PROJECT PROPOSAL: MUSIC REACTIVE LED SYSTEM

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1. Project Objectives

The goal of this project is to design and build a real-time music reactive LED system that combines analog audio circuits with embedded digital control.

This project has four main objectives:

- To design and build a microphone preamplifier using operational amplifiers, producing a clean audio signal with suitable gain and DC bias for ADC sampling.
- To implement an analog active filter network that separates the audio signal into low-, mid-, and high-frequency components before digitization.
- To connect the analog audio front-end to a microcontroller so that the sampled signals to be processed and used to control an addressable RGB LED strip (WS2812B) in real time.
- To implement a simple hardware-based user interface that allows the user to view system status, switch visualization modes, and adjust parameters such as gain.

Rather than relying on pre-built audio modules, this project focuses on hands-on circuit design, system integration, and testing.

2. Methodology

The project follows a mixed-signal design approach that combines analog signal conditioning, embedded firmware, and real-time LED control.

2.1 Analog Audio Front-End

An electret condenser microphone will be used to capture audio signals. Because the microphone output is at the millivolt level, a custom preamplifier circuit will be designed using an LM358 operational amplifier to provide sufficient gain and a stable DC offset compatible with the microcontroller's ADC input range.

After pre-amplification, the signal will be routed through a 3-band active analog filter network implemented with operational amplifiers. The filters separate the audio spectrum into bass (below 200 Hz), midrange (200 Hz to 2.5 kHz), and treble (above 2.5 kHz) components. Performing frequency separation in hardware reduces the processing load on the microcontroller and allows each frequency band to be handled independently.

2.2 Embedded Firmware and Signal Processing

The filtered analog signals will be sampled by the Arduino Uno through three separate ADC input channels. The embedded firmware will process these sampled signals and map them to real-time LED control parameters.

The firmware will be organized to avoid blocking delays, allowing audio sampling, LED updates, and user input to be processed continuously within each main loop cycle. A simple automatic gain control (AGC) function will be included to adapt the system to different input volume levels and acoustic environments.

2.3 User Interface and Output System

A basic user interface will be implemented using a 0.96-inch OLED display (SSD1306) and a rotary encoder with a push-button. The interface allows the user to view system status, switch between visualization modes, and adjust parameters such as gain during operation.

The output stage consists of a WS2812B addressable RGB LED strip. Different frequency bands will control different visual behaviors, with low-frequency signals emphasizing rhythm-based effects, while mid- and high-frequency signals modulate LED color and brightness.

3. Visualization Modes

The system will support several visualization modes that can be selected through the user interface:

- Spectrum Mode: This mode divides the LED strip into sections that respond to bass, midrange, and treble signals, showing how different frequency components of the music change over time.
- Waveform Mode: This mode displays the real-time audio waveform on the OLED screen, while the LEDs provide soft background lighting based on overall signal level.
- Reactive Strobe Mode: This mode highlights rhythmic bass events by triggering brief, high-brightness LED flashes in response to beats.

4. Hardware and Software Components

4.1 Hardware

- Arduino Uno R3 (ATmega328P)
- Two LM358 dual operational amplifiers
- Electret condenser microphone
- WS2812B addressable RGB LED strip
- 0.96-inch I2C OLED display
- Rotary encoder with push-button
- 5V, 3A external power supply

4.2 Software

- Embedded C/C++ firmware
- FastLED library for LED control
- Adafruit_SSD1306 library for OLED display

- Interrupt-based rotary encoder handling

5. Project Timeline

The project is expected to require approximately 60 hours over an 8-week period.

- Week 3: Design, breadboard, and verify the microphone preamplifier to obtain a clean, properly biased audio signal for ADC sampling.
- Week 4: Build and test the three-band active analog filter network to produce separate bass, mid, and treble signals.
- Week 5: Implement the OLED display and rotary encoder to create a functional user interface for system control.
- Week 6: Integrate analog input, firmware logic, and LED control into a single non-blocking system prototype.
- Week 7: Transfer the circuit to a soldered board and assemble the enclosure to improve reliability and portability.
- Week 8: Prepare documentation, schematics, and presentation materials, and rehearse the system demonstration.
- Week 9: Perform extended testing and fine-tuning to ensure stable operation and consistent response.
- Week 10: Conduct the final live demonstration and respond to questions during the project presentation.

6. Conclusion

This project combines analog circuit design with embedded system development to create a complete mixed-signal system. Designing the audio front-end from scratch demonstrates understanding of analog electronics and circuit fundamentals, while firmware development and system integration demonstrate practical embedded systems skills.