LED Flow

Final Report

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Fall 2021 – Spring 2022

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DISCLAIMER

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EXECUTIVE SUMMARY

This project aims at designing and implementing a high-speed high-power pulsed RGB LED light source for a volumetric particle image velocimetry (PIV) system. This system will be used to illuminate a fluid flow for a camera to be able to detect and pick up the light refracted from particle laden fluid. This will then allow the user to be able to detect fluid velocity and motion. The purpose of the project is to develop a system utilizing LED light sources as a cheaper alternative to the traditional light sources in PIV systems, lasers. This LED matrix combines three different colors, namely red, green, and blue which will be controlled independently, using a LED controller and a function generator. The light pulses are synchronized with the camera through the TTL output of the function generator, while the delay and pulse width of the LEDs is controlled by the LED controller. The system is mounted to its own housing which contains all the wiring and cooling systems necessary for operation. This system meets specifications such as accepting a TTL input, having a minimum pulse width of 1 μs, and being able to range in frequency from 1 hz to 10 khz.

ACKNOWLEDGEMENTS

Dr. David Willy for the guidance through the engineering design process thank you.

Dr. Dou for providing the team the opportunity to do this project and succeed thank you.

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1 BACKGROUND

1.1 Introduction

This project is based on flow visualization technology to design and produce an LED matrix to realize the light source supply of the particle image velocimetry (PIV) system. The purpose of this project is to create a red, green, blue (RGB) light system in order to illuminate flow so that a camera can detect the flow. The system has three separate channels that control the different colors individually and must operate within a $1000 budget. This project provides the same functions of laser equipment with less money, which saves the sponsor a high cost and makes the marginal benefit increase significantly.

1.2 Project Description

Following is the original project description provided by the sponsor:

“Light source is a critical component for flow visualization and diagnostics. This project aims at designing and implementing a high-speed high-power pulsed RGB LED light source for volumetric particle image velocimetry (PIV) system. A group of LEDs will be integrated together as a LED matrix. In this LED matrix, three different colors, namely red, green, and blue will be controlled independently, using a home designed circuit board. Furthermore, it requires the following specifications to be met:

- Trigger input: TTL
- Minimum light pulse width: 0.5us
- Frequency: 1Hz – 60 KHz
- Energy per pulse per channel: 0-30 mJ
- Trigger to light pulse min. delay: 500ns
- Trigger to light pulse jitter: 5ns
- Trigger to Sync output min. delay: 100 ns
- Trigger to Sync output jitter: 5ns
- Channels: Red, Green, Blue

Knowledge, skills, and expertise required for this project:

- Strong interests in engineering design and problem solving.
- Familiarity with basic CAD software.
- Familiarity with basic circuit board design.
- Familiarity with a basic machine shop.
- Good communication skills and teamwork.

Budget: $1000”

2 REQUIREMENTS

This chapter mainly introduces Customer Requirements, Engineering Requirements and House of Quality. Customer Requirements are weighted according to the actual needs of customers and the reasons for weighting are explained. Engineering Requirements gives Justifications on engineering standards based on the target value provided by the sponsor. Based on the first two requirements, House of Quality has made a comprehensive calculation to obtain the evaluation criteria of absolute and relative importance.

2.1 Customer Requirements (CRs)

The customer requirements for this project are a bit unique. This is the case because our client gave us the engineering requirements. The customer requirements in Table 1 were derived from the engineering requirements. The weights for each one as well as the reasoning behind each requirement can also be found in Table 1.

Table 1. Customer Requirements

Customer Requirements	Weights	Interpretations
High Frequency	4	High Frequency, as a secondary factor that affects the visualization effect, is not as important as the primary factor. So its weight is of secondary importance.
Short Pulses	4	Customers will care about the duration of a single pulse, because too long exposure time will cause blurring of the visualization. Based on the secondary influence, its weight is of secondary importance.
Adjustable Intensity	5	The intensity of the light effect will directly affect the flow visualization, so it has the highest weight.
Reliability	3	This product will not suffer huge external impact or load during normal use, so customers are least concerned about its reliability.
Durability	3	This product does not have too many mechanical devices, and customers will not pay too much attention to its fatigue durability.
Adjustable Color	5	It is the most important for being able to switch between the three light colors of RGB according to the needs of customers, so the weight is the highest.
Minimal Jitter and Delay	4	Jitter and Delay will cause blurring of the visualization, so weight is the second highest.

Cost	3	This product has a narrow audience, not many similar products, and obvious marginal effects. Therefore, customers do not pay attention to price.

2.2 Engineering Requirements (ERs)

Many of the engineering requirements were given by our client. The requirements that were derived on our own are the Light wavelength, the Temperature of the system and the LED Lifespan. These requirements help to round out the system as well as match the customer requirements for reliability and safety.

Table 2. Engineering Requirements

Engineering Requirements	Target Value	Justifications
Pulse Width(us)	Minimum 0.5us	The pulse width is modulated to ensure the intensity of light. Pulse Width should be at least 0.5us.
Frequency(kHz)	1Hz – 60 kHz	The pulse frequency is the number of effective discharges in the discharge gap per unit time. Frequency is between 1Hz and 60 kHz.
Energy Per Pulse Per Channel(mJ)	0-30 mJ	Measure the radiant energy contained in a pulse. Pulse energy is between 0 and 30 mJ.
Trigger Delay(ns)	Minimum 500ns	Clarify the switch trigger delay time of the pulse power device is no lower than 500ns.
Trigger Jitter(ns)	5ns	Ensure the Trigger jitter of one pulse cycle is 5ns.
Output Delay(ns)	Minimum 100 ns	Make sure the output delay is 100 ns at minimum.
Output Jitter(ns)	5ns	Determine the output Jitter is 5ns.
Light Wavelength(nm)	622-770nm for Red 492-577nm for Green 455-492nm for Blue	The wavelength of light directly reflects the corresponding color on the spectrum. The specific wavelength comes from the visible light spectrum.

Temperature(°C)	Maximum 65°C	Temperature affects reliability. Excessive temperature will cause the resistance value to decrease, thereby affecting the failure rate of the circuit board. 65 degrees Celsius is the critical value.
LED Lifespan(hr)	Maximum 10^5 hrs	The lifespan of the LED light determines its durability. The theoretical life of the LED is a maximum of 100,000 hours.

2.3 Functional Decomposition

2.3.1 Black Box Model

The Black Box model is used to describe the inputs that are going into the system and the outputs that occur after the inputs affect the system. The black box model here revolves around the entire LED system. The inputs are electrical energy, the manual signal, and the air flow. The electrical energy comes from the system having a battery that supplies the system energy when on. The manual signal is what describes the transform of the three channels. The air flow is what is entering the system so it doesn't overheat and get damaged. The outputs occur from the process of the inputs. The outputs leaving the system are light energy, thermal energy, and the digital signal. The light is a result from the electrical energy turning on the LEDs. The thermal energy is a result from the heated air flow and the electrical energy converted to heat instead of light. The digital signal is the system telling us the diagnostics of the system. The black box model can be seen below:

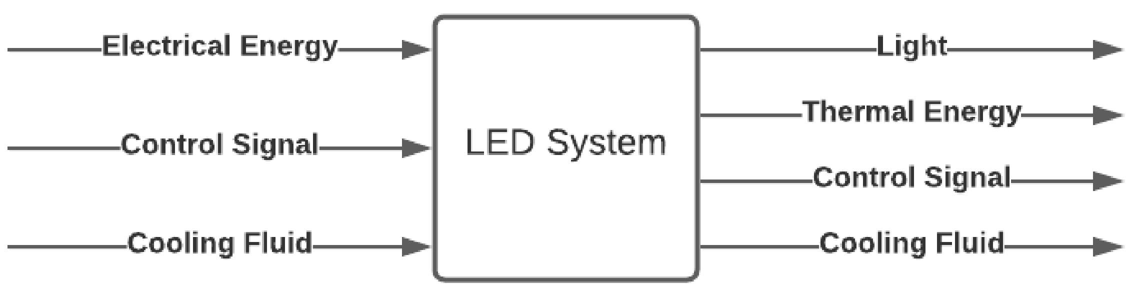


Figure 1: Black Box Model

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The functional model's importance is to show how a system is structured to work. The functional model includes the inputs of energy and how the system works as a whole. The functional model in this report starts with the input of human energy. The person using the system has to turn on it which needs their energy to start the process. When the system is turned on it provides electrical energy from a battery or electrical source. The electrical energy then travels to three different sections of the device. The first section being the system diagnostics, which gives feedback on if and how the system is running. The second area electricity travels to is the cooling system. The cooling system starts the movement of the fluid that will collect the heat from the heat sink and then it will leave the system. This area that the electrical energy transfers to is the circuit board. The circuit board will then convert the electrical energy into light and heat. The light will be transferred into the red, green, and blue LEDs.

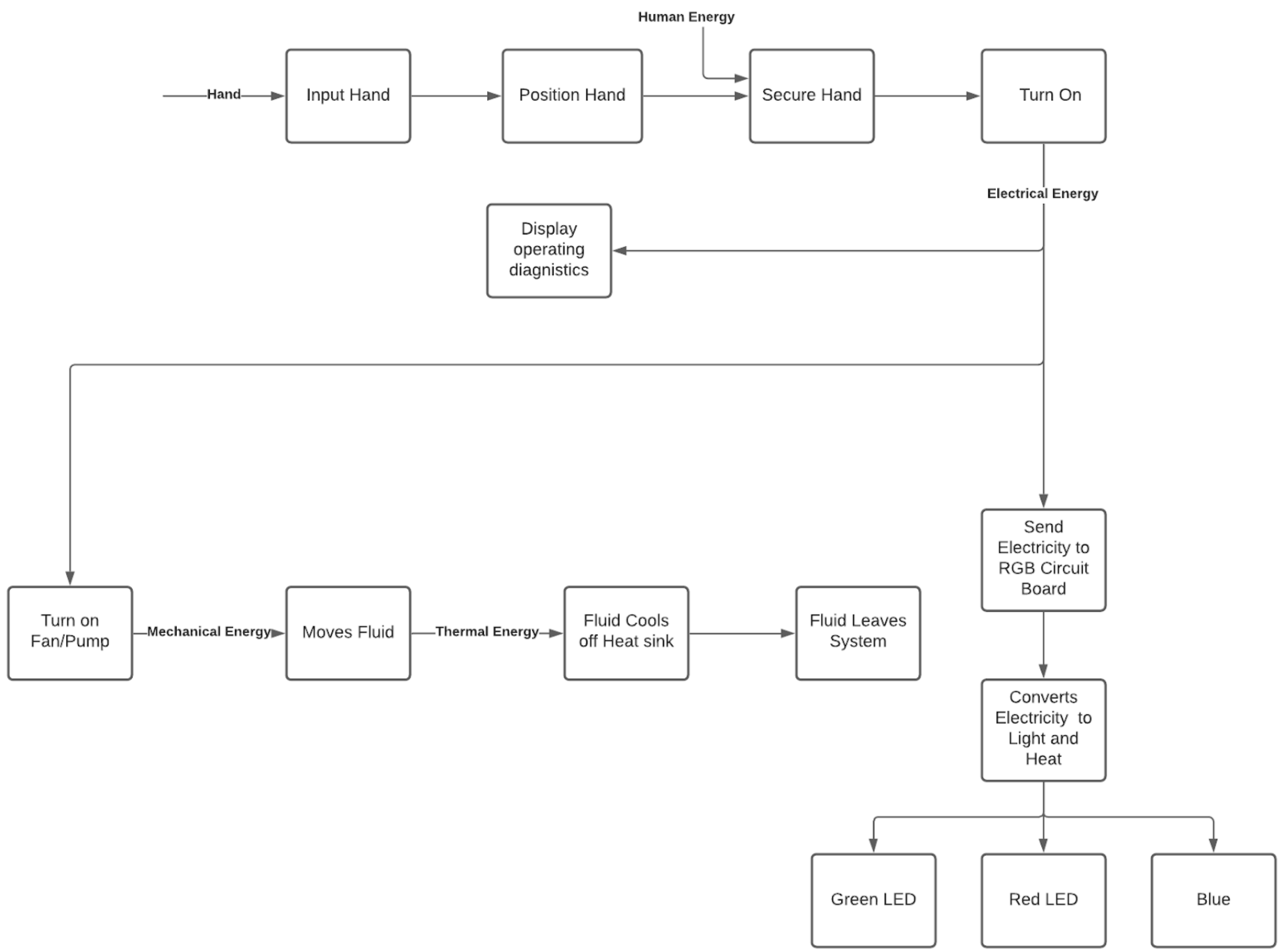


Figure 2: Functional Model One

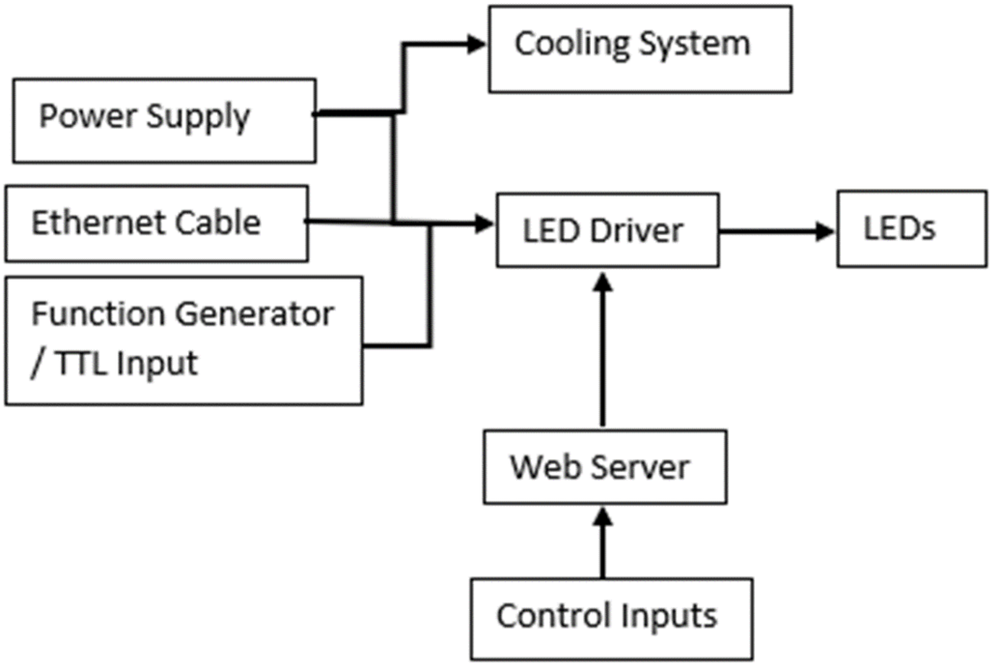


Figure 3: Functional Model Two

2.4 House of Quality (HoQ)

The house of quality is a product planning matrix that is used to discuss customer requirements and engineering requirements. In the customer weights section a scale of one to five is used to measure the importance of the customer requirements. A one being of little importance and a five being of high importance. Then the engineering requirements were compared to each customer requirement and rated as a one, three, nine, or left completely blank. One means it has some relevance, three being a good amount of relevance, and nine being of most relevance. The Absolute Technical Importance (ATI) is the scores under each engineering requirement multiplied by their weight and then added up to get a score. The higher a score the more important that engineering requirement is. The Relative Technical Importance is the average of that ATI over the sum of all the ATI's. This is to show the importance of the engineering requirement in percentages.

The House of Quality helped the team realize that the cooling system will be an integral part of the system since its ATI was 15.8%. This cooling system will need to control the temperature enough so that the LED's work efficiently and are not self-destructive. LEDs lifespan at 12.6% ATI shows the importance of purchasing a good LED that can last long enough for many experiments. A cheap LED would not work as efficiently and be as durable. An upside to quality LED's is that they will save money in the long run, but will cost more up front. With light wavelength as the lowest ATI score it shows that worrying about the wavelengths is not as important. This is because red, green, and blue already have their set wavelengths and there is not much to do about it, other than to try and increase light intensity. Trigger delay really had no effect on our design choices other than implementing it correctly. The TTL trigger was already chosen for the team. The House of Quality showed the team what were the most important design factors to focus on first which as explained previously is mainly cooling and frequency of the light source.

2.5 Standards, Codes, and Regulations

To make ourselves operate in a safe manner, we selected standards including 4 aspects - Housing, Fans, Circuit board, and Eye protection. For the Housing part, we use code INCITS 305-1998 (R2018) to manage the state of the power supplies and the cooling devices in the housing. Then we consider the cooling fans part, using code IEC 60704-2-7 Ed. 2.0 b:2020. Circuit board is also important, it's like a brain to our design, so we use code IEEE 3003.2-2014 to avoid accidental electric shock because of any incorrect operation. Finally, eye protection is necessary in this project, so we use code ANSI Z80.1 to help us select ophthalmic lenses. [3]

Standards and codes come from many organizations and societies. Examples of those that most directly apply to Mechanical Engineering projects include (but are not limited to):

- Aluminum Association (AA)
- American Gear Manufacturers Association (AGMA)
- American Iron and Steel Institute (AISI)
- American National Standards Institute (ANSI)
- American Society of Mechanical Engineering (ASME)
- American Society of Testing and Materials (ASTM)
- American Welding Society (AWS)
- American Bearing Manufacturers Association (ABMA)
- Industrial Fasteners Institute (IFI)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Standards Organization (ISO)
- National Institute for Standards and Technology (NIST)
- Society of Automotive Engineers (SAE)

Table 3: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
INCITS 305-1998 (R2018)	Information Technology - SCSI Enclosure Services (SES)	Help to manage and sense the state of the power supplies, cooling devices, displays, indicators, individual drives, and other non-SCSI elements installed in an enclosure.

ANSI/ISEA Z87.1 / ANSI Z80.3 / ANSI Z80.1	Ophthalmics - Prescription Ophthalmic Lenses - Recommendations (ANSI Z80.1)	Direct what kind of ophthalmic lenses we can use. Prevent users from eye injury.
IEEE 3003.2-2014	Recommended Practice for Equipment Grounding and Bonding in Industrial and Commercial Power Systems	It helps the users avoid electric shock because of incorrect use.
IEC 60704-2-7 Ed. 2.0 b:2020	Household And Similar Electrical Appliances - Test Code For The Determination Of Airborne Acoustical Noise - Part 2-7: Particular Requirements For Fans	It contains electrical fans (including their accessories and their component parts) for household and similar use, designed for AC or DC supply.

3 DESIGN SPACE RESEARCH

3.1 *Literature Review*

The literature review will include up to 19 sources on circuits, LEDs, control signals, and the cooling system. Each of these topics are an integral part of the design and making of the LED system. Without knowledge of each the system could easily fail.

3.1.1 Student 1(Ryan Schuster)

This literature review covers the design of the circuit. Specifically covering how to use pulse width modulation on a scale of nanoseconds to power a large quantity of LEDs. The goal is to have a circuit that operates at roughly 300 W and contains at least 3 color channels for Red, Green, and Blue.

3.1.1.1 Electric Circuits [1]

This textbook is a good source of information for the analysis and design of circuits. Specifically chapters 2 and 3 as well as section 4.12 and 5.5. The textbook is mostly just a baseline resource to reference for equations and conditions as well as examples that can be used when designing the circuit. Chapters 2 and 3 review basic analysis equations for power, voltage, current and resistance. Section 4.12 discusses the maximum power transfer within a system which is important in developing a system designed to run at the max power. While Section 5.5 covers non-inverting amplifier circuits which may be an option to increase the voltage and current outputted by the pulse input allowing for a wider range of development options.

3.1.1.2 Pulsed Operation of high-power light emitting diodes for imaging flow velocimetry [2]

This article covers the operation of a single LED emitter that is utilized for flow velocimetry. There are a few major differences between the purpose of this circuit and the one needed in the design project. The first among these is that the circuit controls a single LED that emits the light into a fiber optic cable that converts the light into a single plane of light. Due to being a single LED it is much larger and pulls much more current and voltage than the system that we must design. The most interesting aspect of this circuit is that it utilizes the TTL input through a driver to control a gate mosfet which allows the current to flow through the circuit to power the LED in timing with the pulse signal.

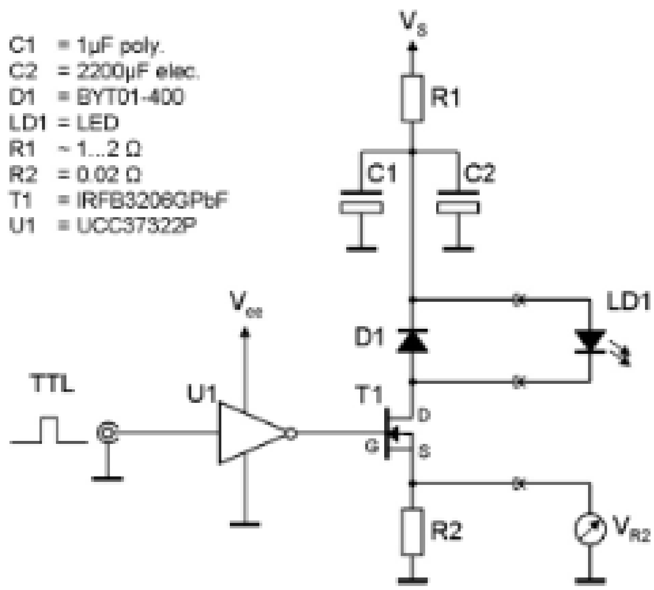


Figure 4: Flow Velocimetry Circuit [2]

3.1.1.3 Characterization and Evaluation of PIV Illumination System Using High Power Light Emitting Diodes for Water Tank Applications [3]

This next article is very similar to the previous one. As with the previous article the 2 LEDS are directed into fiber optic cables then converted to a single plane of light, an important differentiation between our project and this article. However in comparison to the previous article this circuit gives a much better idea of how to set up our own circuit due to having LEDs in parallel. As with the previous circuit the TTL pulse signal is utilized to control a mosfet gate which will open the circuit powered by a controllable voltage source. The capacitors help to keep a steady flow within the circuit. The biggest take away from this article is that a 5 v pulse signal can be split to control multiple gates and a single voltage source V+ can be used to power the circuit. This article also goes into specifics about the reasoning behind each component used, especially the gate types allowing to see the reasoning in the selection and how they can be adapted.

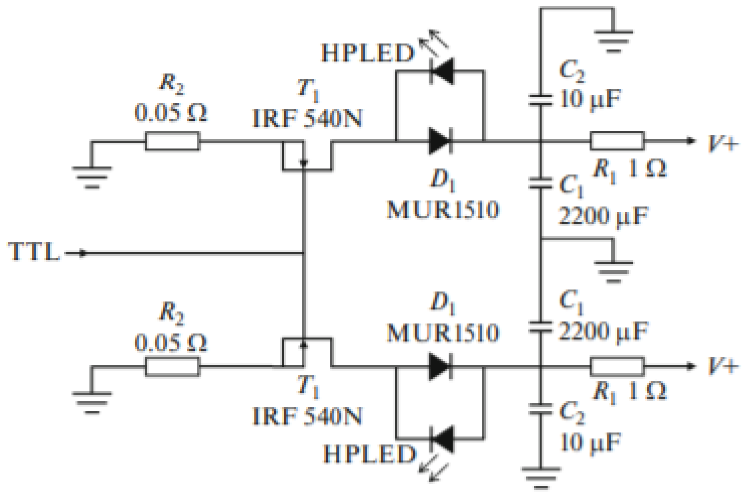


Figure 5: Water Tank Circuit [3]

3.1.1.4 Pulsed Over-Current Driving of Cree XLamp LEDs: Information and Cautions [4]

Since the LEDs we selected are the Cree XLamp XM-L Color, it is important to understand how this line of LEDs function under overcharged pulsing. This can be seen within table X. Another thing to note is that this document discusses the reduction of lifespan of these LEDs on the scale of tens to hundreds of thousands of hours. The final note is that LEDs have reduced output when temperature is increased. Cree argues that this makes pulsed operation ineffective due to the increases in temperature within the system. However with a proper cooling system this effect should be avoided creating an effective system when used with pulsed operation.

Table 4: Xlamp Power Table [4]

Current (mA)	V_f (volts)	Average Power
175	2.84	0.100
350	2.99	0.209
700	3.21	0.449
1000	3.35	0.671
1500	3.56	1.067
2000	3.74	1.494
2500	3.89	1.944
3000	4.04	2.422
3500	4.17	2.920
4000	4.30	3.442

3.1.1.5 High speed, high current pulsed driver circuit [5]

The final literary source that was reviewed is a patent on a pulsed LED driver, by Sandia Corporation. This patent is a more advanced version of the goal of this project. It is the driver for an array of LEDs similar to what we are looking to do, however these leds are larger than what we are looking to use. This system is also much more complex than this project needs, essentially there is much more digital control involved within this system. Another interesting aspect of this system is that it uses large capacitor banks to supply the power to the system. Figure X shows the control circuit and Figure X shows another example circuit within the patent.

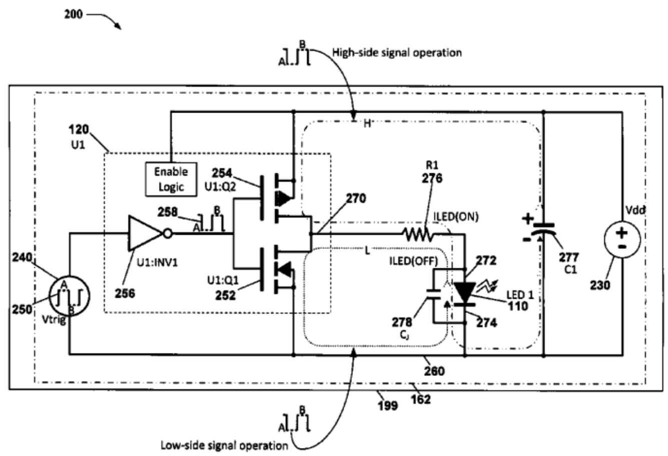


Figure 6: Patent Circuit controller [5]

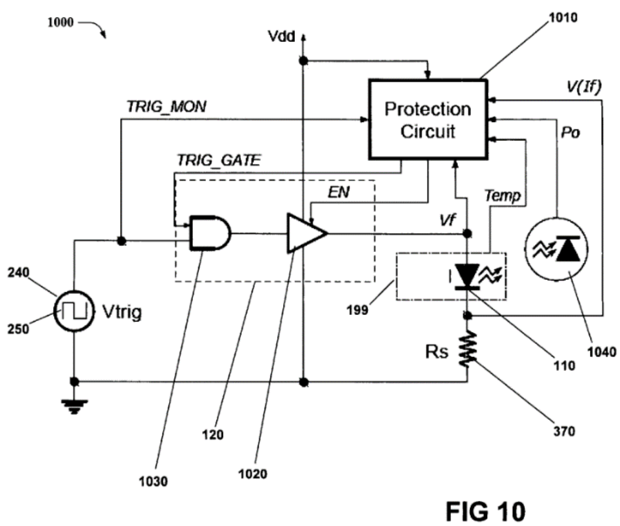


Figure 7: PatentCircuit [5]

3.1.2 Student 2(Gavynn Breed)

This literature review contains the information and aspects of an LED and how it can be incorporated into the system. The LED's in the system need to have a high illumination for the flow tracking, must be able to handle pulses at high rates, be placed in a certain array for collimating particles, not be overdriven to the point of destruction, and every color must be separate from one another.

The basis of using RGB LEDS is to use it for measuring fluid flow in a system. In depth "In a backlit configuration, liquid droplets appear as shadows in each color channel" , which allows for "Color reversal and color cross-talk correction yield a series of three frozen-flow images that can be used for further analysis" [1]. This shows that droplet velocity can be measured with particle tracking to show exactly how a fluid is flowing with the reflection of the colors.

The five articles helped the team understand how the LED system needs to be set up and what will need to be done for it to work.

3.1.2.1 Multi-Pulse [6]

This article particularly explains the use of the LEDS and how they were set up to measure each color's frozen pictures for particle velocity. The illumination of the particles is very important. Since the colors need to be alternated "each color's pulse duration and the delay between the pulses were independently adjusted with a digital delay generator" [6]. This will be very important towards the success of the project. This can be done with coding so we are not receiving mixtures in the light sources being outputted. This article also gives information on the maximum power for operation of LEDs. The article says "The maximum power used to operate LEDs is limited by the mean energy dissipation in the device" [6]. The mean energy dissipation is how much of that energy going into the device is being lost to the surroundings. This is basically used to calculate the efficiency of how much energy is going to be transferred to light and how much is going into the surroundings such as heat. The article provides information on how one can put more power into their LEDs without them being affected. To do this the LEDs can be put into a "pulsed" mode [6]. A pulsed mode is when the LEDs are turned on and off in quick succession, instead of being continuously run. One good note to have is that the green diode will need to be driven in longer pulses to achieve the same per-pulse output as the red and blue diodes [6].

3.1.2.2 High-power LED [7]

This article describes what light sources are available for multi-led emitters and the light projection from each color. The systems using the LEDs are mainly designed for surface emitters with constant intensity distribution per unit area. To do this it is achieved through " photonic lattice bonded to the surface of the emitter which channels the light through micron-sized, surface-normal holes" [7]. This means that the system is able to collimate particles more easily. This can be useful towards the project, just in case our particles are not collimating effectively. In this article it provides information on relative LED-radiant power distribution as seen in figure one.

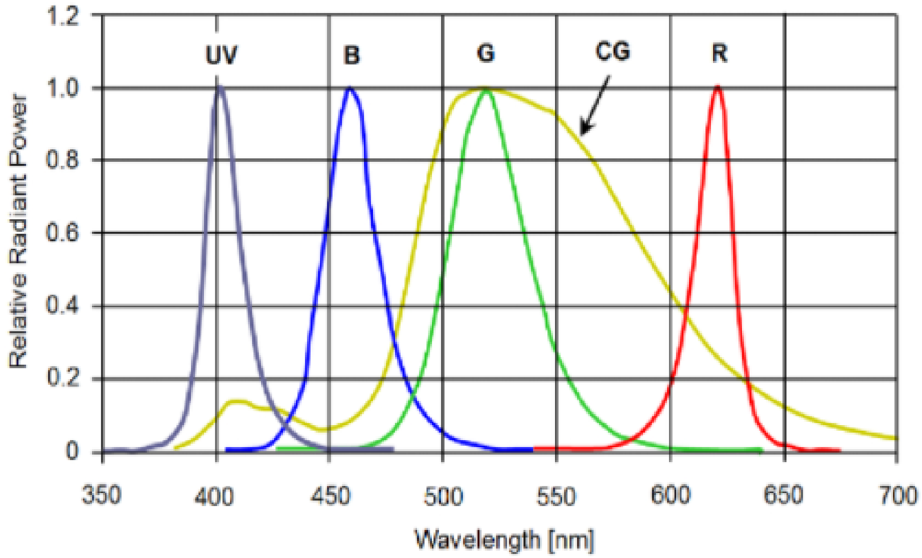


Figure 8: Relative LED-radiant power distribution [7]

This graph shows the wavelengths of each color compared to radiant power. This is important for the team to realize at what wavelengths the light gives off more power. This can help us decide the pulses for each color. This article also provides information of how the nominal operating current can be exceeded when used with a pulsed current. As shown in figure the LED pulse current in amps exceeds the max CW current when run in a pulsed operation.

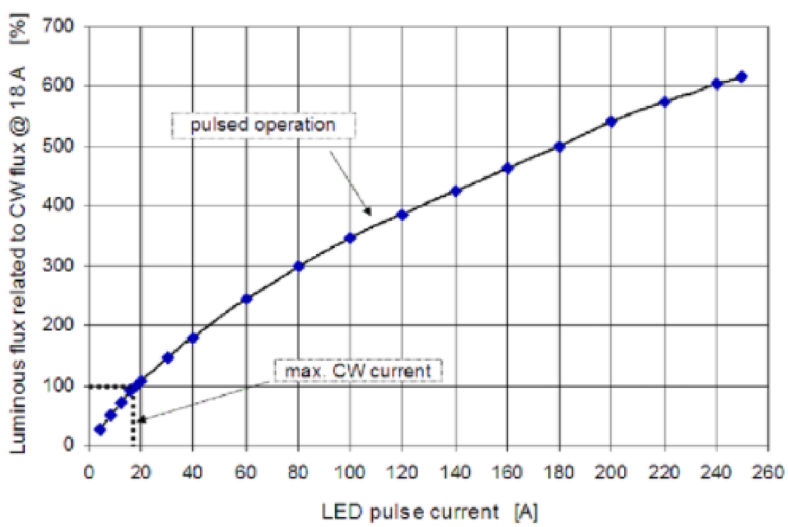


Figure 9: CW vs Amps [7]

3.1.2.3 Performing Calibration [8]

The main information taken from this article is the information provided about the RGB light-emitting diode. To get a better light illumination a huge number of LEDs are required [8]. Using the data from the article we can determine how many LEDs the team might need for the illumination scaled down to the size of the control that is going to be illuminated. This article also shares the importance of the different light sources. Different fluids being measured will require different wavelengths. The article also describes how the light intensity of the LEDs is more useful for measurement. The article explains “spectral width, which is defined as the wavelength range that presents an emission intensity greater than/equal to 50% of the maximum value. So, wavelengths located below that threshold have a lower influence on the samples” [8]. This shows that the light intensity matters to getting accurate measurements.This is shown in figure 3.

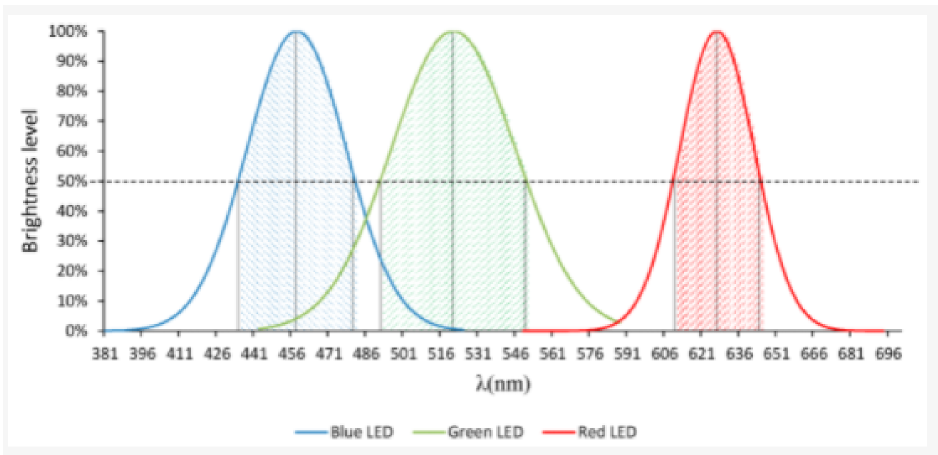


Figure 10: Intensity Vs Wavelength [8]

The information in this article will help determine how many LEDs the team can implement into the system. It also teaches how LEDs work to provide particle measurement at different wavelengths to get the right amount of light intensity for measurement of particles.

3.1.2.4 LED Color Control [9]

This article describes many benefits for light emitting diodes (LED) and how to obtain the right color for measurement, and how to set up the systems. One important factor for the project is that each light source needs to be controlled independently and also contain color mixing. When mixing colors it can be determined by ratios of each diode's light intensity and can be controlled linearly by a PMW dimming technique [9] . PMW is an abbreviation for pulse-width modulation, which changes the cycle of the diodes and will adjust the current proportionally. This article provides a block diagram to show how a system could be set up to control each diode as seen in figure 4.

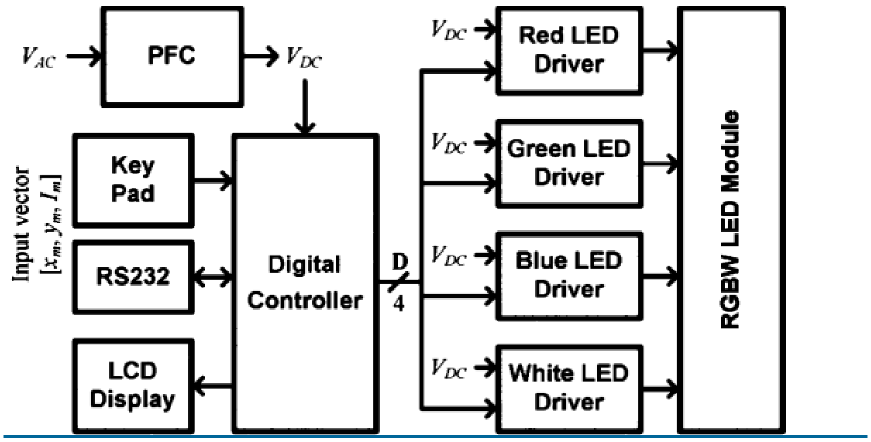


Figure 11: color controllable LED System [9]

The team also needs to know how to set up the color temperature and illuminance so that our system gives off the desirable amount of light from the diodes. The color mixing theory is important to determine the relationship between each LED. Color mixing theory is " the chromaticity coordinate of the mixed light is a weighted linear combination of the individual chromaticity coordinates". The equations for discovering the values of the light sources are in the Appendix.

3.1.2.5 RGB LED Driver [10]

This article provides information on a LED driver and its technique to track the required driving voltage for LED strings to improve efficiency of the LEDs by decreasing power loss in the system. Firstly a LED driver is an electrical device whose purpose is to regulate the power output to a string of LEDs. LEDs are mainly used over lasers for lighting and backlighting due to their lifespan, efficiency, and reliability. Even though LEDs are more efficient than lasers, there are still ways to make them even more efficient. This article will talk about using adaptive driving voltage and energy-saving technique. The power loss from this technique can decrease up to 58% [10]. The article provides the layout of the technique as seen in figure 6.

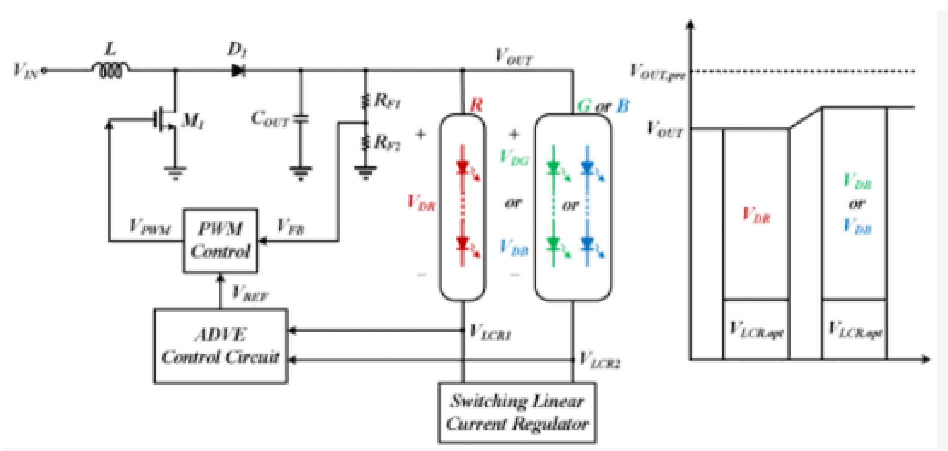


Figure 12: LED Driver (ADVE) [10]

In summary this article provides plenty of calculations that can be used for setting up the LED driver such as frequencies, voltages, and the power loss. This is important towards the project because we can create our system to be more efficient and give off less heat. The important calculations are in the appendix.

3.1.3 Student 3 (Yixiang Zhang)

This literature review clarifies TTL triggering and its application in this project. TTL trigger is a kind of Transistor-Transistor Logic, which is used for waveform transformation and converts triangular waves, sine waves and other irregular signals into rectangular pulses[11], and it is convenient for the reading of the subsequent circuit system.

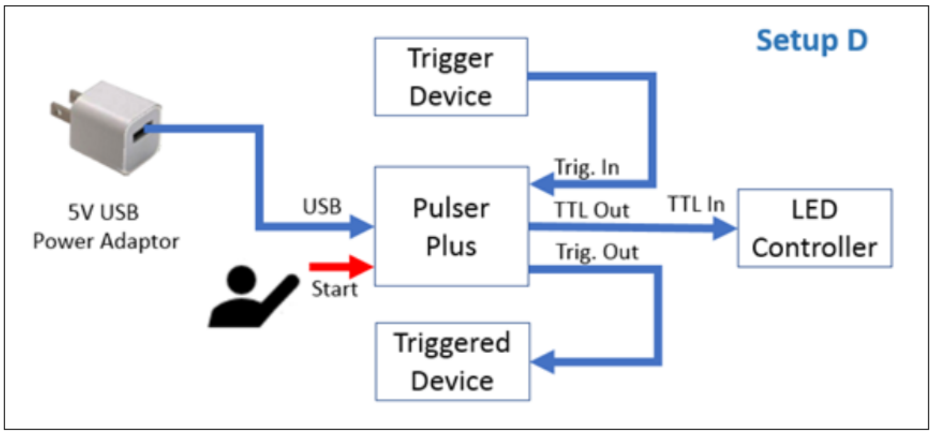


Figure 13: Manually activated trigger model[11]

3.1.3.1 TTL interface overview[12]

TTL is transistor-transistor logic, and TTL level signals are generated by TTL devices. The TTL interface is an interface that transmits data in parallel.[12] When using this interface, it is not necessary to use a dedicated interface circuit in the LED matrix, but the TTL data signal output by the main control chip of the driver board is directly transmitted to the input interface of the circuit board through the cable.

3.1.3.2 TTL output signal[12]

The TTL output interface of the driver board generally contains three types of signals: RGB data signals, clock signals and control signals.[12] To realize the reception and control of the RGB digital signal, the TTL output signal directs the RGB signal to be transmitted in order and ensures the correctness of the data transmission.

3.1.3.3 TTL Applications and Advantages[13]

The advantages of TTL include high speed, reliability, and low power.[13] Since this project requires fast pulses, low delay, and control current, TTL is suitable for use as triggers and controllers.

3.1.3.4 TTL Circuit Design[14]

The TTL circuit is composed of a series of logic gate circuits. To realize the control of excitation and pulse delay, it is necessary to integrate the time oscillation circuit, the adjustable timer and the manual gear control switch into the TTL circuit.[14]

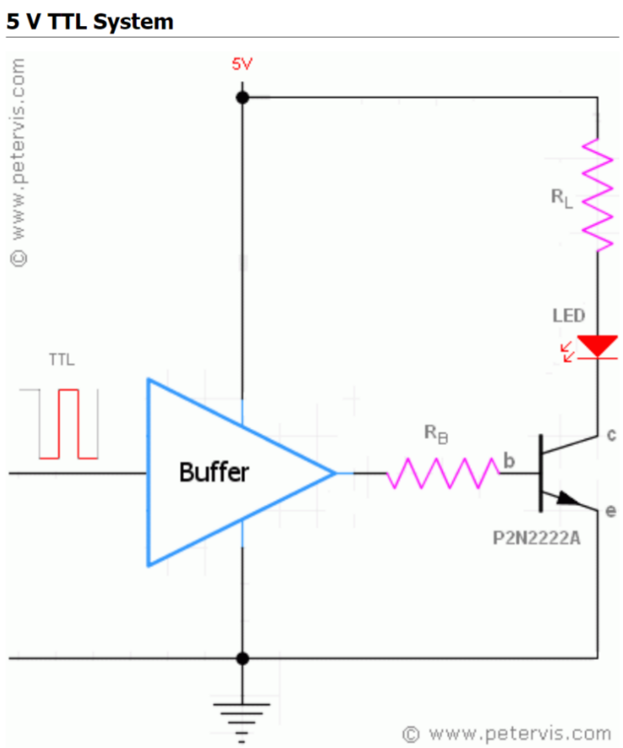


Figure 14: The TTL System for LED[15]

3.1.4 Student 4 (Hengling Zhu)

This literature review mainly focuses on the cooling system of the LED array. The temperature of an LED array is very important because the optical output and lifetime of LEDs is greatly affected by the temperature of LEDs. Also we can increase the reliability of LEDs by efficient thermal management with a cooling system.

3.1.4.1 Thermal Analysis of LED Arrays for Automotive Headlamp With a Novel Cooling System[16]

This article introduces the designed air flow cooling system, and then gives the thermal analysis between cooling systems with and without fins, how pin numbers and flow velocity affect the temperature.

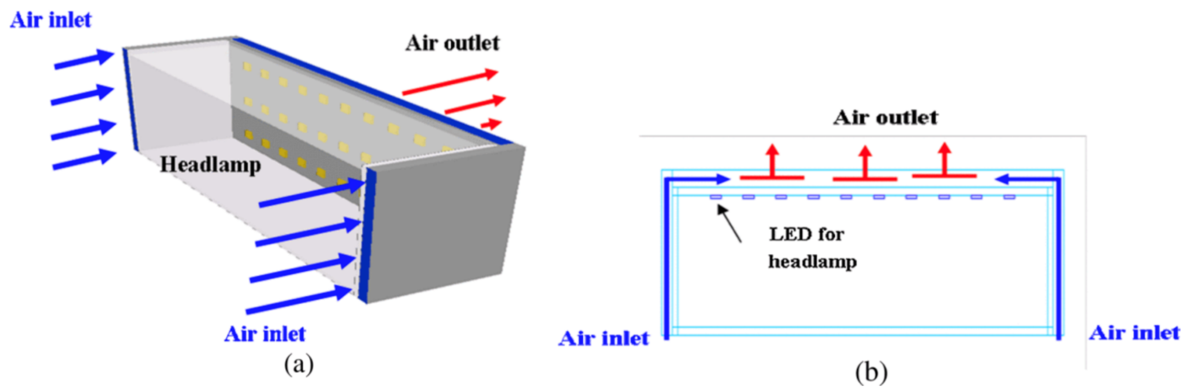
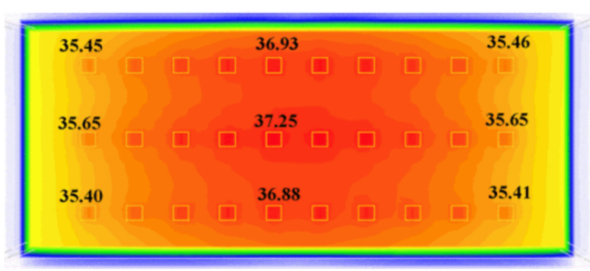


Figure 15: Isotropic View and Top View of the Air Flow Cooling System[16]



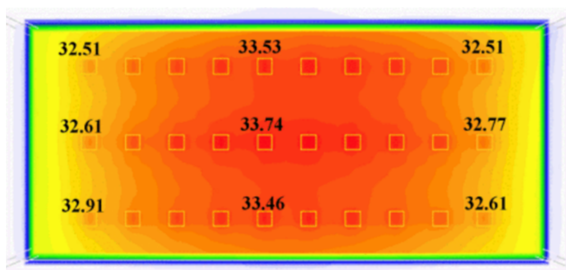


Figure 16: Temperature Distribution Without Fin[16] Figure 14: Temperature Distribution With Fins[16]

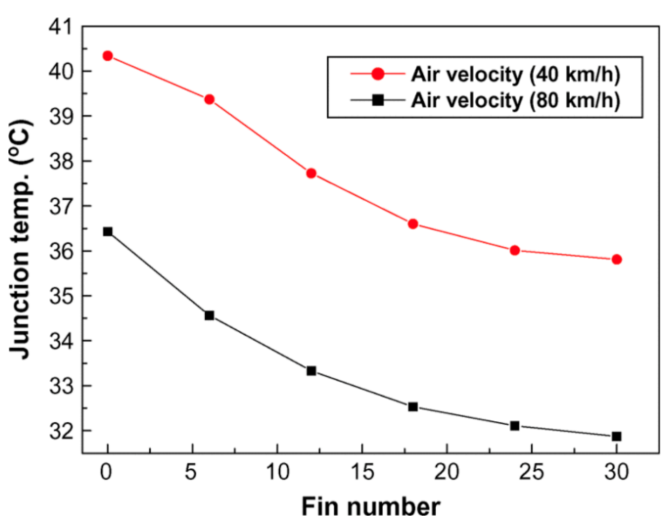


Figure 17: Temperature With Different Fin Numbers and Air Velocities[16]

The result comes out that we should try to use more fins and provide as high flow velocity as possible to keep the temperature at a low level.

3.1.4.2 A Microjet Array Cooling System for Thermal Management of High-Brightness LEDs[17]

In this paper, there is a microjet-based cooling system which is a little bit complicated because they created multiple microjets and builded a closed-loop cooling system with a micropump. They analyzed temperature with 2 different flow rates, 2 different microjet diameters, and 2 different metal shell materials.

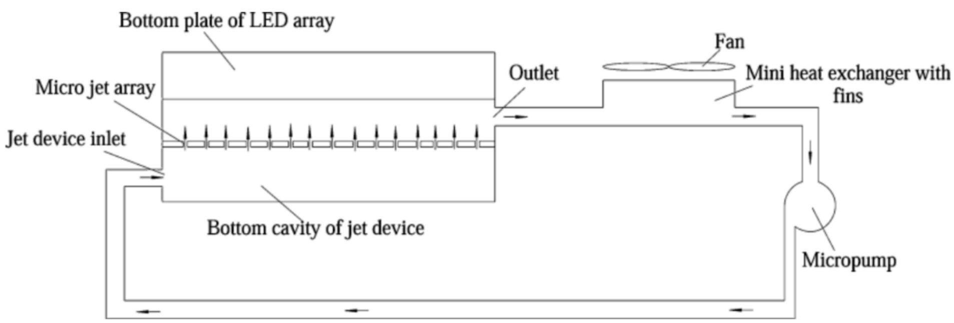


Figure 18: The Closed-loop Microjet Array Cooling System[17]

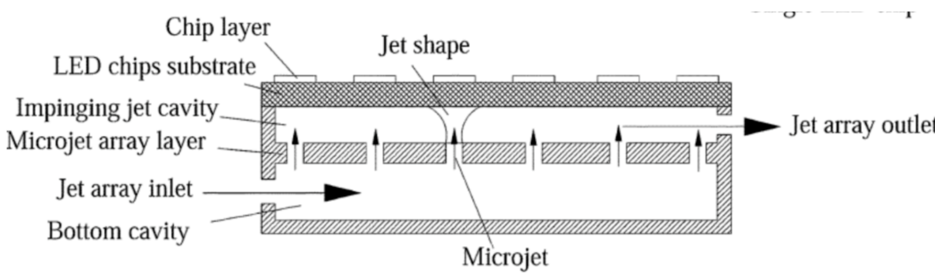


Figure 19: Detailed Microjet Design[17]

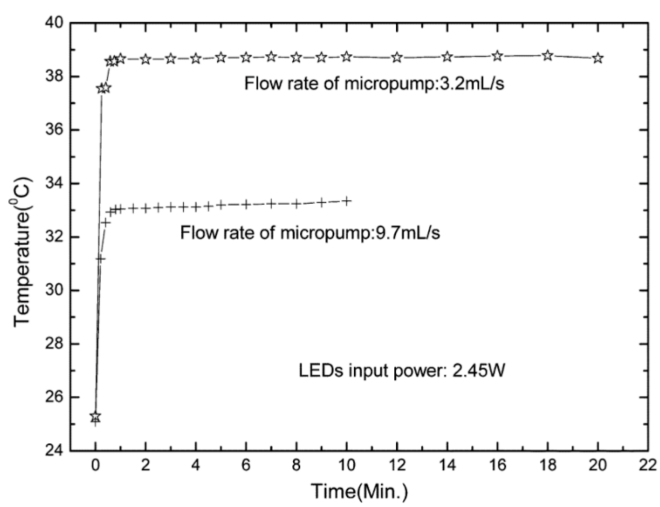


Figure 20: Temperature With Different Flow Rate[17]

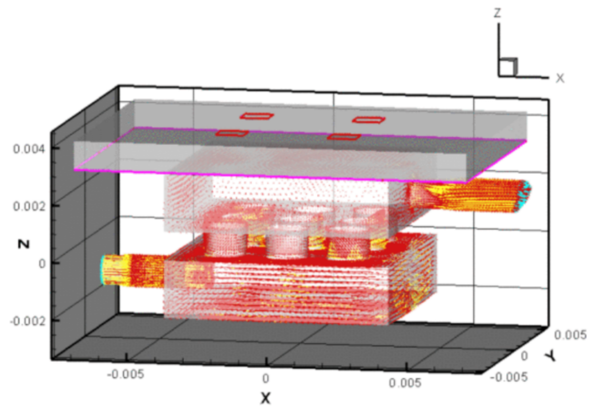


Figure 21: Flow Distribution With 1.5mm Jet Diameter[17]

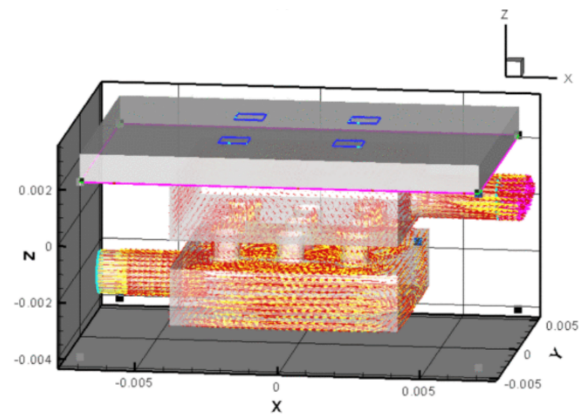


Figure 22: Flow Distribution With 1mm Jet Diameter[17]

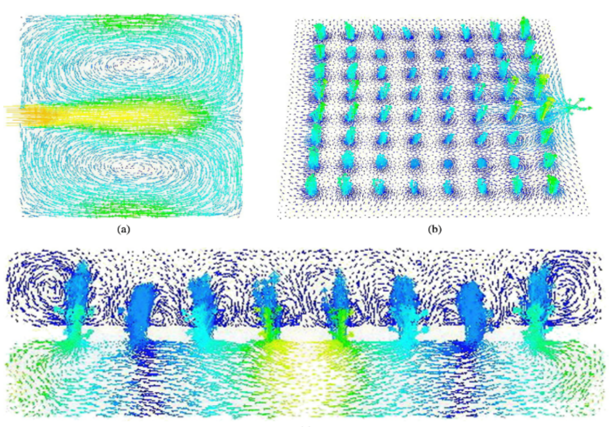
Table 5: Temperature With Different Metal Shell Materials[17]

Shell material	Maximum temperature of LED chips(℃)	Flow resistance (Pa)
Aluminum	48.63	18928.83
Copper	45.84	18493.31

The flow velocity result keeps the same with last paper that higher flow velocity comes with lower temperature. And 1mm diameter jets are stronger than 1.5mm diameter jets. Copper is the better metal material for heat transfer.

3.1.4.3 Structural optimization of a microjet based cooling system for high power LEDs[18]

The same cooling system as the last paper is used for thermal analysis because both of these papers are from the same authors and this paper is a continuation of the previous work. So, they analyzed how different inlets and outlets affect the flow temperature distributions(FTD).



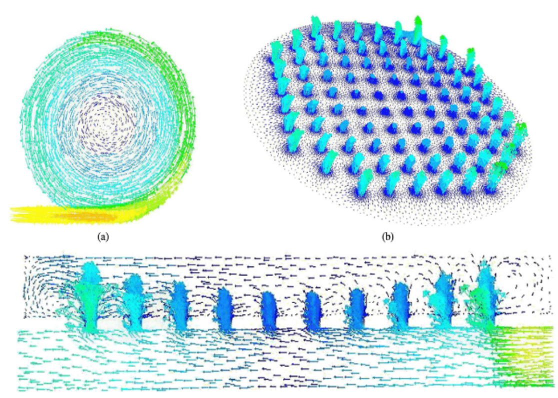


Figure 23: FTD with Rectangular Housing, Figure 24: FTD with Circular Housing,

1 MidInlet, 1 MidOutlet[18] 1 BotInlet, 1 TopOutlet[18]

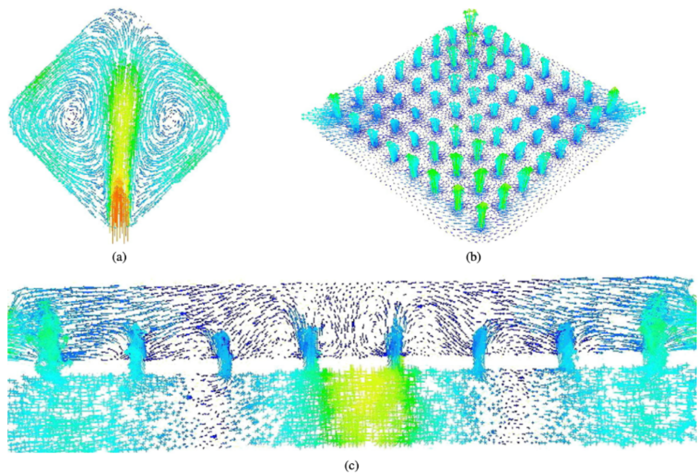


Figure 25: FTD with Rectangular Housing, 1 BotInlet, 2 TopOutlets[18]

For the closed-loop microjet cooling system, design with one inlet and two outlets can achieve the best cooling performance. More outlets may help lower down the temperature.

3.1.4.4 A microspray-based cooling system for high powered LEDs[19]

In this paper, the author used a water spray to cool the LED chip. Also compared different sprays' characteristics.

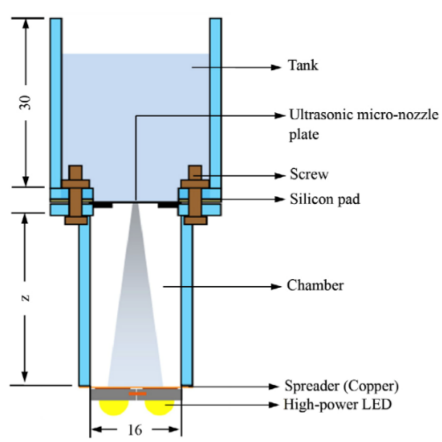


Figure 26: Water Spray Cooling System[19]

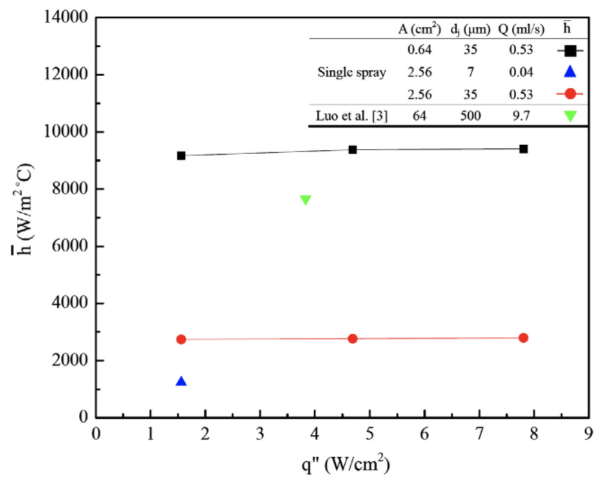


Figure 27: Heat Transfer Coefficient with Different Spray[19]

As a result, spray with a bigger diameter can cool the system better than the smaller one.

3.1.4.5 A liquid metal cooling system for the thermal management of high power LEDs[20]

In this paper, liquid metal is used as the coolant for an active cooling solution.

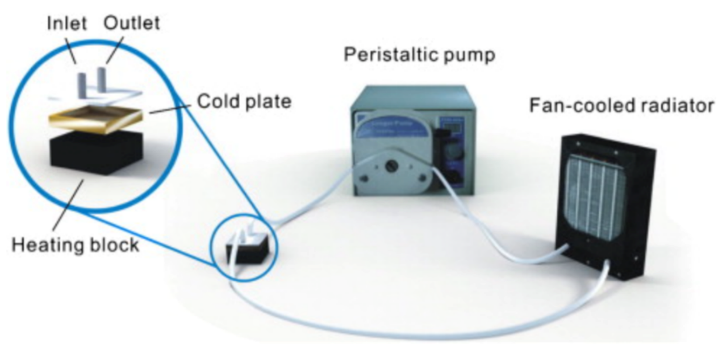


Figure 28: Liquid Metal Cooling System[20]

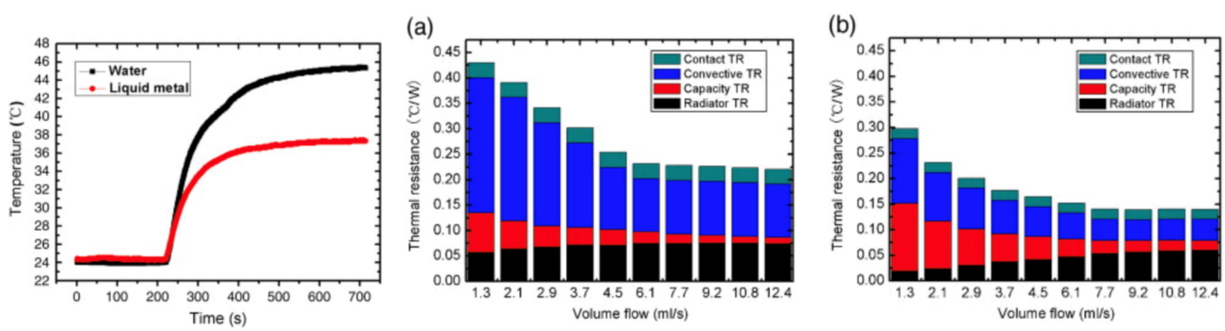


Figure 29: Liquid Metal and Water Cooling Performance with Different Flow Rate[20]

Result from the chart above is liquid metal cooling is better than water and higher flow rate, lower temperature.

3.2 *Benchmarking*

The benchmarking is generally finished online including the articles shared by Dr. Dou and Google. Existing LED arrays in the market are really similar and we are trying our best to figure out the new design and the way to create cheaper products. So, analyzing the whole system and subsystems are necessary. Basically, we decided to go through 3 different subsystems-LED housing, cooling, and circuit, which are easy to research and analyze.

3.2.1 System Level benchmarking

For system level benchmarking, documents from Dr. Dou are cited. There are totally 3 existing designs found.

3.2.1.1 Existing Design #1: A mini-LED illuminator

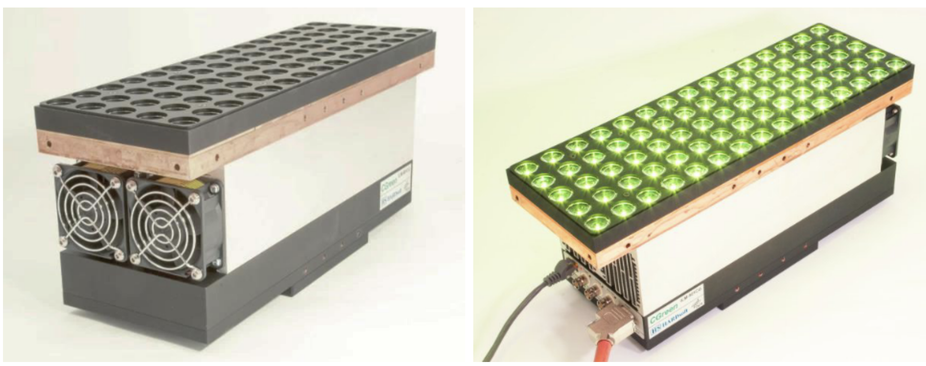


Figure 30: A mini-LED illuminator[21]

Multiple LEDs with rectangular LED housing, tight packing and metal heat sink with two fans.

Benefits:

- Carrible weight

Disadvantages:

- light intensity

3.2.1.2 Existing Design #2: A single-LED illuminator

Figure 31: A single-LED illuminator[21]

One single powerful LED with fans cooling system.
Benefits:

- Light can focus on one single point

Disadvantages:

- Irradiate areas may not be enough

3.2.1.3 Existing Design #3: LED-Flashlight 300

Figure 32: LED-Flashlight 300[22]

Similar to Existing design#1, the only difference is the position of fans.

Benefits:

- Good light intensity and enough irradiate area

Disadvantages:

- Body is too big and heavy

3.2.2 Subsystem Level Benchmarking

For detailed subsystem level benchmarking, searches from Google scholar are cited. The device is considered to design from 3 different subsystems, LED housing, cooling, and circuit. Each subsystem contains 3 existing designs. Both benefits and drawbacks of existing design are listed below for future comparison.

3.2.2.1 Subsystem #1: LED Housing

The housing of the system is what will hold the LEDs. The housing variants can change the overall light intensity, cost, durability, and assembly. This LED housing is the most important component when first trying to design a system because the rest of the system will have to complement it.

3.2.2.1.1 Existing Design #1: Rectangular

Figure 33: Rectangular LED Housing[21]

Normal packing used in the labs. Meets the light intensity requirement.

Benefits:
- Good for the size requirement
- Avoid repeated waste of light, reduce light loss and simplify the structure

Disadvantages:
- Not so good for light intensity requirement
- Less effectively reduce weight and decrease safety

3.2.2.1.2 Existing Design #2: Circular

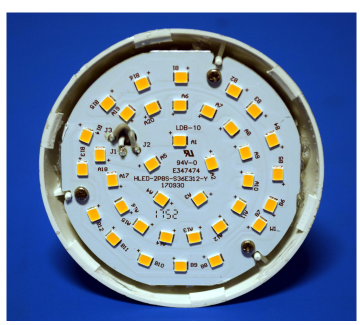


Figure 34: Circular LED Housing

The most commonly used packing for family lighting.
Benefits:
- Best light intensity
- Size requirement

Disadvantages:
- Hard to packing LEDs
- If the heat sink is not done well, it is easy to cause safety problems

3.2.2.1.3 Existing Design #3: Triangular

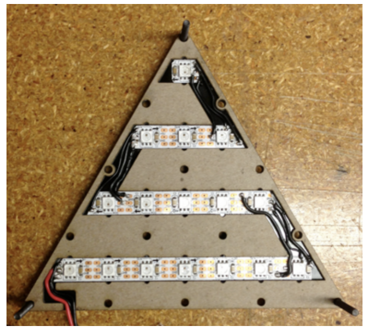


Figure 35: Triangular LED Housing

Weird housing which may attract people's attention.
Benefits:
- The triangle LED housing has an attractive shape, which is charmful
- Screen utilization is greatly improved

Disadvantages:
- The triangle LED housing will have some limitations in shape condition
- Limited by the honeycomb arrangement of pixels, the dot pitch cannot be too small
- Software writing is also more troublesome.

3.2.2.2 Subsystem #2: Cooling

The cooling of the system is a top priority. The system will need to be cooled or the LEDs can overheat and cause damage to the overall system. These cooling components will be mainly used to cool the heat sink if needed. This subsystem will only be needed in the final design if the heat sink doesn't fulfill its job.

3.2.2.2.1 Existing Design #1: Fans

Figure 36: Cooling fans[21]

Most commonly used cooling method.
Benefits:
- No technical problem will appear

- Cost is lower than other cooling systems
- Don't need much maintenance
- Easy to set and safe

Disadvantages:

- Cooling performance is not so impressive
- The use of many fans may produce louder noise

3.2.2.2.2 Existing Design #2: Water Spray

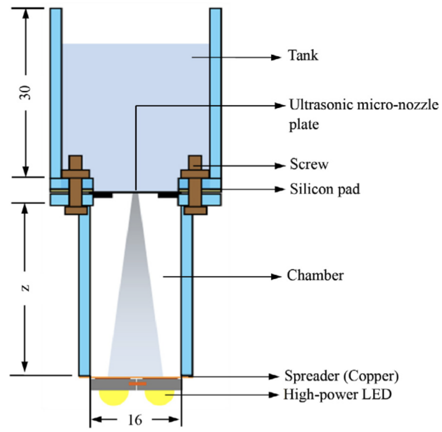


Figure 37: Water Spray Cooling[19]

Strange way to cool with water spray.

Benefits:

- Cooling fast

Disadvantages:

- Not safe because leakage can cause huge safety problems
- Complex to build and heavy maintenance because of rust

3.2.2.2.3 Existing Design #3: Liquid Meta

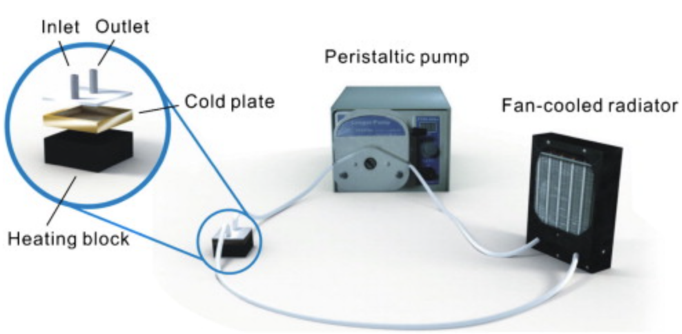


Figure 38: Liquid Metal Cooling[20]

Using liquid metal to cool.

Benefits:

- Leakage won't cause big safety problems

- Higher thermal efficiency than water

Disadvantages:

- Liquid metal may be unstable at times.
- It is hard to get liquid metal, so it may be expensive.

3.2.2.3 Subsystem #3: Circuit

The circuit subsystem focuses on the design of the circuit powering the LEDs, the minimum requirement for this subsystem is for the TTL control system to control the pulse width modulation for the LEDs.

3.2.2.3.1 Existing Design #1: Generate High Current Pulse Circuit

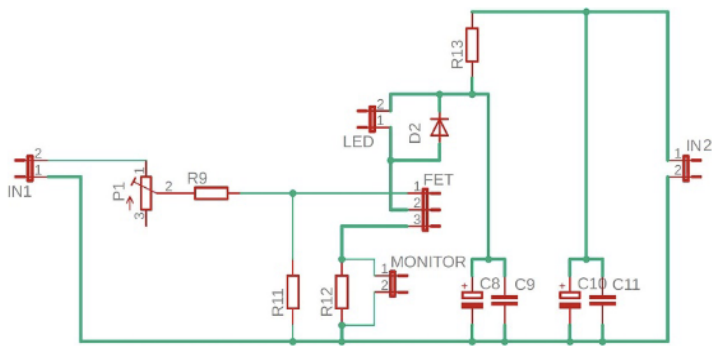


Figure 39: Generate High Current Pulse Circuit [23]

The high current pulse circuit controls a single LED, it has 2 inputs one being a control input and the other being a voltage source. The circuit also contains a capacitor bank to ensure steady flow within the circuit. Finally there is a serial monitor built into the circuit to view it in real time. This circuit has the advantage of being easily analyzed while it's running, however is much more complex than the other designs. It also only supports a single LED operating at high voltages.

3.2.2.3.2 Existing Design #2: Flow Velocimetry Circuit

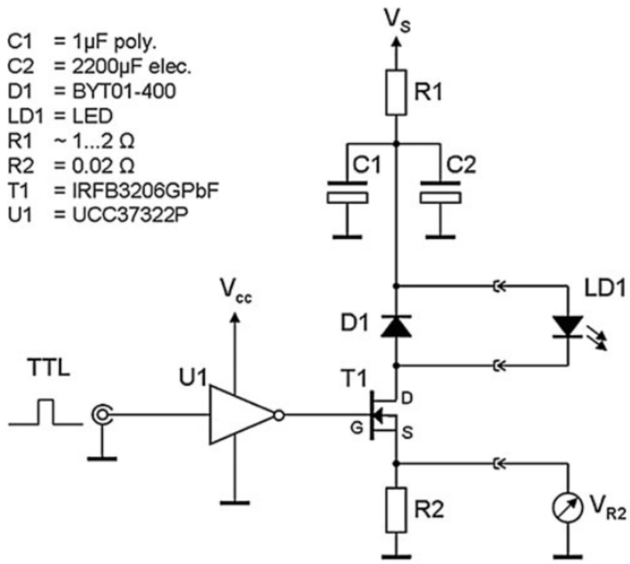


Figure 40: Flow Velocimetry Circuit [2]

As mentioned in the literature review above the Flow Velocimetry Circuit pulses a single LED which has its light converted into a single plane of light. The circuit is controlled by a TTL input signal to a gate enabling and disabling the flow from a voltage source that is kept constant by a capacitor bank. While this circuit is easier to manufacture than the one above it suffers from the same problem that it supports only a single LED. Another Benefit is that the circuit accepts a TTL control input.

3.2.2.3.3 Existing Design #3: Water Tank Circuit

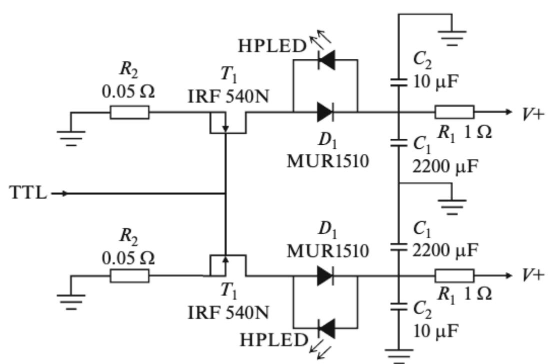


Figure 41: Water Tank Circuit [3]

The final benchmarking circuit was also taken from the literature reviews above. The Water Tank Circuit has the advantage of running 2 LEDs in parallel. It also uses a capacitor bank to keep the voltage source constant. Finally it uses a TTL input signal into two gates to enable the circuit and power the LEDs. While this design is slightly more complex than the Flow Velocimetry Circuit it enables multiple LEDs in parallel, a requirement of this project.

4 Concept Generation

Chapter 4 contains five subsystem concepts and 3 full system concepts selected by pugh chart from full 8 concept variants. Both advantages and disadvantages of each subsystem and system are listed. The subsystem concepts were put into a morphological matrix from which the 8 full concept variants were derived.

4.1 Full System Concepts

Chapter 4 contains five subsystem concepts and 3 full system concepts selected by pugh chart from full 8 concept variants. Both advantages and disadvantages of each subsystem and system are listed. The subsystem concepts were put into a morphological matrix from which the 8 full concept variants were derived.

4.1.1 Full System Design #1: Concept Variant 1

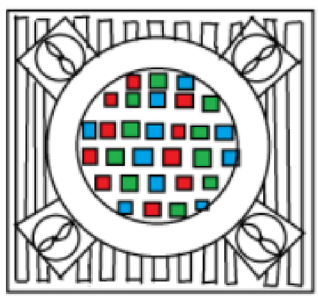


Figure 42: Concept Variant 1

This design is a circular housing with tightly packed LEDs, four medium size fans under a rectangular fin copper heat sink. The LEDs in this system all use the RGB LED chips.These chips allow the team not to worry about the set up of the colors since they contain all of the colors. The circular housing is good for light intensity and directing light such as a flashlight uses circular housing. The downside of circular housing is that it is more expensive to manufacture and the difficulty of manufacturing is a lot harder than rectangular. The LEDs were tightly packed. The four medium sized fans will cool off most of the area under the copper heatsink. The copper heatsink uses rectangular fins because they are more useful than the pin fins when it comes to this set up. No coolant system was needed because the heatsink and fans were assumed to be enough.
Benefits:

- Stronger light intensity
- Good cooling system

Disadvantages:

- Manufacturing cost
- Manufacturing
- Assembly

4.1.2 Full System Design #2: Concept Variant 5

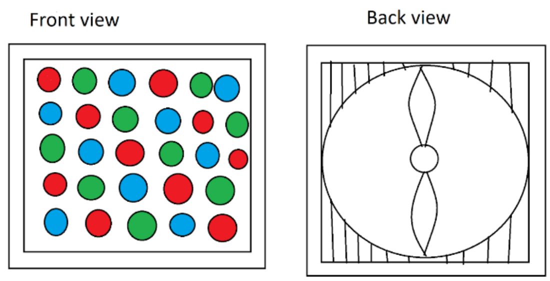


Figure 43: Concept Variant 5

This design is a rectangular housing with loosely packed LEDs, rectangular copper heat sink with one large fan. The rectangular housing is good for light intensity, but the loose packing is not, so the light intensity isn't so good. Both rectangular housing and loose packing make the size of this design large. The large fan cannot cover everywhere, so the cooling performance is bad.

Benefits:

- Easy manufacturing
- Lower manufacturing cost
- Durability

Disadvantages:

- Cooling performance
- Size
- Bad light intensity

4.1.3 Full System Design #3: Concept Variant 8

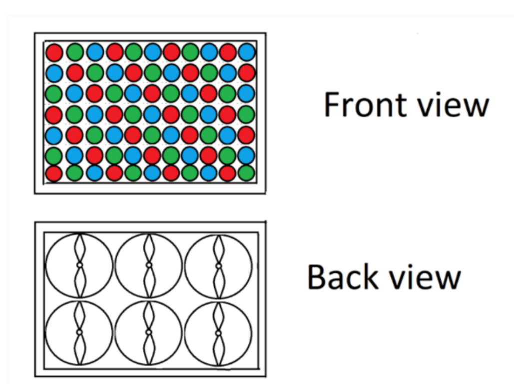


Figure 44: Concept Variant 8

This design is a rectangular housing with tightly packed LEDs, rectangular copper heat sink with many fans. Both rectangular and tight packing are good for light intensity, so the light intensity of this design is over average level. The size of this design will not be too large since tight LED packing is applied. Many fans are able to cool the copper heat sink very fast, so the cooling performance is good.

Benefits:

- Easier manufacturing
- Manufacturing cost low
- Light intensity good

Disadvantages:

- Harder to assemble more fans
- Lower durability

4.2 Subsystem Concepts

4.2.1 Subsystem #1: LED Housing

The housing of the system is what will hold the LEDs. The housing variants can change the overall light intensity, cost, durability, and assembly. This LED housing is the most important component when first trying to design a system because the rest of the system will have to complement it.

4.2.1.1 Design #1: Circular

The circular design is used in things such as light bulbs and flashlights. The circular housing although would be great for light intensity would require many manufacturing issues. Everything such as the heat sink would have to fit on it correctly.

Pros:

- Best light intensity
- Commonly used for light sources

Cons:

- Manufacturing costs
- Manufacturing difficulty

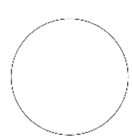


Figure 45: Circular housing

4.2.1.2 Design #2: Rectangular

The rectangular design was a design that most examples we viewed used. It has the easiest manufacturing and assembly with other equipment. The downside would be that using this type of housing would give up some light intensity.
Pros:

- Easy to manufacture
- Good light intensity

Cons:

- Size

Figure 46: Rectangular Housing

4.2.1.3 Design #3: Triangular

The triangular design was a design choice due to the variability it could bring. The triangular design would most likely include multiple of them set into a specific configuration. They could also be interchangeable.
Pros:

- Variability
- Good light intensity (multiple)

Cons:

- Hard assembly
- Poor light intensity (single)
- Cost

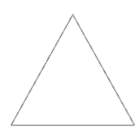


Figure 47: Triangular Housing

4.2.1.4 Design #4: Lego

The lego design would be multiple housing with each containing a single LED. The housings then will be connected together like legos. So pieces will have to be made differently for where they are placed into the system.
Pros:

- Fun
- Light intensity is descent

Cons:

- Hard assembly

- Hard manufacturing
- Need special circuitry

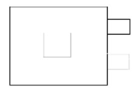


Figure 48: Lego Housing

4.2.2 Subsystem #2: Cooling

The cooling of the system is a top priority. The system will need to be cooled or the LEDs can overheat and cause damage to the overall system. These cooling components will be mainly used to cool the heat sink if needed. This subsystem will only be needed in the final design if the heat sink doesn’t fulfill its job.

4.2.2.1 Design #1: Many Small Fans

This design includes using many small fans covering all of the surface of the heatsink.
Pros:

- Good cooling area
- Easily placeable in all regions

Cons:

- Difficult assembly
- Less durable
- Higher occurrence of problems

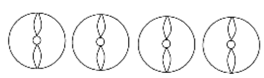


Figure 49: Many Small Fans

4.2.2.2 Design #2: Some Medium Fans

This design includes a good amount of medium sized fans that cover most areas of the heatsink.
Pros:

- Good cooling area
- Average layout over area

Cons:

- Okay assembly
- Medium durability
- Average amount of problems

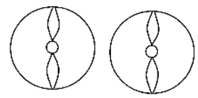


Figure 50: Some Medium Fans

4.2.2.3 Design #3: One Large Fan

This design is one large fan in the center of the system for cooling. The one fan design will not cover all of space due to circular design.
Pros:

- Durability
- Assembly
- Low amount of problems

Cons:

- Subpar cooling area

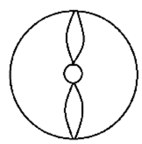


Figure 51: One Large Fan

4.2.2.4 Design #4: Coolant

Coolant would be in a system that uses a liquid to gather heat out of the heat sink, then be cooled and rerun through. This system will require a pump for the liquid of choice.
Pros:

- Excellent cooling

Cons:

- Assembly
- Cost
- Needs a pump

Figure 52: Coolant

4.2.3 Subsystem #3: Packing

The packing subsystem details the layout of LEDs that will be encased in the housing. The packing can affect the cost, light intensity,and circuitry/assembly difficulty. This is important because it will have a huge impact on the function of the design.

4.2.3.1 Design #1: Tight

Tight packing is when the LEDs are prepared closely together. There will be minimal space between them if any.
Pros:

- Excellent light intensity
- Small size

Cons:

- Cost
- Circuit set up

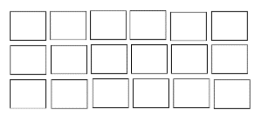


Figure 53: Tight Packing

4.2.3.2 Design #2: Loose

The loose design will have the LEDs prepared with a distance between them. This means less LEDs will be used.
Pros:

- Cost
- Easier circuitry set up.

Cons:

- Weak light intensity
- Big size

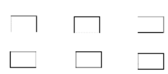


Figure 54: Loose Packing

4.2.3.3 Design #3: Bayer

The Bayer layout is a design that has been mostly used for cameras and capturing most of the light. There is more green in it because green is in the sweet spot of wavelength for measuring. LEDs will be set up this way if we only have single color LEDs.
Pros:

- Common use/it works
- Easy design layout and assembly

- Circuit setup

Cons:

- Only useful when using separate color LEDs

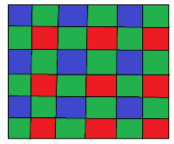


Figure 55: Bayer Pattern

4.2.3.4 Design #4: RGB Chip

This multicolored chip will include red, green,blue, and white as its light sources. This will make it easier to set up the LEDs since they won't need to be in a special arrangement.

Pros:

- Circuit set up
- Easy Assembly
- Contains all needed colors

Cons:

- N/A

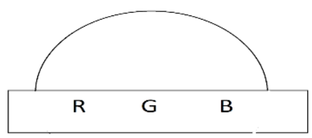


Figure 56: RGB Chip

4.2.4 Subsystem #4: Heat Sink

A passive device used to exchange heat produced by an electronic to a fluid or surrounding. This is an integral part of the system since it is what will cool the LEDs keeping them from destroying themselves. The heat sink captures the heat by being made out of a conductive material. The material that we are going to use is copper.

4.2.4.1 Design #1: Pin Fin

The pin fin heat sink uses multiple cylinders to transfer heat through the heat sink and out the end. This allows the heat to leave the system

Pros:

- Better in situations where the heat sink may be oriented in multiple orientations.
- Cost low

Cons:

- Worst in performance in most situations

Figure 57: Pin Fin

4.2.4.2 Design #2: Rectangular Fin

The rectangular fin heat sink is just like the pin fin, except it has thin rectangles that cover more area. The rectangles are parallel to each other. The rectangles reach from one end of the heat sink to the other.

Pros:

- Best performance in most situations
- Cost

Cons:

- Worst performance in multiple orientation situations.

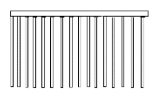


Figure 58: Rectangular Fin

4.2.4.3 Design #3: Coolant Reservoir

A coolant reservoir is a pool of liquid that the LED system would sit in. This liquid would absorb the heat out of the LED system.

Pros:

- Quick cooling

Cons:

- Safety
- Durability

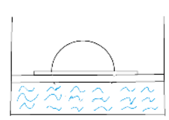


Figure 59: Coolant Reservoir

4.2.4.4 Design #4: Fins and Reservoir

This design involves having a heat sink sitting in the cooling reservoir.The heat sink will collect heat from the electrical system and then the coolant will collect the heat from the heat sink. This concept is not very reliable and more of a hypothetical to our design.

Pros:

- Best cooling

Cons:

- Cost
- Safety
- Durability

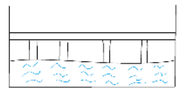


Figure 60: Fin and Reservoir

4.2.5 Subsystem #5: Circuit

The circuit subsystem focuses on the design of the circuit powering the LEDs, the minimum requirement for this subsystem is for the TTL control system to control the pulse width modulation for the LEDs.

4.2.5.1 Design #1 : Single Input Circuit

One of our clients goals is to only control the system utilizing a pulse generator, this circuit reflects that. Figure X displays a snippet of the circuit, the voltage source represents the input of the signal generator and is the only power source to the system, as such the LEDs are then directly connected to ground. All of the LEDs in a color channel are connected in parallel while each color channel is separate and controlled by an independent voltage source. The benefit of this system is the simplicity in both the design and the control. However a downside is a potential lack of power to the system. Ideally a pulse generator acts as an ideal voltage source, however if this is not the case the system may lack in current due to containing every LED in parallel.

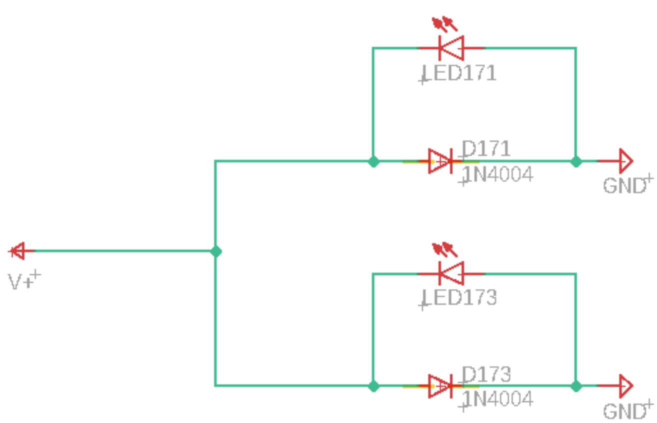


Figure 61: Single Input Circuit

4.2.5.2 Design #2: Gate Controlled Circuit

The Gate Controlled Circuit is essentially a contingency for the Single Input Circuit. This circuit has an independent voltage source that each LED is connected in parallel to. This voltage source is also connected to two capacitors to ensure a steady flow in the circuit. To control the circuit the signal generator is connected to a N-Channel Power Mosfet that functions as a gate opening and closing the circuit to ground. When the signal generator outputs a high signal the gate will open and the LEDs will turn on, when the pulse lowers it will close the circuit. This design is much more complex to manufacture and has a higher cost. It also could have limitations on speed dependent on the reset speed of the mosfet. It can however be better adjusted to the size of the system for the necessary voltage, because if the system in parallel is too large some of the LEDs can be put in series and the input voltage can be increased above 5 volts.

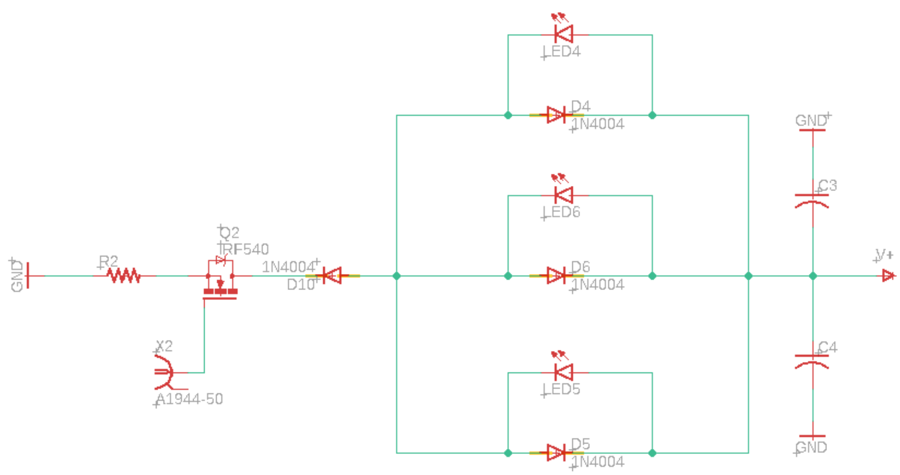


Figure 62: Gate Controlled Circuit

5 DESIGN SELECTED – First Semester

This section of the paper shows the designs that were selected in the first semester. This includes the Pugh chart, the decision matrix, the calculations, selected design, housing design, and the Circuit design.

5.1 Technical Selection Criteria:

5.1.1 Rationale for Design Selection:

5.1.1.1 Pugh Chart:

The Pugh chart is a tool that is used to rate and rank all of the concept variants. In a Pugh chart the team set a datum concept variant of choice. From that datum the other concept variants are rated with a plus, a minus, or an s. A plus being better, a minus being worse, and a s being equivalent. These ratings are based on the criteria and have values associated with them as seen in the key of the figure. The criteria of the concept variants were the cost, light intensity, durability, size, cooling performance, and safety of the system. After this criterion all of the concept variants were evaluated off of the datum. Once all of the evaluations were completed concept variant 1, concept variant 5, and concept variant 8 were chosen to be the best three designs.

Table 6: Pugh Chart

Engineering Criteria		Concept							
		1	2	3	4	5	6	7	8
1	Cost	Datum	-	-	-	+	-	-	S
2	Light Intensity		-	-	S	+	S	-	+
3	Durability		-	-	S	S	-	-	S
4	Size		-	-	-	+	-	-	+
5	Cooling Performance		+	+	+	-	+	+	S
6	Safety		+	+	+	S	+	-	S
Total -		0	4	4	2	0	3	5	0
Total +		0	2	2	2	2	2	1	2
Scores		0	-2	-2	0	2	-1	-4	2

5.1.1.2 Decision Matrix:

The decision matrix is the tool used to evaluate the best three designs from the Pugh chart. The decision matrix uses the same criteria from the Pugh chart, but instead they are weighted differently to determine what factors of the design are most important. Light intensity was the most important at 30%. Light intensity is the most important because the whole purpose of this system is based on light intensity and measuring through light reflection. Next cost and cooling performance came in second at 20%. Cost is important because the team only has a 1000$ budget. The cooling of the system is important so the system does not overheat. Third place was safety at 15%, fourth was durability at 10%, and last was size at 5%. Safety was not weighted as high because the parts of the system are not all too dangerous from one another, but still weighted decently because the system should not harm anyone. Durability is really low because most of these systems will have very similar life spans. Size is the least important because it does not affect the outcome of what the system is built to do. The criteria are then rated on a scale from one to ten. Then you multiply that raw score by the decimal point value of the percentage to get the weighted score. Weighted score is much more important than the raw score because it takes the weights of each criteria into factor. From the decision matrix it was found that concept variant 8 was the best overall design, concept variant 5 was the second best, and concept variant 1 was ranked third.

Table 7: Decision Matrix

		CV 1		CV 5		CV 8	
	Weights	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
Cost	20%	4	0.8	7	1.4	6	1.2
Light Intensity	30%	8	2.4	6	1.8	6	1.8
Durability	10%	6	0.6	7	0.7	5	0.5
Size	5%	6	0.3	8	0.4	8	0.4
Cooling Performance	20%	6	1.2	5	1	8	1.6
Safety	15%	6	0.9	6	0.9	6	0.9
Total		36	6.2	39	6.2	39	6.4
Relative rank			3		2		1

5.1.1.2.1 Size

One of the goals from our client is that the size of the array be less than that of a laptop. However since the circuit is unknown it is difficult to gauge the size of the device. As such each device was calculated to have an area of 0.5 ft^2. Since this value is the same the devices were all originally given a score of 6. Due to the rectangular designs being more modular and could potentially be stacked together to increase their size the score was raised to an 8.

5.1.1.2.2 Light Intensity

The light intensity of the device can be calculated fairly simply. The selected LEDs operate at roughly 111 Lm/W. Each system is meant to run at roughly 300 W. As such the intensity for each device can be measured with the overall lumen output. This value comes out to 33,300 Lumens. While dividing this over the area comes out to 66,600 Lumens per ft^2. However due to the shapes the light will not collimate as well in a rectangular design as in a circular design due to the greater distance between LED chips, since the light does not properly collimate the intensity won't be ; as such the circular design received a score of 8 while the rectangular designs were scored at 6.

5.1.1.2.3 Cooling

The cooling in the system is a bit tricky to calculate in depth due to the presence of a multi-finned heatsink. So, the first thing that was done was to evaluate the differences between the pin fin and the rectangular fin heatsinks. Simple calculations showed us that the surface area achieved by the rectangular heat sinks as well as their greater ease of acquisition made it the better choice. The preliminary heat transfer evaluation can be seen in Appendix F. Assuming that the LEDs have roughly 50% efficiency the heat rate generated by the system would be equivalent to 150 W. While the calculated heat transfers out of the system without considering forced air or fins is 152 W. This value is higher than the expected heat generation while not considering the cooling from the forced air flow and the fins. It however also does not consider any heat generated by the circuit itself. This shows us while the design is feasible a more in-depth heat transfer analysis must be conducted on the system as a whole once the design is further finalized.

5.1.1.2.4 Durability

Due to the designs being very similar functionally and component wise the difference in durability was mostly decided by the number of moving parts due to an increased number means there is a higher likelihood of a single part failing. Due to this CV 5 with its 6 fans scored the lowest, CV 1 with its 4 scored slightly above CV 5 and CV 8 with its singular fan was scored the highest with an 8. If the system was passively cooled it would score a 9 with the remaining point lacking incase of any electronic malfunctions.

5.2 Selected Design

through the processes mentioned above the original 8 CVs were reduced down to 2. The top design is concept variant 8 while the second best is concept variant 5. Both concept variants have many similarities with their rectangular design, copper heat sink and tight packing of the LEDs. The major difference is the size of the fans being used. Concept variant 8 uses 6 fans on the back plate while variant 6 uses a singular fan. This difference makes variant 6 easier to assemble and maintain due to a lower number of fans but because it is a singular fan there is less forced air flow moving through the system, the opposite is true of variant 8. It was decided that the increased cooling efficiency was more important as a baseline, however as seen in section 5.2.3.3. the cooling system is potentially more than potent enough for the process and later in the design stages the ease of manufacturing and assembly could be prioritized.

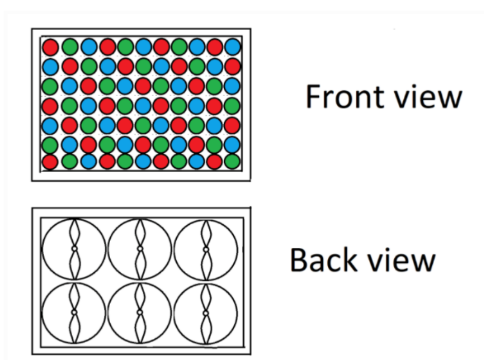


Figure 63: Final Design- CV8

5.3 Housing:

5.3.1 1st Iterations:

These two designs were the first iterations of the housing type that the team decided to go with in the first semester. Both designs are the same concept other than in figure 64 is a fitted design, and in figure 65 is a screw design. The only thing that the team knew by this time is that a multiple number of fans and a heatsink would be used for the cooling system.

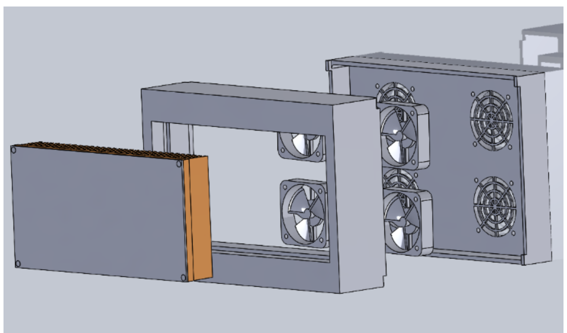


Figure 64: Fitted Design

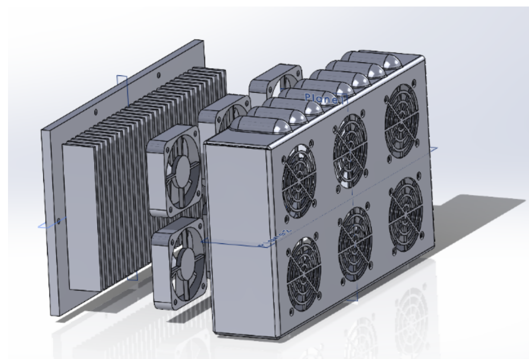


Figure 65: Screw Design

5.3.2 2nd Iteration:

This design was the final selected design of the first semester. This design utilized housing that would be purchased from McMaster. This purchased housing was 8x6x6 inches. This housing would then be modified to fit the cooling and the LED's. The front plate of the housing is what would have the LED's fit onto it while the heatsinks are attached to the backside of the plate.

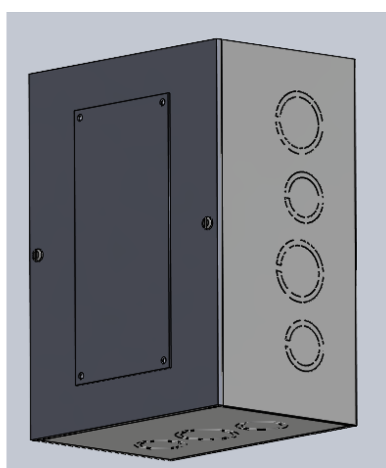


Figure 66: 2nd Iteration Housing

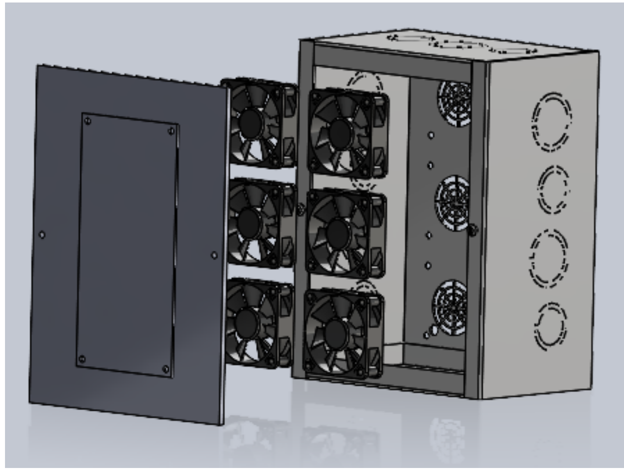


Figure 67: The Exploded Diagram of 2nd Iteration Housing

5.4 Circuit Design:

5.4.1 1st Iteration (selected): Single Input Circuit

One of our client's goals is to only control the system utilizing a pulse generator, this circuit reflects that. Figure 68 displays a snippet of the circuit, the voltage source represents the input of the signal generator and is the only power source to the system, as such the LEDs are then directly connected to ground. All of the LEDs in a color channel are connected in parallel while each color channel is separate and controlled by an independent voltage source. The benefit of this system is the simplicity in both the design and the control. However, a downside is a potential lack of power to the system. Ideally a pulse generator acts as an ideal voltage source, however if this is not the case the system may lack in current due to containing every LED in parallel.

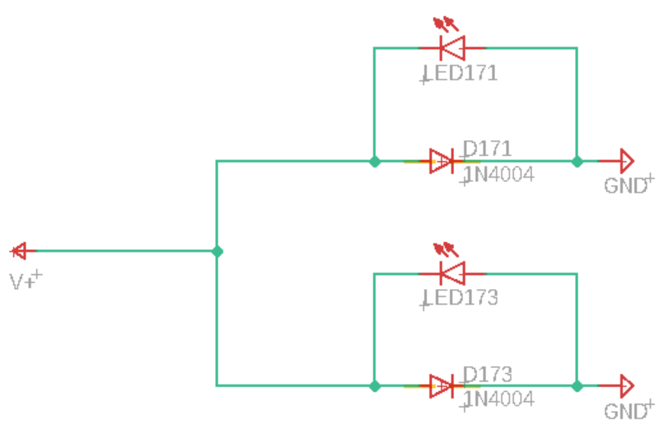


Figure 68: Single Input Circuit

5.4.2 2nd Iteration (selected) : Gate Controlled Circuit

The Gate Controlled Circuit is essentially a contingency for the Single Input Circuit. This circuit has an independent voltage source that each LED is connected in parallel to. This voltage source is also connected to two capacitors to ensure a steady flow in the circuit. To control the circuit the signal generator is connected to a N-Channel Power Mosfet that functions as a gate opening and closing the circuit to ground. When the signal generator outputs a high signal the gate will open and the LEDs will turn on, when the pulse lowers it will close the circuit. This design is much more complex to manufacture and has a higher cost. It also could have limitations on speed dependent on the reset speed of the Mosfet. It can however be better adjusted to the size of the system for the necessary voltage, because if the system in parallel is too large some of the LEDs can be put in series and the input voltage can be increased above 5 volts.

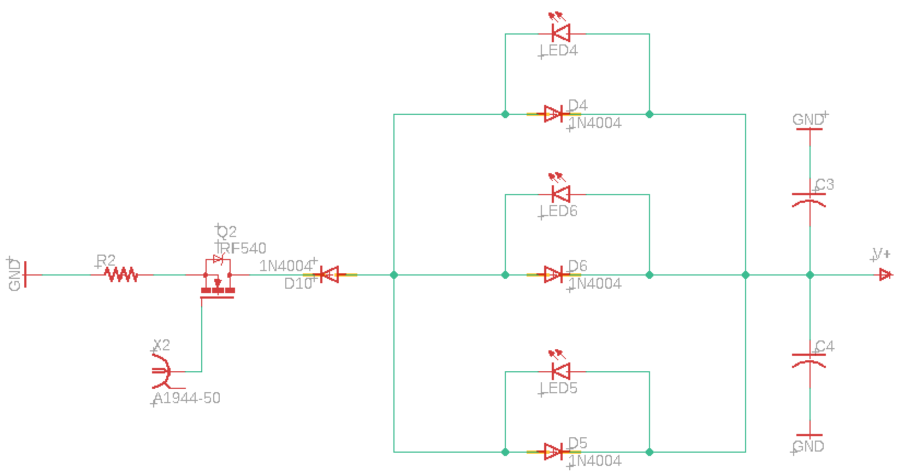


Figure 69: Gate Controlled Circuit

5.5 Prototype

After all those design selections, the team built a prototype with a circuit board and an Ardurio board connected to a computer to show how basically the project works.

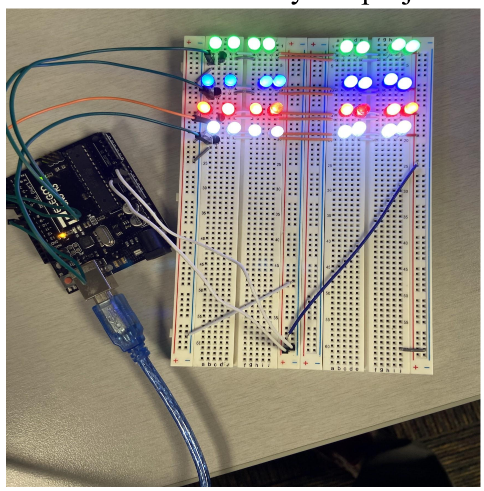


Figure 70: Prototype

6 DESIGN SELECTED - Second Semester

After the first semester our client wanted us to change our design from a constant voltage to a constant current source. This led to the team making a design that had to work with a LED controller. This second section will cover the housing, LED selection, and circuit design that went in to make these changes.

6.1 Housing:

6.1.1 3rd Iterations:

For the third iteration of the housing design the team needed mounts for the driver. The mounts will connect the Driver to the Housing and will allow the driver to be secured close to the LED's so that the wiring can be minimized. The knockouts on the purchased housing are going to be knocked out on the top and sides for ventilation. Also, A LED array and lens array were created to hold them together on the front plate. As seen in the exploded view there is still heat sinks and fans integrated into the system for cooling.

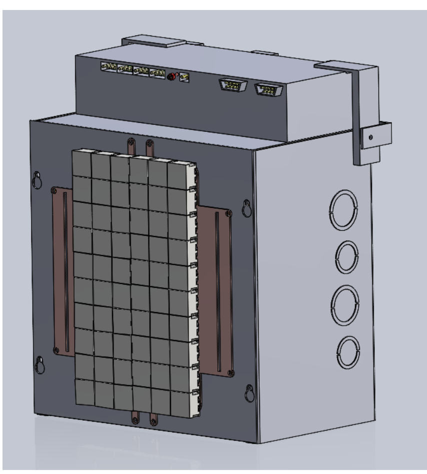


Figure 70: 3rd Iteration Housing

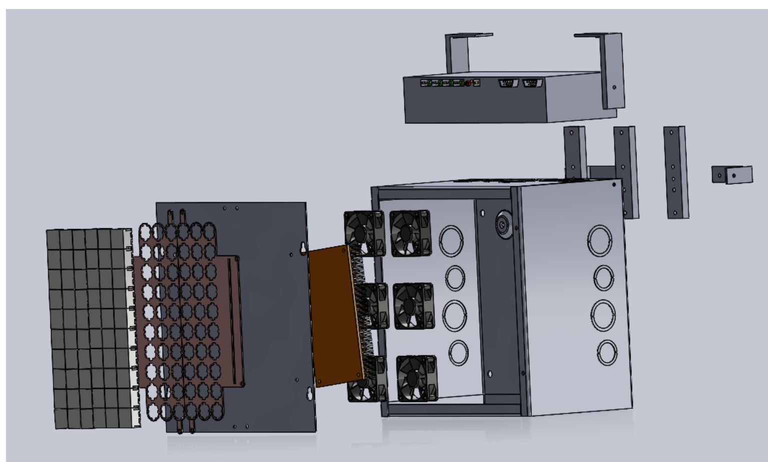
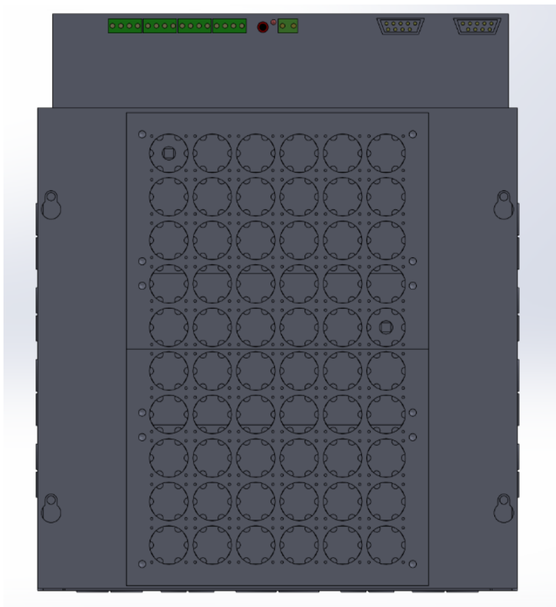


Figure 70: The Exploded Diagram of 3rd Iteration Housing

6.1.2 4th Iteration:

This was the final iteration of the Housing. This Housing design changed the bracket design into a much simpler one. This bracket design only includes the rear brackets since after manufacturing and assembling, these three rear brackets were more than sufficient. This design also included stand-offs as seen in figure 72. The stand-offs allow the lens to rest on top of the LED. Another change to this final housing was to the front plate. The front plate had a rectangular section cut out of it since the LED's are going to be resting on the heatsinks. This Housing includes the same cooling as the first iterations.



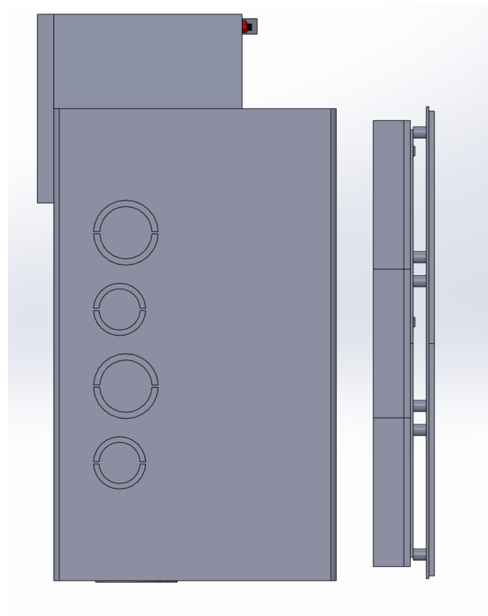


Figure 71: The Front Plane of 4th Iteration Figure 72: The Side Plane of 4th Iteration Housing

6.2 LED Selection

The LED selected was the Cree X-Lamp XM-L. This LED was selected because it is a small surface mounted LED that has a high efficacy. The small size of the LED allows for tight packing which was one of the team's design choices. The area of a LED is 25mm^2. The LED had up to 111 Lm/W which is a very efficient and illuminating LED for its size. Also, these LED's had all three-color channels which met a customer requirement.

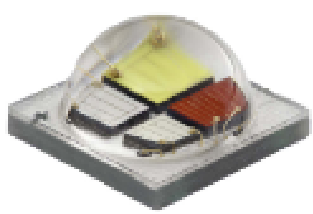


Figure 73: Cree X-Lamp XM-L LED[26]

6.3 *Circuit Design*

6.3.1 3rd Iteration:

The acquisition of an LED driver during the second semester made the team rethink how we were approaching the circuit design. There was no longer a need for control gates, or current determining resistors. The driver took care of both of these problems. As such the circuit design was simplified. Instead the team had to focus on how to arrange the LEDs between the different output channels to maximize the number of LEDs present as well as the current they are receiving. This design process was done mostly through a long series of simulations in Autodesk Eagle, a circuit design and SPICE program. The results from this simulation resulted in the circuit design in figure 74. This design contains 60 LEDs. Split up between the 8 driver channels, 2 for each color. The Output of each channel powers 10 parallel strings of 3 LED diodes

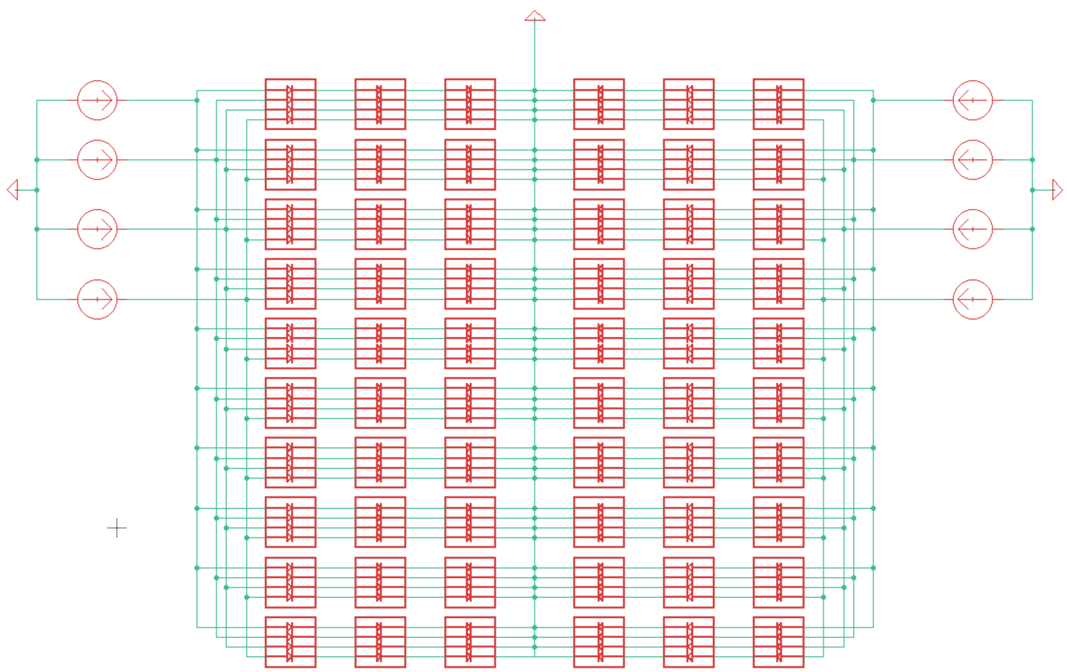


Figure 74. Overall Circuit Design

7 PROJECT MANAGEMENT – Second Semester

7.1 Gantt Chart

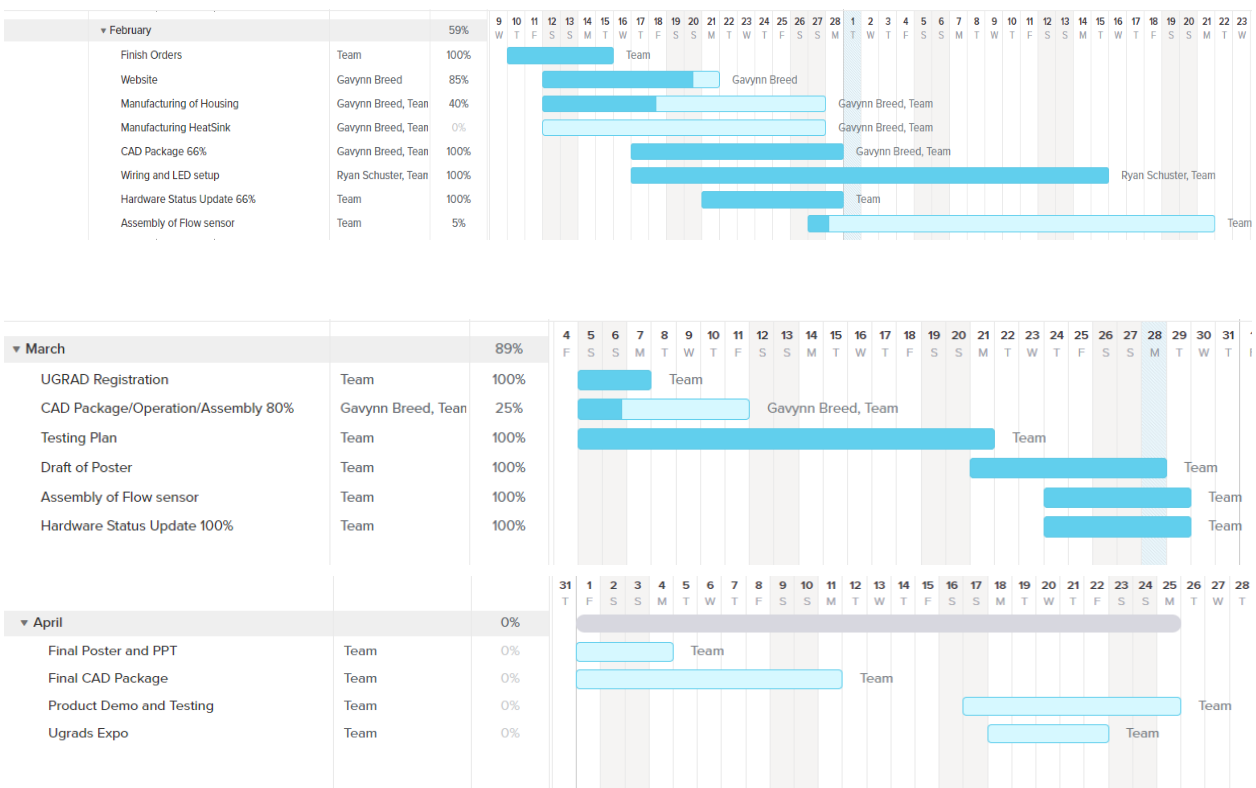


Figure 75: Gantt Chart for the second semester

Our progress at the beginning of the semester was slow, at 33% presentation, we were just getting the material, and the manufacturing process was behind. By March, we ramped up the manufacturing process and caught up to 66% of the overall process. At the end of March, we were 100% on time and started testing. At the end of April, we completed the test, CAD model and UGRADS on time. We can do better in February, although the material doesn't arrive until the fourth week of February.

7.2 Purchasing Plan

The total project budget is expected to be $1000, but the actual cost is $1005.53. The LED chips are the core original that costs $320, its selection and cost have not changed, and the delivery time is also within the estimated time. The LED holders were originally used to fix the LED chips, but during the actual installation process, the team found that the LED holders took up the space of the wires connecting the LED chips, so the LED holders changed, and the team used 3D printing models to solve this problem. The LED holders and lens are purchased together, the budget for this part is $199.Regarding the purchase of the heat sink, this part has undergone major changes, the team originally purchased a heatsink, but its arrival was delayed so long that it affected the manufacturing process, the team decided to replace it with an aluminum plate. Tests have proven it to be equally reliable. Fans, housing, screws and power all arrived on time with no changes.Heatsink is an unused part of all purchases. The reason for the over-budget is that we have not properly connected fund management with heat transfer analysis. We later found out that the temperature requirements could be met with aluminum plates. This is where we need to improve.

Table 8: Bill of Material

No.	Qt.	Name	Function	Obtained From	Cost	Make/Buy	Primary Vender	Manufacturer	Part Status
1	60	LED Chip	Convert the electrical energy into light	Cree LED	$320	Buy	eBay	Cree	Delivered
2	2	LED Holder	Hold LEDs	3D-printer	$0	Make	N/A	Ryan	Manufactured
3	60	LED Lens	Take the light beam in	www.mouser.com	$199	Buy	Mouser	Ledil	Delivered
4	2	Lens Holder	Holds the Lens to the LED	3D-printer	$0.00	Make	N/A	Ryan	Manufactured
5	1	Aluminum Plate	Acts as a backplate for the LEDs and disperses heat	Owned	$0	-	-	-	Obtained
6	6	Fan	Push air and keep cooling	www.mcmaster.com/1939K46/	$145	Buy	McMaster	McMaster	Delivered
7	1	Housing	Holds the system together	www.mcmaster.com/75065K12/	$32	Buy	McMaster	McMaster	Delivered
8	28	Screws	Holds together housing assemblies	Undetermined	$10	Buy	-	-	Obtained
9	1	Power Supply	Power system	Undetermined	$300.00	Buy	-	Meanwell	Delivered
Total Budget ($1000)					$1,005.53				

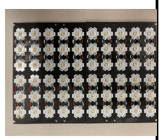
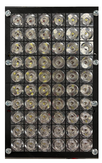
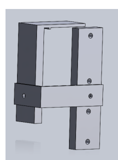
7.3 Manufacturing Plan

Actual manufacturing plan that was implemented. Place an image of your BOM manufactured items with details (when, from where, how much, etc). Describe everything and then reflect on how your actual is different from the original one that you created at the beginning of the semester. What could you have done better?

For the Manufacturing plan there were five main parts that needed to be manufactured. The first being the housing. The cost of the housing was 32 U.S. dollars from McMaster. As seen in the design selected section from above, the housing needed to be modified. For the knockouts on the housing a flathead screwdriver and a hammer were used to remove the knockouts on the top and the sides. The knockout holes are mainly used for ventilation. Then the next step was to drill out a hole for the wiring on top of the housing. A step bit was used for the drilling of this hole. Then the top and bottom part of the housing that the front plate rests on needed to be removed to fit the heatsinks. To do this the tool used were shears. Then holes needed to be drilled for the BNC ports on the side of the housing. A step bit was also used for this to get the right size hole. Then the housing was set up to a drill press after center holes were drilled for the fan placement on the Vertical Mill. Then a holesaw was set in the drill and used. This caused a lot of rattling since the housing is thinner. This process can be seen in figure 75 of Ryan. Then the srewholes needed to be drilled so the fans could be attached to the housing. To do this the Housing was set up to the vertical mill. To do this L clamps and staircases were used. Once set up, edgefinders were used to find the origin. After this a drawing was referenced and the vertical mills x.y.z axis tracker was utilized to find the right places for the screw holes. For the front plate an angle grinder was used to cut out a rectangular hole. This is meant so that the LED's could rest on the heat sink. Then since the housing was already set-up on the mill screw holes were drilled for the Brackets. This process can be seen in figure 75 of Gavynn. Then that front plate was set up to the vertical mill. The front plate could not fit in the vice so it was set up on top of a piece of wood that was clamped while using staircases. A staircase is a tool used to be able to position clamps in special ways. This time edgefinders were not used since the placement of the holes were already found and punched. Then using the smallest bit they were drilled. Fillers were then used on anything that might be sharp and could potentially harm a user.

For the heatsink the team was going to drill holes on the vertical mill. Instead the team used an aluminum plate instead. For this we placed the array over the plate and punched the places into the plate. Then using a hand drill and having the plate hang over the edge of a table we drilled the screw holes. For the Lens Array it was made in solidworks, and then 3d-printed. Then the Lens fitted into the array. For the LED Array it was also made in solidworks and the 3d-printed. Then the LED's fitted into the array. Then wiring needed to be soldered from LED to LED. Then lastly the three back brackets were made from scraps found in a student bucket of material. The brackets started as thicker pieces of aluminum scrap. They were then cut down to a smaller size using the horizontal band saw. Then the brackets get placed into the vice on the vertical mill. Then edgefinders are used to find the origin of the left bottom corner. Then end mills, and shell mills are utilized to shave off any more excess material. Then using a drawing and the mills x,y,z capabilities screw holes are made.

Table 9: Manufacturing Plan

No.	Part Name	Picture	Who	When and Time	Raw Material	Where
1	Housing		Gavynn, Ryan	2/27/22 - 3/13/22 7 hours	Powder Coated Steel	The Machine Shop
2	LED with LED holder		Ryan Yixiang Hengling	02/27/22 5 hours	Wires and PLA	EGR 108
3	Lens with lens holder		Ryan,	02/20/22 30 minutes	PLA	EGR 108
4	Brackets		Gavynn	2/27/22-3/13/22 5 hours	Aluminum	The Machine Shop

This table shows the part number, part name, a photograph, the time completed, the material, and place of manufacturing. This table is just a simplified version of the manufacturing plan/process.

Figure 75: Manufacturing Process of the Housing and Front Plate

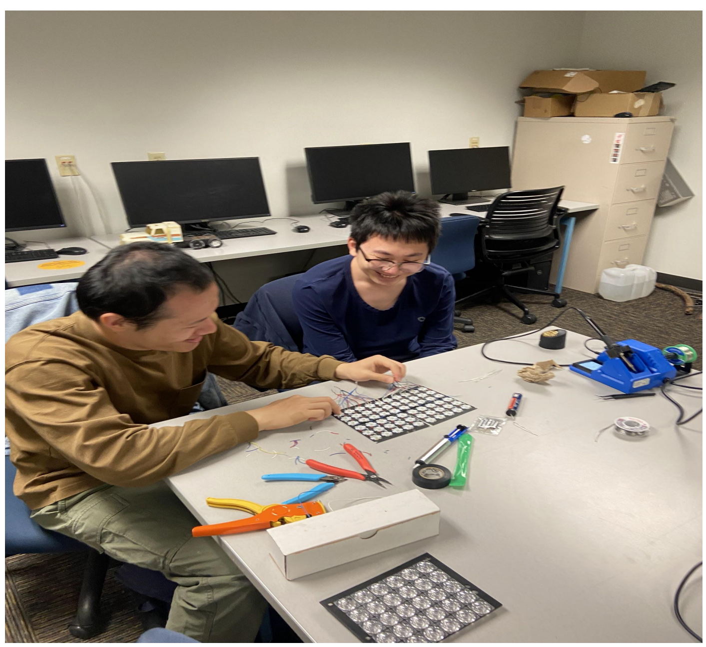


Figure 76: Soldering Process

8 FINAL HARDWARE

This section of the paper includes the images of the final product and the description of how the system functions.

8.1 Final Hardware Images and Descriptions

Figure 77 shows the fan installation from the rear view of the system. The fans will pull in air from the back and push it towards the aluminum plate that is attached to the LED's. The fans have their own wiring and will be plugged into a different power supply then the rest of the system. In figure 78 it shows the internal wiring of the system. The wires connecting from the fans to its own power supply, and the wiring from the switch that turns on and off the rest of the system.. The wiring from the switch is connected to the LED driver. The LED driver that is sitting on top of the housing is used for controlling the outputs for the LED's. In figure 78 it shows a side view of the housing. The side of the housing has the knockouts punched out for ventilation, the BNC ports for each color channel, and the switch to turn on the LED Driver. The BNC ports are important because they allow the user to choose the color that they want to use. The colors are red, green, blue, and all three running together. In figure 79 it shows the LED Array and Lens Array attached onto the front plate. The standoffs allow the lens to sit perfectly above the LED's. The LED's being attached to the front plate allow for easy removal of all components of the system. It also allows for the system to be turned on without any removal of any parts since the LED's rest externally. In figure 81 it shows the wiring and aluminum plate installation. This wiring is all connected to the LED's and then connected to the driver so that they can receive the output signals from the driver.

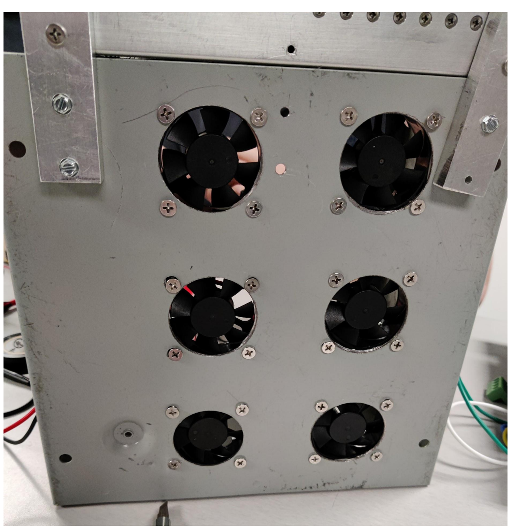


Figure 77: Fans Installation

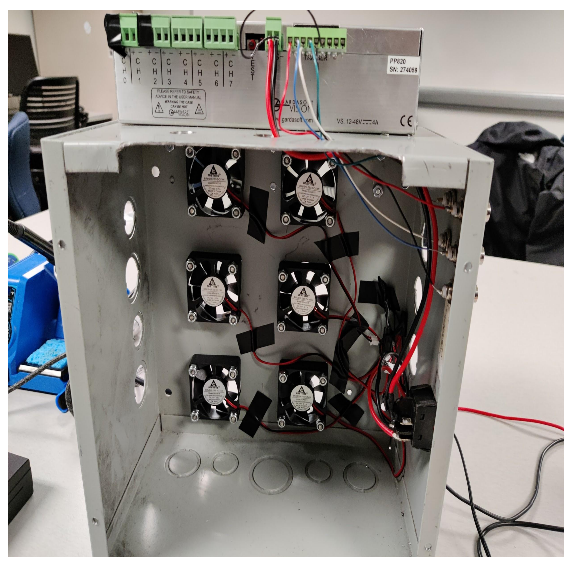


Figure 78: Power and Trigger Wiring

Figure 79: Lens Installation   Figure 80: Switch and TTL Trigger Port

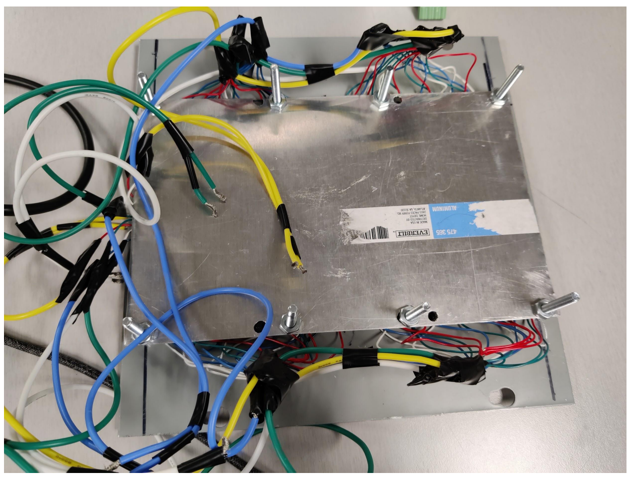


Figure 81: Aluminum Plate Installation

8.2 Design Changes in Second Semester

8.2.1 Design Iteration 1: Change in Cooling Component (HeatSink)

Our first design included 3 copper heatsinks. This is because the team through calculation thought that the system would need the cooling capacity of the heatsinks. After testing we realized that the system did not reach the max allowable temperature or anywhere close to it. This allowed the team to use a thin aluminum plate instead, due to the fact that the fans cooling of the LED's was sufficient.

8.2.2 Design Iteration 2: Change in Circuit Design

During the second semester our client acquired an LED driver for the team. As such the electrical design had to be reworked into the design discussed in section 6.3.1. This change simplified much of the wiring and electric systems allowing for an easier manufacturing process for the LED sub system.

8.2.3 Design Iteration 3: Change in Housing Size

The housing size had to be increased in the second semester due to a change in the LEDs. The LED chips and the Lens combination was much larger than originally planned so a larger housing was acquired in order to fit the larger overall design.

8.3 Challenges Bested

The team's main problems occurred when trying to reach the 33% and 66% benchmarks. For the 33% the team had barely started the actual manufacturing and assembly process. By this time we had the purchased housing in hand and the first LED Driver. The team expected to have the LED Driver up and running with the testing LED array. This did not occur since the driver had a malfunction and would not work. After this first hardware check failure the team realized that the effort needed to be stepped up. For the next hardware check was 66%. This time the team was more prepared. Most of the manufacturing of the housing was completed. There was still one problem and that was that the driver was not yet set up with LEDs. This meant the team could not demonstrate the system another time. To overcome this and make sure the project was completed 100% the team worked long and hard. This ensured that by the time the team reached 100% everyone in the room got a light show. This overcoming led the team to a final product that was reaching the standards.

9 Testing

9.1 Testing Plan

9.1.1 Testing Procedure 1: Synchronization Test

9.1.1.1 Objective

The goal of this test is to determine how the light source will synchronize with the camera that it will be utilized with. This test will specifically determine the delay that the system will need in order for the image to be properly captured. The only equipment that will be used during the test is the device, the camera and a computer. Other than the delay which will be determined experimentally no other variables need to be isolated or calculated.

9.1.1.2 Procedure

Steps:

- Set up the project, camera and computer so that the setup can be observed and the camera is able to capture a surface illuminated by the device.
- Connect the device and camera to a function generator so that the input for each device is synchronized.
- Run the camera and red color channel of the device together to collect image results.
- Repeat step 3, adjusting the delay for the light pulse until the device and camera are synchronized.
- Repeat steps 3 and 4 for the green, blue and white channels.
- Record the delays for future use.

9.1.1.3 Results

The team is looking to find the optimal delay for each channel in order to synchronize the camera with the light pulse so that the image is as bright as possible. Currently there is no expected value for what this delay might be and can only be determined experimentally. The device can adjust the delay between 3 μs to 1 s which will give the team more than enough space to determine the proper delay.

9.1.2 Testing Procedure 2: Pulses and Frequency Test

9.1.2.1 Objective

The goal of this test is to determine how fast and how short of pulses that the LED driver actually delivers to the device. This test specifically determines engineering requirements 2 and 3 as well as customer requirements 2 and 3. For this test the device with a function generator, and an oscilloscope are required. The test will determine the exact pulse width and frequency of the device by isolating the outputs of both the function generator and the LED driver with the Oscilloscope.

9.1.2.2 Procedure

Steps:

- Set up the project along with an oscilloscope connected to the output of the LED driver as well as the input from the function generator.
- Set the pulse width to 1 µs.
- For pulses ranging from 1 Hz to 60 Khz analyze the input and output of the driver to determine if the driver is pulsing at the correct speed as determined by the function generator.
- Set the function generator to 100 Hz
- Adjust the pulse width from 1 µs to 100 µs and watch the oscilloscope to determine what the actual pulse width that the LED driver is outputting.

9.1.2.3 Results

The team is expecting that the device can operate with a minimum of 1 µs pulse width with a 1% tolerance as determined by the manufacturer. The device should also be able to operate between 1 Hz and 60 kHz due to there being no maximum frequency tolerance determined by the manufacturer and this remains above the minimum pulse width.

9.1.3 Testing Procedure 3: Temperature Test

9.1.3.1 Objective

The goal of this test is to determine the maximum working temperature of the LED chip and the housing. Once the temperature is higher than the maximum working temperature, the LED chip could have less lifespan or performance. This test will only utilize the device, a thermocouple, an arduino and a computer. The thermocouple will be able to isolate the temperature during this test.

9.1.3.2 Procedure

Steps:

- Set up the project and run the device for 30 seconds.
- Calibrate the thermocouple using boiling and ice water.
- Use the thermocouple to measure the LED chip temperature and run the temperature data acquisition device to collect the temperature data.
- Repeat step 2 to measure the temperature inside the box.

9.1.3.3 Results

The temperature tested should not exceed seventy-five degrees Celsius, if it exceeds, according to the manufacturer's manual, the temperature will affect the luminous flux efficiency. The team is expecting a temperature for the system to be around 60 ℃.

Assumptions:

k=401 W/m*K [23]

h= 350 W/m^2*K [24]

L=10 mm

A=0.0116129 m^2

Using Conduction and Convection equations to find T_2:

-kDTDX=h(T2-T)

T_2= 59.65 C

Using the convection equation to calculate the heat rate, q:

q = h*A* (T2-T)

q = 161.36W

9.1.4 Testing Procedure 4: Variable Channels

9.1.4.1 Objective

The goal of this test is to see if channels in the device can work independently and together. The device should meet CR5 - Variable channels. The only equipment needed for this test is the device itself.

9.1.4.2 Procedure

Steps:

- Set up the project and make sure the drive is ready to control the device.
- Run each color channel independently and adjust the pulse to see if that works.
- Run 2 channels together and adjust the pulse width to see if that works.
- Run 3 channels together and adjust the pulse width to see if that works.
- Run all channels together and adjust the pulse width to see if that works.

9.1.4.3 Results

The expected result is each channel can work independently and together with the adjustable pulse width which will allow for the overall color of the light to be adjusted.

9.1.5 Testing Procedure 5: Power Test

9.1.5.1 Objective

The goal of this test is to determine how much power is being used by the driver during each pulse. This test will determine the energy used per pulse by the driver with expected values being between 0 and 30 mJ. The equipment needed are the device and a multimeter. The test will isolate the voltage and the current used during each pulse. These variables will be used to calculate the power per pulse as well as the energy per pulse.

9.1.5.2 Procedure

Steps:

- Setup the device.
- connect the multimeter between the positive output of the driver and the LEDs and set it to record current.
- Record the results
- Reconnect the device as normal
- Set up the multimeter between the positive and negative terminal of the LED driver output
- Record the voltage output during a pulse.
- Calculate the power and energy of each pulse.

9.1.5.3 Results

$P = IV$

$P = 20 * 14 = 280$ W

$E = PT$

$E = 280 * (1*10^{-6}) = 0.28$ mJ per pulse

$E_{tot} = 80 * E = 22.4$ mJ per pulse

As can be seen from the equations above, the expected energy per pulse is well within the expected values. This will allow the device to be operated safely and the experiment will ensure what the actual value is.

9.1.6 Testing Procedure 6: Over Pulsing Test

9.1.6.1 Objective

The goal of this test is to determine the maximum current that the LEDs can withstand. This test will determine the energy used per pulse by the driver with expected values being between 0 and 30 mJ. The equipment needed are the device and a multimeter. The test will isolate the voltage and the current used during each pulse. These variables will be used to calculate the power per pulse as well as the energy per pulse.

9.1.6.2 Procedure

Steps:

- Setup the device.
- Connect a test setup of 3 LEDs to the driver
- Run the LEDs at 3 A, 1% duty cycle and 1 kHz for 1 min
- Record the Temperature
- Repeat the test at 3.5 A and 4 A
- Run the LEDs at 2 A, 10% duty cycle and 1 kHz for 1 min
- Record the Temperature

9.1.6.3 Results

The results of this test showed that with a low enough duty cycle the LEDs can be over-pulsed to a much higher degree than is currently being done. It also showed that the temperature outputted by the system has a higher relation with the duty cycle as compared to the operating current.

9.2 Testing Results

Table 10: Customer Requirement Summary

Customer Requirement	CR met (Yes/No)	Client Acceptable (Yes/No)
CR1-Brightness	Yes	Yes
CR2-Short pulses	Yes	Yes
CR3-High frequency	Yes	Yes
CR5-Variable channels	Yes	Yes
CR6-Synchronization	Yes	Yes

Table 11: Engineering Requirement Summary

Engineering Requirement	Target	Tolerance	Measured/ Calculated value	ER met (Yes/No)	Client Acceptable (Yes/No)
ER1-Energy	30mJ per pulse	10%	21.6 mJ per pulse	No	Yes
ER2-Pulse Width	1us	1%	1us - 300 ms and Continuous	Yes	Yes

ER3-Frequency	1Hz – 60kHz	-	1 Hz - 40 kHz	No	Yes
ER4-Temperature	65°C	Up to 75°C	38°C	Yes	Yes
ER5-Output Delay time	100ns	-	3 us - 300 ms	No	Yes

Table 9 shows a summary of customer needs. The test results prove that we have achieved all the customer's needs, and after the customer consultation, the client agrees with our test results.Table 10 shows our fulfillment of engineering requirements. After measurement or calculation, the pulse width and temperature reach the allowable range of engineering requirements. Energy, frequency, and output delay all fall short of demand. Calculations showed the calculated energy to be 21.6mJ per pulse, not reaching 30mJ. The frequencies are between 1Hz and 40kHz, not fully covering 1Hz to 60kHz. The shortest output delay is 3us, which is higher than the engineering requirement of 100ns. The client affirmed the pulse width, frequency, temperature, output delay, and expressed uncertainty about the result of the energy.

10 RISK ANALYSIS AND MITIGATION

This section of the memo includes the parts of the system and their potential failures. To do this a Failure Modes and Effects Analysis is used (FMEA). The FMEA includes the part section which just simply can have the part name and or number. Then the FMEA has the potential failure mode which is how the system fails. This can include yielding, fractures, fatigue, corrosion, wear, and many more factors. After stating the failure mode, the effect of the failure is stated. The effects of failure share how much the system will change or be ruined due to the failure mode of that part. Next the severity rating is rated through a 1-10. A one being it does nothing to the system and a ten being it completely ruins the system. Then the potential causes to reach that failure are named. Then it is rated on a level of occurrence a one being the utmost of rarest occurrences and a ten being extremely likely to occur. Then a current design control test is named to test if the product will fail and also to test when the system does fail. A one being that it is easy to detect and a ten that is almost impossible to detect. Then a RPN is rated by multiplying the severity, occurrence, and detection scores. The higher the score the more critical the failure mode is. If the failure does happen then one follows the recommended action to see what has gone wrong and how to improve the situation so it does not happen again. The critical failure section is used to evaluate the failure modes in more depth. This also allows us to recognize how to mitigate the larger processes on a more in depth level. The risks and trade-off analysis allow the team to compare and analyze how one change in the system can affect the other. The team must choose the best failure analysis to focus on.

10.1 Potential Failures Identified First Semester

This is the first semester summary of the FMEA. This semester used some of our older parts but is mostly the same as the second semester as you will see. This shows the potential failures and how we can fix and or identify them.

Table 11 : Shortened FMEA

	A	B	C	D	E	F	G
1	Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action	
2	LED Chips	Temperature Induced Defor	Decreased Light Intensity, Fail	Assembly of cooling syste	56	Improve the cooling system	
3	LED Chips	Thermal Fatigue	Decreased Light Intensity, Fail	Cooling system malfunctio	144	Improve the cooling system	
4	LED Chips	Electrical Overstress	Decreased Light Intensity, Fail	Over Voltage/Over Curren	96	Use less current/voltage. change circu	
5	LED Chips	Low-Cycle Fatigue	Decreased Light Intensity, Fail	Over Usage/ Continous pu	56	Run in Pulse. Let rest in given period o	
6	LED Chips	Impact Fracture	Cracked plastic covering, Failu	High Force on LED chips	48	Change assembly	
7	Heat Sink	Thermal Fatigue	Unable to cool LEDs	Bad Ventialtion	20	Modify Housing	
8	Heat Sink	Dust and Debris	Unable to cool LEDs	Not Cleaning Heatsink	40	Clean heatsink frequently	
9	Heat Sink	Brittle Fracture	Unable to cool LEDs	High Forces	10	Apply less force to next Heat Sink	
10	Heat Sink	Corrosion	Unable to cool LEDs	Reaction to Oxygen	20	Enviromental change	
11	Fan (bearing)	Corrosion	Decreased cooling	Overstressing	30	Enviromental change	
12	Fan (bearing)	Fretting Wear	Slower Fan rotation leads to d	Over use of fans/ Time	45	Purchase better Fans, change bearing	
13	Fan (bearing)	Yielding	Decreased cooling	Over use/ Time	60	Run fans at lower power	
14	Fan (blade)	Brittle Fracture	Decreased cooling	Poor maintenace, and ass	72	Modify Assembly	
15	Fan (motor)	Thermal Fatigue	Decreased cooling	Overheating, Poor mainten	90	Run Fans less, Take better care	
16	Fan (motor)	High-cycle fatigue	Decreased cooling	Time	28	Purchase new fans	
17	Circuit Board	Thermal Fatigue	Light intensity, Light display, C	Overheating, Poor mainten	150	Improve the cooling system	
18	Circuit Board	Temperature deformation of	Light intensity, Light display, C	Over voltage, failure of co	60	Improve the cooling system	
19	Circuit Board	Dust and Debris	Light intensity, Light display, C	Not Cleaning	24	Clean frequently	
20	Circuit Board	Electrostatic Discharge (ESI	Light intensity, Light display, C	Over Voltage/Voltage spik	100	Circuit design, Measure and change a	
21	Circuit Board	Solder Flux Corrosion	Light intensity, Light display, C	Acidic Flux, Overheating	64	0	
22	Circuit Board	Brittle Fracture	Light intensity, Light display, C	High Applied force	160	Modify Assembly	
23	BNC Port	Thermal Fatigue	Short circuiting, breaking circu	Debris, lack of cooling	108	Modify Cooling system	
24	Rectifier Diode	High-cycle fatigue	Dimmed lights, poor power su	Over voltage,current,heat	20	Measure inputs and readjust	
25	NPN Transistor	Avalanche failure	Unable to control voltage and	Over voltage	294	Reduce stray Inductances	
26	Housing	Ductile Rupture	Parts won't be encased, syst	Heavy loads, bad assembl	42	Evaluate design and make changes	
27	Housing	Brinelling	Unattractive look	Ballpoint force applied	5	N/A	
28	Housing	Thermal fatigue	Can lead to failure of housing	Cooling system failure	45	Modify Cooling system	
29	Housing	Cracking in Powder-Coating	Unattrctive and can lead to rus	Time and Poor care	18	Take better care	
30	Housing	Impact Fracture	Parts won't be encased, syst	Dropped, High force applie	21	N/A	
31	Housing	Impact Deformation	Unattractive Look, Failure to h	0	20	N/A	
32	Wiring	Thermal Fatigue	Dimmed lights, poor power su	Lack of cooling, Over Volt	80	Replace Circuit Board	
33	Wiring	Entanglement	Can ruin chord insulation and	Poor care and setup	16	Untangle, Set up wiring more proficien	
34	Aluminum Plate	Brinelling	Connection to the housing	Ballpoint force applied	24	Modify Assembly	
35	Aluminum Plate	Thermal Fatigue	Can lead to damage of Circuit	Cooling system failure	60	Modify Cooling system	
36	Aluminum Plate	Yielding	LED and Heatsink won't be co	High forces applied over ti	28	Modify Assembly	
37	Screws	Hydrogen Damage	Cracked screw that leads to f	Degredation reaction with	18	Buy stronger screws	
38	Screws	Bolt Overload	Cracked screw that leads to f	Large forces applied over	18	Buy stronger screws	
39	Screws	Fatigue Failure	Cracked screw that leads to f	Large forces applied over	18	Buy stronger screws	
40	Screws	Shear Fatigue	Cracked screw that leads to f	Cyclic Shear Loads	18	Buy stronger screws	

10.1.1 Potential Critical Failure 1: LED Thermal Fatigue

The LED chips in the system have a risk of failure due to thermal fatigue. Thermal fatigue is when cracking and deformation occurs due to changes in temperature and or high temperatures over a given period of time. The LED chips might go through this since they will be used at high pulses and will give off heat. This amount of heat that the LEDs will be giving off can cause this thermal fatigue. Thermal fatigue on the LEDs will damage them and lead to the system not functioning properly. Although it is inevitable that the LEDs will have heat associated with them, one can use cooling methods and heat transfer to help. To mitigate this a cooling system such as a heat sink, and fans will be implemented to try and remove as much heat as possible out of the system.

10.1.2 Potential Critical Failure 2: Circuit Board Thermal Fatigue

Thermal Fatigue in the circuit board will also be a major issue. Thermal Fatigue will cause the circuit board to not function properly. The circuit board not functioning properly means that the entire system will be useless so this critical failure is severe. This failure will be caused if the cooling system does not successfully transfer enough heat out of the system. To ensure that this does not occur the cooling system needs to be working at all times. Also tests need to be done to see if the current cooling system is efficient enough for the current heat that will be given off in the system.

10.1.3 Potential Critical Failure 3: Circuit Board Brittle Fracture

Brittle fracture is when something breaks without giving much yield. Usually a stronger material, yet it does not bend as much without just snapping. The circuit board if it has enough force or pressure applied to it can fracture. This is a very severe scenario since the circuit board is expensive and the main component to the system. The fracture is on the lower spectrum of actually occurring as seen in the Appendix E. To prevent this from happening the assembly of the system can be set up in a way that the circuit board does not receive as much force applied to it. The circuit boards biggest threat is outside sources such as people from accidentally applying too much force on it. To prevent this a safety covering will be implemented for when it is not in use.

10.1.4 Potential Critical Failure 4: Circuit Board Electrostatic Discharge

Electrostatic discharge is when there is a quick and sudden flow of electricity between two components in a circuit. This is a severe failure as seen in the FMEA chart in the Appendix E. It can occur quite often and without a good detection of it happening before it does. If this happens it can damage or even destroy components of the circuit board. This is important to try and prevent since the circuit board is the main component of the system. This will cause system failure. To prevent this the circuit should avoid static and be placed in static-free containers.

10.1.5 Potential Critical Failure 5: NPN Transistor Avalanche Failure

Avalanche failure is when a voltage spike occurs and causes the transistor to smoke and fail. This failure is mainly caused by a spike in voltage, or providing too much voltage. This failure will break the transistor which will lead to not having control over systems and voltage. This type of failure can also lead to the damage of other parts in the system since it does have the possibility of catching fire. To mitigate this failure, care and precision of controlling the amount of voltage entering the system has to be measured frequently. Reducing stray inductances will help keep this resistor in good shape.

10.1.6 Potential Critical Failure 6: LED Chips Electrical Overstress

Electrical Overstress is when the LEDs will be put through undesired voltages, currents, and powers. This will then cause damage to the LEDs. As seen in the FMEA chart in Appendix E it has a high severity rating. This is because it will damage the LEDs which are also an integral part of the system. To mitigate this circuit design will need to be correct, power inputs must be reasonable to not damage the LEDs.

10.1.7 Potential Critical Failure 7: BNC Port Thermal Fatigue

Thermal Fatigue of the BNC port also comes from high temperatures being present in the system and the circuit board. This failure can cause short circuiting and failure of the circuit operation. As seen in Appendix E this failure has one of the highest occurrences in the system. This means that extra precautions need to be taken to ensure that this does not occur. This system is easily overheated at times so to mitigate this the cooling system must be strong enough to cool it.

10.1.8 Potential Critical Failure 8: Fan Blade Brittle Fracture

Fan blade brittle fracture is when the blade of the fan completely snaps. The snapping of the fan blade would make the cooling that the fans give less effective. The more that this happens throughout the fans the more cooling decreases. The severity of this issue increases as the amount of fan blade fractures increase. The reason why this issue is serious is because detecting the fans' damage needs the assembly to be taken apart. So, a fan blade can be broken for a while before it is fixed. To mitigate this situation the fans need to be checked on a regular basis, and run efficiently.

10.1.9 Potential Critical Failure 9: Aluminum Plate Thermal Fatigue

Thermal Fatigue from the aluminum plate is the deformation and cracks from the temperature being too high. The aluminum plate is between the heatsink and the circuit board. This is important for the aluminum plate to cool, so it can hold the heatsink and circuit board together. To mitigate this failure the cooling system needs to be functioning properly. If the cooling system is not doing its job then a lot of parts in the system will ultimately break.

10.1.10 Potential Critical Failure 10: Wiring Thermal Fatigue

Thermal fatigue of the wiring will start to damage and destroy it. The wiring is important to allow electricity to run through the system. The thermal fatigue of the wiring is caused from the cooling system functioning poorly. This would affect the complete function of the system since the circuit board will need this wiring and the fans which are a part of the cooling system. To mitigate this the cooling system needs to be functioning properly and make sure that heat is being exited through the system. Another way to mitigate this is with better ventilation in the housing.

10.2 Potential Failures Identified Second Semester

The potential failures in the second semester became much clearer with the new design and the testing of the device. After setting up the system and testing the components, the team ran into many failures that were unexpected. The full FMEA can be found in Appendix A.

Table 12: Second FMEA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN
LED Chips	Temperature Induced Deformation to plastic	Decreased Light Intensity, Failure to operate	Assembly of cooling system	56
LED Chips	Thermal Fatigue	Decreased Light Intensity, Failure to operate	Cooling system malfunction	144
LED Chips	Electrical Overstress	Decreased Light Intensity, Failure to operate	Over Voltage/Over Current	150
LED Chips	Low-Cycle Fatigue	Decreased Light Intensity, Failure to operate	Over Usage/ Continous pulse	56
LED Chips	Impact Fracture	Cracked plastic covering, Failure to operate	High Force on LED chips	48
Heat Sink	Thermal Fatigue	Unable to cool LEDs	Bad Ventialtion	20
Heat Sink	Dust and Debris	Unable to cool LEDs	Not Cleaning Heatsink	40
Heat Sink	Brittle Fracture	Unable to cool LEDs	High Forces	10
Heat Sink	Corrosion	Unable to cool LEDs	Reaction to Oxygen	20
Fan (bearing)	Corrosion	Decreased cooling	Overstressing	30
Fan (bearing)	Fretting Wear	Slower Fan rotation leads to decreased cooling	Over use of fans/ Time	45
Fan (bearing)	Yielding	Decreased cooling	Over use/ Time	60
Fan (blade)	Brittle Fracture	Decreased cooling	Poor maintenace, and assembly	72
Fan (motor)	Thermal Fatigue	Decreased cooling	Overheating, Poor maintenance	90
Fan (motor)	High-cycle fatigue	Decreased cooling	Time	28
Circuit Board	Thermal Fatigue	Light intensity, Light display, Circuit Control	Overheating, Poor maintenance	150
Circuit Board	Temperature deformation of the plastics	Light intensity, Light display, Circuit Control	Over voltage, failure of cooling	60
Circuit Board	Dust and Debris	Light intensity, Light display, Circuit Control	Not Cleaning	24
Circuit Board	Electrostatic Discharge (ESD)	Light intensity, Light display, Circuit Control, Burns wires	Over Voltage/Voltage spike	100
Circuit Board	Solder Flux Corrosion	Light intensity, Light display, Circuit Control	Acidic Flux, Overheating	64
Circuit Board	Brittle Fracture	Light intensity, Light display, Circuit Control	High Applied force	150
BNC Port	Thermal Fatigue	Short circuiting, breaking circuit	Debris, lack of cooling	108
Rectifier Diode	High-cycle fatigue	Dimmed lights, poor power suppply, revered current shorting LEDs	Over voltage,current,heat	20
NPN Transistor	Avalanche failure	Unable to control voltage and current	Over voltage	294
Housing	Ductile Rupture	Parts won't be encased, system can not function properly	Heavy loads, bad assembly	42
Housing	Brinelling	Unattractive look	Ballpoint force applied	5
Housing	Thermal fatigue	Can lead to failure of housing and collapse.	Cooling system failure	45
Housing	Cracking in Powder-Coating	Unattrctive and can lead to rust	Time and Poor care	18
Housing	Impact Fracture	Parts won't be encased, system can not function properly	Dropped, High force applied to it	21
Housing	Impact Deformation	Unattractive Look, Failure to hold integral parts.		20
Wiring	Thermal Fatigue	Dimmed lights, poor power suppply	Lack of cooling, Over Voltage/current	80
Wiring	Entanglement	Can ruin chord insulation and cause damage to them	Poor care and setup	16
Aluminum Plate	Brinelling	Connection to the housing	Ballpoint force applied	24
Aluminum Plate	Thermal Fatigue	Can lead to damage of Circuit board/ Failure to Hold components	Cooling system failure	60
Aluminum Plate	Yielding	LED and Heatsink won't be connected to the housing correctly	High forces applied over time	28
Screws	Hydrogen Damage	Cracked screw that leads to failure of holding system together	Degredation reaction with hydrogen	18
Screws	Bolt Overload	Cracked screw that leads to failure of holding system together	Large forces applied over time	18
Screws	Fatigue Failure	Cracked screw that leads to failure of holding system together	Large forces applied over time	18
Screws	Shear Fatigue	Cracked screw that leads to failure of holding system together	Cyclic Shear Loads	18
LED Driver	Unfunctionable/Damaged	Can not send LED's signal outputs	Damage of ethernet chord plug in	60
LED Driver	BNC port damaged	Cannot connect to color channel	Electrical Overstress	90
LED Driver	Electrical Overstress	Can not send LED's signal outputs for pulses	To much frequency	50
Function Generator	Transistor Damage/ loosened	Can not supply power to the Driver	Damged transistor	48

10.2.1 Potential Critical Failure 1: LED Driver Damaged

After receiving the first LED Driver, the team tried to run tests with it. After trying to run tests with it we realized that the driver could not connect to the server to make the inputs (code) for the driver to make outputs to the LED's. Since the Driver could not connect to the server, another had to be purchased

10.2.2 Potential Critical Failure 2: LED Electrical Overstress

During testing of the LED's ten of them broke. This was due to electrical overstress. We found that too much current and voltage ran through the LED's. To make sure this did not happen again the spec sheet of the LED's was analyzed, and testing was done to see how much they could handle. If the LED's break then there would be no light source for the device.

10.2.3 Potential Critical Failure 3: Function Generator Transistor Damage

This is important to mitigate since it is the power supply of the device. When a transistor gets damaged and or is not functional the system can not operate. To fix this one will need to open the power supply and replace or fix the loose transistor.

10.2.4 Potential Critical Failure 4: Damage of Wiring

The damage of the wiring can come from two separate possibilities. The first being dropping the device and the wiring coming loose. To fix this one would need to rewire. The second being from electrical overstress. This would be from running the system at a current/voltage that is inoperable with the wiring. To fix this wiring would need to be replaced.

10.2.5 Potential Critical Failure 5: Driver BNC Port Electrical Overstress

Electrical Overstress is when the system is put through undesired voltages, currents, and or power. This would lead to damage of the BNC port on the driver leaving it inoperable causing a certain channel of colors to be nonfunctional. This is what occurred leaving the white channels to be inoperable.

10.2.6 Potential Critical Failure 6: LED Driver Electrical Overstress

When the LED's are pulsed too quickly then the driver shorts out and stops functioning as intended. The driver is an important piece of equipment that gives the LED's the output. So when this happens the functionality of the system is ruined.

10.3 Risk Mitigation

10.3.1 1st Semester:

Thermal fatigue of the fans (motor) is an important factor to take into consideration. The fans will need to be run efficiently enough to cool the system, while also not being overrun. If the fans are overrun that can cause overheating to the motor of the fans. A tradeoff of trying not to thermally fatigue fans and the rest of the system needs to be a fair trade off. The fans need to run at enough power to cool while also maintaining its thermal integrity. If the fans are not cooling the rest of the system enough, more important parts of the system will be damaged. So the more important thing is that the fans run efficiently enough to cool the system, while trying not to overheat itself. This made us have to choose durable well made fans that can be handled running at long times.

The yielding and brinelling of the aluminum plate is one failure mode that trades off thermal fatigue off the system. The aluminum plate can decrease its chances of bending or breaking if its thickness is increased. The downside is that with the thickness being increased in the plate the thermal fatigue will increase in the circuit board. The aluminum plate is in the middle of the circuit board and the heatsink. The thicker the plate the longer it takes for the heat to transfer from the plate to the heatsink. At a certain thickness the aluminum plate will start holding on to too much of the heat which will start making the circuit board overheat also. This is why the team needs to choose a thinner aluminum plate. The aluminum plate will need to be carefully assembled to ensure that it does not yield.

Bolt overload is also an important factor. The screws in the system need to be strong enough to hold together, while also not being too big. The screws need to connect the heat sink, aluminum plate, and the circuit board. If the screws are too big they will take out more area from the copper heatsink which will decrease the cooling of the heat sink and cause thermal problems. Also the screw size can affect the layout of the circuit board and cause damage to it also if they are too large. The team needs to choose a smaller screw size that can withstand the loads of holding the assembly together, while also not affecting the cooling performance.

There are not many risks and trade-offs in this system since most of each other's risks fall under the same cause and effect. There are trade-offs in other fields other than just failure modes. Such as the cooling system. The cooling system is an integral part of keeping the system up and running. The problem is the better the cooling system, the more money it is going to cost. There needs to be a balance of efficient cooling and expenditures. Also the circuit design has to be set up so that no destruction comes to the parts in the system from things such as overvoltage and overcurrent which can lead to electrical discharge and stress.

10.3.2 2nd Semester:

The hardest thing to mitigate this semester for the team was the LED Driver. The driver caused a lot of issues for the team. The main issue at first was that the driver would not work because it could not connect to the server where the code can be inputted. This caused the team to be unable to run the LED’s at the outputs that were wanted. To fix this problem we contacted the company that made the driver. They stated that with this type of situation the driver needed to be replaced. The second problem we had with the replacement driver was the BNC port getting damaged. This occurred because too much voltage ran through the driver. This caused a shortage in the driver causing damage to the BNC ports that were being used. This caused the team to not be able to utilize the white channels of the LED’s. The third problem the team had with the driver was sending too much frequency through it. When the driver was told to run at a frequency higher than its max it shut off the whole system. Overall the driver gave the team the most issues. To solve the problem of the driver, the team needs to operate it within its specifications.

The second sub-component that ran into issues was the LED’s. The problem was when the LED’s came into electrical overstress. This when the LED’s would be given a current or voltage that was too much for them to handle. This caused a shortage in the LEDs causing 10 of them to break. When this happens the LED’s need to be replaced. This is not a cheap break so minimizing the occurrence of this is important. To minimize this make sure to run the LEDs at a 10 percent duty cycle.

The last subcomponent that the team ran into main issues with was the function generator. The function generator is the power supply. Many times when trying to run the system the power supply was too low. This is because a transistor in the power supply got loose causing it not to supply enough power. This leads to the driver not receiving enough power and not run the LEDs. To fix this the function generator needs to be disassembled. Then the transistor needs to be replaced and or tightened. This causes the power to rise again.

11 LOOKING FORWARD

This section of the report goes into detail of the future work that would be done on the system to improve and modify it. No future testing needed.

11.1 Future Iterations

Make suggestions for iterations if this project was to move forward with another hypothetical team.

11.1.1 Future Iteration 1: Housing

For the future work on the housing, the team would prefer to move to a plastic based housing instead of powder coated steel. Most likely a design would be done in solid-works and then 3d-printed. This iteration would improve the weight of the system so that it could be mounted without stripping the mounts.

11.1.2 Future Iteration 2: LEDs

The team would like to update the LED's that are in the system. The LED's that we are using are the Cree X-Lamp XM-L. More recently the company released the Cree X-Lamp XM-L Color Gen 2. The generation 2 has more light output, while also increasing the efficiency. This would allow the device to output more illumination while running more efficiently.

11.1.3 Future Iteration 3: LED Arrays

Rewire the LEDs to be in 5 strings of 6 LEDs, and redo the 3d-printed holder. This will allow for higher current pulses for the Gen 2 LEDs.

12 CONCLUSIONS

12.1 Reflection

Security concerns are the most important factor. As far as circuit safety is concerned, our team needs to pay more attention to the problem of short circuits. In this system, there are a lot of potential short circuits because the solder between the different channels of the LED is very close. Once short-circuited, some LEDs do not work this time, and some are overloaded. If a printed circuit board is used to integrate the LEDs and connect the circuit, the risk of short-circuiting of exposed wires is greatly avoided.

Another safety hazard is the wiring of the LED driver to the TTL Trigger and LED matrix. The connection between the wires of the TTL Trigger and the LED matrix and the LED driver is exposed, which is an imperfect place in the engineering design. The exposed wires of the product may cause electric shock hazards to the public. In principle, we should avoid this situation. For example, we should design a Housing with built-in LED driver. A safer approach is to make a TTL signal generator, signal converter and amplifier into an integrated circuit system.

12.2 Resource Wishlist

- Need more training in Electric Engineering from university.
- Enough research of articles from the client.
- Guide of housing (manufacturing or purchasing) from the beginning of design.

12.3 Project Applicability

This project can be used to illuminate flow in fluid with 3 different colors (Red, Green, Blue). Meanwhile the special camera can detect the flow through those 3 colors. Also, the device can change pulses to increase the power and illuminate micro flow fluctuation.

8

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14 Appendices

14.1 Appendix A:

System Name: LED Flow measurer						FMEA Number			
Subsystem Name:						Date: 11/27/21			
Component Name:									
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
LED Chips	Temperature Induced Deformation to plastic	Decreased Light Intensity, Failure to operate	7	Assembly of cooling system	4	Thermocouple	2	56	Improve the cooling system
LED Chips	Thermal Fatigue	Decreased Light Intensity, Failure to operate	8	Cooling system malfunction	6	Thermocouple	3	144	Improve the cooling system
LED Chips	Electrical Overstress	Decreased Light Intensity, Failure to operate	10	Over Voltage/Over Current	5	Multimeter	3	150	Use less current/voltage. change circuit design
LED Chips	Low-Cycle Fatigue	Decreased Light Intensity, Failure to operate	7	Over Usage/ Continous pulse	4	Multimeter	2	56	Run in Pulse. Let rest In given period of time
LED Chips	Impact Fracture	Cracked plastic covering, Failure to operate	6	High Force on LED chips	4	Visual	2	48	Change assembly
Heat Sink	Thermal Fatigue	Unable to cool LEDs	10	Bad Ventialtion	1	NEMA	2	20	Modify Housing
Heat Sink	Dust and Debris	Unable to cool LEDs	10	Not Cleaning Heatsink	4	Compressed air	1	40	Clean heatsink frequently
Heat Sink	Brittle Fracture	Unable to cool LEDs	10	High Forces	1	Tensile and impact strength test	1	10	Apply less force to next Heat Sink
Heat Sink	Corrosion	Unable to cool LEDs	10	Reaction to Oxygen	1	Visual	2	20	Enviromental change
Fan (bearing)	Corrosion	Decreased cooling	2	Overstressing	5	Take apart	3	30	Enviromental change
Fan (bearing)	Fretting Wear	Slower Fan rotation leads to decreased cooling	3	Over use of fans/ Time	5	Take apart	3	45	Purchase better Fans, change bearings
Fan (bearing)	Yielding	Decreased cooling	4	Over use/ Time	5	Take apart	3	60	Run fans at lower power
Fan (blade)	Brittle Fracture	Decreased cooling	6	Poor maintenace, and assembly	2	Visual	6	72	Modify Assembly
Fan (motor)	Thermal Fatigue	Decreased cooling	6	Overheating, Poor maintenance	3	RPM test	5	90	Run Fans less, Take better care
Fan (motor)	High-cycle fatigue	Decreased cooling	4	Time	7	N/A	1	28	Purchase new fans
Circuit Board	Thermal Fatigue	Light intensity, Light display, Circuit Control	10	Overheating, Poor maintenance	5	Visual/ Magnetic Particle Testing	3	150	Improve the cooling system
Circuit Board	Temperature deformation of the plastics	Light intensity, Light display, Circuit Control	10	Over voltage, failure of cooling	3	Multimeter	2	60	Improve the cooling system
Circuit Board	Dust and Debris	Light intensity, Light display, Circuit Control	3	Not Cleaning	8	Visual	1	24	Clean frequently
Circuit Board	Electrostatic Discharge (ESD)	Light intensity, Light display, Circuit Control, Burns wires	10	Over Voltage/Voltage spike	5	Multimeter	2	100	Circuit design, Measure and change amount of voltage/current supplied
Circuit Board	Solder Flux Corrosion	Light intensity, Light display, Circuit Control	8	Acidic Flux, Overheating	2	Thermocouple	4	64	
Circuit Board	Brittle Fracture	Light intensity, Light display, Circuit Control	10	High Applied force	4	Visual, Tensile strength test	4	160	Modify Assembly
BNC Port	Thermal Fatigue	Short circuiting, breaking circuit	6	Debris, lack of cooling	6	Thermocouple	3	108	Modify Cooling system
Rectifier Diode	High-cycle fatigue	Dimmed lights, poor power suppply, revered current shorting LEDs	5	Over voltage,current,heat	4	Multimeter	1	20	Measure inputs and readjust
NPN Transistor	Avalanche failure	Unable to control voltage and current	6	Over voltage	7	Multimeter	7	294	Reduce stray Inductances
Housing	Ductile Rupture	Parts won't be encased, system can not function properly	7	Heavy loads, bad assembly	3	Tensile Strength testing	2	42	Evaluate design and make changes
Housing	Brinelling	Unattractive look	1	Ballpoint force applied	5	Brinell Hardness Test	1	5	N/A
Housing	Thermal fatigue	Can lead to failure of housing and collapse.	5	Cooling system failure	3	FEA	3	45	Modify Cooling system
Housing	Cracking in Powder-Coating	Unattrctive and can lead to rust	3	Time and Poor care	2	N/A	3	18	Take better care
Housing	Impact Fracture	Parts won't be encased, system can not function properly	7	Dropped, High force applied to it	3	Visual	1	21	N/A
Housing	Impact Deformation	Unattractive Look, Failure to hold integral parts.	5		2	Spring Test	2	20	N/A
Wiring	Thermal Fatigue	Dimmed lights, poor power suppply	8	Lack of cooling, Over Voltage/current	5	Multimeter	2	80	Replace Circuit Board
Wiring	Entanglement	Can ruin chord insulation and cause damage to them	2	Poor care and setup	8	Visual	1	16	Untangle, Set up wiring more proficiently
Aluminum Plate	Brinelling	Connection to the housing	3	Ballpoint force applied	8	Brinell Hardness Test	1	24	Modify Assembly
Aluminum Plate	Thermal Fatigue	Can lead to damage of Circuit board/ Failure to Hold compor	6	Cooling system failure	5	Thermocouple	2	60	Modify Cooling system
Aluminum Plate	Yielding	LED and Heatsink won't be connected to the housing correct	4	High forces applied over time	7	Visual	1	28	Modify Assembly
Screws	Hydrogen Damage	Cracked screw that leads to failure of holding system togethe	3	Degredation reaction with hydrogen	2	N/A	3	18	Buy stronger screws
Screws	Bolt Overload	Cracked screw that leads to failure of holding system togethe	3	Large forces applied over time	2	N/A	3	18	Buy stronger screws
Screws	Fatigue Failure	Cracked screw that leads to failure of holding system togethe	3	Large forces applied over time	2	N/A	3	18	Buy stronger screws
Screws	Shear Fatigue	Cracked screw that leads to failure of holding system togethe	3	Cyclic Shear Loads	2	N/A	3	18	Buy stronger screws
LED Driver	Unfunctionable/Damaged	Can not send LED's signal outputs	10	Damage of ethernet chord plug in	3	Plug in and see if it connects	2	60	Purchase New Driver or email company to repair
LED Driver	BNC port damaged	Cannot connect to color channel	10	Elecrtical Overstress	3	Plug in BNC and see if color oppe	3	90	Fix Driver or replace
LED Driver	Electrical Overstress	Can not send LED's signal outputs for pulses	5	To much frequency	5	See if system is still running	2	50	Stop running system, and dont run over max frequency
Function Genera	Transistor Damage/ loosened	Can not supply power to the Driver	8	Damged transistor	3	Plug in and check power supply	2	48	Unscrew and check tranistors