HIP HOP XPRESS AUDIO SYNCHRONIZED LIGHT EMITTING DIODE SYSTEM

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1. Introduction

1.1 Objective

Dr. William Patterson's Hip Hop Xpress vehicles have been symbols of African American music and learning in the Champaign-Urbana community for many years. It exists to educate people in under-resourced communities about science, technology, engineering, and mathematics (STEM) education concepts, through hip hop music [4]. Furthermore, people will have the opportunity to learn more about STEM and how it relates to professional audio systems, musical instruments, and sound engineering equipment and lighting. While the bus can be acoustically captivating when music is playing, it lacks the visual appeal to capture people's attention. The best way to accessorize and personalize vehicles today is by using Light Emitting Diodes (LEDs) that are both visually appealing and entertaining. However, simple LED strips are not quite enough to make the Double Dutch Boom Bus as visually captivating as possible.

To solve this problem and to fulfill Dr. Patterson's vision of integrating STEM education with hip hop culture, we will be creating an automated LED lighting system. The LED system will be a scalable system that can be synchronized to the frequencies of any audio that can be played from the bus. This will be accomplished through a combination of frequency filters to process the audio signals and a microcontroller to synchronize it with the LEDs. The colors, brightness, and lighting patterns of the LED system will be automated and will have the flexibility to be installed externally or internally.

1.2 Background

With the recent technological advancements in LED lighting systems and automation, the application of LEDs to various systems and structures is limitless. Considering autonomous cars can drive through traffic, and drones can take pictures of you from 30 ft in the air, most LED controllers still blink erratically to music, and most audio-synchronized LED lighting systems acquire audio input through a small cheap microphone. Our LED lighting design will be receiving a clean analog audio signal directly from an audio line-out source. This is far superior to using a cheap microphone because a crying baby in the room will not interfere with the LEDs' performance. Additionally, receiving a clean line-out analog signal means that the integrity of our audio signal will be much higher than a microphone's. Furthermore, the audio signal will be converted to a digital signal which will be translated to a program that will illuminate the LED lights in beautiful patterns and colors. The LED components of the system will be low-heat, and safe to the touch. It will also be IP67 waterproof rated [2] which is ideal for internal and external vehicle applications.

1.3 High-Level Requirements

- Acquire and decompose the analog audio signal into bass, mid, and tweet signal components.
- Convert bass, mid, and tweet analog signals to valid LED strip configurations such that the human eye does not notice any lag between the music and the lights.
- Drive nine-meter-long LED strips with negligible color distortion from configurations calculated in the previous requirement.

1.4 Sketch of Final Product

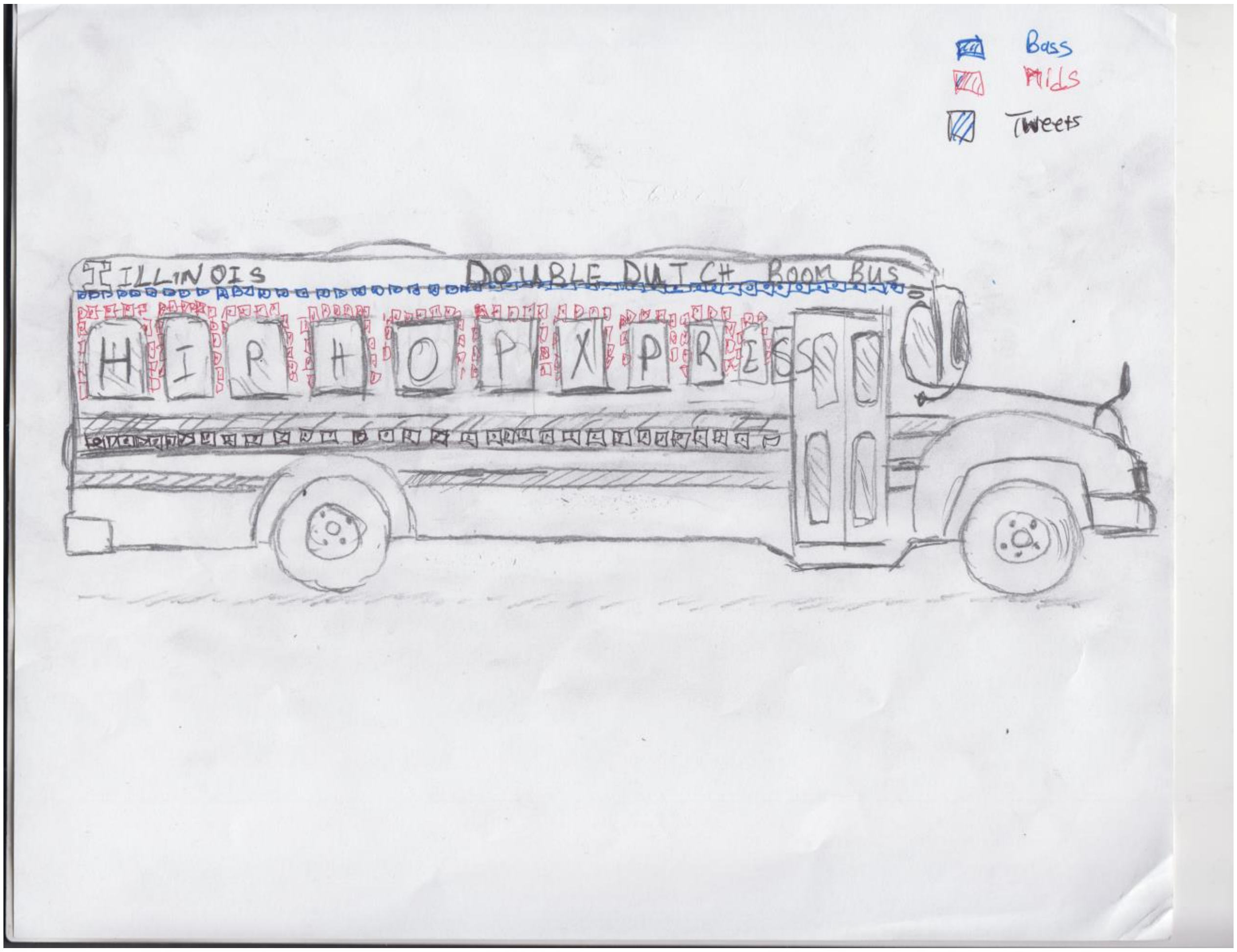


Figure 1. Physical Design Sketch

2. Design Diagrams and Descriptions

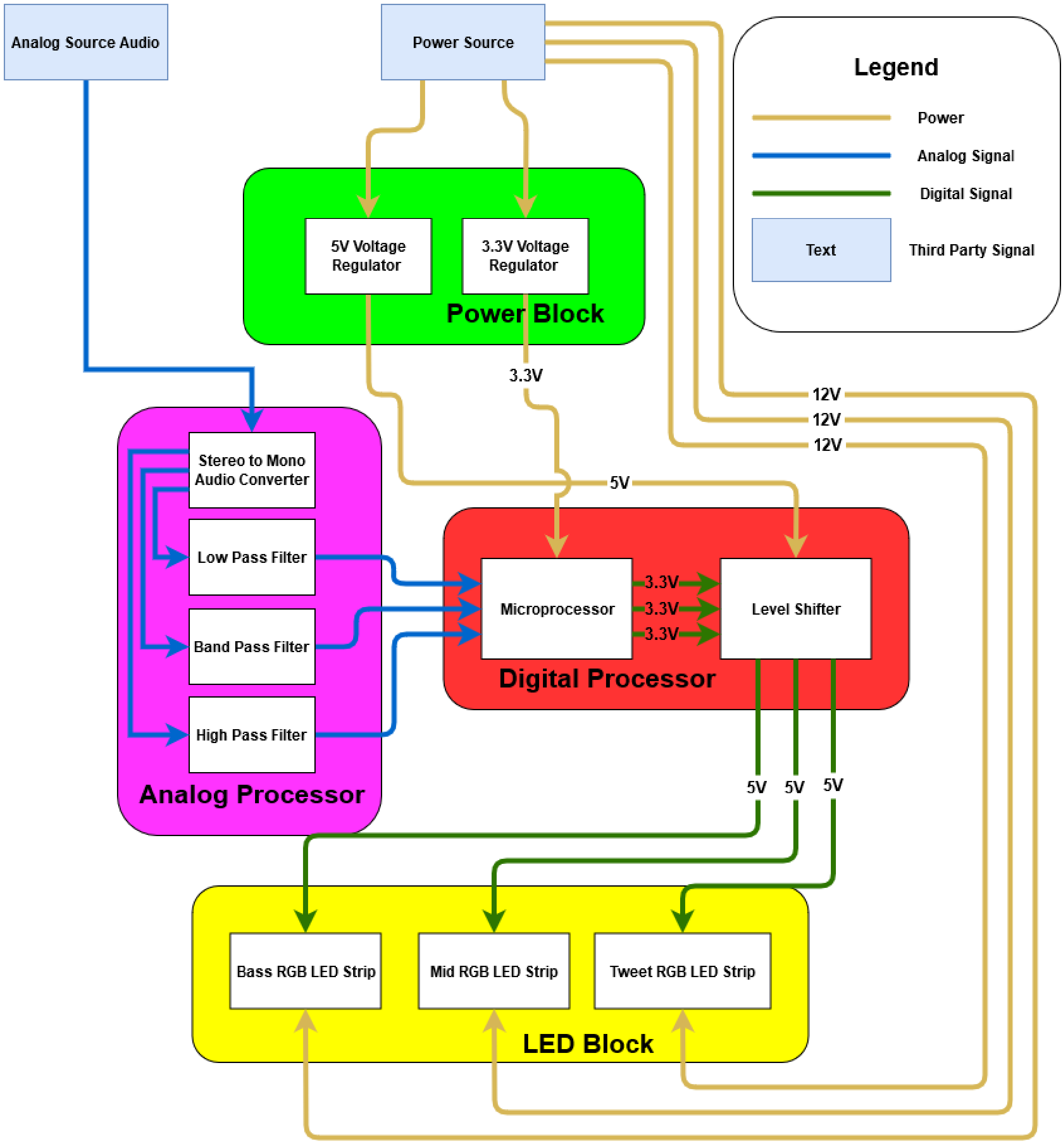


Figure 2. Block Diagram

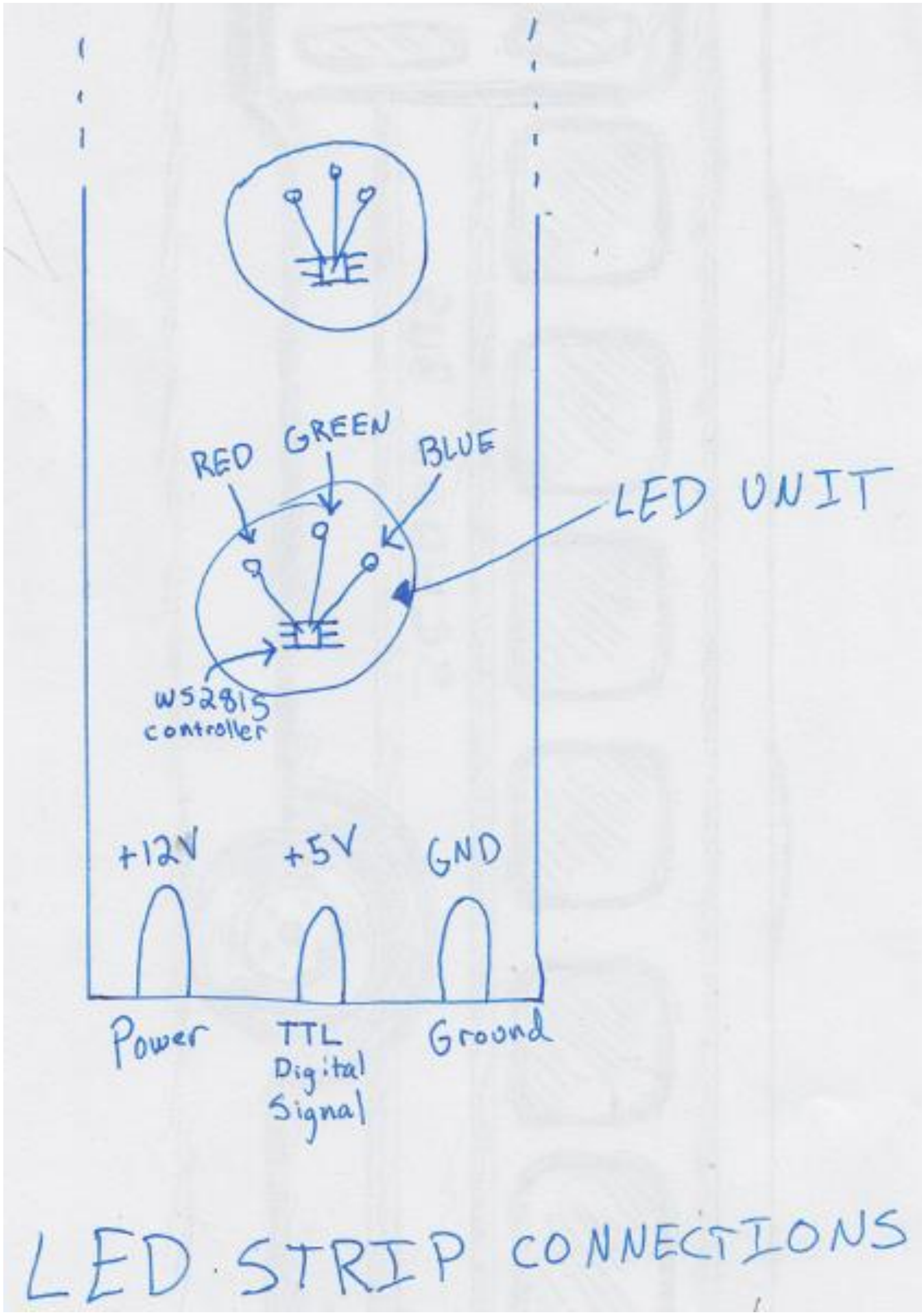


Figure 3. LED Strip Sketch

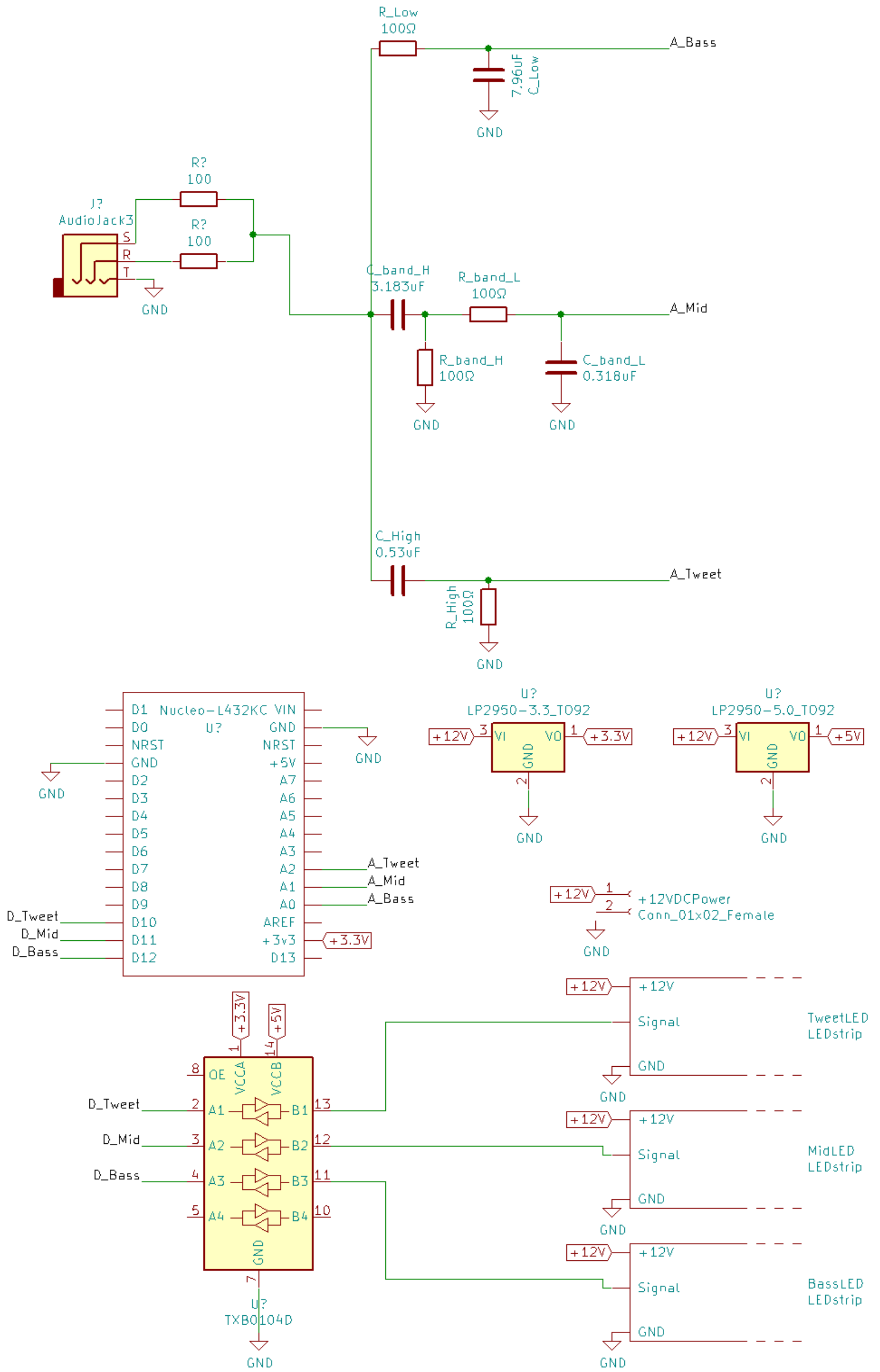


Figure 4. Schematic Design

2.1 Power Block [10 Points]

A third-party power supply (Automobile power systems generally run on 12VDC) will be used to power the project. Voltages will be regulated according to each component's required voltage using a linear voltage regulator.

2.1.1 +5V Voltage Regulator (L7805CV)

The voltage regulator will step the third-party power supply voltage down to +5V±5% to power the level shifter and microprocessor.

- Inputs: +12VDC from a third-party power supply
- Outputs: +5VDC for integrated circuit chips

Requirements	Verification
1. Supply voltage must be between +12VDC and +30VDC. 2. Must provide stable +5±5% VDC output voltage.	1. Read the input voltage signal to the L7805CV on a multimeter to verify voltage values. 2. Read the output voltage signal from L7805CV on a multimeter to verify voltage values.

2.2 Analog Processor Block [20 Points]

The analog processor will be supplied with an analog audio signal. This signal will be converted from stereo to mono and then split into three (bass, mid, and tweet) frequency-based signals. The bass, mid, and tweet signals will be sent as inputs to the digital processor after it has been correctly biased and amplified.

- Input: Analog source audio through an auxiliary 3.5mm stereo audio jack and +5V/GND for power.
- Output: Properly filtered, amplified, and biased bass, mid, and tweet analog signals (0 to +3.3VDC) to their respective analog inputs on the Teensy 4.0 microprocessor.

2.2.1 Stereo to Mono Audio Converter

The stereo to mono audio converter converts an analog stereo audio signal to an analog mono audio signal. If the input is mono, then the signal just stays a mono signal.

- Input: Analog source audio through auxiliary 3.5mm stereo audio jack.
- Output: Analog mono audio signal to the audio filters.

Requirements	Verification

3. Must combine left and right audio stereo signals into one signal.	3. Play analog audio in either right or left channel only and listen to our demo audio output speakers to verify that both right and left channels are playing the mono audio signal.

2.2.2 Low Pass Filter

The low-pass filter will be supplied with an analog audio signal. The filter will only allow low frequency less than 200Hz components of the signal to pass.

- Input: Analog audio signal from the stereo-to-mono converter
- Output: Bass analog signal to the bass signal biasing operational amplifier circuit

Requirements	Verification
4. The filter will only allow frequencies lower than 200Hz to pass through at > -3dB±10% bandwidth.	4. Using equation (b) from section 2.7.1, our cutoff frequency is 312Hz. Furthermore, using equation (d) in section 2.7.1, the -6dB cutoff frequency is 200Hz.

2.2.3 Band Pass Filter

The band-pass filter will be supplied with an analog audio signal. The filter will only allow frequency components within 310 Hz and 660Hz to pass.

- Input: Analog audio signal from the stereo-to-mono converter
- Output: Mid analog signal to the mid signal biasing operational amplifier circuit

Requirements	Verification
5. The high pass stage of the band-pass filter will only allow frequencies greater than 310Hz to pass through at > -3dB ±10% bandwidth. 6. The low pass stage of the band-pass filter will only allow frequencies less than 660Hz to pass through at > -3dB ±10% bandwidth.	5. Using equation (b), our cutoff frequency is 482Hz. Furthermore, using equation (d) in section 2.7.1, the -6dB cutoff frequency is 310Hz. 6. Using equation (b) in section 2.7.1, our cutoff frequency is 1026Hz. Furthermore, using equation (d) in section 2.7.1, the -6dB cutoff frequency is 660Hz.

2.2.4 High Pass Filter

The high-pass filter will be supplied with an analog audio signal. The filter will only allow high-frequency components greater than 1410Hz of the signal to pass.

- Input: Analog audio signal from the stereo-to-mono converter
- Output: Tweet analog signal to the tweet signal biasing operational amplifier circuit

Requirements	Verification
7. The high pass filter will only allow frequencies above 1410Hz to pass through at > -3dB ±10% bandwidth.	7. Using equation (b) in section 2.7.1, our cutoff frequency is 2192Hz. Furthermore, using equation (d) in section 2.7.1, the -6dB cutoff frequency is 1410Hz.

2.2.5 Voltage Biasing Circuits

The three voltage biasing circuits are supplied with their respective filtered analog audio signal. Each biasing circuit is specifically designed to add a DC bias and amplify the filtered audio signal to a range between 0 to +3.3VDC.

- Input: Filtered analog audio signals and +5V/GND for power
- Output: Correctly biased and amplified analog audio signals.

Requirements	Verification
8. Must provide DC offset of audio signals to correctly bias to +1.65V±0.32VDC. This equates to a value of 511±100 on a 0 to 1023 digital scale. 9. Must provide amplification of audio signals to a minimum of 100 peak-to-peak value on a 0 to 1023 digital scale during high amplitude portions of the audio signal.	8. Energize circuit and visually verify the digital scale level with no audio input using the Arduino serial plotter. 9. Energize circuit and visually verify the digital scale level with audio input using the Arduino serial plotter.

2.3 Digital Processor Block [10 Points]

The bass, mid, and tweet analog signals are converted to their respective digital signals and translated into an output LED data signal.

- Input: Filtered, biased, and amplified analog bass, mid, and tweet signals to analog-in terminals of microprocessor and +5V/GND for power.
- Output: Digital bass, mid, and tweet +5V TTL signals to respective LED strips.

2.3.1 Microprocessor (Teensy 4.0)

The microprocessor is supplied with the bass, mid, and tweet analog signals and convert them to digital signals via an internal analog-to-digital signal converter (ADC). Next, the digital values will be analyzed in code and translated into a +3.3V LED data signal. The processor will be powered by the +5VDC output signal from the +5V voltage regulator.

- Inputs: Filtered analog bass, mid and tweet signals to analog-in terminals of microprocessor and +5V/GND for power.
- Outputs: +3.3V TTL LED data signals to +3.3VDC inputs on the level shifter.

Requirements	Verification
10. Must successfully read analog inputs and convert them to digital without any clipping.	10. Use the programming IDE's serial plotter interface to verify that digital values do not reach the min/max value of the digital scale (0 to 1023) more than 10 times per second.
11. The program successfully deciphers between wanted and unwanted frequencies (e.g. bass channel will react only to bass frequencies, etc.)	11. Visual verification that each respective LED strip reacts to its intended frequency range.
12. ADC must sample analog signals at a minimum of twice the highest frequency of interest.	12. Visual verification of sample rate through sample count variable printed to terminal of the IDE.

2.3.2 Level Shifter (SN74AHCT125N)

The level shifter receives the LED digital data signals from the microprocessor and amplifies them to their respective +5V LED digital data signals. The +5V LED data signals will be sent to their respective (bass, mid, or tweet) LED strip signal wire

- Input: Three (bass, mid, and tweet) +3.3V LED digital data signals and +5V/GND for power.
- Output: Three (bass, mid, and tweet) +5V LED digital data signals

Requirements	Verification
13. Pin VCC receives between +5VDC±5%	13. Read the VCC voltage signal on a multimeter.
14. All +3.3VDC data signals are amplified to +5VDC successfully.	14. Visual verification that each respective LED strip lights up, thus receiving a +5VDC signal.

2.4 LED Block [10 Points]

The three LED strips contain one microprocessor for each LED. They will receive the +5V LED data TTL signals. For each signal, (bass, mid, and tweet) the TTL signals will energize their respective LEDs to the proper color and luminosity.

- Input: Bass, mid and tweet +5V TTL signals and +12V/GND for power.
- Output: Visual LED representation of original analog audio signal.

2.4.1 Bass RGB LED Strip

The bass RGB LED strip will receive the "low frequency" +5V digital data signal that will instruct the embedded LED microcontrollers (WS2815) which LEDs to energize. The strip will be powered using +12VDC.

- Input: +12V/GND and +5V TTL LED data signal from the microprocessor.
- Output: Visual LED representation of bass analog audio signal.

Requirements	Verification
15. Changes in LED lighting configurations must contain less latency with respect to the original audio signal than the human eye can reasonably notice. 16. All LEDs must energize to their respective color and luminosity with negligible losses.	15. Visually confirm that the latency with respect to the original audio signal cannot be noticed. 16. Visually confirm that the LED strip energizes to intended colors that can be found in the program.

2.4.2 Mid RGB LED Strip

The mid-RGB LED strip will receive the "bandpass frequency" +5V digital data signal and will be powered by +12VDC. The data signal will instruct the embedded microcontrollers (WS2815) which LEDs to energize. The strip will be powered using 12V direct current.

- Input: +12V/GND and +5V TTL LED data signal from the microprocessor.
- Output: Visual LED representation of mid analog audio signal.

Requirements	Verification

17. Changes in LED lighting configurations must contain less latency with respect to the original audio signal than the human eye can reasonably notice. 18. All LEDs must energize to their respective color and luminosity with negligible losses.	17. Visually confirm that the latency with respect to the original audio signal cannot be noticed. 18. Visually confirm that the LED strip energizes to intended colors that can be found in the program.

2.4.3 Tweet RGB LED Strip

The tweet RGB LED strip will receive the "high frequency" +5V digital data signal and will be powered by +12VDC. The data signal will instruct the embedded microcontrollers (WS2815) which LEDs to energize. The strip will be powered using 12V direct current.

- Input: +12V/GND and +5V TTL LED data signal from the microprocessor.
- Output: Visual LED representation of tweet analog audio signal.

Requirements	Verification
19. Changes in LED lighting configurations must contain less latency with respect to the original audio signal than the human eye can reasonably notice 20. All LEDs must energize to their respective color and luminosity with negligible losses.	19. Visually confirm that the latency with respect to the original audio signal cannot be noticed. 20. Visually confirm that the LED strip energizes to intended colors that can be found in the program.

2.5 Third-party Inputs

For this project to function properly, two different third-party inputs are required. The Hip Hop Xpress has its own power system that this project will utilize. Additionally, the onboard DJ equipment will be providing the analog audio source that will be an input to our system.

- Input: Analog source audio through an auxiliary cable, and +12V to +30VDC power signal.

2.6 Flowchart

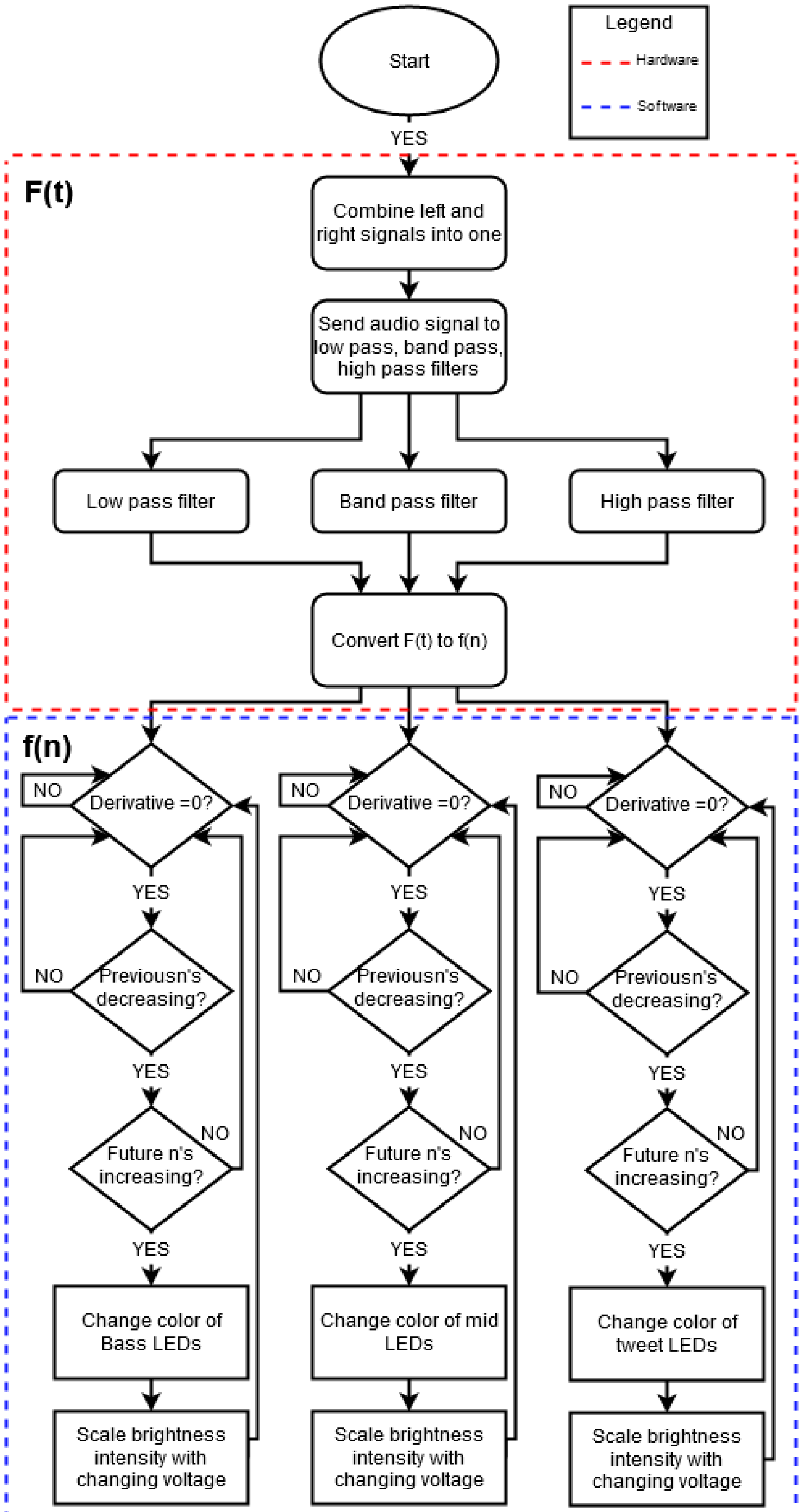


Figure 5. Hardware/Software Flowchart

2.7 Equations and Simulations

2.7.1 Filtered Frequencies

This is how the cutoff frequency is calculated for the filters. The cutoff frequency is where the roll-off in the frequency domain hits -3dB and the output is attenuated by an amount in relation to the number of filter stages as the roll-off increases.

$$f_{cutoff,1^{st}\,order} = \frac{1}{2\pi RC}[Hz]$$ ... (a)

$$f_{cutoff,2^{nd}\,order} = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}[Hz]$$ ... (b)

The low pass filter gain at the cutoff frequency shown below. For a second-order passive filter the gain at the corner frequency will be equal to 0.7071 * 0.7071 = 0.5Vin (-6dB).

$$A_{f_{cutoff}} = \left(\frac{1}{\sqrt{2}}\right)^n$$ ... (c)

The new -3dB pass band frequency as a result in the increase of the filters order can be calculated using the equation below where 'n' is the filter order number (number of reactive components)

$$f_{-3dB} = f_{cutoff}\sqrt{2^{\frac{1}{n}} - 1}[Hz]$$ ... (d)

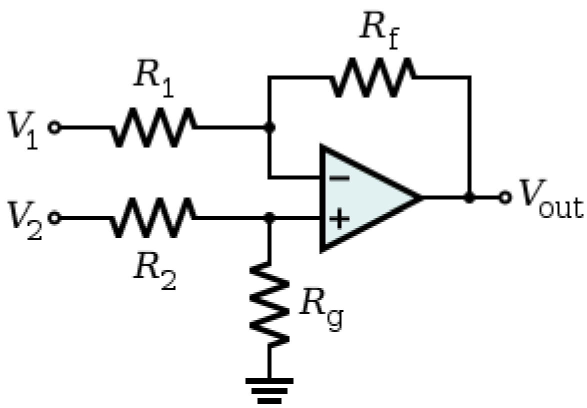
2.7.2 Nyquist Frequency

The Nyquist frequency is the frequency at which the ADC needs to sample to ensure correct digital values are attained.

$$f_{nyquist} = 2f_{\max}[Hz]$$ ... (a)

2.7.3 Voltage Biasing Operational Amplifier with Gain

Using a differential amplifier shown below, is the combination of both inverting and non-inverting amplifiers. The difference between the two input voltages are amplified. The non-Inverting stage of the amplifier has a closed loop gain to control the voltage gain of the amplifier. The closed loop voltage gain equation is shown below.



$$V_{out} = \left(\frac{R_1 + R_f}{R_1}\right) \times \left(\frac{R_g}{R_g + R_2}\right) V_2 - \frac{R_f}{R_1} V_1 = \frac{R_f}{R_1}\left(V_2 - V_1\right) \text{ ... (a)}$$

$$A_v = \frac{R_f}{R_1} \text{ ... (b)}$$

2.7.4 Power Supply Voltage

Even though we are getting power from a third-party source, most automobiles operate on a +12VDC system, we are making a “safe” assumption that the power source will provide us with a clean +12VDC signal to power our equipment.

3. Tolerance Analysis

In order to drive the LEDs without a visible lag to the human eye, we require no more than 175 ±50 ms lag time in total from the whole system. The bulk of our delay will come from our software component within the microprocessor. The FastLED libraries take approximately 30ms to retrieve the necessary variables and translate them into the LED data signal. While tested on an ESP32, an average latency of 30ms was measured using a logic analyzer while driving LEDs with the FastLED library [10]. The ESP32 uses the LX6 CPU which has been found to be comparable to the Cortex M4 CPU that is on our Nucleo-L432KC development board.

Furthermore, other sources of latency such as data transmission in the wires are all under 1ms and are thus negligible.

All our input voltage tolerances come from the respective device’s datasheets. Additionally, the voltage regulators that we are using should provide voltage to well within the limits that are required by the manufacturers. In many cases, the voltage powering the system will be within ±1% of the target voltage.

When dealing with audio frequencies from 0Hz to 20kHz, it is necessary to choose a proper Nyquist

Table 2 Components Cost

frequency sampling rate. 44.1kHz is an industry audio standard sampling rate since it is just over 2 times the max audio frequency of the system.

4. Costs and Schedule

4.1 Cost Analysis

4.1.1 Labor

Estimating at $35/hour for three people and 8 hours per week for the remaining duration of the semester (~10 weeks), the labor cost will be the following:

$$3\ person * \frac{\$35}{hour} * \frac{8hours}{week} * 2.5 * 10weeks = \$33,600$$

Table 1 Labor Costs

Name	Hourly Rate	Hours	Total Cost ($)	Total Cost ($) * 2.5
Oluwatosin Akinsanya	$35/hour	128	$4480	$11200
Kowei Chang	$35/hour	128	$4480	$11200
Paul Donnelly	$35/hour	128	$4480	$11200
Total				**$33600**

4.1.2 Parts

Part Name	Manufacturer	Part Number	Vendor	Quantity	Retail Cost ($)	Total Cost ($)
NUCLEO-L432KC	STMicroelectronics	NUCLEO-L432KC	Amazon	1	$19.95	$19.95
Non-addressable LED strip	Daybetter	DAYBETTER-1505010126023RGB6544A	Amazon	1	$31.99	$31.99
Individually addressable LED strips	Alitove	AL2815WH300WP	Amazon	12	$58.99	$707.88
Level Shifter (+3.3V to 5V)	Texas Instruments	TXB0104D	Digi-Key	1	$1.32	$1.32
PCB		Estimated	ECE Shop		$15	$15
Plastic, waterproof PCB enclosure		Estimated	ECE Shop		$15	$15
Audio jack	Hydens	B07VJZRV5H	Amazon	1	$0.80	$0.80
100Ω Resistors		Estimated	ECE Shop	6	$0.10	$0.60
Capacitors (one 3.183µF, 0.318µF, 0.53µF, & 7.96µF)		Estimated	ECE Shop	4	$0.15	$0.60
LP2950-N Low-Dropout voltage regulator (+3.3 and +5V variant)	Texas Instruments	LP2950ACZ-3.0/NOPB	Texas Instruments	2	$0.67	$1.34
Total						**$794.69**

4.1.3 Grand Total

Table 3 Grand Total Cost (Labor + Parts)

Section	Total
Labor	$33600
Parts	$794.69
Grand Total	**$34,394.69**

4.2 Schedule

Table 4 Project Phase Schedule and Task Allocation

Name	Task	Responsibility
02/24/20	**Mock Designs Review & Design Document Submission**	
	1. Research circuit hardware and components	Paul

	2. Research software libraries and FastLED algorithms	Kowei
	3. Research regulations and IEEE ethics and safety	Tosin
	4. Conduct component verification and filter calculations	Paul & Tosin
	5. Draft circuit schematics and prepare for design review	All
03/02/20	**Design Review & Initial Conversation with Machine Shop**	
	1. Purchase hardware and circuit components	Paul
	2. Draft PCB layout and pinout assignment	Paul & Kowei
	3. Prototype and verify components and circuit design	Paul & Tosin
	4. Software integration and programming	All
03/09/20	**PCB Design. Soldering. Components Validation. Programming**	
	1. Finalize orders for any additional components for PCB	Paul
	2. Begin programming microprocessor and control unit	Kowei
	3. Validate input and output voltage/data signals of each block	Tosin & Paul
	4. Begin first PCB design and finish soldering assignment	All
03/16/20	**PCB Draft. PCB enclosure CAD Design Research. Programming**	
	1. Program microcontroller. Input/output data signal validation	Kowei
	2. Research and begin PCB enclosure CAD design	Tosin
	3. Finalize the first draft of PCB design. Circuit design testing.	Paul
03/23/20	**PCBway Orders. Enclosure CAD Design Draft. Programming**	
	1. Revise PCB design and submit PCBway orders	All
	2. Validate audio signal transmission and ADC functionality	Paul & Tosin
	3. Program brightness & color control of bass LEDs	Kowei
	4. Validate low, mid, and high-frequency filtration	Paul & Tosin
	5. Finalize the first draft of enclosure design	Tosin
03/30/20	**PCB Revision. PCB enclosure CAD Design Draft 2. Circuit Design**	
	1. LED strips power analysis. Validate circuit connections	Paul & Tosin
	2. Revision enclosure CAD design draft	Tosin
	3. Programming LED units' color and brightness control	Kowei
	4. Test microcontroller communication with LED strips	Kowei & Paul
	5. Power circuit analysis and voltage signal evaluation	Paul & Tosin
	6. Conduct overall circuit performance analysis	All
04/06/20	**Final Round PCBway Orders. Finalize PCB & CAD Designs.**	
	1. Revise and validate PCB design with updated circuit	All
	2. Revise and validate PCB enclosure CAD design	Tosin
	3. Program brightness and color control of mid and tweet LEDs	Kowei & Paul
04/13/20	**Testing & Debugging. Performance Analysis. PCB Soldering**	
	1. Validate communication between microcontroller and LEDs	Tosin & Paul
	2. Debug program and test control signals for edge cases	Kowei & Paul
	3. Solder and assemble the device	Tosin & Paul
	4. Performance analysis and data latency test	Paul
	5. System integration and enclosure design with machine shop	Tosin
04/20/20	**Mock Demo. Programming. Simulation & Performance Analysis**	
	1. Prepare for demonstration	All
	2. Test and debug the soldered circuit. Debug program.	All
	3. Verify pin assignments and prepare for project presentation	All
04/27/20	**Final Demonstration and Mock Presentation**	

	1. Integrate PCB onto enclosure & RF code circuit information	All
	2. Test the entire project. Performance power analysis	All
	3. Prepare for the mock presentation. (photos, slides, & videos)	All
05/04/20	**Final Paper. Final Presentation Lab Notebook.**	
	1. Complete and submit final documents and lab notebook	All
	2. Practice and prepare to deliver the final presentation	All

4.3 Risk Analysis

Different color LEDs require different turn-on voltages, the outputs from our microprocessor will need to be adjusted for each color that it is controlling. Fortunately, the FastLED package in C++ contains a variable for brightness [0,255] that removes the need to manually input different voltages for different LEDs. Since FastLED is an open-source project, if the package does not function properly, this project will not be successful. That is why we reviewed the FastLED documentation and chose a microprocessor that is explicitly supported by the FastLED library.

We expect to power our system through the bus' 12V power system. Since the power is being handled by another team's project, if their project does not work, our project will be able to be powered by an independent power system such as a bank of +12VDC batteries or a lab bench power supply .

Furthermore, our schedule in Table 4 lists and assigns a weekly task to group members for completion. If one of us fails to complete the assigned task for the week, this would place our project at risk for completion. In order to maintain progress throughout the semester and to complete priority tasks for our project, some tasks have been assigned to two people. We will also be testing, simulating, and conducting performance analysis on our circuit in order to make sure we achieve the desired output on our LED units. We will be consistently debugging and revising our microcontroller programs in order to accurately control the brightness and colors of our LED strips to create an entertaining atmosphere.

4.4 Ethical and Safety Considerations

Utilizing LED lighting for vehicle applications is a great way to accessorize and personalize one's vehicle. However, when adding any electrical component to a system, proper safety precautions must be taken to prevent personal injury to the user and others around the system. According to the IEEE Code of Ethics [7], we will ensure that our product design, specifications, and implementations "hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices and to disclose promptly factors that might endanger the public or the environment." The IEEE Code of Ethics #7 and #10 talks about accepting criticism from others and assisting our co-workers in their professional development [7]. We will be working as a group just like the course has been designed and will accept an honest criticism from the course's staff and our peers. We will make sure to credit each person's contribution to the project and make sure we all assist each other in accomplishing the project on time.

4.4.1 Electric Shock Hazards and Grounding Protection

When a grounded tool or appliance is used with ineffective or faulty grounding connections, there is a high risk of being shocked. An LED strip will require about 1.5 Amps per meter, which creates a hazard of being shocked. Currents on the order of milliamperes flowing through the nerves that control breathing may restrict a person's respiratory flow and may last for a considerable period, even after the current flow has been interrupted. Fault current flowing in a broken grounding system also presents shock hazards to the user. Following the IEEE Code of Ethics [7], our LED strips will be properly grounded at multiple points throughout the system to ensure that if one of the ground connections fail, there will be alternate ground connections to keep the system operational and safe. We also need to make sure that the power supply is correctly connected to each component requiring power. This is crucial to avoid conditions such as short circuits or where too much current is being drawn posing a severe burn hazard. (fuse)

4.4.2 Overheating Hazards and Insulation

A valuable feature of LED technology is the ability to operate in extreme climates. However, for applications where people will be near the LED strips, precautions need to be taken to prevent accidental harm. LED strips typically reach a temperature of about 30 degrees Celsius over ambient temperature [3]. Additionally, human skin begins to burn at around 50 degrees Celsius. LED strips can sometimes be dangerous to touch, especially if there is a malfunction and the strips overheat. Since our LED strips will be encased in translucent silicone tubing, they will have a layer of heat insulation to protect against burns from accidental skin contact.

4.4.3 Seizure Warning and Precautions

Since this product involves flashing lights with contrasting light and dark patterns at different speeds, this device can pose a health risk for people with high photosensitivity or heightened seizure triggers. Flashing, flickering, or geometric patterned lights between 3 to 60 Hz can trigger photosensitive people into seizures or cause them to be disoriented [6]. We will be creating and attaching a warning label to the PCB enclosure in order to inform people about photosensitive triggers. Keeping the IEEE Code of Ethics [7] in mind, we will be creating a label with the standard cautionary message that says, "WARNING: This lighting system may potentially trigger seizures for individuals with high photosensitivity. Viewer discretion advised. Colored or photochromic glasses may be needed to reduce light sensitivity or visual distortions."

4.4.4 Splash Protection

Since the LED lighting system will have the flexibility of being installed on the outside of the bus, moisture could cause damage to the LED units. We chose an LED strip that is IP67 compliant in order to keep the internals of the LED weather-proof [2]. The LED strip is housed inside translucent silicone tubing with sealant adhering the endcaps to the tube. This will ensure that when the vehicle is traveling at highway speeds, no water will contact the LEDs. In alignment with the IEEE Code of Ethics, the plexiglass will also aid to protect the circuit board from splashes, dust, and unauthorized access that can jeopardize an individual's health or the intended operation of the system [7].

5. References

[1] Amazon.com, [Online]. Available: https://www.amazon.com/Waterproof-600leds-Flexible-Changing-Controller/dp/B01IQOV13G/ref=pd_ybh_a_2?_encoding=UTF8&psc=1&refRID=2SZHCKBTXKA6H9SSVVGT&smid=A8YLPB3J8M60B. [Accessed: 11-Feb-2020].

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