4: Pure Sine Wave Inverter with Microcontroller. Reprinted with permission from WPI

In the diagram below, a microcontroller constitutes an even better solution to the problem of Pure Sine wave Inverter. With fewer components and more ways to control the output to the load, we expect to have more efficient results which at the end comply with our established goals. The Microcontroller simplifies then the circuit and gives and easy solution, and as a result we can approximate our approach saying that this solution is adequate and will use as the reference for our Pure Sine Wave Inverter building project.

There are so many configurations when it comes to build a Pure sine Wave Inverter; however, we have limited our research on three (3) of the most used among the configurations. The following table establishes the difference between each of the configuration chosen:

Specifications	Inverter using boost-converter	Inverter using transformer	Inverter using Microcontroller
Circuit diagram	Expanded	Expanded	Reduced
Efficiency	Good	Good	Very good
Control	Good	Average	Very good
Waves	Modified square	Square	Pure or true sine

Table 4.4.3-1: Inverters Configuration System Table

The comparison above between some types of configurations used allow us to conclude that the H-bridge configuration with microcontroller presents better features for our design project and may be used as a reference design.

4.4.4 Operational Description:

Inverters or power inverters are not about one single electronic component, but many electronic parts and components combined together to carry out a specific goal. As stated in the previous section, the process of invert DC voltage into AC voltage can realize through a series of steps, and each step corresponds exclusively of a separate component that for itself corresponds to another series of steps. This sub-section of the report will discuss and describe each and every component that is part of the whole inverter particularly the Pure Sine Wave Inverter that we will consider and design on this project.

Before we start to describe the operation of each component, let us first consider what are the most essential components that intervene in the process of inversion by taking in count the Pure Sine wave Inverter.

As we explained it on the previous section, in order to convert 12V DC into 120V AC, the pure sine wave inverter performs two (2) main functions: it first takes the low DC voltage, converts it into high DC voltage and then converts that high DC voltage into the desired AC need.

Basically, the first function to perform is the DC to DC conversion. This process consists on either using a boost converter or another electronic component that can perform the same function. Let us first look at the description and operation of the Boost Converter.

Boost Converter

In order for the Pure Sine Wave Inverter to complete its first function which consists on elevating the low DC voltage, we need a boost converter capable of converting the low DC voltage read across the DC source into high DC voltage.

There are many ways and many references available in order to come to realize the circuit of a boost or DC/DC converter. Among them, we have selected four (4) types based on their performance, the cost of their parts, and also their efficiency.

1. The first circuit to consider is the simple 12-180V boost converter using the 555 timer as a controller. That particular circuit is shown below in Fig. 4.4.4-1 :
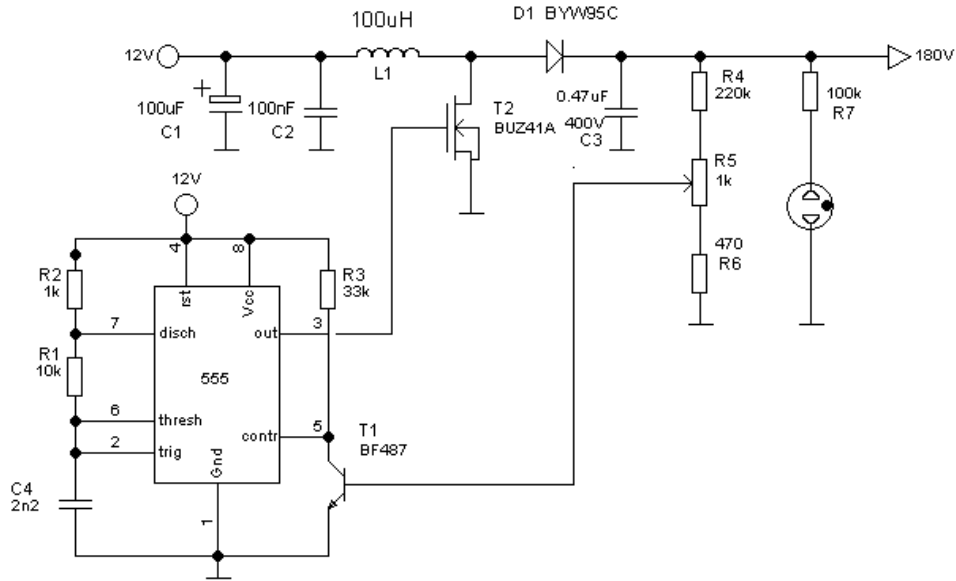
Figure 4.4.4-1: 180V DC/DC Boost Converter Using 555 Timer

The interesting thing about this circuit is the use of the 555 timer which is a cheap device in order to perform the output desired. However, there are so many ICs controllers today that can perform the same job that the use of 555 timer is not so current even though the 555 time presents strong, stable, and longer life than ICs controllers and most importantly production forever.

2. The second circuit to consider is called cheap high voltage low current DC to DC converter. It can operate in the range of input 8 to 12V DC into the output voltage from 120 up to 300V. The circuit was built based on general equipment such as transformer, integrated circuit, transistors, capacitors, and resistors. The integrated circuits produce the waves that go to the output. The circuit below is shown the configuration of the called cheap high voltage low current DC to DC converter Fig. 4.4.4-2:
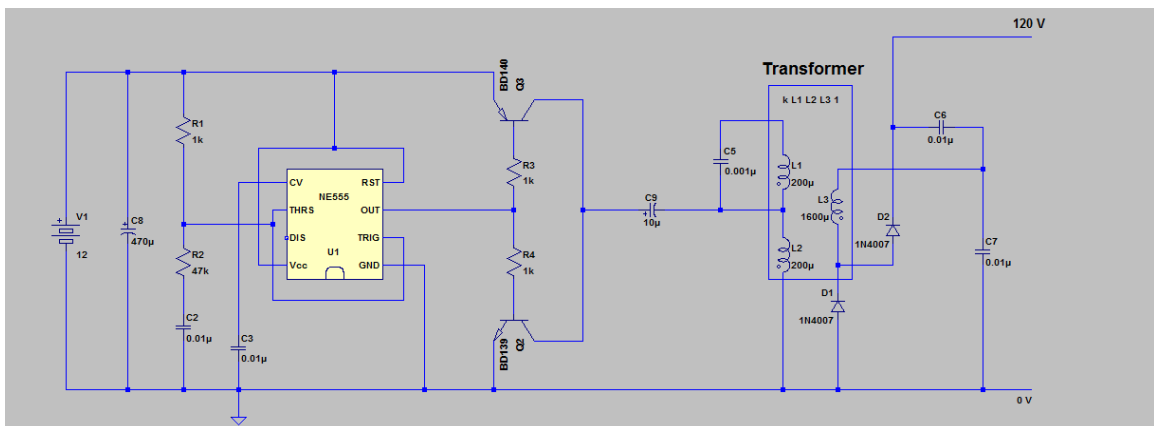
Figure 4.4.4-2: Cheap High Voltage Low Current DC to DC converter

3. The third circuit to consider is the 12V to 120V DC to DC converter. The circuit can be described in two stages: firstly it will consist of a basic inverter stage then a rectifier filter stage.
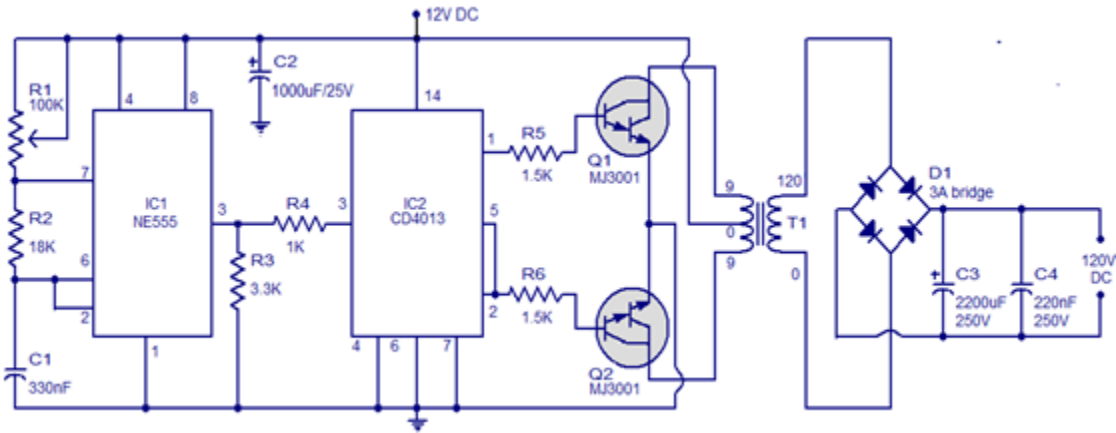
Figure 4.4.4-3: 12V to 120V DC to DC Converter. Reprinted with permission from Circuit Today

The circuit above Fig. 4.4.4-3 is shown the configuration of the 12V to 120V DC to DC converter. The IC NE555 is connected as an unstable multi-vibrator that can be adjusted using R1. The IC CD4013 is controlled by MOSFETS Q1 and Q2. When Q1 is activated, current flows in the half upper part of the transformer's primary winding. When Q2 is activated, current flows through the half lower part of the transformer's primary winding. As a result, a 120V AC is induced in the secondary of the transformer. This voltage is rectified using bridge D1 to produce 120V DC output. Capacitor C2 is the input DC filter while C3, C4 are output filters.

4. The fourth and last circuit we have considered is the called Boost converter DC to DC converter using LM3488 integrated circuit. The range of the input voltage is from 8 to 14V DC and produces an output of 120V DC. The data sheet of the LM3488 explains that the LM3488 is a versatile Low-Side N-FET high performance controller for switching regulators. It also said that the LM3488 has built in features such as thermal shutdown, short-circuit protection and over voltage protection. The following figure Fig. 4.4.4-4 is shown of the Boost Converter that we will consider in the project.
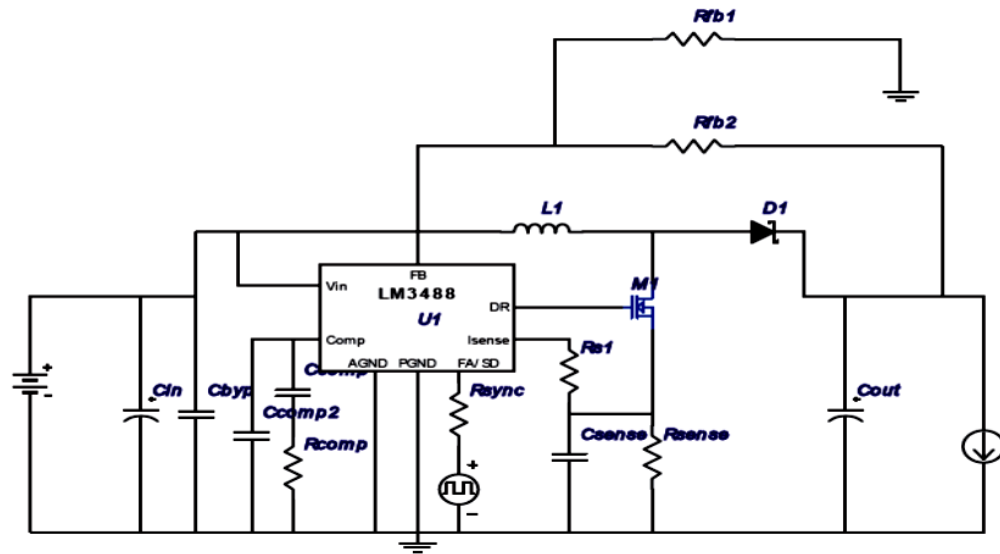
Figure 4.4.4-4: Boost Converter. Reprinted with permission from Texas Instrument

From the four (4) different types of DC to DC converter considered in the previous paragraphs, the one that offers more convenience for the purpose of our project is the last one recently considered. Because of its efficiency, the ease on building the circuit, and also the very low price of the equipment, this configuration will be consider on our project.

Bridge Converter

Once we finished elevating the DC voltage, our focus is to convert the high DC voltage resulted into AC voltage. The most convenient way to do it is to use a half-bridge or an H-bridge (Full-bridge) Converter. Half-bridge and Full-bridge converters have a lot of similarities – same configuration for example - , but their operation carries out some differences in the output. In fact, both converters are shown in the following figures.

Half-bridge converter

The figure below is a representation of a half-bridge converter. V1 is the bridge input DC voltage incoming from the DC/DC converter. Each capacitor C1 and C2 has half of the input voltage DC. The half voltage across the capacitor is switched to the output of the bridge by MOSFETs T1 and T2 alternatively. As a result, the switch that is off contains the full voltage across it.
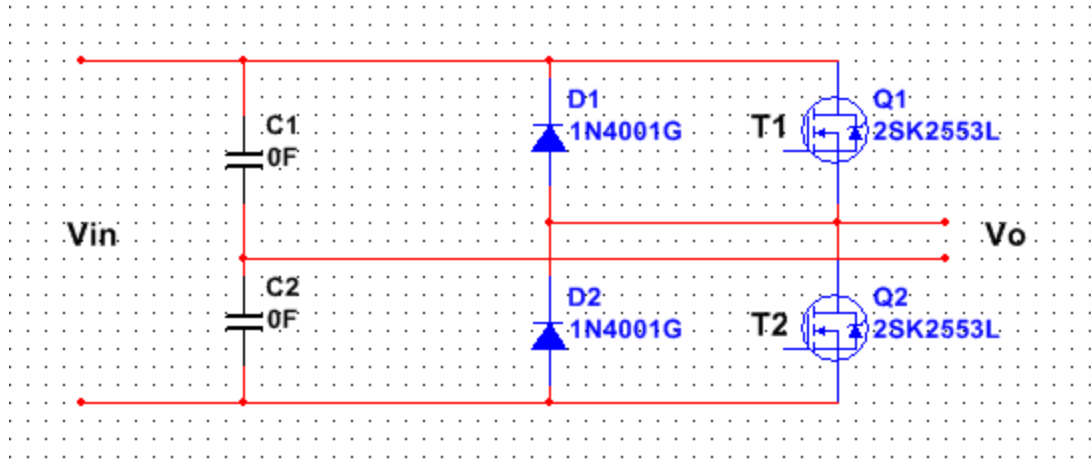
Figure 4.4.4-5: Half-bridge

Full bridge converter

Unlikely to the half bridge converter, the full-bridge one has a configuration of four (4) transistors mounted with four (4) diodes connected in parallel to these transistors.
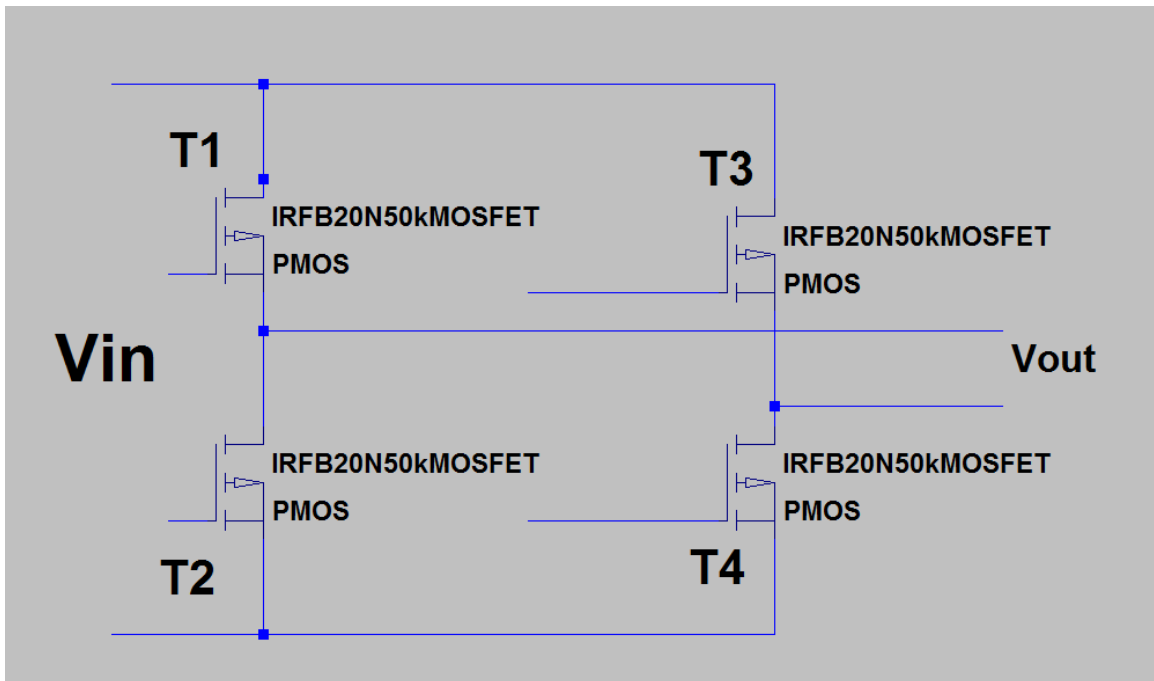
Figure 4.4.4-6: Full-Bridge

We need a full bridge to convert the high DC voltage generated from the boost converter into AC voltage. As we can easily identify, it consists of four (4) switches that control the operation of the output of the AC resulted voltage. These switches are transistors and can be made of either MOSFET or IGBT or high power transistors that can be also GTO or GTC.

55

The pair of switches T1 and T3 is switched simultaneously, and then T2 and T4 come after. The requirement for gates isolation circuits impose for a minimum of two (2) of the bridge. And as a result, the output voltage is twice of that of the half-bridge. The following table shows different positions of the switches as well as the sign on the load for the output voltage.

High side left	High side right	Low side left	Low side right	Voltage load
On	Off	Off	On	Positive
Off	On	On	Off	Negative
On	On	Off	Off	Zero
Off	Off	On	On	Zero

Table 4.4.4-1: Switches Position and Load Sign

From the table above, we can draw the following summary explaining that the voltage across the load can be either positive, negative, or zero depending whether the switch is closed or opened at any given moment.

In choosing which type of power transistors to use as switches, we have considered four (4) options:

Power MOSFET

The MOSFET is a voltage but not current controlled device. It has a body-drain diode, which is particularly useful in dealing with limited free-wheeling currents. It also has a positive temperature co-efficient, stopping thermal runaway. Because of its on-state-resistance that is no theoretical limit, its on-state losses are pretty much lower. Considering all these advantages, the MOSFET has become the choice for our power switch design.

IGBT

The IGBT or Insulated Gate Bipolar Transistor is a cross between the bipolar and MOSFET transistors. It has the output switching characteristics and also conduction of a bipolar transistor but it is like MOSFET voltage controlled. It has then advantages of high-current handling capability, but its disadvantages comply on the fact that it has no body drain diode.

GTO

The GTO or Gate Turn-off Thyristor is a variant device of the Thyristor form standard. It is a four (4) layers-device having three junctions. It behaves somehow differently to a standard thyristor which can only be turned on and cannot be turned off via the gate. The key capability of the GTO is its ability to be turned off by the use of the gate electrode on the device.

GCT

The GCT (Gate Commutated Thyristor) is a new thyristor device that is similar to a GTO. However, its goal is to reduce the cost and complexity of the gate and snubbers required in GTO applications.

The following table summarizes and compares the four (4) types of power transistors considered through our research paper. As the table clearly explained it, based on the requirement of our design and the advantages of the MOSFETs over the other types considered, we have come to suggest that power MOSFET presents better features and has most of the characteristics that carry out our goals. One important feature of power MOSFETs, in fact, is they have a large stray capacitance between the gate and the other terminals.

Device type	Rated voltage	Rated current	Rated Freq.	Forward volt.
MOSFET	500 V	50 A	1 MHz	3 – 4 V
IGBT	1.2 kV	400 A	20 kHz	3 – 4 V
GTO	4.5 kV	3 kA	2 KHz	3 – 4 V
GCT	6 kV	4 KA	1 KHz	1.5 – 3 V

Table 4.4.4-2: Power Transistors Comparison

After identifying which type of power transistors, MOSFET, which present better features to use, it is also crucial to choose which type of MOSFETs will meet better the specifications and considerations of our design since there are two (2) types of them: P-channel and N-channel devices. It we did not have to use MOSFET drivers on both sides of the bridges, high and low sides, P-channel MOSFETs would be a good solution with easier route. However, since we have to use MOSFET drivers on both side of the bridge, N-channel would be the best solution for our project.

MOSFET Drivers

As with any design decision, there are multiple variables involved when selecting the proper MOSFET driver for the MOSFET being used in the design. Parameters such as input-to-output propagation delay, quiescent current, latch-up immunity and driver current rating must all be taken into account. Power dissipation of the driver also affects your packaging decision and driver selection.

In selecting which type of MOSFETs drivers to use, there are many chips available from several companies. Because we need a voltage of at least 10 volts to set the gate terminal in order to turn on a power MOSFET, it is important to use a driver MOSFET across the gate terminals capable of supplying a reasonable current so the stray capacitance can be

charged up fast. Some MOSFETs drivers request that the MOSFET source terminals to be grounded; some others do not require that. For example, TDA340 also controls the switching sequence of the MOSFET source. And so, we have developed a table that provides the manufacturer name, the driver name, as well as some available features for the driver.

Manufacturer	IC	Features
Maxim and others	ICL 7667	Dual inverting driver
Maxim	MAX622/MAX1614	High side drivers
Maxim	MAX626/MAX627/MAX628	Low side drivers
International rectifier	IR2110	High and low side driver
Harris/ Intersil	HIP4080/40821/4082	Full bridge drivers
SGS	TD340	New full bridge driver with analog or PWM speed demand input
Other	Alpha/semiconductor/Motorola	

Table 4.4.4-3: Driver MOSFETs Comparison

The following Fig.4.4.4-7 is a representation for the MOSFET driver circuit. The connection is shown below:
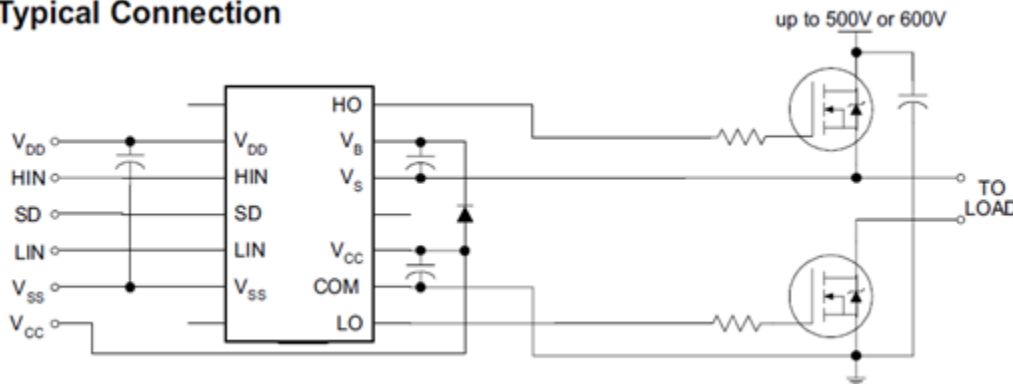
Figure 4.4.4-7: MOSFET Driver Circuit Connection. Reprinted with permission from International Rectifier

Pulse Width Modulation (PWM)

The PWM consists in a way to control the output voltage of the inverter internally. It may also be considered as a method of generating AC power. We can modify the duty cycle of a PWM by using a DC voltage and makes it look like AC across a load. In order to do so, the use of analog circuit or a microcontroller that will generate the duty cycle of the PWM signals is required. On this section of the report, we will consider both the analog circuitry and microcontroller uses.

The operation of the analog circuit as generator of PWM signals reside on the fact that we have to use electronic components like Op-Amps, transistor, Diodes, Resistors,

capacitors, Inductors to build elements of the circuit as generator of sine wave, generator of triangle wave, comparator, and other elements that are part of the circuit. The PWM signals then can be generated by feeding a reference sine wave and a carrier triangle wave through the comparator which produces the output voltage based on the difference of the two (2) inputs. It is convenient to set the reference sine wave at the frequency and the form of the output desired.

In our case, the reference is a sinusoidal at 60 Hz. At this point, the output is a 2 level PWM signals and it does not completely look like the sinusoidal wave. In order to complete the process of getting the output as a complete sinusoidal wave, we need to use an H-bridge converter. After passing through the bridge converter, the output signals should look like the following one in the figure Fig. 4.4.4-8. At this point, the output corresponds to a 3 level PWM sinusoidal signals.
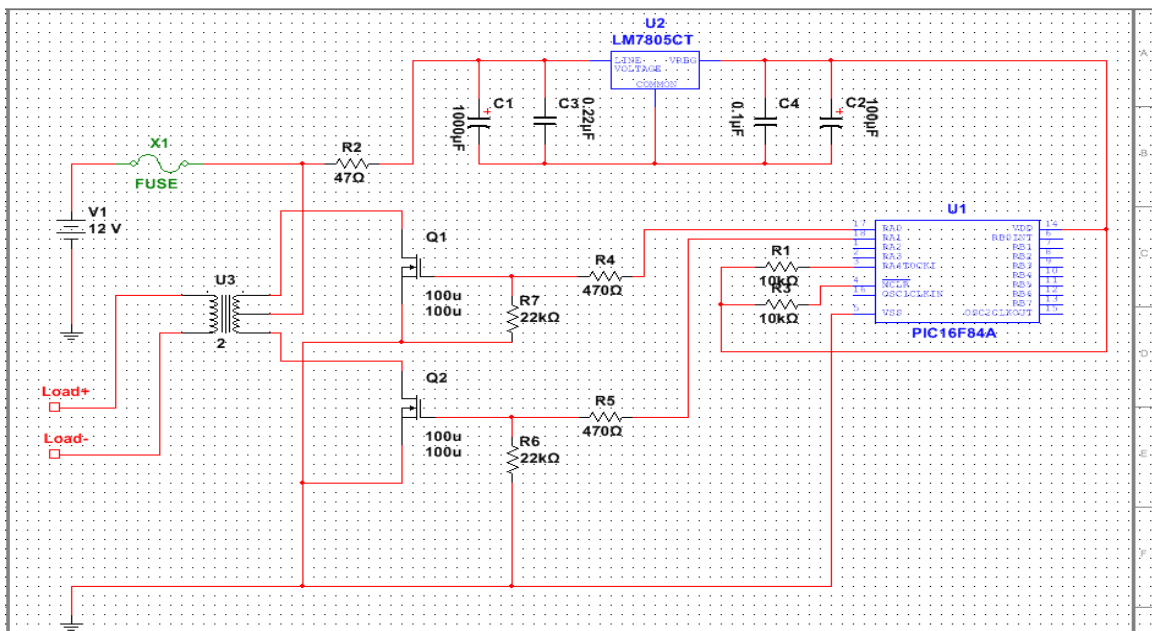
Figure 4.4.4-8: Sinusoidal output for a pure sine wave inverter

The use of a microcontroller instead of analog circuit can reduce the circuit and helps it have a better performance for the desired output. For this particular configuration, a microcontroller is used instead of using analog circuitry or integrated circuits. Since we used four (4) MOSFET drivers, the microcontroller will be generating control signals. Two (2) of these signals will be sinusoidal signals at 60 Hz; they will be considered reference sine waves. The two (2) signals will be triangle signals at 40 kHz or 50 kHz, and they will be considered as carrier signals. As we explained it below, the output from will be a 2-level signals, and after passing through the bridge, will become 3-level signals. The following figure Fig. 4.4.4-9 shows the block diagram of the microcontroller connected to the MOSFET driver.
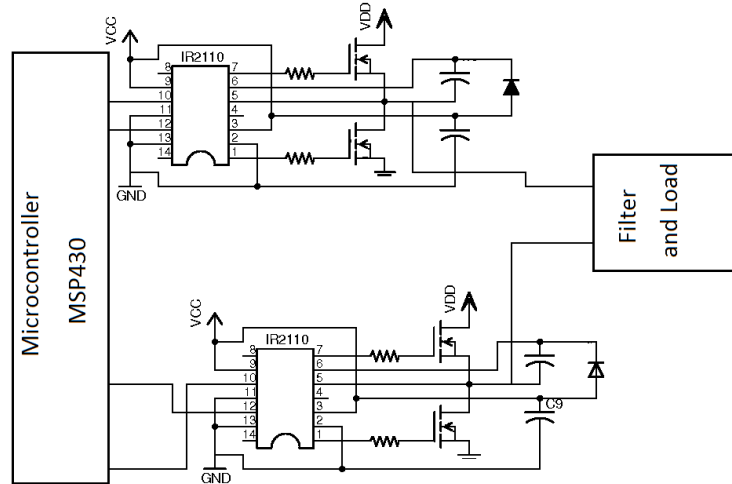
Figure 4.4.4-9: Block Diagram for the Microcontroller Connected to the Circuit. Reprinted with permission from International Rectifier

Microcontroller

As we explained it in the previous paragraphs, we need a controller to capable of controlling the MOSFET drivers and also make the real time decision in generating the required input signals in order for the PWM signals to create and produce . Another feature that reveals a lot of importance is also the size of that particular since our project means to be the most likely portable possible. When we put all these specifications together, the best device that fit our project is the use of a Microcontroller.

In selecting which types of Microcontrollers to choose, it becomes really hard since there are so many microcontrollers in the market today that are able to get the job done. However, for the purpose of this project we have considered the three following types:

- The MSP430 from TI
- The Atmega328 from AVR
- The PIC1628A from Microchip

Indeed, each of the Microcontrollers listed above presents some kind of advantages over the other, as well as disadvantages; however, all of them can actually carry out the realization of the project maybe one with less efficiency than the other.

We have developed thus a table of comparison on the three types of Microcontroller considered in the project. The comparison is shown in the following table:

Specifications	MSP430	Atmega328	PIC16F377A
Voltage	1.8-3.6 V	1.5-5.5 V	4-5.5 V
Current		20mA	-
Clock rate	8MHz	20MHz	20MHz
Timers		3	3
Pins	48	28	40
Input/output		23	33
ADC	12 bit	10 bit	10 bit
Program Memory		32k bytes	14.3k bytes
EEPROM		1k byte	256 bytes
PWM	Yes	Yes	Yes
USART	Yes	Yes	yes
Language	C	C	C
Mounting	Hole	Hole	Hole

Table 4.4.4-4: Microcontrollers Comparison

Since we do not have previous experience on microcontroller, it becomes difficult to pick the one that will present more features to our project. However, we realize that MSP430 library function is more suitable and easier to use. So, we decided to use and go with MSP430 since it is the one we are able to handle better not only when it comes for the connection but also it pretty much help us with simplifying the coding of the project.

Filter

The output filter constitutes the last element of the inverter circuit. It takes the sinusoidal output PWM generated and passed through the bridge and filters it so that it is now usable across any electronic devices. It also allows us to output a real pure sine wave with less distortion and little attenuation by performing digital processing functions, removing undesired frequency components on the signals, and also using wanted ones or both. In fact, we can distinguish low pass filter, high pass filter, and band pass filter.

- Low pass filter
  This type of electronic filters lets pass signals with low-frequency and reduces the ones with frequency higher than the cut-off frequency.
- High pass filter
  This filter, unlike the low-pass filter, lets pass signals with high-frequency and reduces the ones with frequency lower than the cut-off frequency.
- Band pass filter
  This type of filter is considered as a device that lets pass frequencies in a certain range and reject frequencies outside that range.

Considering that the output AC voltage derived from the inverter supposes to be at 60Hz which is considered to be low frequency signals, we have decided to build a low-pass filter in order to reduce and reject the high-frequencies that may be resulted. A representation of this particular circuit is shown in the following figure Fig. 4.4.4-10:
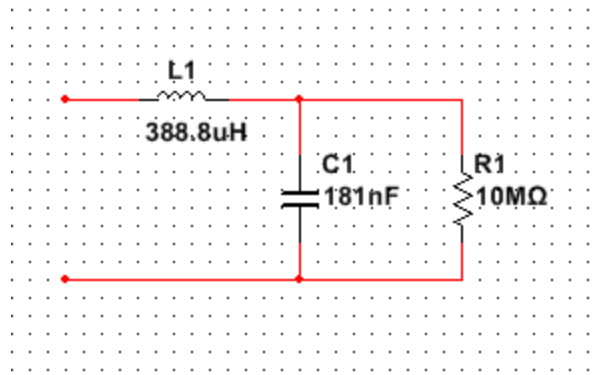
Figure 4.4.4-10: Low-Pass Filter Design

In fact, even though the output voltage incoming from the Pure Sine Wave inverter may be free of noise and attenuations, there might be situations when the voltage level changes. These changes are called sags when they correspond to voltage drops and they are called surges for voltage peaks. And so, in order to be able to respond to these changes, a static voltage stabilizer or voltage regulator is required.

4.5 DC/DC Converter

4.5.1 DC Regulator Operational Requirements:

The DC to DC converter is used today for everyday use. We are going to have a converter that will have three 2.0 USB output port. The converter will take a certain voltage from the battery and step down to a max of 5 V. Essentially, the DC to DC converter that we will be using is going to take a voltage input within a certain range and output a 5 volt and 500ma current. There are multiple schematics that you could use to achieve the converter, but an efficiency of 90 % or higher is what we are seeking to achieve.

4.5.2 DC/DC Converter Types and Specifications:

LM2576 Step-Down Switching Regulator

The LM2576 is a monolithic integrated circuit that is suited to have an easy and convenient design of a step-down switching regulator. This device can have a fixed output voltage of 5V, but the circuit that was implemented has a 3.0 amp current output. The circuit is shown below in figure 4.5.2-1. We would have to use a current divider to get a 500 ma current. Since the converter is a switch-mode power supply, its efficiency is significantly higher in comparison with popular three terminal linear regulators. This regulator does not specify what the input voltage could be; it just states that it has a wide

variety of voltage input. The figure 4.6.2-1 does show the unregulated voltage being 7 – 40V range. The LM2576 has a guaranteed +- 4% tolerance on output voltage within specified input voltages and output load conditions, and a +- 10% on the oscillator frequency. The long pins make it easy to connect to the breadboard, making the connection of the circuit simple. The regulator was unable to be tested in any of the simulators because it was not in our simulators library. The only way to test this chip would be to order through the company, and experimentally find the values. A schematic for a fixed 5V output is shown below in figure 4.5.2-1:
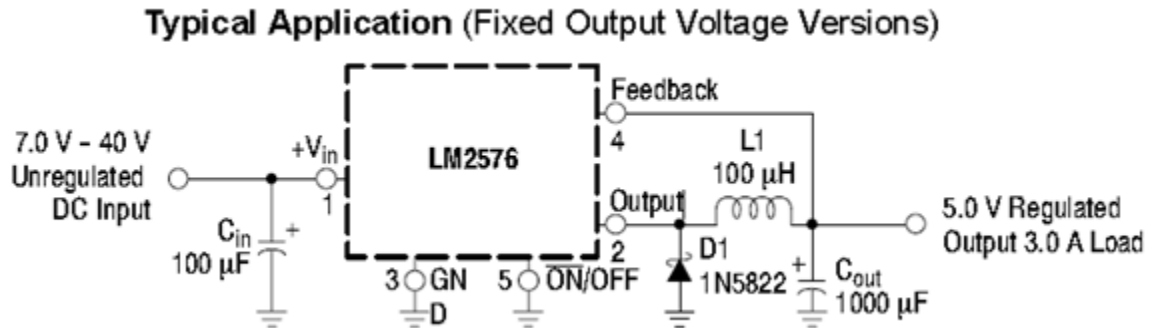

Figure 4.5.2-1 – LM2576 Schematic for a fixed 5 volt output. Reprinted with permission from Semiconductor

LM2574 Step-Down Switching Regulator

The LM2574 is a step-down switching regulator as well. All circuits of this series are capable of getting a 500ma load with a precise line and load regulation. This circuit also has fixed voltages, 5V being one of them. The figure 4.5.2-3 below shows an output voltage of 5V and 500 ma circuit design. This caught our attention for the DC to DC converter because it has the correct output voltage and current needed. The LM2576 chip had an output current of 3 amps which could complicate the circuit and affect the efficiency. The LM2574 has an input voltage range of 4.75 to 40V. They both have a guaranteed +- 4% tolerance on output voltage within specified input voltages and output load conditions, and a +- 10% on the oscillator frequency. This IC can easily be connected to the breadboard for experimental purposes. Again, the regulator was unable to be tested in any of the simulators because it was not any of our simulators libraries. Therefore, the only way to test this chip would be to order through the company, and find the values experimentally.

Typical Application (Fixed Output Voltage Versions)
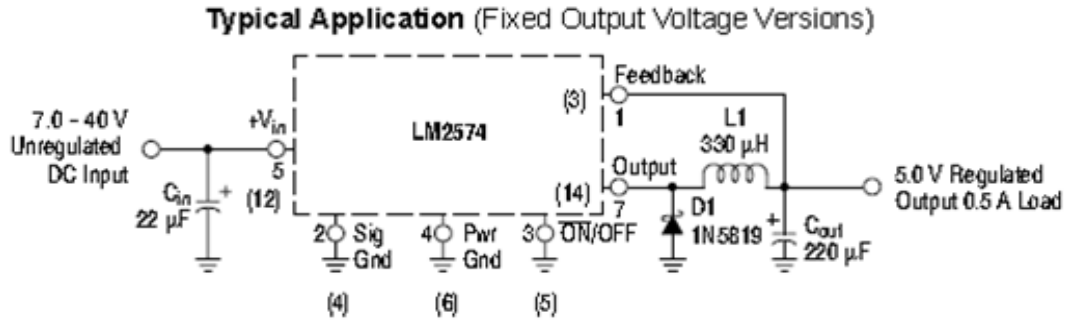
Figure 4.5.2-2 – LM2574 Schematic for a fixed 5 volt output. Reprinted with permission from Semiconductor

LM3481 Switching Regulator

The LM3481 is a versatile Low-Side N-FET high performance controller for switching regulators. This regulator is suitable for use in topologies requiring a low side FET, such as boost and flybacks. The LM3481 has switching frequencies that can be adjusted to any value between 100 kHz and 1 MHZ. This regulator can take in a voltage input range of 3.0 to 48V, and outputs 5V and 1 amp. We would have to use a current divider to cut the current output to 500 mA. The figure 4.5.2-3 shows a schematic of the regulator for the specific output that we are trying to accomplish.
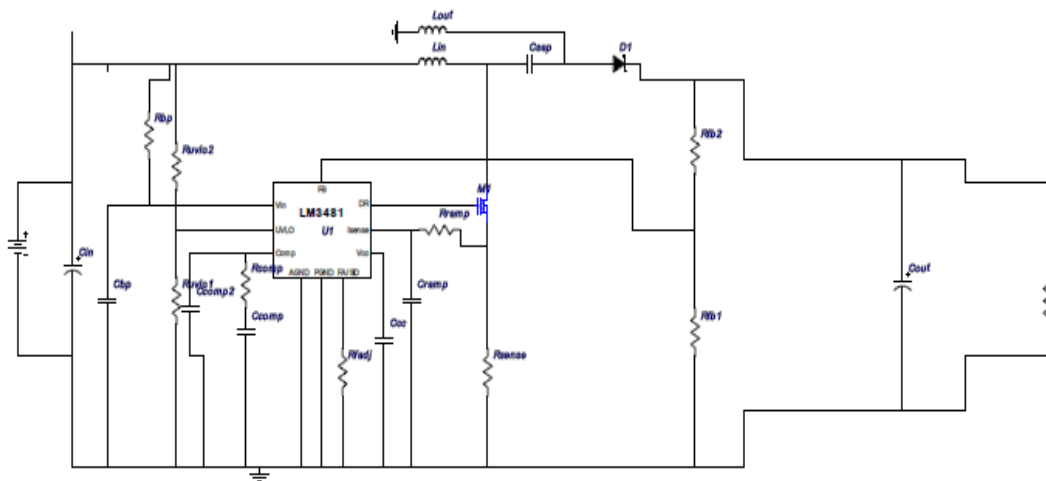
Figure 4.5.2-3: LM3481 Schematic for a fixed 5 Volt Output. Reprinted with permission from Texas Instruments

This circuit was tested using a simulator that the supplier uses. We graphed Vin vs. Vout, Iout. The first figure will show an input of 15V, which will then output around 5V and 500 mA current. The figure 4.5.2-6 below will demonstrate the graph.
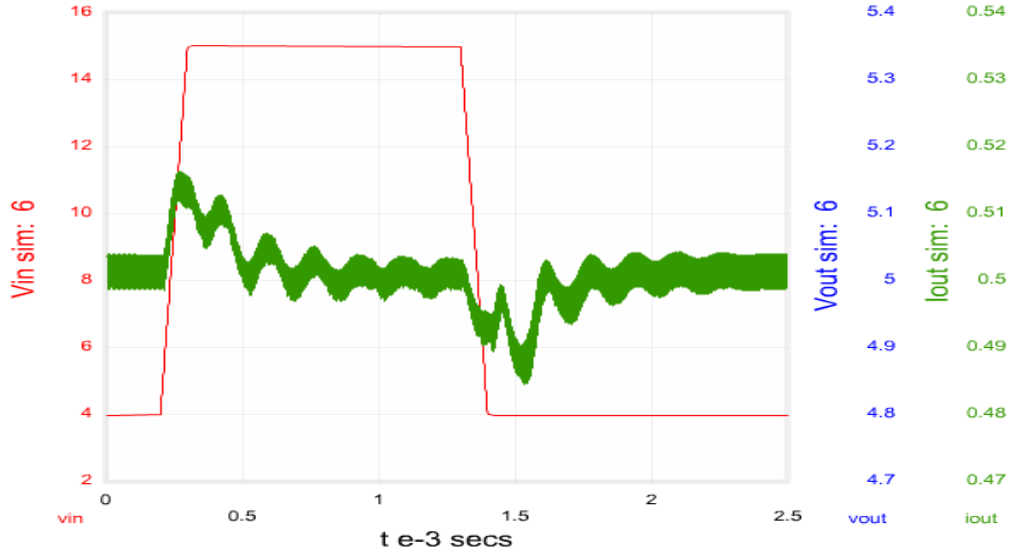
Figure 4.5.2-4: LM3481 Vin vs. Vout,Iout for Vin = 15V

The figure 4.6.2-5 below demonstrates the same Vout graph for the schematic above, but we changed the input to be 22V. We were trying to observe whether the regulator will be able to bring down the input voltage to 5V.

Figure 4.5.2-5: LM3481 Vin vs. Vout,Iout for Vin = 22V

The figure 4.5.2-6 below shows the efficiency this regulator will have according to the schematic showed above in figure 4.5.2-3. The different colors in the graph demonstrate the different efficiency rates depending on which schematic you use for the regulator. The schematic that will be used for our project would be the blue line, which will give an efficiency rate of 84%.
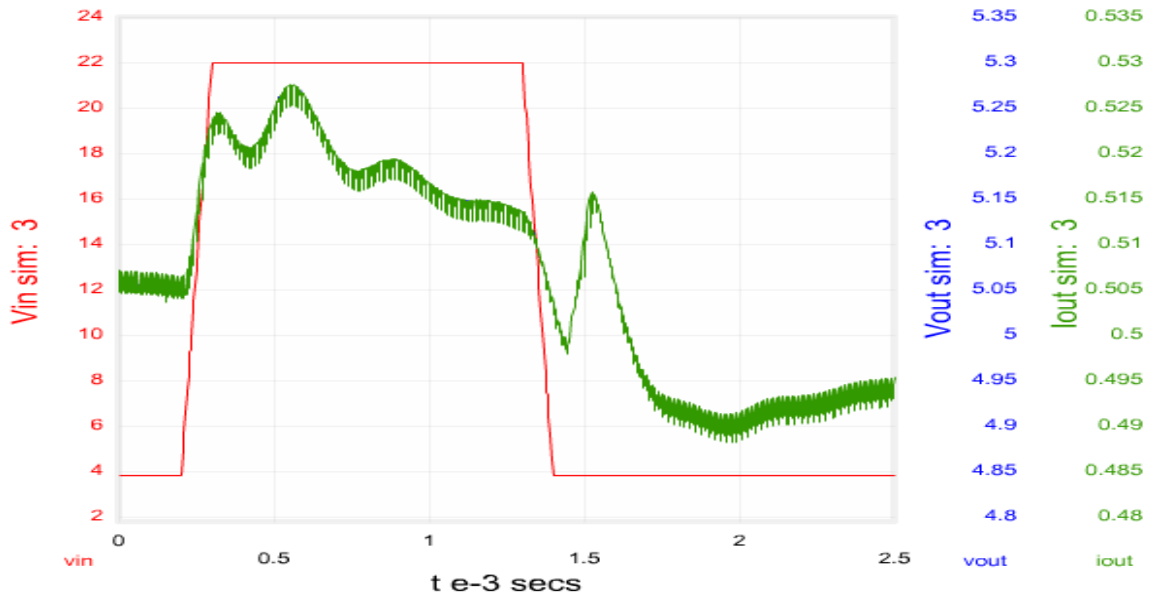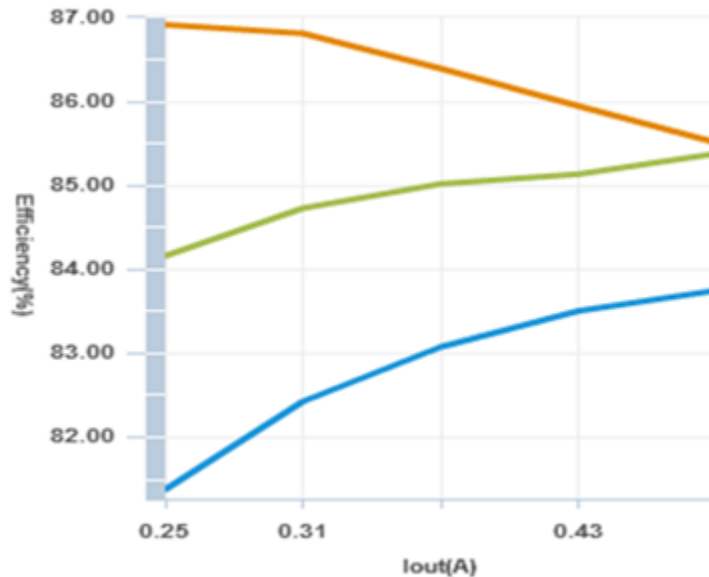

Figure 4.5.2-6: LM3481 84% Efficiency Chart. Reprinted with permission from Texas Instruments

LT3502 Step-Down DC/DC Converter

The LT3502 are current mode PMW step-down DC/DC converters with an internal 500mA power switch. The LT3502 has a wide input voltage range from 3 to 40V. The high operating frequency allows the use of inexpensive and small inductors and capacitors. This will result in having a very small simple circuit. This step-down converter has a switching frequency of 2.2MHz. The LT3502 has an amplifier and comparator that monitor the current flowing between the Vin and SW pins, turning the switch off when this current reaches a level determined by the voltage at Vc. The figure 4.5.2-7 below shows the schematic that outputs 5V.
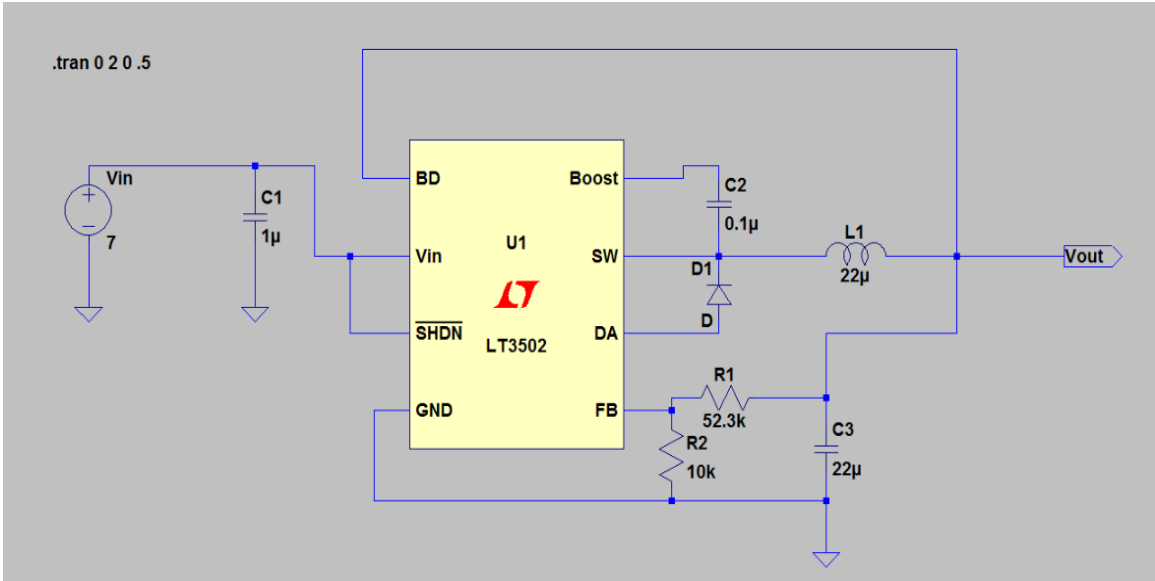
Figure 4.5.2-7: LT3502 Vin 7V Schematic

From the schematic above you can see that the circuit is very simple and easy to design, only consisting of 7 components. The circuit was tested using the supplier's simulators; this is shown in figure 4.5.2-8 below.
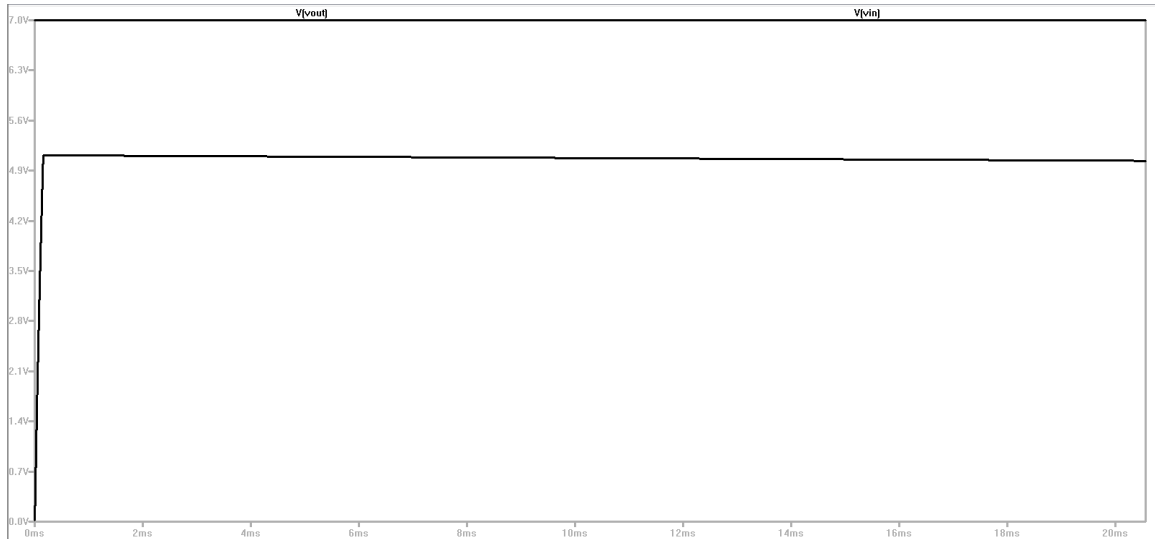
Figure 4.5.2-8: Graph Vin vs. Vout graph for Vin = 7V

We see that the input will step down the voltage to 5V. To verify that the step-down regulator will step it down with the input voltage range, we tested the schematic changing the voltage input to 25V. The figure 4.6.2-9 below shows the Vin vs. Vout graph for an input voltage of 25V.
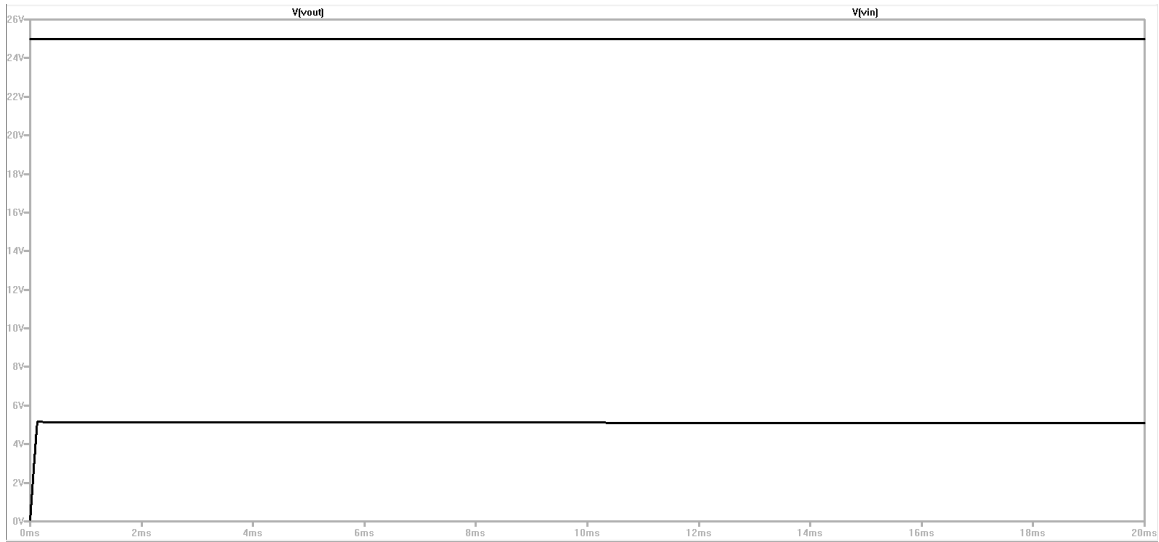
Figure 4.5.2.9 Graph Vin vs. Vout for Vin = 25V

The graph above proves that the input voltage of 25V is stepped down by the regulator to 5V. With a fixed 5V output, we have an efficiency of 87% which is demonstrated below in figure 4.5.2-10.
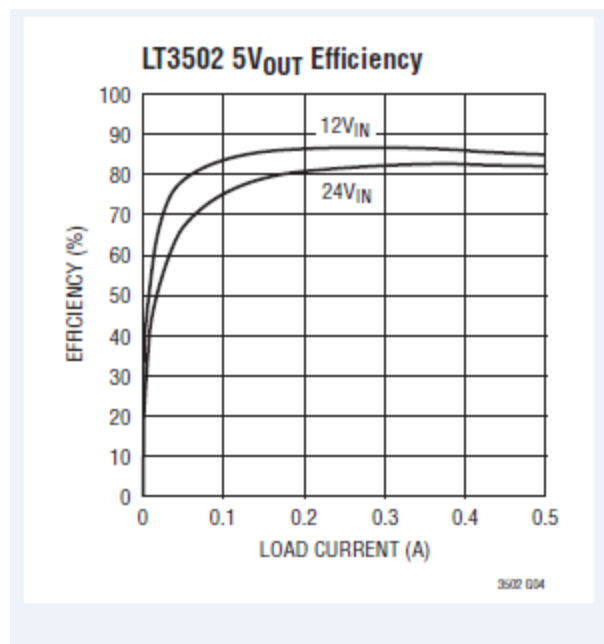
Figure 4.5.2-10 LT3502 Efficiency Chart. Reprinted with permission from Linear Technology

4.6 DC Output

4.6.1 DC Output Description:
DC connectors are electrical plugs for supplying direct current (DC). They are used in most of the cases to charge some specific electronic devices that may require DC voltage across them. Indeed, we need to add DC output connectors in order to make the Portable Solar Power Supply more convenient to use. Among the considerations we have made, two types of DC output sockets will be address in the next section.

4.6.2 DC Output Consideration:

1. USB power A-type

The USB power A-type standard form is capable of providing voltage in the range of 4.4 to 5.25 volts of DC at 900 milliamps. And we can use it to power electronic devices such as: type memory stick, digital camera, cellphone and many other kinds of electronic devices and accessories. The operation is nothing but a DC to DC converter. The A-socket connector provides a downstream connection that is intended for use solely on host controllers and hubs. It was not intended for use as an upstream connector on a peripheral device. This is critical because the host controller or hub is designed to provide 5V DC on one of the USB pins.

2. USB power B-type

As we explained on the paragraphs above, the USB power B-type also operates in the range of 5 volts of DC at 900 milliamps as well. However, the use of this particular USB type is limited to some specific electronic devices. The B-style connector is designed for use on USB peripheral devices. This USB type interface is square in shape, and has slightly beveled corners on the top ends of the connector. It is to note that the B-socket is an upstream connector that is only used on peripheral devices.

Since the USB B-type is most likely used on peripheral devices, we have decided to choose and implement the A-type in our report because our purpose is not much to make peripheral connections but to be able to charge electronic devices like the ones listed above. And of course, the portability of our project gives us limitations on some other DC output sockets we could use.

Also, since the DC voltage generated from either the solar panel or the battery is 12 volts, we are not able to use it and connect the USB power socket. We need to create a circuit that can step down the voltage so it can be usable on a 5 volts device. The following circuit diagram showed below takes the 12v DC and converts it into 5v DC so it can be possibly used to feed a USB power A-type.
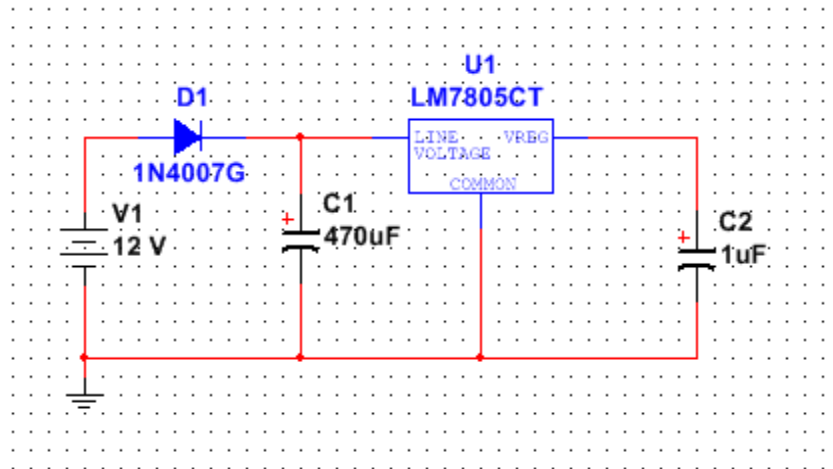
Figure 4.6.1-1: DC to DC 12V/5V Converter

4.7 AC Output Sockets

AC output sockets are electrical power supplies that are suitable for using and connecting electronic devices. They come in different shapes, sizes, form, model, and prices. It is to note that the AC output can be obtained from the DC battery or the solar panel with the use of an inverter in conjunction with a standard power strip to provide outlets that can be used to supply devices such as projector and laptop to tap into the power system.

It is to note that because many different electric sockets are found around the world, the thing is to know what adapter plug will fit the various types of receptacles. Indeed, two important approaches come into consideration when it comes to identify the AC outputs – frequency and voltage listed.

Although the electric power frequency is shown in the number of Hertz (cycle per second), it does not mean that all AC components have the same frequency requirement. 60-hertz clock or tape recorder my not function property on 50 hertz current. If the requirements say 60 hertz and a 50-hertz rated component is connected to it, it will may not work or function properly.

The other important consideration is the voltage listed. Some outlets are rated 120V AC, some other 220, and some other outlets 230 for residential and some commercial and industrial uses. However, most industrial uses are rated up to 400V AC. The difference in the voltage rated is essentially inconsequential, as most appliances are built to tolerate current a certain percentage above or below the rated voltage since severe variations in current can damage electrical equipment.

The other considerations like shapes, size, model, and prices, on choosing which types of receptacles to use do not reveal so important when it comes for the selection of AC output sockets even though some models may present better and more durable products than other. From type A to type L, all the AC output sockets used around the can be set to 50 or 60 Hz. The difference resides more on the voltage ratings.

The purpose of our project is to build a project that can be portably used as a power supply to charge the battery, and use it for some other appropriate circumstances when the use of electricity is not possible. Since that is the case, we want that the AC output sockets be according to the 120V AC at 60Hz. And so, we opted for the type B configuration that will allow us to output the 120V AC at 60Hz with one hot wire, one neutral wire, and another ground wire. This type of output socket also provides protection in case of exposition on a wet place.

5.0 Design

After the group performed a thorough analysis of the research obtained to design a portable solar power supply, a conclusion on how to design each component for this device was obtained.

5.1 Solar Panel

In order to get the best efficiency out of the solar panels, the group decided to use monocrystalline silicon. The costs of this type of solar panels are typically more expensive, but have the higher efficiency rate. The solar panel chosen will be a 50 Watt Monocrystalline Photovoltaic (PV) Solar Panel with Nominal Output Voltage 12V, and grade A solar cells with 17% efficiency. The solar panel will be mounted on the solar panel mount having a horizontal rotation for solar tracking. This solar panel is from the manufacture Ramsond who use the most premium components and raw materials. The solar panels they sell are not reused or second hand cells. The solar cells are coated with nitride anti-reflection coating that will provide a blue hue color and increase the light absorption in all weather conditions. The panel is made with iron, patterned, tempered gas which enhances the strength of the panels 60% more than the conventional photovoltaic glass. This panels are made for very strong resistant weather conditions, even hail that measures about one inch and at speeds of 50 miles per hour. One of the hardest things of finding the solar panel was having it adjust to the budget set for the project. The panel is only costing $169.99, which we found to be the all-around best solar panel for the project. The table 5.1-1 below shows the characteristics of the solar panel chosen.

Manufacturer	Ramsond Corporation
Product name	50 Watt Solar Panel
Product Type	Monocrystalline Photovoltaic Solar Panel
Voltage	12 Volts DC
Maximum	Up to 50 Watts (power) Up to 2.92 Amps (current)
Transform efficiency	17%
Weight(each)	8.8 lbs.

Table 5.1-1: Characteristics of 50W Solar Panel

5.2 Charge Controller

The charge controller circuit for the portable solar power supply will be composed of the circuit schematic listed in Figure 5.2-1below. This is the same circuit illustrated in Figure 4.2.1-6. This circuit is designed to work with the Arduino Duemilanove microcontroller. The Arduino Duemilanove microcontroller circuit schematic is illustrated in Figure 5.2-1 below and is also the same circuit schematic illustrated in Figure 4.2.1.3-2.
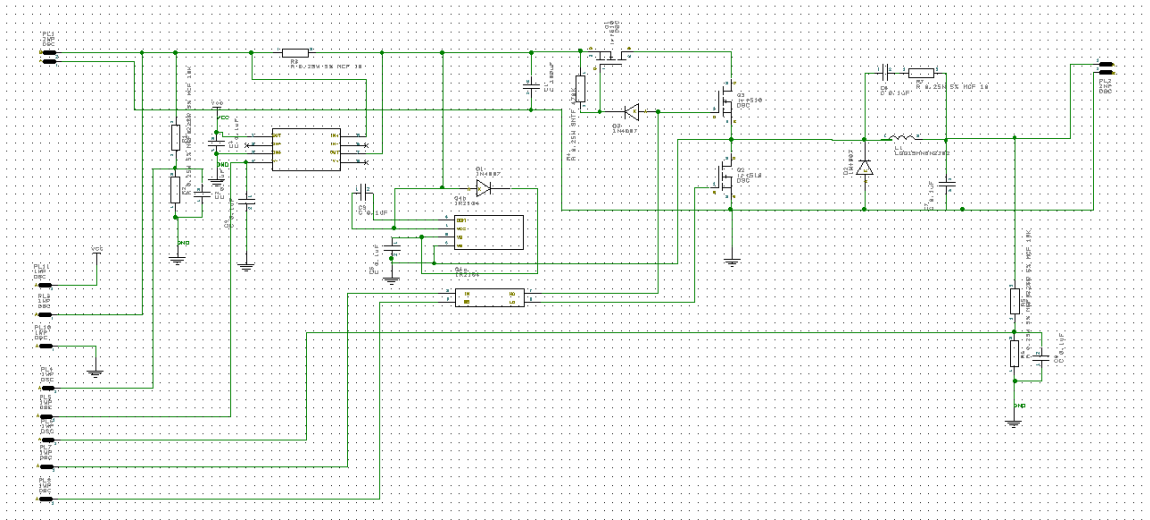

Figure 5.2-1 Charge Controller circuit schematic diagram.

This circuit is basically a DC/DC converter (in a buck configuration) controlled by the software in the microcontroller's processor. It is the software's task to figure out the voltage of the solar panel where the maximum power is produced and controls the DC/DC converter to match the solar panel's voltage to the battery's voltage. The processor controls the DC/DC converter by generating a pulse width modulated (PWM) signal that switches the MOSFETs at a frequency of 50kHz. The transfer ratio of input voltage versus output voltage is based on the duty cycle of the PWM signal.

Looking at the circuit schematic in Figure 5.21 above, the connector (J1) for the solar panel input is in the upper left corner. There is no protection for polarity reversal so, if this charger circuit were to be implemented, careful attention to connecting the solar panel with the proper polarity with have to be taken.

The solar panel input voltage is connected to the Vin or Raw input to the Arduino board which goes to a voltage regulator to generate 5 volts to run the processor. The solar panel input voltage is divided down by the R4 and R5 resistors and sent to the Analog_0 input of the Arduino to be read by the processor.

The solar panel input current is read by R1, the 0.005 ohm current sense resistor that generates a very small voltage when the current flows. That voltage is picked up and amplified by IC1, the MAX4173H which is a high side current sense amplifier. The MAX4176H has an amplification factor of 100. To better understand how this amplification works, assume that 4 amps is flowing through R1. This would generate 4 amps * 0.005 ohms = 0.2 volts * 100 = 2 volts to be to be read by the processor.

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Q1 is the blocking MOSFET that prevents the battery power from flowing back into the solar panels at nights. This is normally done by a diode in the power path but since all diode have a voltage drop, a MOSFET is much more efficient.

Below in Table 5.2-1 is a list of the parts for the charge controller circuit illustrated in Figure 5.2-1.

Part	Value		Digikey Oart Number (www.digikey.com)
C1	0.1uF		399-4266-ND
C2	100uF	35V	493-1318-ND
C3	220uF	16V	493-1284-ND
C4	0.1uF		399-4266-ND
C5	0.1uF		399-4266-ND
C6	0.1uF		399-4266-ND
C7	0.1uF		399-4266-ND
C8	0.1uF		399-4266-ND
C9	0.1uF		399-4266-ND
D1	UF4007		UF4007CT-ND
D2	1N4148		1N4148FS-ND
D3	1N4148		1N4148FS-ND
IC1	MAX4173H		MAX4173HESA+-ND
IC2	IR2104		IR2104PBF-ND
J1	CON2		WM7853-ND or ED1609-ND
J3	CON2		WM7853-ND or ED1609-ND
L1	33uH		M8852-ND
Q1	IRFIZ44		IRFIZ44GPBF-ND
Q2	IRFIZ44		IRFIZ44GPBF-ND
Q3	IRFIZ44		IRFIZ44GPBF-ND
R1	0.005		12FR005E-ND
R3	470k		470KQBK-ND
R4	10k		10KQBK-ND
R5	2.2k		2.2KQBK-ND
R6	10k		10KQBK-ND
R7	2.2k		2.2KQBK-ND
R10	200		200QBK-ND
x1	8p Socket		AE9986-ND (for IC1)
x2	8p Socket		AE9986-ND (for IC2)
HS1	Heatsink		HS106-ND (for Q1)
HS2	Heatsink		HS106-ND (for Q2)
HS3	Heatsink		HS106-ND (for Q3)
	Battery Fuse		

Table 5.2-1: Charge Controller Part List

5.3 Microcontroller

Based on the group's research on microcontrollers, the group decided that the open source hardware platform of the Arduino Uno microcontroller is the best choice to use to perform the MPPT function. This microcontroller board is based on the ATmega168 or

ATmega328. This is a high performance, Low Power AVR® 8-bit microcontroller. Some of the features of the Arduino Uno that made the group choose this microcontroller are:

Advanced RISC Architecture	131 Powerful Instructions – Most single clock cycle execution 32 * 8 general purpose working registers - Fully static operation - Up to 2 MIPS throughput at 20MHz - On-chip 2-cycle multiplier
Special Microcontroller Features	- Power-on reset and programmable brown out detection - Internal calibrated oscillator - external ind internal interrupt sources - six sleep modes: idle, ADC noise reduction, power-save, power-down, and extended standby.
Operating Voltage	1.8 – 5.5V for ATmega48PA/88PA/168PA/328P
Low power consumption at 1MHz, 1.8V, 25 deg C for ATmega48PA/88PA/168PA/328P	- Active mode:0.2ma - Power-dowm mode: 0.1uA - Power-save mode: 0.75uA (including 32kHz RTC)

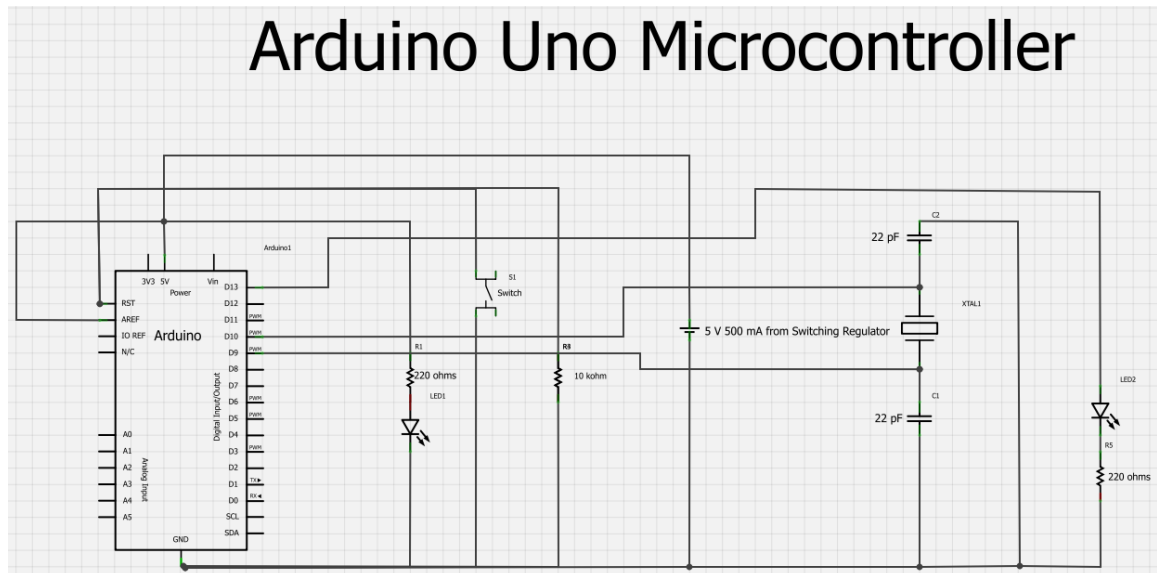**Table 5.3-1: Features of the Arduino Uno**

Figure 5.3-1: Arduino Uno Microcontroller

The charge regulator will be built on the ProtoShield prototype board. The ProtoShield prototype board is illustrated in Figure 5.3-2 below.
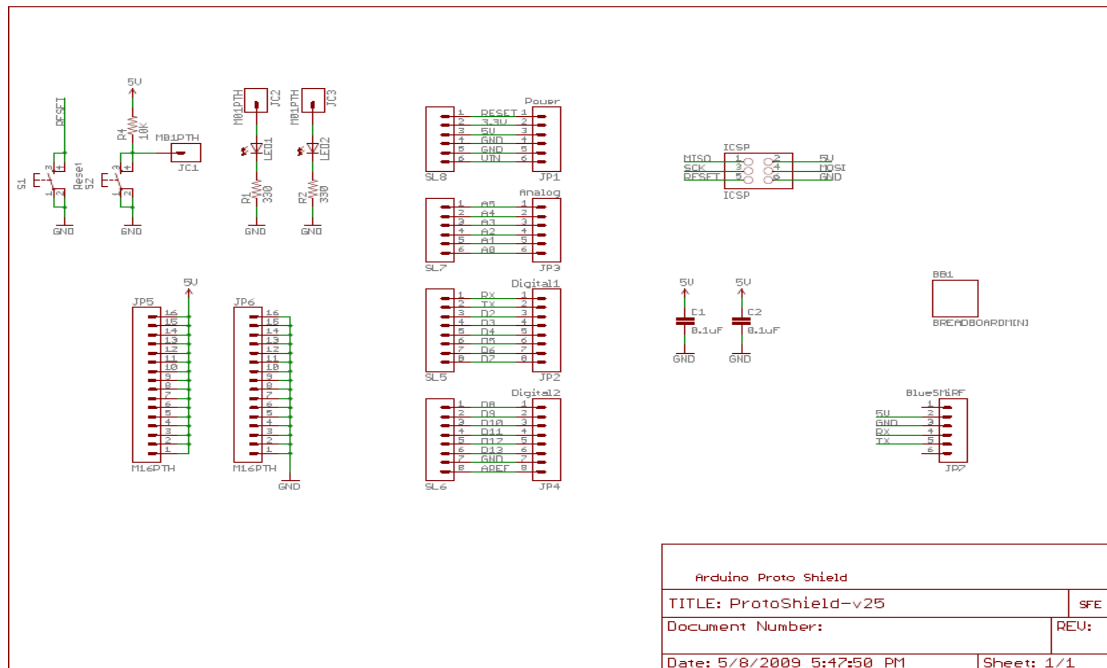
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Figure 5.3-2: ProtoShield schematic Diagram . Reprinted with permission from SparkFun Electronics

The ProtoShield is designed to sit on top of the Arduino, extending the functionality of the Arduino platform. The ProtoShield is designed to facilitate prototyping. It provides an easy connection between a breadboard and an Arduino. The ProtoShield provides the Arduino with easy access to a prototyping area, two general LEDs, access to a BlueSMiRF socket, a general use push button, and most important of all, the Arduino reset button.

5.4 LCD Display and Driver

An LCD display is essential for monitoring the functionality of the portable solar power supply. The voltage, current, and power, of the battery and solar panel needs to be monitored to ensure that the solar panel is charging the battery in the most effective way and that battery is being charged properly. A two line dot matrix LCD display is sufficient for displaying the items that needs to be monitored from the previous sentence mentioned. It would be difficult to know what is happening internally with the portable solar charger without an LCD display.

To use an LCD display with this microcontroller, an LCD display that is compatible with the Hitachi HD44780 driver would be connected to the Arduino microcontroller. The low power supply (2.7V to 5.5V) of the Hitachi HD44780U dot-matrix liquid crystal display controller and driver LSI is suitable for any portable battery-driven product requiring low power dissipation.

An LCD display that will be used for this project is the SSC2F20. This LCD display meets the requirements of the Hitachi HD44780 driver. This LCD display is a 20

character by 2 line blue HD44780 Super Twisted Nematic (STN) with built-in HD44780 equivalent controller (also known as alphanumeric displays) . The interfacing is simplified with 4-bit or 8-bit communications. The LCD display also has an LED backlight. Below in Figure 5.4-1 is a functional block diagram for the SSC2F20 LCD display:
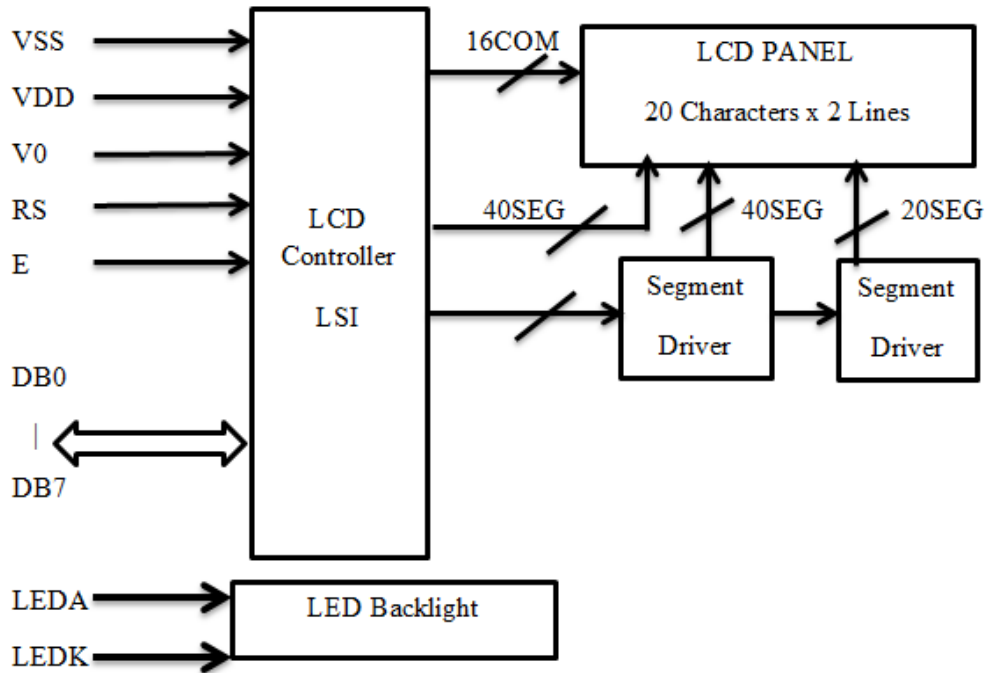
Figure 5.4-1: Block Diagram of SSC2F20 LCD Display

For this project, the interfacing will be configured using 4-bit communications. The specifications of this LCD display are described in Tables 5.4-1 (a-d) below.

Mechanical Data

Item	Nominal Dimensions	Unit
Module Size (W*H*T)	116.0*36.0*13.0	mm
Viewing Area (W*H)	83.5*18.4	mm
Character Size (W*H)	3.25*5.39	mm
Dot Size (W*H)	0.61*0.63	mm

Table 5.4-1 (a.): LCD Mechanical Data

Pin Connections

Pin	Symbol	Level	Functions
1	VSS	----	GND (0V)
2	VDD	----	Supply Voltage for Logic (+5V)
3	V0	----	Power supply for LCD
4	RS	H/L	H: Data; L: instruction Code
5	R/W	H/L	H: Read; L: Write
6	E	H/L	Enable Signal
7	DB0	H/L	
8	DB1	H/L	
9	DB2	H/L	
10	DB3	H/L	Data Bus Line
11	DB4	H/L	
12	DB5	H/L	
13	DB6	H/L	
14	DB7	H/L	
15	LEDA	----	Backlight Power (+5V)
16	LEDB	----	Backlight Power (0V)

Table 5.4-1 (b.): LCD Pin Connection

Electrical Characteristics

Item	Symbol	Min	Type	Max	Unit
Input High Voltage	V_{IH}	2.2	----	VDD	V
Input Low Voltage	V_{IL}	0	----	0.6	V
Output High Voltage	V_{OH}	2.4	----	VDD	V
Output Low Voltage	V_{OL}	0	----	0.4	V

Table 5.4-1 (c.): LCD Electrical Characteristics

Absolute Maximum Ratings

Item	Symbol	Min	Type	Max	Unit
Operating Voltage	VDD	4.5	5.0	5.5	V
Operating Current	IDD	1.2	1.6	2.0	mA
LED Voltage	V_{LED}	4.5	5.0	5.5	V
LED Current	I_{LED}	77	120	180	mA
Operating Temp.	T_{opr}	-20	----	+70	deg. C
Storage Temp.	T_{sto}	-30	----	+80	deg. C

Table 5.4-1 (d.): LCD Absolute Maximum Ratings

An illustration of how the Arduino Duemilanove microcontroller will be connected to the SSC2F20 LCD display is illustrated in Figure 5.4-2 below.
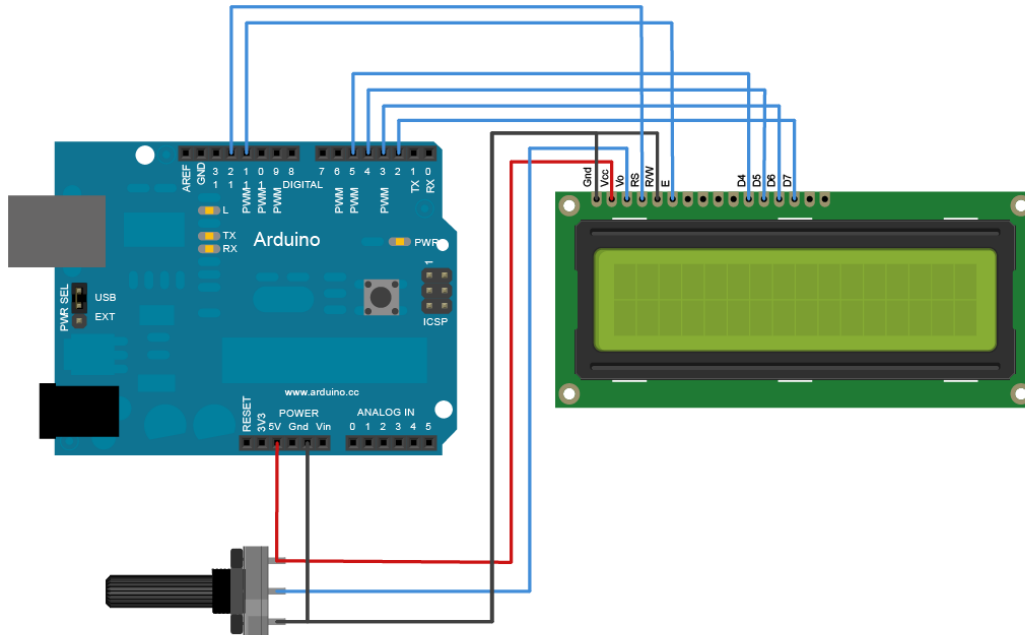

Figure 5.4-2: Connecting a Hitachi HD44780 Driver compatible LCD display to an Arduino Board. Reprinted with permission from Arduino

5.5 Solar Tracker

A solar tracker can increase the amount of energy delivered into the portable solar power supply system. The group's goal is to use a single axis tracking system that follows the azimuth of the sun. According to the group's research, this is estimated to increase the efficiency of the portable solar power supply up to 26 percent. The group plans to implement an active tracking system. An active tracking system signifies that a light intensity sensor provides solar irradiance feedback for the system to optimize the position of the solar panel.

Below in Figure 5.5-1 is the schematic design of the circuit that the group will use to implement the solar tracker. The values read from each photoresistor into the Arduino microcontroller is compared and then the microcontroller decides whether or not the position of the solar panel needs to be adjusted. For instance, if the left photoresistor inputs a higher value than the right, then this means that there is more sunlight striking the left photoresistor. The goal of solar tracking is to move the solar panel into a direction that optimizes the amount of sunlight that can strike the surface of the solar panel. Therefore, the microcontroller will detect that the left protoresistor has a higher value

after comparing the photoresistor values. Then, microcontroller will make the servo motor rotate the solar panel in the direction of the left photoresistor until both the left and right photoresistors are at the same value.
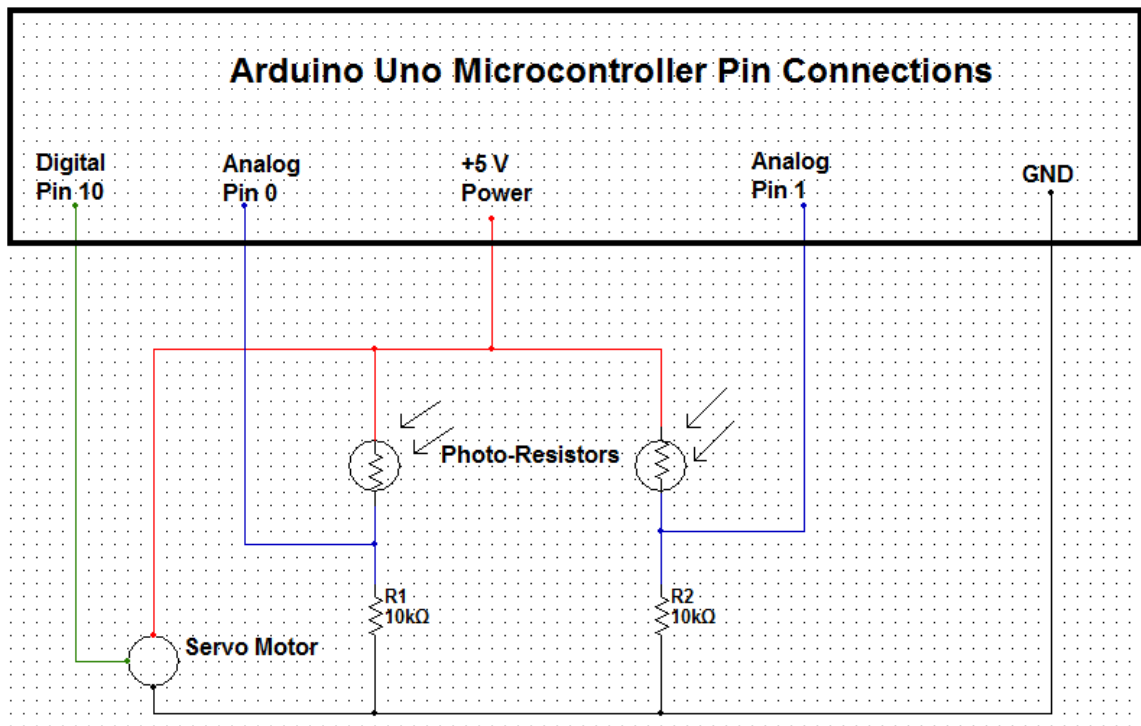

Figure 5.5-1 Circuit Schematic Diagram for Solar Tracker

Below in Figure 5.5-2 is an illustration of the Arduino microcontroller that the group built that will connect to the solar tracker circuit that is illustrated in Figure 5.5-1 above.
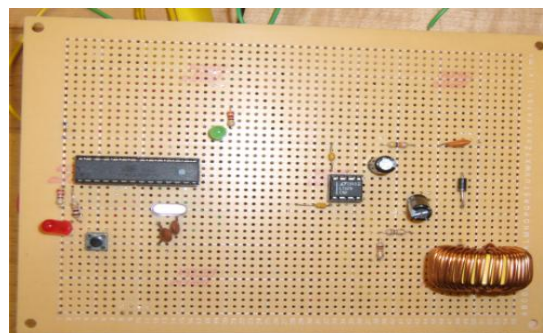

Figure 5.5-2: Arduino Microcontroller with a Switching Voltage Regulator

Below in Table 5.5-1 is a table that lists the bill of materials to build the schematic diagram in Figure 5.5-1 above.

Ref	Mfg.	Part No.	Description
R1	--	--	resistor, 10K
R2	--	--	resistor, 10K
Photoresistor	Excelitas Technologies	VT935G	
Photoresistor	Excelitas Technologies	VT935G	
Servo		ROB-09064	

Table 5.5-1: Parts Lists for the Solar Tracker Circuit schematic in Figure 5.2-1

Below in Table 5.5-2 is the absolute maximum ratings for the VT935G photoresistors that was selected for this project.

Parameter	Symbol	Rating	Units
Continuous Power Dissipation	P_D	80	mW
Derate Above 25 ˚C	$\Delta P_D/\Delta T$	1.6	mw/˚C
Temperature Range Operating and Storage	TA	-40 to +75	˚C

Table 5.5-2: Absolute Maximum Ratings for the VT935G Photoresistors

5.6 Casing

Below in Table 5.6-1 is a list of the specifications of the transparent plastic container that all of the components (excluding the solar panel and the solar panel mount) will be placed into.

Brand Name	Office Depot
Built-in Handles	No
Color	Clear
Container capacity	64 quarts
Dimensions	12"H x 16 1/8"W x 24 1/5"D
Distributor	Swinton Avenue Trading Ltd., Inc.
Lid Closure Type	snap-on
Postconsumer Recycled Content	0%

Table 5.6-1: Container Specifications

5.7 Battery

The battery that was chosen was a sealed lead-acid battery. It is a 12 volt 35 Ah AGM sealed lead acid battery that is rechargeable, recyclable, and has no memory effect. The battery was built for rugged construction that could be useful in case it drops or falls. The high-impact resistant battery case was made either of non-conductive styrene. Usually large capacity batteries frequently have polypropylene cases. The materials that were listed above have great resistance to shock, vibration, chemicals and heat. The battery has a low self-discharge rate that allows for storage of fully charged batteries for longer periods of time before charging is required. It also has a dependable service life that can be expected under normal operating conditions. The battery will be connected to multiple areas of the project. The figure 5.7-1 below demonstrates which components will be connected to the battery.
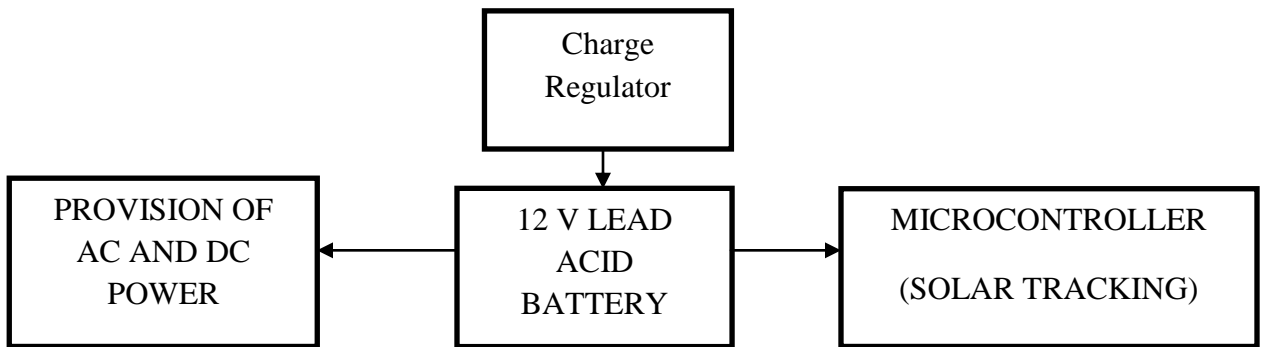

Figure 5.7-1: Connections to the Battery

The battery will be connected to the charge regulator, microcontroller, and the AC and DC power. The table 5.7-1 shows the specifications of the battery chosen.

BM Part#	SLA-12V35
Voltage:	12 Volt
Capacity	35 Ah
Type	AGM Sealed Lead Acid Battery
Warranty	1 Year
Shipping Weight	29.00 Pounds
Length	7 5/8"
Width	5 1/8"
Height	7 3/16" - Top of Terminal

Table 5.7-1: SLA-12v35 Battery Specifications

5.8 DC to DC Converter

For the DC to DC converter the group decided to use a step down buck regulator. The buck regulator is a LT1676 that could be ordered through Linear Techonology. The LT1676 has an 84% efficiency when is connected in a certain way, which is shown in the figure 5.8-1 below. The DC to DC converter will be connected to a DC output, which is a USB type A. This schematic can take in a range of 8V to 40V and step it down to 5V with a current of 500 mA. Since the LT1676 is a DIP chip, I will solder it on a proto-board. This circuit is very simple, so building it and soldering it on the board should decrease the amount of errors. Figure 5.8-1 is shown below:
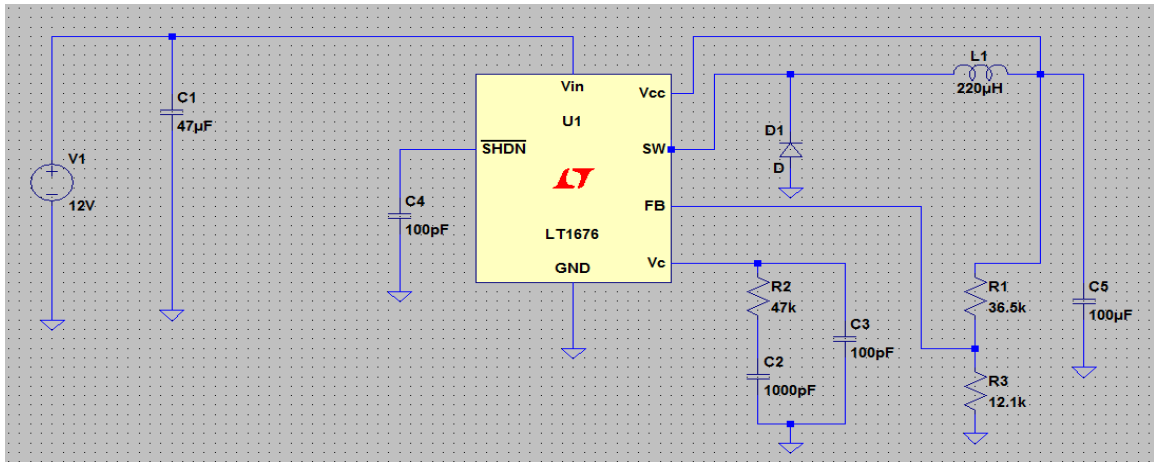

Figure 5.8-1: LT1676 Schematic for a regulated 5 Volt Output.

The part list to build the schematic of the LT1676 is listed below in table 5.8-1. The cost of this schematic is totaled to $17.35.

Ref	Mfg.	Part No.	Description
C1	Jameco ValuePro	R47/50	capacitor, 47uF
C2	Jameco ValuePro	CD1000/1000-R	capacitor, 1000pF
C3	Jameco ValuePro	SA102A101JAA	capacitor, 100pF
C4	Jameco ValuePro	SA102A101JAA	capacitor, 100pF
C5	Jameco ValuePro	R100/25	capacitor, 100uF
D1	Major Brands	MBR1100	diode
L1	Jameco ValuePro	2316-V-VP	inductor, 220uH
R1			resistor, 36.5K
R2			resistor, 47K
R3			resistor, 12.1K
U1	Linear Technology	LT1676	integrated circuit

Table 5.8-1: LT1676 Part List

5.9 Inverter Design

After completed the research, it was for the group to determine which one of the examples to consider for the design. From the research, it was concluded that a pure sine wave inverter would best meet the design specifications and criteria of the project. The group has then taken in account all the possible factors and a smart decision was made based on why a pure sine wave inverter should be best to implement the portable solar power supply.

Indeed, because most of pure sine wave inverters in the market today are very expensive, the cost of the potential parts considered in order to build the pure sine wave inverter reveals the biggest deciding factor that came across to consider. And so, we have come to consider the lowest cost possible of a sine wave inverter.

Another important factor that came across in choosing what type of inverter to build was to maximize the efficiency at the lower cost for the inverter built. Basically for a pure sine wave inverter, the range of efficiency is about 90 to 95%. As specified in section 4.4.1 and table 1, efficiency has a lot to see with the performance of the inverter and how well it will be able to use since, the group goal is to design the best and most efficient pure sine wave inverter capable of dissipating less power and producing the maximum possible of wattage necessary.

A final factor that came into considerations when it was to choose which type of inverter to use was its best way of applications. As noted in section 4.4.1 and table 1, pure sine wave inverter is configured in a way that it is usable to operate sensitive equipment. Since the group expectation is to use the device across sensitive equipment, they made the decision to build a pure sine wave inverter.

In order to come across the goal of building the pure sine wave inverter, the group has considered some steps to follow. At first, the idea was to build a DC to DC converter that would take the 12V DC from the battery or the solar panel and convert it into 120V DC as it would require in the next process. However, after considerations of some parts also after talking to some experts from Texas Instruments (TI), we have come up with the conclusion that the idea to build a high voltage DC to DC converter was not a good one. They even suggested that we used another method to elevate the voltage. The best and most convenient idea was to use a transformer in order to elevate the voltage so we can have the 120V AC desired. And so, the group has come up with the following transformer that also confirms the following specifications:

Figure 5.9-1: 120 VAC Transformer at 60 Hz

The table 5.9-1 below shows the specifications of the transformer used:

With Wire Leads	
Input Nominal Voltage	12.6 VAC
Input Center Tap Voltage	6.3 VAC
Current	3.5 A
Nominal Output Voltage	120 VAC 60Hz
Size	2" H 1-7/8" D
Width	2-1/4" or 3" (Base Width).

Table 5.9-1: Transformer's Specifications

Also, the group has come to decide that among the many different considerations on the research, the Full-bridge converter will be used. In fact, as we noted on section 4.4.4, bridge converter is a way to build modern converter. As also we explained, H-bridge converter presents more features that fit better the purpose and requirements of our design. And so, we have decided to use the following H-bridge converter:
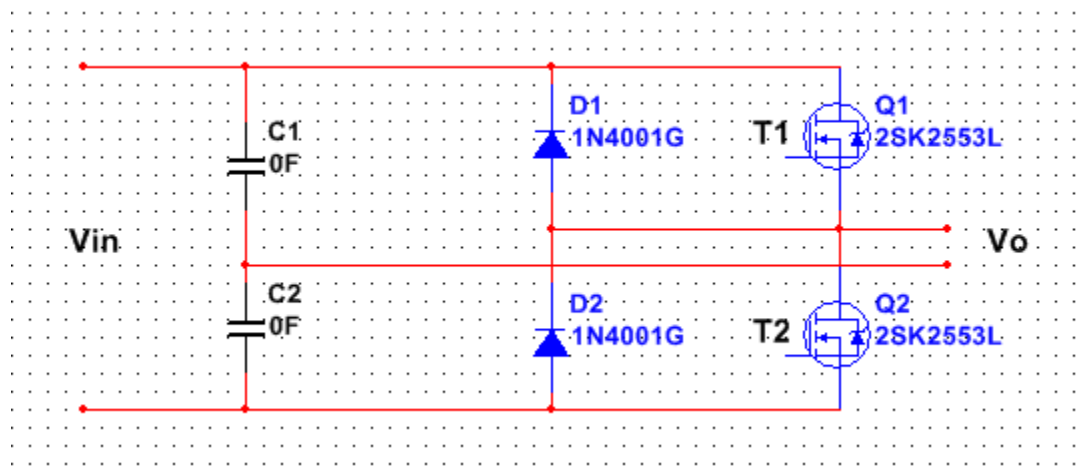

Figure 5.9-2: Half-Bridge

We have also specified the power transistors that we have used on this project. Since Power MOSFET meets most of our requirements when it comes for its cost, its efficiency, as well as its electrical and design characteristics, we have decided to use power MOSFETs in order to build the H-bridge converter.

As we progress, we come to realize that MOSFET drivers are as important as the MOSFETs themselves, so in the process of the design, we need to include the MOSFET driver in order to make the circuit works. After careful consideration on which type of MOSFET drivers to use, the come has come to select the IR2110 MOSFET Driver. In fact, most MOSFET drivers present similar characteristics and have good performance, however, IR2110 MOSFET Driver makes it easier and more convenient to use than the other. In the following table, we listed the most important characteristics of this particular MOSFET driver along with the design specifications:
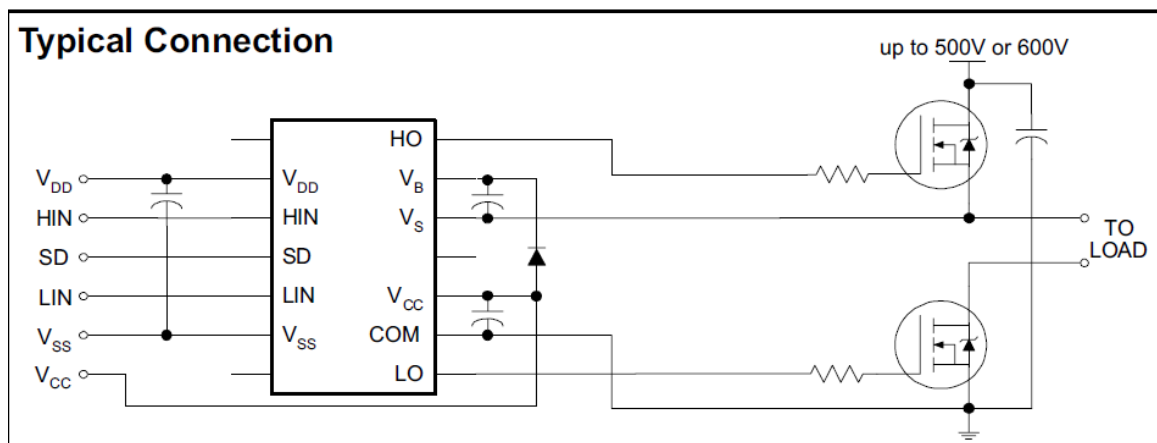

Figure 5.9-3: MOSFET Driver Circuit Connection. Reprinted with permission from International Rectifier

When it comes to choose which microcontroller to select for the design of the inverter, the group had to decide on three categories as stated on the section 4.4.4 above. After completed the research, we have come to realize that the microcontroller will have to perform two simple tasks which consist on first generating the signal that we need across the MOSFET drivers and also on modulating the wave so that the output can look like a true sine wave. Normally, all microcontrollers searched have the ability to perform the same tasks; however, one has more requirements than other. And so, the group has decided to use the MSP430 from Texas Instruments because of its simple configuration and its ease to use since the code can be written on C language.

In fact, we need to feed the microcontroller from the low DC voltage. Once the microcontroller is fed, it will generate the signals required by the MOSFET drivers, and the MOSFET drivers will drive, run, and activate the Power MOSFETs. As we also explained on the research part, the MOSFET drivers are connected to the low side of the H-bridge converter and we connect the output 120V DC of the DC/DC boost converter to the high side of the bridge. The high voltage capacity of the H-bridge is in the range of 500V DC, so the 120V DC incoming from the output of the Boost converter should not be a problem.

As stated earlier, operation of the IR2110 device will be controlled through the signals genearted by the microcontroller. Each driver will input either both of the PWM signals or the square wave signals, being fed into the HIN and LIN pins simultaneously. If the internal logic a logic high is detected, the HO pin will be driven and if a logic low is detected, the LO pin is driven. As they are not needed in the operation of the circuit V_{SS}, V_{DD}, and SD will be grounded. The compents for the bootstrap capacitors and diode are connected as shown above and their values are calculated using International Rectifiers AN-978 application notes. The formula for the minimum bootstrap capacitor values obtained from this document is:

$$ C \geq \frac{2[2Q_g + \frac{I_{qbs}}{f} + Q_{Is} + \frac{I_{Cbs}}{f}]}{V_{CC} - V_f - V_{LS} - V_{Min}} $$

Using the values determined from the data sheets of the components used as seen below, we calculated the square wave side of the bridge to be 2µF and the PWM side of the bridge to be 56nF. The diode used is an IR 8ETu04-ND 8A 400V Ultrafast Rectifier.

Qg = Gate Charge of High Side FET = 110nC
Iqbs = Quiescent current for high side driver circuitry = 230uA
Qls = Level shift charge required per cycle = 5nC (given in application note)
Icbs = Bootstrap capacitor leakage current = 250uA
f   = Frequency = 60Hz for left side of bridge, 50kHz for right side of bridge
Vcc = Supply Voltage = 12V
Vf   = Forward voltage drop across bootstrap diode = 1.3V
Vls = Voltage drop across low side FET = 1.5V
V_{min} = Minimum voltage between V_B and V_S

Driving the four MOSFETs in an H-Bridge configuration allows +170, -170, or 0 volts across the load at any time. To achieve this, the left side of the bridge is driven by the PWM signals to determine whether the output voltage is non-zero or zero while the right side of the bridge is driven by the square wave signals to determine the polarity, either positive or negative.

The output of the bridge is then connected to the filter that takes care of the attenuations and noises produced during the conversion process. The filter used in this project is a low pass filter. It reduces all kind of noises then and allows wave to get it sinusoidal form. The filter is the last part of the inverter design and it reveals of crucial importance. The following figure is the filter design along with the parts specifications we will use in the project:
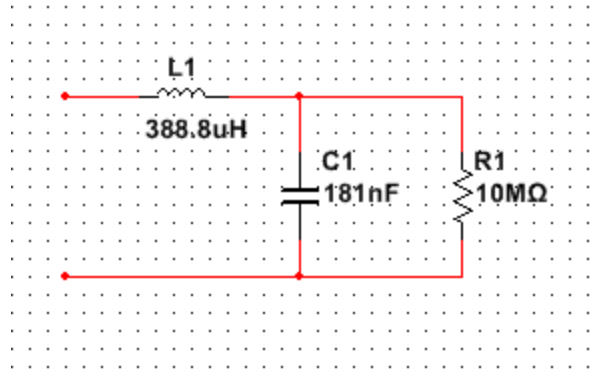
Figure 5.9-4: Low Pass Filter

As a whole, the inverter design will include three main parts – a circuit that elevates the low DC voltage into a high DC voltage or the Boost Converter, another circuit that takes the high DC voltage and converts it into 120V AC or the H-bridge converter using a microcontroller to generate the signals across the drivers, and a circuit that takes the 120V AC generated through the H-bridge and reduces all kind of high-frequency's noises and attenuations across it. Combined together, we have considered the following configuration design for the inverter with the bill of materials we will use:
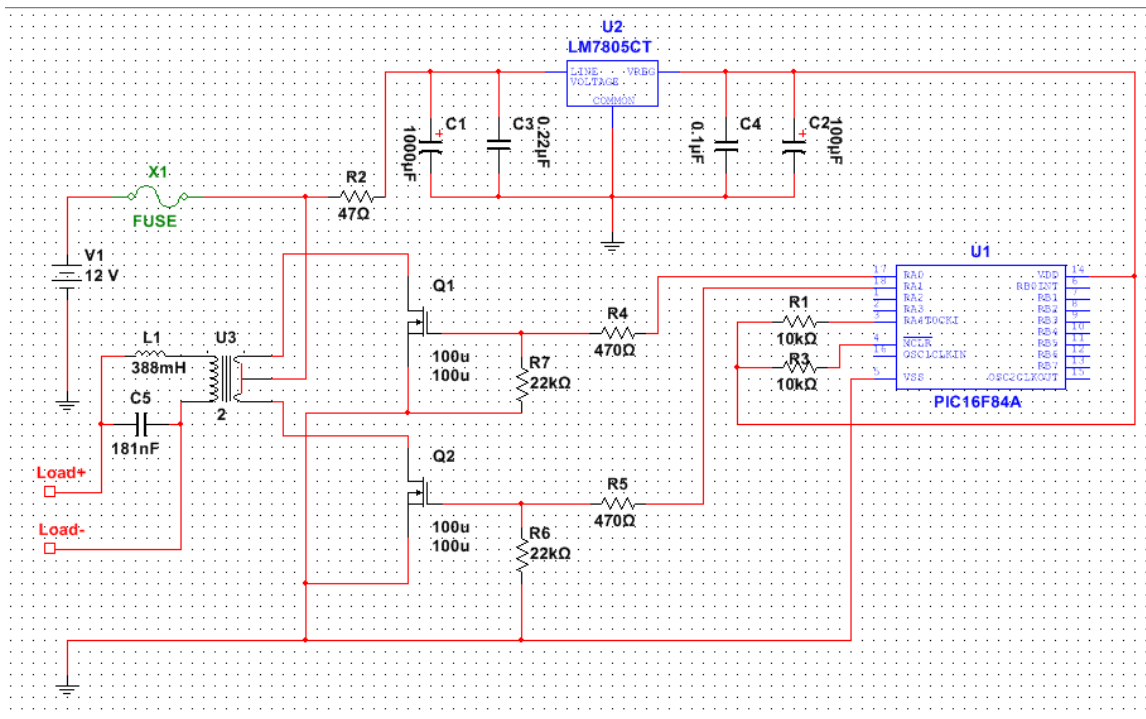

Figure 5.9-5: Inverter Final Design Configuration.

The table 5.9-2 below shows the build list of the inverter shown in figure 5.9-5:

Quantity	Parts number	Cost	Total Cost
2	STP55NF06L	5.26	10.52
1	LM7805T	1.73	3.46
4	470 Ω Resistor	0.1	0.4
4	22k Ω Resistor	0.1	0.4
2	10k Ω Resistor	0.1	0.2
4	0.22 µF Capacitor	0.4	1.6
4	1nF Capacitor	0.4	1.6
2	IR2110 MOSFET Driver	4.68	9.36
2	388mH Inductor	0.19	0.36
1	50 A Fuse	2.15	2.15
1	12 – 0 – 12 Transformer to 120 VAC	20	20
1	PIC16F628A	10.1	10.1

Table 5.9-2: Inverter Bill of Materials

5.10 Solar Panel Mount

The group plans to custom design a solar panel for the portable solar charger. Due to the fact that the solar panel mount will be custom designed, the group will create the design for the solar panel mount based on the results of the other parts from the prototype. The solar panel mount will be designed to track the Azimuth of the sun only. Therefore, it will only be able rotate horizontally 360 degrees in either a clockwise or anticlockwise direction. It is easier and cheaper for the group to custom design the solar panel mount from wood as opposed to metal.

6.0 Build

When the team starts to build the portable solar power supply, the building process will start from the components that come into the contact with the battery. These components are the DC/DC converter that provides DC output power for devices, the AC/DC inverter that provides AC output power for devices, the charge controller that charges the battery and the input power terminals for the solar tracker circuit. Essentially, constructing the solar panel mount, connecting the solar panel to the charge controller, and installing the DC and AC power outlets are the next stages in the build procedure.

When all the components excluding the solar panel, the solar panel mount, and the DC and AC outlets are tested and are confirmed to be working properly, they will be placed in the transparent plastic container. All the components excluding the solar panel and the solar panel mount will be inside or attached to the transparent plastic container.

When the portable solar power supply is complete, the solar panel mount and the solar panel will never be attached to the transparent plastic container. When the product needs to be transported to a location, the solar panel and its mount will have to be carried separately from the transparent plastic container.

Prototype

The team's goal is to build the portable solar power supply in the senior design lab. All the integrated circuits will be manufactured on PCBs. The schematic of the PCBs required for this project will be sent to a PCB manufacturing company to have the wiring printed on a board. Then, in the senior design lab, the components will be soldered and the chips stamped onto the PCB. The only voltage terminals that will not be soldered is the voltage terminals of the battery. The battery needs to be replaced so it is wise to leave it unsoldered. This makes the battery easier to replace.

All the PCBs will be taped or glued inside the plastic container to prevent them from moving around inside the plastic container when it is being transported. The solar panel's wiring will be connected to the charge controller from the top opening of the container. This is the same case for the solar tracker's gearbox. The gearbox will be outside of the plastic container but, the wiring for the gear box will be connected to the microcontroller inside the plastic container through the top opening of the plastic container. Then the plastic container's covering will rest directly on top of it without it creating a sealed closing.

The solar panel mount will be either purchased or built. If the solar panel's mount is built by the group, then a support for the gearbox will have to be made on the solar panel mount.

7.0 Test Procedure

The first part of the portable solar power supply that will be tested is the 12 volt, 35Ah battery. In the senior design lab, a positive and negative terminal from a three output power supply will be attached to match the positive and negative terminals of the battery. Then after a period of time, the terminals of the three output power supply will be removed from the battery. Then a multimeter's positive and negative terminal will be connected to match the positive and negative terminals of the 12 volt 35Ah battery. The multimeter's display will be checked to see if there is a voltage and current reading from the battery. The process described above will be repeated if a voltage and current reading from the multimeter is not obtained. If the test procedure for the battery above has to be repeated more than three times, then there is high probability that the battery is defective.

Next, the solar panel will be placed in the sunlight or in an area with bright lighting and the positive and negative output terminals will be connected to match the positive and negative terminals of a multimeter. Then, the multimeter's display will be checked for a

voltage and current reading. This process will be repeated several times if a voltage and current reading is not obtained. If this process has to be repeated several times, then this means that the solar panel is defective.

After the battery and the solar panel are confirmed to be working properly, the charge controller will be connected to the microcontroller. Also, the LCD display will be attached to the microcontroller. Then a simulated solar panel input voltage from the positive and negative terminals of three output power supply will be applied to match the positive and negative input terminals of the charge controller. Then, the positive and negative output terminals of the charge controller will be attached to match the positive and negative terminals of a multimeter. Both the multimeter and the LCD display will be observed for a voltage and current reading. If there are voltage and current readings on both the LCD display and the multimeter, then the readings on both displays will be checked for consistency. If the readings on both displays are consistent, then this confirms that the microcontroller and the charge controller work properly. Also, it confirms that the LCD display is configured properly and works properly. If the expected results of the test procedure just mentioned are not obtained, then, the configuration of the charge controller, the microcontroller, and the LCD display will have to be analyzed for errors. The components were each tested and proved to be working before they were connected so, there is a high probability that the configuration of the microcontroller, the charge controller, and the LCD display is incorrect.

Now, the charge controller's positive and negative input voltage terminals can be attached to the solar panel's output's positive and negative voltage terminals. Also, the output positive and negative voltage terminals of the charge controller will be attached to match the battery's positive and negative terminals. Also, a multimeter's positive and negative terminals will be attached to match the positive and negative terminals of the battery. Then, the display of the multimeter will be observed for a voltage and current reading. If there is a reading, then the battery, the charge controller, the microcontroller, and the solar panel all work properly when they are all connected.

Then, both the DC/DC converter and the AC/DC inverter will be tested next. They both will be tested before being attached to the 12 volt battery. To test the DC/DC converter, attach the positive and negative terminals of a three output power supply to match the voltage input of the DC/DC converter then, attach a multimeter's positive and negative terminals to match the output voltage terminals of the DC/Dc converter. Then apply a voltage within the specified voltage range of the DC/DC converter. The multimeter's display will be observed for a voltage and current reading. If a reading is displayed on the multimeter that is very close to the expected output voltage, then the DC/DC converter works properly and is ready to be connected to the 12 volt battery. If the obtained readings from the multimeter was not close to the expected output readings, or if the no reading were obtained, then the test procedure for the DC/DC converter will have to be repeated. The DC/DC converter circuit may have to be reanalyzed if no readings or inaccurate readings are still observed from the multimeter.

Originally, the AC/DC converter had several parts that must be individually tested before the inverter is tested as an entire unit. The first stage of the inverter was the DC/DC converter. The positive and negative terminals of a three output power supply would were

attached to match the positive and negative input voltage terminals of the DC/DC converter. Then the positive and negative terminals of a multimeter were also attached to match the positive and negative output voltage terminals of the DC/DC inverter. After applying 12 volts DC, the multimeter did not display the 170 volts DC that we needed to put across the high side of the bridge. Since the high voltage DC to DC did not work properly, we decided to use a transformer in order to elevate the AC voltage.

The next stage of testing for the inverter was generating the signals that will control the MOSFET driver we will used. In fact the signals from the microcontroller operate at approximately 5V, and so we used a linear regulator LM7895 from TI to step down the voltage taken from the battery. At this point, we connected all the necessary pins and we run the program using a PIC development board in order to create the signals to activate the MOSFET driver use. Once activated, the MOSFET driver created the Pulse width modulation and produced the sine wave.

With a voltage applied lower than 12 volts, we were able to output 85 VAC and with a voltage applied higher than 12 volts, we obtained 124 VAC at 60 Hz. So, the range of efficiency for this inverter is between 88 to 92% which revealed really decent when we consider the type of inverter produced. Since the goal is to have true and pure sine wave output, we also implemented a low pass filter consideration on the output of the transformer and we were able to reduce the noises and attenuations produced in the circuit.

8.0 Evaluation Plan

After all the components are tested and constructed together to create the prototype of the portable solar power supply, the prototype will then be evaluated as a whole unit. The group plans to take the portable solar power supply outside on a day that has favorable weather to test it. For the group, favorable weather means a day that is not too cloudy and has adequate sunlight to charge the battery. Because the group does not have any practical experience charging a 12 volt battery from a solar panel, no assumptions by the group can be made on how long the battery will take to charge under any type of conditions.

9.0 Vendors and Budget

The group has now compiled a list of parts and pricings that could be used for the final design. These were chosen for the project because they showed the best pricing and specifications for the project trying to be achieved. Some of the parts below have been ordered already through the manufactures. Reason the group ordered early was just in case of backorder, or if the group had to adjust on the components chosen. This is not the final design components that will be definitely used, but an accurate pricing and specifications that will be. The table 9.0-1 is displayed below:

Table 9.0-1: Vendors and Budgets

Items	Description	Price (US $)	Amount	Total
Solar panel	Monocrystalline Solar Charger 50W	$169.99	1	$169.99
Solar Panel Mount	8" Solar Panel Mount	$175.00	1	$175.00
DC Motor	12 V Motor and Gearbox	$11.20	1	$11.20
Battery	Sealed Lead-Acid Battery	$64.95	1	$64.95
DC/AC Inverter	Sine wave 12V DC to 120V AC @ 60 Hz	$160.00	1	$160.00
DC/DC Converter	5V/500mA Buck Converter	$100.00	1	$100.00
Microcontroller	Arduino Duemilanove	$20.00	1	$20.00
Microcontroller	PIC16F628A	$4.95	1	$4.95
AC Output	Duplex GFCI Receptacle	$12.95	1	$12.95
DC Output	Neutrik NAUSB Female Type-A to Type-B	$5.39	1	$5.39
Case	Plastic Casing	$12.59	1	$12.59
LCD Display	Hitachi HD44780U	$11.49	1	$11.49
TOTAL				**$748.56**

10.0 Summary and Conclusion

10.1 Project Summary

The project was now explained in detail of how it will work and what type of designs will be implemented. As the amount of time researching grew, the understanding and knowledge of the group started to increase. The team went through many changes and challenges from all the possibilities that could have been chosen. The team is now aware of all parts of the project, and have grasp of even more knowledge in their individual tasks. The team realized that organization and communication were key indicators in this project. The team tried to accurately follow the milestones that were given in the beginning of the semester. In addition, the group went through many past projects that had the same fundamentals as the project they are trying to achieve. This was a great source to have. Reviewing different examples from all over the country helped to see

what they have designed, therefore, analyzing their areas of opportunity. For example, to better the product with efficiency and cost effectiveness.

Ultimately, the group's goal was to design and develop a device that would help supply the demand for power from portable devices in today's mobile society. The main expectations of the portable solar power supply for the group was that it would be light and small enough for an average person to haul around, it would be able to provide power for many different types of portable devices, and that it would have a very high overall efficiency rating. The design portion of the project is now built, so the focus is now going to be on the 2012 Fall semester.

10.2 Project Conclusion

In conclusion, the group is overall determined and excited to make this project work. After doing research, the group was able to develop a design for the portable solar power supply. During the research phase of this project, there were some large obstacle that we finally able to be resolved. The expected final result of the project is almost within our initial design idea. Provided that everything from the design phase occurs as expected in the prototype phase, this project will fulfill the goal and objective of this project successfully.

The group did not just learn about the research and design portion of the project, but also a few other learning's. The group was now able to apply what they have learned in previous classes to an experiment. Multiple classes like Electronics, Embedded Systems, Linear Control, DSP , and many other classes have been great resources to this project. The project helped understand the concept of having a budget and learning how to stand by that budget. There were many times throughout the research portion that the group would find a perfect item, but the price was not at the budgeted price. The individual or team would then have to start from the beginning and research an alternative that could be just as good, but less expensive.

It is now time to use everything we have acquired our last four years and make a engineering project professionally and of high-quality. This will give the group a overview of what's to come later down the future. The group design and research portion of the project is now finished, so the focus is going to be on the 2012 Fall semester.

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Appendix B: Permission

To   techteacher@technologystudent.com
          Add Cc   Add Bcc
Subject   Permission to use an illustration
          Attach a file   Insert: Invitation

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V.Ryan,

Hi Ryan. I am an electrical engineering student at the University of Central Florida,
I would like to know if I could use your illustration on how a light dependent resistor
works for my senior design project. The illustration is on the link below.

http://www.technologystudent.com/elec1/ldr1.htm

This figure demonstrates how a light sensor works.

Thank you for your time,

David Carvajal
Undergraduate Electrical Engineering Student
College of Electrical Engineering and Computer Science
University Of Central Florida
Email: DavidCharles@knights.ucf.edu
Phone: 407-516-8370

Reply Reply All Forward Chat

Permission to Use Figures from Datasheets

peterobeng
Wednesday, August 01, 2012 11:55 PM

To: mylinear@linar.com

Dear Linear Technology

This is Peter Obeng. I am a senior electrical engineering student at the University of Central Florida. I am a member of a senior design group. My group is writing a design report on a project that will be built in the fall 2012 semester. Can I get permission from you to use some of the pictures from the datasheets of your LTC3780 and LCT3112 chips, please? I would appleciate this.

Thank you very much.

Sincerely,

Peter Obeng
Undergraduate Student
College of Electrical Engineering and Computer Science
University of Central Florida
Orlando, Florida 32816
Phone:1-407-504-8670
E-mail:peterobeng@knights.ucf.edu

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Permission to Use Figures from Datasheets

peterobeng
Wednesday, August 01, 2012 11:55 PM

To: ✉ mylinear@linar.com

Dear Linear Technology

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Thank you very much.

Sincerely,

Peter Obeng
Undergraduate Student
College of Electrical Engineering and Computer Science
University of Central Florida
Orlando, Florida 32816
Phone:1-407-504-8670
E-mail:peterobeng@knights.ucf.edu

🗐 **Stefan Vorkoetter**   ◀ Messages   ❋ Ac

David Carvajal   Wednesday

Stefan,

Hello. I am a undergraduate electrical engineering student at the University of Central Florida and I was hoping I can get permission to use one of your graphs from your website stefanv.com.

Thank you for your time,

David Charles Carvajal
Electrical Engineering Undergraduate Student
407-516-8370
DavidCarvajal8370@gmail.com

peterobeng
Wednesday, August 01, 2012 3:27 PM

To: ☐ cdselectronics@optusnet.com.au

Dear CdS Electronic Kits

This is Peter Obeng. I am a senior electrical engineering student at the University of Central Florida. I writing a report on a group project that my group and I would be building in the Fall 2012 semester. I plan to purchase a solar tracking kit from you in the Fall 2012 semester. I would like to know if you can give me permission to copy some of the photos of the solar tracking kit into my project report.

The photos in particular that I would like to have permission to copy are located at the website below:

http://cdselectronics.com/Kits/SolarTracker.htm

I would appreciate this very much.

Sincerely,

Peter Obeng
Undergraduate Student
College of Electrical Engineering and Computer Science
University of Central Florida
Orlando, Florida 32816
Phone:1-407-504-8670
E-mail:peterobeng@knights.ucf.edu

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To... williamchapman@WPI.EDU; orich@WPI.EDU

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Subject: Permission on using your designs

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Good evening;

My name is Amos Nortilien, an Electrical Engineering Student at University of Central Florida. I am working on a project that requires that we build an Inverter, and I found your reference design online. And so I was really fascinated by the way you approached the idea of having 120V AC with 60 Hz.

And thus, I decided to write you today in order to ask you for your permission so I can you use your reference design on my project. The link for that project is https://www.wpi.edu/Pubs/E-project/Available/E-project-042412-155252/unrestricted/MQP_Report_Final_2012-04-26.pdf, and the design I am interested in using is the Figure 13: Final circuit diagram.

I am looking forward to hearing from you soon.

Regards,

Amos Nortilien
Undergraduate Electrical Engineering
College of Electrical Engineering and Computer Science
University of Central Florida
email: amos2011@knights.ucf.edu
Phone: 407-591-2401

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To... williamchapman@WPI.EDU; orich@WPI.EDU

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Subject: Permission on using your designs

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Good evening;

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And thus, I decided to write you today in order to ask you for your permission so I can you use your reference design on my project. The link for that project is https://www.wpi.edu/Pubs/E-project/Available/E-project-042412-155252/unrestricted/MQP_Report_Final_2012-04-26.pdf, and the design I am interested in using is the Figure 13: Final circuit diagram.
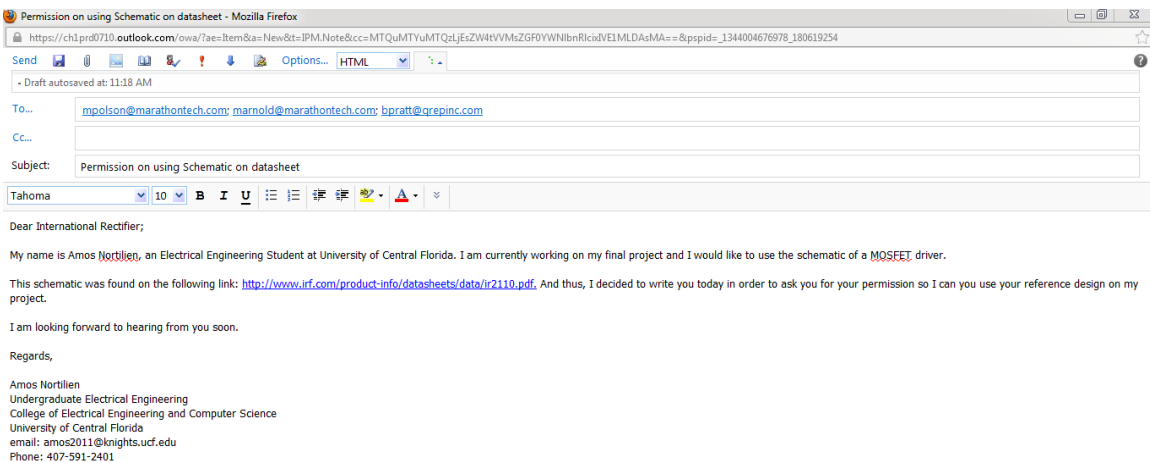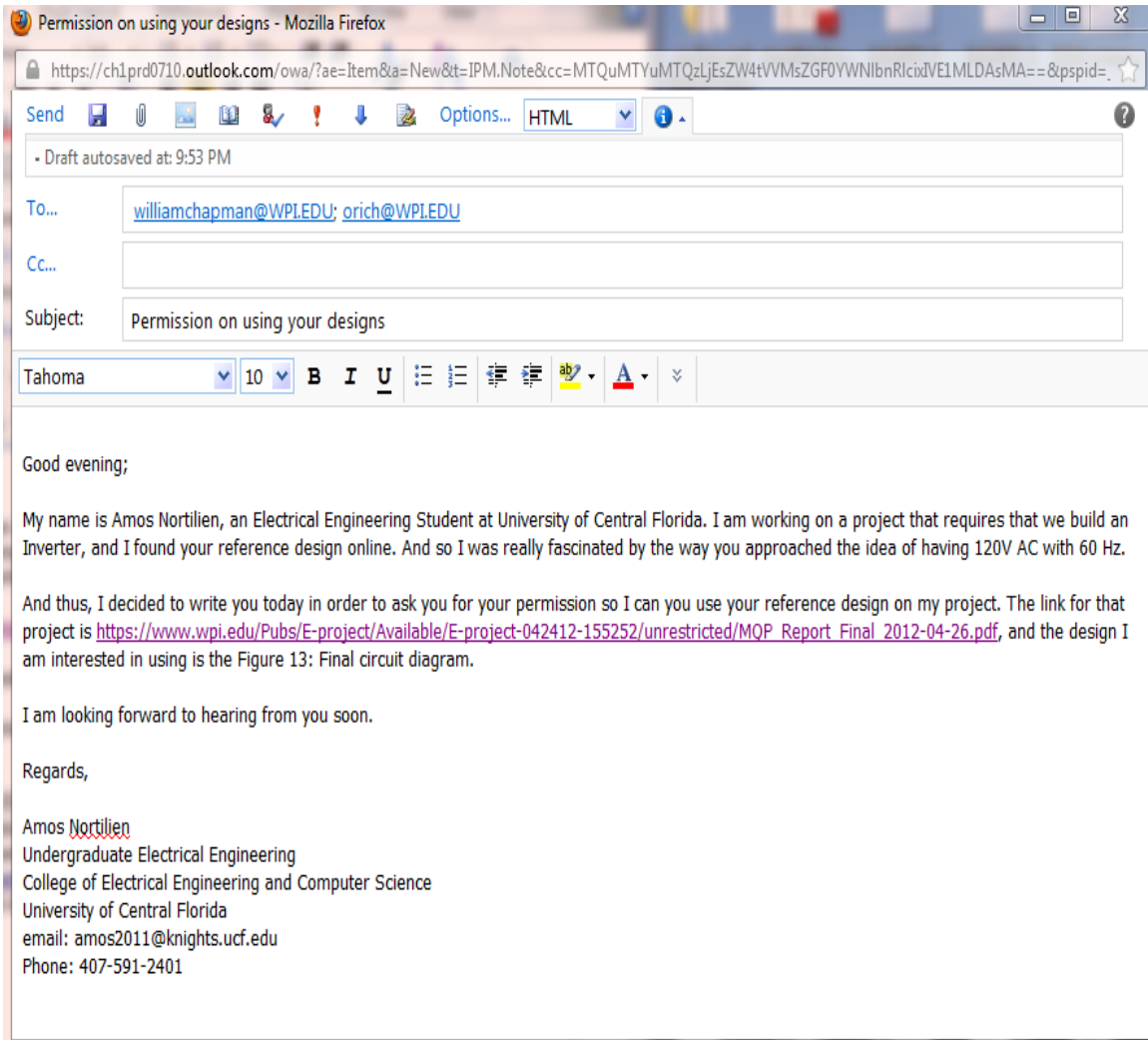
I am looking forward to hearing from you soon.

Regards,

Amos Nortilien
Undergraduate Electrical Engineering
College of Electrical Engineering and Computer Science
University of Central Florida
email: amos2011@knights.ucf.edu
Phone: 407-591-2401

Permission on using Schematic on datasheet - Mozilla Firefox

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To... mpolson@marathontech.com; marnold@marathontech.com; bpratt@qrepinc.com

Cc...

Subject: Permission on using Schematic on datasheet

Tahoma | 10

Dear International Rectifier;

My name is Amos Nortilien, an Electrical Engineering Student at University of Central Florida. I am currently working on my final project and I would like to use the schematic of a MOSFET driver.

This schematic was found on the following link: http://www.irf.com/product-info/datasheets/data/ir2110.pdf. And thus, I decided to write you today in order to ask you for your permission so I can you use your reference design on my project.

I am looking forward to hearing from you soon.

Regards,

Amos Nortilien
Undergraduate Electrical Engineering
College of Electrical Engineering and Computer Science
University of Central Florida
email: amos2011@knights.ucf.edu
Phone: 407-591-2401

This is Peter Obeng. I am a senior electrical engineering student at the University of Central Florida. I am a member of a senior design group for my senior design class. I am writing a report on a project that my group will build in the fall 2012 semester. Can you give me permission to use the hardware schematic of your Arduino Duemilanove, please?

I would greatly appreciate this.

Sincerely,

Peter Obeng
Undergraduate Student
College of Electrical Engineering and Computer Science
University of Central Florida
Orlando, Florida 32816
Phone: 1-407-504-8670
E-mail: peterobeng@knights.ucf.edu

Dear SparkFun Electronics Customer Service

This is Peter Obeng. I am a senior electrical engineering student at the University of Central Florida. I am a member of a senior design group for my senior design class. My senior design group has to build a project in the fall 2012 semester and plans to purchase an Arduino ProtoShield board from you. My group has to write a report on the project this summer 2012 semester. Can your give my group permission to use the schematic file of the Arduino ProtoShield board into my report, please? The Arduino ProtoShield board schematic file can be found at the URL address below:

http://www.sparkfun.com/datasheets/DevTools/Arduino/ProtoShield-v25.pdf

I would appreciate this very much.

Sincerely

Peter Obeng

Undergraduate Student

College of Electrical Engineering and Computer Science

University of Central Florida

Orlando, Florida 32816

Phone:1-407-504-8670

E-mail:peterobeng@knights.ucf.edu

Dear National Instruments

I am a senior electrical engineering student at the University of Central Florida. Can I get permission to use a figure on your tutorial on maximum power point tracking in a report that I will be using to build a project next semester, please?

The figure in particalar is Figure 1 from the URL below:

http://www.ni.com/white-paper/8106/en

I would appreciate this very much.

Sincerely,

Peter Obeng

Undergraduate Student
College of Electrical Engineering and Computer Science
University of Central Florida
Orlando, Florida 32816
Phone:1-407-504-8670
E-mail:peterobeng@knights.ucf.edu

NATIONAL INSTRUMENTS

August 14, 2012

Peter Obeng
12203 King's Knight Way Apt. 104
Orlando, FL 32817

Re: Permission to Use Certain Copyrighted Materials of National Instruments Corporation ("NI")
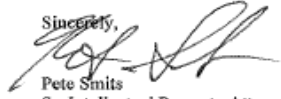
Dear Peter:

In response to your request to use NI's copyrighted materials, by this letter, NI grants you the limited right to reproduce figures from the NI Developer Zone article "Maximum Power Point Tracking" located at http://www.ni.com/white-paper/8106/en (collectively, the "NI Materials"), for use in your Senior Design group report at the University of Central Florida (UCF), which will be posted on UCF's College of Electrical Engineering and Computer Science website.

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WITH ITS USE OF THE NI MATERIALS.

Sincerely,

Pete Smits
Sr. Intellectual Property Attorney
National Instruments Corporation

Dear Texas Instuments Semiconductor Support

**This is Peter Obeng. I am a senior Electrical Engineering
student at the University of Central Florida (UCF). I am
working in a group with two other students to create a
project for a Senior Design class that I am currently
enrrolled in. My group has to write a report that will be
posted on UCF's College of Electrical Engineering and
Computer Science's website at the end of the fall 2012
semester. The link to this website is listed below:
http://www.eecs.ucf.edu/seniordesign/**

**Can you give me permission to use the hardware schematic
illustrations of your MSP-EXP430G2 LaunchPad
Experimenter
Board, please? My group already own an MSP-EXP430G2
LaunchPad Experimenter Board and plans to use it into our
project. Below is the link to the PDF document that has the
figures that I would like to use:
http://www.ti.com/lit/ug/slau318b/slau318b.pdf**

**In particular, I would like to get permission to use Figures
6, 7, and 8.**

Thank you very much.

Sincerely,

**Peter Obeng
Undergraduate Student
College of Electrical Engineering and Computer Science
University of Central Florida
Orlando, Florida 32816
Phone: 🇺🇸 ▾ 1-407-504-8670 📞
E-mail:peterobeng@knights.ucf.edu**

Permission to Use Figures from Datasheets

Steve Knoth [sknoth@linear.com]
Wednesday, August 08, 2012 10:49 AM

Actions ▾

To: peterobeng@knights.ucf.edu
Cc: floridasales@linear.com

Sure Peter – thanks for asking.

Good luck with your project.

Steve

Steve Knoth
Senior Product Marketing Engineer
Power Products Group
Linear Technology Corporation
408-432-1900 x2364

P.S.: If replying to this email, please include all previous correspondence. This retains the history and helps us keep up with your situation. Thank you!!!

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Permission to use Arduino ProtoShield Board Schematic File

Level 1 [level1@sparkfun.com]
Monday, August 06, 2012 2:56 PM

To: peterobeng@knights.ucf.edu

Permission granted. Good luck on your project.

Michelle

```
Technical Support
SparkFun Electronics
6175 Longbow Drive Suite 200
Boulder, CO 80301
techsupport@sparkfun.com


1-303-284-0979
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In response to the message from peterobeng, 9/13/2012

To: peterobeng [peterobeng@knights.ucf.edu]

- You replied on 9/24/2012 9:53 AM.

Thank you for your interest in Texas Instruments. We grant the permission you request in your email below.

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Regards,

Larry Bassuk
Deputy General Patent Counsel &
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