Guitar Entertainment System

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Concept of Operations

Concept of Operations
for
Guitar Entertainment System

Team <28>

Approved by:

Monte Martin III **9/14/2023**
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Change Record

Rev.	Date	Originator	Approvals	Description
-	9/11/2023	Rishabh Ruikar		Draft Release
2	12/2/2023	Rishabh Ruikar		Final 403 Release

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1. Executive Summary

The Guitar Entertainment System is an innovative integration of an amplifier, signal processing pedal, and a mobile app with Bluetooth connectivity. Instead of relying on traditional power management methods, the app acts as a centralized control hub, enabling users to wirelessly customize both the amplifier and pedal's effects and settings. The amplifier utilizes an MCU, DSP, DAC, and ADC for advanced audio processing, while the pedal, equipped with its DSP, provides an interactive interface for effect adjustments—all of which are easily manageable through the app. This project seamlessly merges cutting-edge technology with the realm of musical expression, with the primary goal of delivering a dynamic and immersive playing experience to musicians. The user-friendly interface is designed to cater to individuals with minimal knowledge of guitar amplification systems, allowing them to experiment with various sound effects without requiring expertise in signal processing.

2. Introduction

The Guitar Entertainment System, a capstone project, blends technology with musical expression. It integrates a top-notch amplifier, signal processing pedal, and a Bluetooth-enhanced mobile app, transforming the guitar experience. Musicians can effortlessly control audio effects and settings remotely, highlighting our electrical engineering expertise and catering to modern musicians. Our goal is to revolutionize musical interfaces for a dynamic and immersive platform.

2.1. Background

For decades, guitarists have employed pedals to modify and enrich their sound, offering effects like distortion, delay, and chorus. With the advent of solid-state amplifiers, which replaced tubes with reliable and consistent transistor circuits, guitarists gained access to a clearer and more adaptable sonic palette. Now, our innovative app adds a modern twist to this evolution. By interfacing with both pedals and the solid-state amp via Bluetooth, it streamlines the process of sound manipulation. Historically, adjusting tones required manual knob tweaking, but with our app, these modifications are at a guitarist's fingertips, offering an unprecedented level of control and convenience in shaping their unique sound.

2.2. Overview

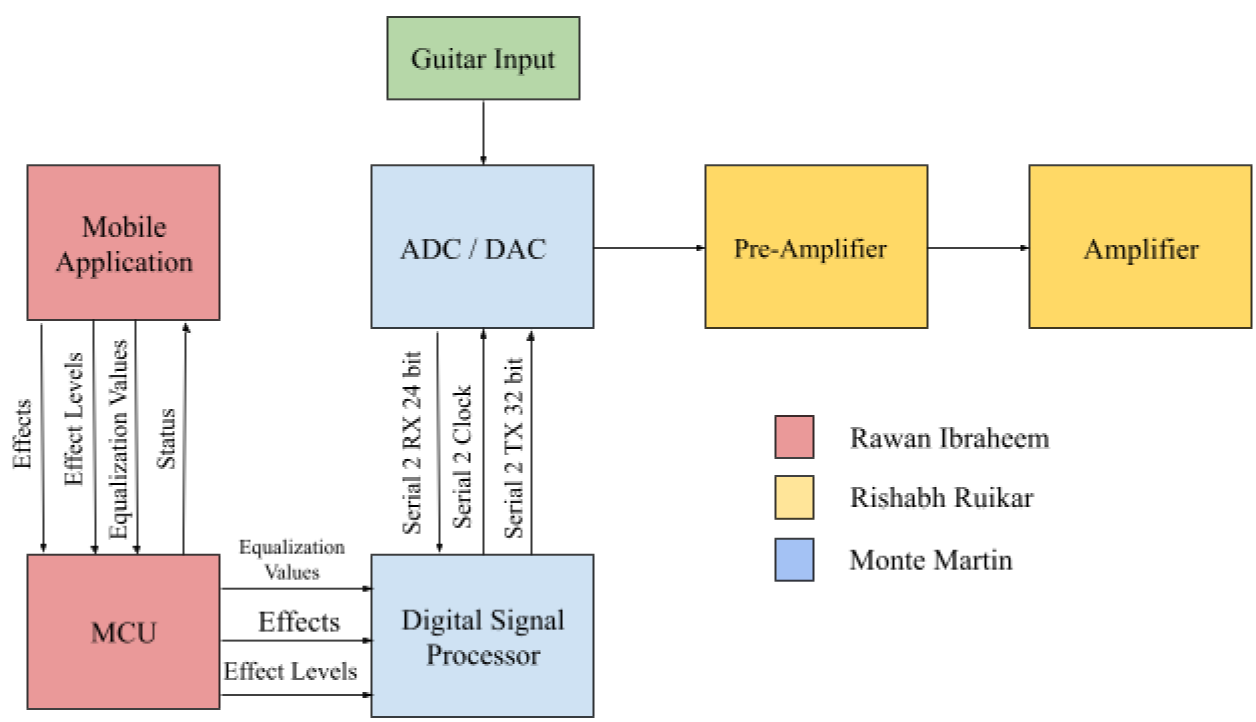


Figure 1: Guitar Entertainment System Block Diagram.

Our Guitar Entertainment System seamlessly blends traditional guitar equipment with cutting-edge technology. Its core components include a solid-state amplifier renowned for its clarity and reliability, enhancing the guitar's sound. The system incorporates pedals that introduce various audio effects, enriching the output with depth and character. A game-changing feature is the Bluetooth-enabled app, offering users unparalleled convenience in remotely controlling and customizing amp and pedal settings. This system caters to guitarists seeking an intuitive and advanced method for sound shaping, effectively merging the best of both worlds: the tried-and-true and the innovative.

Within the system's architecture, the mobile application communicates sound effect information to the MCU, which, in turn, transfers data to the DSP. The DSP receives the serial 2 RX 24-bit data from the ADC/DAC and forwards the serial 2 clock and serial 2 TX 24-bit data back to the ADC/DAC. The ADC/DAC, in the signal chain, receives the guitar input signal, which then passes through the pre-amplifier before reaching the amplifier stage.

2.3. Referenced Documents and Standards

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

- IEEE 802.11 Standards for Wireless and Bluetooth Communication: https://www.ieee802.org/11/
- IEEE Analog Need-To-Knows: https://technav.ieee.org/topic/analog-circuits
- TI Digital Guitar Effects Pedal: https://www.ti.com/lit/ml/sprp499/sprp499.pdf
- ESP32 Series Datasheet: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf

3. Operating Concept

3.1. Scope

The Guitar Entertainment System will allow for the user to amplify their sound signal and adjust the signal to allow for effects such as distortion, reverb, and chorus. The entertainment system will be operated through an android application. This project covers both the software and hardware developments in this system. The deliverables include the amplifier, pedals, a fully functional android based mobile application, as well as a user manual. Furthermore, the device must have bluetooth connectivity. The user will be able to save presets so that they will not have to adjust the settings every time they enter the application, especially if they are repeatedly adjusting the application in the same way.

3.2. Operational Description and Constraints

The Guitar Entertainment System is designed for real-time sound modulation and customization for guitarists. Users will connect their guitars to the system, then use the Bluetooth-enabled app to select and adjust effects, modify amp settings, and even save or recall specific sound profiles. This system will be especially useful during live performances, allowing for swift sound adjustments without the need for physical contact with equipment.

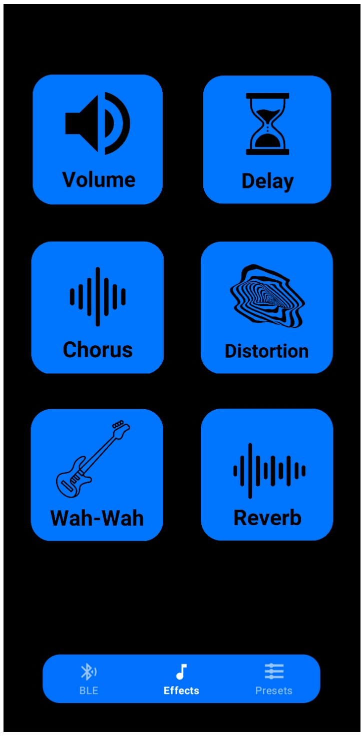
The constraints for operating the system are as follows:

- **Stable Bluetooth Connection:** A stable Bluetooth connection is essential for system operation.
- **Limited Range:** The system operates within a 10-meter range (Class 2 Bluetooth), making operation beyond this distance impractical.
- **Android Compatibility:** The mobile app must be compatible with Android devices.
- **Power Management:** Ensuring power is maintained while the app is in use is critical.
- **Maintenance Requirements:** Regular maintenance, including component cleaning and inspection, is necessary for sustained performance.
- **Budget and Time:** Parts must be budget-friendly (under $300) and available within a one-month time frame due to budget and time constraints.

3.3. System Description

The Guitar Entertainment System is an integrated solution designed to elevate the guitar playing experience. At its heart lies a solid-state amplifier, ensuring consistent and clear sound amplification. Paired with this is a pedal, which allows for diverse audio effects that alter the audio signal. The system's marquee feature is a Bluetooth-enabled mobile app, serving as a control platform. Through this app, users can wirelessly tweak the settings of both the amplifier and the pedal, customize effects, and save preferred sound profiles. Collectively, this system harmonizes traditional sound equipment with digital innovation, providing guitarists with an intuitive, modern, and versatile musical toolkit.

3.4. Users



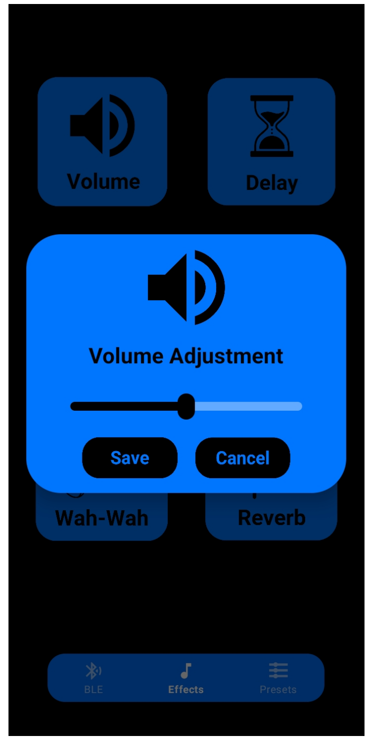


Figure 1. Effects of Sound Effect Controlling Application.

Figure 2. Sound Effect Adjustment Example.

Our Guitar Entertainment System is tailored for a broad spectrum of guitarists, from budding enthusiasts to seasoned professionals. The system is designed with user-friendliness in mind; thus, minimal training is required for installation and use. Users familiar with traditional amplifiers and pedal setups will find it intuitive, while those accustomed to digital tools will appreciate its app-based interface. Beyond the immediate musical community, sound engineers and recording studios can also benefit from the system's versatility and ease of customization. Essentially, our system appeals to anyone in the music domain seeking an amalgamation of traditional sound quality and modern control.

3.5. Support

Each system will come with a comprehensive, user-friendly manual that provides detailed instructions for setup, operation, and troubleshooting. The manual will include information about the system's components, making it easy for users to replace parts if needed. Additionally, it will offer insights into the mobile application, explaining the purpose and impact of each sound effect on the signal. This information will be valuable for users with varying levels of signal processing knowledge, enhancing their understanding of the system's capabilities.

4. Scenarios

4.1. Guitar Practice

The amplifier and pedal setup is versatile, offering the flexibility to practice guitar at a comfortable, moderate volume while maintaining clear sound quality. Even at lower volumes, the effects can be fully harnessed, enabling users to practice in a performance-like manner. Additionally, the system allows users to effortlessly create and save presets with their preferred effects during a performance, eliminating the need for time-consuming adjustments in the midst of a live show.

4.2. Performance

The amplifier is designed to deliver a powerful sound, making it suitable for live performances to small crowds. At high volumes, all the effects maintain their full functionality, ensuring users can fully harness the capabilities of the amp and pedal system during performances.

In scenarios involving multiple genres or performers, the system offers the convenience of saving distinct presets for each, facilitating quick and seamless transitions between different musical styles or artists. This feature streamlines performance preparations and enhances adaptability, catering to various performance contexts.

4.3. Recording Sessions

Musicians can use the system for recording sessions in a studio environment. The amplifier and effects offer the versatility to capture different tones and textures, enhancing the recording process.

5. Analysis

5.1. Summary of Proposed Improvements

Our Guitar Entertainment System revolutionizes the traditional guitar setup in several key ways. Firstly, it introduces wireless convenience through the Bluetooth-enabled app, eliminating the need for physical tweaking and allowing on-the-fly adjustments. This seamless integration of amp, pedals, and digital control ensures an efficient and clutter-free setup. Furthermore, the system offers a central platform for customizing and saving preset sound profiles, a boon for versatile players. By merging analog sound quality with digital enhancements, the system also promises consistency and reliability, especially with the solid-state amp design. In essence, our solution modernizes the guitar experience, making it more intuitive, adaptable, and in tune with today's tech-driven world.

5.2. Disadvantages and Limitations

While our Guitar Entertainment System offers several advantages, it's not without potential drawbacks. Relying on Bluetooth connectivity can introduce latency issues, potentially disrupting real-time play. The system's complexity, combining pedals, amp, and an application, might pose a learning curve for traditionalists. Additionally, as with any tech-driven solution, there's a dependence on battery life and software updates. Maintenance complexity, including the periodic need for cleaning and inspecting system components, can be cumbersome. Signal interference, often encountered in crowded or noisy environments, may affect the system's performance. Limited compatibility may restrict usage to specific mobile devices or operating systems, potentially excluding users with non-compatible devices.

5.3. Alternatives

6. Traditional Analog Setups: Using standalone amp and pedal setups without digital interfacing.
   - 6.1. *Trade-offs:* Provides tactile control and often preferred "warmth" of sound, but lacks the convenience of remote customization and digital enhancements.

7. Digital Multi-effects Processors: All-in-one units that combine multiple effects and amp simulations.
   - 7.1. *Trade-offs:* Portable and versatile, but may sacrifice the authenticity of individual pedal sounds and the tactility of standalone units.

8. Guitar Plug-ins on Computers: Software that simulates amps and effects.
   - 8.1. *Trade-offs:* Highly customizable and ideal for recording, but less practical for live performances and dependent on computer processing power.

9. Dedicated Hardware Controllers: Physical units that control digital effects, eliminating the need for an app.
   - 9.1. *Trade-offs: Offers a more tactile experience than an app but lacks the flexibility of wireless control and may require a bulkier setup.*

9.2. Impact

The production and disposal of electronic components in our Guitar Entertainment System could contribute to e-waste if not managed responsibly. Ethical concerns arise if the materials sourced for manufacturing aren't obtained sustainably or if production practices harm the environment. Ensuring responsible sourcing, energy-efficient design, and promoting recycling or safe disposal methods for end-of-life products are pivotal to address these concerns.

Guitar Entertainment System

Rawan Ibraheem, Rishabh Ruikar, Monte Martin

FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – Draft
25 September 2023

Functional System Requirements
for
Guitar Entertainment System

Prepared by:

Team 28 9/28/23
Author Date

Approved by:

Monte Martin III 9/28/2023
Project Leader Date

John Lusher, P.E. Date

T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	9/25/23	Rishabh Ruikar		Draft Release

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All relevant tables are appropriately cataloged in the subsequent sections of this document.

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1. Introduction

1.1. Purpose and Scope

The Guitar Entertainment System represents a groundbreaking integration of advanced audio technology, including a preamplifier, solid-state amplifier, Analog-to-Digital Converter (ADC), Digital-to-Analog Converter (DAC), Digital Signal Processor (DSP), and Microcontroller Unit (MCU). The MCU will be controlled by an Android application through a Bluetooth connection. This innovative system is aimed at elevating the guitar playing experience to new heights.

The scope of this project encompasses the design, development, and integration of these critical components, both on the hardware and software fronts. Specifically, it involves the construction of a preamplifier that conditions the incoming guitar signal, a solid-state amplifier renowned for its clarity and reliability, and the incorporation of ADC and DAC modules to facilitate high-quality signal conversion. The DSP unit is responsible for advanced audio processing, while the MCU serves as the central control unit for the system.

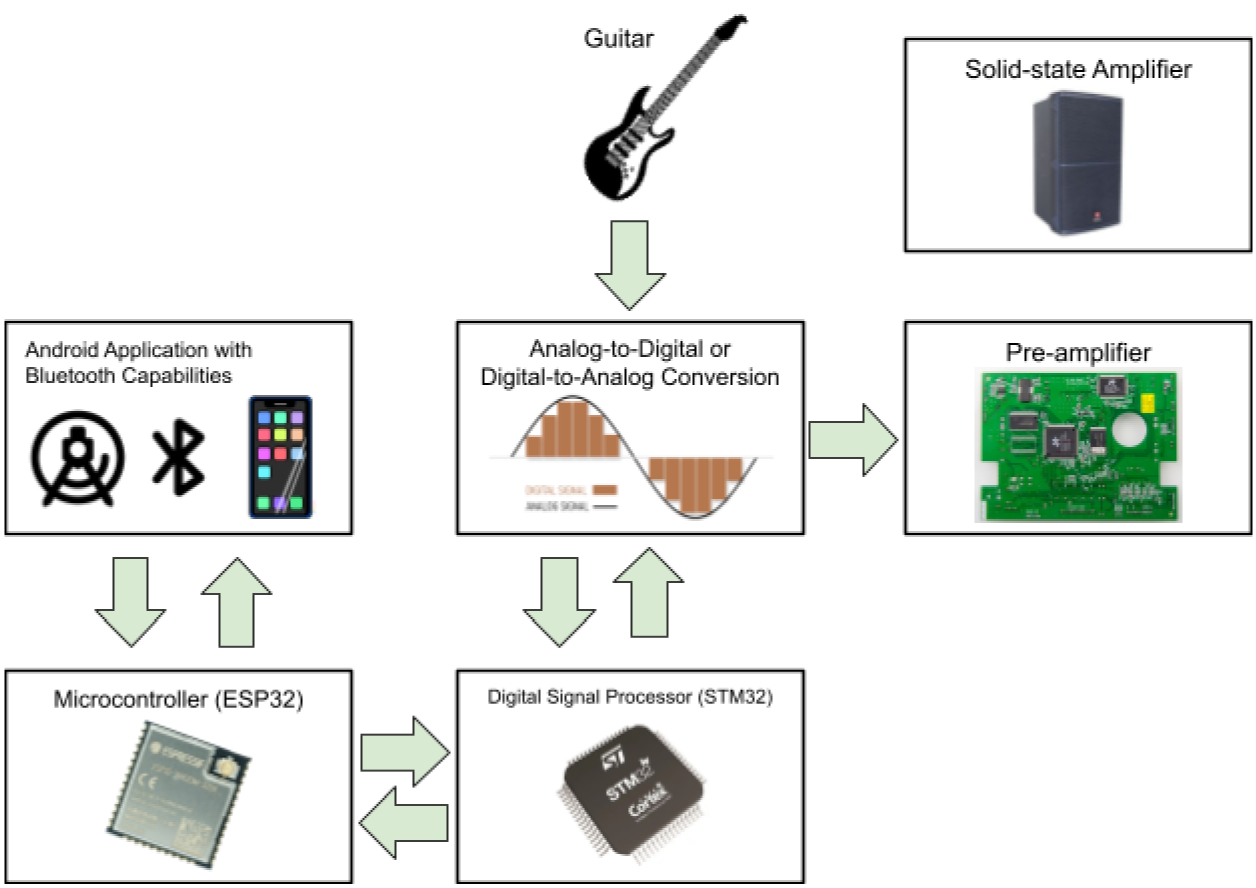

Figure 1. Guitar Entertainment System Communication Diagram

The ESP32-S3 has been chosen as the MCU for the project, and it will be programmed using Visual Studio Code with the PlatformIO extension. The Android mobile application will be developed using Android Studio, an integrated development environment (IDE) specifically designed for programming and previewing applications. As far as signals go, the sine wave from the pedals will travel to the amplifier via a ¼ inch tip sleeve. This jack will also go from the guitar to the pedals.

1.2. Responsibility and Change Authority

The team leader, Monte Martin, is responsible for ensuring all requirements for the project are met. Furthermore, Peng-Hao Huang has the authority to make changes to the plan.

Subsystem	Responsibility
Microcontroller Unit & Android Application	Rawan Ibraheem
Pre-amplifier & Amplifier	Rishabh Ruikar
ADC, DAC, and DSP	Monte Martin

Table 1. Responsibility for each subsystem.

2. Applicable and Reference Documents

2.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
IEEE 802.15.4	6/4/2002	IEEE Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN - Specific Requirements - Part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)
1910.95	8/27/1971	Occupational Safety and Health Standards - Subpart G
IEEE 1613	3/20/2003	EEE Standard Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations

2.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
ISO/IEC/IEEE 12207:2017	11/2017	Software Life Cycle Processes

2.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

3. Requirements

The following section defines the minimum requirements for the Guitar Entertainment System.

3.1. System Definition

Our project is a guitar sound system that contains 3 main subsystems, with subcomponents inside each subsystem.

- Amplifier
  - The amplifier will contain an amplifier, a pre-amplifier, and a speaker.
- Pedals
  - The pedals will modify the audio signal to implement effects and volume control.
- App
  - The app will have Bluetooth connectivity which will allow the user to customize the effects to their liking. In addition, the app will also allow users to save presets for added convenience.

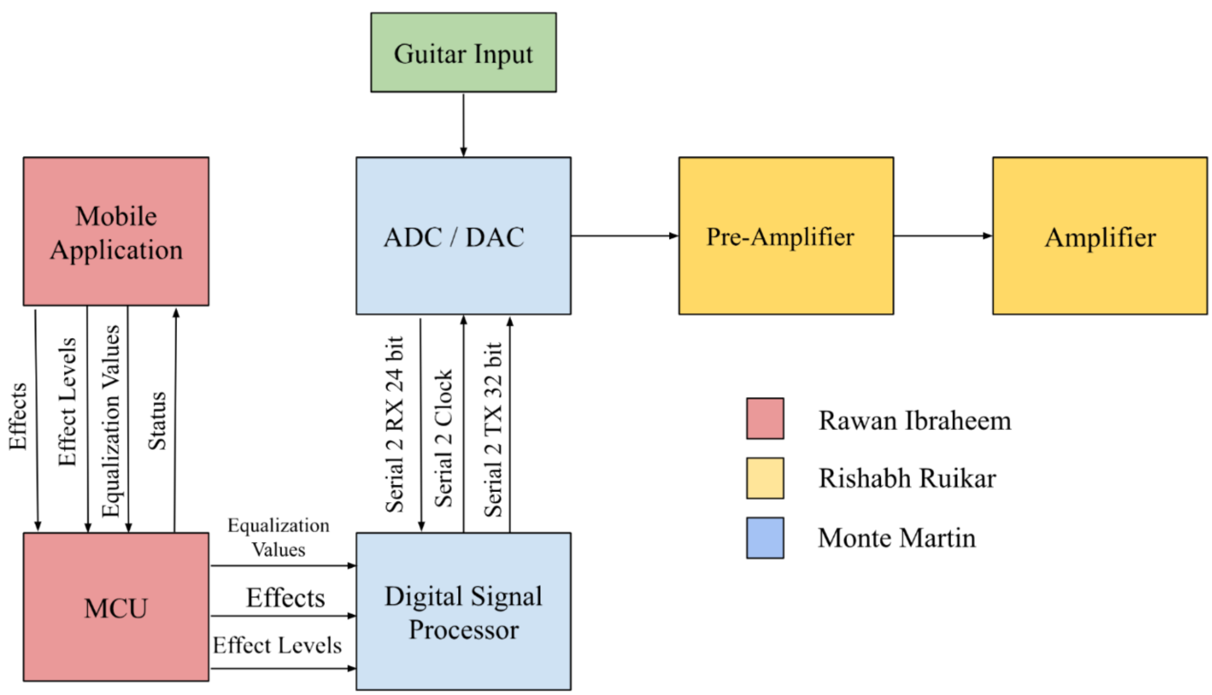

Figure 2. Block Diagram of System

This block diagram illustrates the relationship between our three subsystems. As seen the first “stage” will be the guitar signal, which will travel to the pedals (it is to be noted that the user will set the effects to be used via the app prior to using the guitar). The MCU relays the status of the DSP to the mobile application, and the app sends what effects and levels for the DSP to use. The input from the guitar goes to the ADC to convert into a digital signal so that it can be read by the DSP. Then the DSP can take the digital signal and run functions to implement the effects. Then the DAC converts the digital signal back into an analog signal which is sent to the pre-amplifier. The pre-amplifier amplifies the voltage of the signal to line level so that the amplifier can amplify the voltage and current enough to drive the speakers.

3.2. Characteristics

3.2.1.1. Frequency of Measurements

The system will be taking continuous measurements.

Rationale: The entertainment system should have a continuous audio output when in use.

3.2.1.2. Accuracy of Measurements

Less than 5 dBs of noise between the pedal analog input and output. The effects will produce waves within 5 dB of calculated values. It will also produce the output signal within 10 ns of the input signal, and can store up to 2 seconds of signal.

Rationale: The pedal system will modify the signal without reducing its quality.

3.2.1.3. Lifespan and Maintenance

The Guitar Entertainment System will be expected to last at least 15 to 20 years. If there is any loss in sound quality, the capacitors might need to be replaced. Check capacitors every 5 years, don't open the housing unless for maintenance.

Rationale: The system doesn't have anything that needs to be constantly monitored or checked on, so it should last for a long period of time.

3.2.1.4. Communications Range and Connection Time

The communication range for the system will be a minimum of 10 meters. The mobile device shall be able to connect to the system by Bluetooth within 5 seconds.

Rationale: The amplifier shall be able to be controlled by the consumer through an Android application, which may be operated from a distance.

3.2.1.5. Communications Range and Connection Time

The mobile application will communicate with the MCU to obtain status updates and send control signals when the user selects a certain guitar effect. The application is designed to run on any Android mobile device. The mobile application shall be tested on an emulator before it is tested on a mobile device.

Rationale: These requirements focus on the functionality and testing of the mobile application, ensuring it is versatile, compatible with various Android devices, and undergoes rigorous testing before consumer use.

3.2.2. Physical Characteristics

Listed below are the physical characteristics of the Guitar Entertainment System.

3.2.2.1. Mass

The mass of the Guitar Entertainment System shall be less than or equal 13 to kilograms.

Rationale: This is a requirement in order for the system to be easily portable.

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3.2.2.2. Mounting

Our system will not be “mounted”, but rather housed in sound-device-specific enclosures. This will happen in the 404 part of this project.

Rationale: Subsystems will be developed in 403, and components will be mounted in 404.

3.2.3. Electrical Characteristics

3.2.3.1. Inputs

The primary input will be a voltage signal from an electric guitar, through a 6.3 mm mono cable connection. This will be the same input from the pedal to the amplifier. The cable receptacles will be securely connected to the frame of the boxes to prevent damage upon use.

3.2.3.1.1 Power Consumption

The power consumption specifications for the various components of the Guitar Entertainment System are as follows. The ESP32 Microcontroller Unit (MCU) consumes approximately 792 milliwatts (mW) of power. The Analog-to-Digital Converter (ADC) requires 330 watts, while the STM32 MCU Digital Signal Processor (DSP) draws 43 watts. The Digital-to-Analog Converter (DAC) has a power consumption of 32 milliwatts (mW), and finally, the amplifier component utilizes 60 watts of power. These power consumption figures are essential considerations to ensure efficient and stable operation of the system, aligning with the overall design and performance requirements.

3.2.3.1.2 Input Voltage Level

The input voltage level for the Guitar Entertainment System shall be +15 VDC. The voltage coming from the amp to drive the speaker to 25W is approximately 14.14 volts RMS. The input voltage level for the ESP 32 shall be +3.3 VDC and shall not exceed +3.6 VDC. Input for the STM32 will be +3.3 VDC and wont exceed +3.6 VDC. Input for the ADC will be +5.2 VDC and +3.3 VDC for the DAC.

> *Rationale: If the input voltage of components such as the ESP32 and STM32 exceeds +3.6 VDC, it will damage the components and the system will either be damaged or no longer functioning.*

3.2.3.2. Outputs

3.2.3.2.1 Sound Output

The Guitar Entertainment System sound output shall not exceed 95 dB.

Rationale: According to the Occupation of Safety and Health Administration's standard 1910.95, it is safe to listen to 95 dB noise for a period of up to 4 hours. In the case the consumer uses the entertainment system for several hours, it is imperative that the volume levels are reduced by the user.

3.2.3.2.2 Diagnostic Output

The diagnostic output sent from the MCU to the app will be displayed to the user on the Android application. Further details can be found in the Interface Control Document (ICD).

3.2.3.3. Connectors

The Guitar Entertainment System shall use ¼ inch tip sleeves to transfer signal signals between the guitar, the pedals, and the amplifier.

Rationale: This is the standard type of connector for guitar equipment and allows for compatibility with the majority of equipment for guitars.

3.2.4. Environmental Requirements

The Guitar Entertainment System shall be designed to withstand and operate in the environments and laboratory tests specified in the following section.

3.2.4.1. Thermal

The Guitar Entertainment System may be operated in the temperature range 0°C to 35°C but shall not exceed 43°C.

Rationale: This is a requirement due to the nature of our customers and the environment in which the systems will be used. High temperatures will damage the hardware components in…

3.2.4.2. Humidity

The Guitar Entertainment System shall not be operated in an environment with the humidity exceeding 95%.

Rationale: IEEE 1613 often requires networking devices to operate reliably under high humidity conditions, with an operating humidity range of 5% to 95% relative humidity (RH) without condensation.

4. Support Requirements

The application boasts an intuitive user interface, eliminating the need for supplementary documentation. Users will seamlessly tailor effects to align with their individual preferences.

Appendix A: Acronyms and Abbreviations.

ADC	Analog-to-Digital
DAC	Digital-to-Analog
Hz	Hertz
ICD	Interface Control Document
MCU	Microcontroller Unit
mW	Milliwatt
PCB	Printed Circuit Board
RMS	Root Mean Square

Guitar Entertainment System

Rawan Ibraheem, Monte Martin, Rishabh Ruikar

INTERFACE CONTROL DOCUMENT

REVISION – 1
25 September 2023

Interface Control Document
for
Guitar Entertainment System

Prepared by:

Team 28 9/28/2023
Author Date

Approved by:

Monte Martin III 9/28/2023
Project Leader Date

John Lusher II, P.E. Date

T/A Date

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Rev.	Date	Originator	Approvals	Description
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1. Overview

This Interface Control Document (ICD) will provide a comprehensive overview of the interfaces governing our guitar sound system. The project consists of three critical subsystems: an amplifier, effect pedals, and a Bluetooth-controlled application. Each of these subsystems possesses distinct interfaces which interact in harmony to allow users to manipulate and customize their guitar sound with precision and ease.

2. References and Definitions

2.1. References

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

- IEEE 802.11 Standards for Wireless and Bluetooth Communication: https://www.ieee802.org/11/
- IEEE Analog Need-To-Knows: https://technav.ieee.org/topic/analog-circuits
- TI Digital Guitar Effects Pedal: https://www.ti.com/lit/ml/sprp499/sprp499.pdf
- ESP32 Series Datasheet: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf

2.2. Definitions

API	Application Programming Interface
BLE	Bluetooth Low Energy
°C	Degrees Celsius
DSP	Digital Signal Processor
ESP32	Espressif System's ESP32 microcontroller
Inch	Inches (2.54 centimeters)
GATT	Generic Attribute Profile
MAC	Media Access Control
MCU	Microcontroller Unit
PCB	Printed Circuit Board
W	Watts (power unit)
XML	Extensible Markup Language

3. Amplifier: Physical Interface

The amplifier itself will contain 3 “sub-components” within it. It will contain a speaker, an amplifier circuit, and a pre-amplifier circuit. The speaker will be a Jensen C8R 8-inch 25W speaker, and it, along with the amplifier and preamplifier circuit will be contained with a 8 in. x 5 in. printed circuit board (PCB).

3.1. Mounting Locations

The amplifier involves housing the entire setup within a specialized audio enclosure or box. This design choice is driven by our aim to centralize the system components and maintain a streamlined appearance while ensuring the functional integrity of the amplifier. As of our current stage in 403, the actual integration of the amplifier into this audio box has not yet been undertaken. Our strategic plan dictates that the housing process will be initiated during 404. Once all other subsystems are finalized and ready for integration. This phased approach ensures that all components are tested, optimized, and ready for assembly, minimizing potential complications during the final integration.

4. Pedals: Physical Interface

The pedal system consists of three subsystems: the digital to audio converter, analog to digital converter, and digital sound processor. They will all be housed within the same box, on the same printed circuit board.

4.1. Mounting Locations

The Pedal System board will be securely connected to the pedal Box using screws and brackets. The box itself will have mounting brackets so that the user can mount it to something.

5. Amplifier: Thermal Interface

Our amplifier has been designed to perform optimally within the standard commercial temperature range, spanning from 0°C to 35°C. This range has been selected based on typical ambient conditions, ensuring reliable operation under most everyday environments. It's worth noting that our sound system is not tailored for extreme conditions or high-demand scenarios often found in concert venues or outdoor performances. Instead, our design focus is directed towards more controlled settings, mirroring the conditions where our system will be showcased during demonstrations. Consequently, we anticipate a stable performance without temperature-related disruptions, as we have factored in the environmental variables of our intended use-case and are not subjecting the amplifier to the higher stresses seen in more demanding professional settings.

6. Pedals: Thermal Interface

The pedals are engineered for peak performance within the standard commercial temperature range of 0°C to 35°C. This range has been determined by prevalent ambient conditions to ensure dependable functionality in most common environments. However, it's pertinent to highlight that these pedals are not designed for extreme conditions or intense demands often encountered in live concert settings or outdoor events. Our primary design objective caters to controlled environments, akin to those where our system would typically be demonstrated. As such, we expect consistent and uninterrupted performance, given that we've calibrated the pedals with the environmental variables of our target use-case in mind and have steered clear of the rigorous conditions seen in some professional settings.

7. Electrical Interface

The amplifier and pedal system will be powered via a wall outlet. In short, the power will come to the circuit from the outlet, and then go into a transformer, and that signal will go to a linear voltage regulator.

7.1. Primary Input Power

Our sound system's amplifier and pedal systems will derive their power from a standard wall outlet. To ensure the power is compatible and safe for our circuitry, we will employ a transformer as a critical component in the power input stage. The transformer will serve to step-down and possibly isolate the incoming voltage from the mains to a level suitable for our amplifier. Following the transformation process, we will implement a series of voltage and current regulations to further refine the power quality. These techniques will ensure a consistent and clean power supply, eliminating fluctuations and potential risks before the energy reaches the circuits. This multi-step approach not only ensures the safety and longevity of our components but also guarantees optimal audio performance by minimizing electrical noise and interference.

8. Communications / Device Interface Protocols

The Guitar Entertainment System utilizes Bluetooth Low Energy (BLE) as its primary communication protocol, allowing wireless control between the Android application and the system components. The system defines error codes and messages to facilitate communication between the mobile app and the MCU, ensuring effective error handling and user feedback during operation.

8.1. Bluetooth Communication Protocols

The Guitar Entertainment System employs the Bluetooth communication protocol to enable seamless wireless connectivity and control. Specifically, it utilizes Bluetooth Low Energy (BLE), also known as Bluetooth 4.2, for efficient and low-power data exchange. BLE is chosen for its compatibility with modern mobile devices and its capability to facilitate real-time communication between the system components. To enable specific functionalities, the system implements Bluetooth profiles and services, with a focus on the Generic Attribute Profile (GATT). GATT is used for data exchange, allowing users to interact with the amplifier and pedal settings via the dedicated mobile application. This standardized Bluetooth protocol ensures reliable and user-friendly wireless control, enhancing the overall musical experience.

The Android application will be connected to the amplifier via Bluetooth using an ESP32. The ESP32 will be configured as a Bluetooth peripheral using the BLEPeripheral library for Bluetooth Low Energy (BLE). The Android app developed using Android Studio will have a user interface for controlling and interacting with the ESP32 device, using elements like buttons and sliders for sending commands and data. Bluetooth functionality will be integrated into the Android app by leveraging the Android Bluetooth API and ensuring proper permissions in the AndroidManifest.xml file. Pairing the mobile device and ESP32 will require the ESP32's Bluetooth MAC address for a secure connection. Bluetooth sockets, such as BluetoothSocket, will be used to exchange data between the devices.

To ensure seamless operation, logic will be implemented in both the Android app and ESP32 to handle responses to commands or data sent. This shall involve updating the app's user interface based on ESP32 responses and executing specific actions on the ESP32.

8.2. User Control Interface

Our user control interface will consist of an app which allows the user to customize the sound system to their liking. Effects that the user will be able to customize include distortion, reverb, chorus, and echo. Currently, these are subject to change, and will be finalized as the semester progresses.

Key Features:

Sound Effects Customization: Users can tailor specific sound effects to their preference. At the present stage, effects available for customization include distortion, reverb, chorus, and echo. The application interface will offer adjustable parameters for each effect, enabling users to fine-tune their sound to a precise degree.

Bluetooth Connectivity: The app will connect to the sound system via Bluetooth, ensuring a wireless, hassle-free connection. This enables real-time adjustments and feedback, allowing users to make changes on-the-fly and immediately hear the results.

User Profiles: (If applicable) Users can save their preferred settings as profiles, allowing for quick access to their favorite sound configurations in future sessions.

8.3. Real Time Control

The MCU continuously monitors user inputs, both from the physical controls on the hardware (if available) and from the mobile app. It processes these inputs and communicates with the DSP in real-time to provide immediate feedback and control over signal processing parameters.

8.4. Synchronization and Timing

The DSP shall provide feedback and status reports to the MCU, indicating the current processing state, applied effects, and any error conditions. The MCU shall use this information to update the user interface on the mobile app or to trigger specific actions based on system status.

8.5. Error Handling Protocol

A list of error codes will be defined with corresponding error messages for communication between the mobile application and MCU. The error codes shall include data validation error, communication timeout, bluetooth connection lost, etc. When the Android app receives an error code from the ESP32, it shall display a message to the user on the application. When the ESP32 receives a command, if the command fails or is not validated, the ESP32 should respond with an error code. Error handling scenarios such as Bluetooth connection lost and invalid commands shall be tested during the validation process.

Subsystem	Paragraph	Deliverable	Methodology	Owner
MCU & Application	3.2.1.5	Application is able to run on emulator	Run application in Android Studio on Pixel 2	Rawan
MCU & Application	3.2.1.5	Application is able to run on mobile device	Run application on Samsung S20	Rawan
MCU & Application	3.2.1.4	Establish connection between application and ESP32 within 5 seconds	Use timer to measure time it takes to connect send signal to MCU	Rawan
MCU & Application	3.2.1.4	Application and MCU have a bluetooth connectivity range of at least 10 meters	Measure distance of signal meter by meter using measuring tape	Rawan
MCU & Application	3.2.3.2.2	Ensure MCU can send volume adjusting signal to DSP	Measure the output of the DSP sine wave using oscilliscope	Rawan
ADC/DAC, DSP	3.2.1.2	Practical Filter eliminates noise and creates a differential signal	Use oscilloscope to provide an input signal and the output signal	Monte
ADC/DAC, DSP	3.2.1.2	The filters will work within 5ms of delay	Simulate through Multisim and monitor values	Monte
ADC/DAC, DSP	3.2.1.2	All effects work as intended, with outputs within 5 dB of calculated values	Use oscilloscope to provide an input signal and the output signal	Monte
ADC/DAC, DSP	3.2.1.2	have less than 10 ns of delay between signal input and output	Use an oscilloscope to measure delay between input and output signals	Monte
ADC/DAC, DSP	3.2.1.2	The delay function can create up to 2 seconds of delay without loss of signal quality	Use a timer and oscilloscope to measure delay and signal quality	Monte
Amplifier	3.2.3.3	Preamp circuit will be able to receive an input signal	Simulate the preamp circuit in Multisim	Rishabh
Amplifier	3.2.3.3	Preamp circuit will be able to receive a signal from the pedals	Simulated via a digital medium (not finalized yet)	Rishabh
Amplifier	3.2.3.3	Preamp is able to pass this signal on to the amplifier	Use an oscilloscope to measure output signal	Rishabh
Amplifier	3.2.3.1	Amplifier is able to process this signal and "amplify" it	Test amplifier signal in Multisim	Rishabh

Task	**Owner**	**9/25**	**10/2**	**10/9**	**10/16**	**10/23**	**10/30**	**11/6**	**11/13**	**11/20**	**11/27**	**12/4**
Assign members to specific subsystems.	All											
Subsystem - Mobile Application & MCU										Not Started		
Design mobile app's user interface (UI).	Rawan									In Progress		
Familiarize self with ESP32's IDF.	Rawan									Completed		
Develop features that allow users to adjust and customize effects.	Rawan									Behind schedule		
Implement Bluetooth communication modules into app.	Rawan											
Create functionality for users to save and recall preset sound profiles.	Rawan											
Test the app on a variety of Android devices to ensure compatibility.	Rawan											
Integrate app-related instructions and guides into comprehensive user manual.	Rawan											
Subsystem - ADC/DAC, DSP												
Design Layout	Monte											
Decide on Parts	Monte											
Order Parts	Monte											
Design Practical Filter(Analog Filter PreADC)	Monte											
Create PCB	Monte											
Code for Digital Filters	Monte											
Build mock system	Monte											
Load code onto actual components	Monte											
Testing	Monte											
Write Code for Effects	Monte											
Solder PCB	Monte											
Subsystem - Pre-amplifier, Amplifier												
Create detailed circuit schematics for the preamplifier and amplifier stages	Rishabh											
Choose components op-amps, transistors, capacitors, and resistors	Rishabh											
Design a prototype PCB for the preamplifier and amplifier stages.	Rishabh											

Assemble and solder components onto PCB.	Rishabh											
Conduct tests to validate performance of preamplifier and amplifier stages.	Rishabh											

Guitar Entertainment System

Monte Martin III, Rishabh Ruikar, Rawan Ibraheem

Subsytem Report

SUBSYSTEM REPORT
FOR
Guitar Entertainment System

TEAM <28>

APPROVED BY:

<u>Monte Martin III   12/3/2023</u>
Project Leader   Date

____
Prof. Lusher   Date

____
T/A   Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	9/11/2023	Rishabh Ruikar		Draft Release
2	12/2/2023	Rishabh Ruikar		Final 403 Release

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1. Pedal Subsystem Report

1.1 Subsystem Introduction

The pedal subsystem works by taking in an analog signal from the guitar and sending a modified analog signal out to the amplifier subsystem. When it takes in the signal, It first goes through a practical filter which eliminates high frequency noise and any other form of interference to prevent contamination from aliased noise. It also converts a mono signal into a differential signal, which is then fed into the Analog to Digital converter (ADC). The digital signal is sent to the STM32 which is acting as the Digital Signal Processor (DSP). Then, based on the inputs received from the ESP32 which communicates with the application, it modifies the signal by running functions to implement sound effects. Once modified, it is sent to the Digital to Analog converter (DAC) to be converted back into an analog signal.

1.2 Sub System Details

1.2.1 Hardware

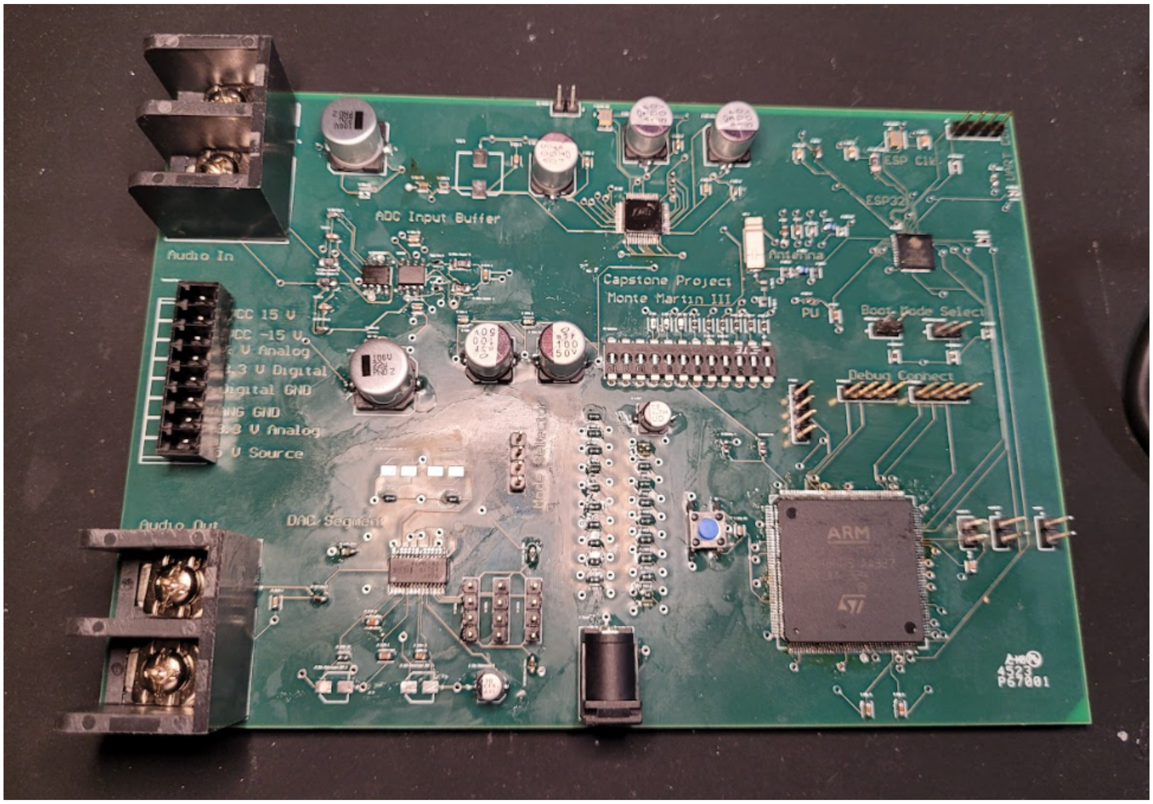


Figure 1: Pedal System PCB

The PCB for the subsystem consisted of a board with terminal inputs for power supply connections, pins for testing, and terminal blocks for input and output. Some of the pins used for testing were also used for selecting operation modes or other adjustable variables, and the dip switches are for adjusting specifically the Audio to Digital Converter (ADC). The ADC is configured in hardware mode based on how the pins are connected, and the DAC is configured into hardware mode utilizing a pull down resistor. Because they are in hardware mode, they do not require any outside signal such as I2C or SPI to operate. The ESP32 and STM32 require a connection to function properly, so that must be put onto the board. The ESP32 is programmed through UART and by selecting flash download boot using the boot mode select pins on the board. The STM32 is programmed using JTAG, which also allows for debugging.

1.2.2 Software

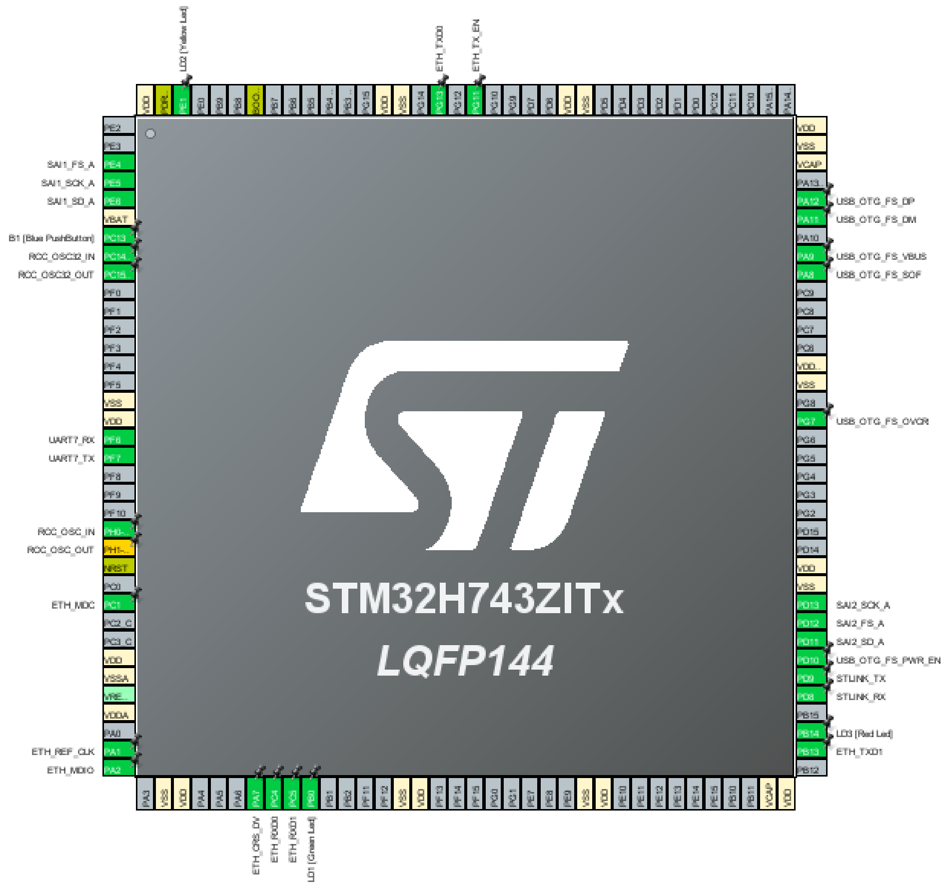


Figure 2: STM32CubeIDE.ioc File for Pin Layout and Function

Both the ESP32 and the STM32 require software to function properly. The code for the ESP32 will be provided by the application subsystem, and the STM32 will be programmed using STM's STMCubed IDE. The STM32's program will get inputs from the ESP32 to determine what effect functions to run on the input signal. The effects are created utilizing the functions in the CMSIS library provided by STM.

1.3 Sub System Validation

During testing it was determined that the +3.3 VDC power polygon is shorted somewhere on the board. Due to this, a lot of the board wasn't operating as intended, if operating at all during the demonstration. After the demonstration, the ADC was removed as it was determined that it had faulty soldering and needed to be removed, the area around it cleaned of any excess solder, and then put back onto the board.

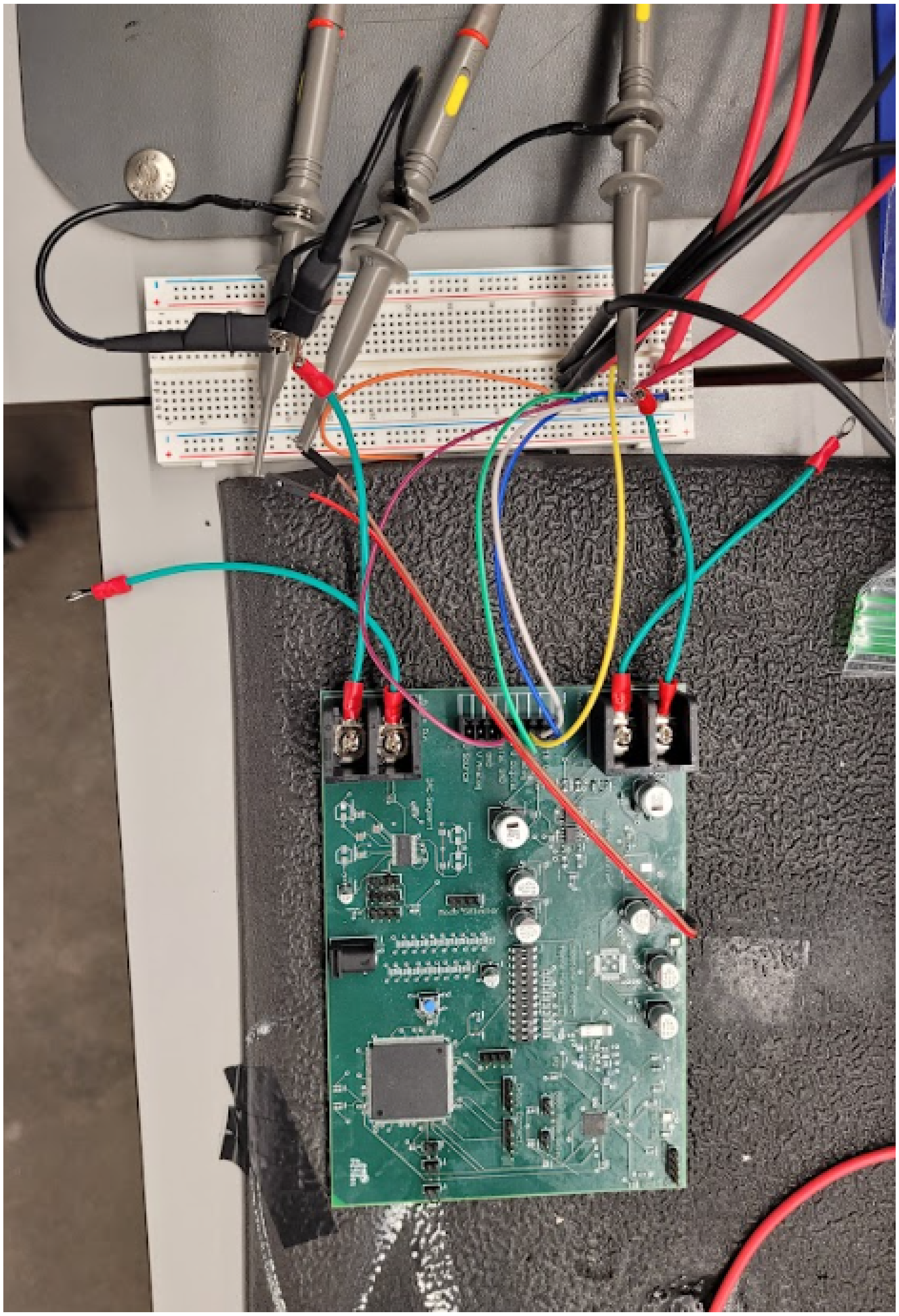


Figure 3. Pedal Subsystem PCB Connected to Power Supply and Oscilloscope

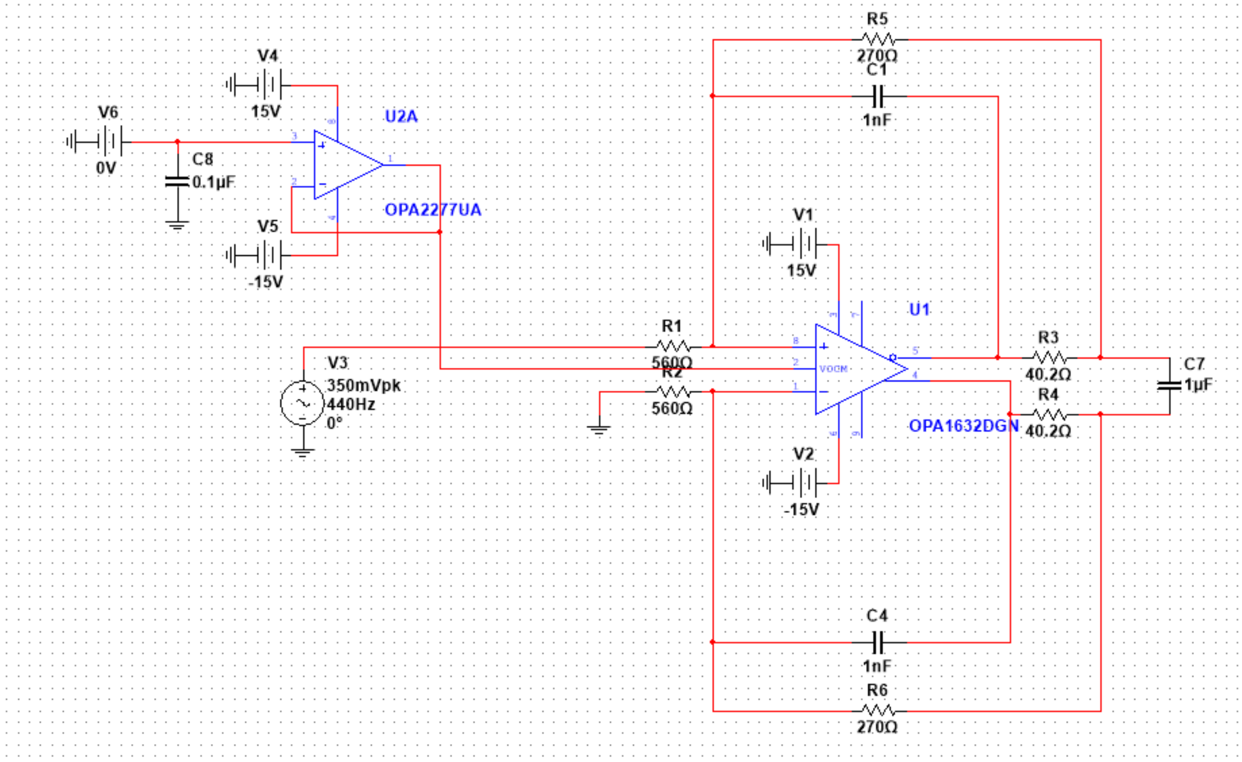


Figure 4. Practical Filter and Mono to Differential Signal Converter in Multisim.

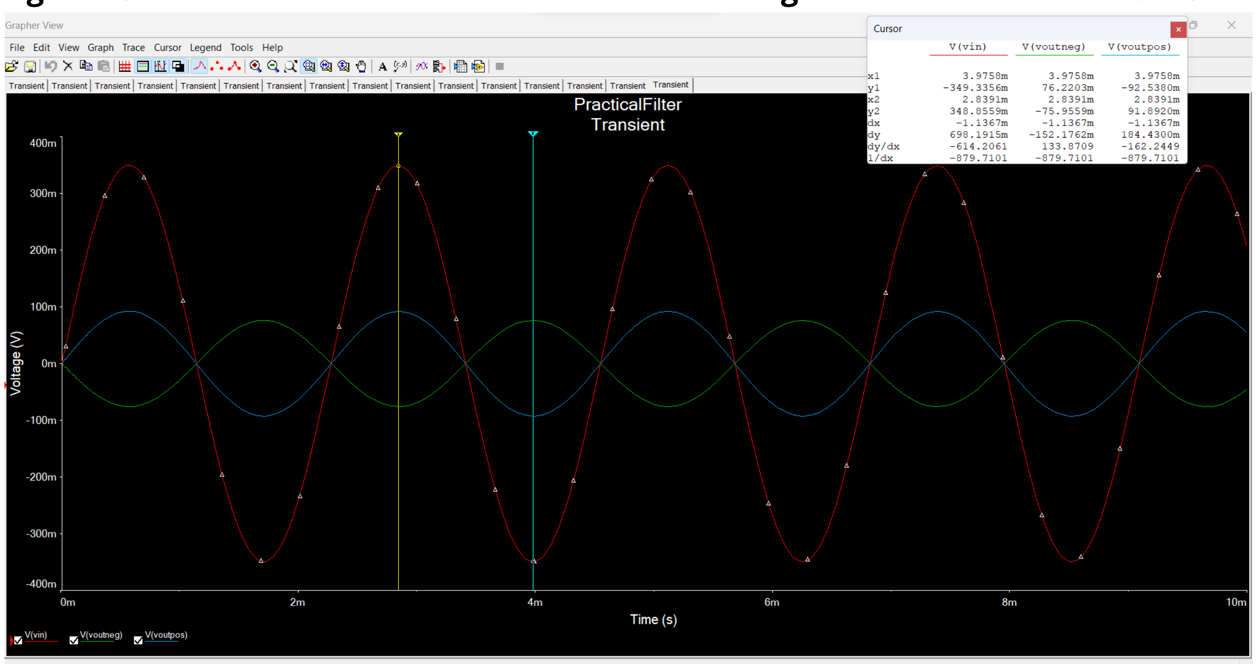


Figure 5. Transient Response of Simulated Practical Filter and Converter.

Shown above is the transient response of the simulation. The outputs match the frequency of the input signal, and when subtracted equal the input signal, showing that we successfully made a differential signal out of a mono signal.

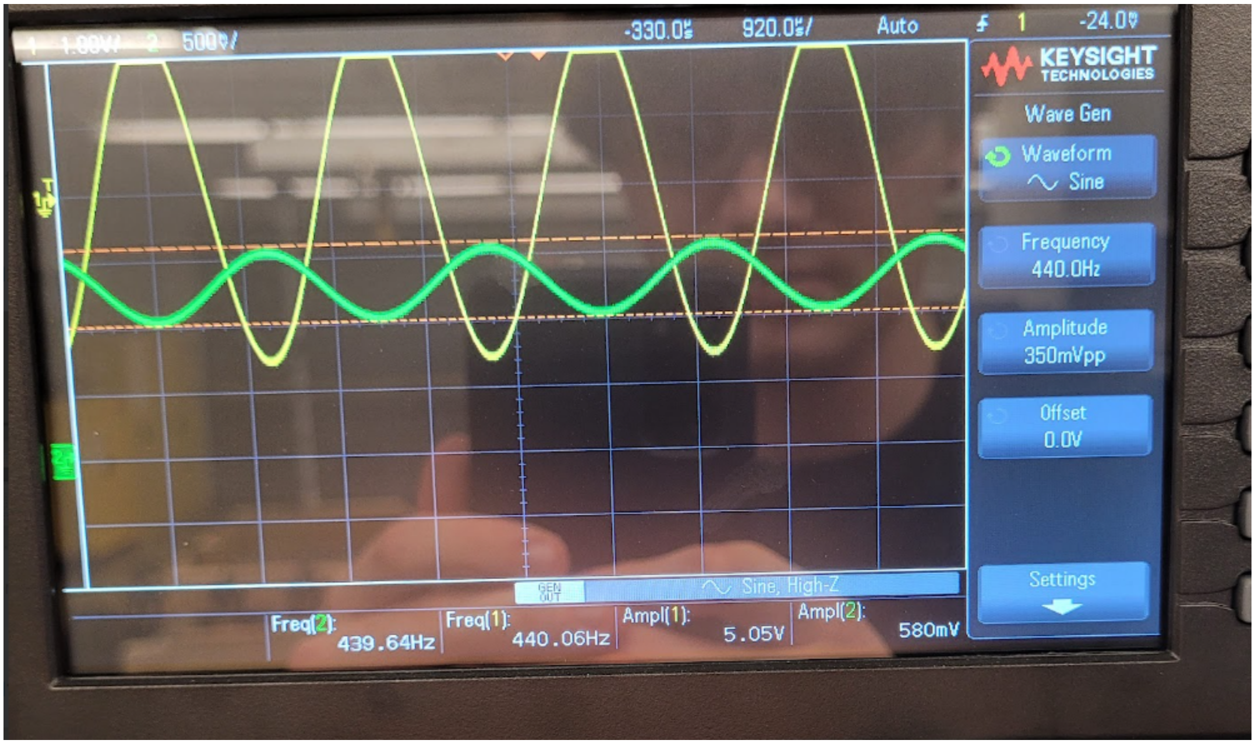


Figure 6. Oscilloscope readings of differential output of the Filter and Converter

The oscilloscope reading of testing the output signal of the practical filter and converter. Both of the signal frequencies are within 0.08% of the input frequency, but the amplitude of the signals are inconsistent with the simulation.

Figure 7. Power Supply Values

Shown above is the power supply readings showing that the 15 and -15 V supplies are operating as expected. The value shown for the +3.3 VDC source indicates that there is a high power draw which is suspected to be a short somewhere.

1.4 Sub System Failure Analysis

Three out of the 4 ICs require 3.3V power to function properly so the +3.3 VDC net is all over the board. Due to this, it is difficult to determine where the cause of the high draw of power is. Because that power supply is not operational, the majority of the board is unable to be properly tested. In order to remedy this, the plan is to trace all components connected to the +3.3 VDC net and check their connections. Then, determine which components are most likely to be causing the high power draw and begin removing them one by one testing the power draw until the culprit is found. Then once it is fixed, test the entire board and run through validating it.

Another thing that will be worked on in the upcoming time before 404 is programming the STM32 and running tests on the code to determine whether or not it can process the data effectively or not. Then, all of this information will be utilized in the design of a new board at the beginning of 404.

2. Android Application Subsystem Report

2.1 Subsystem Introduction

Figure 8. Guitar Sound Effects Logo

The Android application titled “Guitar Sound Effects” is used to send control signals through a Bluetooth Low Energy (BLE) connection to the microcontroller, the ESP32. If the user desires to change effects such as the volume, chorus, reverb, distortion, delay, or wah-wah, they may update the value of these variables in the application, and then the corresponding update is sent in string format to the ESP32.

2.2 Subsystem Hardware

Figure 9: Samsung Galaxy A03s in Black, [32GB]

The subsystem was validated with an android application that runs on the Samsung Galaxy A03s with a RAM of 3 GB and a storage capacity of 32 GB. The mobile runs Bluetooth 5.0 and supports BLE.

Figure 10: ESP32 Development Board Manufactured by Flutesan

The microcontroller used to validate the subsystem was the ESP32 WROOM on a development board purchased from Flutesan. The ESP32 WROOM has the Bluetooth LE specification. The MCU supports data transmission at a rate of 150 Mbps. The radio transmission is through a Near Zero Intermediate Frequency (NZIF) receiver with a sensitivity of –97 dBm. This allows for data to transmit to a distance of over 10 meters.

The application was developed in Android Studio on the Surface Book 3 with the Intel(R) Core(TM) i7-1065G7 processor with a CPU of 1.30 GHz. The device has 32 GB of RAM and has a 64-bit operating system.

2.3 Subsystem Software

The Samsung Galaxy A03s runs on Android Version 13 and on One UI Core version 5.1. The development environment was downloaded on the Surface Book running Windows 10 Pro.

Figure 11: Android Studio Logo

The application was developed in Android Studio Giraffe, Version 2022.3.1. The application was developed in the language Java, specifically version 8. The target Software Development Kit (SDK) is 33 and the compile SDK is 34. The Kotlin plugin version is managed through the Kotlin Bill of Materials (BOM) with the specified version 1.8.0. Several AndroidX libraries are included, such as appcompat, material, constraintlayout, lifecycle-livedata, lifecycle-viewmodel, navigation, gson, kotlin, legacy-support-v4, recyclerview, and bluetooth. Special permissions required by the application include Bluetooth, Bluetooth Scan, Access Fine Location, Access Coarse Location, Bluetooth Admin, and Bluetooth Connect to ensure that the device can scan for BLE devices and establish a secure connection.

The ESP32 development board was programmed in the Visual Studio (VS) Code IDE version 1.84.1, using core version 6.1.11 of the PlatformIO extension.

2.4 Application Screenshots

The application home page is the BLE scanner page. Upon opening the application, the application begins scanning for nearby BLE devices with a signal strength of minimum -100 dBm. This is in the case that the ESP32 is far away or the Guitar Entertainment system is across the room of the performer. The user can then navigate to the effects page, where they can press on the desired effect and change the level then save the adjustment. Lastly, the user can save and recall preset profiles if they repeatedly use the same combination of effect levels. The preset profile will be saved to the mobile phone and retrievable upon closing and opening the application.

Figure 12: BLE Scanner Home Page

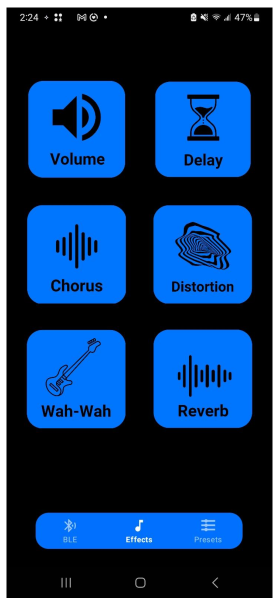


Figure 13: Sound Effect Page

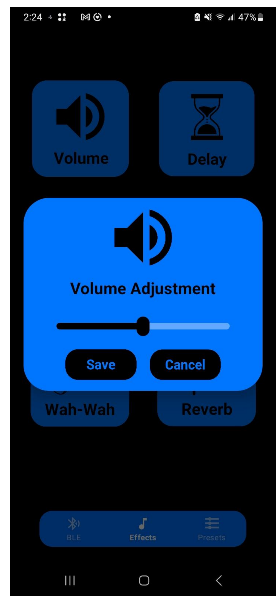


Figure 14: Volume Adjustment Dialog Pop-up

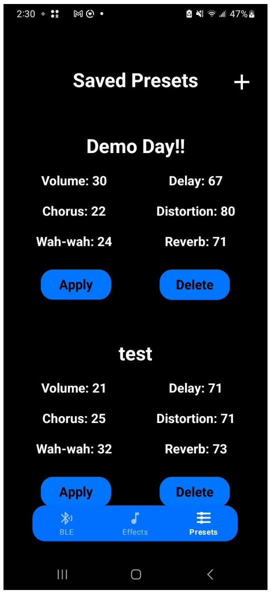


Figure 15: Presets Page with User Saved Presets

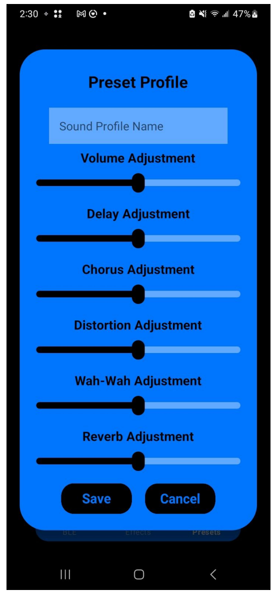


Figure 16: Preset Profile Dialog Pop-up

2.5 User Manual

Below is the user manual, which shows how to operate and navigate throughout the application, and update desired sound effects. While the app is self explanatory, the user manual is to ensure it is accessible to all users, even those who may be unfamiliar with modern technology and software.

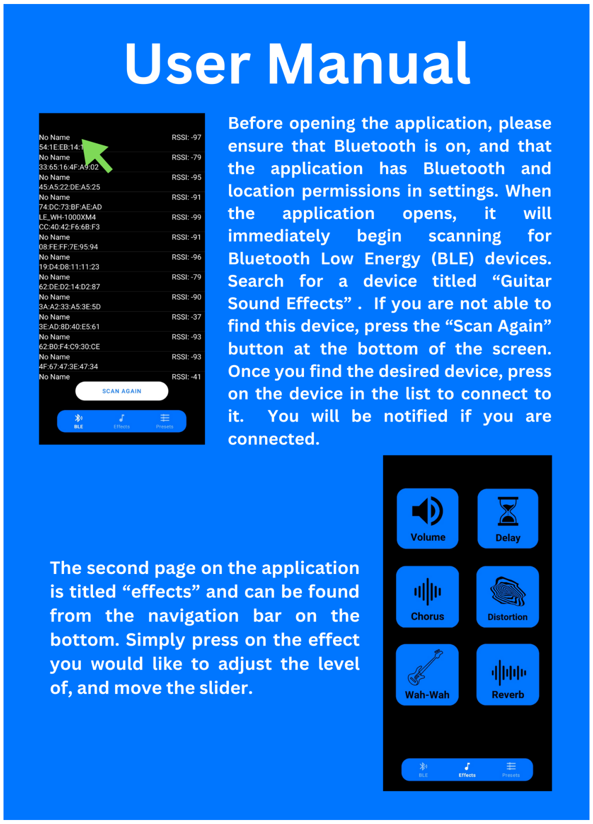


Figure 17: Page 1 of the User Manual.

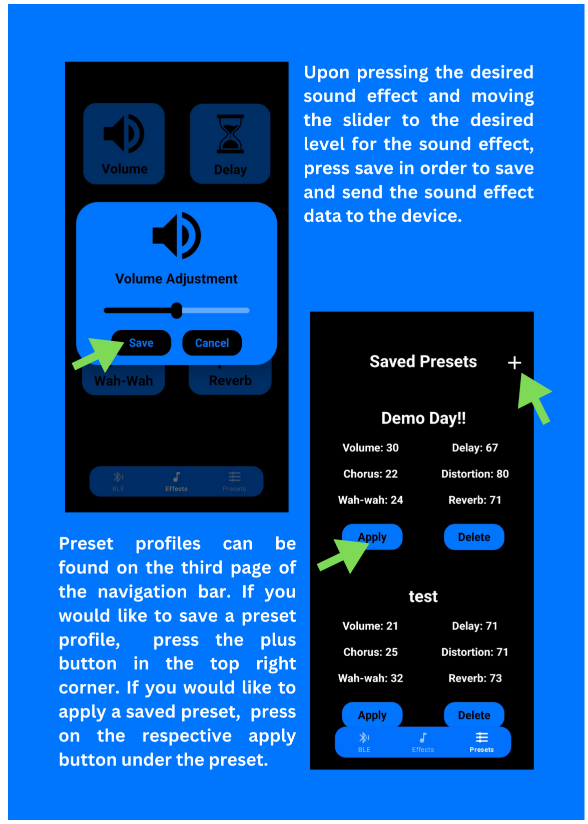


Figure 18: Page 2 of the User Manual

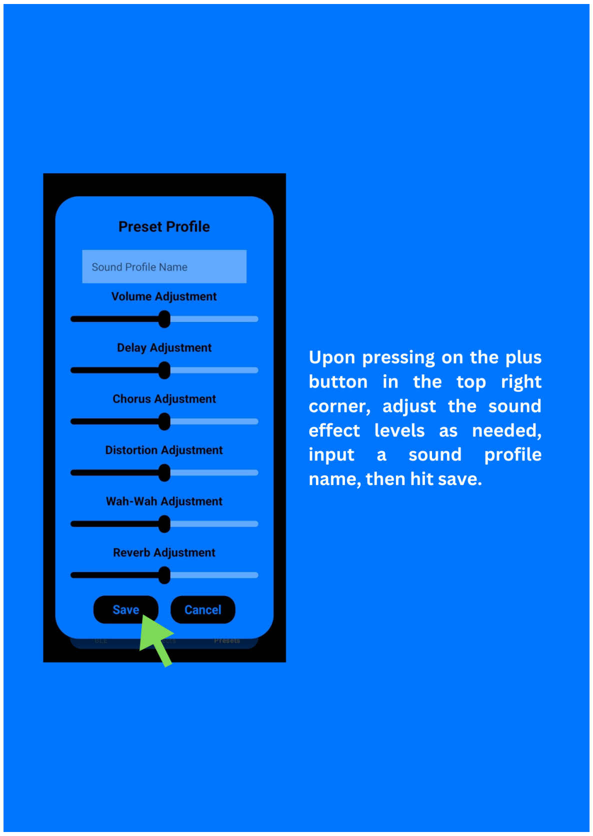


Figure 19: Page 3 of the User Manual

2.6 Subsystem Validation

Figure 20: Guitar Sound Effects Application Prototype

Above is a screenshot from the original application ran on an emulator in Android Studio, specifically the Pixel 7 with an API of 26. This was prior to incorporating Bluetooth into the application and redesigning the user interface. The subsystem was then tested and validated on the Samsung Galaxy A03s to ensure Bluetooth functionality.

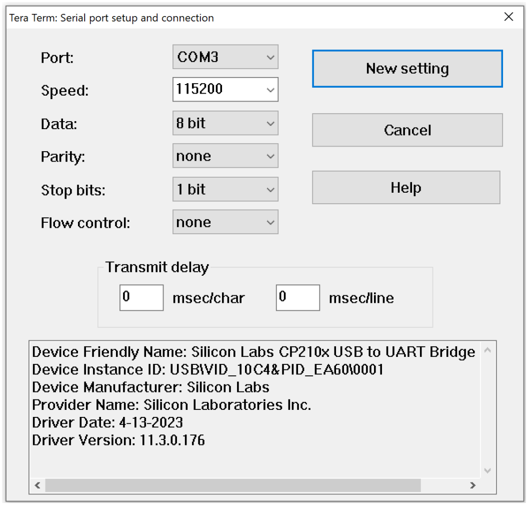
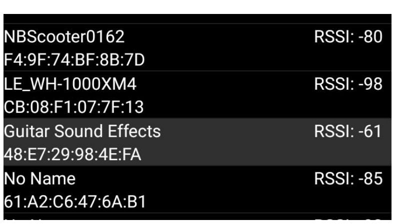
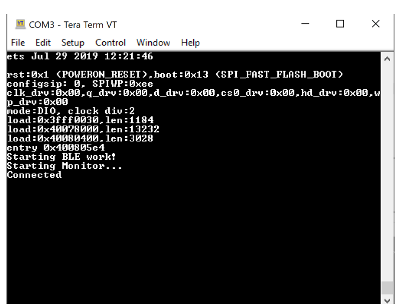
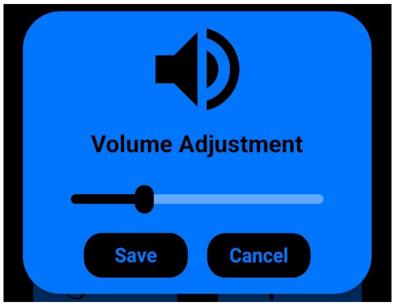
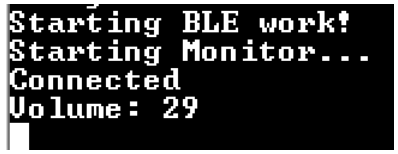
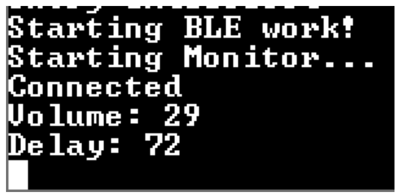
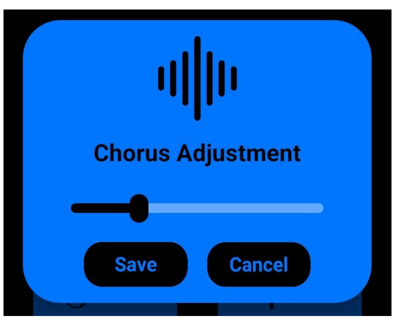
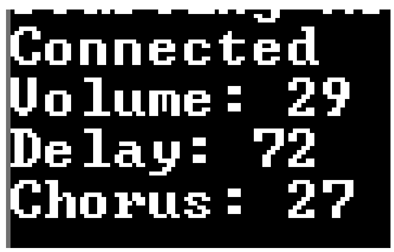
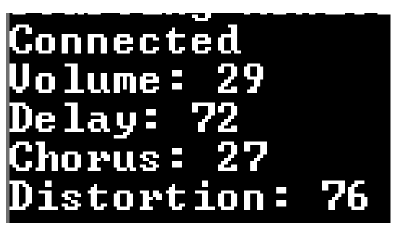


Figure 21: Serial port setup for the ESP32 development board.

Shown below is the time it takes to send a sound effect adjustment from the "Guitar Sound Effects" application on the Samsung Galaxy A03s. The ESP32 signals were read through Tera Term, by connecting the development board to the Surface Book through a micro-USB cable. The setup details are shown in Figure 20.

Table 1: Signals sent from the application to the ESP32 and the time it took to receive the signal.

Signal Sent	Signal Received	Time To Receive Signal (seconds)
 "Connected" upon pressing on the "Guitar Sound Effects" device, the discoverable name of the		2.51

ESP32.		
 Volume: 29		1.06
 Delay: 72		0.71
 Chorus: 27		0.63
 Distortion: 76		0.63

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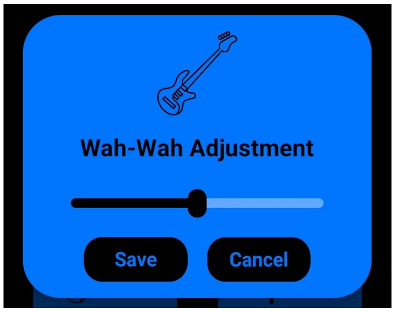
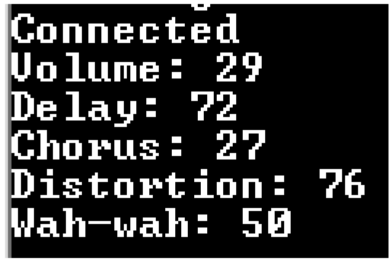
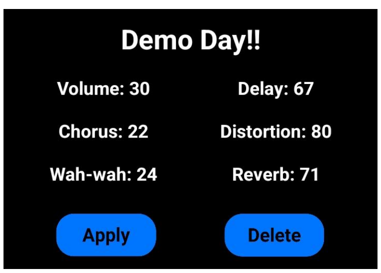
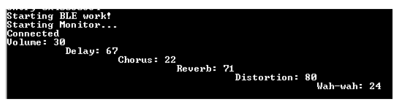
<td>

Wah-wah: 50</td>
<td>
</td>
<td>1.03</td>
</tr>
<tr>
<td>

Reverb: 66</td>
<td>
</td>
<td>1.26</td>
</tr>
<tr>
<td>

Preset: “Demo Day!!”
Volume: 30
Delay: 67
Chorus: 22
Distortion: 80
Wah-wah: 24
Reverb: 71</td>
<td>
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</table>

2.7 Subsystem Conclusion

The subsystem was shown to operate as intended with all effect adjustment signals working and no application crashes. The mobile connected to the ESP32 within 2.51 seconds, and within 3 seconds with a distance of exactly 10 meters between the MCU and the mobile device. All sound effects and presets were validated using Tera Term as shown in Table 1. The intent for ECEN 404 is to enhance the user interface and ensure that the MCU is able to send and receive signals from the DSP that can be interpreted in the application.

3. Amplifier Subsystem

3.1 Subsystem Introduction

The amplifier subsystem consisted of a preamplifier as well as an amplifier. The role of the preamplifier is to boost the weak electrical signal from a guitar (in this specific instance, it would boost the signal from the pedal system) for further processing. The preamplifier contains potentiometers for mid, bass, treble, and gain, which allow for frequency-specific equalization; this means that the user is able to modify tonal balance by boosting or reducing the frequencies in these ranges. The gain potentiometer deviates a little from the others in terms of role; it allows for the user to control the input signal strength, which is important for managing the signal-to-noise ratio. Once the signal has been processed inside the preamplifier, the output goes to the input of the amplifier. The LM1875 chip is a power amplifier IC that was utilized.

The LM1875 boosts the voltage and current of the preamplifier output, which allows for an audio signal to be outputted out of an 8 ohm 25 W speaker.

3.2 Subsystem Hardware

The preamplifier and amplifier were both made on 2 separate printed circuit boards PCBs. They were attached together using terminal connectors.

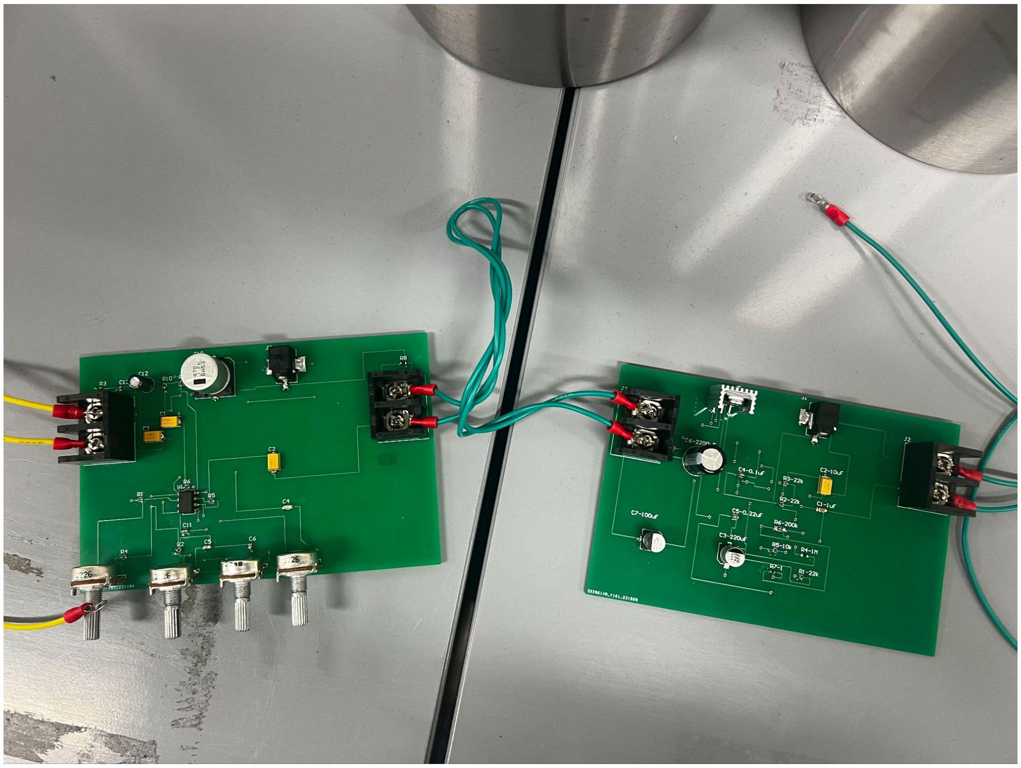

Figure 22. Amplifier PCB setup (preamplifier on the left, amplifier on the right)

3.2 Subsystem Hardware (Cont.)

As seen in the implementation image above, the left-side preamplifier contains potentiometers which allow for tone controls. The amplifier on the right contains a LM1875 chip on the top left of the board, while having more capacitors, which is crucial for power amplification stages where signal stability and power handling are paramount. The green wire “bundle” in the middle of both is the audio signal transmission path, which carries the processed signal from the preamplifier to the amplifier.

3.3 Subsystem Validation

Through the capstone course, the subsystem was validated in multiple ways. The preamplifier went through a rigorous testing process. This included conducting multiple digital circuit simulations to verify the integrity and performance of the circuit.

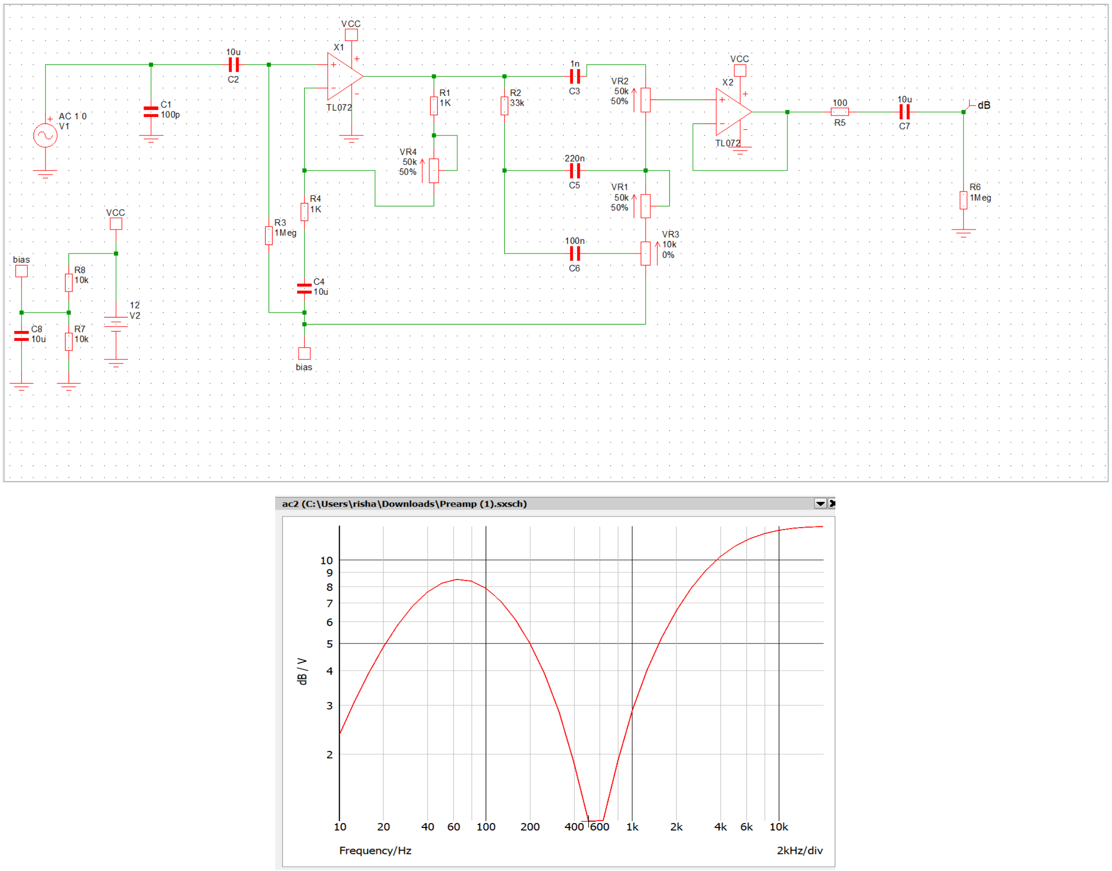

Figure 23: Digital Simulation results for the Preamplifier Circuit

As seen, when running an AC simulation from 20 Hz -1 kHz at 1 V amplitude, this digital simulation shows that the circuit outputs a frequency response curve delineating a pronounced gain peak around 65 Hz, which is indicative of a low-frequency resonance in the bass region. Most notably though, there is an attenuation in the mid-range frequencies between 400-600 Hz. At around 400 Hz, guitar impedance characteristics naturally have a damping factor at these midrange frequencies. After the signal frequency surpasses the 400-600 Hz range, the gain starts to increase again, which is indicative of a normal preamplifier design. **Note that a preamplifier is not supposed to have a gain that is supposed to be outputted by a speaker.* When testing in the lab, the preamplifier was “fed” a 1 V amplitude 440 Hz sine wave, however, due to power issues on the board itself, this signal was unable to be received by the preamplifier and therefore the amplifier as well.

For the amplifier design, it was taken from the TI LM1875 datasheet. The specific application that was used was one for a single DC supply.

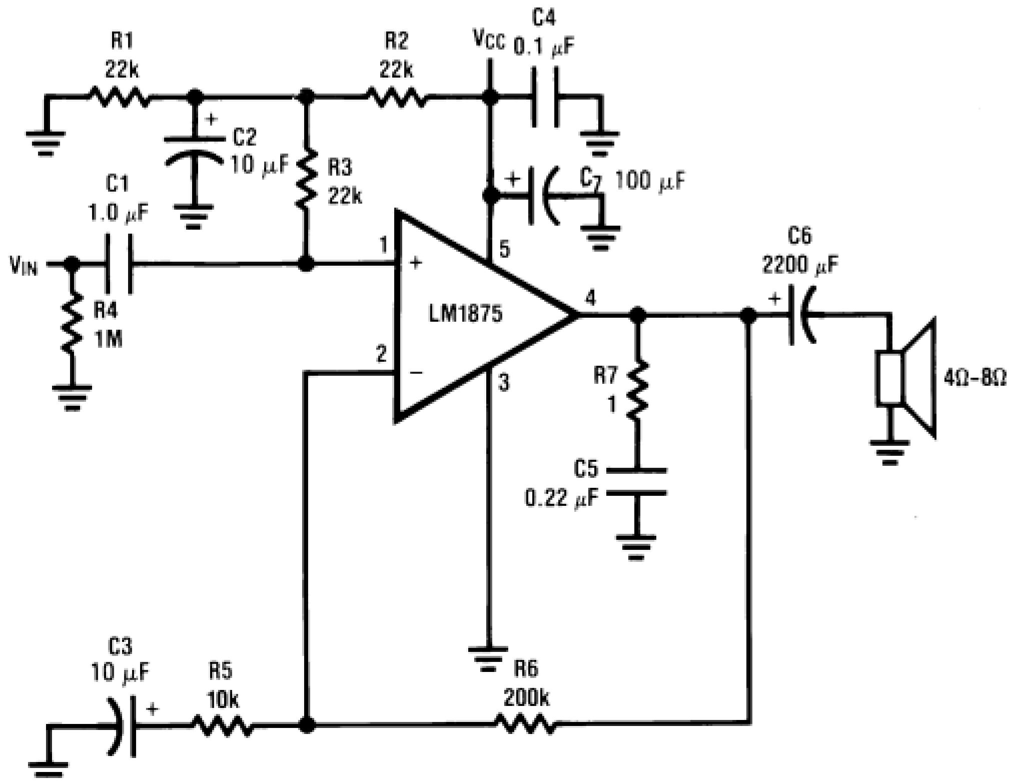

Figure 24: Amplifier design via TI datasheet

This schematic shows the typical LM1875 application. It includes a non-inverting configuration where the gain is set by the resistor ratio of R3 to R7 and is stabilized for high frequencies by C5. The output to the speaker includes a Zobel network to counteract the inductive nature of the speaker load and ensure amplifier stability. The circuit is designed for straight-forward operation with minimal external components, suitable for driving a speaker with impedances between 4-8 ohms.

3.4 Subsystem Failure Analysis

Due to hardware as well as power issues, the amplifier subsystem as a whole was unable to produce presentable results. However, the reasons for failure are known and will be addressed to mitigate any issues in 404. Taking a look at what caused the failure, it can be first and foremost pinpointed to the fact that a reverse polarity power signal was fed into the preamplifier. Typically with guitar preamplifiers, they require a center-negative polarity DC jack. What this means is that the center "pin" or tip of the jack is connected to a negative terminal of a power supply. In the preamplifier that was built, the schematic demonstrated that it was designed for a single-polarity power supply with the ground referenced to the tip of the barrel connector and the VCC connected to the sleeve, indicating a requirement for a negative voltage rail. Consequently, this requires the use of a -15 V supply to align with the negative ground scheme. Employing a positive voltage supply in the preamplifier configuration (which was done) results in a reverse bias condition across the entire circuit, which led to the op-amp overheating. The TL072, which is a FET-input op-amp, is particularly sensitive to correct power supply polarity to function within its specified range. In addition, to accommodate the current demands of a 25 W speaker, both PCB trace widths must be increased in order to allow for safe conduction of the signal's power level. Utilizing 10-mil traces was inadequate for this application as they would have likely succumbed to overheating and potential vaporization. Therefore, increasing the PCB trace size would be optimal to let the speaker function at its correct operating parameters.