Hip Hop Xpress Audio Synchronized LED Lighting 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 with different brightness levels and will have the flexibility to be installed externally or internally.

1.2. Background

- The Hip Hop Xpress is an initiative pioneered by Dr. William Patterson with the purpose of using hip hop music as a medium to educate people in under-represented areas in the Champaign-Urbana community about STEM innovations related to music [4]. From showcasing the African-American music experience and legends through art paintings on the bus to introducing people to emerging technologies in music, the Hip Hop Xpress has been both an educational and entertaining initiative in the Champaign-Urbana community. The third iteration of the Hip Hop Xpress is named the "Double Dutch Boom Bus". Dr. Patterson plans to equip the bus with DJ equipment, and high-end aftermarket speakers in order to project a fun learning environment to attract members of the community towards the bus [4].

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 IP65 waterproof rated [2] which is ideal for internal and external vehicle applications.

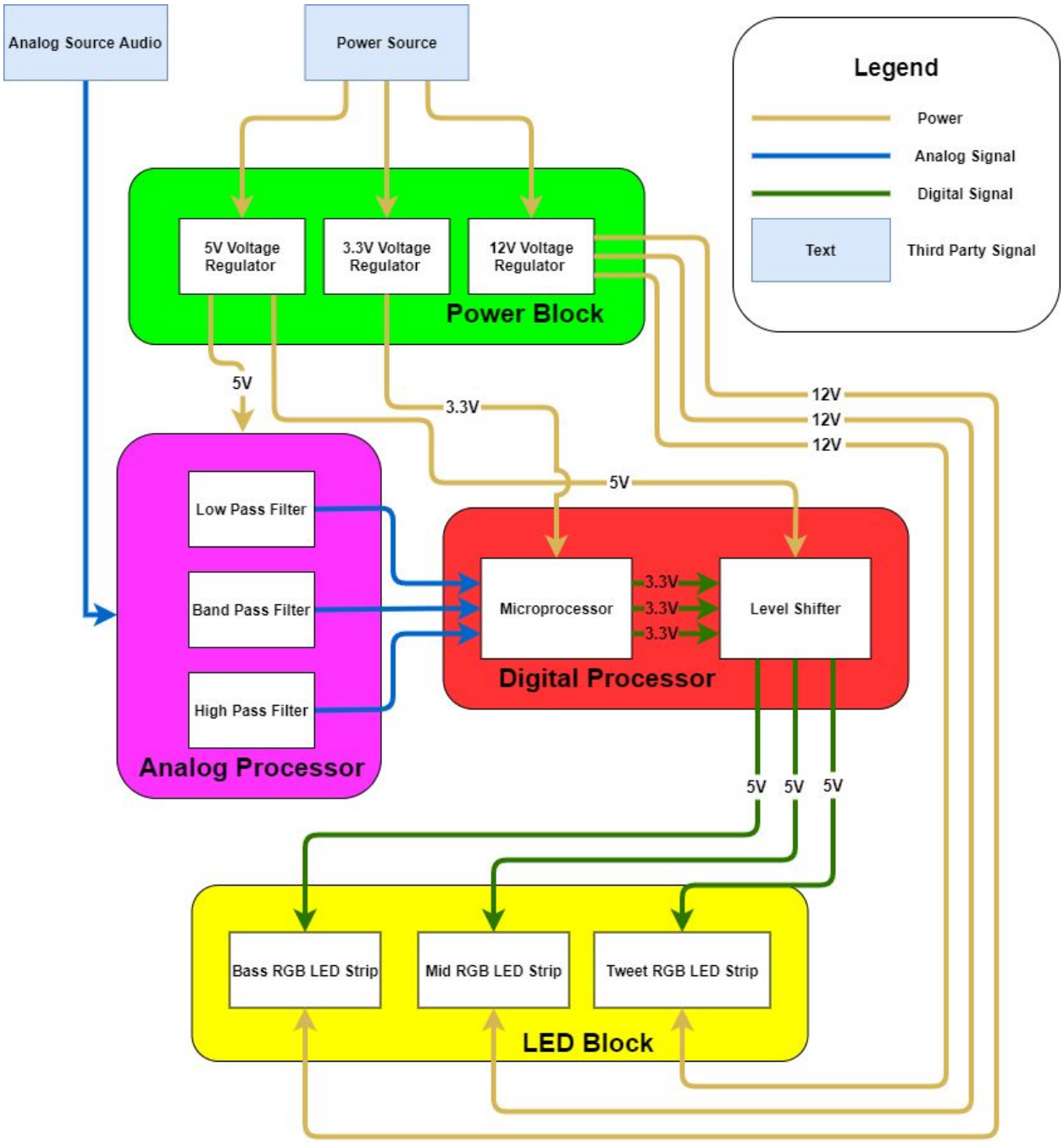
1.3. High-Level Requirements

1.3.1. Acquire and decompose the analog audio signal into bass, mid, and tweet signal components.

1.3.2. Convert bass, mid, and tweet analog signals to valid LED strip lighting configurations.

1.3.3. Drive nine-meter long LED strips with negligible color distortion from configurations calculated in requirement 1.3.2.

2. Design



2.1 Power

A third party power supply will be used to power the signal processors and LED strips with power. Voltages will be regulated according to each component's voltage requirements.

2.1.1 5V Voltage Regulator

The voltage regulator will step the supply voltage down to 5V direct current to power integrated circuit chips within the filter circuit.

Requirement 1: Must provide stable 5V +/-5% voltage from third party power source.
Requirement 2: Must maintain thermal stability below manufacturer specified max temperature at the rated maximum current draw.

2.1.2 3.3V Voltage Regulator

The voltage regulator will step the supply voltage down to 3.3V direct current to power the microcontroller.

Requirement 1: Must provide stable 3.3V +/-5% voltage originating from the third party power source.
Requirement 2: Must maintain thermal stability below the manufacturer specified max temperature when drawing no greater than 300 mA.

2.1.3 12V Voltage Regulator

The voltage regulator will step the supply voltage down to 12V direct current to power the three LED strips.

Requirement 1: Must provide stable 12V +/-5% voltage originating from third party power source.
Requirement 2: Must maintain thermal stability below the manufacturer specified max temperature when drawing at most 1.5A per meter of powered LED strip.

2.2 Analog Processor

The analog processor will be supplied with an analog audio signal. This signal will be 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.

2.2.1 Low Pass Filter

The low-pass filter will be supplied with an analog audio signal. The filter will only allow low-frequency components of the signal to pass through it.

Requirement 1: Filter must only allow frequencies between 20Hz and 250Hz to pass through at > -3dB +/-10%.
Requirement 2: All other frequencies must pass through at max -3db +/-10%.

Requirement 3: Must maintain thermal stability below the manufacturer specified max temperature at the rated maximum current draw.

2.2.2 Band Pass Filter

The band-pass filter will be supplied with an analog audio signal. The filter will only allow frequency components within the defined band of the signal to pass through it.

Requirement 1: Filter must only allow frequencies between 250Hz and 4000Hz to pass through at > -3dB +/-10%.
Requirement 2: All other frequencies must pass through at max -3db +/-10%.
Requirement 3: Must maintain thermal stability below the manufacturer specified max temperature at rated maximum current draw.

2.2.3 High Pass Filter

The high-pass filter will be supplied with an analog audio signal. The filter will only allow high-frequency components of the signal to pass through it.

Requirement 1: Filter must only allow frequencies between 4000Hz and 20000Hz to pass through at > -3dB +/-10%.
Requirement 2: All other frequencies must pass through at max -3db +/-10%.
Requirement 3: Must maintain thermal stability below the manufacturer specified max temperature at the rated maximum current draw.

2.3 Digital Processor - The bass, mid, and tweet analog signals will be converted to their respective digital signals and translated into an output LED data signal.

2.3.1 Microprocessor

The microprocessor will be supplied with the three bass, mid, and tweet analog signals and convert them to digital via an internal analog to the digital signal converters. Next, the digital signals will be analyzed in code and translated into a 3.3V LED data signal.

Requirement 1: Microprocessor must successfully read analog inputs and convert to digital without any clipping.
Requirement 2: Microprocessor must analyze digital signals and translate to a max 3.3V +/-5% transistor-transistor logic LED digital data signal.

2.3.2 Level Shifter

The level shifter will receive the three 3.3V LED digital data signals and amplify 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.

Requirement 1: Level shifter must amplify the 3.3V +/-5% LED data signal to a 5V +/-5% LED data signal.

2.4 LED

The three LED strips contain a total of 1800 microprocessors that will receive the 5V LED data transistor-transistor logic signals. For each signal, (bass, mid, and tweet) they will energize their respective LEDs to the proper color and luminosity.

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 which LEDs to energize. The strip will be powered using 12V direct current. Power wires will be spliced and soldered onto the LED strips power contacts every 5 meters to prevent voltage drop from affecting the color of the energized LEDs.

Requirement 1: LEDs must light up within 175 +/-50 ms of analog signal being acquired by the filter circuit so as to prevent noticeable lag time between music and LED response.
Requirement 2: All LEDs must energize to their respective color and luminosity with negligible losses (+/-1%).

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 12V direct current. The data signal will instruct the embedded LED microcontrollers which LEDs to energize.

Requirement 1: LEDs must light up within 175 +/-50 ms of analog signal being acquired by the filter circuit so as to prevent noticeable lag time between music and LED response.
Requirement 2: All LEDs must energize to their respective color and luminosity with negligible losses (+/-1%).

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 12V direct current. The data signal will instruct the embedded LED microcontrollers which LEDs to energize.

Requirement 1: LEDs must light up within 175 +/-50 ms of analog signal being acquired by the filter circuit so as to prevent noticeable lag time between music and LED response.

Requirement 2: All LEDs must energize to their respective color and luminosity with negligible losses (+/-1%).

2.5 Third-party Inputs

In order 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.

3. Ethics and Safety

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"

3.1. 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.

3.2. 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 in close proximity to 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.

3.3. Seizure Warnings

- Due to the fact that 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 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 .”

3.4. 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 IP65 compliant in order to keep the internals of the LED splash-proof [2]. The LED strip is resistant to lightly pressurized water streams. Additionally, we will enclose the LED strips inside translucent silicone tubing with sealant adhering to the endcaps to the tubing. This will ensure that when the vehicle is traveling at highway speeds, no water will come into contact with 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 individuals health, or the intended operation of the system [7] .

1. References

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