LED Flow Sensor

Final Proposal

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DISCLAIMER

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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:

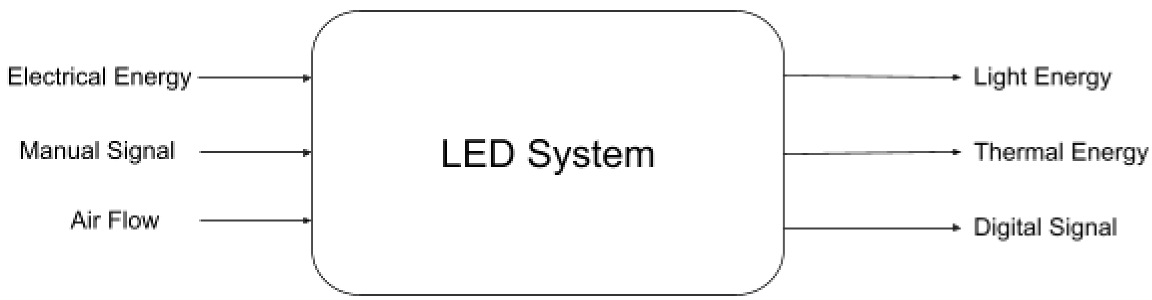

Figure 1: Black Box Model

We updated the black box model and removed the cooling liquid, because we adopted an air-cooled heat dissipation solution and modified some of the details to make them more accurate.

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.

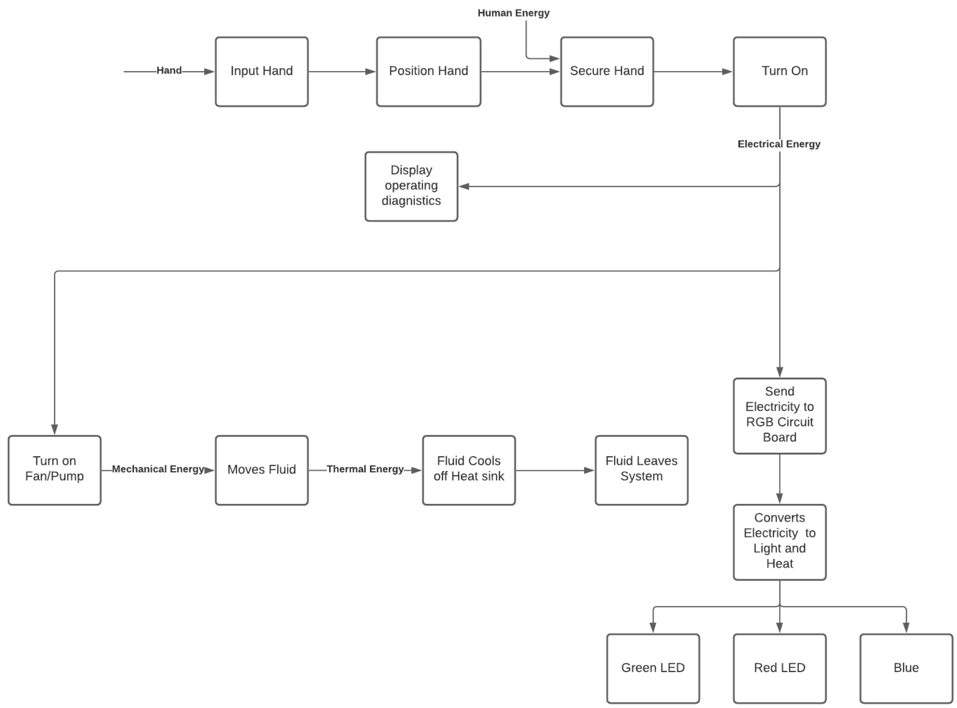

Figure 2: Functional Model

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 a;ready 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	Recommended Practice for Equipment Grounding and	It helps the users avoid electric shock because of

3003.2-2014	Bonding in Industrial and Commercial Power Systems	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 Testing Procedures (TPs)

The testing procedures are followed by engineering requirements - Pulse width, Frequency and Wavelength, Energy per pulse per channel, Trigger delay and trigger, Output delay and trigger, Temperature, and Lifespan. Each testing procedure includes Objective, Resources, and Schedule.

3.1 Testing Procedure 1: Pulse Width

The oscilloscope can transform electrical signals that are invisible to the naked eye into waveform curves. In this test, the pulse width is measured with an oscilloscope to make the pulse width meet the engineering requirements.

3.1.1 Testing Procedure 1: Objective

This test is to connect the pulse current to an electronic oscilloscope, and use the oscilloscope to analyze the pulse width. The purpose of this test is to ensure that the pulse width meets the requirements.

3.1.2 Testing Procedure 1: Resources Required

The tester uses an electronic oscilloscope to measure the wavelength of the pulse current wave. An electronic oscilloscope and test samples are required. The testing is carried out in the lab.

3.1.3 Testing Procedure 1: Schedule

Using a manual measurement method, press the cursor button, and then select time measurement. Use the multi-function knob to adjust the starting position of measuring line X to the rising edge of the waveform, and measuring the position from line Y to the end of the falling edge of the pulse. At this time, the oscilloscope can automatically calculate the width of this pulse. The time should be controlled in 1 minute and the testing is arranged in 486C semester.

3.2 Testing Procedure 2: Frequency and Wavelength

The spectrometer can decompose light into light of various wavelengths, and by studying the peaks of different wavelengths, the optical properties of the material can be qualitatively analyzed. In this experiment, the LED spectrometer is used to measure the main peak wavelength of the LED, and then the frequency is calculated by $c = \lambda f$.

3.2.1 Testing Procedure 2: Objective

This experiment runs under a spectrometer to measure the main peak wavelength of the LED keeping it energized. Its purpose is to obtain the wavelength of light. Then the frequency is determined by the formula $c = \lambda f$.

3.2.2 Testing Procedure 2: Resources Required

This experiment requires a tester, a portable spectrometer, which can be an integrated all-in-one machine or an application such as GoSpectro and StellarRAD App. The testing is carried out in the lab.

3.2.3 Testing Procedure 2: Schedule

Point the LED spectrometer at the light source to be measured and press the key to obtain the spectrum-related data of the light source to be measured without connecting to a computer. The time should be controlled in 1 minute and the testing is arranged in 486C semester.

3.3 Testing Procedure 3: Energy Per Pulse Per Channel

The laser energy meter is used to detect the single-shot energy of a repetitive pulse laser and the energy of a single-pulse laser. This test uses a laser energy meter to measure the pulse energy to complete the pulse energy evaluation.

3.3.1 Testing Procedure 3: Objective

This test uses a Gentec energy meter to measure pulse energy. Its purpose is to make the pulse intensity meet the engineering requirements. It helps us to adjust the voltage to control the energy in 0 - 30 mJ.

3.3.2 Testing Procedure 3: Resources Required

The tester requires a Gentec-EO laser energy meter and test samples. The energy meter must be used with the maestro meter head. The testing is carried out in the lab.

3.3.3 Testing Procedure 3: Schedule

Point the probe at the light source, and the product will automatically display the value of the pulse energy. The time should be no more than 1 minute and the testing is arranged in 486C semester.

3.4 Testing Procedure 4: Trigger Delay and Trigger Jitter

This test is related to the synchronization analysis. Both trigger delay and trigger jitter are needed as requirements.

3.4.1 Testing Procedure 4: Objective

"The idea is to make a trigger-echo application. Triggers are sent to a trigger channel . Then we can read from that trigger channel and once the trigger is detected, we can either write to another trigger channel, or write to the same channel but use different values for the trigger."

3.4.2 Testing Procedure 4: Resources Required

The resources contain a computer with Matlab, a whole LED array with the control system operated by at least 2 teammates in a lab of an Engineering building.

3.4.3 Testing Procedure 4: Schedule

This test will probably take 10 minutes and could be done in the first few weeks of Spring 22. If the test is in assignments of ME486C, then it will be finished by the exact due date.

3.5 Testing Procedure 5: Output Delay and Output Jitter

This test is related to the synchronization analysis. Both output delay and output jitter are needed as requirements.

3.5.1 Testing Procedure 5: Objective

Basically similar to the trigger test. Maturing timing between 2 signals.

3.5.2 Testing Procedure 5: Resources Required

The resources contain a computer with matlab, a whole LED array with the control system operated by at least 2 teammates in a lab of an Engineering building.

3.5.3 Testing Procedure 5: Schedule

This test will probably take 10 minutes and could be done in the first few weeks of Spring 22. If the test is in assignments of ME486C, then it will be finished by the exact due date.

3.6 Testing Procedure 6: Temperature

This test is important because the LED chip has a maximum working temperature. Once the temperature is higher than the maximum working temperature, the LED chip could have less lifespan or stop working. So we have to do this temperature testing without a cooling system.

3.6.1 Testing Procedure 6: Objective

The test will use a thermometer to show the temperature, and record the temperature from different times. 1min, 5mins, 10mins, 30mins. Then compare the temperature, if it has an upward trend after 30mins. And if the 30mins' temperature is over the maximum working temperature.

3.6.2 Testing Procedure 6: Resources Required

The resources include a thermometer, a working LED chip(power needed) operated by 1 teammate in a lab of the Engineering building.

3.6.3 Testing Procedure 6: Schedule

This test will probably take 35 minutes and could be done in the first few weeks of Spring 22. If the test is in assignments of ME486C, then it will be finished by the exact due date.

3.7 Testing Procedure 7: Lifespan

This test is about the maximum life of an LED sample realized by utilizing an accelerated life test method. It proves the durability of the LED by a lifespan schedule testing.

3.7.1 Testing Procedure 7: Objective

This test is to illuminate an LED, keep it energized, and record the time after the lamp is extinguished due to a malfunction.This test method adopts different drive currents (Electron flow), selects 5 LED lamps, and uses different currents to carry out accelerated life tests at 25°C ambient temperature to obtain a mathematical model of light output attenuation. The reason for this is to make the LED highly reliable.

3.7.2 Testing Procedure 7: Resources Required

This experiment requires a tester, 5 LEDs, a functional generator, a test circuit board, and an illuminance meter. The testing is carried out in the lab.

3.7.3 Testing Procedure 7: Schedule

The whole test process is divided into three stages. All the tools and materials are prepared before the experiment, and then the five LEDs are tested with different currents at room temperature. In the final data processing stage, the attenuation constant is calculated to obtain the LED's life. We expect it to be tested in 1 week in the 487C semester.

4 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.

Table 4 : Shortened FMEA

	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 asse	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 ar
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, syste	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, syste	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 Volta	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

4.1 Critical Failures

4.1.1 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.

4.1.2 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.

4.1.3 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.

4.1.4 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.

4.1.5 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.

4.1.6 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.

4.1.7 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.

4.1.8 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.

4.1.9 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.

4.1.10 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.

4.2 Risks and Trade-offs Analysis

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.

5 DESIGN SELECTED – First Semester

This section contains the updated design in comparison to what was presented in the previous paper. It also includes the reasoning behind these changes. This chapter also includes the implementation plan for next semester with our prototyping, and testing steps along with a schedule for the completion of these steps.

5.1 Design Description

5.1.1 Housing

Originally the team designed a housing specific to the project. This however was replaced with a prebuilt housing to save costs. The selected housing is a Powder-Coated Steel housing that is 8”x6”x4”. It also has knockouts on the sides so that the airflow in the system can be adjusted. The housing itself can be seen in Figure 3. This housing will be adapted to the design by cutting out 6 fan holes in the bottom of the design. This might require additional reinforcement if the housing itself is too weak after doing this. A plate will also be constructed to hold the circuit and heatsink to the housing. It will also function as a ground to the circuit. The plans for the updated housing can be seen in Appendix A.

Figure 3: Housing Unit

5.1.2 Circuit

A specific design was selected for the circuit. This can be seen in Appendix B. The circuit consists of 60 LED chips in parallel with each other. As with the previous designs this circuit is controlled by an NPN transistor that is powered by the output of a function generator. The power source is run through two capacitors that are connected to ground, these capacitors are to ensure the current is smooth throughout the cycle of the circuit.

5.1.3 Power Supply

The device will be powered by a 450W , 5V power supply, this supply provides enough power to run the system at the 300W goal along with having a high enough rating that overdrawing current is not a worry. The system also has internal protections against overloading, over current and short circuiting. These protections are all self recoverable and the system will revert to normal once the problem is fixed. To ensure the safety of the circuit from being overloaded, a 70 A DC fuze will be placed between the circuit and the power supply to ensure the LEDs are safe. The fan array will be connected to a separate output channel for the power supply with a step up in between to increase the system to the desired voltage. The power supply is a meanwell SE-450-5 and can be seen in Figure 4.

Figure 4: Meanwell SE-450-5 [2]

5.1.4 Prototype

The prototype that has been created up to this point was meant to ensure the validity of the circuit design. It connected 4 parallel rows of 8 LEDs in parallel together. These LEDs were powered by an Arduino Uno with the 5V pin. The LEDs were pulsed using an NPN transistor and the PWM pins on the Arduino board. This prototype shows the team that the circuit was feasible in running the circuit. It also showed that a transistor is able to switch at a speed of at least 1 khz which is a beginning step in the testing procedure. This prototype circuit can be seen in Figure 5.

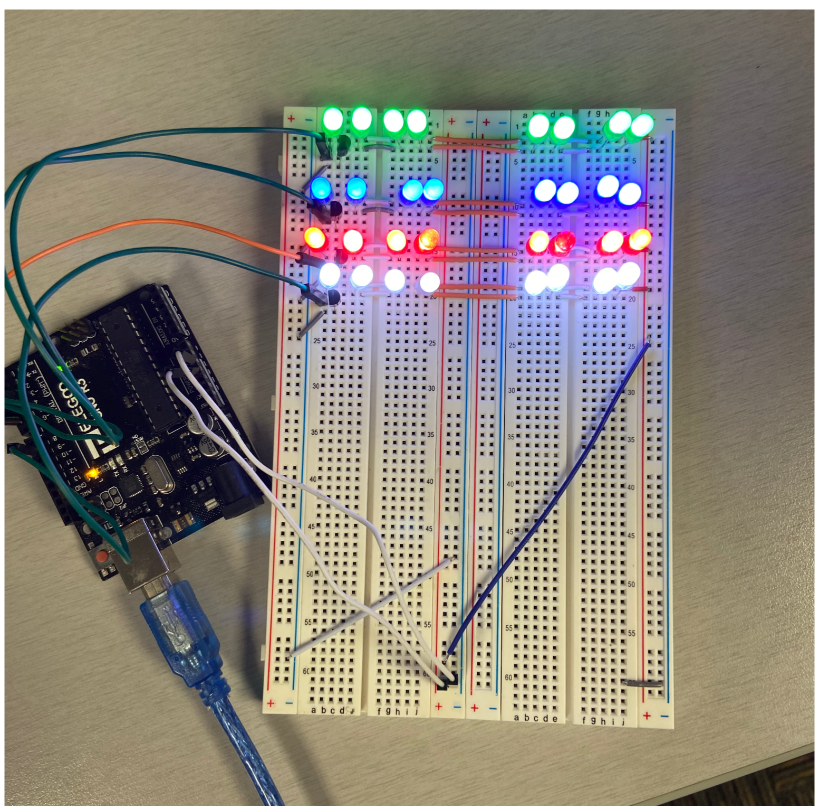

Figure 5: Prototype Circuit

5.1.5 Calculations

5.1.5.1 Size

The size of the circuit was decided to be 0.25 ft^2. This size is more than large enough to fit enough of the 5mm x 5mm LEDs and extra components because of this small size. The size of the circuit fits in within the requirements given to us by our client. It also is small enough to be mounted to the housing and to fit the heatsink.

5.1.5.2 Heat Transfer

The heat transfer for the system is based on a couple assumptions. The first being that the system must be able to cool off the LEDs if they operate at a 50% efficiency, meaning they generate 150W of heat. This heat must be dispersed within the system through the heatsink. The System also must be limited to a temperature of 60 °C. Running the calculations with these assumptions results in a convection coefficient of 350 W/m^2K. This is the necessary convection within the system that the forced air must be able to obtain in order to keep the system at a temperature of 60°C during peak usage. The calculations for this can be found in Appendix D.

5.2 Implementation Plan

5.2.1 Prototyping

The first step for the next semester is to design a functional circuit prototype with a few of the actual LEDs that will be used. The purpose of this prototype is to verify a few aspects of the LEDs that will be necessary in the final evaluation of the circuit before it is finalized for manufacturing. These aspects will include the signal delay that the LEDs may experience, the actual current being pulsed through the circuits at 5v, the overall resistance of the system in parallel and the switching speed of the transistors that will be the limiting factor for the circuit to function at the desired speed. The prototype will also be helpful in determining the actual heat generated by each chip in order to get a more accurate heat transfer analysis.

5.2.2 Testing

After the construction of the next prototype a series of tests will be conducted utilizing this prototype to determine the aspects described above. The first test will be a luminosity output test using photoresistors. This test will determine the brightness of the LED at different pulse speeds. It will help to determine the expected brightness of the system to ensure it will be bright enough, it will also help to determine the exact effects of adjusting the pulse width, and frequency which will be useful in determining guidelines for the use of the device. Next the delay within the system will be determined by pulsing the system normally and analyzing the current around the circuits with the assistance of an oscilloscope. By determining the resistance of each chip the overall resistance can be determined for the system. By doing this it allows the team to determine the exact current travelling through the circuit. Finally the heat generated will be determined using thermocouples. This will determine the exact efficiency of the LEDs when running under pulsed operation, The efficiency will allow the Team to determine the heat generated in the complete system and if the implemented cooling system will be enough to keep the system at operable temperatures.

5.2.3 Final Design construction

The final housing design can be found in Appendix A while the final circuit design is in Appendix B. The main steps that will need to be completed in order to finish the housing will be to order the selected housing, cutting out the holes for the fans that allow for their mounting and for airflow as well as any needed holes to wire the system. The plate that connects the housing to the circuit board and heat sink will need to be manufactured. The heatsink will also need to be drilled and tapped so that it can be mounted. The circuit board will need to be sent to a board house to be manufactured and to have the necessary components soldered to it. The Bill of Materials can be found in Appendix C and contains all the necessary components for the completion of the final design and where they will be obtained from.

5.2.4 Implementation Timeline

The timeline for the continued development of the project next semester is laid out in a gantt chart. The chart lays out the aforementioned steps in a way so that they can be completed within the necessary time frame of the spring semester. The prototype development and testing will be done quickly so that all the necessary parts can be manufactured in time for the final deadline. The biggest unknown for the timeframe of this project is how long it will take to complete the circuit board, being the most critical part of the project this can lead the project to a failure in the end if not enough time is planned. The gantt chart can be found in Appendix F.

6 CONCLUSIONS

This paper contains the results of the LED Flow Capstone project. The project is to design an LED array that increases the outputted light by running the LEDs in pulsed operation at high frequencies. The end goal is to create a viable product that can be used to illuminate fluid flow so that a camera can record the flow to be used in analysis. The LED system potentially represents a cost effective alternative to lasers, the devices traditionally used for this type of analysis. Overall this semester got the team close to manufacturing the device. The team determined the housing and circuit designs and decided on the testing measures for a prototype to ensure the designs will be effective. With the original prototype we showed that the circuit can be run in a pulsed operation with no major delay. The design itself allows for the adjustment of color and intensity within the system and allows for the system to be controlled by a function generator and powered by its own power system. The final design includes a prebuilt housing that will be purchased off of McMaster-Carr and will be further adapted to suit the needs of the design. The circuit utilizes a 450W power supply to power 60 LEDs arranged in a parallel array, Each color channel is connected to its own transistor that is operated through the function generator signal allowing the system to work in pulsed operation. A set of 6 fans pulling air into the housing and a copper heatsink will be utilized to keep the system within operable temperatures.

7 REFERENCES

[1]"Measuring the timing delay and jitter for a real-time application - FieldTrip toolbox", Fieldtriptoolbox.org, 2021. [Online]. Available: https://www.fieldtriptoolbox.org/example/measuring_the_timing_delay_and_jitter_for_a_real-time_application/. [Accessed: 22- Nov- 2021].

[2]“SE-450-5 - mean well - TRC Electronics,” *TRC Electronics, Inc.* [Online]. Available: https://www.trcelectronics.com/View/Mean-Well/SE-450-5.shtml. [Accessed: 22-Nov-2021].

[3]“Find your perfect solution for access to standards,” *ANSI Webstore*. [Online]. Available: https://webstore.ansi.org/?_ga=2.62134629.855544563.1637558485-92337607.1637558485. [Accessed: 22-Nov-2021].

8 APPENDICES

8.1 Appendix A: Housing CAD

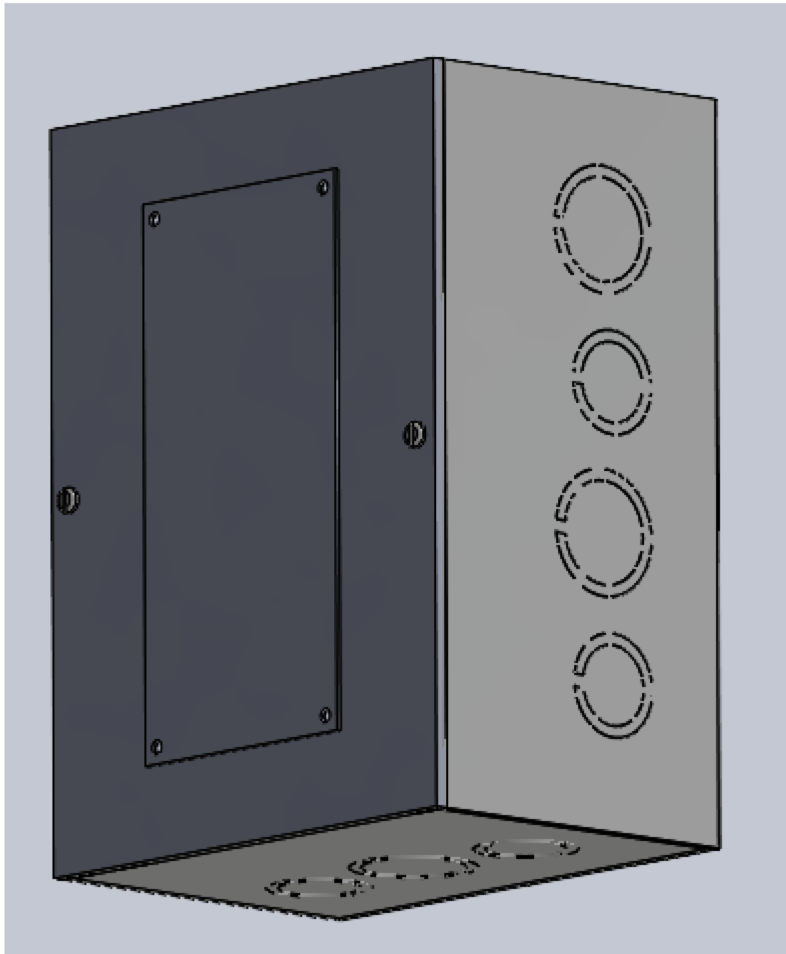

Figure 6: Housing Isometric View

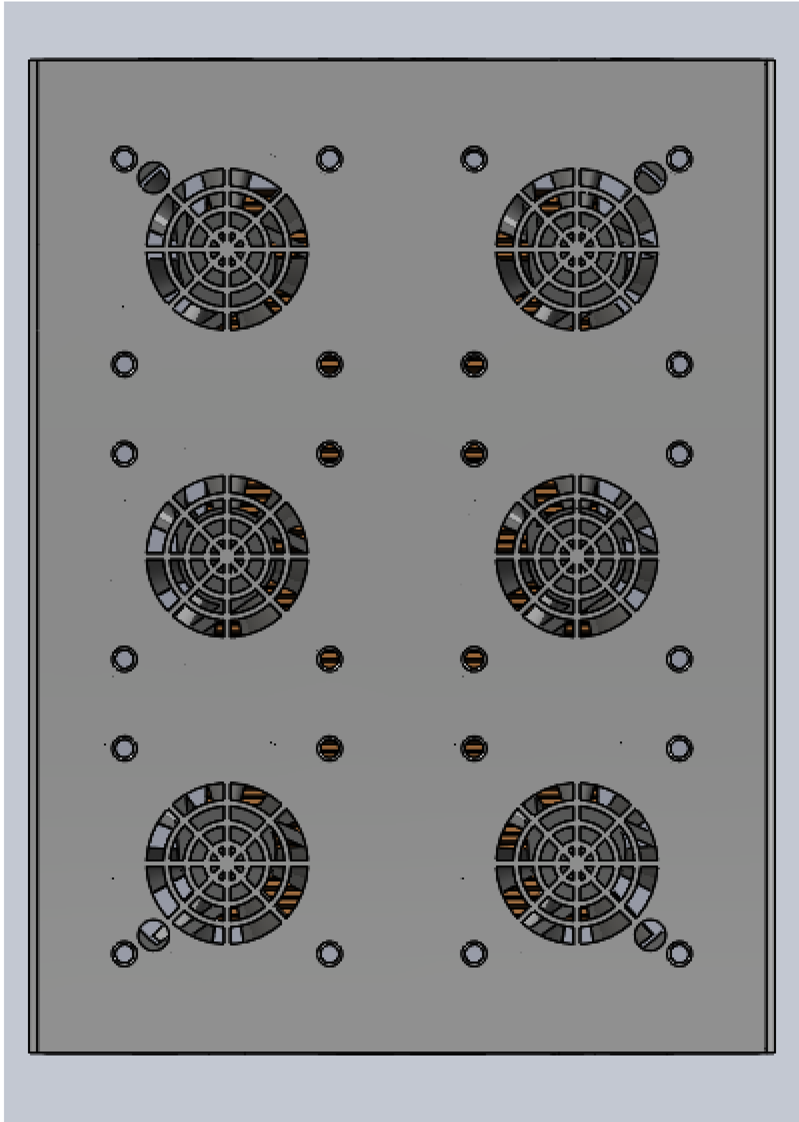

Figure 7: Housing Back View

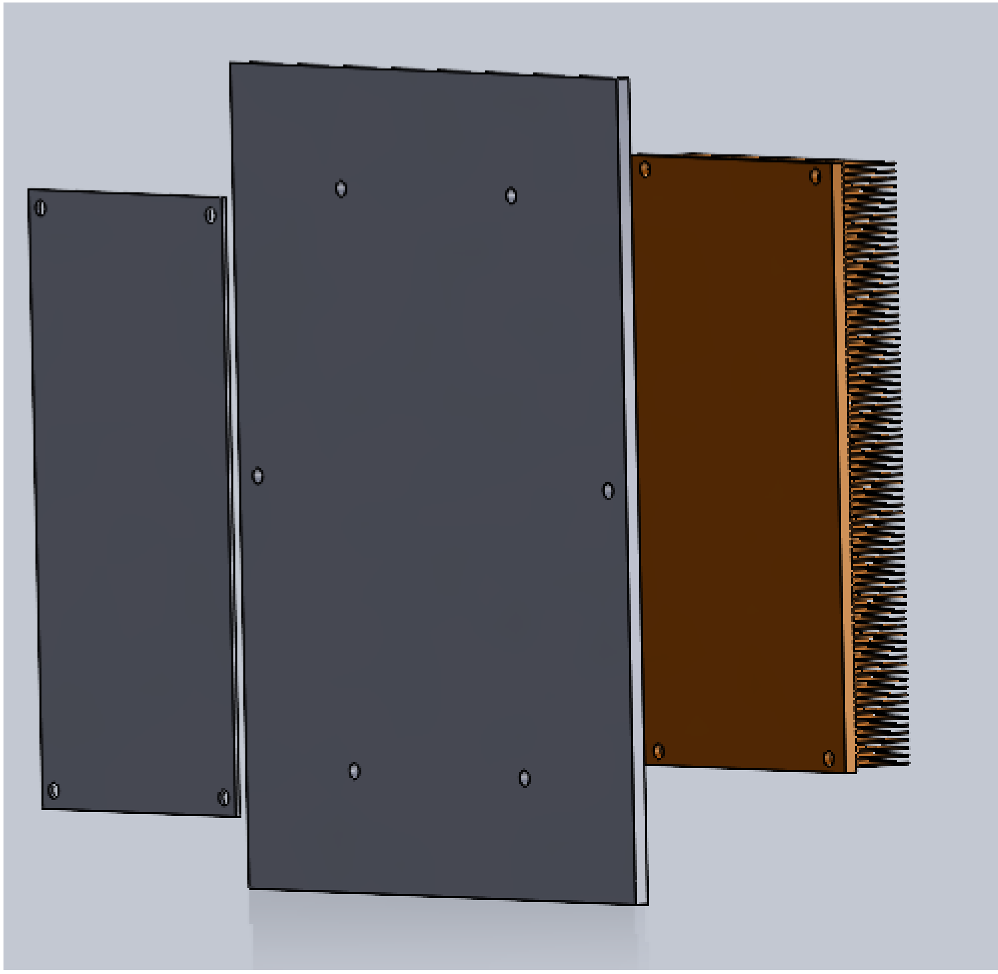

Figure 8: Circuit sub assembly exploded view

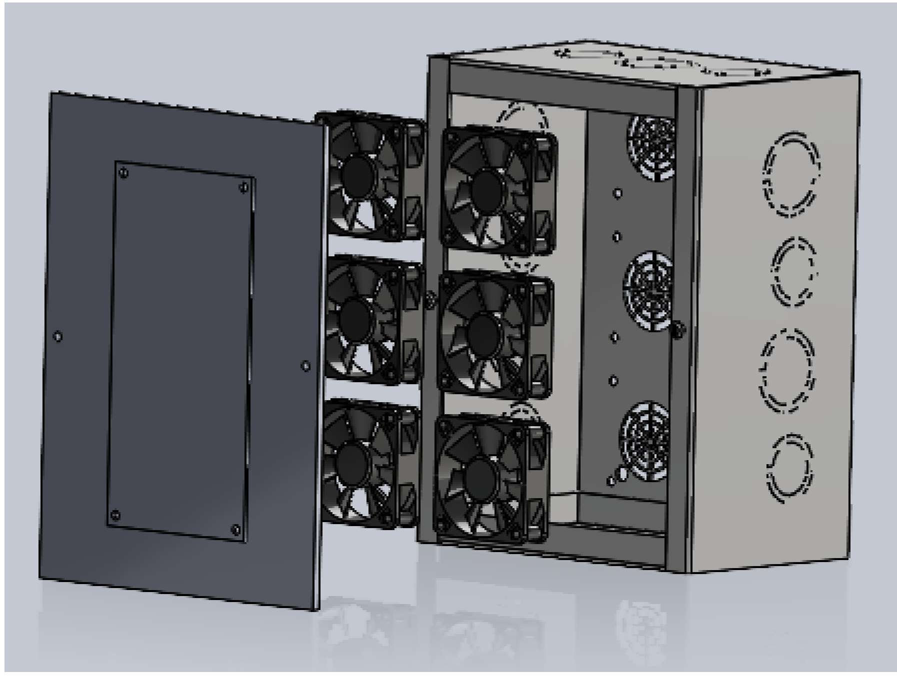

Figure 9: Housing Exploded View

8.2 Appendix B: Circuit design

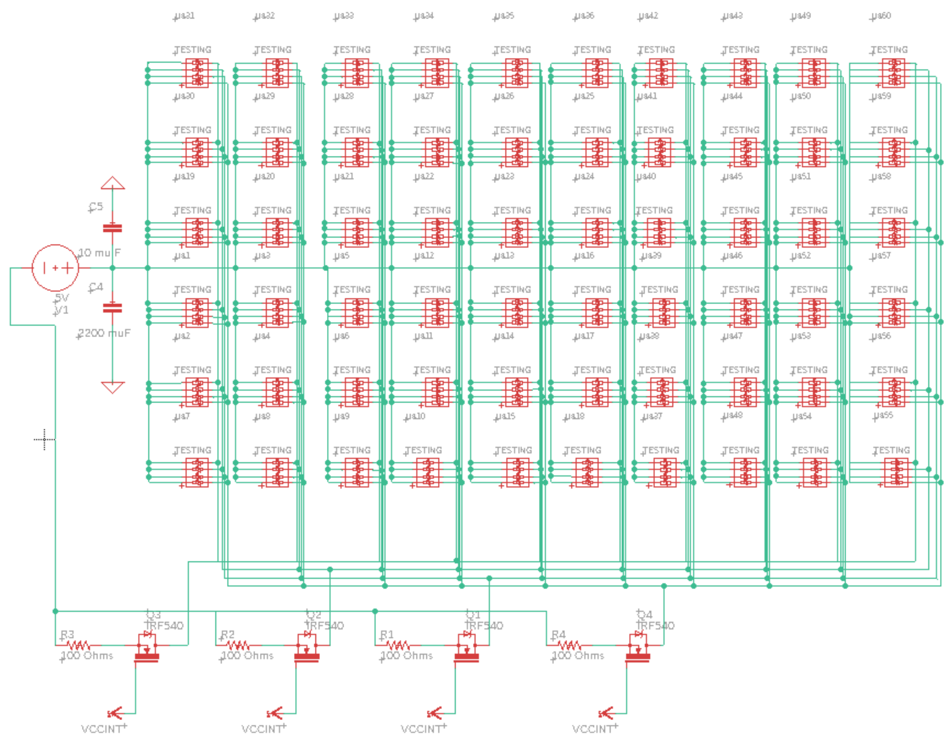

Figure 10: Full Circuit Design

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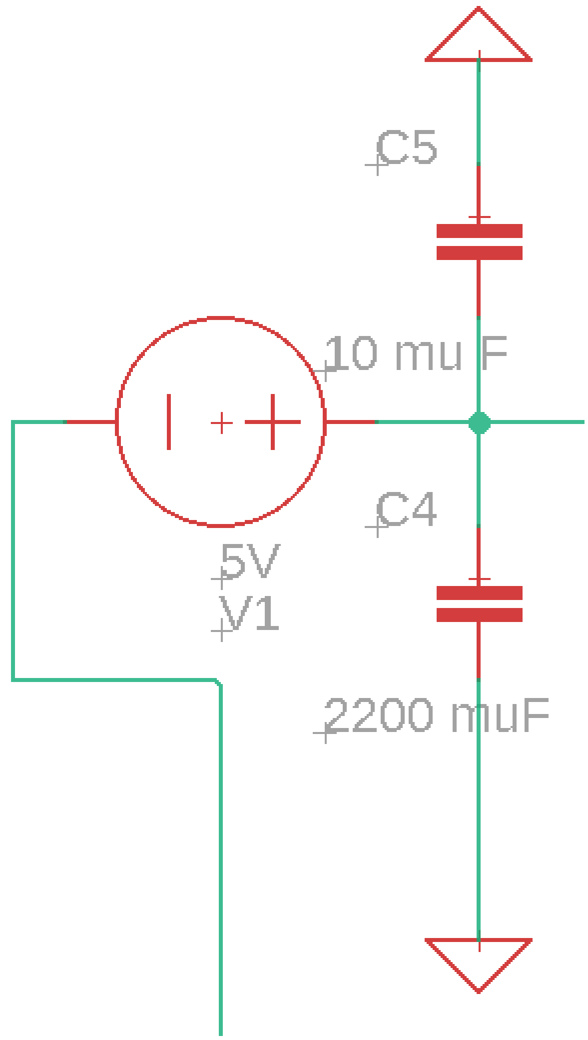

Figure 11: Power and Capacitor input

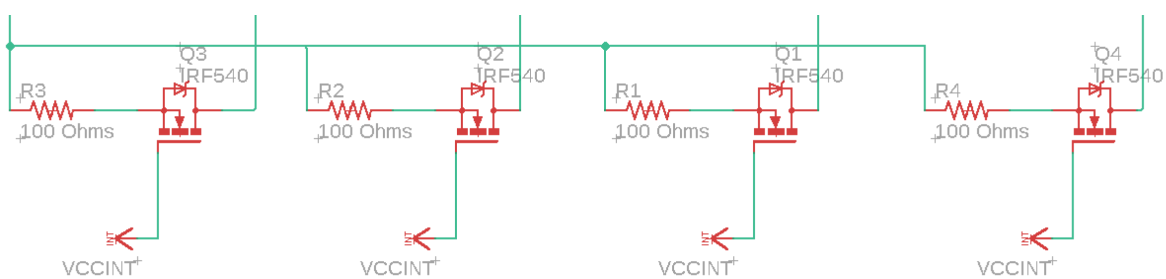

Figure 12: Switch Array

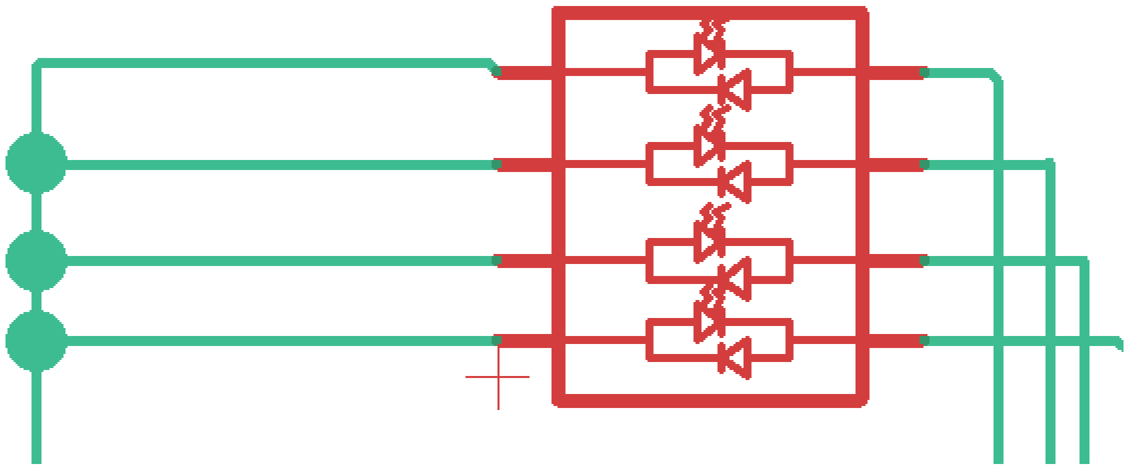

Figure 13: Single LED Chip

8.3 Appendix C: Bill Of Materials

Table 5: Bill of Materials

No.	Qt.	Name	Function	Obtained From	Cost
1	60	LED Chip	Convert the electrical energy into light	Cree LED	$300
2	1	Heat Sink	Fill gaps between the fan and cooling part, make cooling more efficient	Amazon	$50
3	1	Aluminum Cover	Secure the Heatsink + Board to the housing	Manufactured Ourselves	
4	6	Fan	Push air and keep cooling	www.mcmaster.com/1939K46/	$96
5	1	Circuit Board	Control the system	From a board house	$150
6	4	BNC port	Cable Input port for the TTL signal	Undetermined	$10
7	2	Capacitor	Protect the power source from reverse flow	Undetermined	$4
8	4	NPN Transistor	An N-Channel power transistor to stabilize the pulse input.	Undetermined	$5
9	4	Resistor	Circuit component	Undetermined	$2
10	1	Housing	Holds the system together	www.mcmaster.com/75065K12/	$32
11	1	Transformer	5v 300W transformer to power the circuit	www.trcelectronics.com/View/Mean-Well/SE-450-5.shtml	$65
12	28	Screws	Holds together housing assemblies	Undetermined	$10
13	1	Voltage Step Up	Increases the voltage for the fans	https://www.aliexpress.com/item/32870309861.html	$3.00
Total Budget ($1000)					$727.13

8.4 Appendix D: Calculation of Heat Transfer

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:

$$-k\frac{DT}{DX} = h(T_2 - T_\infty)$$

T_2= 59.65 C

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

$$q = h * A * (T_2 - T_\infty)$$

q = 161.36W

8.5 Appendix E: Failure Modes and Effects Analysis (FMEA)

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	8	Over Voltage/Over Current	4	Multimeter	3	96	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

8.6 Appendix F : Second Semester Gantt Chart

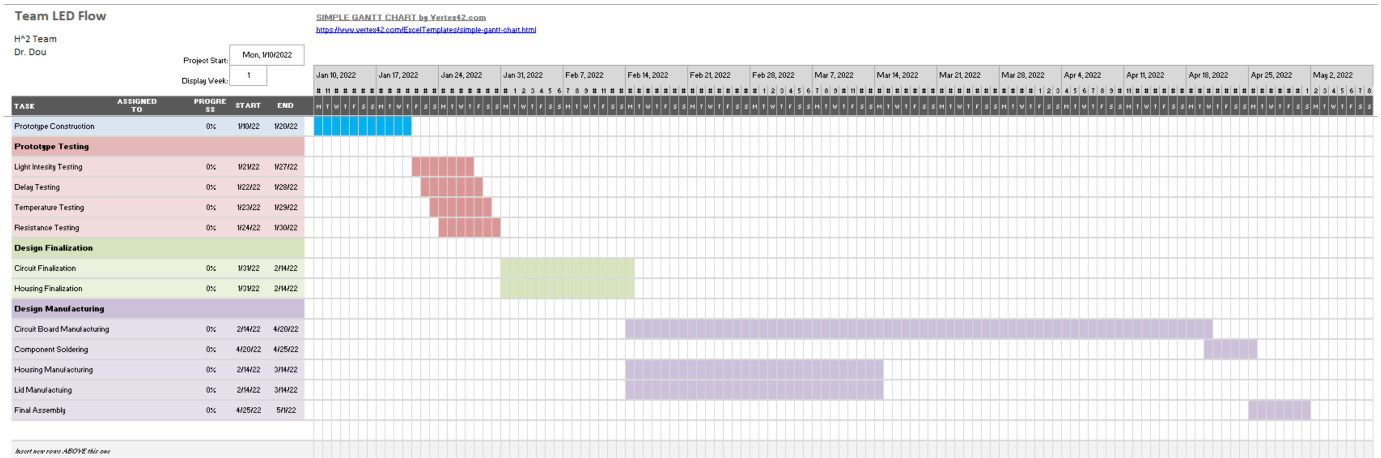

Figure 14 : Implementation Gantt Chart

TASK	ASSIGNED TO	PROGRESS	START	END
Prototype Construction		0%	1/10/22	1/20/22
Prototype Testing				
Light Intesity Testing		0%	1/21/22	1/27/22
Delay Testing		0%	1/22/22	1/28/22
Temperature Testing		0%	1/23/22	1/29/22
Resistance Testing		0%	1/24/22	1/30/22
Design Finalization				
Circuit Finalization		0%	1/31/22	2/14/22
Housing Finalization		0%	1/31/22	2/14/22
Design Manufacturing				
Circuit Board Manufacturing		0%	2/14/22	4/20/22
Component Soldering		0%	4/20/22	4/25/22
Housing Manufacturing		0%	2/14/22	3/14/22
Lid Manufactuing		0%	2/14/22	3/14/22
Final Assembly		0%	4/25/22	5/1/22

Figure 15: Gantt Chart Tasks