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 this 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 or 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 leaps and bounds made in BJT technology (in efforts to model the tube amp), and despite the considerable financial benefit to producing solid state amplifiers on a commercial scale, solid state technology still, for the most part, plays second fiddle to vacuum tubes amongst professional musicians. We believe this is largely due to a failure to properly address the sonic aesthetics surrounding vacuum tube amplifiers.

We believe that, if the key musical parameters around the tube amplifier are quantitatively observed, a tube 'effect' can be digitally or analog-ly generated and superimposed onto the signal entering any run-of-the-mill amplifier (solid state or otherwise). This effects module, along with generating the tube tone, could incorporate other desirable effects such as overdrive, reverb, tremolo, etc. In our proposed solution we have a small form factor effects module that can superimpose desired effects onto the incoming signal, and then overlay the tube sonic qualities onto the signal prior to output into any amplifier-speaker system. This 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 and effects pedalboard rig.

1.3 OPERATING ENVIROMENT

Our effects module 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 module be reasonably water and dust resistant. In a live performance, the guitarist rarely has a free hand to adjust effects parameters - this means that most effects modules have large knobs and buttons that can be operated with one's foot. Some guitarists will simply put their full weight into compressing and decompressing a switch, thus the module must be encased in a durable enclosure (optimally aluminum) that can withstand ~200lbs/in2 of pressure. Additionally, as the module 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. – This information is necessary in order to design an end product that can withstand the hazards that it is expected to encounter.

1.4 INTENDED USERS AND INTENDED USES

The intended users would be avid musicians that either do not have or do not want to spend the money for a $1000+ amp but instead are looking for a quality amplifier with, at most, a couple hundred dollar price tag. They would want the sound quality of tube amplifier, without the cost. This type of amplifier could be used in conjunction with most any instrument, but would be mostly designed for and marketed towards string instruments, as our teams' musical connections and experience is in the domain of string instruments.

The effects module would be intended for use in conjunction with an amplifier, resulting in a higher quality output sound that emulates the smooth and warm tones commonly associated with tube amplifiers. Additionally, the module would include several other common sound effects that could be selected and adjusted to suit the musician's desires.

1.5 ASSUMPTIONS AND LIMITATIONS

Assumptions

Will be used in conjunction with any amplifier maintains quality even hours into use. Input would be a TRS monophonic audio jack, or ¼" jack (TRS for short) outputs TRS to an amplifier. Single input and output from device. If applicable only language available is English.

Limitations

Is not operated in temperature outside -30 to 50 degrees Celsius. Cannot be operated in very wet conditions. Cost doesn't exceed $200. Minimal tests were run on wind and percussion, and brass instruments.

1.6 EXPECTED END PRODUCT AND OTHER DEVIVERABLES

Effects Module: to be delivered April 2018

The finished effects module will include several analog effects circuits along with a microcontroller to run all digital effects. This will all be packaged in a painted and decaled aluminum enclosure. This 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 signal out of the module.

9V Power supply: to be delivered April 2018

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

User Manual: to be delivered April 2018

A user's manual shall be included with the package. The manual will cover topics such as module set up, proper use of the device, instructions of how to adjust parameters of the module, limitations of the device, device safety, etc. This manual will be cleanly illustrated, delivered in small form factor, as it is intended to be carried along with the module for troubleshooting/module 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 our module. The sound profile resulting from vacuum tube amplification continues to be the leading preference in the pro 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 our device, as well as serve as a novel approach to audio design (semiconductor devices). This amplification stage will be used for the output gain stage of the FX system, which allows for the superposition of tube quality amplification over both digital and analog sound effects.

Dynamic Effects Processor

The other fundamental requirement for our project is to give the user the ability to apply one or more sound effects to their instrument. The most effective way to do this is to have the "all-in-one" approach; the module has an inclusive list of producible effects that the user can choose from through the module interface. This list of effects will include several popular items such as:

- Distortion/Overdrive
- Phasor/Chorus (modulation effects)
- Delay/Reverberation

In implementing the effects processor, we intend to place each effect into one of two categories: implementation via analog signal processing and implementation via digital signal processing. Categorizing each effect will be a dynamic process that is heavily influenced by time and the unforeseen challenges that come with trying to create an effect through analog design versus digital micro processing.

Ergonomic User Interface

The minimum requirements for ergonomic user interfaces (UI) continue to increase as improved hardware and software protocols become more widely available (cheaper to use). With this, our team has determined that implementing an easy-to-use UI is necessary to make our module appealing to the user. This feature currently has an open ended definition, and will be dependent on the actual time frame of our project (not the ideal one defined in this document). Some ideas for the UI include making it accessible through a mobile application and including a LCD display on the module.

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. Some things that need to be considered in this process are items such as 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 module 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 our module are to be used in the production of our 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 module are to be incorporated in the attempt to minimize our electromagnetic (radiated and conducted) footprint, as well as to ensure a thorough level of immunity. This involves designing as closely as possible to IEC and FCC standards for radiated/conducted immunity/emissions.

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

2.3 TECHNOLOGY CONSIDERATIONS

Power:

This module’s main purpose is to provide musicians with the audio profiles that they demand. This being the case, we do not prioritize parameters such as power consumption as highly as performance. While we acknowledge that time invested in this domain could yield efficiency specifications, in the time-constrained domain in which we are operating, we simply cannot devote the man-hours to designing with power as a primary concern.

ADC/DACs and the Microcontroller:

The ultimate quality of the effects we incorporate digitally will be at least partially derived by the bit resolution of our signal conversion. A crucial compromise is made here between audio quality and program latency - our reconstructed 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 our implemented program is critical - the user must not be able to perceive any amount of delay between the input signal and the output signal (unless, of course, the implemented effect is delay). As higher bit resolution will increase program latency, it is crucial that we find the optimal bit resolution such that audio quality is maintained while keeping latency low.

Additionally, our constraints dictate that we operate in a specified cost range - this necessitates that the components we use optimize around their intended parameters, but maintain low cost.

2.4 SAFETY CONSIDERATIONS

The main safety concern surrounding our proposed module involves shock protection for both the user and the module 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, we will design our module and module control system in such a way as to maximizer stability and minimize the risk of such occurrences.

2.5 PREVIOUS WORK AND LITERATURE

In the pro 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. This may provide reasonable competition with the product we intend to create.

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

2.6 POSSIBLE RISKS AND RISK MANAGEMENT

Trying to find what makes a tube amplifier higher quality in a quantitative way, then figure out if/how we could modulate a signal to sound similar. Doing this in such a way to not lose accuracy, precision, limiting time dilation. Static shock to user or components. Having the knowledge to know what components are best suited for each job like; amplifier, microcontroller, power supply etc. The next challenge that will be hard to overcome is convincing consumers that this is indeed a high quality accent to your amplifier comparable to high end tube amplifiers

2.7 PROJECT PROPOSED MILESTONES AND EVALUATION CRITERIA

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 3.3

<u>Tube Emulation Research</u>

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 variables that can be manipulated in an amplifier to generate a sound output that emulates a tube amplifier

<u>Tube Emulation Design</u>

Completion Criteria:

1. Calculation/Determination of key variable values 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

<u>Tube Emulation Prototype</u>

Completion Criteria:
1. Operational emulator prototype built based off of simulated design
2. User tested to ensure that emulator functions as desired

<u>Dynamic Effect Controller Prototype</u>

Completion Criteria:
1. Selection of desired effects
2. Necessary code for operation of desired effects written, debugged, and properly formatted
3. Physical module for effect controller designed and built
4. Development of rudimentary design for UI controls
5. Completion of initial testing to ensure proper function and compatibility with emulator

<u>Integrated Tube Emulator and Effect Controller Prototype</u>

Completion Criteria:
1. Successful integration of effect controller and tube emulator prototypes
2. Design and integration of functional UI for controlling dynamic effects
3. Completion of testing to ensure that integrated devices work as desired and produce desired effects

2.8 PROJECT TRACKING PROCEDURES

We have project timeline (see figure 2 in section 3.3) this is a rough guideline of where we're looking to be when. Early meetings on what we are looking toward guides us on how we can get critical deliverables on due dates. Checking back with clients on weekly basis to verify we have a realistic goal and objectives for each segment.

2.9 OBJECTIVE OF THE TASK

The goal of this project is to create an effect pedal that has intuitive easy interface, and has multiple effects that can be selected and adjusted. Some particular ambitious goals are to have multiple effects to select, an amount of fx, tone and level dials. Also possibly a tube emulator effect that might be able to be adjusted or blended to different degrees with source signal.

2.10 TASK APPROACH

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

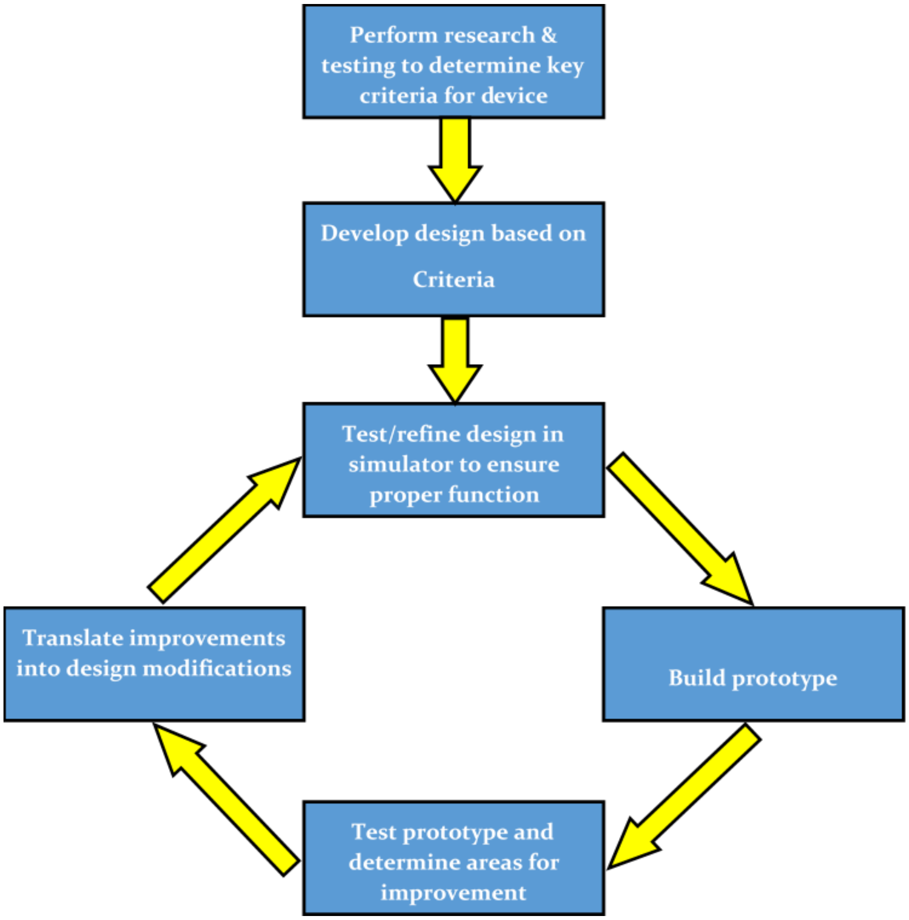

Figure 1: Method to approach and development

2.11 EXPECTED RESULTS AND VALIDATION

We intend 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 operations. We want an emulator that make a solid state amplifier sound like a tube amplifier. Also have multiple other effects that can each be selected and adjusted.

We can test the effectiveness of emulator by asking musicians to compare a tube amplifier sound quality to our emulator in sequence with similar solid state amplifier, this may or may not be best as a blind test. Also for interface and affects quality again ask some musicians we know to experiment with it.

3 Estimated Resources and Project Timeline

3.1 PERSONNEL EFFORT REQUIREMENTS

Table 1: Estimated Hourly Requirements

Task	Estimate Work Hours
Tube Amplifier Effect Research	200
Tube Emulation	150
Tube Emulation Prototype	300
Dynamic Effect Controller Prototype	50
Integration of Controller & Tube Emulation	50
Prototype Testing	100
UI Design/Prototype of Dynamic Effect Controller	150
Tube Emulation Revision/Optimization	50
Integration of Tube Emulation, Controller, and UI	150
Final Product Build	200
Total	1400

The project is estimated to take 1400 work hours to complete over the two semester period, and is broken down in Table 1, above. A total of 650 hours is expected to researching, emulating, and prototyping the tube amplifier effect. The team has determined this task to be the bulk of the work because currently the physical phenomenon is unknown and debated by many audio professionals. The team expects the dynamic effect controller design to be a straightforward task, as it is used in many audio effect modules. A simple reverse engineer will suffice on controlling the audio effect. Additionally, controller and emulator integration should be quick as each is designed with the usability of the other in mind. Testing, although has a task, 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. Considerations were given for an extra amount of type as it unresolved whether it will be a digital or physical device to controller the emulator. Either will have different 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

We need 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. That way we can tell what it is we need to be trying to do in our emulator to make sounds like tube amplifier. Other resources would be CAD tools, simulated circuit design software, ETG components for testing. Compiler and editor software in order to interface and setup our microcontroller (if we end up using it).

3.3 FINANCIAL REQUIREMENTS

This 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 and several commercial sound effects modules. This equipment will be used to perform spectral and temporal analysis on the ‘ideal’ sound desired by musicians. The components required to build and test our device are widely available solid state components and will be relatively inexpensive to acquire.

3.4 PROJECT TIMELINE

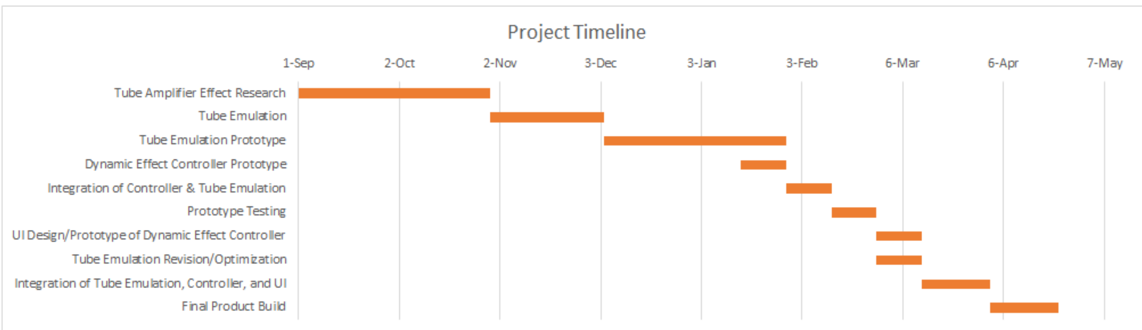

Figure 2: Project Timeline

The initial two months of the project will be dedicated to researching the effects of tube amplifier. The research will consist of reading, testing, and experimenting with tube amplifiers to quantifiably extract the physical phenomenon associated with a tube amplifier. After research, the team will spend a month designing and analyzing different techniques of emulating the tube affect though analog and digital purposes. The most promising emulation technique will then be prototyped over two months. Overlapping towards the end of prototyping of the tube emulation, the team will spend two weeks designing and prototyping the emulation controller. The controller must be able to manipulate the amount of emulation, tone, and volume. By February 12th, the team will like the integration of both prototypes to be completed and ready for testing. The prototype testing and analysis will consist of two weeks to determine tweaks and upgrades to the prototypes. 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 controller. The final two months 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

Again, with this effects module, we attempt to construct an audio profile that meets the demands of professional musicians, without compromising on cost or ease of use. This includes quantifying and reconstructing the positive textures surrounding vacuum tube amplification, on a modular small signal platform (pre-gain). Given the hardware required to meet this initial task, it simply makes sense to incorporate other effects in our module, such as distortion, chorus, and reverb, among other things. The versatility of our platform allow us to operate as the jack-of-all-trades when it comes to superimposed guitar effects, 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.

4.2 REFERENCES

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4.2 APPENDICES