Sound Effect Devices for Musicians

PROJECT PLAN

Team Number

39

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1 Introductory Material

1.1 ACKNOWLEDGEMENT

Dr. Randall Geiger and Dr. Degang Chen have served as technical advisors on the project – they have acted to guide us in direction and pace, and motivated us in our pursuit of understanding of the project's material. Dr. Geiger and Dr. Chen acted to fuel our ambition and turn our curiosities into a reality. This acknowledgement is intended to serve as our expression of gratitude to our advisors, without whom project progress would surely suffer.

1.2 PROBLEM STATEMENT

In the audio amplification world, particularly with respect to electric guitar signal amplification, musicians have historically chosen to use amplifiers driven by vacuum tube technology. Up until around the 1970s, vacuum tubes dominated the audio market, and many of the 'classic' rock albums that listeners hold in high esteem are recordings of vacuum-tube drive amplifiers. The sonic footprint these albums left on the modern musician is considerable, and many guitarists refuse to perform with amplifiers driven by tube alternatives – the dominant alternative being the BJT solid state amplifier – solely because of the 'classic' tones associated with vacuum tubes.

There are significant advantages to utilizing solid state technology for guitar amplification. Solid state devices are significantly more power efficient than vacuum tubes, and the physical footprint of BJTs are magnitudes of order less than that of vacuum tubes. Additionally, solid state technology is far more resilient to abuse – both physical and electrical – than tubes. Perhaps most importantly, BJTs are significantly less expensive than vacuum tubes.

Despite the advances made in BJT technology (in efforts to model the tube amplifier) and the considerable financial benefit to producing solid state amplifiers on a commercial scale, solid state technology still, for the most part, is undervalued to vacuum tubes amongst professional musicians. The team believes this is largely due to a failure to properly address the sonic aesthetics surrounding vacuum tube amplifiers.

The team believes that, if the key musical parameters around the tube amplifier are quantitatively observed, a tube 'effect' can be modelled and reproduced. In the proposed solution, the team designs an emulator that can impose vacuum tube amplifier characteristics onto the incoming guitar signal. The solution offers an all-in-one module that addresses the tone demands of guitarists while maintaining a comparatively less convoluted and expensive package compared to the boutique vacuum tube amplifier.

1.3 OPERATING ENVIROMENT

The vacuum tube emulator will be built to survive in the often harsh environment musicians (particularly performing musicians) use their equipment in. Often, musicians play in adverse weather conditions, necessitating that the emulator be reasonably water and dust resistant. Additionally, as the emulator will operate at nontrivial voltages (~9V) and currents (~300mA), sufficient low impedance ties from chassis ground to earth ground will be engineered to avoid any shock risk to users, as well as to protect the module from ESD. The operating environment information is necessary in order to design an end product that can withstand the hazards that the device is expected to encounter.

1.4 INTENDED USERS AND INTENDED USES

Users

The intended users would be avid musicians that either do not have or do not want to spend the money for a $1000+ amplifier, but instead are looking for affordable and high quality emulator to be used in conjunction with a standard amplifier. Users want the sound quality of tube amplifier, without the cost. The proposed type of emulator could be used in conjunction with most any instrument, but would be mostly designed for and marketed towards electric guitars, as the teams' musical connections and experience is in the guitar domain.

Uses

The emulator would be intended for use with an external power amplifier, addressing both the tonal and power demands of the user.

1.5 ASSUMPTIONS AND LIMITATIONS

Assumptions

The emulator will be used in conjunction with any amplifier, and will maintain quality even hours into use. The input is to be a TRS monophonic audio jack, and ¼" jack output TRS to the desired amplifier.

Limitations

The emulator is not operated in temperatures outside of -30 to 50 degrees Celsius. Additionally, the device cannot be operated in excessively wet conditions. The cost will not exceed $500.

1.6 EXPECTED END PRODUCT AND OTHER DEVIVERABLES

Emulator

The finished emulator will include a microcontroller to run all algorithmic processes. The device will all be packaged in a painted and decaled aluminum enclosure. The enclosure will have all of the necessary adjustment knobs and switches mounted on the top panel for ease of access. A female ¼'' jack on the left panel will be designated for the input signal, and a female ¼'' jack, mounted on the right panel of the enclosure will be provided for the output signal of the emulator.

9V Power Supply

The package will also include a 3rd party 9V power supply for driving the emulator. The product is designed around the parameters of the power supply included. Consequently, the team encourages users to use the power supply included, as the electronics will be designed to operate around the supply voltage, current, noise rejection, and grounding parameters surrounding the supply.

User Manual

A user's manual shall be included with the package. The manual will cover topics such as emulator set up, proper use of the device, instructions of how to adjust parameters of the emulator, limitations of the device, device safety, etc. The manual will be cleanly illustrated, delivered in small form factor, as it is intended to be carried along with the emulator for troubleshooting and tuning purposes.

2 Proposed Approach and Statement of Work

2.1 FUNCTIONAL REQUIREMENTS

Tube Amplifier Emulation

The ability to emulate the positive characteristics of a vacuum tube amplifier is considered the fundamental requirement for the proposed device. The sound profile resulting from vacuum tube amplification continues to be the leading preference in the professional audio industry, according to musicians. The ability to capture that profile and implement in a solid state (i.e. semiconductor) setting will drive the marketability of the device, as well as serve as a novel approach to audio design.

Ergonomic User Interface

The minimum requirements for ergonomic user interfaces (UI) continue to increase as improved hardware and software protocols become more widely available. With this, the team has determined that implementing an easy-to-use UI is necessary to make our emulator appealing to the user. The UI feature currently has an open ended definition, and will be dependent on the actual time frame of the project. Some ideas for the UI include making it accessible through a mobile application and including a LCD display on the device.

Final Module - Standalone PCB and Customized Encasing

Once the design of the system has been optimized and completed, the module must be implemented on a single PCB. Items to be considered regarding the process are the integrity of the signal path traces and the optimal placement of components to achieve a minimal size. The enclosure that the PCB is placed in will need to be a durable material (e.g. metal), and the features for the user interface will need to be securely placed so that the emulator can survive the rugged environment of live performance.

2.2 CONSTRAINTS CONSIDERATIONS

As a large portion of circuit fabrication is expected to be done in house, all safety techniques specified by IEEE will be followed, including the use of only unleaded solder. Only components rated for the power specifications of the device are to be used in the production of the proposed design.

All code to be employed on the microcontroller will be synthesized in accordance to the Agile method to ensure baseline deliverables can be met. All communication between the microcontroller and any peripherals will be SPI (for ADCs and DACs) and I2C.

Additionally, all constituent components included in the emulator are to be incorporated in the attempt to minimize the electromagnetic (radiated and conducted) footprint, as well as to ensure a thorough level of immunity. The process involves designing as closely as possible to IEC and FCC standards for radiated/conducted immunity/emissions.

Furthermore, the overall cost of the intended design must be closely monitored and kept at or below the defined budget constraint. The budget restraint is due to the need to preserve the market potential of the end product.

2.3 TECHNOLOGY CONSIDERATIONS

Power

The device's main purpose is to provide musicians with the audio profiles that they demand. With this in consideration, the team does not prioritize parameters such as power consumption as highly as performance. While the team acknowledges that time invested in this domain could yield improved efficiency specifications, the team simply cannot devote the man-hours to designing with power as a primary concern within the project time constraint.

ADC/DACs and the Microcontroller

The ultimate quality of the emulator incorporated digitally will be at least partially derived by the bit resolution of the signal conversion. A crucial compromise is made here between audio quality and program latency - the reconstructed signal needs to be sampled at a high enough frequency such that the all of the desired harmonics of our signal and retained. Inversely, maintaining low latency in the implemented program is critical - the user must not be able to perceive any amount of delay between the input signal and the output. As higher bit resolution will increase program latency, it is crucial that the team finds the optimal bit resolution such that audio quality is maintained while keeping latency low.

Additionally, the project constraints dictate that the team operates in a specified cost range - this necessitates that the components the team uses optimize around the intended parameters, but maintain low cost.

2.4 SAFETY CONSIDERATIONS

The main safety concern surrounding the proposed emulator involves shock protection for both the user and the device due to significant operating currents (~300 mA) and voltages (9V). A properly implemented low impedance tie shorting the chassis ground to earth ground should be sufficient to prevent damaging electrostatic discharges within the module and minimize risk of shock to device operators.

An additional safety concern to be addressed is the risk of hearing damage to users due to sudden bursts of loud, unintended feedback. To minimize this risk, the team will design our internal control system in such a way as to maximize stability and minimize the risk of such occurrences.

2.5 PREVIOUS WORK AND LITERATURE

In the professional audio industry (especially guitar) it is still widely known that the best performance comes from vacuum tube amplifiers. However, several well-known audio equipment manufacturers (e.g. Dunlop, Electroharmonix, Ibanez etc.) have worked to create products that achieve tube-like sound from solid state components. However, these devices tend to be limited to a 1 pedal -1 function design, and fail to deliver tube-like sounds for all signal types/combinations. Recently, the company Korg has created a product called the “NuTube” that is advertised as a “solid state /vacuum tube hybrid”, which implies that it is a unique semiconductor device that has both features to it. The device may provide reasonable competition with the produced product.

In terms of research, some effort has been made to identify the factors behind why people still prefer tube amplifiers over solid state. The team intends to analyze this information and develop experiments that test the quantitative results of this research.

2.6 POSSIBLE RISKS AND RISK MANAGEMENT

As addressed above, creating an emulator that accomplishes all of the device requirements while maintaining accuracy, precision, and limiting latency is a substantial task – thus some inherent risk exists in achieving desired performance given the aforementioned constraints. Additionally, static discharge to the user, or delivered to the device poses some level of risk to the project – which is to be handled in the ESD protection design procedure described in previous sections. As with all products new to market, some latent risk resides in the consumer’s perception and interpretation of the product – fair and representative promotion of the product should ensure its positive reception.

2.7 PROJECT PROPOSED MILESTONES AND EVALUATION CRITERIA

The key milestones and completion/testing criteria are listed below. The anticipated milestone and testing completion dates are further broken down in the schedule outlined in section 3.4.

Tube Emulation Research

Completion Criteria:

1. Determination of major differences between tube and solid state amplifiers with respect to sound output, supported with experimental data
2. Isolation of several key parameters that can be emulated to generate the tonal qualities of a tube amplifier

Tube Emulation Design

Completion Criteria:

1. Calculation/Determination of key parameters and their corresponding weights, that will result in “ideal” emulator sound
2. Circuit design with mathematical calculations to determine required components and ideal values
3. Preliminary simulator circuit testing using Simulink (or similar program) to ensure design has desired spectral and temporal response

Tube Emulation Prototype

Completion Criteria:

1. Operational emulator prototype built based off of simulated design
2. User tested to ensure that emulator functions as desired
3. Physical encasing for effect emulator designed and built
4. Development of rudimentary design for UI controls

Integrated Tube Emulator

Completion Criteria:

1. Design and integration of functional UI for controlling device parameters
2. Completion of testing to ensure that integrated devices work as desired and produce desired output.

2.8 PROJECT TRACKING PROCEDURES

The project timeline (see figure 2 in section 3.3) is a rough guideline of where the team is to have completed on specific dates. Checking back with clients on weekly basis ensures that the team maintains realistic goals and objectives for each segment.

2.9 OBJECTIVE OF THE TASK

The goal of this project is to create a user-tuned emulator that has intuitive interface.

2.10 TASK APPROACH

Due to the high complexity of sound processing, the team is focused on a cyclical design approach, as can be seen in the figure below. The design process allows for constant revision and improvement of the device design throughout development. Additionally, the process will allow the team to make an aggressive start in developing and testing the initial design while leaving flexibility for constant improvement and development.

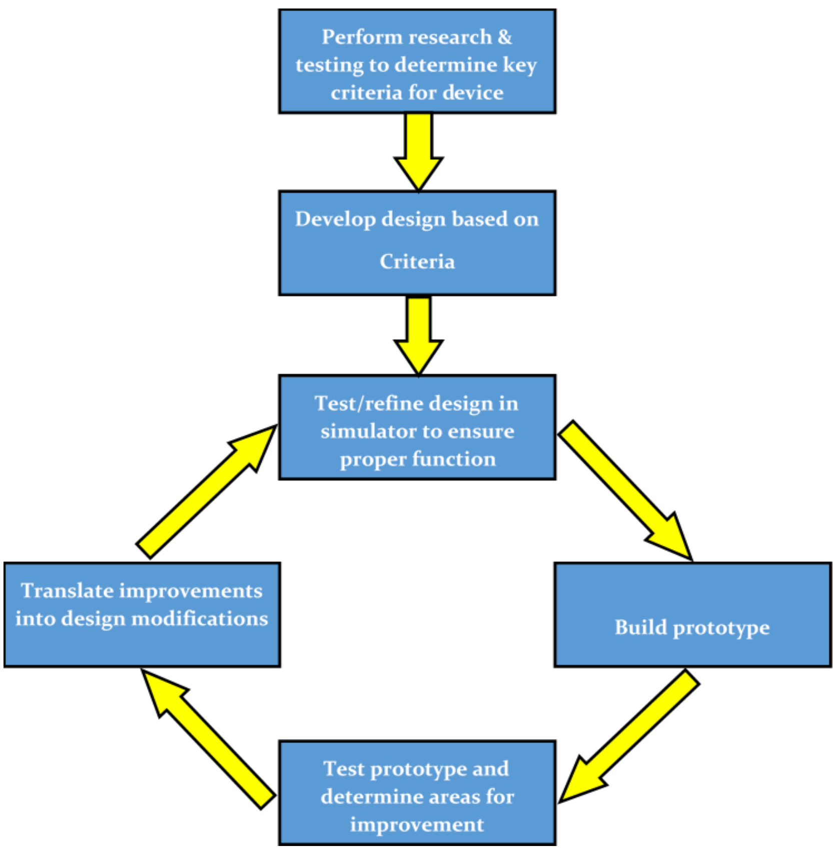

Figure 1: Method to Approach and Development

2.11 EXPECTED RESULTS AND VALIDATION

The team intends to have a working product that is capable of being reproduced for any prospective buyers. An important aspect of this is the requirement to have a good interface that takes new users only moments to figure out basic device operations. The goal is to achieve emulation such that a tube-like tone can be faithfully synthesized, and tonal parameters can be tuned to the user's demands.

The team can test the effectiveness of emulator by asking musicians to compare a tube amplifier sound quality to the final emulator in sequence with similar solid state amplifier, this may or may not be best as a blind test.

2.12 ASSESSMENT OF PROPOSED SOLUTION

Presented below are some of the strengths and weaknesses surrounding of the proposed solution. As in any design, sacrifices are made to improve technical aspects of the device, as well as its marketability – such sacrifices are discussed below:

<u>Strengths</u>

- Addresses tonal demands of guitarists seeking more authentic sound
- Small form-factor makes the device optimal for the traveling/performing musician, as well as the studio artist
- Ease-of-use (with incorporated UI) ensures that the emulator can be incorporated into artists signal chain, right out of the box

<u>Weaknesses</u>

- As the emulator was designed with performance in mind, power consumption was not prioritized, potentially yielding less than ideal efficiency ratings
- The computationally expensive DSP required by the emulator makes low-end microcontrollers unrealistic for the design, somewhat driving up product cost

<u>Trade-Offs</u>

- Certain emulation parameters (particularly items requiring internal spectral DSP/analysis) are more computationally rigorous. The user may be in a position where they must select between desired emulation properties, and the latency of the device.
- As the majority of the demand for this devices exists in the guitar market, the team have specialized such that the device can no longer cater to other instruments. While this narrows the product market, this was done so that the team can commit the majority of time to optimizing guitar-tube emulation, improving the performance of the device.

3 Estimated Resources and Project Timeline

3.1 PERSONNEL EFFORT REQUIREMENTS

Task	Estimate Work Hours
Tube Amplifer Parameter Research	300
Tube Emulation	200
Tube Emulator Prototype	200
Hardware Controller Prototype	50
Prototype Testing	100
Integration of Controller & Tube Emulator	50
UI Design	150
Tube Emulator Revision/Optimization	50
Integration of Emulator, Hardware, and UI	150
Final Product Build	200
Total	**1450**

Table 1: Estimated Hourly Requirements

The project is estimated to take 1450 work hours to complete over the two semester period, and is broken down in Table 1, above. A total of 700 hours is expected to researching, emulating, and prototyping the tube amplifier effect. The team has determined the task to be the bulk of the work because currently the physical phenomenon is unknown and debated by many audio professionals. Additionally, emulator integration should be quick as each the device is designed with the usability of the user in mind. Testing, although has a time requirement, it will be expected to done throughout prototyping to avoid a complete rework at the end of the project. A formal testing portion will be completed after integration to confirm the results of the prototype. The UI design and prototype is estimated to take 150 hours. Additional time is allotted for details regarding our interface implementation, as user controls could either be software-defined or hardware-defined. Both UI designs include their challenges, but each should fit in the time constraint. The final 350 hours will be spent on final product integration and build. It is expected to take a significant time to build a clean, modular product ready to use with the user.

3.2 OTHER RESOURCE REQUIREMENTS

The team needs access to oscilloscopes, high quality probes and a spectrum analyzing software (such as MATLAB) in order to analyze on a quantitative level the quality and nuances of both tube and solid state amplifiers. The tools will allow the team to analyze the sound parameters in the emulator to make sounds like tube amplifier. Other resources would be CAD tools, simulated circuit design software, and ETG components for testing. A compiler and editing software are required in order to interface and setup our microcontroller.

3.3 FINANCIAL REQUIREMENTS

The project will not require a large amount of funding to complete, and has a tentative budget set of $1,000. The majority of this budget will be used to purchase a high-end sound recorder. The equipment will be used to perform spectral and temporal analysis on the 'ideal' sound desired by musicians. The components required to build and test the device are widely available solid state components and will be relatively inexpensive to acquire.

3.4 PROJECT TIMELINE

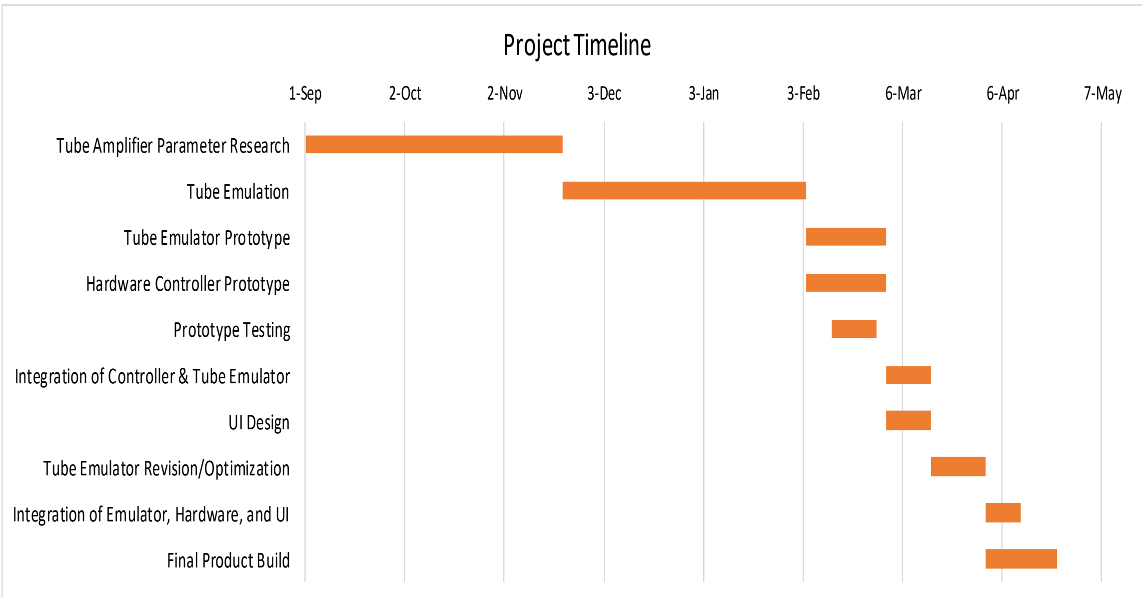

Figure 2: Project Timeline

The initial three months of the project will be dedicated to researching the qualities of tube amplifier. The research will consist of reading, testing, and experimenting with tube amplifiers to quantifiably extract the physical parameters associated with a tube amplifier. After research, the team will spend a month designing and analyzing different techniques of emulating the tube parameters. The most promising emulation technique will then be prototyped over three months. Overlapping towards the end of prototyping of the tube emulation, the team will spend two weeks designing and prototyping the emulation hardware controller. The controller must be able to manipulate the emulation parameters. By March 1st, the team desires to be prepared to begin the integration of the prototype to be completed and ready for testing. The prototype testing and analysis will consist of two weeks to determine tweaks and upgrades to the prototype. The following two weeks will consist of completing the tweaks and optimizing the design. Additionally, a user friendly UI will be designed to interact will the emulator. The final month will be spend integrating the final components and building the tube emulation device to be production ready with user interaction capabilities.

4 Closure Materials

4.1 CONCLUSION

The proposed emulator attempts to construct an audio profile that meets the demands of professional musicians, without compromising on cost or ease of use. The design includes quantifying and reconstructing the positive textures surrounding vacuum tube amplification, on a modular small signal platform (pre-gain). The versatility of the platform allow the product to operate as universal when it comes to user-defined tube emulation, negating the need for musician to spend thousands of dollars on top of the line equipment, whose greatest advantage is the use of archaic technology.

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