HIP HOP XPRESS AUDIO SYNCHRONIZED LIGHT EMITTING DIODE SYSTEM

By

Oluwatosin Akinsanya

Kowei Chang

Paul Donnelly

Final Report for ECE 445, Senior Design, Spring 2020

TA: Yichi Zhang

8 May 2020

Project No. 50

Abstract

Despite the recent technological advancement in LED lighting systems and automation, LED controllers still blink erratically to music. The Hip Hop Xpress Audio Synchronized LED Lighting System is an integrated entertainment system that synchronizes the pitch of any music playing from a vehicle to the LED lights. The primary goal of this design is to create a visually appealing and entertaining LED lighting system for the Hip Hop Xpress: Double Dutch Boom Bus. This system contains a stereo-to-mono converter that receives a clean analog audio signal from the user, filters, and converts the analog signal to a digital signal using it to drive and automate the LED lights. The LED lighting strip contains individually addressable, red, green, and blue LED pixels that react to the bass, mid, and tweet digital audio signals. In conjunction with the powerful Teensy 4.0 microcontroller and the FastLED library that bridges the microcontroller to interact with the LED strips, the user can scale and personalize their lighting experience as they desire. This report describes the design and development processes of the Hip Hop Xpress Audio Synchronized LED Lighting System with thorough analysis, results and future plans.

Table of Contents

1. Introduction

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 [1]. 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 Hip Hop Xpress 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 created an automated LED lighting system. The LED system is a scalable system that can be synchronized to the frequencies of any audio that can be played from the bus. This is 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 thirty feet 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 lab-bench version of LED strips with negligible color distortion from configurations calculated in the previous requirement.

The only-modification made to the high-level requirements of this project since the ***Project Proposal*** and ***Design Document*** was from driving nine-meter long LED strips to driving lab-bench version of the LED strips. This is further addressed in the **uncertainties** sub-section of section 5.2.

2 Design Diagrams and Descriptions

2.1 Sketch of Final Product

Figure 1 is a rough depiction of what the final design looks like, when installed on the Hip Hop Xpress Bus. The blue, red, and black LED strips represent their respective bass, mid, and tweet channels.

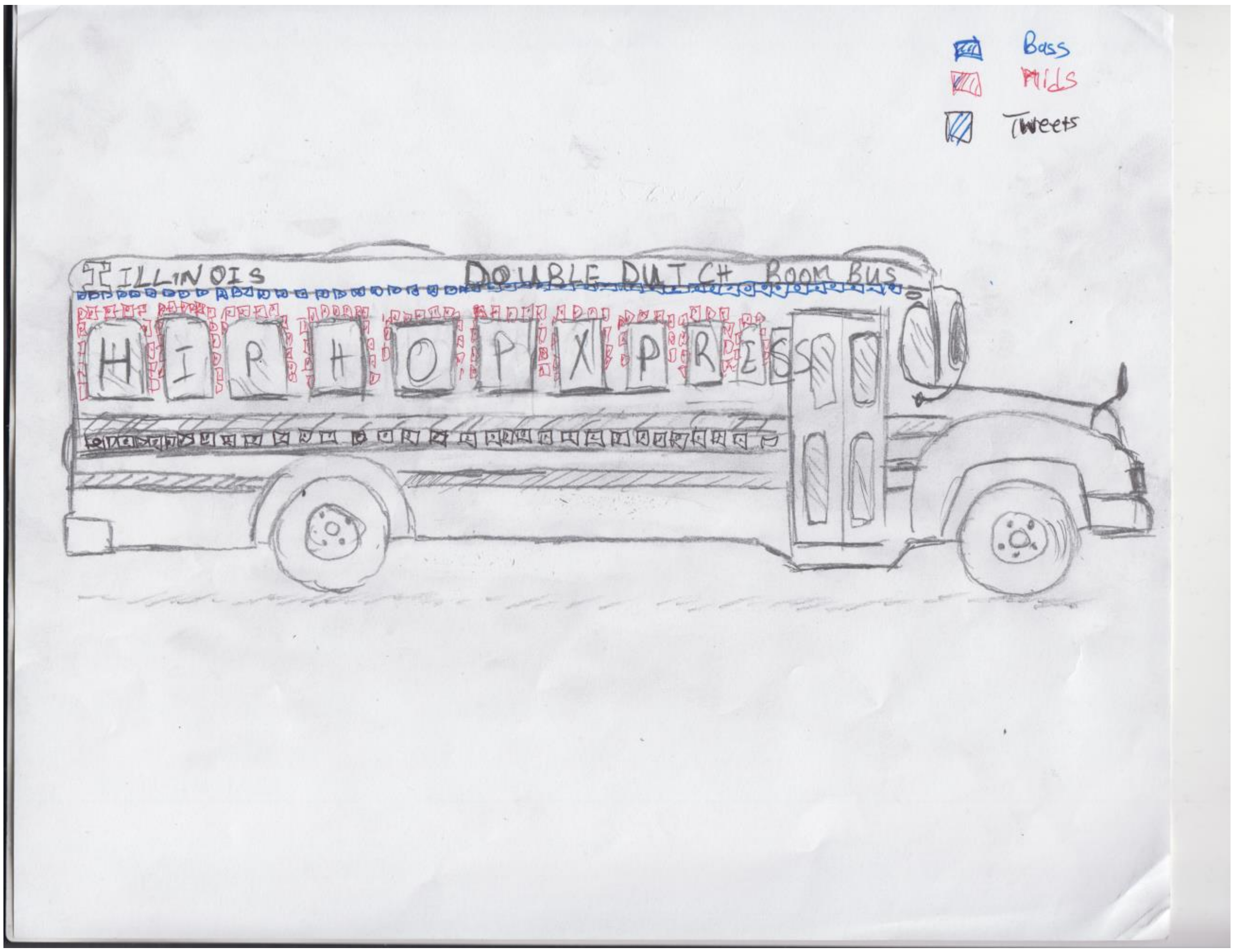

Figure 1: The Hip Hop Xpress With Installed LED Strips

2.2 Project Block Diagram

A modular representation of the key entities in the audio-synchronized LED lighting system are represented by the block diagram shown in Figure 2 below. The main control unit of the design is the digital processor block which samples, automate, and steps-up the filtered audio signals to and ideal 5 V TTL data signal used to drive the RGB LED strips. The power block simply steps down the 12 V direct-current source to 5 V in order power the biasing circuits, the microcontroller, and the level shifter. The analog block correctly receives, filters, biases, and amplifies the audio signal to be converted to digital signals. All these sub-systems are essential to provide an optimal audio-synchronized LED lighting system.

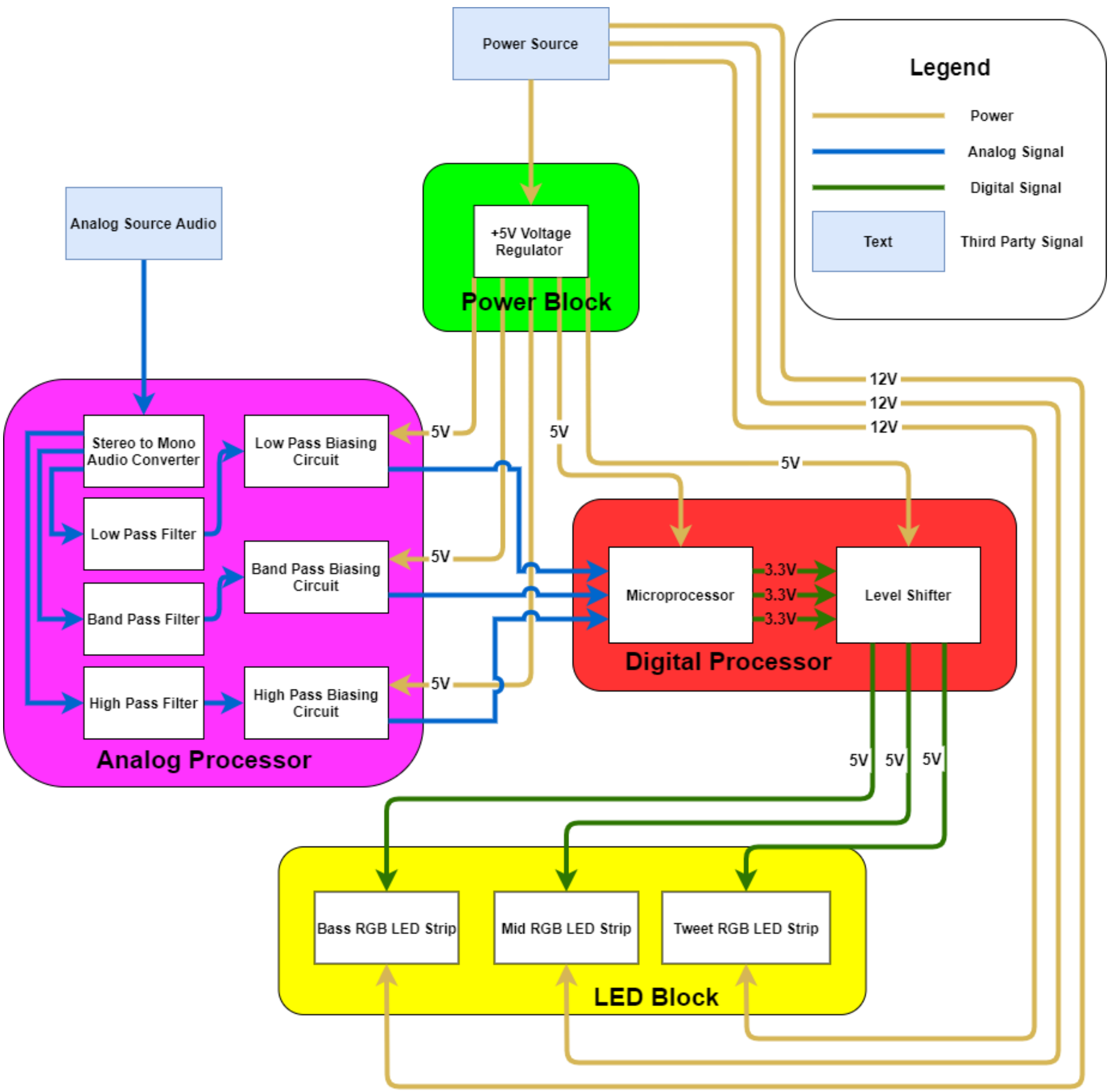

Figure 2: Block Diagram

2.3 Power Block

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

5 V Linear Voltage Regulator (L7805CV)

The voltage regulator will step the third-party power supply voltage down to 5±0.25 V to power the level shifter, op-amps, and the microprocessor. The connected capacitors are to remove voltage ripple from the input/output power signal.

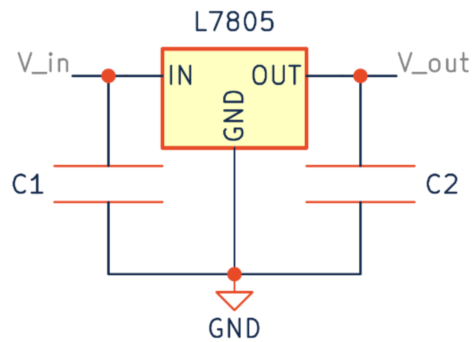

Figure 3: Linear Voltage Regulator

2.4 Analog Processor Block

The analog processor receives an analog audio signal as input. The signal is converted from stereo to mono and then split into three (bass, mid, and tweet) frequency-based signals. The bass, mid, and tweet signals are sent as inputs to the digital processor after being correctly biased and amplified.

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

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. The right and left channels are shorted to produce the mono signal.

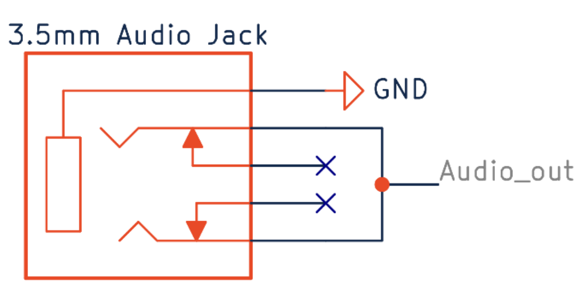

Figure 4: Stereo to Mono Converter

Low-pass Filter

The low-pass filter is supplied with an analog audio signal. The filter only allows low frequency components of the signal to the output at full power. The cutoff frequency of the filter is calculated using equation (A.1).

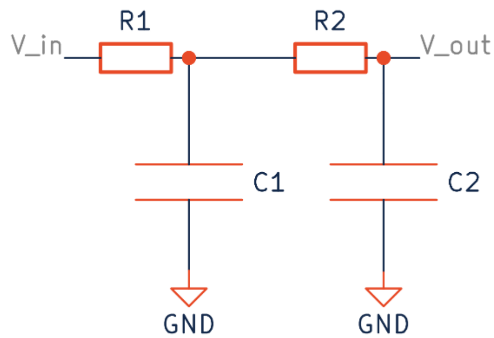

Figure 5: Passive Low-Pass Filter

Band-pass Filter

The band-pass filter is supplied with an analog audio signal. It is constructed by putting a low-pass filter in series with a high-pass filter. This creates a specific bandwidth that is passed to the output at full power. The cutoff frequency of the filter is calculated using equation (A.1) twice. Once to calculate the high-pass filter frequency cutoff, and again, to calculate the low-pass filter frequency cutoff.

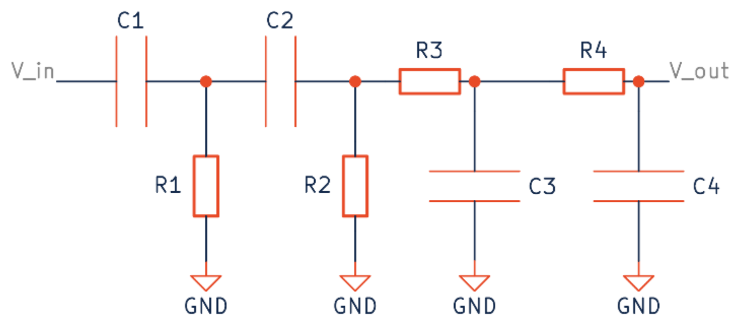

Figure 6: Passive Band-Pass Filter

High-pass Filter

The high-pass filter is supplied with an analog audio signal. The filter only allows high-frequency components to the output at full power. The cutoff frequency of the filter is calculated using equation (A.1).

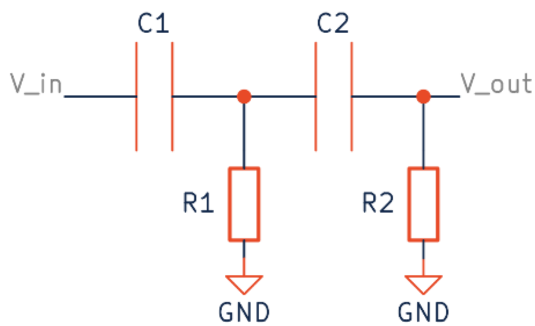

Figure 7: Passive High-Pass Filter

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 positive voltage level that the ADC can accept. The DC bias of the circuit is found using equation (C.1), and the gain using equation (C.2).

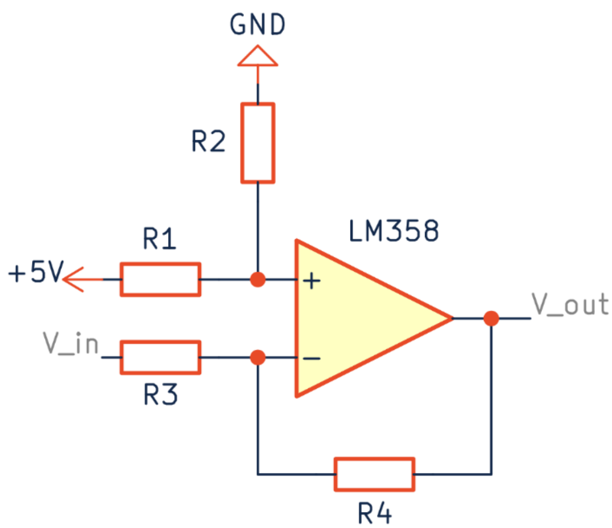

Figure 8: DC Bias and Amplification Circuit

2.5 Digital Processor Block

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 5 V/GND for power.
- Output: Digital bass, mid, and tweet 5 V TTL signals to respective LED strips.

Microprocessor (Teensy 4.0)

The Teensy 4.0 is supplied with the bass, mid, and tweet analog signals through its analog-in pins. The signals are analyzed in code and translated into a 3.3 V LED data signal. The processor is powered by the 5 V output signal from the 5 V voltage regulator [3]. The processor is programmed using the Arduino IDE and it is specifically mentioned in the FastLED library documentation that the Teensy 4.0 is fully compatible with the library. The processor is fast enough to minimize latency between audio signal and LED data signal through it's 600MHz clock rate[3].

Figure 9: Teensy 4.0 Microprocessor

Analog to Digital Converter

The analog to digital converters (2) on the Teensy 4.0, are responsible for converting the analog audio signals to digital values for the microprocessor to generate lighting patterns. The analog to digital converters must obey the Nyquist rule for sampling rate. Equation (B.1) dictates that the sampling rate must be at least two times the highest frequency component in the analog signal that we are interested in.

FastLED Library

The FastLED library is the framework that bridges the gap between the digital input and the output to the LED strips. It is responsible for generating lighting patterns and sending data to the LED strips. A major reason why the project switched from using a STP32 microcontroller to the Teensy 4.0 is due to the FastLED library specifically lists the Teensy 4.0 as a compatible chip [4]. The library also specifically allows the Teensy 4.0 to use parallel output to overcome the timing complications when trying to write to a large number of LEDs across multiple strips.

Level Shifter (SN74AHCT125N)

The level shifter receives the LED digital data signals from the microprocessor and amplifies them to their respective 5 V LED digital data signals. The 5 V LED data signals will be sent to their respective bass, mid, or tweet LED strip signal wire. Figure 9 shows the use of a level shifter with channel 1 disabled, and channel 2, 3, and 4, enabled.

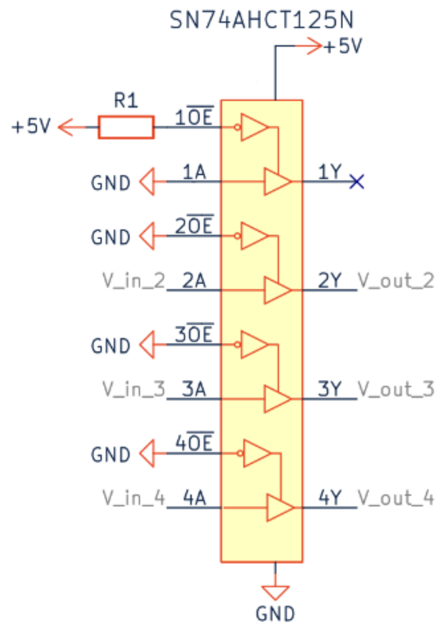

Figure 10: Level Shifter

2.6 LED Block

The three LED strips contain one microprocessor for each LED. They will receive the 5 V 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 5 V TTL signals and 12 V/GND for power.
- Output: Visual LED representation of original analog audio signal.

Bass/Mid/Tweet RGB LED Strips

The three LED strips receive their respective 5 V digital data signals that instruct the embedded LED microcontrollers (WS2815) which LEDs to energize. The strips are powered with 12 V power signals.

2.7 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 uses for power. Additionally, the onboard DJ equipment supplies the analog audio source that is an input to our system.

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

2.8 Flowchart

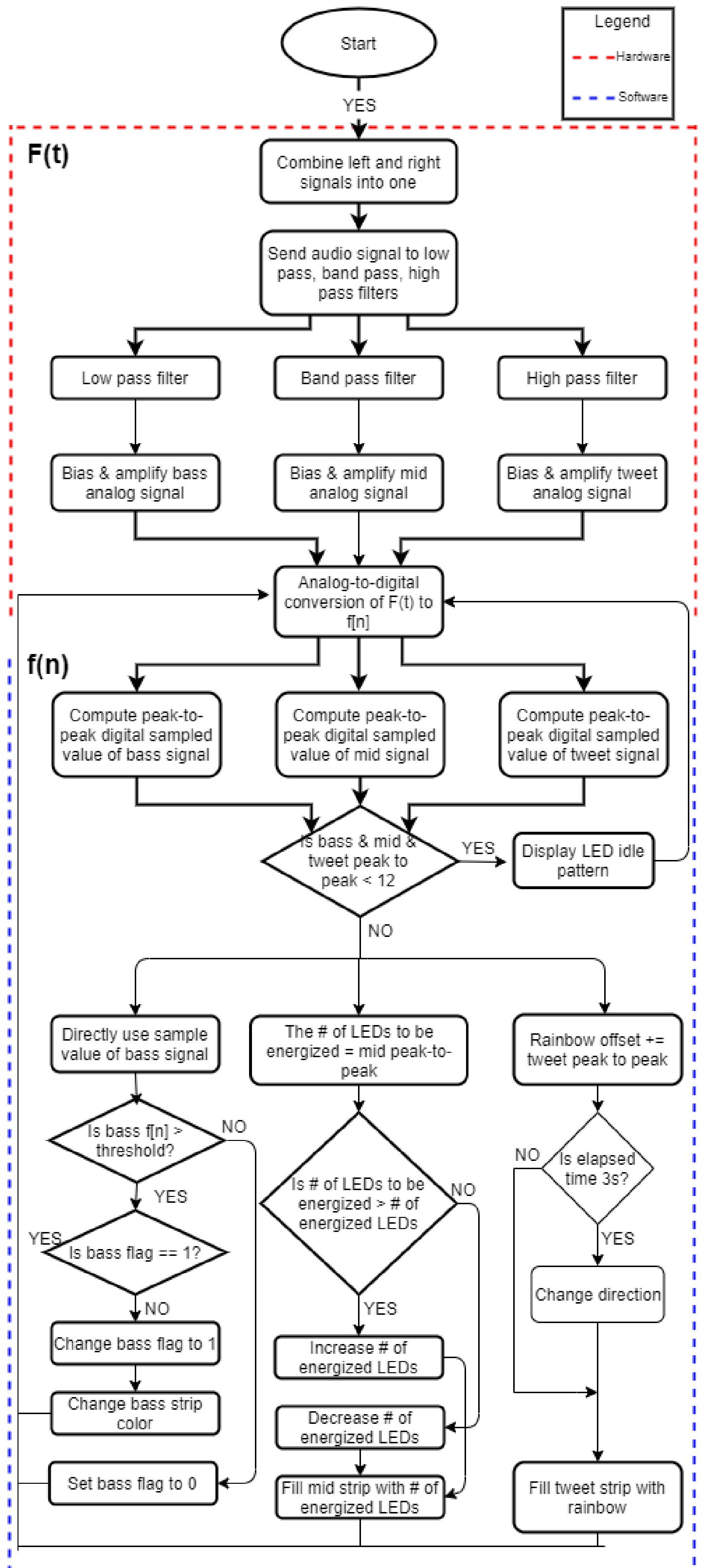

Figure 11: Hardware/Software Flowchart

2.9 Equations and Simulations

All the equations and figures shown in this section were used to predict, calculate, and verify that the audio signal was properly filtered, biased, amplified, and sampled.

Filtered Frequencies

The cutoff frequency (fc) is where the filter gain in the frequency domain decreases by -3dB. The output is attenuated by an amount in relation to the number of filter stages (n) as the roll-off increases. When the resistors and capacitor values are different in a "n" order filter, the cut-off frequency in Hertz can be calculated using the right-most relationship in equation (A.1)

$$f_c = \frac{1}{2\pi RC} \Rightarrow \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}[Hz] \tag{A.1}$$

For an n^{th} order filter, the gain at the corner frequency can be calculated using equation (A.3) where "n" is the number of reactive components in the filter network.

$$A_v = \left(\frac{1}{\sqrt{2}}\right)^n \tag{A.2}$$

The "new -3dB" pass-band frequency, in Hertz, as a result in the increase of the filters order can be calculated using equation (A.4)

$$f_{-3dB*(n)} = f_c\sqrt{2^{\left(\frac{1}{n}\right)} - 1}[Hz] \tag{A.3}$$

The bandwidth of the band-pass filter is the difference between the high and low cut-off frequencies. This is shown in equation (A.5) below.

$$BW = f_{c,high} - f_{c,low} \tag{A.4}$$

Nyquist Frequency

The Nyquist frequency is the frequency at which the ADC needs to sample to ensure correct digital values are attained and to avoid unwanted signal overlap.

$$f_{nyquist} = 2 f_{\max}[Hz] \tag{B.1}$$

Voltage Biasing Operational Amplifier with Gain

A differential amplifier is the combination of both inverting and non-inverting amplifiers. The difference between the two input voltages are amplified [5]. The non-Inverting stage of the amplifier has a closed loop gain to control the voltage gain of the amplifier. The output voltage (properly biased and amplified signal) can be calculated using equation (C.1). The closed loop voltage gain relation is shown in equation (C.2)

$$DC_{bias} = 5\left(\frac{R_2}{R_1 + R_2}\right)[V] \tag{C.1}$$

$$Gain = \frac{R_4}{R_3} \tag{C.2}$$

Power Supply Voltage

Most automobiles operate on a 12 V power system. We are making a "safe" assumption that the power source will provide us with a clean 12 V signal to power our equipment.

3. Design Verification and Tolerance Analysis

5 V Voltage Regulator

The circuit schematic of the L7805 5 V voltage regulator is shown in figure x below. Using a Fluke 12 multimeter, the input voltage from the 12 V source and the output voltage of the voltage regulator were measured. The verified voltage measurements of the input voltage and output voltages are shown in figure x and figure y below. The input voltage can range from 12 V < V_in < 30 V and the output voltage has an uncertainty of V_in ± 0.5 V.

Figure 12: Multimeter Display of Input/Output Voltage from Voltage Regulator

Stereo-to-Mono Converter

Rather than using high valued resistors connected at the left and right stereo channels for channel isolation, we shorted the left and right inputs to create a mono audio input to the filters and minimize signal voltage drop in the analog processor block. The shorted input can be seen in the figure 4.

To verify that the converter is working, we played an analog audio in either right or left channel only and listened to our demo audio output speakers to verify that both the right and left channels are playing the combined mono audio signal. Furthermore, by inspection of the circuit in figure 4, we can confirm that the audio output to the converter is a single channel connected to the junction point.

Filters

Using equations A.1, A.2, and A.3, the -6dB cut-off frequencies of the 2nd order RC filters are verified and tabulated in table [x] below.

Table 1: 2nd Order Filter Cut-off Frequencies

Filter Type	Low-pass Filter	High-pass Filter	Band-pass Filter
-6dB Cut-off Frequency [Hz]	210	1410	310 (low), 660 (high)

Analog to Digital Converter

To properly sample the audio signals, our analog to digital converters need to sample at double the highest frequency in music (Nyquist). For reference, the highest note on the piano is 4186Hz. To double that frequency and to add some room for possible higher frequencies, the analog to digital converters require a sample rate higher than 10kHz. To verify this, the code incremented a count every time the audio signal is sampled during the 8ms sampling window. On average, the 8ms sampling windows sample the signal about 127 to 128 times, which is equivalent to 16kHz and much higher than the requirement.

LED Strips

The LED strips must have individually addressable LEDs to display the lighting patterns generated from our digital processor block. According to our original requirements, the LED strip should also be waterproof. Our LED strips should be able to display lighting patterns without any visible data corruption and latency at a reasonable and safe brightness.

4. Costs

4.1 Cost Analysis

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:

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

Table 2: 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**

Parts

Table 3: Components Cost

Part Name	Manufacturer	Part Number	Vendor	Quantity	Retail Cost ($)	Total Cost ($)
Teensy 4.0 USB Development Board	PJRC	TEENSY40	PJRC	1	$19.95	$19.95
Individually Addressable LED Strips	Alitove	AL2815WH300WP	Amazon	1	$58.99	$58.99
Level Shifter (3.3 V to 5 V)	Texas Instruments	74NAHCT125N	Digi-Key	1	$1.32	$1.32
LM358P Operational Amplifier (50 Pack)	Bojack Electronics	IC LM358N LM358 DIP-8	Amazon	1	$6.99	$6.99
925 Pieces 37 Values 5% Carbon Film Resistors	Austor	AMA-18-571	Amazon	1	$8.99	$8.99
550Pcs 0.1uF-10uF DIP Monolithic Multilayer Ceramic Chip Capacitors	Hilitchi	HDR-550	Amazon	1	$14.85	$14.85
Voltage Regulator (5 V)	Texas Instruments	L7805CV	Texas Instruments	2	$0.67	$1.34
AC 100V/240V to DC 12V 20A 240W Switching Converter	LEDMO	B01E6S0JS4	Amazon	1	$21.99	$21.99

10 Pack RGB 4Pin LED Strip Connector	RGBZONE	FB1142	Amazon	1	$9.99	$9.99
Total						**$144.41**

Grand Total

Table 4: Grand Total Cost (Labor + Parts)

Section	Total
Labor	$33600
Parts	$144.41
Grand Total	**$33744.41**

5. Conclusion

5.1 Accomplishments

Our project met our expectations in terms of success and functionality. The power block successfully steps down the 12 V supply voltage to 5 V and provides power to the level shifter, microprocessor, and voltage biasing and amplification circuits. The passive RC filters were filter the mono audio signal into the bass, mid, and tweet frequency bands. The voltage biasing and amplification circuits provided the adequate DC biasing and closed-loop voltage gain for each filtered audio signal. The microprocessor configured the LED lighting and color configurations using the FastLED library and the C++ programming language. The level shifter successfully stepped-up the 3.3 V data signal from the microprocessor to 5 V data signal with little to no signal loss. The RGB LED strips are powered by the 12 V source and driven by the 5 V data audio signal from the digital processor block. Although we expected the passive filters to not be accurate due to the filter roll-off slope and noise from the environment, you can distinctly see and hear relative differences in the filtered signals. We successfully integrated and combined the sub-systems of our project and were able to accomplish our objective which is to take in a clean audio signal, convert it to a digital signal that is later translated to a program that illuminates the LED lights in beautiful patterns and colors.

Professor Rakesh was very impressed by our tenacity and efforts to complete this project amidst the unforeseen pandemic. There are also plans to iterate over the hardware and scale the software program in order to implement this system on Dr. Patterson's Hip Hop Xpress.

5.2 Uncertainties and Risk Analysis

Uncertainties

Although our expectations were mostly met for this project, certain unsatisfactory results became evident throughout the course of the semester. The passive RC filters were inexpensive; therefore the -3dB cut-off frequencies for each filter design was not as precise and accurate in comparison to other passive or active filter designs. This lack of desired precision and accuracy resulted in increased noise and voltage drop in the filtration circuits which probably propagated as a significant uncertainty of the signal power at the -3dB cut-off frequency. At the cut-off frequency of a 1st order passive RC filter, the output power decreases to one half of its maximum passband value. The passband incudes those frequencies where the relative power is greater than the half-power point which is 0.707 of the maximum transfer functions Despite not knowing how to find the measure the power at the cut-off frequency of filter caused us to use a different method of verifying the gain and cut-off frequencies of the filters mentioned in equations in section 2.9.

This project needed to be completed within the scope of the semester, and due to the limited time, financial logistics, limited access to electronic equipment, and the unprecedented pandemic, we were unable to implement the audio-synchronized LED lighting system on the Hip Hop Xpress itself. For the purpose of the class, it was sufficient to demonstrate a lab-bench version of the audio-synchronized LED lighting system with lab-bench version of the LED strips and a circuit board with the electronic components and processor mounted on it. Furthermore, the current prototype is scalable and can be installed on the Hip Hop Xpress with full functionality.

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' 12 V 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 12 V batteries or a lab bench power supply.

5.3 Ethical 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 [6], 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 [6]. 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.

Due to unforeseen complications, we were unable to implement much of safety and ethical considerations. However, these considerations *must* be implemented for this project to be a successful one.

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 [6], 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)

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 [2]. 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.

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 [7]. 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 [6] 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."

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 [6].

5.4 Future work

There are two main aspects of our project that we could improve on in the future. The first improvement is that we would implement an audio-plug indicator LED that energizes when an audio-plug has been inserted into the 3.5mm audio-jack. The audio-jack shown in figure 4 behaves like a normally closed switch that breaks and makes a connection when and audio plug is inserted. When the audio-jack is it in its "un-plugged state" the circuit is closed. When the audio plug is inserted, the tip pushes the left and right stereo-in terminals away from the shaded contact terminals, thereby causing the switch to be open. To accomplish this, we can connect a pull-up resistor in the left and right shaded contact terminals to a supply rail terminal. This ensures that when the switch is open, that is an audio-plug has been inserted, the LED is effectively energized as it is connected to the supply rail via the pull-up resistor. Hence, indicating when the audio-plug is inserted.

Another facet of our project that can be refined is the filtration of the audio signal. We could further improve this by implementing a fast fourier transform (FFT) algorithm in code with advanced filtering techniques to isolate frequencies to make the LED strips react beautifully to the music. This would be accomplished by utilizing the Teensy 4.0 microprocessor. The Teensy 4.0 is a powerful cutting-edge microprocessor that can perform a 1024-point FFT and inverse FFT while consuming 52% of the CPU time on 1 of every 4 audio updates [8]. The processor power load is so low during FFT computation and does not differ much between the different FFT sizes. However, the memory usage can be excessive for larger FFT computation sizes which can decrease the resolution of the signal, and cause signal instability issues [8].

Additionally, a power optimization feature could be implemented in the voltage regulator to reduce effectively dissipate the heat of generated from stepping down the 12 V source to a 5 V source. We could attach an aluminum heat shrink to the voltage regulator to optimize the heat dissipation of the voltage regulator. Heat shrinks are materials that absorb or dissipate unwanted heat from a power electronic component. They are typically made of aluminum and are widely used in amplifiers, regulators, and other electronic component that dissipate heat. The aluminum heat shrink will be bolted to the 5 V regulator.

References

[1] William Patterson: Hip Hop Xpress PowerPoint Pitch, [Online]. Available: https://courses.engr.illinois.edu/ece445/lectures.asp [Accessed: 01-Jan-2020]

[2] The Enclosure Company, [Online]. Available: https://www.enclosurecompany.com/ip-ratings-explained.php. [Accessed: 11-Feb-2020].

[3] Pjrc.com. 2020. [online] Available at: https://www.pjrc.com/teensy/IMXRT1060RM_rev2.pdf [Accessed 9 May 2020].

[4] GitHub. 2020. *Fastled/Fastled*. [online] Available at: <https://github.com/FastLED/FastLED/wiki/Overview> [Accessed 9 May 2020].

[5] En.wikipedia.org. 2020. *Differential Amplifier*. [online] Available at: <https://en.wikipedia.org/wiki/Differential_amplifier> [Accessed 9 May 2020].

[6] Ieee.org, "IEEE code of Ethics", 2020. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 13-Feb-2020]

[7] Waveform Lighting, [Online]. Available: https://www.waveformlighting.com/home-residential/how-hot-do-led-strips-get-is-it-normal [Accessed: 13-Feb-2020].

[8] Pjrc.com. 2020. [online] Available at: https://www.pjrc.com/teensy/td_libs_AudioRoadMap.html [Accessed 9 May 2020].

[9] TI.com. 2020. *SN54AHCT125, SN74AHCT125 QUADRUPLE BUS BUFFER GATES WITH 3-STATE OUTPUTS*. [online] Available at: <http://www.ti.com/general/docs/suppproductinfo.tsp?distId=10&gotoUrl=http%3A%2F%2Fwww.ti.com%2Flit%2Fgpn%2Fsn74ahct125> [Accessed 9 May 2020].

[10] St.com. 2020. [online] Available at: <https://www.st.com/content/ccc/resource/technical/document/datasheet/41/4f/b3/b0/12/d4/47/88/CD00000444.pdf/files/CD00000444.pdf/jcr:content/translations/en.CD00000444.pdf> [Accessed 9 May 2020].

Appendix A Requirements and Verifications Table

Table 5: System Requirements and Verifications

Requirement	Verification
1. Supply voltage must be between 12 V and 30 V. 2. Must provide stable 5±0.25 V 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.
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.
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.
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.
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.

8. Must provide DC offset of audio signals to correctly bias to 1.65±0.32 V. This equates to a value of 511±100 on a 0 to 1023 digital scale. 9. Must amplify 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.
10. Must successfully read analog inputs and convert them to digital without any clipping. 11. The program successfully deciphers between wanted and unwanted frequencies (e.g. bass channel will react only to bass frequencies, etc.) 12. ADC must sample analog signals at a minimum of twice the highest frequency of interest.	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. Visual verification that each respective LED strip reacts to its intended frequency range. 12. Visual verification of sample rate through sample count variable printed to terminal of the IDE.
13. Pin VCC receives between 5±0.5 V 14. All 3.3 V data signals are amplified to 5 V successfully.	13. Read the VCC voltage signal on a multimeter. 14. Visual verification that each respective LED strip lights up, thus receiving a 5 V signal.
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.
17. Changes in LED lighting configurations must contain less latency with respect to the original audio signal than the human eye can reasonably notice.	17. Visually confirm that the latency with respect to the original audio signal cannot be noticed.

18. All LEDs must energize to their respective color and luminosity with negligible losses.	18. Visually confirm that the LED strip energizes to intended colors that can be found in the program.
19. Changes in LED lighting configurations must contain less latency with respect to the original audio signal than the human eye can reasonably notice	19. Visually confirm that the latency with respect to the original audio signal cannot be noticed.
20. All LEDs must energize to their respective color and luminosity with negligible losses.	20. Visually confirm that the LED strip energizes to intended colors that can be found in the program.

Appendix B Circuit Schematic

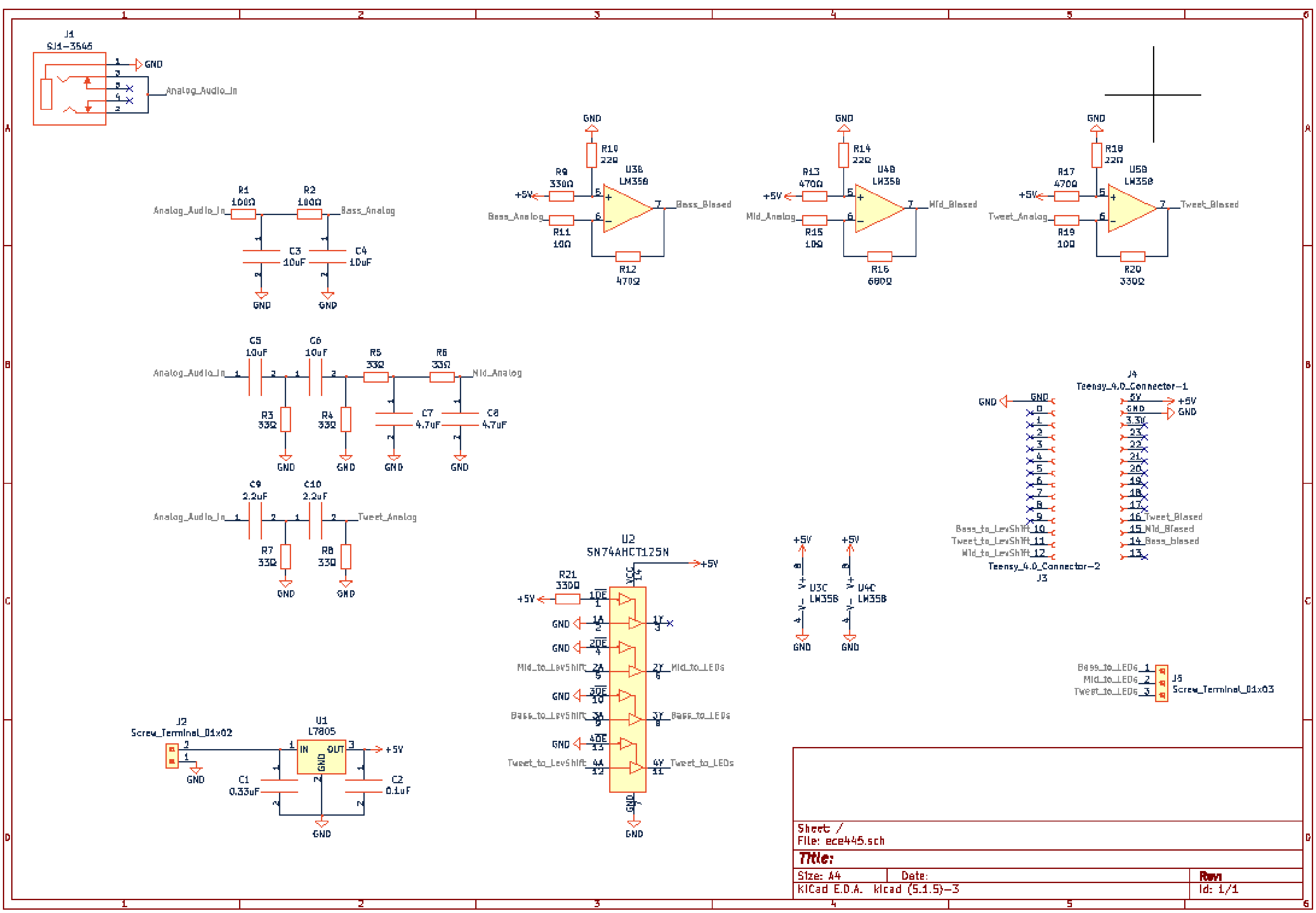

Figure 13: Schematic of Project

Appendix C Printed Circuit Board Layout

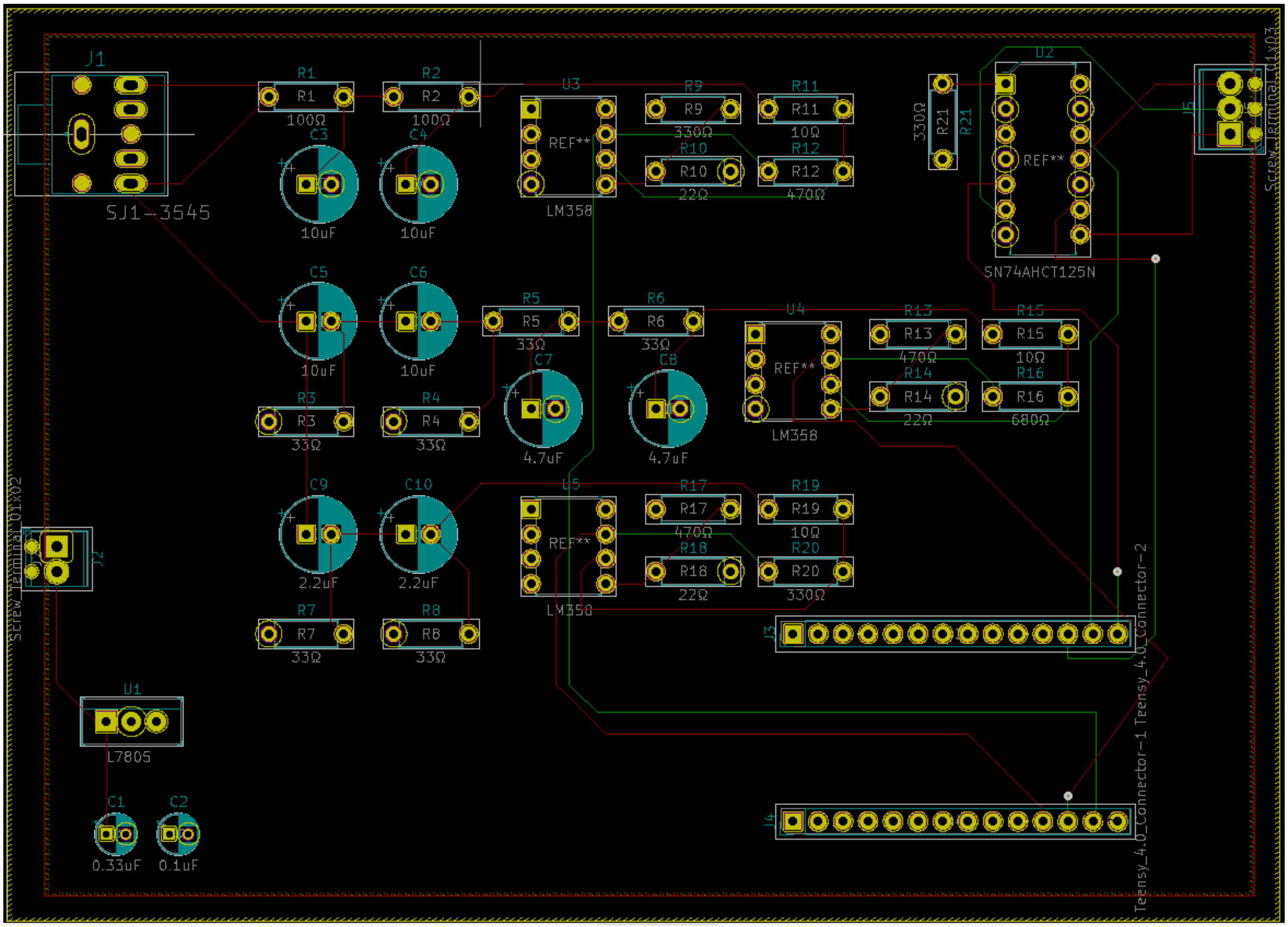

Figure 14: Printed Circuit Board Layout