Adjustable Focus, Intensity, and Gradient Light for Commercial Photography

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Group 30

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Contents

1 Introduction

1.1 Objective

The concept of light painting has existed as long as photography. By taking long exposure shots of still objects, photographers can quickly achieve complex lighting effects that would take hours to create in photoshop. Because of the niche nature of this technique photographers have to use custom-made filters for individual photoshoots and change out the filters depending on the effect desired. Commercial photographer Rick Kessinger would like a photography light that can be adjustable based on specific photoshoot requirements.

Our proposed solution is to create a programmable light array which can control three criteria. Our light should have adjustable intensity, how bright the overall light is, focus, the location of the brightest spot of the light, and gradient, the gradient of light from bright to dark. Each of these criteria will be controlled by an external knob which regulates the light settings independent of each other. These control inputs will then be routed to an array of LED lights which output light at an intensity depending on user input. The entire design will be portable and include a battery system that is internally rechargeable.

1.2 Background

Because of the niche use of a controllable LED bar light, a retail product does not exist. Despite that, this product would allow unprecedented freedom for a photographer. According to Mr. Kessigner, a controllable light would allow "painting with light." Unfortunately because of the lack of an existing solution, Mr. Kessinger is forced to create a makeshift gradient out of diffusion paper and then tape it onto an LED light bar. This solution is clumsy and very restrictive as it forces the user to make a new filter every time a different gradient is needed. Additionally, because the LED bar is not purpose built for a photographer, it has the disadvantage of being powered by a wall outlet. This is difficult for a photographer as, at times, the only light on in the photography studio is the light bar.

With our solution, the photographer will be mobile and in full control of the lighting for a photoshoot. This control would allow for fast adjustment and turnaround between different angles or different photoshoots and the ability to fully realize the artist's vision.

1.3 High-Level Requirements

- The brightness of all the LEDs must at least range from 0 lumens output to 156 lumens per LED circuit of 6 for a total of 0 to 2500 lumens for the entire light bar of 16 strips.
- Must be able to adjust the gradient of light from bright to dark from 60 lumens per inch to 11 lumens per inch across an interval of 3 inches to 48 inches respectively.
- Must Operate for 30 minutes on battery alone.

2 Design

2.1 Block Diagram

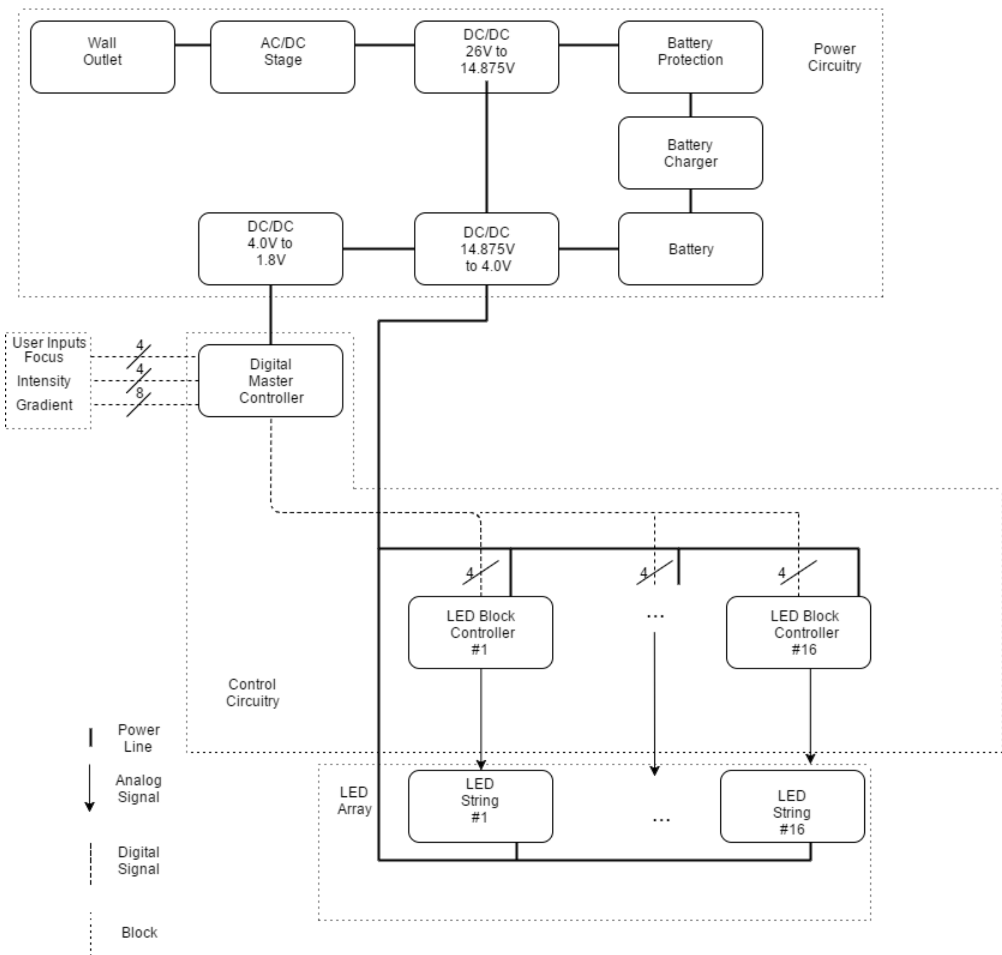

Figure 1: Top Level Block Diagram

2.2 Housing

The housing will consist of a rectangular bar 52 inches by 4 inches by 4 inches with a handle that is 52 inches along the entire backside of the bar. As shown in the figures below. The bottom of the bar will contain the transformer and power circuitry which will take up a 4 x 4 x 4 inch block at the bottom of the bar. Additionally, the battery has a separate 0.75 inch diameter x 3 inch container. There will be three user input knobs at the back of the bar. There will be 16 LED PCBs connected to one Digital Controller PCB which is powered by the power PCB.

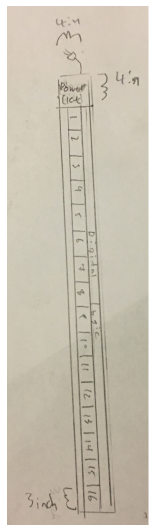

Figure 2: Top Down View of Light Bar

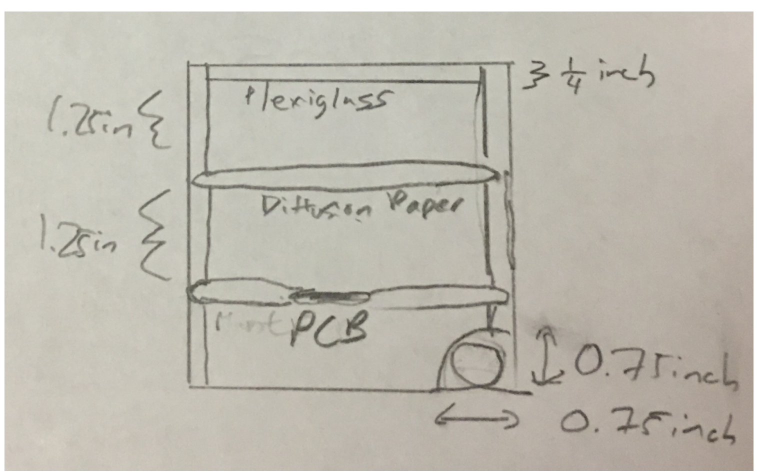

Figure 3: Cross Section View of Light Bar

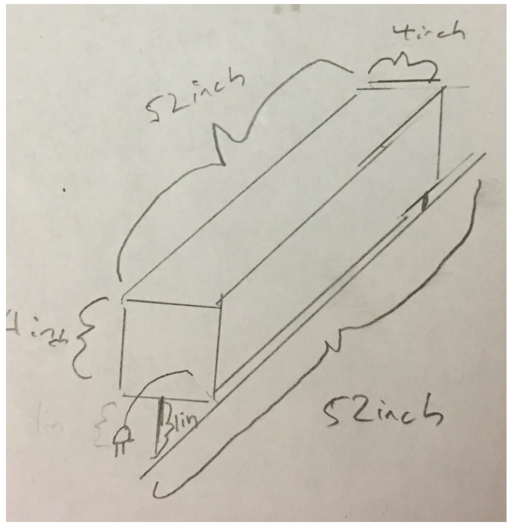

Figure 4: Isometric View of Light Bar

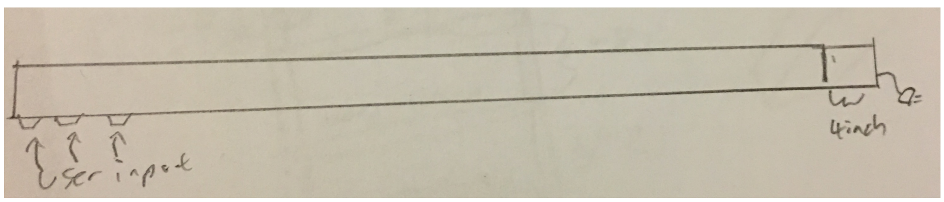

Figure 5: Side View of Light bar

2.3 User Inputs

Inputs: 3 user controlled knobs

Outputs: Focus, intensity, gradient, and mode as two 4-bit signals, one 8-bit signal, and one 2-bit signal respectively

Description: The user input will consist of three digital encoders and one three position switch. The first encoder will control the focus of the light which is where the center of the light gradient is. The second will control the controls the intensity of the light which describes the maximum brightness across the light bar. The third encoder will control the gradient of the light which describes how wide or thin the gradient is across the bar. The three position switch will control gradient mode of the light. There will be three gradient modes, the first is that the gradient is equal on each side of the focus. The other two modes will make the light on one side of the focus operate at full intensity while the gradient fade happens on the other side. The encoder uses 8 bits to describe its absolute position. We will use the four most significant bits and for the gradient encoder we will use the five most significant bits.

2.4 Power Supply

In order to power the lightbar, the following estimates were given for power consumption:

- LED's and PWM Circuits: 96 LED's * 0.1A * 4.0V = 38.4W
- CPLD's: 4 CPLD's * 0.125A * 1.8V = 0.9W
- 1 NiMH battery pack of at most 13.2V charging at a rate of 2.25A = (13.2V * 2.25A) = 29.7W
- Total = 38.4W + 0.9W + 29.7W = 69W

Additionally, the battery pack will need to store enough energy to power the LED's and CPLD's for at least 30 minutes.

2.4.1 AC/DC Stage

Inputs: Standard US Wall outlet voltage at $120V_{rms}$

Outputs: 26V ± 8V at 3.0A

Description: A DC voltage is required to power all circuitry inside of the lightbar and stardard wall outlets output AC voltage. To remedy this, the AC/DC Stage will step down the $120V_{rms}$ wall plug voltage to $24V_{rms}$ using a 5:1 transformer. The $24V_{rms}$ will then be rectified using a bridge rectifier to 26V ± 8V DC voltage. A schematic of the block is shown in Figure 6 on the next page:

In order to keep the output voltage ripple within ± 8V it was calculated that:

$$C = \frac{I_{Load}}{2f\Delta V} \tag{1}$$

$$C = \frac{3.0A}{2(60Hz)(16V)} \tag{2}$$

$$C = 1.56mF \tag{3}$$

A capacitance of 2.0mF will be used as the next closest value to account for ± 20% component tolerances.

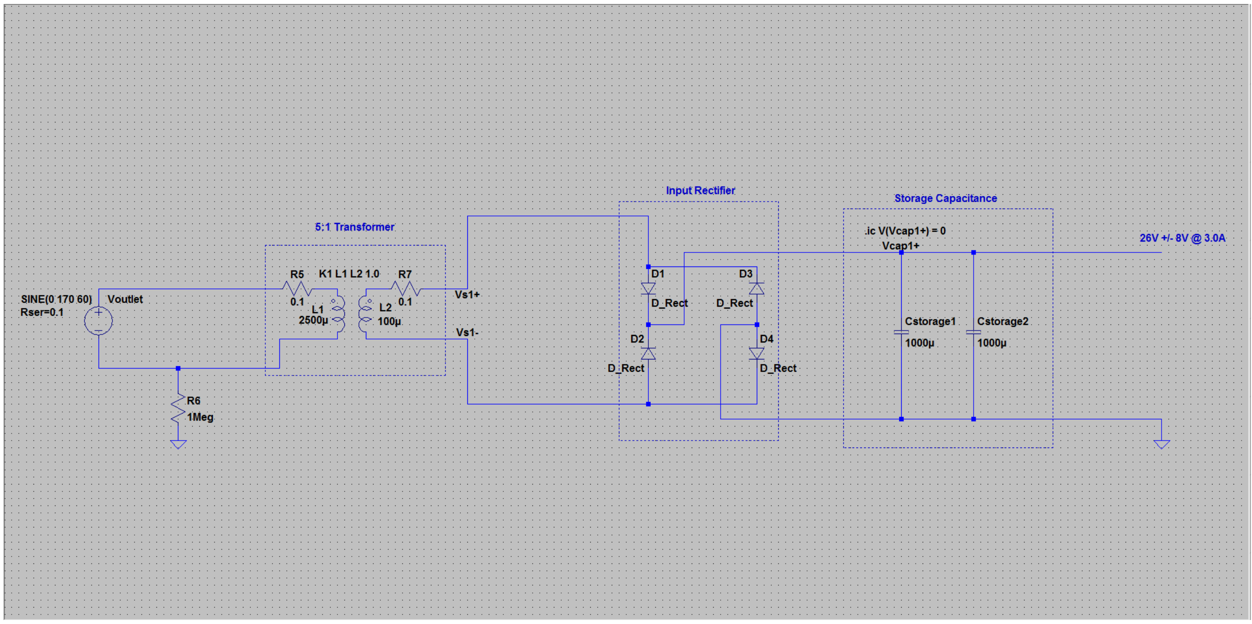

Figure 6: AC/DC Stage Schematic

Simulating the AC/DC Stage in LTSPICE, it was found that the peak current drawn from the transformer secondary side was as shown in Figure 7 below:

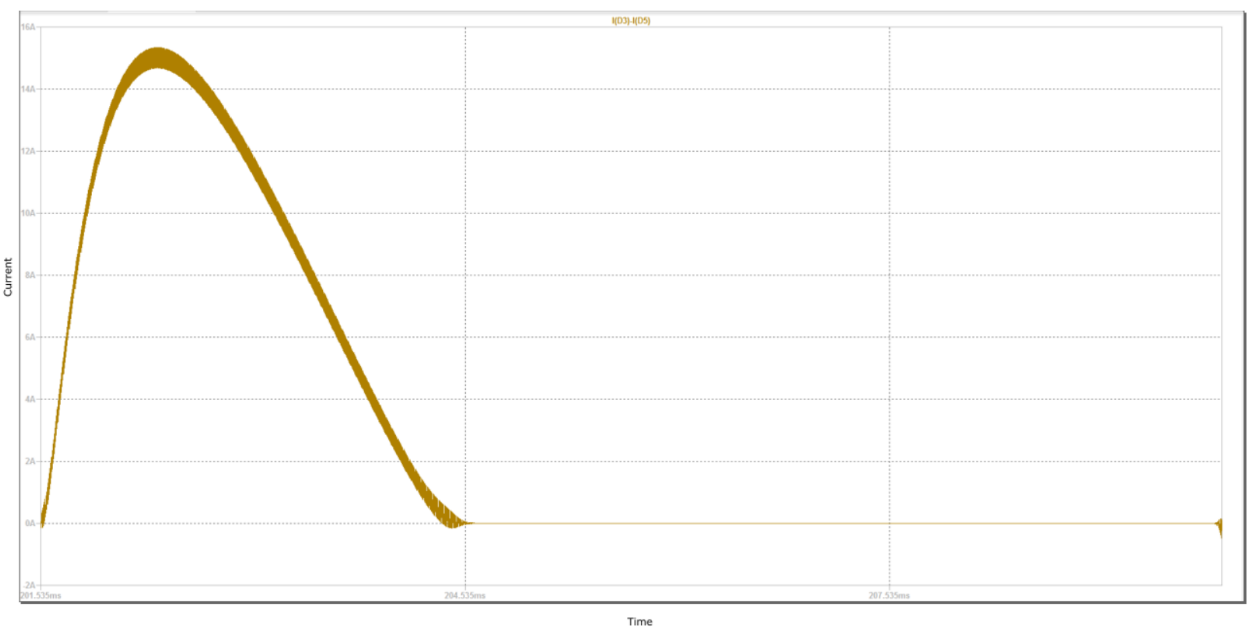

Figure 7: AC/DC Stage Transformer Secondary Peak Current

so, a $10.4A_{rms}$ rated secondary side will suffice. A fuse will be connected to the 120V primary side of the transformer in order to protect the inner electronics from large currents. A current of 17.5A on the 24V secondary side will be the upper limit for secondary side current. When the secondary side is has an output current of 17.5A, the primary side will draw a current of:

$$\frac{I_{primary}}{N_{secondary}} = \frac{I_{secondary}}{N_{primary}} \tag{4}$$

$$I_{primary} = \frac{17.5A}{5} \tag{5}$$

$$I_{primary} = 3.0A \tag{6}$$

so, a 3.0A fast blow fuse will be connected to the primary side.

A simulation of the output voltage ripple at full load is shown in the Figure 8 below:

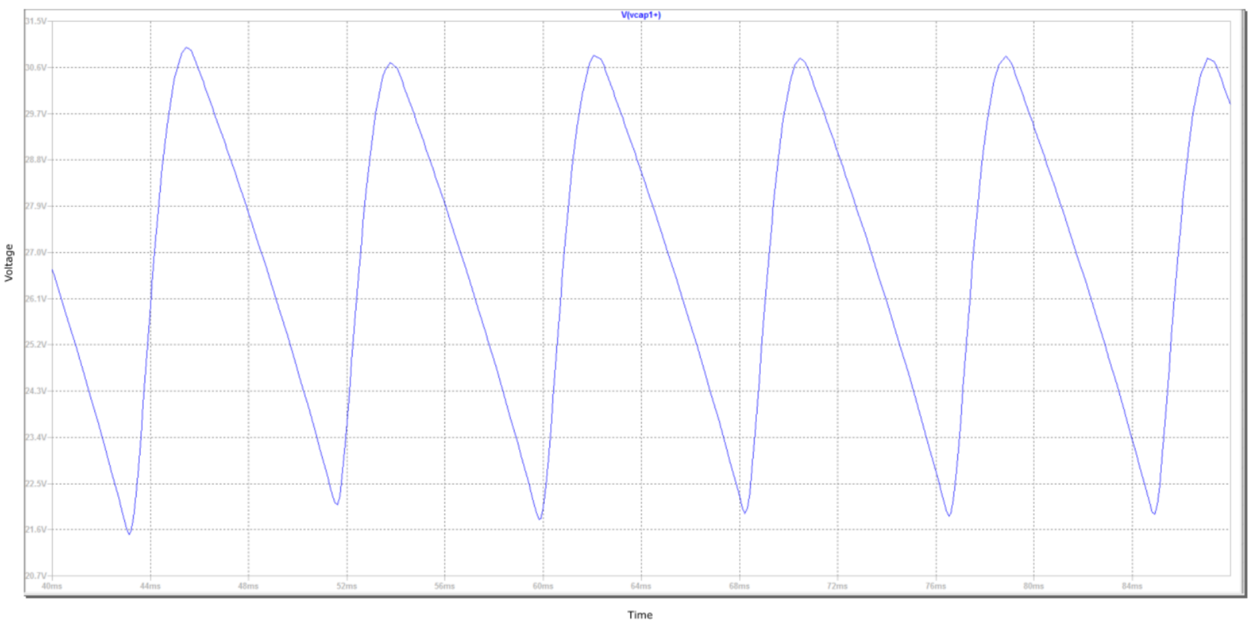

Figure 8: AC/DC Stage Full Load Output Voltage Ripple

2.4.2 DC/DC Buck 26-to-14.875V

Inputs: AC/DC Adapter at 26V ± at 3.3A

Outputs: 14.875V ± 0.15V at 5.5A

Description: To power the DS2715 battery charger IC, a voltage supply between 4.5 and 16.5V is needed. A buck step-down converters will be implemented that will step-down the AC/DC adapter output to a level of 14.5V ± 0.15V. The LTC1624 controller IC was chosen for this task. Note that this controller has a switching frequency of 200kHz. A schematic of this converter is shown in the Figure 9 below:

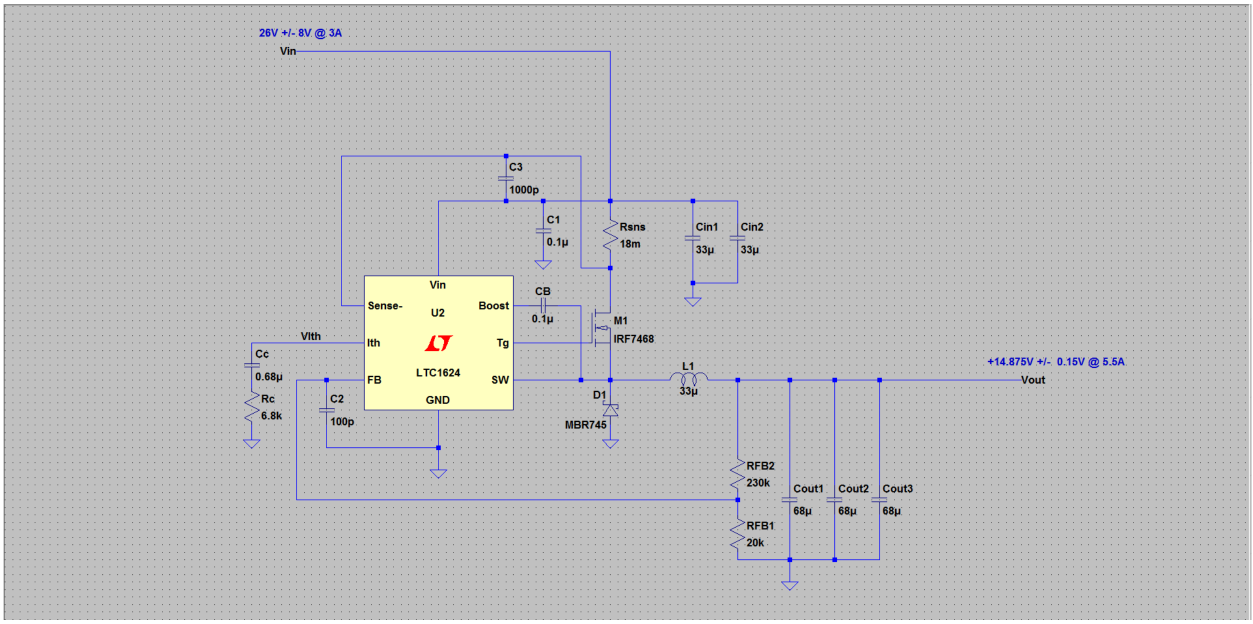

Figure 9: DC/DC Buck 26-to-14.875V Schematic

The feedback resistors connected to the feedback pin 'FB' of the converter will set the output voltage of the converter. The converter will regulate this voltage to 1.19V as described in [5]. The output voltage is given by:

$$V_{out} = 1.19V \left(1 + \frac{R_{FB2}}{R_{FB1}}\right) \tag{7}$$

Where V_{out} is the output voltage, R_{FB1} is the lower feedback resistor, and R_{FB2} is the upper feedback resistor. Choosing R_{FB1} as 20kΩ to keep the feedback resistor current low, R_{FB2} must be 230kΩ for an output of 14.875V.

Using the formula for the duty cycle of the duty cycle of a buck converter, the duty cycle that this converter will operate at is:

$$V_{out} = DV_{in} \tag{8}$$

$$D = 0.57 \tag{9}$$

A $\Delta I_{L_{pp}}$ of 1.5A was allowed. Using volts-seconds balance on the inductor when the MOSFET is conducting:

$$V_L = V_{in} - V_{out} = L\frac{di_L}{dt} \tag{10}$$

$$V_{in} - V_{out} = L_{min}\frac{\Delta I}{DT} \tag{11}$$

$$L_{min} = \frac{(V_{in} - V_{out})D}{\Delta I_{L_{pp}} f_{sw}} = 21.14\mu H \tag{12}$$

A $33\mu H$ inductor was chosen to account for $\pm$ 20% component tolerances. For an output voltage ripple of 1.0V, $\Delta V_{out} = 0.15$V:

$$\Delta I_{L_{pp}} = \Delta I_{C_{pp}} = 1.5A \tag{13}$$

$$C = \frac{\Delta Q}{\Delta V} = \frac{\frac{1}{2}\frac{1}{2f_{sw}}\frac{\Delta I_{C_{pp}}}{2}}{\Delta V} \tag{14}$$

$$C = \frac{\Delta I_{L_{pp}}}{8f_{sw}\Delta V_{out}} \tag{15}$$

$$C_{out} = 6.25\mu F \tag{16}$$

For an input voltage ripple of 0.25V, when the MOSFET is conducting:

$$I_{in} = I_c + I_{out} \tag{17}$$

$$I_c = 3.0 - 5.4 = -2.4A \tag{18}$$

because average current in the capacitor must be zero in periodic steady-state:

$$C = \frac{\Delta Q}{\Delta V} = \frac{\frac{I_c D}{f_{sw}}}{\Delta V} \tag{19}$$

$$C_{in} = \frac{I_c D}{f_{sw} \Delta V_{in}} = 27.4\mu F \tag{20}$$

The LTC1624 has an upper limit on the output ESR of $2R_{sns}$ in order to maintain control loop stability. Including the effects of ESR:

$$\Delta V_{out} = \Delta V_{out,capacitor} + \Delta I_{out} ESR \tag{21}$$

After several iterations, it was determined that three $68uF$, $70m\Omega$ ESR capacitors will be used on the output and two $33uF$, $75m\Omega$ capacitors will be used on the output in order to meet the requirements. The output voltage ripple of this converter is plotted in Figure 10 below:

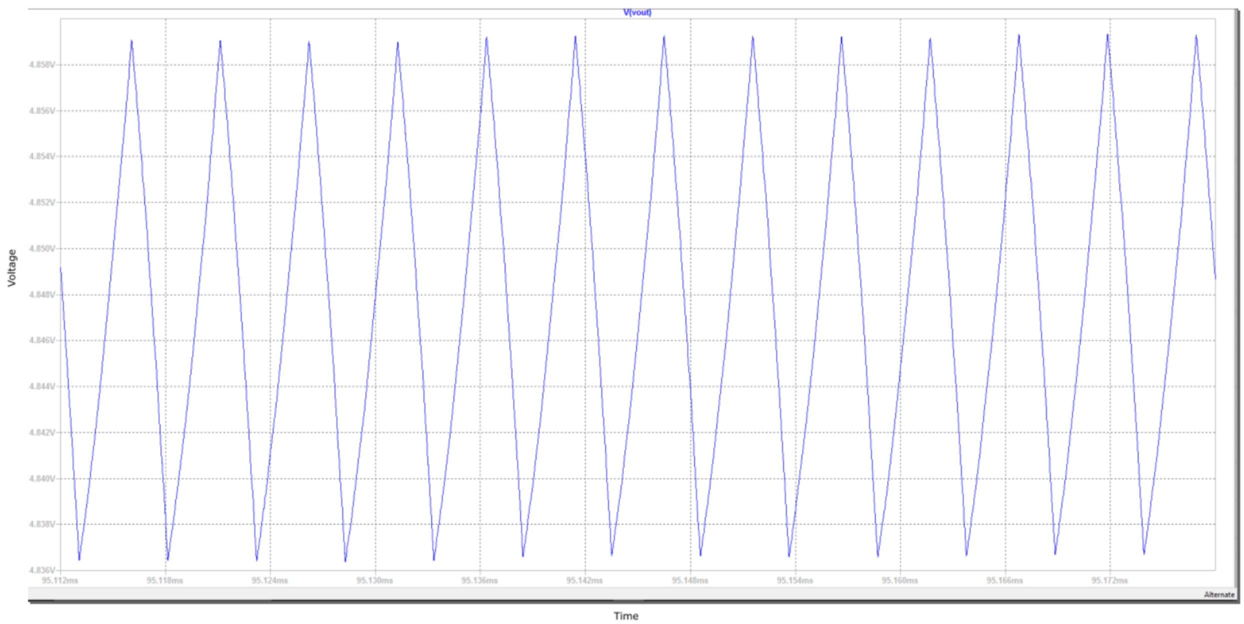

Figure 10: DC/DC Buck 26-to-14.875V Full Load Output Voltage Ripple

2.4.3 DC/DC Buck 14.875-to-4.0V

Inputs: 14.875V ± 0.15V from the 26-to-14.875 converter or 9.6V ± 1.6V from the batteries

Outputs: 4.0V ± 0.04V

Description: The battery voltage can range from 8.0V to 13.2V depending on the level of charge. In order to regulate this to a consistent 4.0V that the LED's require, another buck converter was needed. Again, the LTC1624 buck controller IC was chosen. A schematic of the controller is shown in the Figure 11 below:

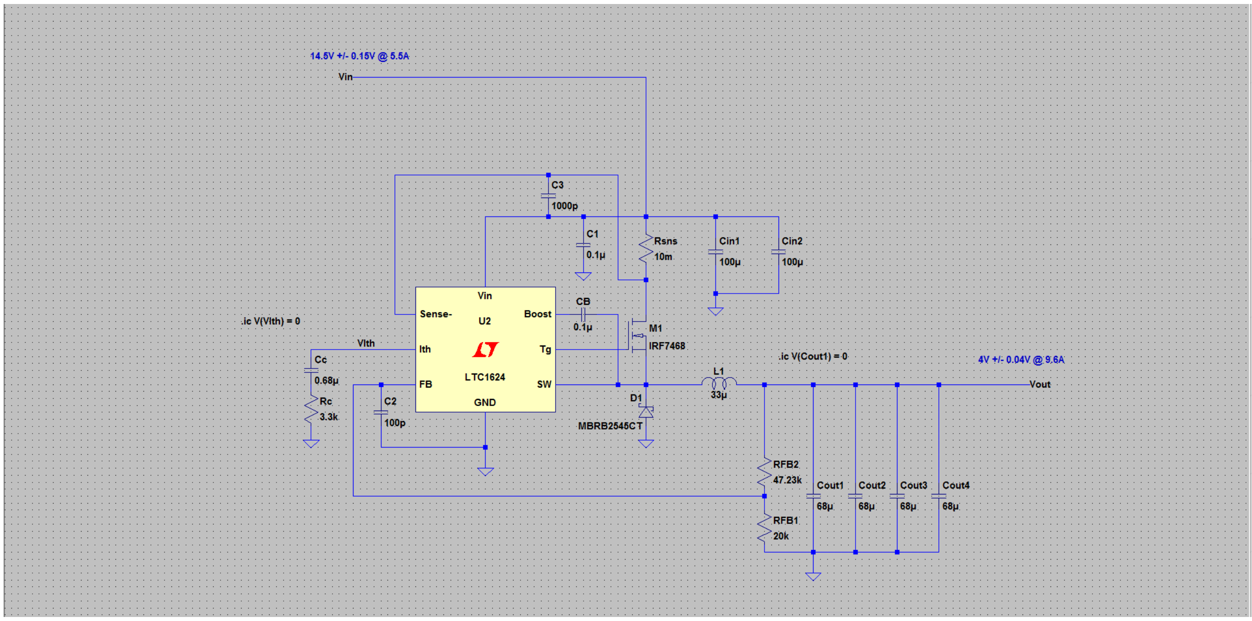

Figure 11: DC/DC Buck 14.875V-to-4.0V Schematic

Using equation (7):

$$V_{out} = 1.19V\left(1 + \frac{R_{FB2}}{R_{FB1}}\right) \tag{22}$$

for a V_{out} of 4.0V, choosing R_{FB1} to be $20k\Omega$, R_{FB2} must be $47.2k\Omega$. Using equation (8):

$$D = \frac{V_{out}}{V_{in}} = \frac{4.0V}{14.875V} = 0.27 \tag{23}$$

Allowing a $\Delta I_{L_{pp}}$ of 0.75A, equation (12) gives:

$$L_{min} = \frac{(V_{in} - V_{out})D}{\Delta I_{L_{pp}} f_{sw}} = 19.57\mu H \tag{24}$$

The inductance was increased to $33\mu H$ as a near value. Using equation (15) with a ΔV_{out} of 0.04:

$$C_{out} = \frac{\Delta I_{Lpp}}{8 f_{sw} \Delta V_{out}} = 11.719\mu F \tag{25}$$

Using equations (17) and (20) with an input voltage ripple of 0.30V:

$$I_c = 5.5 - 9.6 = -4.1A \tag{26}$$

$$C_{in} = \frac{I_c D}{f_{sw}\Delta V_{in}} = 18.45\mu F \tag{27}$$

Taking ESR into account as in equation (21), four $68uF$, $70m\Omega$ ESR capacitors will be used on the output and two $100uF$, $85m\Omega$ capacitors will be used on the output in order to meet the requirements. The output voltage ripple of this converter is plotted in Figure 12 below:

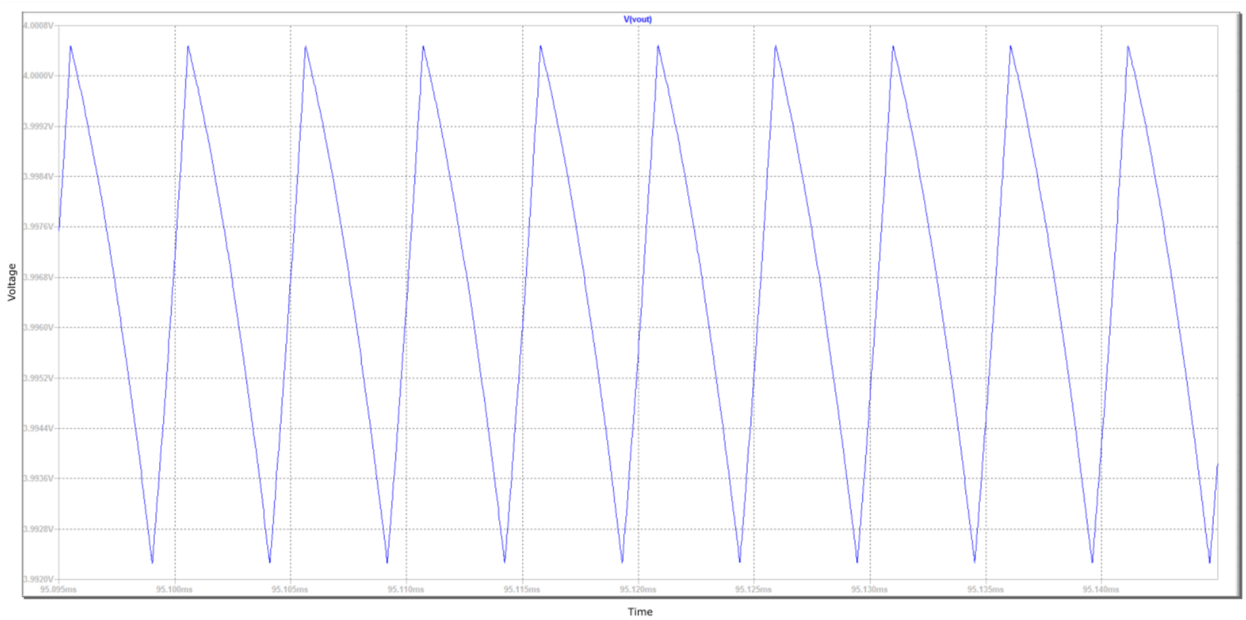

Figure 12: DC/DC Buck 14.875-to4.0V Full Load Output Voltage Ripple

2.4.4 NiMH Battery Chargers

Inputs: 14.875V ± 0.15V at 5.5A

Outputs: 2.25A fast charge current to the batteries

Description:

The Maxim DS2715 battery charger IC will be a standalone chargers for the NiMH battery. The battery will be fast charged at 0.5C (2.25A) for no more than 200 minutes. Charging will be terminated by dT/dt using a 10k NTC thermistor mounted to the battery pack to sense temperature. After the batteries reach full charge, a maintenance charge of no more than 0.033C (148mA) will be used to offset any battery leakage. A schematic of the charging circuit is shown in the Figure 13 below:

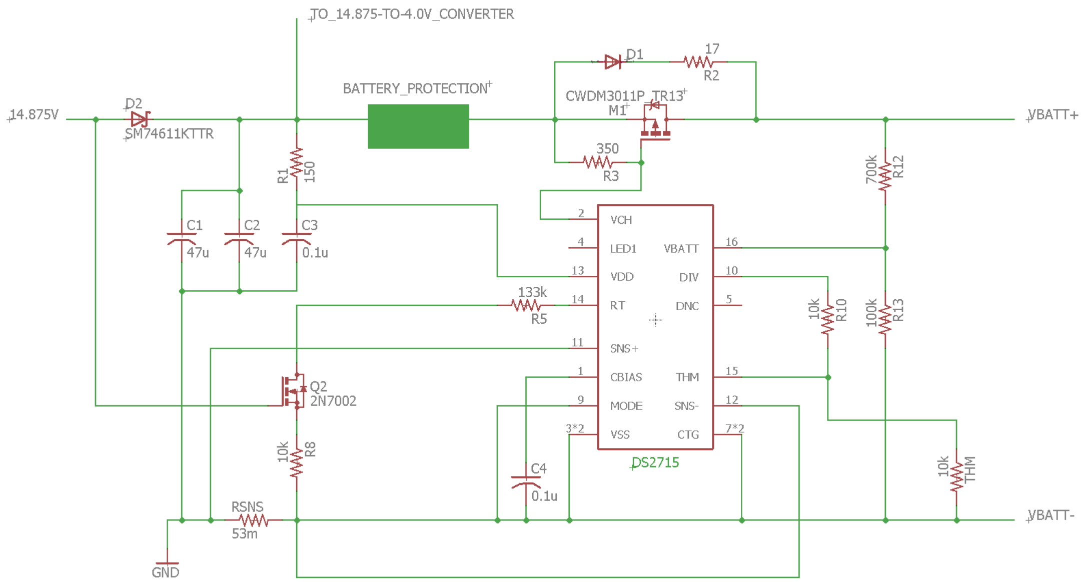

Figure 13: NiMH Battery Charger Schematic

The DS2715 regulates the charging of up to 10 NiMH cells in series configuration. To do this, the DS2715 acts as a linear regulator, controlling current through the pass transistor M_1. After the IC confirms that there is a cell present, it enters precharge mode. This mode slowly charges depleted cells at $\frac{1}{4}$ the rate of fast charge until they are above the 1.0V per cell required for safe fast charging. Once the cells have been precharged, the IC proceeds to the fast charge phase. Fast charging is terminated using the dT/dt method. When the cell pack's thermal rate of change exceeds $0.5C^{\circ}$ per minute, fast charging terminates. To prevent damage to the battery caused by overcharge, fast charging also terminates if the battery pack temperature exceeds $50C^{\circ}$ at any time or if the charging time exceeds the duration set using the charging timer resistor, R_5. Once the battery is deemed to be fully charged, the DS2715 enters topoff mode. A small maintenance current is used to offset the charge lost to any leakage of the battery. The DS2715 remains in this state until it detects that the battery has begun to discharge or that a fault has occurred.

The resistors R_{12} and R_{13} are used to ensure that the cell voltage is presented to the V_{batt} pin. Because each battery pack is 8 cells: Choosing R_{13} as $100k\Omega$ to keep the resistor current low, then R_{12} must be $700k\Omega$.

The maintenance charge current into the battery is set by the resistor R2, for a current of 148mA:

$$R_2 = \frac{(V_{in} - V_{f,D1}) - (\#cells * V_{cell,\text{full charge}})}{I_{maintenance}} = 17\Omega \tag{28}$$

The CWDM3011P TR13 transistor was chosen as the pass element in the battery charging circuit. The CWDM3011P TR13 has an RDS, On of $20m\Omega$. The battery packs will be charged at a current of 2.25A. This corresponds to a power dissipation of 100mW, which is acceptable. The gate source voltage of the CWDM3011P TR13 is at most 3.5V. The DS2715 operates most efficiently when 10mA is sunk into the VCH during charging. R3 was chosen such that this is the case:

$$R_3 = \frac{3.5V}{10mA} = 350\Omega \tag{29}$$

The DS2715 measures the charging current through the battery back using a sense resistor in series with the battery pack. The sense resistor was determined by:

$$R_{SNS} = \frac{V_{fc}}{I_{FC}} = \frac{121mV}{2.25A} = 53m\Omega \tag{30}$$

The resistor R_5 sets the fast charge timeout period. According to the HHR-450AB21L2X4 datasheet [9], the batteries should be fully charged within at most 200 minutes of charging:

$$R_5(0.0015) = t_{max(minutes)} = 200 \tag{31}$$

$$R_5 = 133k\Omega \tag{32}$$

2.4.5 NiMH Battery

Inputs: 2.25A charging from the battery charger

Outputs: 9.6V ± 1.6V depending on the level of charge of the battery

Description: In order to function throughout the entirety of a photoshoot, the batteries must be able to sustain the lightbar for at least 30 minutes. By far, the components that draw the most power are the LEDs, which can draw up to 100mA per string when the lightbar is fully illuminated. A nickel metal hydride battery pack were chosen to power the lightbar for this purpose. The

Panasonic HHR-450AB21L2X4 nickel metal hydride battery pack operates at 9.6V nominal with a capacity of 4.5mAh for a total of:

$$9.6V * 4.5Ah = 43.2Wh \tag{33}$$

of stored energy per pack. Each pack is made up of 8 cells at 1.2V nominal. The discharge characteristic of one of the cells in the pack is shown in Figure 14 below.

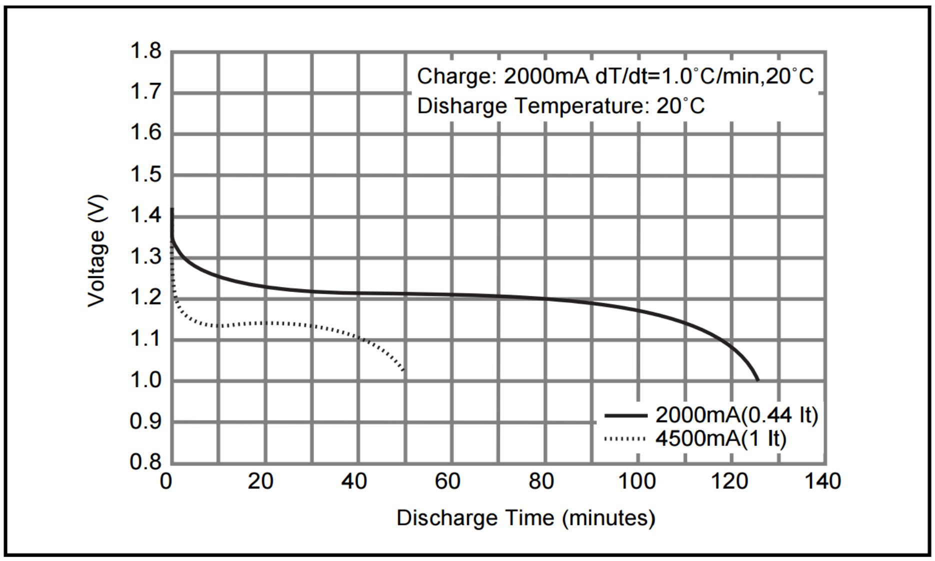

Figure 14: Typical Discharge Curve of a single NiMH Cell

The dotted curve represents a 1C discharge, which is roughly what is expected for the battery under maximum load. Judging by this curve, the batteries should be able to supply the lightbar for at least 40 minutes under ideal conditions.

2.4.6 NiMH Battery Protection

Inputs: 9.6V ± 1.6V from the battery

Outputs: No less than 8.0V at no more than 4.5A to the DC/DC Buck 14.5-to-4.0V converter

Description: In order to protect the batteries from undercharge or overcurrent, the LTC-4356 surge stopper will be used to provide undervoltage lockout at 8.0V and overcurrent protection at 9.5A. Below 8.0V, continued discharge of the battery could damage the cells. At more than twice the rated capacity of 4.5A discharging, the battery could be damaged. A schematic of the battery protection circuit is shown in Figure 15 below:

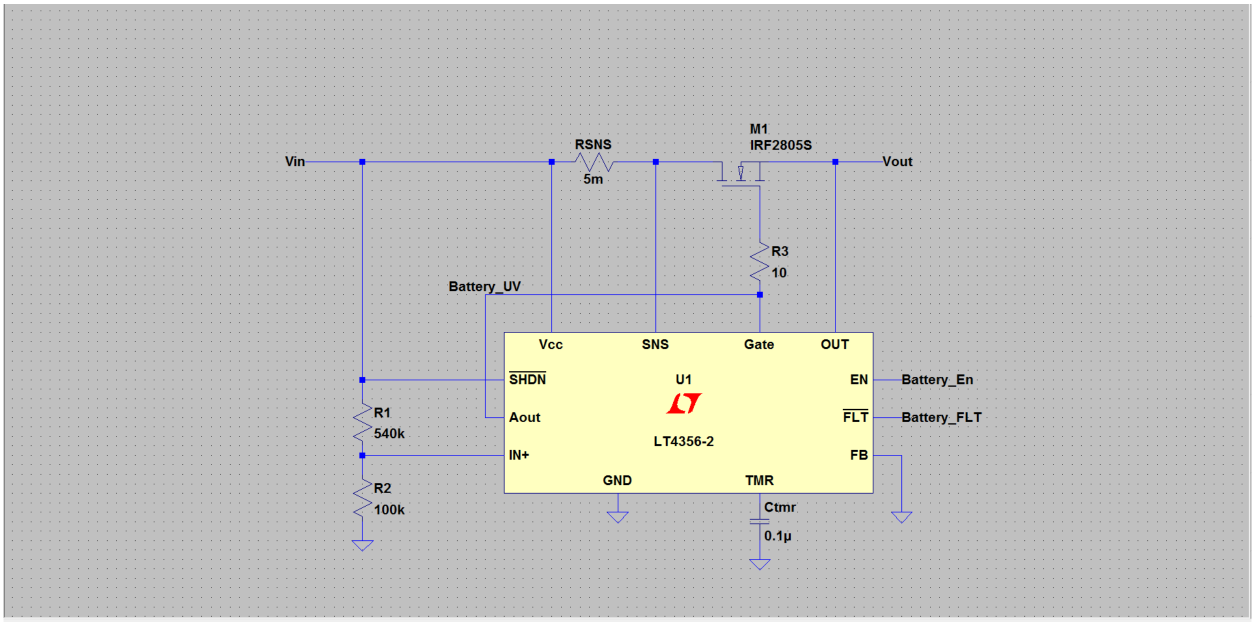

Figure 15: NiMH Battery Protection Circuit Schematic

The safest and most efficient route to implementing undervoltage and overcurrent protection for the battery was to use an IC specially made for this purpose. The LT4356-2 surge stopper IC was chosen for this purpose. Undervoltage lockout is set by a resistor divider on the IN+ pin. The undervoltage lockout lower limit is given as:

$$V_{limit} = \frac{1.25V(R_1 + R_2)}{R_2} \tag{34}$$

for the lower limit of 8.0V required by the battery packs, R2 was chosen to be 100kΩ and R1 was chosen to be $540k\Omega$. For any voltage on the VCC pin lower than this, the LT4356-2 will pull the gate of the MOSFET M1 low, disconnecting the load from the battery.

Overcurrent protection is set the R_{sns} sense resistor. If the voltage across this resistor is greater than 50mV, the surge stopper will pull the gate of the MOSFET M1 low, disconnecting the load from the battery.

$$I_{limit} = \frac{50mV}{R_{sns}} \tag{35}$$

RSNS was chosen to be $5m\Omega$ in order to limit current to 9.0A.The $R_{DS,On}$ of the MOSFET M1 is

$4.7m\Omega$. At maximum load, this corresponds to a power dissipation of:

$$P_{M1} = I^2 R_{DS,on} = (4.5A)^2 (4.7 * 10^{-3}\Omega) = 0.095W \tag{36}$$

which is well below the maximum power rating of the MOSFET. At maximum load, the maximum sense resistor dissipation is:

$$P_{M1} = I^2 R_{DS,on} = (4.5A)^2 (5 * 10^{-3}\Omega) = 0.101W \tag{37}$$

so a $\frac{1}{2}$ W resistor will be chosen for the sense resistor.

2.4.7 4.0-to-1.8V Linear Regulator

Inputs: 4.0V from the DC/DC Buck 14.5-to-4.0V converter

Outputs: 1.8V to the CPLD's

Description: Some form of conversion will be necessary to create the 4.0V needed by the digital logic. In order to accomplish this, a linear regulator was chosen. Because the CPLD consumes relatively little power, the small power loss was considered acceptable. The LT1963 Linear Regulator was chosen for this purpose. $10\mu F$ capacitors were added to the output as per the datasheet specification in order to prevent oscillations. A schematic of the linear regulator is shown in Figure 16 on the next page:

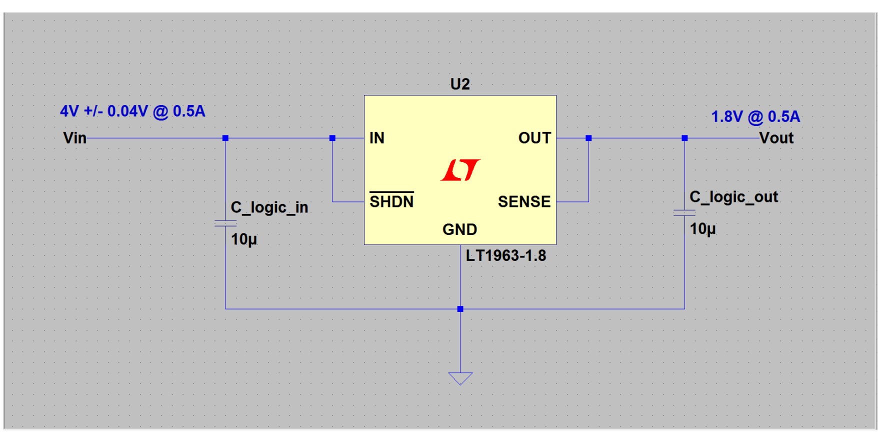

Figure 16: Linear Regulator Circuit Schematic

Worst case power dissipation in the regulator will be:

$$P = I_{out,max}(V_{in} - V_{out}) = 500mA(4.0V - 1.8V) = 1.1W \tag{38}$$

given that the package has a thermal resistance of $55°C/W$ the part will have a temperature rise of:

$$T_J = P(55°C/W) + T_A \tag{39}$$

$$T_J = 1.1W(55°C/W) + 40°C \tag{40}$$

$$T_J = 60.5°C + 40°C = 100.5°C \tag{41}$$

which is less than the maximum rating of $125°C$ for this package.

2.5 LED Array

Inputs: 1MHz PWM'ed Square Wave, 4.0 V Supply Voltage

Outputs: Light from LEDs

Description: Each LED Array will consist of 6 Cree MLC LEDs in parallel with a forward voltage of 3.2V, a current at 100m, and a lumen output around 180 lumens[11]. This is in series with a T2N7002AK,LM transistor with an R_{DS} value of 3.9Ω which is in series with a ballast resistor of 4Ω as in Figure 17 [12]. The entire light bar will consist of 16 of these LED arrays to make a total of 96 LEDs with a total lumen output around 2800 lumen. The schematic in Figure 17 shows one string of 6 LEDs which is the base unit of the LED array.

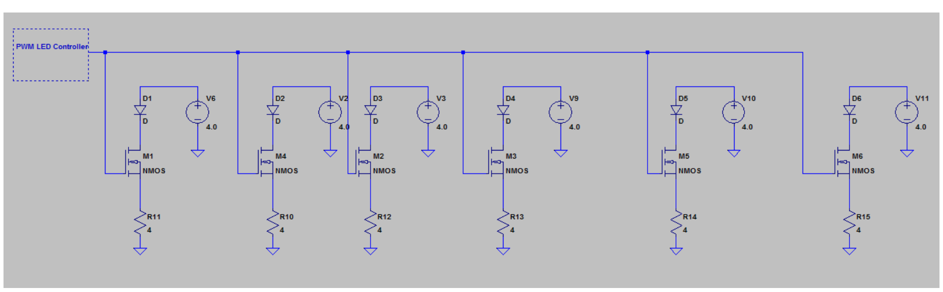

Figure 17: LED string of 6

2.6 Control Circuitry

The control circuitry will dictate the brightness level of each individual LED which overall will form the gradient, focus, and intensity of the light bar. This will control the brightness of the LEDs to 16 different levels which will produce a gradient from 0% to 93.75% across the bar.

2.6.1 Digital Controller

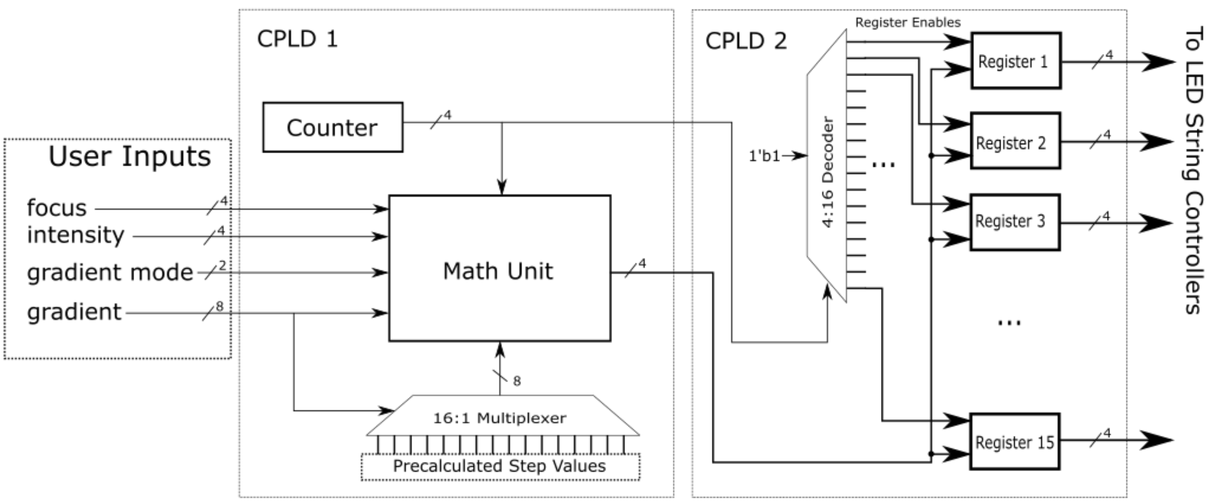

Figure 18: Block Diagram for Digital Controller

Inputs: Focus (4-bit binary signal), Intensity (4-bit binary signal), Gradient (8-bit binary signal), Gradient Mode (2-bit binary signal)

Outputs: 16 4-bit intensities

Description: The Digital Controller will take the previously discussed user inputs and output 16 4-bit signals, one for each string controller, describing the intensity each light should be outputting. The output intensity of the controller ranges from 0% (4'b0000) to 93.75% (4'b1111). The controller will be made entirely from digital logic rather than an MCU to create a simple, low power design. The most efficient way to create the digital logic is to use a CPLD which allows all of the circuitry to be on one chip rather than the 60 chips we would need to implement it with other integrated circuits.

On the CPLD, the main blocks are the registers and the math unit. The registers are 4 bit synchronous registers. These hold the intensity data for each LED string. Each register has a data input from the math unit and an enable signal from the 4:16 multiplexer. The math unit is responsible for determining the intensity that should be stored in each register. It uses information from the user inputs to calculate a four bit intensity value for each of the 16 LED strings.

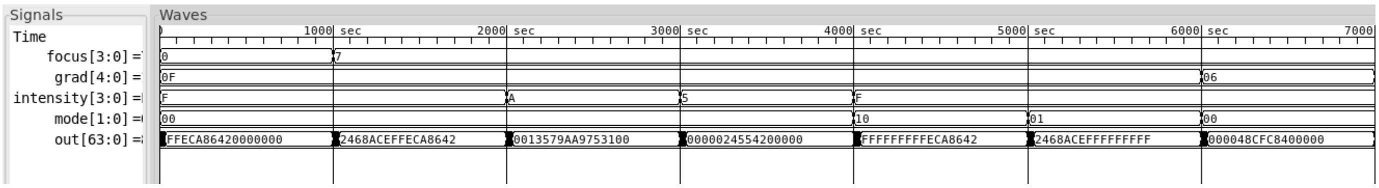

Figure 19: Digital Controller Verilog Simulation

In this waveform simulation of the digital logic the output can be seen relative to various inputs. Inputs focus, gradient, and intensity are displayed as hex values and the mode input is displayed as a two bit binary number. The output is is string of 16 hexadecimal values. Each value represents the digital logic's 4-bit output to that respective LED string. The first 1000 seconds of the waveform are to show an example gradient. The next section shows that the center of the gradient can be moved. The third and fourth section show that the intensity can be lowered while still maintaining a consistent gradient. The fourth and fifth section show the two alternative modes of light output. The sixth section shows that gradients of different sizes can be made by the controller.

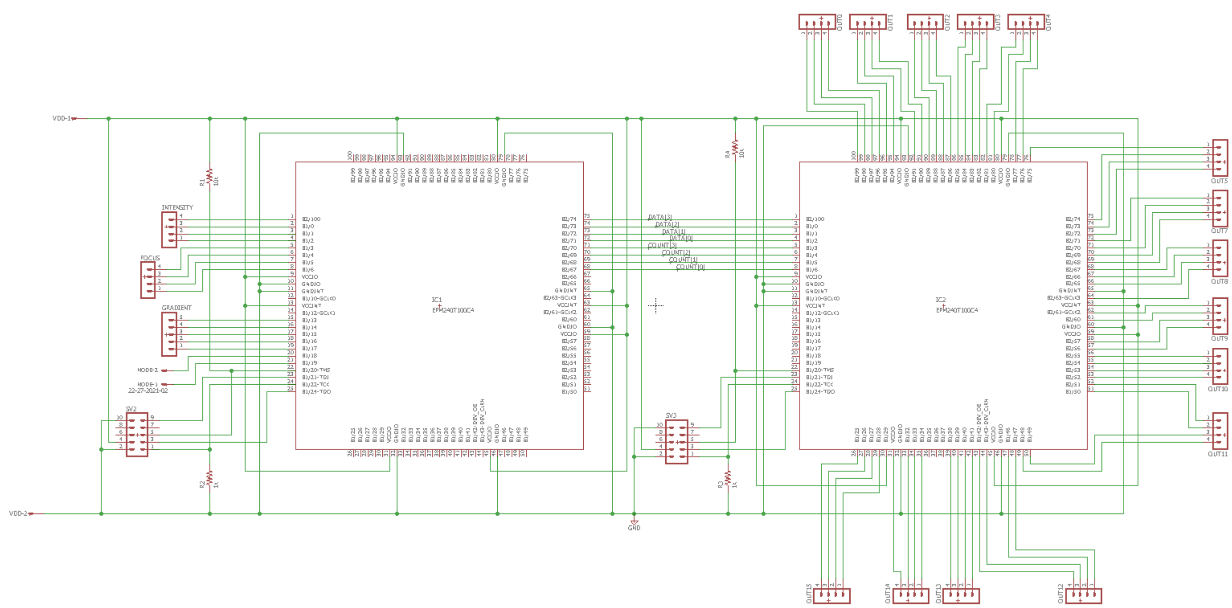

Figure 20: Eagle Schematic for Digital Controller

2.6.2 LED String Controller

Inputs: 4-Bit Binary Control signal from Digital Controller at 1.8V

Outputs: Pulse Modulated Square Wave at 4.0V at 1.0MHz

Description: The LED String Controller will have a PWM(Pulse-Width-Modulation) control circuit that will take the 4-Bit control signal from the master digital controller and alter the duty cycle of a clocked square wave based on this 4-bit control signal. The LED string controller takes the 4-Bit Digital signal, converts that to an analog voltage level which the LTC6992-1 chip maps to a pulse-modulated square wave output at 4.0V max level. The 4-bit control signals will be stepped down from 1.8V to 1.0V because the LTC6992-1 PWM chip's modulation input can only range from 0-1V[10]. This is accomplished with a voltage divider consisting of a 80kΩ in series with a 100kΩ. Each bit of the 4-bit control signal is routed through this voltage divider and then connected to an R-2R ladder. This R-2R ladder's base resistance R will be 1kΩ which the simulation in Figure 21 on the next page generates an output which is only 0.5% off from the actual value of 0.875V.

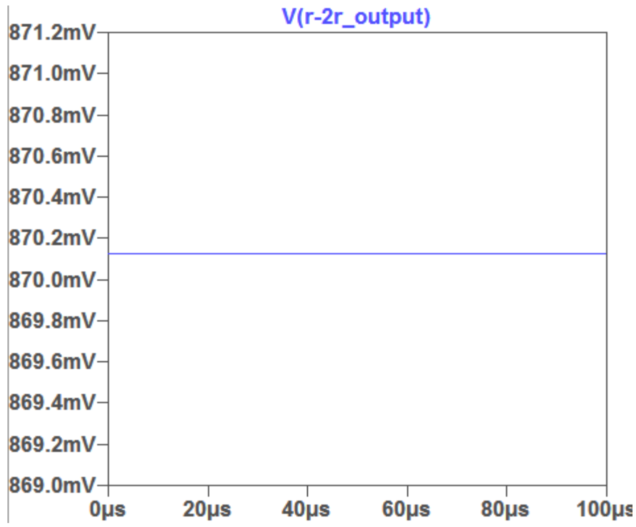

Figure 21: R-2R ladder Output with Voltage Divider at 87.5% Duty Cycle

After the 4-bit control signal is converted to an analog voltage, The LTC6992-1 chip will take this voltage and map it to a square wave with duty cycle from 0% to 100%. The LTC6992-1 chip has frequency control, and the frequency of the square wave and therefore the light flicker must be higher than 1kHz. The frequency of the output of the LTC6992-1 chip is:

$$f_{master} = \frac{1MHz * 50k}{R_{Set}} \tag{42}$$

So by setting the set resistance to 50kΩ, the output frequency will be set to 1MHz. The square wave output will be routed to the gate of a T2N7002AK,LM transistor which will turn on and off the drain source current based on the PWM square wave. However, the LTC6992-1 cannot output a higher than 90% duty cycle, so the 4'b1111 control input is clipped to 100% duty cycle.

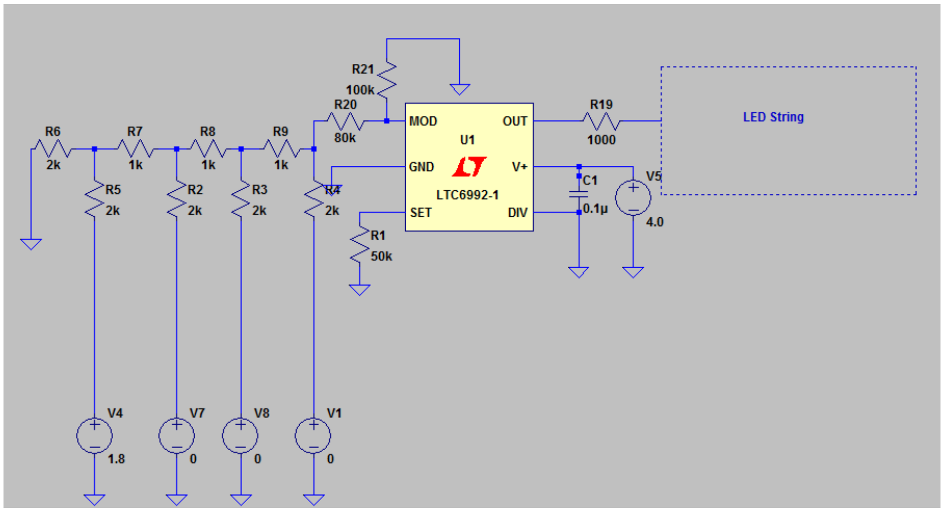

Figure 22: PWM LED Controller Circuit

In the simulations below, the control inputs are set to 4'b0100, 4'b0101, and 4'b1111, respectively. These illustrates that our LTC6992-1 chip with the R-2R ladder input works to supply 25%, 31.25%, and 93.75% cycles for operation at 1MHz.

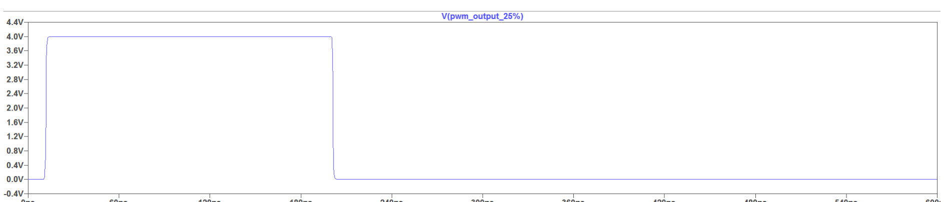

Figure 23: PWM 25% Output

The 25% duty cycle simulation shows that the pulse width is not precisely 25% and this is similar for all other cases; however, we are not concerned with absolute brightness in terms of gradient, only relative brightness from one level to another.

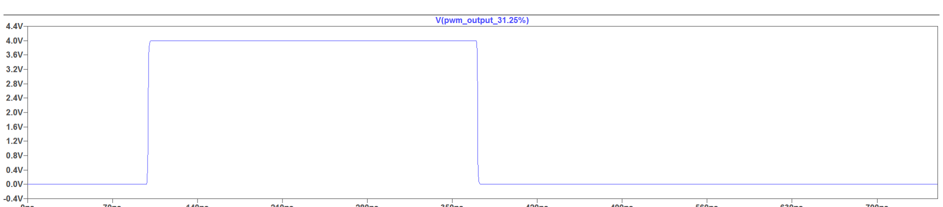

Figure 24: PWM 31.25% Output

As shown in the above figure, the Duty Cycle of 31.25% or $\frac{5}{16}$ has a 6.25% duty cycle difference from the 25% Duty Cycle which means that despite the differenc between calculated and simulated duty cycle, we can utilize the LTC6992-1 chip to produce a gradient effect

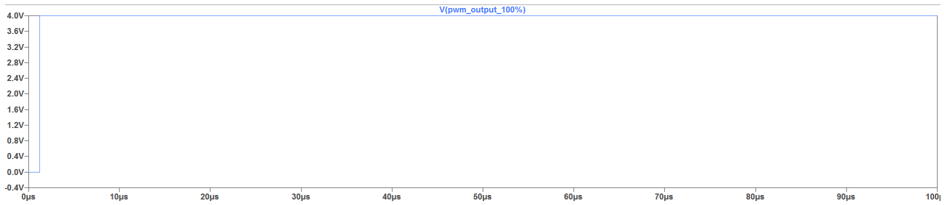

Figure 25: PWM 93.75% Output

In the 93.75% duty cycle, the output of the LTC6992-1 is set to 100% after a short delay to turn on the LTC6992-1. This is in fact beneficial because now the light bar can utilize the full light output of the LEDs not the 93.75% envisioned which improves overall light yield.

3 Requirements and Verifications

Requirements and verifications for the design are included beginning with the table on the next page. A total of 50 points were allotted among all of the modules based on their importance to the functionality of the design.

Block	Requirement	Verification
Digital Controller [15 Points]	1. Digital Controller operates at 1.8V. 2. Output digital signals that describe a gradient ranging of zero, where one LED string is on and the next is off 3. Output digital signals to describe a gradient of 31, where one LED is on at full intensity at one end of the light and each LED string down the light is one intensity level lower than the last 4. Any of the 15 LED strings will be able to be the center of the gradient	1. Verification for requirement 1: a. Connect CPLD and supplementary chips to a benchtop DC power supply set to 1.8V b. Load a test design that will pulse every output pin of the CPLD high and low. c. Attach an oscilloscope to the outputs of the CPLD pins d. Verify that each output pin pulses 1.8V to 0V e. Repeat at 1.8V ±10% to account for supply fluctuations 2. Verification for requirement 2: a. Connect CPLD and supplementary chips to a benchtop DC power supply set to 1.8V b. Supply the CPLD inputs with digital signals to describe a gradient of 0, intensity of 15, and focus of 7 c. Use multimeter to read outputs of digital controller. Ensure intensity at focus is 15 and intensity at the neighboring strings is 0 3. Verification for requirement 3: a. Connect CPLD and supplementary chips to a benchtop DC power supply set to 1.8V b. Supply the CPLD inputs with digital signals to

		describe a gradient of 31, intensity of 15, and focus of 0 c. Use multimeter to read outputs of digital controller. Ensure the intensity at the focus is 15 and the intensity goes down one step per string 4. Verification for requirement 4: a. Connect CPLD and supplementary chips to a benchtop DC power supply set to 1.8V. b. Supply the CPLD inputs with digital signals to describe an intensity to be 15 and a gradient of 0 c. Sweep focus from 0 to 15. At each step using a multimeter to measure the corresponding output to ensure it is at level 15
LED String Controller [10 Points]	1. Must be able to PWM from 0 to 93.75% duty cycle 2. Must consume less than 10% of the power of LED strip 3. Must have a frequency above 1kHz to avoid camera flicker	1. Verification for requirement 1: a. Attach 2Ω resistor to drain of control transistor b. Probe with Oscilloscope to determine duty cycle. c. Step through control voltages to R-2R ladder at 1.8V d. Ensure that the duty cycle falls within 6.25% of expected cycle 2. Verification for requirement 2: a. Attach 1.8V sources to the R-2R ladder b. Measure current through last 2R in R-2R

		ladder c. Extrapolate current across 2R to Norton Equivalent to find power sink 3. Verification for requirement 3: a. Attach 1.8V source for worst case scenario on R-2R ladder(4’b0001). b. Attach 2Ω resistor to transistor drain. c. Probe with oscilloscope the control transistor d. Ensure frequency is above 1kHz.
LED Array [5 Points]	1. Each LED circuit must output 26 lumens for total of 2500 lumens across bar 2. Power consumption of LEDs must not be greater than 40W	1. Verification for Requirement 1: a. Attach Power supply with duty cycle of 93.75% to transistor in LED array b. Attach LED to 4.0V benchtop DC supply c. Examine with light meter the overall brightness of one LED circuit d. Make sure each LED circuit outputs 26 lumens e. Repeat for all 16 circuits 2. Verification for Requirement 2: a. Attach transistor to power supply square wave of 4.0V. b. Attach LED to a benchtop 4.0V source c. Probe with Multimeter the voltage across dump resistor d. Probe with Multimeter the voltage across LEDs e. Extrapolate current across resistor and ergo the LEDs f. Calculate total power per LED subcircuit and

		ensure that it is less than 40W
AC/DC Stage [1 Point]	1. The AC/DC Adapter must provide a voltage of 26V ± 8V over the expected range of operation	2. Verification for requirement 1: a. Attach a 8.45Ω resistor to the output AC/DC stage b. Attach oscilloscope probes to the output of the AC/DC Stage. c. Plug the AC/DC Stage into a standard US wall outlet d. Ensure that the output voltage stays within 26V ±8V
DC/DC Buck 26-to-14.875V Converter [1 Point]	1. The converter output remains within 14.875V ± 0.15V at maximum output current.	1. Verification for requirement 1: a. Attach a 2.70Ω resistor to the output of the converter. b. Attach oscilloscope probes to the output of the converter. c. Supply the converter with 26V. d. Ensure that the output voltage stays within 14.875V ± 0.15V
Battery Charger [4 Points]	1. Within 4 hours, the charger must fully recharge the batteries from a completely discharged state to a capacity necessary for 30 minutes of lightbar operation.	2. Verification for requirement 1: a. Take a fully discharged battery pack, as indicated by a battery voltage of less than 1.0V per cell, and attach it to the charging circuit. b. Monitor the battery temperature in 15 minute intervals using a handheld IR sensor to ensure that it remains below 50°C c. Terminate the charging process after 4 hours. d. Using a DMM, measure the battery voltage.

		Ensure that this voltage is at least 9.6V
Battery [4 Points]	1. Sustains operation of the LEDs for at least 30 minutes.	1. Verification for requirement 1 a. Charge the battery up to full charge using the battery charger circuits. b. Connect the battery to a 2.4Ω resistor. Start a stopwatch. Stop when the battery voltage falls below 1.0V per cell. Ensure that the stopwatch time is greater than 30 minutes
DC/DC Buck 14.875-to-4.0V [2 Points]	1. The converter output remains within 4.0V ± 0.04V across the expected range of operation	1. Verification for requirement 1: e. Attach a 0.42Ω resistor to the output of the converter. f. Attach oscilloscope probes to the output of the converter. g. Supply the converter with 14.875V. h. Ensure that the output voltage stays within 4.0V ± 0.04V
Battery Protection [2 Points]	1. Undervoltage lockout engages for an input of lower than 8.0V. The lockout condition remains until the voltage increases above 8.0V 2. Overcurrent protection engages for any current more than 9.6A.	1. Verification for requirement 1 a. Attach a 10kΩ resistor to the output of the LTC4356. b. Attach an oscilloscope probe to the LTC4356 output and input. c. Supply the LTC4356 with 14V d. Slowly decrease the input voltage to a level below 8.0V. Check that the output voltage falls to zero. e. Increase the supply voltage back to 14V. f. Verify that the output is 14V

		2. Verification for requirement 2 a. Attach a 10kΩ potentiometer to the output of the LTC4356. b. Attach an oscilloscope probe to the LTC4356 output and input. Attach a current probe to the device output c. Supply the LTC4356 with 14V d. Slowly decrease the resistance of the potentiometer until the output current rises above 9.6A. Check that the output voltage falls to zero. e. Decrease the output current to 4.5A f. Verify that the output is 14V
4.0-to-1.8 Linear Regulator [1 Point]	1. Regulator output remains within 1.8V ± 0.1V at maximum output current of 0.5A	1. Verification for requirement 1: a. Attach a 3.6Ω resistor to the output of the regulator. b. Attach oscilloscope probes to the output of the regulator. c. Supply the converter with 4.0V. d. Ensure that the output voltage stays within .8V ± 0.1V
User Inputs [5 Points]	1. Focus and Intensity must have 4-bit levels 2. Gradient must have 8-bit levels	1. Verification for requirement 1: a. Attach 1kΩ resistor to outputs of Focus or Intensity b. Alternate each of the 4 bits of signal c. Probe 1kΩ resistor to check for 1.8V drop across each resistor 2. Verification for requirement 2: a. Attach 1kΩ resistor to

		outputs of Gradient b. Alternate each of the 8 bits of the signal c. Probe 1kΩ resistor to check for 1.8V drop across each resistor and verify that the signals are high/low in the correct pattern

4 Tolerance Analysis

Functionality Requirements of LED String Controller:

The LED String Controller is the key component of the entire LED Array with its ability to alter the intensity of the light from 0% to 93.75% with 16 different light levels. Each level must be distinguishable from another which means the end PWM duty cycle must be within one light level, 6.25%, or $\frac{1}{16}$ of calculated value.

The LTC6992-1 chip component is a key component, and the rest of the LED-String Controller must be designed around the tolerances of the LTC6992-1 chip. Unlike the rest of the LED String Controller Circuit, we cannot control the tolerances of the LTC6992-1, and we have to manage tolerances elsewhere. The LTC6992-1 can produce a duty cycle within a 3.0% error [11]. The voltage level output of the PWM square wave is also within a 0.4% error from the datasheet [11]. This overall gives the total tolerance of the LTC6992-1 of 3.5% that we cannot control.

The input of the LTC6992-1 chip which we can control consists of 1 voltage divider and approximation with the R-2R ladder to bias each bit of the Digital Controller 4-bit output signals down to 0-1V. This voltage divider in conjunction with the R-2R ladder will decrease the input voltage by 0.5% which will lower the duty cycle by 0.5%. In addition, the CPLD output voltage has 0.05% error. This overall gives a total uncontrollable tolerance of 3.95% total. The resistor network between the CPLD and the LTC6992-1 chip consists of 10 resistors. By subtracting the uncontrollable error of 3.95% from our ceiling of 6.25% gives us a total tolerance throughout the resistor network. Ergo, the maximum worst-case total error in the resistor network is 2.3%. With ten resistors, this gives the tolerance ceiling of each resistor to be 0.23%. Our resistors that we use are accurate to within 0.1%, so our worst case error is at -4.95% off the calculated duty cycle which is within our tolerance.

5 Cost Analysis

Table 1: Battery and Battery Charger Cost

Mfg P/N	**Mfg**	**Spec**	**Cost Per**	**Name**
RNCP0805FTD150R	Stackpole Electronic	RES SMD 150 OHM 1% 1/4W 0805	$0.10	R1
4-1625868-9	Stackpole Electronic	RES SMD 16.9 OHM 0.1% 1/4W 0805	$0.61	R2
RC0805FR-07348RL	Yageo	RES SMD 348 OHM 1% 1/8W 0805	$0.10	R3
RC0805FR-07133KL	Yageo	RES SMD 133K OHM 1% 1/8W 0805	$0.10	R5
RMCF0805JT10K0	Stackpole Electronic	RES SMD 10K OHM 5% 1/8W 0805	$0.10	R8
RMCF0805JT10K0	Stackpole Electronic	RES SMD 10K OHM 5% 1/8W 0805	$0.10	R10
RC0805FR-07698KL	Yageo	RES SMD 698K OHM 1% 1/8W 0805	$0.10	R12
RC0805FR-07100KL	Yageo	RES SMD 0.04 OHM 1% 3W 2512	$0.10	R13
ERJ-6BWFR051V	Panasonic	RES SMD 0.051 OHM 1% 1/2W 0805	$0.58	Rsns
NXFT15XH103FA2B025	Murata	NTC THERMISTOR 10K OHM 1% BEAD	$0.39	THM
C3216X5R1E476M160AC	TDK	CAP CER 47UF 25V X5R 1206	$1.26	C1
C3216X5R1E476M160AC	TDK	CAP CER 47UF 25V X5R 1206	$1.26	C2
VJ0603V104ZXXCW1BC	Vishay	CAP CER 0.1UF 25V Y5V 0603	$0.10	C3
VJ0603V104ZXXCW1BC	Vishay	CAP CER 0.1UF 25V Y5V 0603	$0.10	C4
CWDM3011P TR13	Central Semi	MOSFET P-CH 30V 11A 8SOIC	$0.94	Q1
2N7002-7-F	Diodes Inc	MOSFET N-CH 60V 115MA SOT23-3	$0.15	Q2
BAX16TR	ON Semi	DIODE GEN PURP 150V 200MA DO35	$0.19	D1
SM74611KTTR	Texas Instruments	DIODE SCHOTTKY 25V 15A TO220AC	$3.68	D2
DS2715	Maxim	IC NIMH CHARGER 16-SOIC	$8.33	DS2715
HHR-450AB21L2X4	Panasonic	BATTERY PACK NIMH 9.6V 4200MAH	$67.44	Bat1
Total Cost			$85.73	

Table 2: Battery Protection Circuit Cost

Mfg P/N	**Mfg**	**Spec**	**Cost Per**	**Name**
LT4356IMS-1#TRPBF	Linear Tech	IC OVERVOLT PROT REG 10-MSOP	$5.49	LT4356-2
RC0805FR-07549KL	Yageo	RES SMD 549K OHM 1% 1/8W 0805	$0.10	R1
ERJ-6ENF1003V	Panasonic	RES SMD 100K OHM 1% 1/8W 0805	$0.10	R2
RC0805FR-0710RL	Yageo	RES SMD 10 OHM 1% 1/8W 0805	$0.10	R3
CSRF1206FT5L00	Stackpole Electronics	RES SMD 0.005 OHM 1% 1W 1206	$0.63	Rsns
IRF2805STRLPBF	Infineon	MOSFET N-CH 55V 135A D2PAK	$2.67	M1
GRM155R71E473KA88D	Murata	CAP CER 0.047UF 25V X7R 0402	$0.10	C1
Total Cost			$9.19	

Table 3: AC/DC Stage Cost

Mfg P/N	**Mfg**	**Spec**	**Cost Per**	**Name**
VPT48-5200	Triad Magnetics	VPT48-5200	$60.60	Xfrm1
SSQ 3.5	Bel Fuse Inc	FUSE BRD MNT 3.5A 125VAC/VDC SMD	$0.39	Fuse
MAL212017102E3	Vishay	CAP ALUM 1000UF 20% 40V AXIAL	$5.58	Cs1
MAL212017102E3	Vishay	CAP ALUM 1000UF 20% 40V AXIAL	$5.58	Cs2
GBU4D-BP	Micro Commercial	RECT BRIDGE GPP 4A 200V GBU	$0.88	Rect1
Qualtek	703W-00/08	PWR ENT RCPT IEC320-C14 PANEL QC	$0.85	Plug
Total Cost			$72.15	

Table 4: DC/DC Buck 26-to-14.875V Cost

Mfg P/N	**Mfg**	**Spec**	**Cost Per**	**Name**
ERJ-8CWFR018V	Panasonic	RES SMD 0.018 OHM 1% 1W 1206	$0.63	Rsns
RC0805FR-0720KL	Yageo	RC0805FR-0720KL	$0.10	RFB1
RC0805FR-07232KL	Yageo	RES SMD 232K OHM 1% 1/8W 0805	$0.10	RFB2
RMCF0805JT6K80	Stackpole Electronics	RES SMD 6.8K OHM 5% 1/8W 0805	$0.10	Rc
CL31B104KBC5PNC	Samsung	CAP CER 0.1UF 50V X7R 1206	$0.16	C1
GRM0335C1E101JA01D	Murata	CAP CER 100PF 25V NP0 0201	$0.10	C2
GRM155R71H102KA01D	Murata	CAP CER 1000PF 50V X7R 0402	$0.10	C3
CL05X684JQ5NNNC	Samsung	CAP CER 0.68UF 6.3V X6S 0402	$0.10	Cc
T495D686K020ATE070	KEMET	CAP TANT 68UF 20V 10% 2917	$1.63	Cout1
T495D686K020ATE070	KEMET	CAP TANT 68UF 20V 10% 2917	$1.63	Cout2
T495D686K020ATE070	KEMET	CAP TANT 68UF 20V 10% 2917	$1.63	Cout3
CL31B104KBC5PNC	Samsung	CAP CER 0.1UF 50V X7R 1206	$0.16	CB
PLV1H330MCL1TD	Nichcon	CAP ALUM POLY 33UF 20% 50V T/H	1.86	Cin1
PLV1H330MCL1TD	Nichcon	CAP ALUM POLY 33UF 20% 50V T/H	1.86	Cin2
7443551331	Wurth	FIXED IND 33UH 5.5A 30.5 MOHM	$3.27	L1
IRF7468TRPBF	Infineon	MOSFET N-CH 40V 9.4A 8-SOIC	$0.94	M1
MBR745G	On Semi	DIODE SCHOTTKY 45V 7.5A TO220-2	$0.73	D1
LTC1624IS8#PBF	Linear Technology	IC REG CTRLR BCK/BST/SEPIC 8SOIC	$8.92	U1
Total Cost			$24.02	

Table 5: DC/DC Buck 14.875-to-4.0V Cost

Mfg P/N	Mfg	Spec	Cost Per	Name
CSNL2010FT10L0	Stackpole Electronics	RES SMD 0.01 OHM 1% 1.5W 2010	$0.65	Rsns
RC0805FR-0720KL	Yageo	RC0805FR-0720KL	$0.10	RFB1
RC0805FR-0747KL	Yageo	RES SMD 47K OHM 1% 1/8W 0805	$0.10	RFB2
ERJ-6ENF2320V	Panasonic	RES SMD 232 OHM 1% 1/8W 0805	$0.10	RFB2_2
P3.3KJCT-ND	Panasonic	ERJ-2GEJ332X	$0.10	Rc
CL31B104KBC5PNC	Samsung	CAP CER 0.1UF 50V X7R 1206	$0.16	C1
GRM0335C1E101JA01D	Murata	CAP CER 100PF 25V NP0 0201	$0.10	C2
GRM155R71H102KA01D	Murata	CAP CER 1000PF 50V X7R 0402	$0.10	C3
CL05X684JQ5NNNC	Samsung	CAP CER 0.68UF 6.3V X6S 0402	$0.10	Cc
CC1210MKX5R7BB107	Yageo	CAP CER 100UF 16V X5R 1210	$1.63	Cin1
CC1210MKX5R7BB107	Yageo	CAP CER 100UF 16V X5R 1210	$1.63	Cin2
CL31B104KBC5PNC	Samsung	CAP CER 0.1UF 50V X7R 1206	$0.16	CB
T495D686K020ATE070	KEMET	CAP TANT 68UF 20V 10% 2917	$1.63	Cout1
T495D686K020ATE070	KEMET	CAP TANT 68UF 20V 10% 2917	$1.63	Cout2
T495D686K020ATE070	KEMET	CAP TANT 68UF 20V 10% 2917	$1.63	Cout3
T495D686K020ATE070	KEMET	CAP TANT 68UF 20V 10% 2917	$1.63	Cout4
7443633300	Wurth	FIXED IND 33UH 12A 11.4 MOHM SMD	$7.88	L1
IRF7468TRPBF	Infineon	MOSFET N-CH 40V 9.4A 8-SOIC	$0.94	M1
SM74611KTTR	Texas Instruments	DIODE SCHOTTKY 25V 15A TO220AC	$3.68	D1
LTC1624IS8#PBF	Linear Technology	IC REG CTRLR BCK/BST/SEPIC 8SOIC	$8.92	U1
Total Cost			$32.87	

Table 6: 4.8-to-1.8V Linear Regulator Cost

Mfg P/N	Mfg	Spec	Cost Per	Name
LT1963AES8-1.8#PBF	Linear Tech	IC REG LDO 1.8V 1.5A 8SOIC	$4.52	U1
T55A106M6R3C0200	Vishay	CAP TANT POLY 10UF 6.3V 1206	$0.69	C_logic_out
T55A106M6R3C0200	Vishay	CAP TANT POLY 10UF 6.3V 1206	$0.69	C_logic_in
Total Cost			$5.59	

Table 7: LED String Controller Cost

Mfg P/N	MFG	Distributor	Distributor P/N	Spec	Cost Per	Number
LTC6992C-1	LinearTech	Digikey	LTC6992CS6-1#TRMPBFCT-ND	PWM	$3.83	20
T2N7002AK,LM	Toshiba	Digikey	T2N7002AKLMCT-ND	MOSFET	$0.15	100
MLCAWT-A1-0000-000XE3	Cree	Cree	MLCAWT-A1-0000-000XE3CT-ND	29 lumen	$0.32	100
K104K10X7RF5UH5	Vishay	Digikey	BC2665CT-ND	0.1uF	$0.13	20
ERJ-3EKF1001V	Panasonic	Digikey	P1.00KHCT-ND	1k	$0.01	100
RC0402FR-07806RL	Yageo	Digikey	YAG3239CT-ND	80k	$0.00	100
RC0805FR-078R06L	Yageo	Digikey	311-8.06CRCT-ND	1k	$0.01	100
RC0603FR-0720KL	Yageo	Digikey	311-20.0KHRCT-ND	2k	$0.01	100
RC0402JR-0710KL	Yageo	Digikey	311-10KJRCT-ND	100k	$0.01	100
RC0603FR-074R02L	Yageo	Digikey	311-4.02HRCT-ND	4	$0.01	100
Total Cost					$129.89	

Table 8: Digital Controller Cost

Mfg P/N	Mfg	Spec	Cost Per	Number
5M160ZT100C5N	Altera	IC CPLD 128MC 7.5NS 100TQFP	$3.70	2
302-S101	On Shore Technology Inc.	CONN HEADER VERT 10POS GOLD	$0.28	2
P0302	Terasic Inc.	USB BLASTER CABLE	$50.00	1
RC0402JR-071KL	Yageo	RES SMD 1K OHM 5% 1/16W 0402	$0.10	1
RC0402JR-0710KL	Yageo	RC0402JR-0710KL	$0.10	1
EAW0J-B24-AE0128L	Bourns Inc	ENCODER MECH ABSOL 8BIT	$8.29	3
OEJL-50-4-5	Kilo International	KNOB BLK/MATTE.50"DIA .250"SHAFT	$6.01	3
300SP1J1BLKM2QE	E-Switch	SWITCH ROCKER SPDT 5A 120V	$2.85	1
Total Cost			$103.99	

Table 9: Labor Cost

Name	Hourly Rate	Hours Invested	Total Cost
Nick	$48.00	100	$12,000.00
Andrew	$48.00	100	$12,000.00
Eric	$48.00	100	$12,000.00
Total Cost			$36,000.00

Table 10: Total Cost

Batteries and Charger	$85.53
Battery Protection	$9.19
AC/DC Rectifier	$72.15
DC/DC Input to Charger	$24.02
DC/DC Charger to LED	$32.87
Logic Linear Regulator	$5.90
PWM Controllers	$129.89
Digital Logic	$103.99
Work Hours	$463.74
Total Cost	**$24,463.74**

6 Schedule

Figure 26: Schedule

Week	Task	Responsibility
2/20	Prepare for mock design review	All
	Finish simulating power circuitry	Nick
	Order PWM circuit components	Eric
	Order power circuitry components	Nick
	Order digital logic IC components	Andrew
	Layout digital logic in EagleCad	Andrew
	Layout PWM circuit in EagleCad	Eric
	Talk to Machine Shop with regards to grounding	Eric
2/27	Prepare design review	All
	Layout Power circuitry	Nick
	Breadboard test the Battery Charger	Nick
	Breadboard test the PWM controller	Eric
	Add new modes to digital logic and program CPLD	Andrew
3/6	Finalize the housing and submit to machine shop	All
	Prototype circuit test DC DC converter stage and Linear Regulator	Nick
	Layout digital logic in EagleCad and order PCB	Andrew
	Begin soldering PWM circuits	Eric
3/13	Continue soldering PWM circuits	Eric
	Solder Digital Logic	Andrew
	Begin soldering power circuitry	Nick
3/20	Verify Digital Logic	Andrew
	Finish soldering PWM circuits	Eric
	Verify power circuits	Nick
3/27	Individual progress reports due	All
	Correct and finish digital logic verification	Andrew
	Verify PWM circuits	Eric
4/3	Bring together power circuitry and PWM circuits. Verify their operation	Eric,Nick
	Bring logic and power circuitry together and verify their operation	Andrew, Nick
	Bring Logic and PWM circuits together, verify their operation	Andrew, Eric
4/10	Prepare first draft of final paper	All
	Debug and prepare form mock demo as needed	All
4/17	Prepare final draft of paper	All
	Mock Demo this week	All
4/24	Finalize final paper	All
	Final demo this week	All
	Edit final paper and perform corrections as needed	All
5/1	Final papers and Lab checkout due	All

7 Safety and Ethics

There are several safety concerns with regards to a portable lighting fixture. nickel-metal-hydride batteries can fail catastrophically in three ways, either temperature failure, undercharge failure, or overcharge failure [1]. To compensate for temperature failure, the battery will have a thermistor which will monitor the temperature of the batteries. The DS2715 will monitor the battery temperature using the thermistor and disconnect the battery from the circuit if the battery temperature is above $50°C$. Furthermore, a voltage and current regulating circuit will control the charging output to prevent overcharge which can lead to a thermal reaction. An undercharge protection circuit will also be implemented to prevent undercharge and the destruction of the battery beyond 1.0V per cell. Additionally, a safety plan will be followed at all times while working with batteries in the lab:

- To prevent runaway current, batteries will be stored in a secure location with the terminals covered by insulating material to ensure that no short circuit can occur.
- If the battery swells, bulges outward, becomes noticeably hot, or makes a noise of any kind, the battery will be disconnected immediately and placed in a battery bag as far away from anything potentially flammable as possible. A TA will then be notified to dispose of the battery as soon as possible.
- A MSDS for the battery will be in the lab at all times when the battery is connected to an electrical circuit.Batteries connected to any electrical circuit will not be left unattended for any amount of time.

In addition, as an electronic device that could operating in limited outside conditions, the outside casing must be built to IP 53 specifications to prevent accidental shorting of the internal circuit. Additionally, while LED lights do not produce a significant amount of heat, the fixture must be kept at under 40°C.

In terms of ethics considerations, we must follow the IEEE code of ethics specifically sections 1 and 5. Section 1 states that we must consider the decisions that we make which will impact the health, safety, and welfare of the public [4]. We must consider the possible health and safety of the consumers when using the light such as potential weight issues with a portable device. In addition, we must consider issues that relate to potential electrocution with high power electronics, and possible rupture and destruction of the battery.

Section 5 states that we must improve the understanding of technology, appropriate application, and potential consequences [4]. So we must work with Rick Kessinger Studios to make sure our technology development applied in such a manner that would be beneficial for photographers. In addition, we must educate photographers at Rick Kessinger Studios of the limits of our design in terms of the lighting effects of PWM and the potential dangers of battery usage and high power design.

References

[1] M. Power Systems, "Nickel Metal Hydride Batteries Handling Precautions," Available: $http : //data.energizer.com/pdfs/nickelmetalhydride_appman.pdf$ in Tayloredge, 2003.

[2] P. Horowitz and W. Hill, The Art of Electronics, 3rd ed. New York [New York]: Cambridge University Press, 2015.

[3] P. Krein, Elements of power electronics, 2nd ed. New York: Oxford University Press, 1998.

[4] Linear Technology, "LT4356-1/LT4356-2 Surge Stopper", Available: $http : //cds.linear.com/docs/en/datasheet/4356fa.pdf$ in Linear Technology, 2009.

[5] Linear Technology, "High Efficiency SO-8 N-Channel Switching Regulator Controller", Available: $http : //cds.linear.com/docs/en/datasheet/1624f.pdf$ in Linear Technology, 1997.

[6] Linear Technology, "1.5A, Low Noise, Fast Transient Response LDO Regulators", Available: $http : //cds.linear.com/docs/en/datasheet/1963aff.pdf$ in Linear Technology, 2005.

[7] Maxim Integrated, "DS2715 NiMH Battery Pack Charge Controller", Available: $https : //datasheets.maximintegrated.com/en/ds/DS2715.pdf$ in Maxim Integrated, 2009.

[8] Panasonic, "NI-MH HANDBOOK", Available: $https : //eu.industrial.panasonic.com/sites/default/pidseu/files/downloads/files/id_ni - mh_1104_e.pdf$ in Panasonic Corporation. 2014.

[9] Panasonic "Nickel Metal Hydride Batteries: Individual Data Sheet HHR450A", Available: $https : //na.industrial.panasonic.com/sites/default/pidsa/files/panasonic_nimh_hhr450a.pdf$ Panasonic, 2005.

[10] Cree, "Cree XLamp ML-C LEDs Data Sheet," Available: $http : //www.cree.com/ /media/Files/Cree/LED-Components-and-Modules/XLamp/Data-and-Binning/XLampMLC.pdf$ in Cree. 2010.

[11] LinearTech, "TimerBlox: Voltage-Controlled Pulse Width Modulator (PWM) Data Sheet," Available: $http : //cds.linear.com/docs/en/datasheet/69921234fc.pdf$ Linear Technology. 2008.

[12] Toshiba, "TOSHIBA Field-Effect Transistor Silicon N-Channel MOS Type Data Sheet," Available: $https : //people.ece.cornell.edu/land/courses/ece4760/labs/f2016/lab4_2SK4017.pdf$ Toshiba. 2009.