ECEB Artwork Illumination

ECE 445 Design Document

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1 Introduction

1.1 Objective

An important aspect of all artwork is visibility. Many modern art pieces are displayed prominently in areas of high visibility that instantly draw attention, but this is not true of all pieces. There is a delicate balance between highlighting the art piece and detracting from the piece itself. While lighting is often used to attract focal attention on art pieces, traditional methods of lighting such as large spotlight installations are not always practical and may instead detract from the art piece. An appropriate system would ideally attract attention to the art piece and not itself, which presents a unique problem that often requires highly specialized solutions. This is of particular importance to the artwork in the ECEB lobby, as it is displayed very prominently across a large area on the wall in an area that has both natural and electric lighting. This means that a lighting solution must both be discrete yet bright enough to properly highlight the art piece.

Our goal is to create a modular, programmable lighting system that is adaptable for various applications. We will start with a basic starting setup of compact, addressable LEDs, after which we will explore various options for artwork-specific lighting applications. We aim to create a modular system that will be both easy to maintain, replace, and expand upon. Our approach should allow for low cost highly expandable discrete control of a large amount of lighting fixtures. We will also explore different fiber optic cables and connections to effectively transfer light into the glass artwork and draw attention. This will allow the ECEB lobby artwork to be discreetly and effectively lit up.

1.2 Background

While many lighting solutions exist on the market, they are expensive and often obtrusive. There is a lack of high power easily customizable modular products that offer easy expansion and programmability options, with many market options only allowing control over approximately 8 lighting fixtures. We intend for our system to comfortably work with independent control of 7 sections, each has ~30 lighting fixtures. Our lighting system should be as compact and discreet as possible, allowing for non-obtrusive integration into art pieces. It must be bright enough to accent the piece under various background lighting conditions, as well as focused enough as to not instead highlight the backing wall or other parts of the surrounding background. This means that a lighting solution must both be discrete yet bright enough to properly highlight the ECEB lobby art piece.

We intend to work very closely with the end product user in order to ensure that the final result will closely match their criteria, especially with regard to finer aesthetic details. As the appearance of our project matters the most, modular design and fiber optics bring the flexibility to our solution and allow variety of moods to meet the user’s preferences. Our end goal is an addressable fiber optic lighting solution that will consist of 7 sections (one for each section of the artwork) mounted using the same mounting bar the artwork currently uses. As each section of the artwork will have ~30 lines, our design will have a controllable lighting fixture for each line to provide the best appearance with any surrounding background.

1.3 High-Level Requirements

- Lighting fixtures must be modular and have the ability to connect to a link to a single DMX wireless receiver.
- Lighting fixtures must provide sufficient light output across the entire piece regardless of external lighting conditions.
- Lighting fixtures must be compact enough to integrate into the existing art piece without extensive modification to its supports.

2 Design

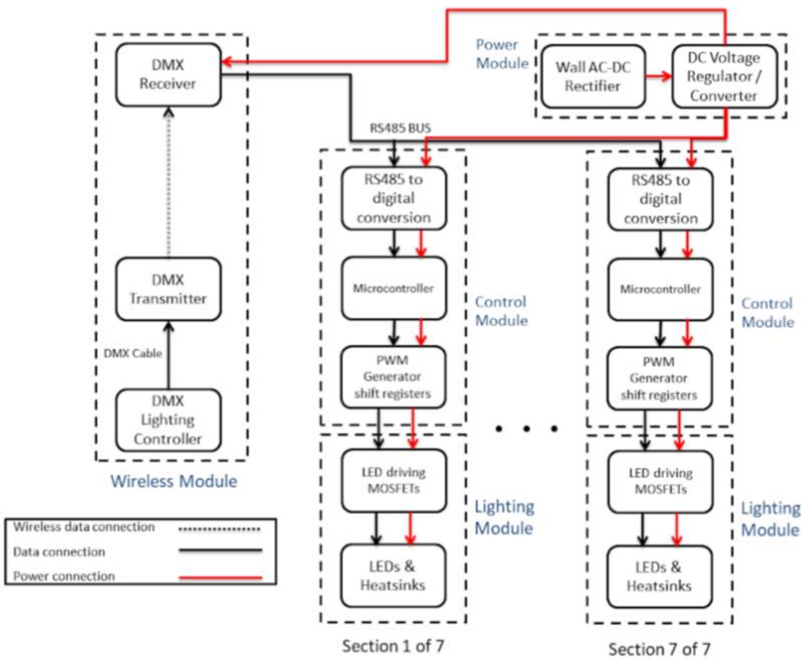

Figure 1: Block Diagram

In our block diagram shown in Figure 1, a generic off the shelf DMX lighting controller will be used to program the lighting sequence for the artwork. The DMX output of the controller will connect to a generic wireless DMX transmitter. A receiver connected to the first module will pick up this input. The first module will pass the signal along to the others and each will read the section of addresses corresponding to the lights they control. Each part of the artwork will use its own RS485 transceiver, microcontroller, PWM generator, and LED driver to light up the fiber optic cables connected to its tubes. The power supply will also be located near the modules above the artwork and supply power for the DMX receiver, microcontroller, ICs, and LEDs.

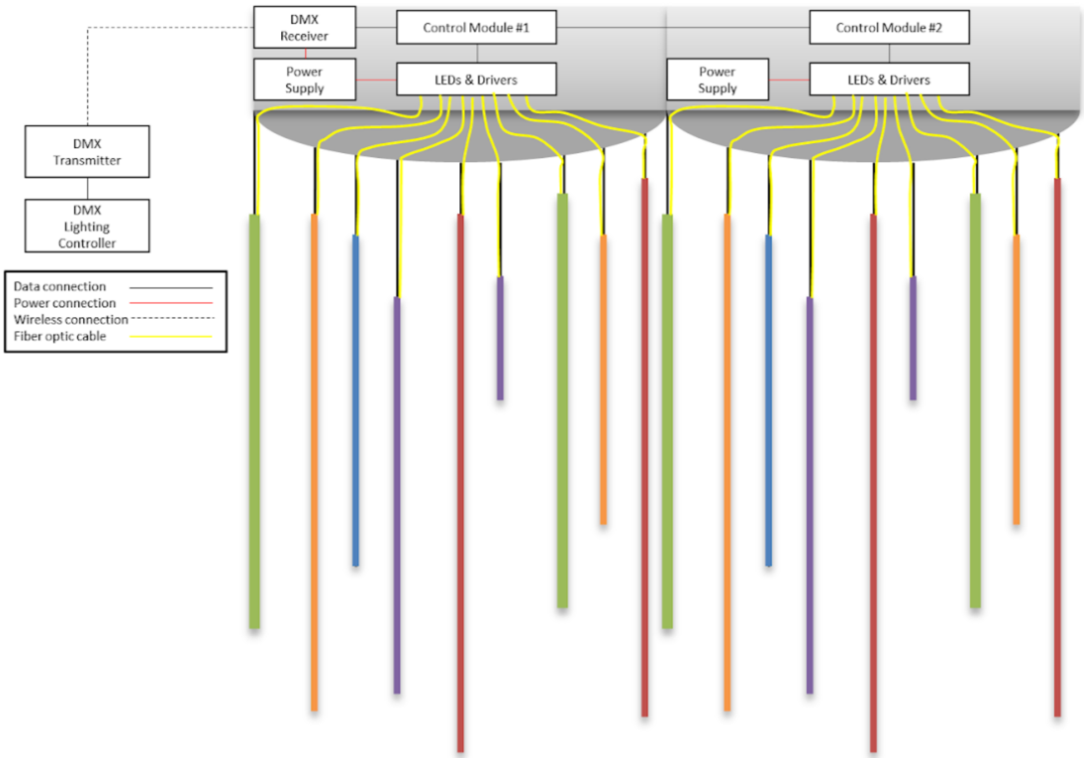

Figure 2: Physical Layout

Figure 2 shows the physical layout for two modules of our project. Complete implementation for this art installation would consist of seven modules, as the piece has seven sections. The lighting controller and DMX transmitter will be positioned in a suitable location to control the project, such as in an adjacent 2nd floor office. The DMX receiver and power supply will be located at one end of the artwork on top of the existing metal support. The control modules, of which one section is pictured, will be connected in series to the output of the receiver. The LEDs and drivers will be located in a second module connected directly to their section's control module. Fiber optic cables will be attached to each LED and route down to the top of the tubes. The light will exit the cable into the tube walls and diffuse through the tubes. We must verify that the weight of the project can be supported by the existing structure and explore options to reinforce the existing structure if required.

2.1 Wireless Module

This module will consist of the commercially available Chauvet Obey 10 DMX512 controller, which has full control of all 512 channels in the DMX512 protocol. The Obey 10 also has the capability to program and run lighting routines at variable speed. The output will be sent using a wireless DMX512/XLR transmitter. This is intended for immediate control for rapid prototyping and diagnostics. For potential expansions and in actual use, a USB to DMX512 cable can be used to send commands from a computer program. For our purposes, the start frame will always be 8 bits of 0. The next frames will consecutively correspond to each individual LED (ie Frame 1: LED 1, Frame 2: LED 2, etc).

Requirement	Verification
Able to provide 512 channels of DMX protocol signal wirelessly up to 100 meters	A. Generate sample lighting data with controller and send via transmitter B. Attach differential DMX output of receiver to oscilloscope and verify output C. Increase transmitter distance to 100 meters and repeat

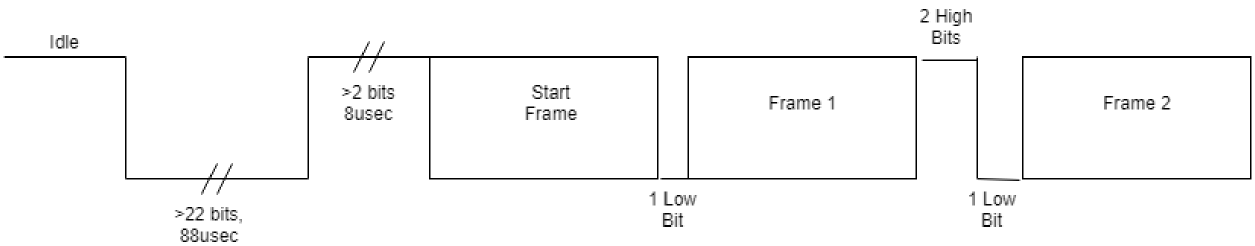

Figure 3: DMX512 Signal Diagram

2.2 Control Module

This module consists of one RS485 transceiver chip, one microcontroller, and the multichannel PWM generator. The RS485 transceiver will take its input from the DMX512 receiver and output a digital signal to the microcontroller. The microcontroller will take this digital signal as input from the RS485, process the data, and output bits to the PWM generator, the PWM generator chip will receive and store the bits to output PWM signals to the lighting module.

2.2.1 DMX to Digital Conversion

A RS-485 transceiver chip will be used in order to convert the differential level DMX512 input signal from the bus into digital logic to be sent to the microcontroller. One chip, placed near its microcontroller target, will be used per section of the artwork to reduce the potential for noise.

Requirement	Verification
- Must operate at 250 kBit/s data transfer rate to match highest rate in DMX protocol - Different receiver levels: binary 1 ($V_a - V_b < -200$ mV) binary 0 ($V_a - V_b > +200$ mV)	A. Connect chip inputs A and B to output of DMX controller with short wires B. Probe chip output D with oscilloscope C. Output typical DMX commands with controller and verify oscilloscope output is as expected

2.2.2 Microcontroller

The microcontroller (ATmega328P) will receive and interpret the digital output from the RS-485 transceiver via a serial input following the DMX512 protocol. It will receive the entire transmission of 512 channels, then depending on the section, the microcontroller will read and store the corresponding number of bytes (first 32 bytes for section 1, second 32 bytes for section 2, etc..), then the 8 data bytes per channel will be normalized to 12 bits (multiplied by 2^4) and sent serially to the PWM generator ICs.

This will need to strictly keep up with the data input, as the entire DMX512 data packet is sent approximately 25ms long with an idle period of 70-90ms [1]. To make our design simpler, easier to replace, and easier to assemble we added three switches to select the module number number. The switches will connect to digital inputs on the microcontroller allowing up to 8 sections to be differentiated. This allows all of the microcontrollers to be programmed with the same code and swapped easily between sections.

Minimum microcontroller specification:

- 1 kB memory
- Nine I/O pins (4 inputs, 5 outputs)
- 2 MHz
- one PWM channel

Requirement	Verification
1. Process the 512 bytes coming from the RS-485 within the duration of typical DMX 512 transmission 2. Output data to PWM generator within duration of DMX 512 transmission (22.6 ms with idle period of 70-90 ms) [8]	1. A. Once correct operation of the RS-485 transceiver chip has been verified, connect the digital logic output of the chip to a serial input on the microcontroller B. Send a DMX transmission to the transceiver and have the microcontroller store all channel values C. Probe an available digital output pin on the microcontroller with the oscilloscope and verify that it is able to output the values from the transmission input 2. A. Connect the PWM generator chips to a serial clocked output on the microcontroller B. Send a DMX instruction to the microcontroller and have it set the output intensities for its LEDs C. Probe the current sink outputs of the PWM generator with the oscilloscope and confirm waveforms are as expected

2.2.3 PWM Generator

The PWM generator will receive the data from the microcontroller in order to determine the rate at which to drive the LEDs allowing for fine control over brightness. A dedicated chip will be used for the generator as most low cost microcontrollers do not supply enough different PWM channels. The 16 channel PWM generator we have selected is unable to sink sufficient current to drive all 16 LEDs simultaneously so it's outputs will be connected to basic MOSFET LED drivers. We will be using two of these per section to control up to 32 LEDs.

- PWM output frequency of >300Hz to ensure steady lighting

2.3 Lighting Module

The lighting module is the module that contains all the LEDs and heat management. This module will focus on powering the LEDs correctly and minimizing power loss and keeping temperatures in a safe range.

Requirement	**Verification**
LEDs must operate below 100℃	A. Drive LEDs at maximum output and wait 10 minutes for thermal build up B. Measure temperature of LED surface with an IR thermometer to ensure under <100℃

2.3.1 LED Driver & LEDs

The LEDs will be white and need to be energy efficient as well as have good thermal characteristics in order to ensure longevity and efficiency. Our PWM generator is capable of driving 16 LEDs via current sink outputs, but it is only able to sink 60 mA of current per output. As our expected current is 1 A per LED at maximum brightness, the PWM generator will need to connect to external LED drivers. Since the generator's sink current can be controlled by a reference resistor, bipolar junction transistors are well suited for drivers as they will allow us to control the LED current. Heat dissipation will be accomplished with copper plated vias underneath the thermal pad on the LED. Heatsinks will be mounted on the other end of these vias, allowing for good thermal management.

- LED drivers must be able to operate at PWM output frequency

2.4 Power Module

The power module is responsible for providing power to the entire system. The power module must provide stable adequate power at various levels required for the different components.

Requirement	**Verification**
1. Maximum 5% voltage variation at all loads 2. Regulated output voltage of 5VDC ± 5%	1. A. Connect simulated load to output of inverter B. Using oscilloscope, measure output voltage and ensure no variations over 5% of set value C. Simulate different valued load and repeat test 2. A. Connect voltage converter to rectifier output B. Connect expected load to converter output and connect variable load to rectifier C. Vary the rectifier load to simulate typical operation conditions and measure the output voltage of the converter with an oscilloscope

2.4.1 Wall AC-DC Rectifier

The input source will be a standard 120 VAC outlet located behind the artwork. A power cable of discreet appearance will run up the wall to the power module located on top of the mount for the artwork. The input AC source will be rectified to the appropriate DC voltage for the LEDs. Since the LEDs will draw a large load, active or passive thermal management may be implemented.

- Power supply must provide sufficient current to drive all LEDs for one module at maximum brightness (30 LEDs * 3 W per LED = 90 W minimum)

2.4.2 DC Voltage Converter

Due to the microcontroller, DMX receiver, and ICs requiring 5 V input, additional DC-DC conversion will be required with a regulated output voltage to protect sensitive components. The input voltage from the rectifier will be 3.3 V or similar, depending on the driving voltage for LEDs. The converter will boost the output voltage to 5V.

- Output current of converter must be sufficient for all components (1 A expected)

2.5 Fiber Optic Module

Fiber optic cables will receive light from the LEDs in the control box above the artwork. The cables will route down the existing supports for tubes in the artwork to their respective tubes. Once a cable is aligned with the top of a tube, its light will diffuse into the tube walls and illuminate it. For sufficient light to be transmitted to the tubes, connections of LEDs to the cables must be efficient. Also, in order to not change the overall appearance of the artwork, the cables must be discrete.

Requirement	Verification
1. >20% coupling efficiency at LED to fiber optic connections 2. Appearance of fiber optic cables is unobtrusive	1. A. Drive LED at maximum power and measure output of lens with flux meter B. Connect LED lens to short, 2 inch fiber optic cable and measure light output from cable with meter 2. A. Photograph the artwork before installation of the lighting system. Install the lighting system and photograph the artwork with the system powered on and off B. Gather feedback from ECEB patrons on the change in appearance to verify a lack of negative feedback on the change

2.5.1 LED to Fiber Optic Connections

Connection of high-powered light sources (>20 W) to fiber optics is typically done using lenses and a large box typically containing all components involved in driving the light source. Despite hopes of a simpler setup, testing has shown that physical connections of LEDs to fiber optic cables is far too inefficient to be feasible for a project of this size. Our coupling will consist of a PCB mountable lens designed for the LEDs we are using. Although the light output of this mounted lens is focused onto a narrow spot, further testing will be required to ensure enough of the light is accepted into the fiber optic cables. Multiple strands of fiber optic cable will be grouped and attached to the light output. This allows us to design the size of the cable to match the light spot diameter as well as transmit more light than with a single cable.

If additional focusing is required, glass optical lenses will be placed after the PCB mounted lens to narrow the light to a point. As the cost of 30 small, powerful optical lenses may exceed $600 for one of seven sections, design reconsiderations may need to be made if these lenses become a necessity.

Due to the nature of fiber optics and light channeling, there is typically a 30% loss of light at illuminator to light couplings [5].

2.5.2 Fiber Optic Cable to Artwork connections

After illumination, the bundles of fiber optic cable will be routed down the 30 preexisting support cables to their destination. Since multiple tubes are attached to some supports, strands of fiber optic cable can be branched off into different tubes. The strands will be aligned with the top of their tube with a clear plastic connector.

2.6 System Enclosure

The power supply and all circuitry for controlling and driving the LEDs will be housed in an aluminum box above the sculpture. This will alleviate leakage light from interfering with the artwork and give the project a professional overall appearance. A computer case fan will be mounted to the enclosure to assist in heat dissipation [6].

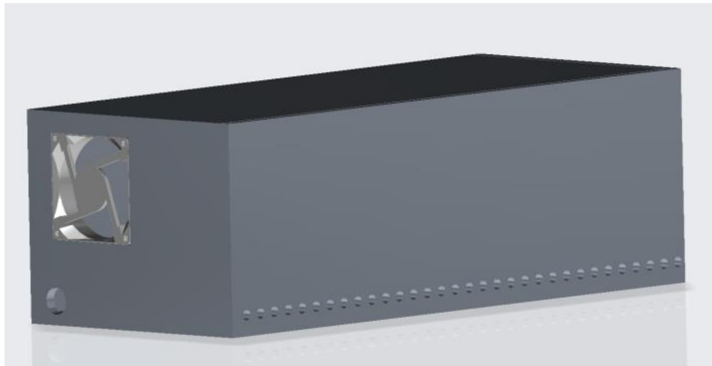

Figure 4: Enclosure Model & Fiber Optic Connection

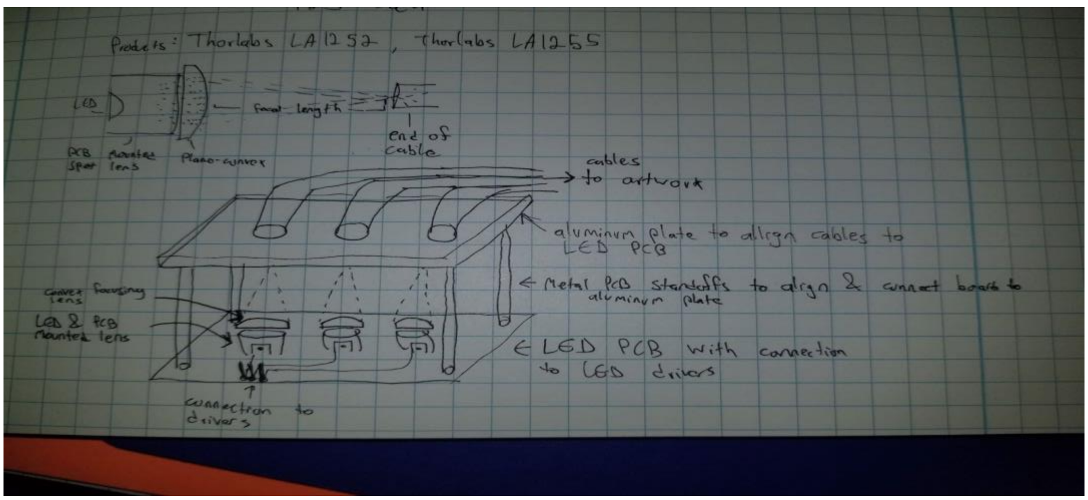

Figure 5:LED to fiber optic cable connection

2.7 Schematics

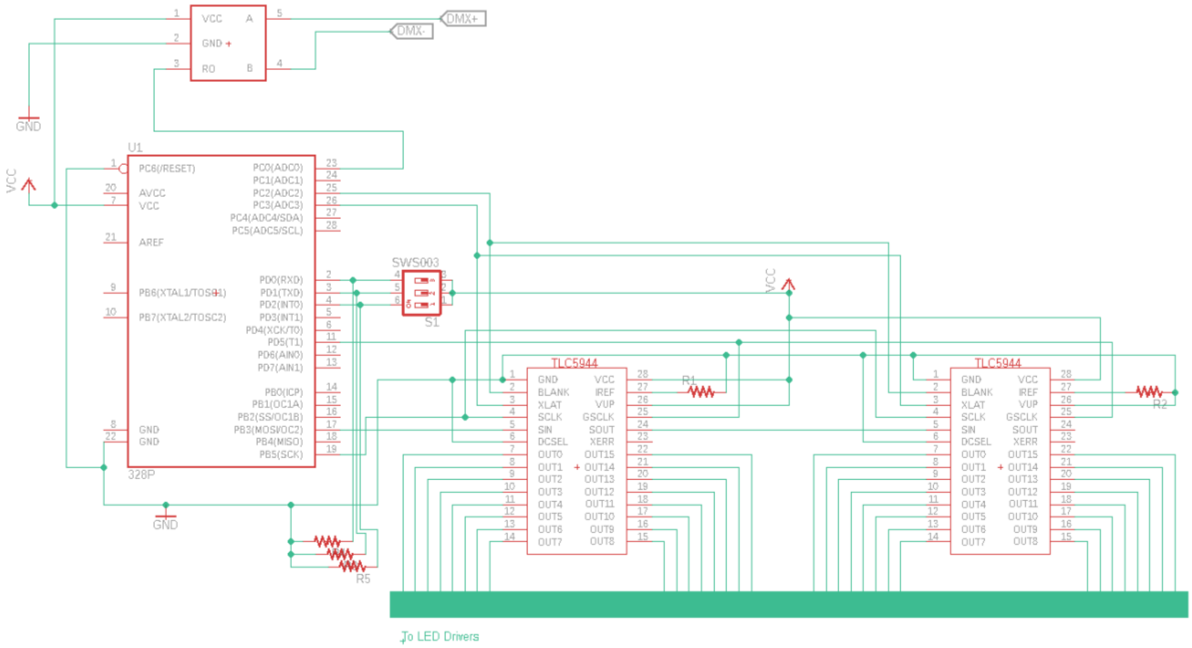

Figure 6: Control Module Schematic

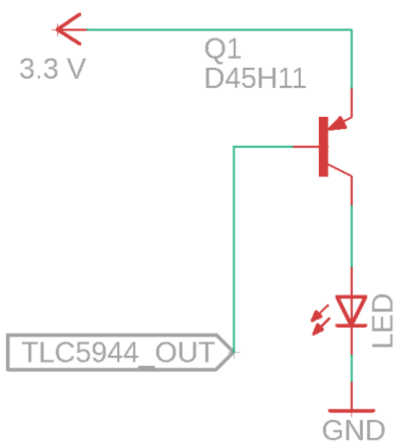

Figure 7: LED Driver Schematic

2.7 Software

We will program the microcontroller using programing language C. After the microcontroller receives the data from th RS-485, the software will process these bits. Each channel of the 512 will contain 11 bits: 1 start bit, 8 data bits, 2 stop bits.. Depending on the input bits to PINs PD0, PD1, PD2 (chip number), the program will store 32 bytes in the memory. The program will process the data that matters to the current chip and ignore the rest. The 3 bits from the switches will identify the chip location (section 1 to 7).

After receiving the 32 bytes, the program will multiply each byte by 16 and stores the new 32x12 bits in memory. The 32x12 bits will be sent to the PWM generator using PINs PB3 (digital output) and PB5 (clock) of the microcontroller.

One last thing our program need to take care of is the X-latch signal we want to send to the PWM generator. This will act as execute for the PWM generator. So, after sending the whole 32x12 bits, this signal will be sent to let the PWM generator execute and send the signals to the LED drivers.

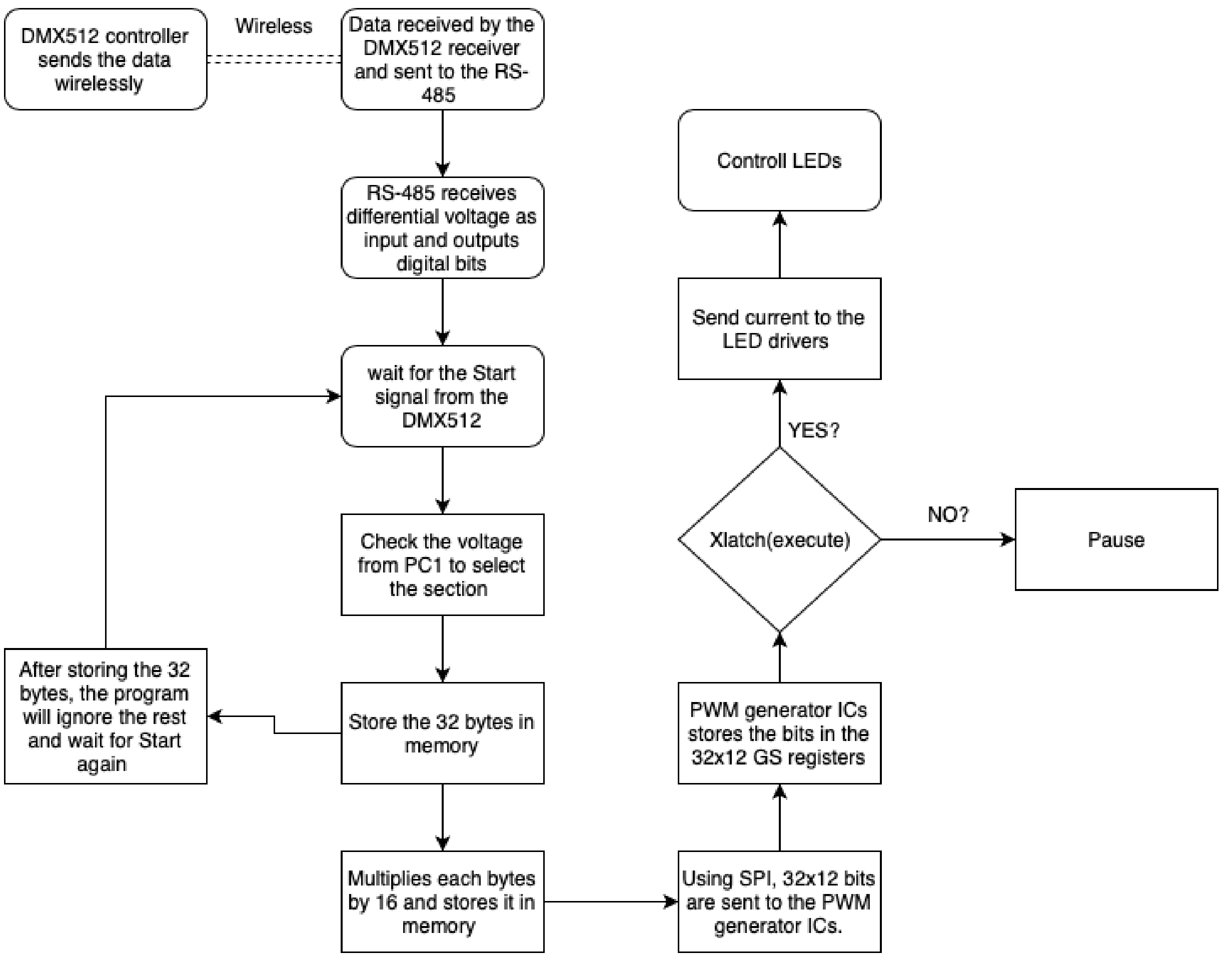

Figure 8: Control Flow Chart

2.8 Tolerance Analysis

Tolerance analysis was initially ran assuming a 5 volt input overall with current limiting resistors for the LEDs. This setup was determined to be far too inefficient and the design was modified. The power supply voltage has been changed to 3.3 V and bipolar junction transistors will be used in place of the previous MOSFET with series current limiting resistor combination. Our PWM generator chips are designed to control lower powered LEDs with current sink outputs. During the initial design, we simply used the chip's outputs to pull the gate of a P channel MOSFET from 5 V to ground and therefore apply a constant voltage to the LEDs. While, in theory, this setup works, there is no method to control the current through the diodes without using series current limiting resistors and greatly reducing the efficiency. Removing the resistors and picking the source voltage similar to the typical forward voltage of the LEDs potentially could alleviate this issue, but minor upwards variances in the input voltage would flood the LEDs with current and destroy them.

Our current approach takes advantage of the current sink properties of the PWM generator's outputs. The amount of current the PWM chip sinks can be precisely controlled with a reference resistor attached to an input pin. This makes the PWM chip an excellent candidate for acting as a current source that can be connected to the base of a BJT. With the BJTs operating in forward active mode, the collector emitter current is proportional to the base current. If the base current is properly set and operation is in forward active mode, the BJT will always allow the proper amount of current to flow through the LED, even with upwards variations in input voltage.

This setup was simulated at various input voltages to observe efficiency and LED power. LED modeling parameters were obtained from the manufacturer's website for the CREE XP-E2 white LED. Current is specified to be between 100 mA and 1000 mA for typical operation. A D45H11 power PNP transistor from On Semiconductors was used and provides up to 10 A of collector emitter current. Efficiency peaks at 99% for input voltage between 2.9 and 3.1 V, corresponding to LED power between 0.88 and 1.78 Watts. At 3.3 V input, the LED operates at 2.63 Watts and 96 % driver efficiency. With input of 3.5 V or above, LED power slowly increases while the BJT begins to dissipate more. Efficiency falls below 50% with an input voltage above 6.6 V, although this scenario should never be encountered. Figure 9 shows the results of the simulation and table lists important values.

The power supply LS150-3.3 by TDK-Lambda Americas Inc should fit our requirements well. The output current is 30 A and output voltage can be regulated between 3.0 and 3.6 V. At 3.3 V output, the expected current draw for 30 LEDs is 30 * 825 mA = 24.8 A, so this supply should be able to run one set of LEDs operating at maximum brightness. A different power supply, or combination of supplies, may need to be used if multiple modules are installed.

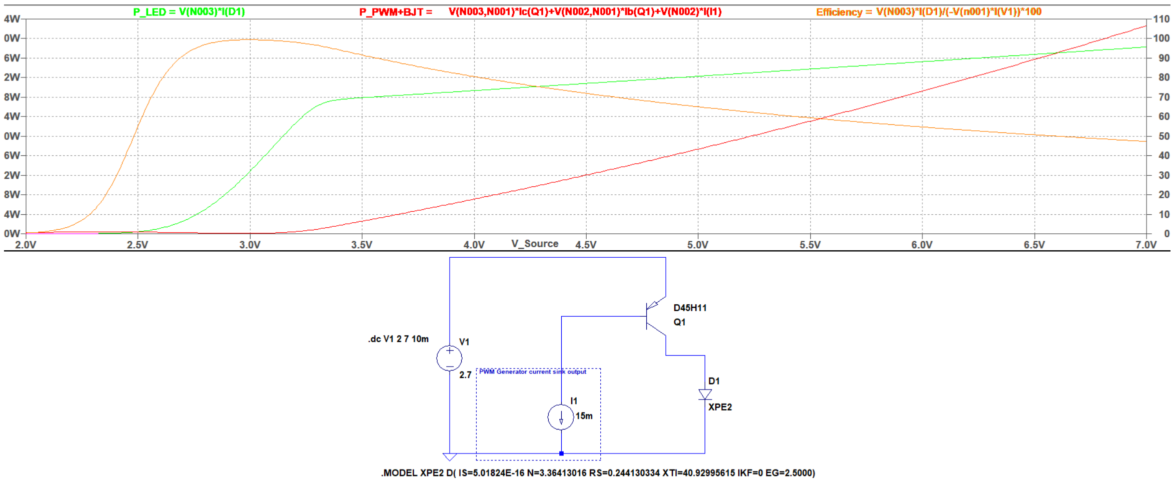

Figure 9: Effect of source voltage variation on LED operation

Input Voltage (V)	LED Power (W)	Efficiency %
2.6	0.102	76
3.0	1.31	99
3.3	2.61	96
3.6	2.81	89
5	3.22	65

Table 1: Highlighted input values and efficiency

3. Costs

Our cost may change dramatically depending on the results of testing with different fiber optic cables and lenses. The estimated $300 for cables is for 500’ of 2.0mm diameter cable. We are unsure as to how many cables need to be bundled for best light transmission. The estimate of $600 for optical lenses breaks down into 30, $20 lenses with 25mm diameter and 50mm focal length; this cost will only be incurred if light focusing from the PCB mounted lenses is insufficient. Cost for full implementation was calculated by multiplying prototype cost by 7 and adding a 25% discount for bulk purchases.

Part	Cost (single module prototype)	Cost (full implementation)
Microcontroller (ATmega328P)	$4.30	$23
PWM Chips (x 3)	$7.92	$42
RS-485 Transceiver	$2.66	$14
LEDs (Cree XP-E2 x 30)	$30	$158
PCB Mount Lenses	$60	$315
Fiber Optic Cables*	$300*	$1,575*
Power Supply	$40	$210
Optical Lenses*	$600*	$3,150*
Misc. (Metal, 3D printed parts, small craft items)	$50	$263
Total if optical lenses are required	**$1,094.88**	**$5,748.12**
Total without lenses	**$494.88**	**$2,598.12**

4. Schedule

Friday of Week	Ansel	Fadi	Lance
10/5/18	Complete and submit design document		
10/12/18	Test LED to fiber optic and fiber to fiber connections	Test LED to fiber optic and fiber to fiber connections	Prototype and test PWM chips
10/19/18	Continue LED fiber optic connection and physical layout	Work on the ATmega328P and its programming tools	Test DMX protocol using oscilloscope and verify wireless transmission, test RS-485 transceiver
10/26/18	Finalize PCBs for round 1 order	Finalize PCBs for round 1 order	Finalize PCBs for round 1 order
11/2/18	Test power module and assemble / test PCBs	Complete debugging the control unit.	Complete microcontroller input and output testing
11/9/18	Revise PCBs for second round order	Revise PCBs for second round order	Revise PCBs for second round order, complete thermal tests
11/16/18	Begin construction of module	Will be out of school for a week (Expecting a baby Nov. 14)	Test expansion for addition of PWM drivers
11/23/18	Thanksgiving break (continue construction of module)		
11/30/18	Continue building final prototype and integrate with artwork	Continue building final prototype and integrate with artwork	Continue building final prototype and integrate with artwork
12/7/18	Prepare for demo and write report		
12/15/18	Finalize report		

5. Ethics and Safety

One possibility safety concern is the lighting itself. LEDs are known to have signature peaks around the 450 nm wavelength region (the generally blue region), which is known to be a wavelength range that human retinas are more susceptible to damage from [2]. This has come in conversations about very bright, glaring lighting installations such as street lights. However, studies have shown that LEDs are no more damaging than other light sources with equivalent correlated color temperature [3]. We do not expect to constantly oversaturate the surrounding area, but we will ensure that no single on the art piece is too bright or concentrating light onto other areas. There have also been concerns raised in the past about how white LEDs in particular can disrupt the body's circadian rhythm. Despite what impression finals week may impart, the ECEB lobby is not an area meant for sleeping so we do not expect this to be an issue.We will keep this issues in mind to ensure that our approach does not affect the health of those around it, aligning with Article 1 of the IEEE code of ethics [4].

Another significant safety issue is power. As we are working with voltage supplied from a wall socket that has significant potential for damage. To ensure that power is regulated at all times the power module will be well overrated for our intended maximum use situations. We also must keep the weight of our design in mind, as too much weight put onto the existing mounting bracket for the art installation will cause structural failure, which violates Article 1 of the IEEE code of ethics by risking the "safety, health, and welfare of the public"[4]. To ensure this does not happen, we will strictly adhere to the engineering design of the current predecessor and reinforce the mounting solution if required.

Article 1 of the IEEE code of ethics dictates that we "strive to comply with ethical design and sustainable development practices"[4]. We intend to adhere to this by ensuring that our design is as efficient as possible, taking advantage of the energy efficiency of LEDs compared to more traditional lighting elements. We will vigorously stress test our design in order to adhere to Article 9 of the IEEE code of ethics: "to avoid injuring others…"[4]. We also will establish clear communication with the end product user in order to be clear and ethical in our presentation of results as Article 3 of the IEEE code of ethics states [4].

References

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