SOLAR BEACH CHAIR

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Project No. 2

Contents

1. Introduction

1.1. Statement of Purpose

The goal of this project is to design and build a beach chair that allows the user to safely and conveniently charge their USB devices while they are away from electrical outlets. This will be accomplished by converting the energy from the sun into power that can be delivered via USB ports. The entire project will be integrated on a canopy beach chair (solar panel on the canopy and USB ports in the arm rests) that is safe, portable, and durable. As an added convenience, a drink cooler will be built into the chair to keep beverages chilled. The product will bring the luxury of power to the serenity of the beach in a convenient and environmentally friendly way.

1.2. Benefits

There is currently no product like this out there on the market. Products exist that can charge cell phones using solar energy but our project aims to go one step further and provide a whole new outdoor experience. With other products, having the ability to charge two devices and cool a drink at the beach would require having to buy one or two separate solar chargers and a drink cooler. All of these things, along with your towel, chair, and devices, would then have to be carried to your destination. The Solar Beach Chair will integrate everything you need to hit the beach into one convenient package. All you have to do is strap on your chair like a backpack and you are ready to go.

This product will provide the user with benefits that include:

- Charge devices while soaking up the sun
- Solar canopy provides the user with shade
- Backpackable for easy transport
- Built-in electric drink cooler
- On/Off safety switch
- Environmentally friendly

Overall, this product will be of great convenience and novelty. Battery life will no longer be a factor in deciding whether you want to work on a tan or catch up on the latest news. Long gone will be those days that you have to go home early because you need to charge your cellphone.

1.3. Features

This device has many features that make it unique and functional. These features include:

- On/Off switch that disconnects the panel from the circuitry
- Two USB charging ports
- Drink Cooler
- 50 W solar panel integrated on the chairs canopy to minimize weight and size and utilize space wisely
- Uses low power microcontrollers to control converter and increase efficiency
- Backpack Straps
- Durable, water resistant, and sandproof to ensure longevity

2. Design

2.1. Block Diagrams

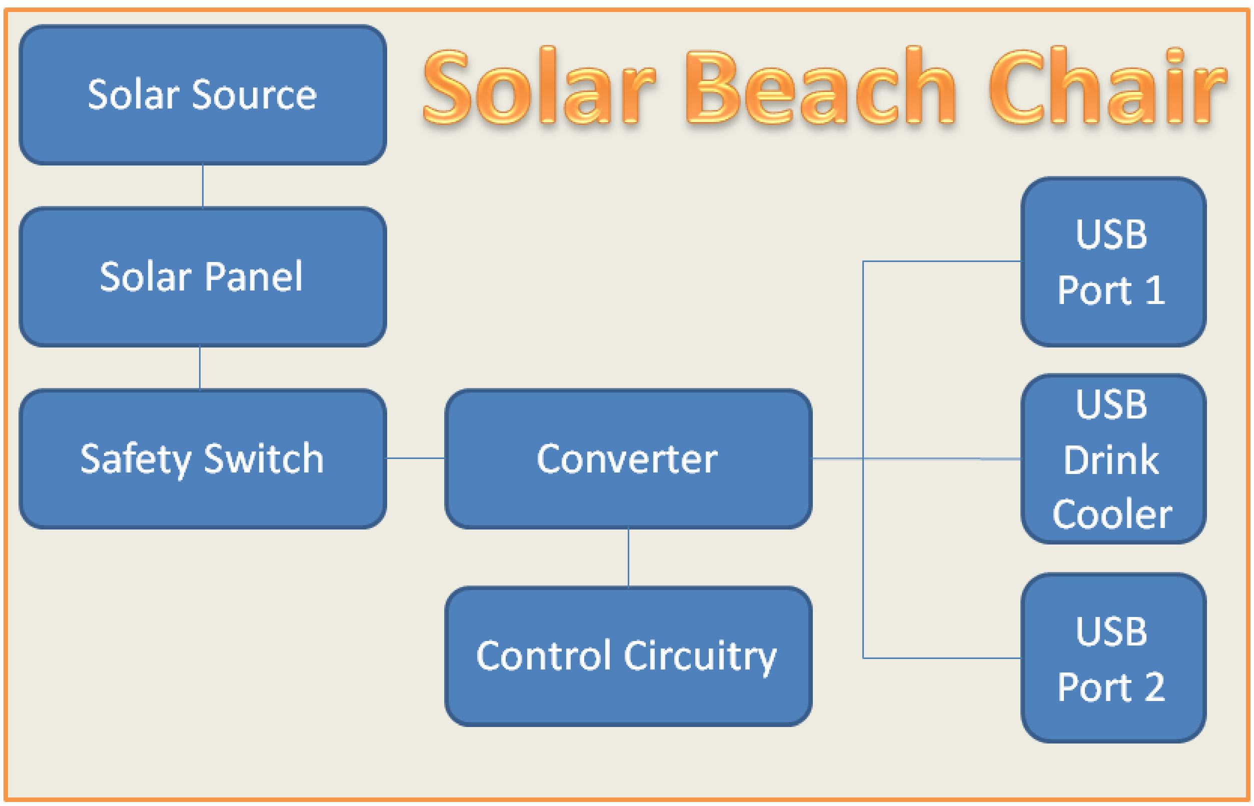

Figure 1: Top Level Block Diagram

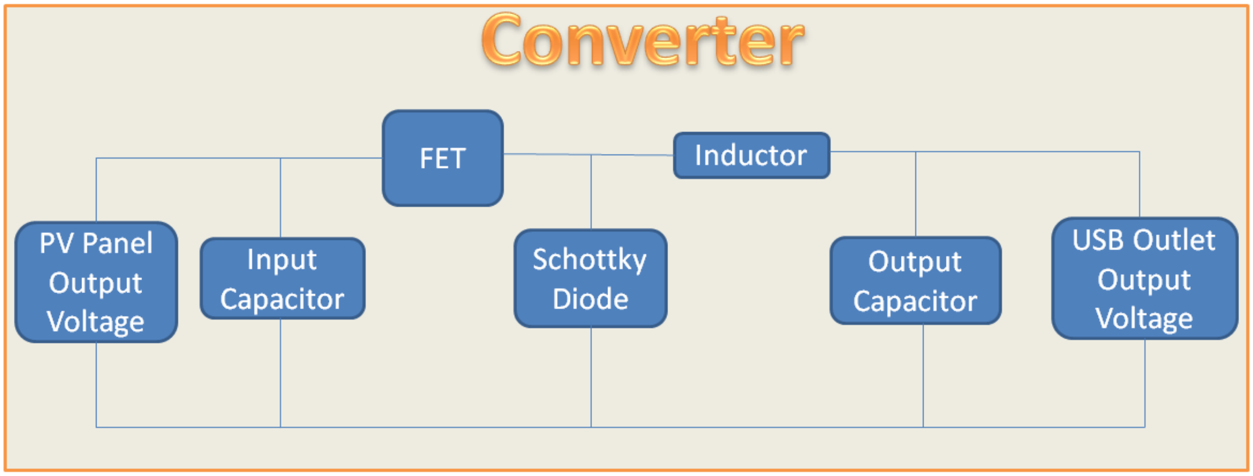

Figure 2: Converter Block Diagram

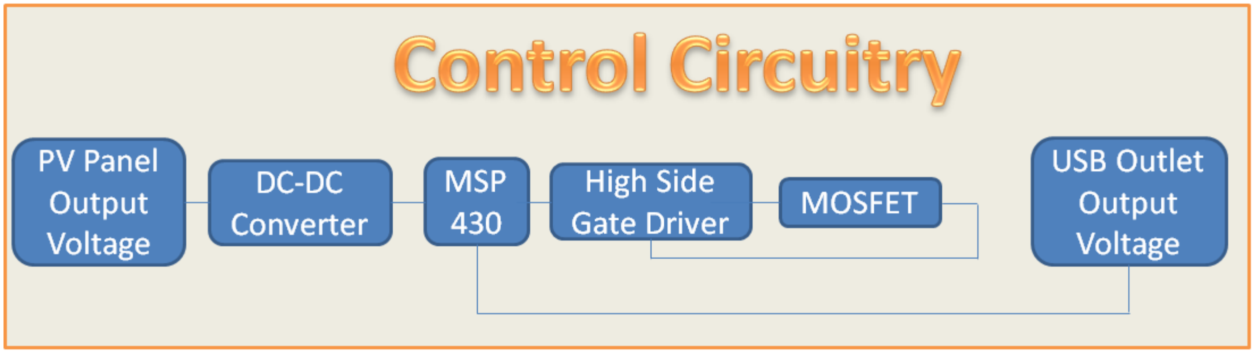

Figure 3: Control Block Diagram

2.2. Block Descriptions

2.2.1. Solar Source

For the final design, the solar source will be the sun. For design and testing purposes in the lab, halogen lamps will be used. The testing solar source will need to have variable light levels in order to mimic the sun.

2.2.2. Solar Panel

A 50 W high efficiency multicrystalline PV Module solar panel from Solarland will convert solar energy into a current and voltage output. This current and voltage will feed into the safety switch. If the switch is open (off) then the solar panel will be open circuited. If the switch is closed (on), then the current and voltage supplied by the panel will go to the converter. The panel is encased in glass to protect it from the elements. The solar panel weighs 12.46 lbs and will be mounted on the canopy of the beach chair.

2.2.3. Converter

The converter circuit will take the power from the solar panel, through the switch, and convert it so that it can be delivered to the devices through a USB port. The voltage from the panel can range from 5 V to 21.6 V. The converter will have to take the input voltage from the panel and convert it to a 5 V +/-5% output for USB charging purposes according to [1]. It will have to have three outputs, one for each of the two USB charging plugs and one to drive the drink cooler.

2.2.3.1. Input Capacitor

A 22.42 μF capacitor will be placed across the input from the solar panel in order to protect the solar panel from damage. It will take ripple current from the panel that does not go to the MOSFET (Metal Oxide Semiconductor Field Effect Transistor) and output it to ground.

2.2.3.2. FET

The FET (Field Effect Transistor) is the major switching component of the buck converter. It will take an outside signal from the control circuitry and allow more or less current to flow through to the output depending on the output voltage. We will be using a NEXFET Power MOSFET, IRF540PbF. According to [2], this MOSFET is able to handle high voltages and currents and has a resistance of only 0.077 Ω when it is on. This will decrease losses and improves efficiency.

2.2.3.3. Schottky Diode

The Schottky diode is used in the buck converter to block current when the FET is conducting and provide a current path for the inductor current when the FET is not conducting. According to [3], the Schottky diode has a forward voltage drop of only 0.6 V so the power loss in it is low.

2.2.3.4. Inductor

The inductor acts as the energy storage element in the buck converter. It draws current from the FET or the diode and charges or expels its energy to the output.

2.2.3.5. Output Capacitor

A 47.78 μF output capacitor will be used to ensure that the output voltage ripple does not exceed +/-5%. Since it is a 5 V output, we need to ensure that the capacitor is large enough so that the output voltage remains in the range of 4.75 V-5.25 V. The output capacitor will take ripple current from the MOSFET so that a more steady current reaches the output.

2.2.3.6. USB Outlet Output Voltage

The USB outlet voltages will feed off the output bus of the converter. Since there will need to be three outputs, the bus will be tapped in three places to account for the two charging devices and the drink cooler.

2.2.4. Control Circuitry

The purpose of the control circuit is to regulate the converter so that it consistently outputs the desired 5 V +/-5%. The control takes the output voltage of the converter as a sample and adjusts the duty cycle for the MOSFET in accordance with the algorithm in Figure 4.

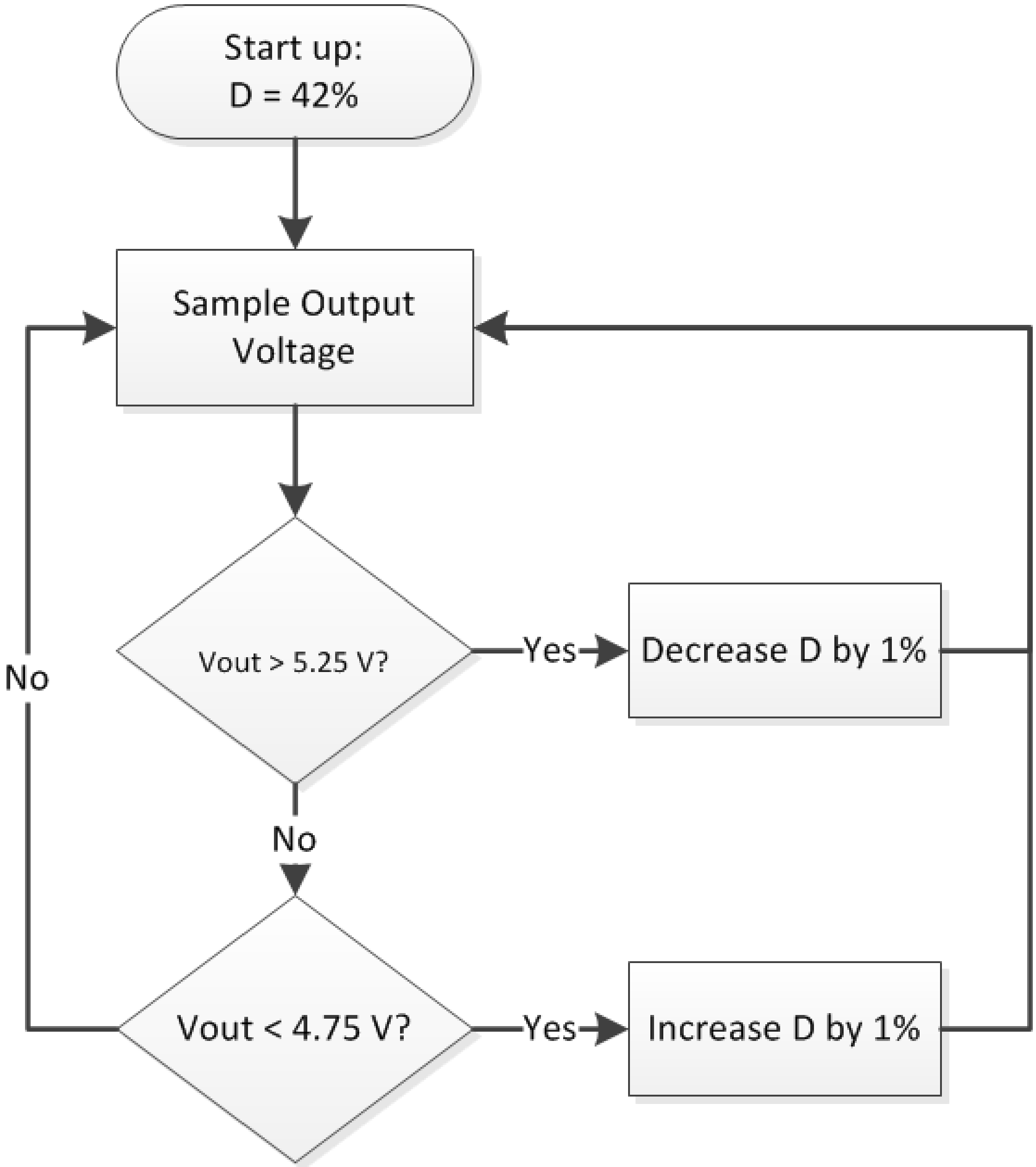

Figure 4: Control Algorithm

2.2.4.1. DC-DC Converter

The DC-DC converter is used to power the MSP430 microcontroller. According to [4], the microcontroller requires a 3.3 V, 1.65 mW input to function. The EP5277-33-ND DC-DC converter can take voltages up to 25 V and outputs a constant 3.3 V. The DC-DC converter will take the voltage from the solar panel and change it so that it can power the microcontroller.

2.2.4.2. MSP430 Microcontroller

The MSP430 microcontroller is a programmable chip that dictates the duty cycle of the control waveform delivered to the MOSFET of the buck converter. The MSP430 takes in the output voltage of the converter and follows the algorithm from Figure 4 to determine how to adjust the duty cycle to ensure a 5V+/-5% output. The output of the microcontroller goes to a high side gate driver which will drive the MOSFET.

2.2.4.3. High Side Gate Driver

The buck converter has a high side gate meaning the reference for the gate voltage is not grounded. Because the reference of the MOSFET is not grounded, a special driver is needed so that the MOSFET will switch on and off at appropriate times. The IR2111PBF-ND high side gate driver was chosen and purchased. According to [5], the chip mitigates the switching problem and allows for correct control of the buck's MOSFET

2.2.4.4. MOSFET

The MOSFET is the switching device of the buck converter. The source of the MOSFET will go into the high side gate driver and the gate of the MOSFET will come from the high side gate driver.

2.2.4.5. USB Outlet Output Voltage

The USB output will be the output of the buck converter. This voltage signal will be sent to the MSP430 microcontroller.

2.2.5. USB Ports 1 and 2

USB Ports 1 and 2 are the charging ports of the project. These ports will be located on the arms of the chair and will allow the user to charge their cell phones, tablets, or other USB devices that have a combined load below 15.71 W. The 5 V output from the buck converter will connect to 5V bus and the ground from the buck converter will connect to the ground bus specified in [1].

2.2.6. Drink Cooler

The drink cooler is an improvement upon a purchased Coolit USB Drink Cooler. The Coolit USB Drink Cooler runs off a USB port that will come from the buck converter. The cooler will be improved so that it can keep 12 oz. of water with a starting temperature of 40°-60° F within 5° F of its starting temperature for fifteen minutes when the ambient temperature is 70° F. The modified cooler will have its own container to standardize this feature.

2.2.7. Safety Switch

A safety on/off switch will be placed between the solar panel and the rest of the circuit. This switch will allow the user to turn off the chair when they are not using it. The output from the solar panel will run through the switch to the converter. When the switch is off, the solar panel will be open circuited and the circuitry will not receive power.

2.2.8. Beach Chair

We have chosen to use the Kelsyus Wave Beach Canopy Chair. The final project will consist of all the components assembled onto the beach chair. The solar panel will be mounted onto the canopy. The circuitry will be weatherproofed and neatly integrated onto the chair so that the drink cooler and USB ports come from the arm of the chair. Placing the chair in adequate sun will allow the user to run the drink cooler and charge two USB devices. The final chair should be able to handle a simulated rain and still work properly. The chair will also be made into a backpack for easier transport. According to [6], a safe weight for a back is said to be 20% of a person's body weight. For this reason, the final beach chair will weigh less than 35 lbs.

2.3. Schematics

2.3.1. Overall Circuit Schematics

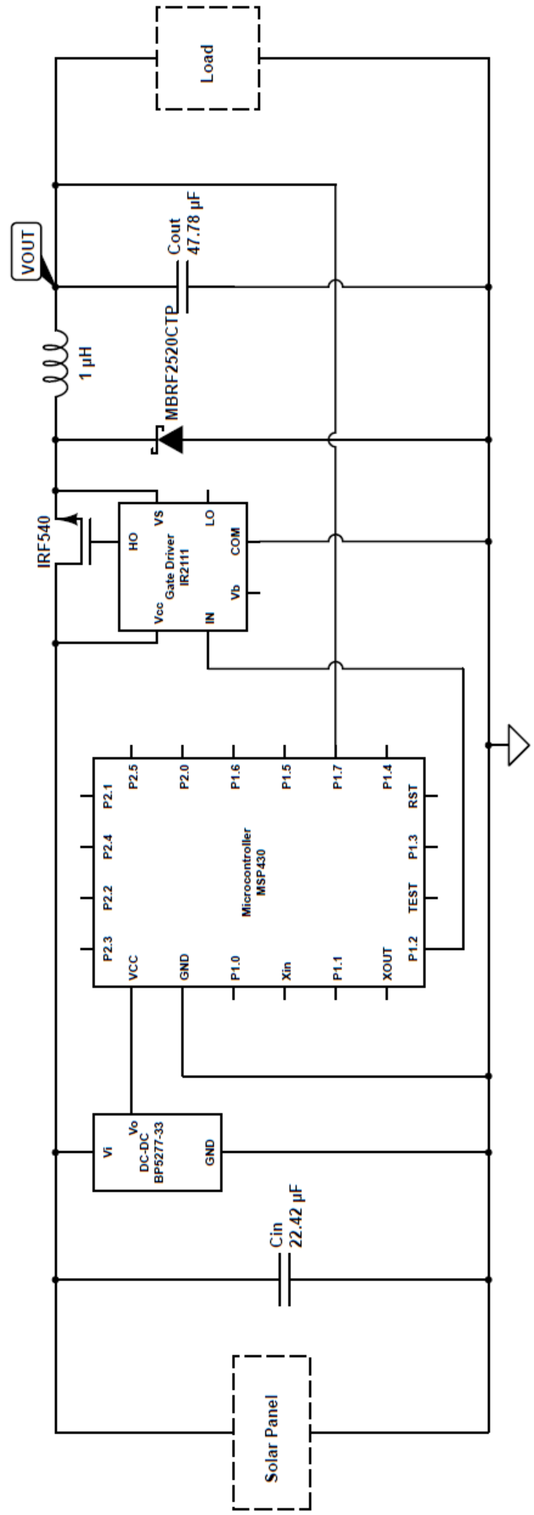

Figure 5: Overall circuit schematic consisting of the integration of the control circuitry into the buck converter.

2.3.2. Buck Converter Schematic

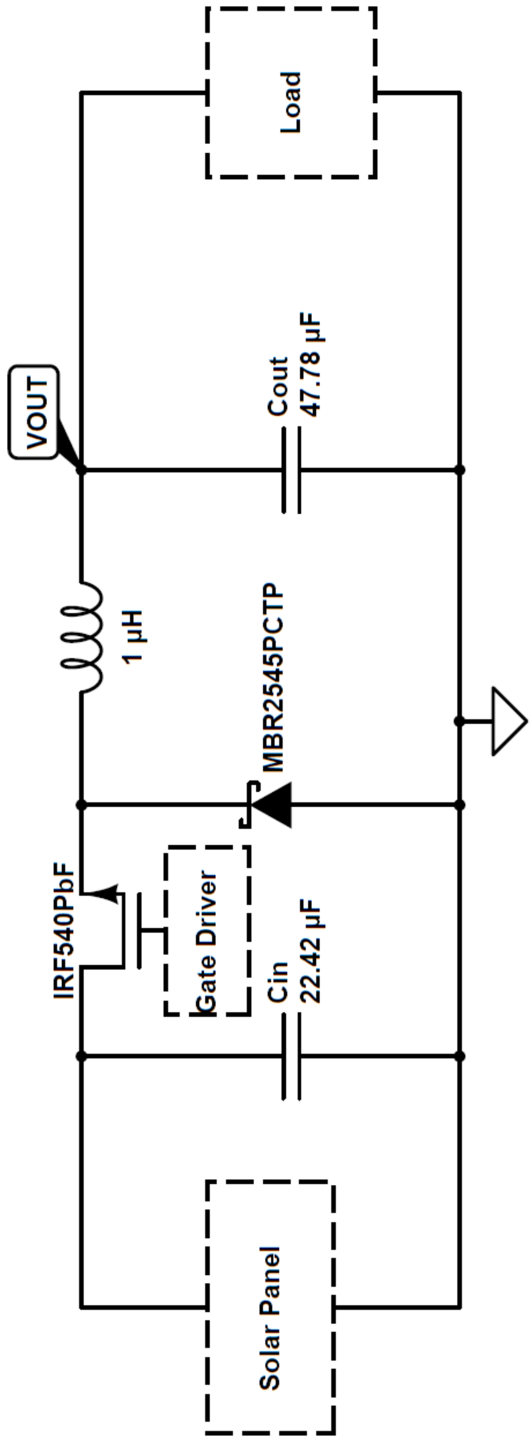

Figure 6: Buck converter showing the exact hookup of the converter sub-block. Upon integration, the gate driver from the control circuitry will drive the IRF540PbF MOSFET and V_{OUT} will be used as the reference point for the microcontroller. V_{OUT} will go to the 5 V bus of the USB and ground will go to the ground bus of the USB.

2.3.3. Control Circuit

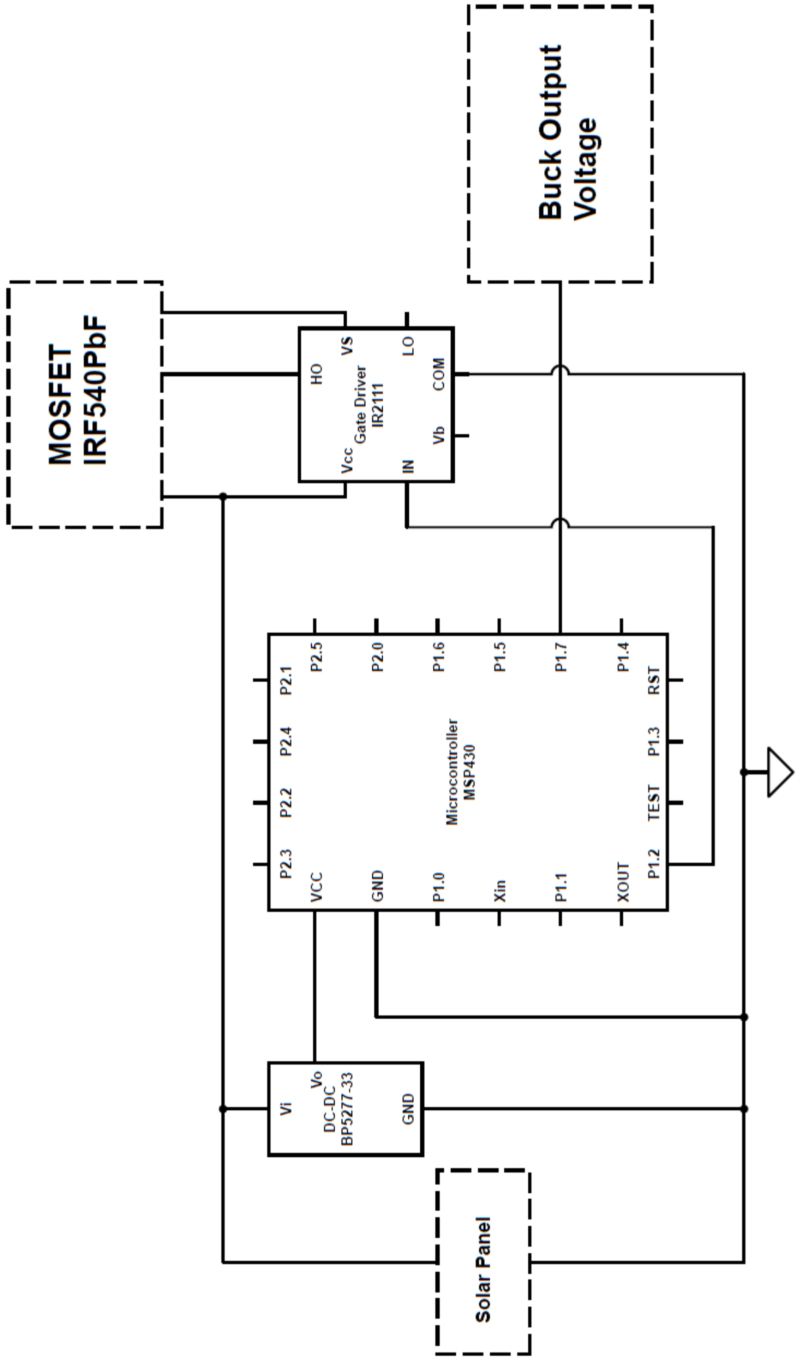

Figure 7: Control Circuit Schematic: The three major aspects of the control are purchased programmable chips with the shown pinouts. The microprocessor is powered by the DC-DC chip and it will take in the output voltage and adjust the duty cycle of the gate driver accordingly. The gate driver will then drive the MOSFET.

2.3.3.1.DC-DC Converter Schematic

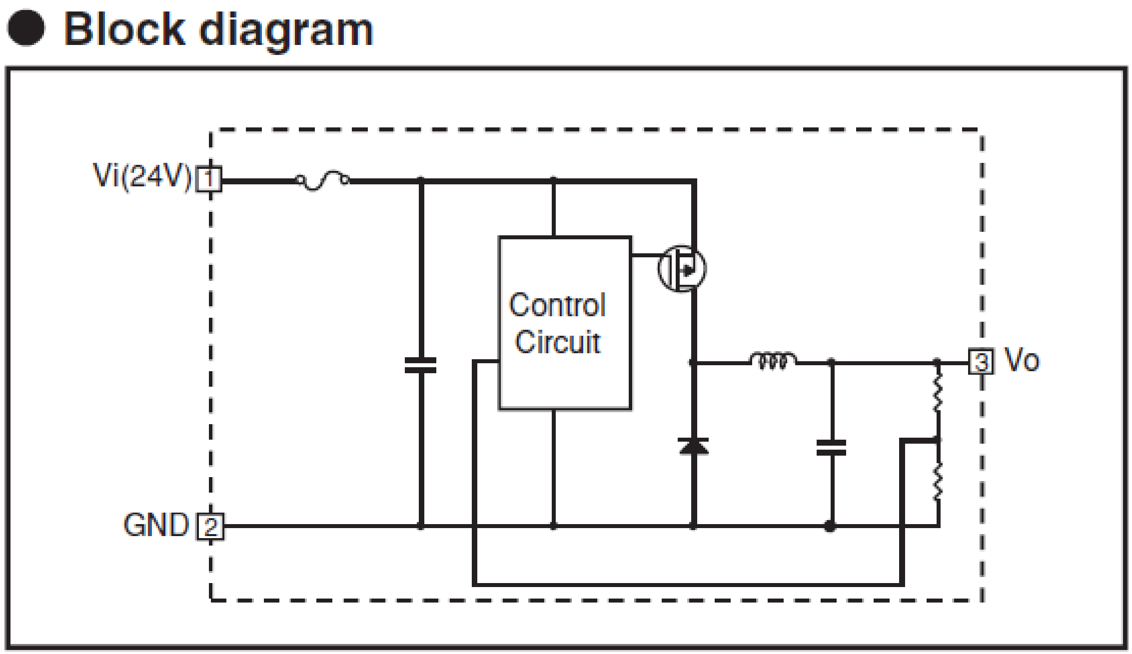

Figure 8: According to [4] the DC-DC converter can be represented by this block diagram taken directly from the datasheet.

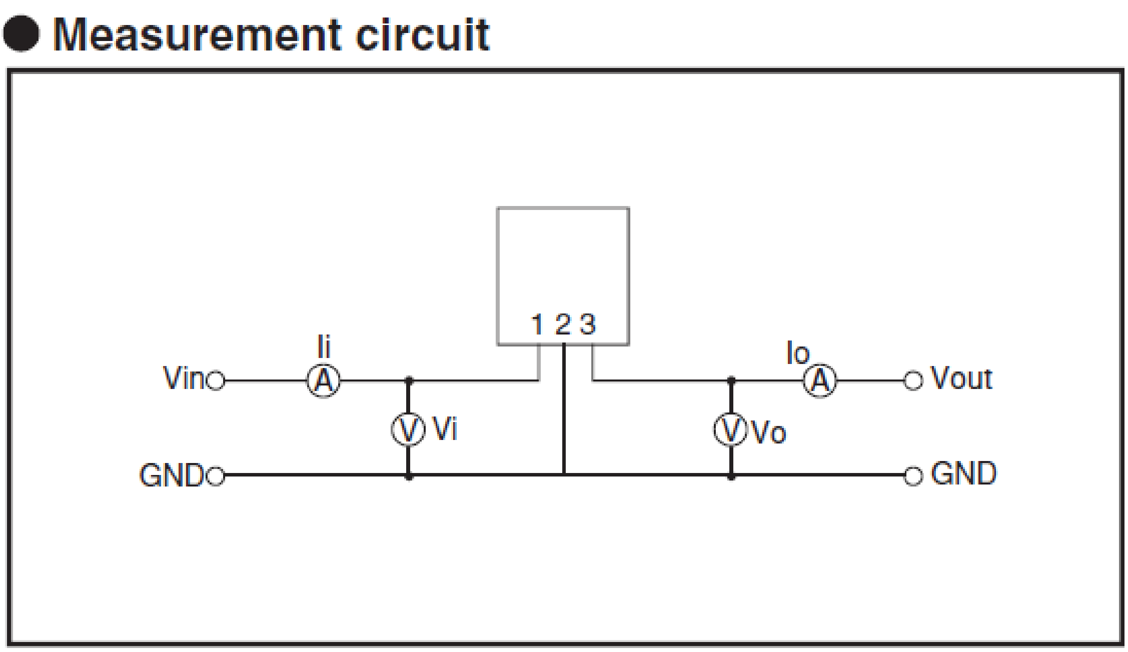

Figure 9: According to [4], the control circuit in the DC-DC chip can be represented by this diagram taken directly from the datasheet.

2.3.3.2.MSP430 Code

The following code will be used to program the MSP430 microprocessor chip. This code has been modeled according to [7].

```
//***************************************************
// MSP430G2553 Control Code
// For University of Illinois ECE 445
// Senior Design Project - Solar Beach Chair
// Description: This code will generate a PWM signal to control a buck
// converter. The ADC will sample the output voltage and if the value
// is too low or too high the duty ratio will be increased or decreased
// if necessary.
// This code was based on the MSP430G2231 Demo from MSP430LaunchPad.com.
// The original comments are shown below.
// Last modified by Andrew Gazdziak on 2/24/2013
//************************************************************************
// MSP430G2231 Demo - Timer_A, PWM TA1, Up Mode, SMCLK
//
// Description: This program generates one PWM output on P1.2 using
// Timer_A configured for up mode. The value in CCR0, 1000-1, defines the
// PWM period and the value in CCR1 the PWM duty cycles. Using SMCLK,
// the timer frequency is about 1.1kHz with a 25% duty cycle on P1.2.
// Normal operating mode is LPM0.
// MCLK = SMCLK = default DCO (about 1.1MHz).
//
//       MSP430G2231
//       -----------------
//   /|\ |               |
//    |  |               |
//    --|RST     P1.2/TA1|--> CCR1 - 75% PWM
//       |               |
```

```
//       |                 |
//
// M.Buccini / L. Westlund
// Texas Instruments, Inc
// October 2005
// Built with CCE Version: 3.2.0 and IAR Embedded Workbench Version: 3.40A
//
// Modified by NJC for MSP430LaunchPad.com - July 2010
//***************************************************************************

#include "msp430G2553.h"
#ifndef TIMER0_A1_VECTOR
#define TIMER0_A1_VECTOR TIMERA1_VECTOR
#define TIMER0_A0_VECTOR TIMERA0_VECTOR
#endif

volatile long tempRaw;

void FaultRoutine(void);

void main(void)
{
    WDTCTL = WDTPW + WDTHOLD;  // Stop WDT
    //Set up the main clock to have a divider of 0, SMCLK divider of 0
    BCSCTL2 |= SELM_0 + DIVM_0 + DIVS_0; // MCLK = DCO/8

    //Set up the output pins
    P1DIR |= BIT2;           // P1.2 to output
    P1SEL |= BIT2;           // P1.2 to TA0.1

    if (CALBC1_1MHZ ==0xFF || CALDCO_1MHZ == 0xFF)
```

```
        FaultRoutine();         // If cal data is erased
                                // run FaultRoutine()

    /*
     * Set up the PWM Timer. This will generate a 10.49 kHz signal
     */
    CCR0 = 100-1;               // PWM Period.
    CCR1 = 50;                  // CCR1 PWM duty cycle. Modify this in the while to change D
    CCTL1 = OUTMOD_7;           // CCR1 reset/set
    TACTL = TASSEL_2 + MC_1;    // SMCLK, up mode
    _BIS_SR(LPM0_bits);         // Enter LPM0
    while(1)
    {
        //Set up the ADC to have P1.4 be the input
        ADC10CTL1 = INCH_4 + ADC10DIV_0;
        ADC10CTL0 = SREF_1 + ADC10SHT_3 + REFON + ADC10ON;
        _delay_cycles(5); // Wait for ADC Ref to settle
        ADC10CTL0 |= ENC + ADC10SC; // Sampling & conversion start
        ADC10CTL0 &= ~ENC;
        ADC10CTL0 &= ~(REFON + ADC10ON);
        tempRaw = ADC10MEM;         //Temporary variable used for debugging
        _delay_cycles(12500);
    }

}

void FaultRoutine(void)
{
   P1OUT = 0x01; // red LED on
   while(1); // TRAP
}
```

2.3.3.3.High Side Gate Driver Schematic

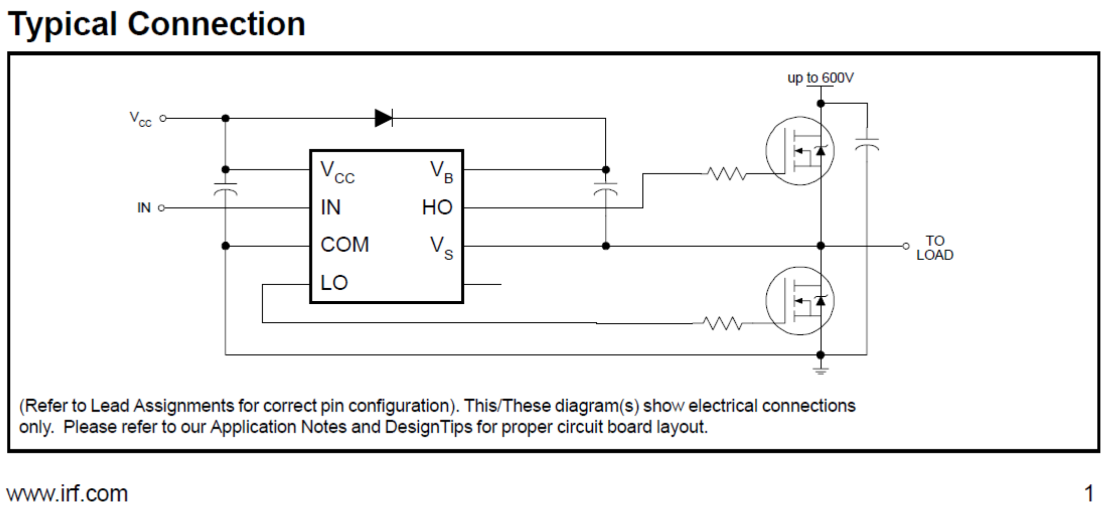

Figure 10: High Side Gate Driver Connection: According to [2] the gate driver can be represented by this figure taken from the datasheet.

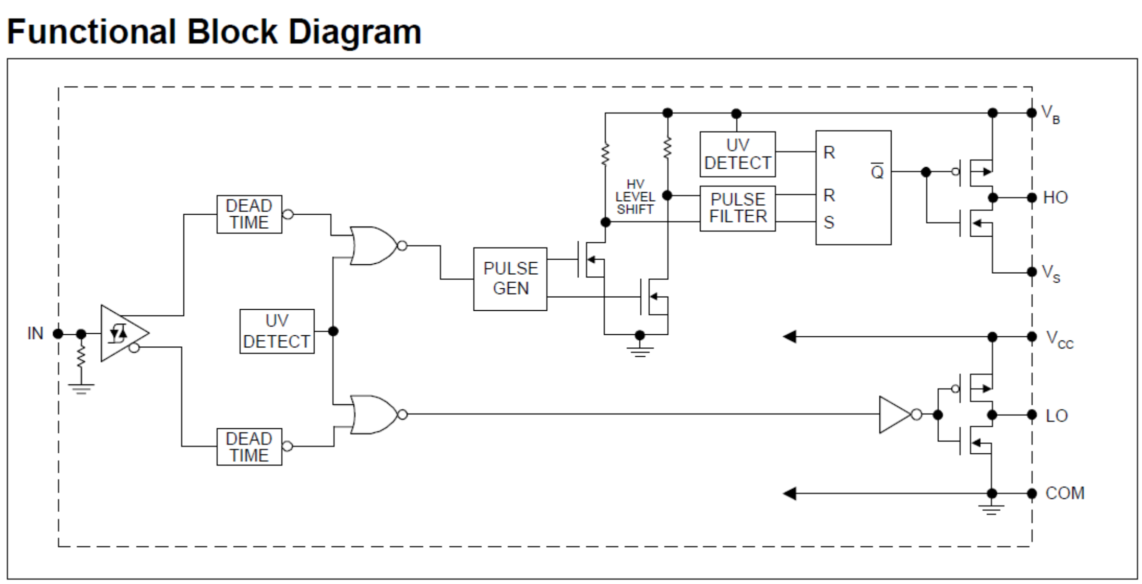

Figure 11: High Side Gate Driver Block Diagram: According to [2] the logic behind the gate driver can be represented with this schematic.

2.3.4. USB Schematic

Pin		Description
1	VBUS	Red
2	D-	White
3	D+	Green
4	GND	Black
Shell	Shield	Drain

Figure 12: According to [1], USB pins are identified according to the figure taken directly from the document.

2.3.5. Solar Panel Schematic

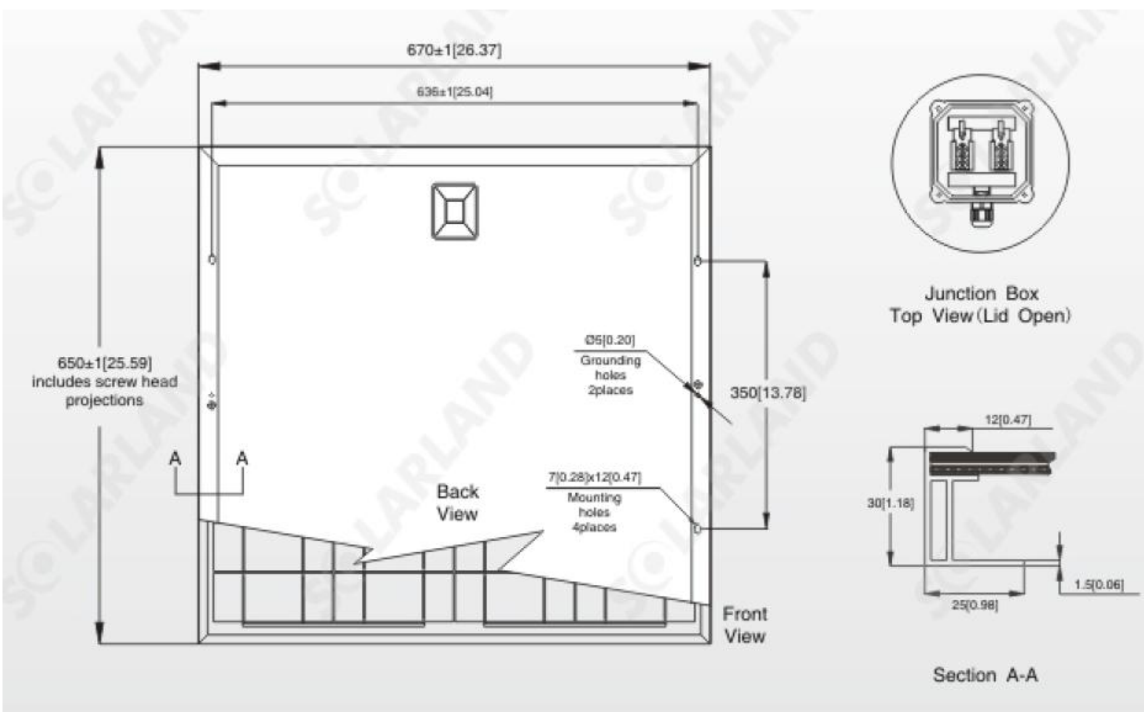

Figure 13: According to [8] the solar panel has these dimensions with a junction box that allows access to the high and low output of the panel.

2.3.6. Safety Switch Schematic

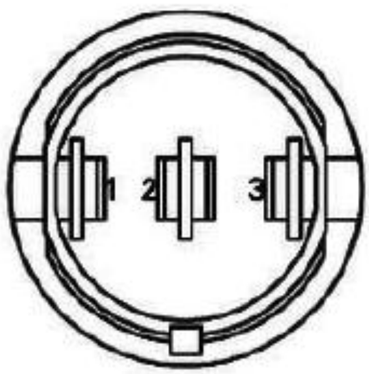

Figure 14: According to [9] the switch pins

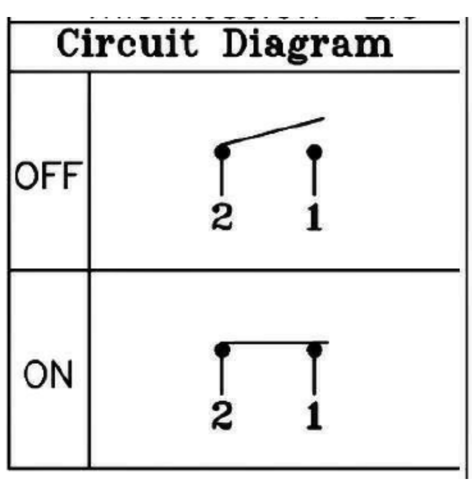

Figure 15: According to [9], the switch circuit diagram is a standard on off switch connected to the pins as shown in this diagram taken from the datasheet.

2.4. Simulations and Calculations

2.4.1. Buck Converter

2.4.1.1. Buck Converter Calculations

To design this system we must first specify our requirements. Shown in Table 1 is a list of the major requirements our converter must meet.

Table 1: Requirements for Solar Beach Chair Power Converter

Input Voltage Range	5V - 21.6V
Output Voltage Range	4.75V - 5.25V
Output Load Range	0W - 50W

As can be seen by this table, we are going to have an input voltage of around 12V, and an output voltage of around 5V. The load will range from no load to 50 watts. With these specifications in mind it is clear that we must design a Buck DC-DC converter. For our buck converter we will use a switching frequency of 200 kHz, which represents a good trade-off between efficiency and converter size.

To minimize inductor size we will operate on the boundary of discontinuous conduction mode (DCM) and continuous conduction mode (CCM). For a peak power of 50W, the first step is to find the critical inductance L_{crit} needed to operate on the boundary of DCM and CCM. Shown below is the data for our particular circuit.

$$V_{in} = 12V, P_{in} = 50W, V_{out} = 5V, f_{sw} = 200\ kHz$$

For a buck converter with all ideal components, the duty ratio is given by (1)

$$Duty\ Ratio = D = \frac{V_{out}}{V_{in}} = \frac{5V}{12V} = 0.417 \tag{1}$$

The input and output current can be found by (2, 3)

$$Input\ Current = I_{in} = \frac{P_{in}}{V_{in}} = \frac{50\ W}{12V} = 4.17A \tag{2}$$

$$Output\ Current = I_{out} = \frac{P_{out}}{V_{out}} = \frac{50\ W}{5V} = 10A \tag{3}$$

At the boundary of DCM and CCM, (4) holds true

$$\text{Change in the Inductor Current} = \Delta I_{Lp-p} = 2 * I_{out} \tag{4}$$

Therefore we have,

$$\Delta I_{Lp-p} = 2 * I_{out} = 2 * 10A = 20A$$

By doing volt second balance on the inductor, it can be found that (5,6) hold true for a buck converter

$$V_L = V_{in} - V_{out} \ \ for\ 0 \le t < DT \tag{5}$$

$$V_L = -V_{out} \ \ for\ 0 \le t < DT \tag{6}$$

Therefore, we have (7)

$$\Delta I_L = \frac{V_{in}-V_{out}}{L} * DT = \frac{V_{in}(1-D)}{L} * DT \tag{7}$$

With all of this information in mind, and using our ECE 464 textbook [10], we have (8)

$$L_{crit} = \frac{V_{in}(1-D)D}{2f_{sw}} * \frac{V_{out}}{P_{out}} = \frac{12(1-0.417)0.417}{2*200{,}000} * \frac{5}{50} = 0.730\mu H \tag{8}$$

The next step is to sketch the inductor current, output and input capacitor currents as well as switch currents. Shown in Figure 16 is the inductor current.

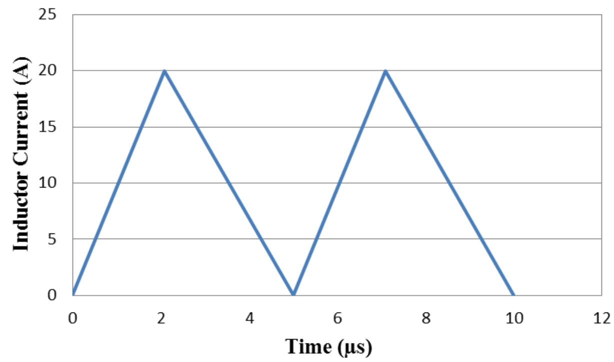

Figure 16: Inductor Current vs. Time

As can clearly be seen from Figure 16, the inductor current obtained is for the critical inductance calculated above. This is the smallest current in order to avoid discontinuous conduction mode. Shown in Figure 17 is the output capacitor current.

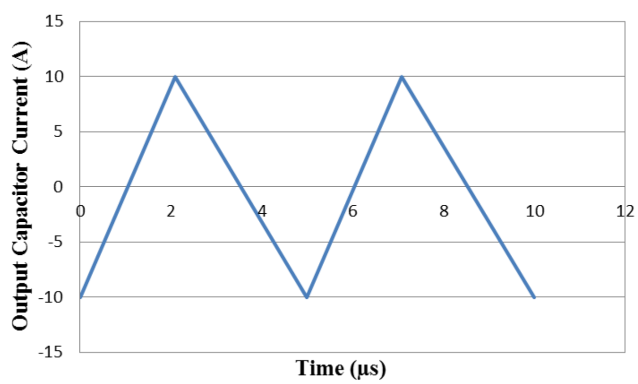

Figure 17: Output Capacitor Current vs. Time

The graph of the output capacitor current was calculated by knowing that the average current through a capacitor is zero. This can be seen by the graph of Figure 17, as the area above the x-axis equals the area below the x-axis. Shown in Figure 18 is the switch current.

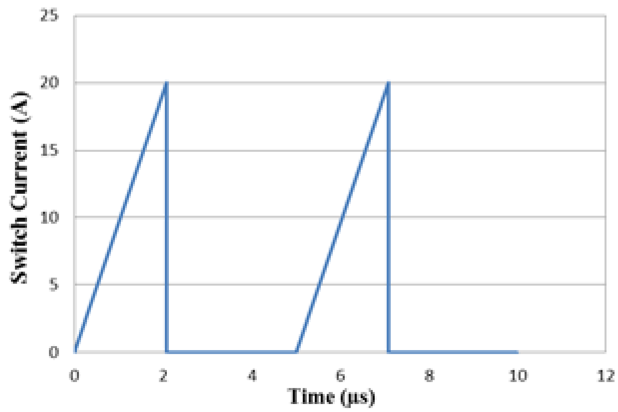

Figure 18: Switch Current vs. Time

The graph of the switch current is obtained by realizing that when the switch is off, there is no current going through the switch. When the switch is on, the current through the switch is equal to the inductor current. Shown in Figure 19 is the input capacitor current.

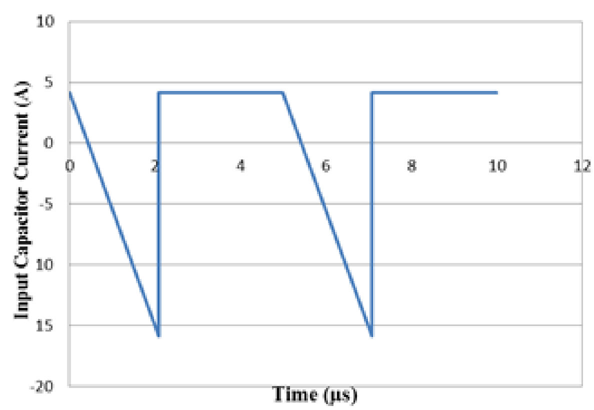

Figure 19: Input Capacitor Current vs. Time

To obtain the graph of the input capacitor current, the fact that the average current through a capacitor is zero was used. This can be seen by the graph of Figure 19, as the area above the x-axis equals the area below the x-axis. Also, when the switch is off, $I_{c_{in}} = I_{in} = 4.17A$, and when it is on $I_{c_{in}} = I_{in} - I_{sw}$. This was computed using KCL on the buck converter.

The next step is to calculate the rms current values in the inductor and both capacitors. Since $I_L$and $I_{c_{out}}$ are both triangular waveforms, their rms value can be calculated by simply dividing their peak value by $\sqrt{3}$. Therefore

$$I_{L_{rms}} = \frac{20}{\sqrt{3}} = 11.547\ A$$

$$I_{c_{out_{rms}}} = \frac{10}{\sqrt{3}} = 5.774\ A$$

To calculate $I_{c_{in_{rms}}}$ the general integration formula is to be used [10]

$$I_{rms} = [\frac{1}{T} * \int_0^T i^2(t)dt]^{\frac{1}{2}} \tag{9}$$

Therefore,

$$I_{c_{in_{rms}}}{}^2 = 0.417 * \int_0^1 (4.17 - 20\tau)^2 d\tau + 0.583 * 4.17^2$$

$$I_{c_{in_{rms}}}{}^2 = 0.417 * 67.3222 + 10.1377 = 38.211$$

$$\sqrt{I_{c_{in_{rms}}}{}^2} = I_{c_{in_{rms}}} = \sqrt{38.211} = 6.1815$$

To extract the maximum power from the photovoltaic panel, it is desired to have the input voltage ripple below $1.00V_{p\text{-}p}$. For the sake of this calculation we will ignore the equivalent series resistance (ESR) of the input capacitor. Using (10 and 11) the required capacitor value can be obtained.

$$\Delta V_{in_{p-p}} = 1.00V$$

$$\Delta V_{in_{p-p}} = \frac{\Delta Q}{Cin} \tag{10}$$

$$\Delta Q = (1 - D)T * 4.17A + 0.5 * 4.17A * \frac{1}{20}T \tag{11}$$

$$\Delta Q = 0.583 * 5 * 10^{-6} * 4.17 + 0.5 * 4.17 * \frac{1}{20} * 5 * 10^{-6} = 1.268 * 10^{-5}C$$

$$C_{in} = \frac{\Delta Q}{\Delta V_{in_{p-p}}} = \frac{1.268 * 10^{-5}}{1} = 12.68\ \mu F$$

For proper USB operation, it is required to have the output voltage ripple of the converter to be below $0.5V_{p\text{-}p}$. The voltage should remain within the range of $4.75 < V < 5.25$. Again neglecting the effects of ESR and using (10 and 12) the output capacitor value is obtained.

$$\Delta Q = \frac{1}{2} * \frac{T}{2} * 10A = 1.25 * 10^{-5}C \tag{12}$$

$$C_{out} = \frac{\Delta Q}{\Delta V_{out_{p-p}}} = \frac{1.25 * 10^{-5}}{0.5} = 25\ \mu F$$

Now that the required values of the inductor and capacitors are determined, the next step is to determine which type of diode is the best for high efficiency operation. A Schottky diode is desired because of its low reverse recovery time t_{rr} and thus a low reverse recovery loss Q_{rr}. Also Schottky diodes have a low forward voltage drop of about 0.2-0.3V, which results in a higher switching speed and a higher efficiency.

Since the critical inductance is determined, the physical inductor that meets the operating specifications will be selected. The maximum volt-second valance on the inductor can be found by (13)

$$\int v(t)dt = NB_{sat}A_c \tag{13}$$

N is the number of turns of the inductor and A_c is the area of the core. This equation can be rewritten into a more usable form to obtain (15) by using (14).

$$v(t)dt = L\frac{di}{dt} \tag{14}$$

$$\int L\frac{di}{dt}dt = NB_{sat}A_c = \int L\,di = L * I_{max}$$

$$L * I_{max} = NB_{sat}A_c \tag{15}$$

The equation obtained in (15) will be used in order to find the required area of the core A_c. It is desired to use a 3F3 inductor for our design. This is because ferrite cores are good at high frequency. Also they do not have any eddy currents, and soft ferrites have low coercivity and thus low hysteresis losses and thus leads to a more efficient converter design [11]. In order to not saturate our core, we will operate our core at a B field less than 0.3T. To select an inductor, we looked at various datasheets. The inductance is given by (16)

$$L = N^2A_L \tag{16}$$

To select the correct inductor, (15) and (16) must both be satisfied. It requires an iterative process to find the optimal inductor size. After multiple iterations, the RM6S/I-3F3-A63 inductor was chosen. This core material has $A_L = 63nH, N = 4$, and $L = 1.008\mu H$ which satisfy all of the requirements.

Since efficiency is the main goal for this design, we want to keep the winding losses as low as possible to minimize the use of copper. To do this we should make the wire radius the same as the skin depth. The diameter is obtained by using (17)

$$d = 2\partial = 2r = 2\frac{7.5cm}{\sqrt{f_{sw}}} = 2\frac{7.5cm}{\sqrt{200{,}000}} = \ 0.3354mm \tag{17}$$

Thus, AWG 27 with a diameter of 0.361mm meets the requirements. If we assume a packing factor of k=0.5 when winding the inductor, we must determine if the wires will fit in the window. From looking at the RM6S/I-3F3-A63 datasheet, the window area is

$$A_{window} = \frac{(12.4 - 6.4) * 8}{2} = 24mm^2$$

For AWG 27, area of the wire is $0.102mm^2$, therefore the area taken up by the wire is

$$A = \frac{N * A_{wire}}{k} = \frac{4 * 0.102}{0.5} = 0.816mm^2$$

Since $0.816mm^2 < 24mm^2$ the wires fit into the core window. To meet the current density requirement of $500\frac{A}{cm^2}$ it is required to use multiple strands of wire in parallel. The maximum current through the inductor wires is $I_{max} = 20$A which can be seen from figure 1. With this in mind, we have (18)

$$Number\ of\ Parallel\ Strands = \frac{I_{max}}{(Current\ Density\ Limit) * A_{wire}} \quad (18)$$

$$Number\ of\ Parallel\ Strands = \frac{20A}{\frac{500A}{cm^2} * 0.102 * 10^{-2}cm^2} = 40\ Parallel\ Strands$$

The final step in this buck converter design is to determine what type of output capacitors to use. Because efficiency is the number one design consideration, we chose to use ceramic capacitors. The advantages of using ceramic capacitors are that they have excellent high frequency characteristics with low losses [12]. We will choose capacitors that have a working voltage higher than three times the expected voltage. Since our expected input voltage is 12V, we will select a capacitor at a working voltage greater than or equal to 36V. For the output capacitor, since our expected output voltage is 5V, we will select a capacitor that has a working voltage of at least 15V. With all of these components selected, we will be able to meet the desired specifications.

2.4.1.2.Buck Converter Electronic Simulations

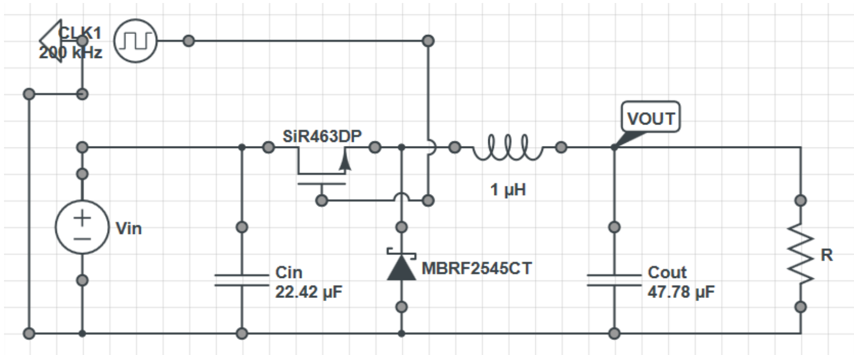

Figure 20: Buck Converter Simulation Circuit

The buck converter in Figure 20 was simulated at maximum voltage (21.6 V), minimum voltage (10 V), and a median voltage (12 V) for maximum power, minimum power, and zero power to ensure that voltage and ripple requirements could be met. Table 2 summarizes the simulated results. For all cases, the desired output voltage could be reached within the ripple requirements for a USB drive (4.75 V- 5.25 V). Figure 21 and Figure 22 and show the steadying voltage and ripple for the 30 W, 12 V case. All cases produced a similar output.

Table 2: Simulated Buck Converter Results

P_{OUT} [W]	V_{IN} [V]	$\langle V_{OUT} \rangle$ [V]	$V_{OUT,MIN}$ [V]	$V_{OUT,MAX}$ [V]
0	10	5.0	4.890	5.197
0	12	5.0	4.821	5.167
0	21.6	5.0	4.846	5.176
5	10	5.0	4.865	5.178
5	12	5.0	4.791	5.135
5	21.6	5.0	4.759	5.091
30	10	5.0	4.846	5.157
30	12	5.0	4.838	5.189
30	21.6	5.0	4.831	5.177

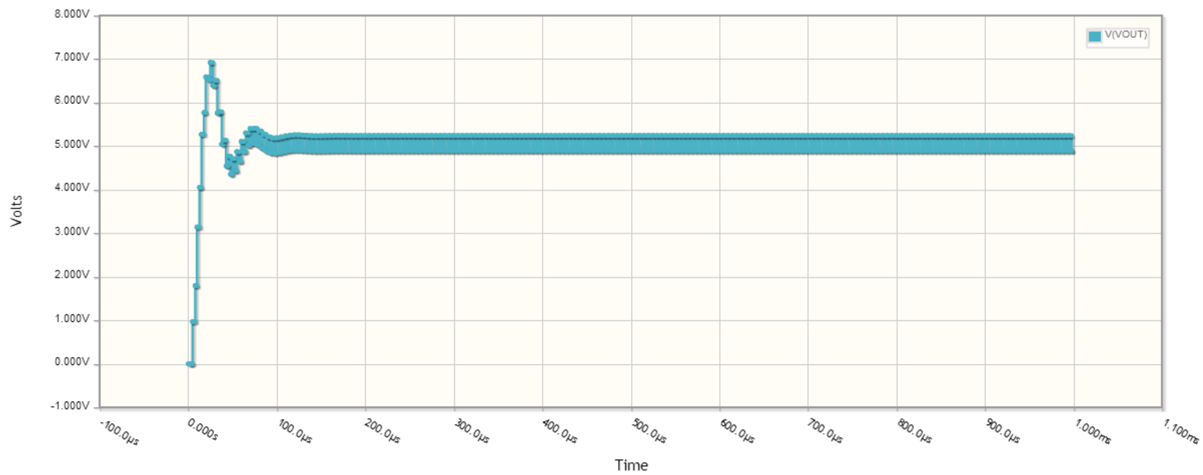

Figure 21: Vout for 12 V, 30 W

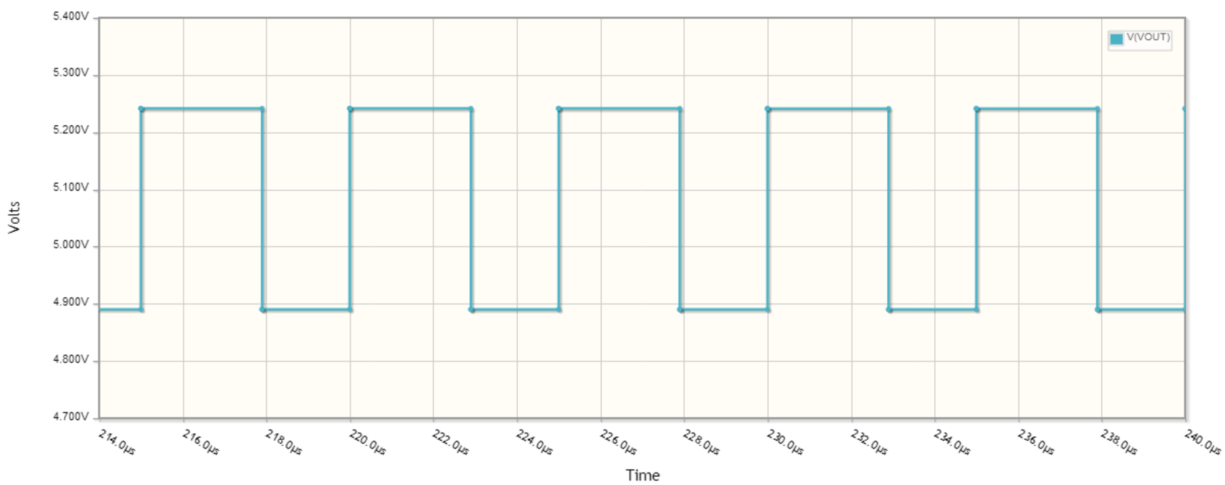

Figure 22: Voltage Ripple at 12 V, 30 W

2.4.1.3. Buck Converter Simulation with FET Box Control

Preliminary simulations were done to test the buck converter individually (open loop). The circuit was tested for various output powers with various input voltages. The results revealed that proper output voltage could be obtained under various conditions. The results are summarized in Table 3.

Table 3: Buck Converter Simulation Results

Vin [V]	Iin [A]	Pin [W]	Vout [V]	Iout [A]	Pout [W]	Rout [Ω]	Switching Frequency [kHz]	Duty Ratio	Efficiency [%]
10	0.54	5.4	4.99	0.902	4.5	5.6	199.2	55.05	83.333
12	0.45	5.4	5	0.903	4.5	5.6	199.3	44.46	83.333
15	0.36	5.4	5	0.902	4.49	5.6	199.6	34.06	83.148
17	0.32	5.44	5	0.904	4.51	5.6	199.9	29.45	82.904
20	0.27	5.4	5	0.903	4.47	5.6	200.9	23.59	82.777
21.6	0.26	5.616	5	0.905	4.51	5.6	203.9	21.45	80.306
10	1.22	12.2	5	1.801	9	2.73	199.8	64.56	73.770
12	1.02	12.24	5	1.804	9.04	2.73	199.5	52.8	73.856
15	0.82	12.3	5	1.805	9.04	2.73	199.6	40.65	73.495
17	0.73	12.41	5	1.804	9.03	2.73	199.9	35.03	72.763
20	0.61	12.2	4.99	1.8	8.98	2.73	199.4	28.13	73.606
21.6	0.57	12.312	5.01	1.791	8.93	2.73	199.1	25.7	72.530
10	1.86	18.6	5	2.612	13.08	1.87	198.8	72	70.322
12	1.56	18.72	4.99	2.604	13.01	1.87	198.8	58.83	69.497
15	1.26	18.9	5	2.615	13.1	1.87	199.7	45.7	69.312
17	1.1	18.7	5	2.607	13.02	1.87	198.9	39.3	69.625
20	0.93	18.6	4.99	2.594	12.95	1.87	199.1	31.9	69.623
21.6	0.86	18.576	5	2.592	12.92	1.87	199	29.02	69.552
10	2.38	23.8	4.98	3.158	15.76	1.57	199.4	76.61	66.218
12	2.02	24.24	5.01	3.169	15.9	1.57	199.5	63.69	65.594
15	1.61	24.15	5	3.162	15.81	1.57	199.3	49.28	65.465
17	1.43	24.31	5.01	3.177	15.95	1.57	199.4	42.7	65.610
20	1.2	24	4.99	3.157	15.74	1.57	199.5	34.66	65.583
21.6	1.13	24.408	5	3.167	15.82	1.57	199.6	31.78	64.815

2.4.2. Controller

2.4.2.1. Controller Simulation

The MSP430 was coded to produce control waveforms with varying duty cycles. The tests confirmed that the controller responded properly to commands from the program. Figure 23 and Figure 24 show two of the tested duty cycles.

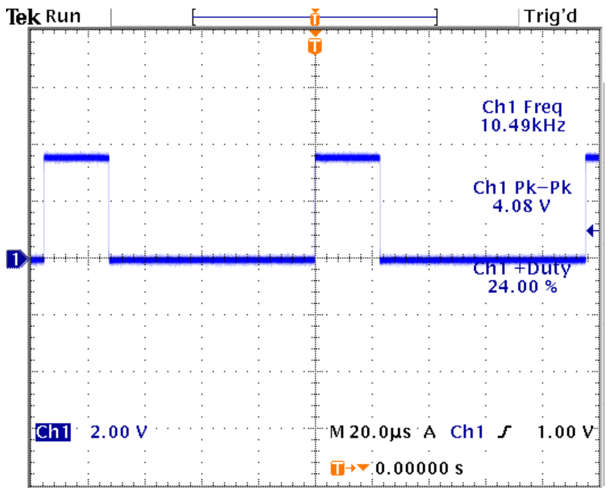

Figure 23: Duty Cyle at 24%

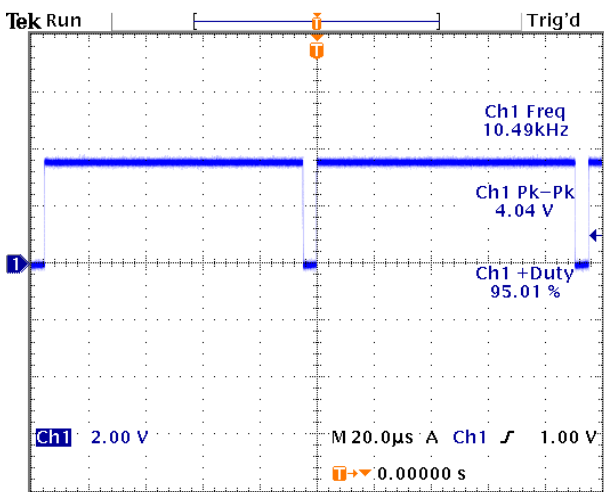

Figure 24: Duty Cycle at 95%

2.4.3. Solar Panel

2.4.3.1. Factory Specifications

We have chosen to use Solarland's SLP050-12U High Efficiency Multicrystalline PV Module. According to [8], this model is advertised as have the technical specifications shown in Table 4.

Table 4: Solar Panel Technical Specifications

Power (W)	50 Watts
Open Circuit Voltage (V)	21.30 Voc
Short Circuit Current (A)	2.94 Isc
Maximum Power Voltage (V)	18.20 Vmp
Maximum Power Current (A)	2.75 Imp
Cell Type	Mono-Crystalline
Junction Box:	Yes
Length	24.80" (629.92) mm
Width	21.30" (541.02) mm
Depth	1.38" (35.05) mm
Weight	11.02 lb (5.00) Kg
Connector	J Box No Cables

It has a V-I Curve as shown in Figure 25.

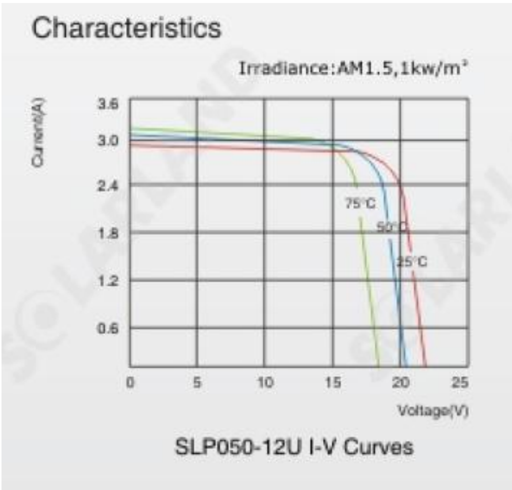

Figure 25: According to [8], the Solar Panel I-V Curve is represented by this graph

We anticipate a maximum load of 21.4 W; 5 W for a cellphone, 10.7 W for a tablet, 5.7 W for the drink cooler, and 0.00165 W for the microcontroller. This panel will be able to supply this load as long as it operates at or above 43% efficient.

2.4.4. Drink Cooler

2.4.4.1. Drink Cooler Theory

The drink cooler works in accordance with the Peltier Effect. According to [13], the heat from the water will flow into the cup and then the heat form the cup will be transferred to the cooling plate. For the purpose of this project, we are marketing the beverage cooler as being able to keep a drink cooled. It will be standardized with a copper cup because copper has one of the highest thermal conductivities at an average of 400 W/m*K. The cup also implements a flat bottom design to maximize the surface area contact with the cooling plate. This will allow the heat to quickly flow out of the cup. Based on preliminary testing, the modified beverage cooler will be able to keep 12 oz. of water with a starting temperature of 40°-60° F within 5° F of its starting temperature for fifteen minutes when the ambient temperature is 70° F.

2.4.4.2. Drink Cooler Performance

The drink cooler was tested by placing 12 oz. of water in a copper cup that was placed on the cooling plate. The temperature was measured using a waterproof thermometer that was clipped to the cup so that the measurement was taken in the same place each time. For this test, the temperature was measured in the upper half of the class assuming that would be the location of the warmest water. The results are summarized in Table 5.

Table 5: Drink Cooler Results with Ambient Temperature of 70°

Time	0 min	5 min	10 min	15 min	ΔT	20 min	ΔT
Temperature (°F)	39.8	41	41.9	42.9	3.1	44.1	4.3
Temperature (°F)	47.1	48	48.9	49.6	2.5	50.3	3.2
Temperature (°F)	58.8	58.7	58.5	58.7	-0.1	58.7	-0.1

3. Requirements and Verifications

3.3. Requirements & Verifications

3.3.1. Requirements Summary

1. Solar Source: Must provide 1 kW/m^2 to the panel.
2. Solar Panel: Must provide a voltage and current when a solar source is shown on it.
3. Converter: Takes the voltage from the solar panel (5V-21.6V) and steps it down so that a 5 V +/-5% (4.75-5.25 V) output is created for loads up to 25 W.
4. Controller: Regulates the duty cycle of the converter based on the measured output voltage so that the output voltage stays at 5 V +/-5%.
5. USB Ports: Needs to provide a 5-10 W output at 5V +/-5%. This means providing a 5V +/-5% and ground bus to a universal USB cord. It also needs to be able to be resistant to sand and water.
6. Drink Cooler: Will run off a USB port and keep 12 oz. of water with a starting temperature of 40°-60° F within 5° F of its starting temperature for fifteen minutes when the ambient temperature is 70° F.
7. Safety Switch: Will allow power to flow from the panel to the circuit when it is on and prevent power from flowing to the circuit when it is off.
8. Beach Chair: Must be structurally sound enough to support the panel, weigh less than 35 lbs., and have weatherproofing aspects to protect the equipment mounted on it up to an IP62 rating [14].

3.3.2. Verifications Summary

1. Solar Source: A solar insulation meter can be used to confirm that proper solar insulation is being provided to the pane.
2. Solar Panel: A Fluke multimeter will be used to confirm that both a current and a voltage are coming from the panel.
3. Converter: The operation of the converter can be verified using the lab in 50 Everitt. A voltage source will be hooked up to the circuit. The duty cycle will be controlled by hand and a wattmeter will be used to confirm the output voltage is 5 V. The oscilloscope will be used to verify that the ripple is within the specified 4.75-5.25 V range.

4. Controller: The controller operation will be verified by showing that it sends the proper signals based off the output voltage that it reads. A voltage supply will be sent to the input of the controller. Based on this voltage, we must show that outputted duty cycle is changed properly; increase if the voltage is too low and decreases if the voltage is too high.
5. USB Ports: To verify the USB port, a physical demonstration will be used to show that the port is universal. A fluke will be connected between the ground and 5 V bus to confirm that the voltage is within the 4.75-5V range. Finally, resistors will be set up between the busses and the Vahala meter will be used to confirm the proper output powers can be obtained.
6. Drink Cooler: The drink cooler will be verified by placing 12 oz. of water in the copper cup and measuring the start temperature and the temperature after 15 minutes to confirm that the temperature difference is within 5°F. This will have to be done at an ambient temperature of 70° F.
7. Safety Switch: The safety switch will be verified by showing that, when the switch is off, current flow is stopped and when it is on, current flow if allowed. This will be shown with a current probe.
8. Beach Chair: A physical demonstration will be used to show that the beach chair can support the panel. The fully assembled chair will be weighed to confirmed that the weight does not exceed 35 lbs. A watering can will be used to simulate rainfall on the chair. With this rainfall, the circuitry will still need to remain dry and unharmed which will be confirmed by its continued functionality.

3.3.3. Converter

Requirement	Verification
Output voltage must be between 4.75 V-5.25 V	**Use a voltage probe on the output capacitor and use an oscilloscope to verify that the voltage ripple is within 4.75 V-5.25 V**
a. Power supply must produce an input voltage of 5 V - 21.6 V	a. Use a voltage probe on the input capacitor and use an oscilloscope to verify that the voltage is between 5 V and 21.6 V
b. MOSFET must be switching at the correct duty ratio $D = \frac{V_{out}}{V_{in}}$	b. Use a differential voltage probe on the from gate to source on the MOSFET and use an oscilloscope to verify that the duty ratio is near $D = \frac{V_{out}}{V_{in}}$. If the MSP430 is not working, a FET box can be used to verify correct operation of the buck converter
c. Inductor does not go into Discontinuous Conduction Mode (DCM)	c. Use a current probe to measure the current through the inductor and display this on the oscilloscope. The inductor current should always be above 0A.

3.3.4. Controller

Requirement	Verification
Control circuit produces the desired PWM switching signal with the correct duty ratio	**Connect a differential probe between pin 1 and 3 of the IRF540 MOSFET. Connect the probe to an oscilloscope. Vary the input voltage from the solar source from 10-20V and observe the operation of the MOSFET. As the input voltage changes, the output voltage should change. The control circuitry should then adjust the duty cycle of signal**

	fed into the MOSFET to bring the output voltage into the range of 4.75-5.25 V.
a. BP5277-83 DC-DC converter produces 3.3V output	a. Use a multimeter to probe between pin 3 and 2 (VO and GND) of the DC-DC converter. Verify that the output voltage is 3.3V + .07V.
b. Microcontroller generates a PWM signal	b. Connect a voltage probe to pin 4 (P1.2) on the MSP430G2553. Use an oscilloscope to view the waveform and to measure frequency and duty cycle. Verify that a square wave is generated
c. Microcontroller responds to changes in output voltage	c. Probe pin 4 (P1.2) on the MSP430G2553 and connect to an oscilloscope. Vary the voltage fed into pin 15 (P1.7) from 3V-20V. Observe the output voltage waveform – a decrease in the feedback voltage should increase the duty cycle of the switching signal, and vice versa.
d. Gate driver is operational	d. Connect pin 2 (IN) on the IR2111 gate driver to an external function generator, such as the FET box in the lab. Connect pin 7 (HO) to an oscilloscope. Vary the duty cycle from 20% to 80% and observe the output waveform. Ensure that the gate driver output waveform is the same waveform as was fed into it. Next, connect the gate driver to the IRF540 MOSFET. Vary the duty cycle again from 20%-80%, this time ensuring that the MOSFET switches on and off.

3.3.5. USB Ports 1 and 2

Requirement	Verification
Referring to Figure 12, when Pin 1 has a voltage of 4.75 V - 5.25 V, and Pin 4 is connected to GND it is able to successfully charge an iPod and iPad.	**Use the power supply to generate a voltage of 4.75 V, and connect this voltage to pin 1 of USB ports 1 and 2. Next connect ground to pin 4 of USB ports 1 and 2. Plug in an iPod into USB port 1, and plug in an iPad into USB port 2. Verify if the charging status bar shows up, which indicates the device is charging. Repeat procedure with voltages of 5.00 V and 5.25 V.**

3.3.6. Drink Cooler

Requirement	Verification
Keep 12 oz. of water with a starting temperature of 40°-60° F within 5° F of its starting temperature for fifteen minutes when the ambient temperature is 70° F.	**Set the ambient temperature of the room to 70° F. Use a waterproof digital food thermometer to measure the starting and final temperature of the water in the middle of the copper cup. Verify that the change in temperature is within 5° F after fifteen minutes.**

3.3.7. Beach Chair

Requirement	Verification
Can support the weight of the panel, does not exceed 35 lbs, is at rated water resistance and sandproofing of IP62.	**Perform tests b) and c) to verify that the IP62 rating is achieved. Weigh the chair to confirm its weight does not exceed 35 lbs.**
a. The beach chair can be folded up into a portable, backpackable package.	a. Fold and unfold the beach chair five times with all of the electronics connected. Ensure that the modifications to the beach chair do not prevent the chair from closing or opening.
b. Resistant to intrusion from sand and other small debris, at least IP6x rating. This is “Dust Tight”	b. Submerge the electronics enclosure in sand and/other debris. Remove. Verify that the circuit is still operational. Remove all debris from the outside of the enclosure and open it up. Ensure that debris has not entered the enclosure.
c. Water resistant to rain and other forms of precipitation: at least IPx2 rating. The electronics will be protected from “Water equivalent to 3mm rainfall per minute”.	c. Simulate rain using a watering can or other source of dripping water. Drip water on the electronics enclosure and ensure that the device remains functional. Thoroughly dry the exterior of the enclosure and open it up. Verify that no liquid has entered the enclosure and is interfering with the operation of the circuit.

3.3.8. Solar Source

Requirement	Verification
To ensure maximum power from the solar panel, there must be $\frac{1kw}{m^2}$ of insolation available from a solar source	Use a solar insolation meter to ensure that the insolation present is at least $\frac{1kw}{m^2}$.

3.3.9. Solar Panel

Requirement	Verification
Solar Panel must produce an output voltage of 5 V - 21.6 V and an output power of at least 50W.	Disconnect the solar panel from the circuit, and hook it up to a 5.78 Ω resistor. Use a Fluke meter to measure the output power and output voltage. Confirm whether the voltage is 5 V - 21.6 V and confirm if the output power is at or above 50W.

3.3.10. Safety Switch

Requirement	Verification
When switch is off, no current reaches the load, and when switch is on, current reaches the load.	Create a circuit consisting of an input voltage (from the power supply) of 12V, and a 5.78 Ω resistor. Between the input voltage and the resistor, hook up a safety switch. Hook up a current probe to measure the current through the circuit and view the current waveform on an oscilloscope. Verify that when the safety switch is on, that current flows through the load, and when the switch is off, the current is zero.

4. Tolerance Analysis

The limiting aspect of our project will be its efficiency. For this projected we are expecting a maximum load of 21.41 W with a drink cooler, an iPod, and an iPad connected. We are expecting losses in all of our components. At 21.41 W, we are expecting the losses in all our components to be approximately 4 W. With this in mind, we will have and efficiency of,

$$Efficiency = \frac{21.41W - 4W}{21.41W} * 100\% = 81.32\% \quad (19).$$

We will verify that our efficiency is met by comparing the input power we receive from the panel to the total output power coming from the three USB ports. Two wattmeters will be used to measure these values and the efficiency will be calculated as

$$Efficiency = \frac{Pusb}{Ppanel} * 100\ \% \quad (20).$$

5. Ethical Issues

The purpose of this project is to provide a user with a way to better enjoy the outdoors by providing a charging station in otherwise powerless places. Since it is a product that will be used by people, it is important that it be safe for their use, which correlates to the first code of the IEEE Code of Ethics [15]:

1.to accept responsibility in making decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

The product is also marketable and therefore must do what it claims to be able to do. No data can be fabricated to make it seem like the product does what it advertises. Whatever, the product claims to be able to do, it must be able to do on the spot. This correlates to the second code of the IEEE Code of Ethics:

2.to be honest and realistic in stating claims or estimates based on available data;

This project will involve using solar energy to charge electronic devices. Through the course of the project, we will gain a better understanding of how solar panels work. In this process, we will also learn about power converters and control mechanisms for those power converters. This correlates to the fifth and six code of the IEEE Code of Ethics:

5.to improve the understanding of technology, its appropriate application, and potential consequences;

6.to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;

Through the scope of the class, we will also be given many opportunities to interact with peers and mentors in a technical and professional manner. We will seek advice from these people and it is our job to follow the advice given and give credit where credit is due in accordance with the seventh, eighth, and tenth codes of the IEEE Code of Ethics:

7.to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

8.to treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin;

10.to assist colleagues and co-workers in their professional development and to support them in following this code of ethics

Finally, throughout this project, we will be representing ourselves, our professors, and our school so it is important that we remember to act in a way that honors all three. This follows the ninth code of the IEEE Code of Ethics.

9.to avoid injuring others, their property, reputation, or employment by false or malicious action;

6. Cost and Schedule

6.3. Cost Analysis

6.3.1. Labor:

Name	Hourly Rate	Number of Weeks	Hours Per Week	Total Hours	Total = Hourly Rate x 2.5 x Total Hours
Damen Toomey	$30.00	12	12	144	$10,800
Andrew Gazdziak	$30.00	12	12	144	$10,800
Emily Mazzola	$30.00	12	12	144	$10,800
Total	**$90.00**	**36**	**36**	**432**	**$32,400**

6.3.2. Parts:

Item	Part Number	Qty	Unit Price	Total Cost	Status
Canopy Beach Chair		1	$46.88	$46.88	Purchased
Solar Panel (50 W)	SLP050-12U	1	$151.00	$151.00	Purchased
Backpack Strap		1	$14.99	$14.99	Identified
Waterproof Enclosure	WH-106	1	$23.19	$23.19	Identified
USB Waterproof Coupler	RR-111200-30	3	$12.95	$38.85	Identified
USB A-A Male-Male Cable		3	$2.50	$7.50	Identified
USB A-A Male-Female Cable 1.8M	AK669/2-18-BLACK-R	3	$3.33	$9.99	Identified
USB Female Covers		1	$10.50	$10.50	Identified
Rocker Switch	CW102-ND	1	$2.08	$2.08	Identified
Schottky Power Diode	MBR2545CPT	1	$1.20	$1.20	Purchased
Power MOSFET	IRF540	1	$3.95	$3.95	Purchased
Resistor 1/2W		1	$0.05	$0.50	
Ceramic Capacitors		4	$0.10	$.40	Purchased
Inductors		1	$1.00	$1.00	
MSP430 Microcontroller	MSP430	1	$5.68	$5.68	Purchased
High Side Gate Driver	IR2111PBF-ND	1	$3.07	$3.07	Purchased
3.3V DC-DC Converter	BP5277-33-ND	1	$7.50	$7.50	Purchased
Drink Cooler Base		1	$34.95	$34.95	Purchased
Copper Cup		1	$7.00	$7.00	Purchased
PCB		2	$0.00	$0.0	
Total Cost				**$370.83**	

6.3.3. Grand Total

Labor	Parts	**Grand Total**
$32,400	$370.83	**$32,770.83**

6.4. Schedule

Weeks	Damen	Emily	Andrew
2/4/2013	• Purchase Solar Panel • Create Detailed Converter Design	• Purchase Beach Chair • Finalize and hand in proposal	• Sign-Up for Mock Review • Create Detailed Control Design
2/11/2013	• Implement Buck Converter with FET Box	• Gather Solar Panel Statistics	• Implement Control Circuit
2/18/2013	• Prepare for Design Reviews: Buck Converter • Sign-Up For Design Review • Learn the Eagle CAD Software	• Prepare for Design Reviews: Drink Cooler • Optimize the Design For Highest Efficiency	• Prepare for Design Review: Control • Work with Machine Shop and Electronics Shop
2/25/2013	• Create PCB	• Edit PCB	• Finalize PCB
3/4/2013	• Integrate Solar Panel Into Chair	• Designing a Weather Resistant Enclosure	• Obtain Finalized PCB
3/11/2013	• Individual Progress Report • Prepare For Mock Demo: Integrate Panel To Converter	• Individual Progress Report • Prepare For Mock Demo: Integrate USB and Weatherproofing	• Individual Progress Report • Prepare For Mock Demo: Integrate Control Circuitry
3/18/2013	• Spring Break • Complete Slides for Presentations: Buck Converter Section	• Spring Break • Complete Slides for Presentations: Drink Cooler Section	• Spring Break • Complete Slides for Presentations: Control Section

	Damen	Emily	Andrew
3/25/2013	• Finalize Mock Presentation	• Sign-Up for Mock Presentation	• Edit and Review Mock Presentation
4/1/2013	• Confirm No New PCB is Needed	• Submit PCB Request for Converter (if needed)	• Submit PCB Request for Control (if needed)
4/8/2013	• Debug: Buck Converter • Confirm all parts work individually	• Debug: Drink Cooler and Integration • Confirm all parts integrate	• Debug: Control • Confirm weather and quantitative specifications were met
4/15/2013	• Complete Final Paper: Buck Converter Section • Prepare Converter for Demo	• Complete Final Paper: Drink Cooler and Paper Flow • Prepare Drink Cooler and Chair For Demo	• Complete Final Paper: Control Section • Sign-Up for Demo • Prepare Control for Demo
4/22/2013	• Finalize Final Presentation and Lab Notebook	• Finalize Final Paper and Lab Notebook	• Review and Submit Final Paper
4/29/2013	• Confirm the final paper was submitted	• Confirm the final paper was submitted	• Confirm the final paper was submitted

7. Safety Considerations

This project will involve the use of electricity with voltages up to 21.6 V and currents up to 20 A. We will also be working with water and electricity as we try to waterproof the devices. If proper safety precautions are not taken, these conditions can be deadly.

Table 6 summarizes the effects electrical currents can have on the human body according to [16]. Since or project deals with currents of 20,000 mA, we must ensure we take all the necessary precautions when performing experiments.

Table 6: Effects of Current on the Human Body

Current in mA		
AC (60Hz)	**DC**	**Effect**
0 - 1	0 - 4	Perception
1 - 4	4 - 15	Surprise, Slight shock felt
4 - 21	15 - 80	Reflex Action, “let-go” range, Painful shock
21 - 40	80 - 160	Muscular Inhibition, Extreme Pain
40 - 100	160 - 300	Respiratory Block, Ventricular fibrillation
Over 100	Over 300	Cardiac Arrest, Sever Burns, Usually Fatal

Our group will be working in the Electric Machinery Lab (Everitt Lab 50). The lab already has its own set of rules and warnings that we will follow. According to [17], these rules and warnings include:

- GROUND! Be aware of which connections are grounded, and which are not.
- RATINGS! Before applying power, check that the voltage, current, and power levels you expect to see do not violate any device ratings.
- HEAT! Small parts can become hot enough to cause burns with as little as one watt applied to them.
- CAREFUL WORKMANSHIP! Check and recheck all connections before applying power.
- Plan ahead: consider the effects of a circuit change before trying it. Use the right wires and connectors for the job, and keep your bench neat.
- WHEN IN DOUBT, SHUT IT OFF! Do not manipulate circuits or make changes with power applied.

- LIVE PARTS! Most semiconductor devices have an electrical connection to the case. Assume that anything touching the case is part of the circuit and is connected. Avoid tools and other metallic objects around live circuits.
- Keep beverage containers away from your bench.

For added safety, the laboratory is equipped with an emergency electrical shutoff system that can be activated by pushing a button located on the benches. The benches and equipment are also fitted with circuit breakers that will stop fault current when necessary and prevent damage.

In addition to these safety guidelines, we will also take added precautions specific to our project. The additional precautions include:

- Know exactly where power switches are located.
- Prevent electrical fires by not overloading circuits.
- Inspect electrical equipment and connections before use to ensure that cords and plugs are in good condition
- Ensure that live parts are effectively insulated or physically guarded.
- Keep flammable materials away from electrical equipment.
- Keep electrical equipment away from water until the equipment is ready to handle the exposure.
- Follow the "one hand rule."

When the point in the project comes where we will be waterproofing our circuit, we will have to be extra cautious. Since our plan is to use weatherproof casings, we will first test the casings before adding our circuit. We will be sure not to supply power to the system until after we have successfully verified that there are no water leakages in our system. When we do fully integrate the circuit and test it for water resistance, we will make sure that no one is touching or around the device while water is being sprayed on it until we have verified its safety.

If all safety precautions are taken, everyone should remain unharmed. However, it is also important to plan for the worst case scenario and have a procedure to follow in case something does happen. So, we have made plans for the event of and electrical fire and the event of someone being electrocuted.

If an electrical fire occurs, the following procedure will be followed [18,19]:

1. Depending on the extent, evacuate the building.

2. Pull the fire alarm and call 9-1-1. Be sure to explain the nature of the fire to emergency responders.
3. If it is safe, cut off the power to the circuit.
4. If it is safe, attempt to extinguish the fire with an appropriate fire extinguisher.
5. Do not throw water on an electrical fire.

If a person receives electrical shock, the following course of action will be taken.

1. Do not touch the person. If their body is live, you could get stuck.
2. Call 911.
3. If it is safe, remove the source of power by hitting the red button in the lab.
4. If power cannot be removed, try to pry the person from the hazard by using non-conductive materials.
5. Check vital signs
    a. If the victim is not breathing, then administer CPR.
    b. If the victim is faint, pale, or shows signs of shock, lay the victim down with the head slightly lower than the trunk of the body and the legs elevated, and cover the person with a warm blanket or coat.
    c. If the victim is otherwise okay but has burns be sure to treat them properly.
6. Stay with the victim until medical help arrives.

The goal is to have zero safety incidences but if an accident does happen, we have a clear plan to deal with the situation and mitigate any issues.

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