Sound Effect Devices for Musicians: Synthesizer

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Acknowledgement

The Sound Effect Devices for Musicians team would like to kindly thank both Dr. Chen and Dr. Geiger for advising us as well as supporting us with knowledge through the duration of this project.

Problem statement

In today's world musicians can be put in a difficult spot when trying to find new equipment that will help them excel in the music world while staying under a reasonable budget. Musical devices, such as synthesizers, can cost anywhere from $500 - $10,000, with this most musician don't have the cash to afford upgrading their equipment to compete in the competitive industry of music.

Our goal is to create a synthesizer for musicians to use that is easy to use, modular, and affordable. Musicians thrive on having the latest and greatest devices to create music. This device we are creating will provide an opportunity to create higher quality music.

Operating environment

The operating environment for the synthesizer, in a perfect world, would be in a controlled environment where the users can make sure that the product is always in the best shape. Naturally, that will not be the case always. Operating environments are really determined by the users. If the user would like to use the product in a controlled environment that is fine and if they would like to take it to live shows that is fine as well. As you can imagine, that means the product needs to be able to withstand normal everyday use both inside and outside a controlled environment. It will need to withstand rough conditions, even if it might never be exposed to these conditions. Simply putting it, our product will be built to last and perform at its highest capabilities.

Intended user(s) and intended use(s)

Intended users of the synthesizer include everyone that has an interest in making music or making noise for entertainment. All musicians, from amateurs to professionals, are the target audience for this product. We aim at making this not only a highly sophisticated tool, but also one that is easy and fun to use.

The intended use is up to the users. Our hope is this tool is being used to help professionals create music but also people that are just having fun. This product in the general realm is intended for musicians who want to make high-quality music on a lower end budget.

Assumptions and limitations

Assumptions:

- Users can read and understand English - to understand brief introduction
- Users will have access to a wall outlet
- All components will work inside the product
- Product will be taken care of by owners

Limitations:

- People without musical knowledge will have a learning curve

- Group members have conflicting schedules so finding an ample amount of time each week to work is difficult

Expected end-product and other deliverables

The final deliverable for this project will aim at handing over a sophisticated synthesizer that is not only easy to use but is also a very powerful tool for musicians to have. The tool will be fully functional and will also include a cord to power the device through a wall outlet.

The final deliverable for this project will also include a brief instruction, specifying modules that are included in the synthesizer and how they work. The instruction manual will target users that already have a musical background, so they can quickly look through the manual and get into making music as quickly as possible.

We estimate completion and delivery of this project to be May of 2019, the end of the Spring 2019 semester.

Proposed Approach

Functional requirements

A synthesizer is a device that generates and shapes waveforms. Therefore, the bare minimum deliverable is a device that has an oscillator and some wave shaping functions. The goal is to make the device easy to use by musicians. This requires a familiar user interface that is quick and responsive. The output of the synthesizer will be a line-level signal. This will allow the synthesizer to be used with speakers.

Constraints considerations

The main constraint on the project is time. The team has 32-weeks to design, build, test, and debug the synthesizer. This puts an upper-limit on the number of features (referred to as modules) that the synthesizer has. We decided that each member can reasonably oversee 3 modules. Based on these constraints, we have developed the block diagram below. Each block in the block diagram represents a module.

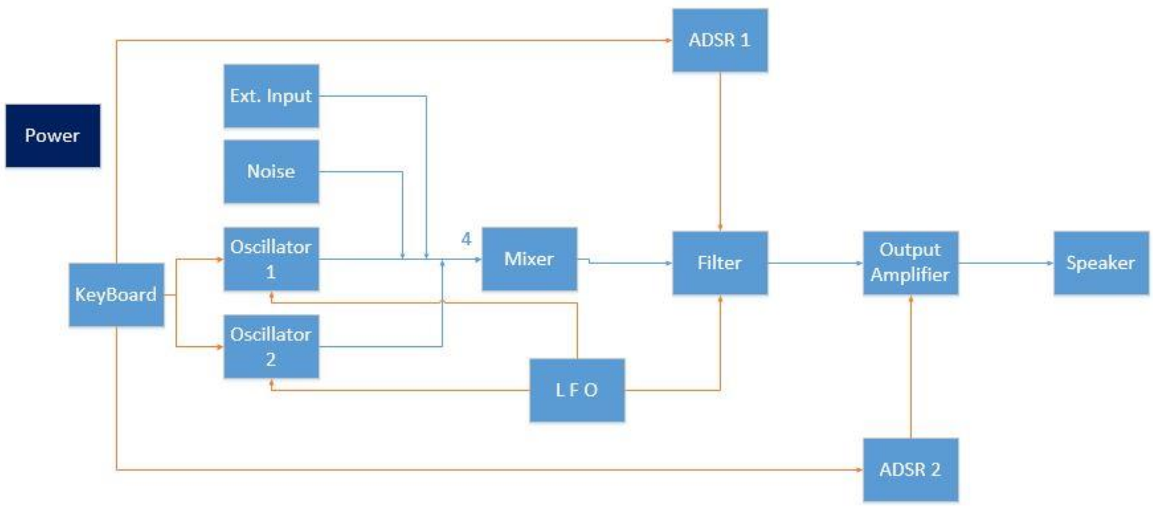

Figure 1

We arrived at the conclusion that we could do 10 modules total. Each member has 1 main module worked on independently and 2 modules worked on with a group. With only 3 modules to work on, the initial design can be done by November. This deadline will give the team all of November and December to test the designs and develop PCBs. If we finish all of these modules early, we can add more.

Technology considerations

A design choice that will be made throughout the project is whether we should design a part in-house or buy the part. Buying the part will guarantee quality and save time. Designing in-house allows customization and compatibility. We are also free to implement certain modules in novel ways. The table below summarizes the options we have at this point.

Module	**Available Options**
Oscillators	On chip oscillators, in-house oscillators
Power	Power supply unit, in-house design
Noise	Antenna, faulty BJT
Keyboard	Capacitive keyboard, MIDI keyboard

Table 1

Technical approach considerations

Every team member is an electrical engineer. We have a high-level of understanding of analog design and a lower-level of understanding of digital design. The synthesizer will mostly be limited to analog and some simple digital design.

Testing requirements considerations

Since the synthesizer is modular, every module should have line-level inputs and outputs. Each output should also be tested to make sure they output the expected waveform. Prior to testing in the lab each module will have a simulation that shows proof of concept. The lab testing will require an oscilloscope and other lab equipment. The modules should also be tested for sonic quality and requires an input signal and a speaker. To ensure that the entire synthesizer functions properly each module will be tested individually. There is enough allocated time that each can be tested individually. From there they will progressively be connected to each other and any part that is needed between the modules will be recognized and fixed.

Safety considerations

Below displays a table of safety Considerations.

Electrical shock	This will be avoided by covering the leads when they are not in use. The team is familiar with electrical properties of the components and will not touch the test parts without justification.
Inhaling solder smoke	This will be avoided by having people on our team who are experienced in soldering do this activity. Those who are not experienced will receive training from the other members
Tripping on cables	Our test equipment is already set up in Coover's labs so there will be no loose cable from those. However, if there is a loose cable on the floor it will be surrounded by tape to provide a caution to on coming people.
Burned from solder	This will be avoided by having people on our team who are experienced in soldering do this activity. Those who are not experienced will receive training from the other members
Eye injuries	Eye protection is a must when doing any activity in the lab that can sent a spark or object into the eye.
High current avoidance	Our team is aware of the dangers of high current and this will be avoided from proper circuit design of the parts.

Clean working space	A clean working space is a productive, efficient, and manageable area. Our team will push to make sure this is the case any time lab equipment is worked with.
Hostile work environment	Our team will report any situation to the team that another member feels they are being harassed or any other form that will make the environment feel hostile.

Table 2

Previous work / literature review (required)

There are many synthesizers on the market. Prior to starting the project, we reviewed the Novation Bass Station II. We used this to learn what a synthesizer is and what typical features are. This synthesizer has two oscillators, a sub-oscillator, a mixer, a filter bank, overdrive, distortion, LFOs, and many other features. We also reviewed Make: Analog Synthesizers to learn more about designing synthesizers. This book contains example circuits. Additionally, members of the team have previous experience in live music performance and/or recording. As well as software synthesizer design, software and hardware audio effect design, and other musical software programs with heavy signal and data processing.

Possible risks and risk management

Risk	**Risk Management**
Time Constraint	Updates on progress are given weekly. Tasks are prioritized.
Bad Schematic	Finalized schematics go through design review.
Parts Malfunction	Finding affordable parts so they can be replaceable.

Table 3

Project proposed milestones and evaluation criteria

There are tasks that needs to be completed for each module on the device. Below is a table that explains each module and its evaluation criteria.

Milestone	**Project Date**	**Evaluation**
Flowchart	Sept 27.	This will show how each module connects. Thus, providing an input and output of a device. This will show what can be directly connected or connected by the user. This will be completed once all members of the team agree and we get approval from our advisors.
Schematic	Oct. 31	Once the team member completes their schematic it will be looked over by another team mate. They will confirm that they have the proper concept and that it takes in the proper inputs and give the desired outputs.
simulation	Nov. 5	Fully testing the schematic this will show evidence that the schematic was made correctly and further confirmation that the circuit takes in the proper inputs and will give the desired outputs. The results will be checked off by another team member.
Hardware Test	Nov. 23	This will show proof that the circuit works as expected. Once the hardware test is complete another teammate will check it.

PCB Design	Dec. 7	The design of the PCB is very key to our final design. This will be checked off by all teammates to confirm that the PCB layout matched what everyone expects.
PCB Delivered	Dec 14	This will be confirmed with a receipt.

Table 4

Project tracking procedures

We have three methods of tracking our progress: weekly status report, a Gantt chart, and Gitlab Kan board

Weekly Status Report

The weekly status report is updated from a shared document that the team has access to. The weekly status report contains a brief reflection about the week, a description of pending problems, and plans for the upcoming week. Each team member writes a brief description about what they did that week and logs the hours that they put into the project. This weekly status report is a way that we can track each other's work throughout the week.

Gantt Chart

The Gantt chart as seen in figure 2 the project time line gives our team an overview of the deadlines for each task. This time line was approved by our advisors and our team as a manageable amount of work that can get done this semester. The timeline for our progress will be further described in the project time line section.

Gitlab Kan Board

The Gitlab Kan Board brakes down the tasks that are on the Gantt chart. This board shows the sequential motion that each module will have to take across its life time. These positions that a module can be in are research, schematic in progress, simulation complete, check, PCB design, check, PCB ordered, Parts soldered, and Fabrication complete. Although most of the last couple task listed are not to be completed this semester it still shows what needs to be done for each module.

Each module also has a team member that is assigned to it. This is described in the table below.

Team member	**Priority 1**	**Priority 2**	**Priory 3**
Tim Day	Mixer	Noise	Envelope
Francisco Alegria	Keyboard	Envelope	Filter
Eric Fischer	Filter	Power	Case
Travis Gillham	Amplifier	Keyboard	Case
Blake Beyer	Oscillator	LFO	Envelope

Table 5

The priority signifies which one is the most important and should be completed first. For most team members their priority 1 is for themselves to focus on. While priority 2 and 3 are for team member to be more of an assistance and will be first available for help if needed.

The Kan board is a way of the team to monitor the progress that the teammates have on their designated modules. This way it will become clear if a teammate is not pulling their weight or needs assistance.

Statement of Work

Keyboard

The keyboard module will be used to generate three signals that will be sent to other modules in the system. The signals will control two different modules; the frequency of the two-main sound generating oscillators, and the gate and triggers of the envelopes. The approach will be to use a microcontroller and the Arduino Capacitive Sensor libraries to build a 1-octave keyboard made up of open copper pads on a PCB. Each pad will essentially be one key. The code will have to be calibrated such that each pad functions as a button that can be pressed for an unlimited amount of time without interfering with the adjacent pad. The final functionality should have different modes of operation. One mode will be a very precise semitone keyboard that requires full contact to trigger the button press. Another mode of operation will recalibrate the sensitivity to allow the button press trigger from a small distance away from the keyboard. The lack of needing to make full contact in the second mode will allow for some creative playing styles of the device. Another desired feature is the ability to transpose the entire keyboard by up to 12 semitones. This will allow the user to play in different key signatures.

Oscillators

The oscillators are the main sound generating modules for the synthesizer. They will create the different waveforms that can be selected by the user; sine, triangle, sawtooth, and a pulse wave with adjustable PWM. The frequency will be controlled by a few different parameters. The main frequency control will come from the keyboard. Additionally, a potentiometer will be used to add a frequency offset of +/- 12 semitones to the frequency value coming from the keyboard. The last frequency control will be an octave selector. This will shift the range of the keyboard from a 16-foot wave to a 2-foot wave. By combining all the frequency controls, the user should have the ability to play a total range of six octaves using only the one-octave keyboard. The oscillators will be implemented using VCO chips that are readily available. This will greatly simplify the design as well as the footprint for each oscillator. In the final design there will be two identical oscillators that have the same functionality, with the ability to hard sync oscillator 2 to oscillator 1. Each oscillator should also have control voltage, (CV), inputs and outputs. CV inputs for the frequency offset and the PWM. The CV outputs will be the actual waveform output; this can be used for frequency modulation.

Noise Source

A white noise source will allow for a wider range of sound pallets to be synthesized, such as percussive sounds. The approach for this will be taking advantage of the avalanche breakdown voltage of a Zener diode. When the diode is reverse-biased with a voltage greater than 7V, it enters avalanche breakdown mode, which amplifies the noise. The noise signal coming out will then be amplified or attenuated to the required signal level. Additionally, a second noise source will be generated by taking the white noise and passing it through a low pass filter with a 3-dB roll off slope. The noise source will be selectable with a switch and the level will be another potentiometer in the mixer.

Mixer

Mixers are used to combine all the sound source signals down to one signal of the same level. This can be implemented in a few ways, the simplest being a summing amplifier configuration. The inputs would be the two oscillators, the selected noise source, and an external input. That totals four channels being mixed down to one channel that would go to the next module. Each source would have its own potentiometer that would determine the percentage of that signal that is being mixed into the output signal.

Filters

Filters are used to allow certain frequencies to pass from the input to the output. A low-pass filter allows low frequencies to pass, while blocking higher frequencies. The high-pass filter does the opposite where high frequencies pass and low frequencies are blocked. The implementation approach will be to design two separate filters, a low-pass and a high-pass. Internally they can be routed in series or parallel to create two additional filters, a band-pass filter and a notch filter. Band-pass filters block both low and high frequencies outside of a set bandwidth. Notch filters block the bandwidth frequencies and allow the low and high frequencies to pass. In the end product the user would use a concentric potentiometer to have the ability to set the cutoff frequency for each filter individually with the function to lock both cutoff frequencies to move together, allowing for the setting of a bandwidth for a band-pass filter or a notch filter. Additionally, control voltage inputs will be required for the cutoff frequencies. Again, the CV inputs would add an offset to the value set by the potentiometers. A switch would allow the user to switch between the four available filter configurations. The user would also have the choice to add resonance to the filters, which means variable Q-factor. Control voltage inputs could also be implemented for modulation of the resonance.

Envelope

Envelopes are modulation control voltage signals that can control parameters of other modules. The control voltage signal of the ADSR envelope is made up of four sections; Attack, Decay, Sustain, and Release. The attack is a time value that controls the time it takes the envelope signal to go from 0 to max on key press. After the attack reaches its peak, the decay phase starts. The decay controls the time the envelope signal goes from the max level to the level set by sustain control. The sustain is a percentage value of the max level set by the output amplifier. After the key is released, the envelope enters the release stage, which is the time the envelope goes from the sustain level to 0. The implementation will be two identical ADSR envelopes with dedicated controls, faders or knobs. One will always be controlling the output amplifier. The other envelope will be used to control any other parameter desired by the user; such as PWM or filter cutoff frequency. An additional feature will be to have the envelopes behave as AR only envelopes. This would bypass the decay and sustain phases to create snappy envelopes that can be used for percussive sounds. The ADSR vs AR function will be set by a toggle switch.

LFO

LFOs are oscillators that have a limited low Hz frequency range, usually from 0 Hz to 20 Hz. The output waveforms from the LFOs are used as control voltage signals for parameters in other modules. The desired approach is to use a similar architecture as will be used in the audio oscillators. This would allow for all the same waveforms to be created and used as control signals. The frequency controls will be limited to the lower frequencies to allow for very precise control within a 0 – 20 Hz range. Additionally, a switch can be implemented to allow the user to use higher frequencies. This would allow for more creative sound design possibilities, such as audio rate modulation of other parameters. Since LFOs are control voltage signals that modulate parameters, the user should also have the ability to change the depth of the modulation effect. This will be done with another potentiometer.

Amplifier

After the audio signal has been generated, modulated, mixed, and filtered it goes out to the desired speaker. The output amplifier will determine the max volume of the synthesizer with a single knob. The output jack from the amplifier will be able to drive either a single monophonic speaker or stereo speakers, like headphones.

Power

Each module will require different power supplies for all of the different components that are used in each system. Since all of the modules have to fit into one enclosure the user should only have to supply one power source to the device. On the inside, each module will take care of the circuits required to step down the main power supply voltages to the required voltages needed to power the smaller components specific to each modules' architecture. On the user's side there will be one wall wart that supplies the main power to the synthesizer via an input jack on the enclosure and a main power switch that controls the main power supply.

Enclosure

The final product will be one unit that contains all of the individual modules in a fixed layout. The system will have fixed internal signal routing that will allow any user to start playing immediately without the need for external patching. Since the modules will have input and output ports for audio and control voltage signals, the user will be able to change the signal routing from the user interface without having to tear open the device. Each module will consist of a minimum of two PCBs. One PCB will be internal and will house the critical system components. The other PCB will be designed to be the user interface and will hold the controls for each module on the top face. Since each module will be newly fabricated and be used as the top face, only the bottom and sides remain to be taken care of. The sides and bottom will be designed, and 3-D printed in such a way that the bottom is removeable to allow for easy assembly of the final product. The goal is for the user to have a reliable and durable product that can be used in a live performance setting.

Estimated Resources

Task	Description
Research	Shall be thorough to the extent where creating a schematic can be achieved.
Build Schematic	Shall be a simple enough design yet also meet the specifications and function ability of each module.
Simulate Schematic	Shall use Multi-Sim to run a simulation model of the designed schematic. Shall run with zero errors.
Test Schematic	Shall simulate all schematics into one single model and run it together and make certain of zero errors so that the PCB design process is done once.
PCB Design	Shall take schematic and upload to a software that designs PCBs.
PCB Fabrication	Shall send PCB designs to get fabricated so that it will make building the physical casing is a lot easier.

Table 6

Item	Price	Quantity
Test Parts	TBD	TBD
Knobs	TBD	TBD
PCB Design	$10 per square inch	x10
3-D Printing	$0.06 / gram	TBD

Table 7

The PCBs we will design are going to get outsourced so that we can ensure they are designed and built correctly. We have decided to implement PCBs for a couple reasons. The main reason is that it will eliminate the possibility of wires and components shorting if we used breadboards. Another big reason is that it will make the internal wiring a lot easier to work with and debug, as well as make it look cleaner and sleeker.

The PCBs are one item we need to purchase. The ones we are looking at are from Osh Park and for a four-layer PCB prototype the cost is $10 per square inch but can be less or more depending on the complexity of the board. For our application the boards will be the $10 per square inch price because this is the best option for what we want implemented. Other items we need to purchase are knobs for tuning each module. These knobs are typically around $5-10. We have been talking about 3-D printing the case for the final product. If we choose to 3-D print the case, a few members are familiar with the 3-D printers on campus and would help the rest of us learn how to use them. Iowa State charges a fee of $0.06/gram of filament that is used with these printers.

Project Time Line

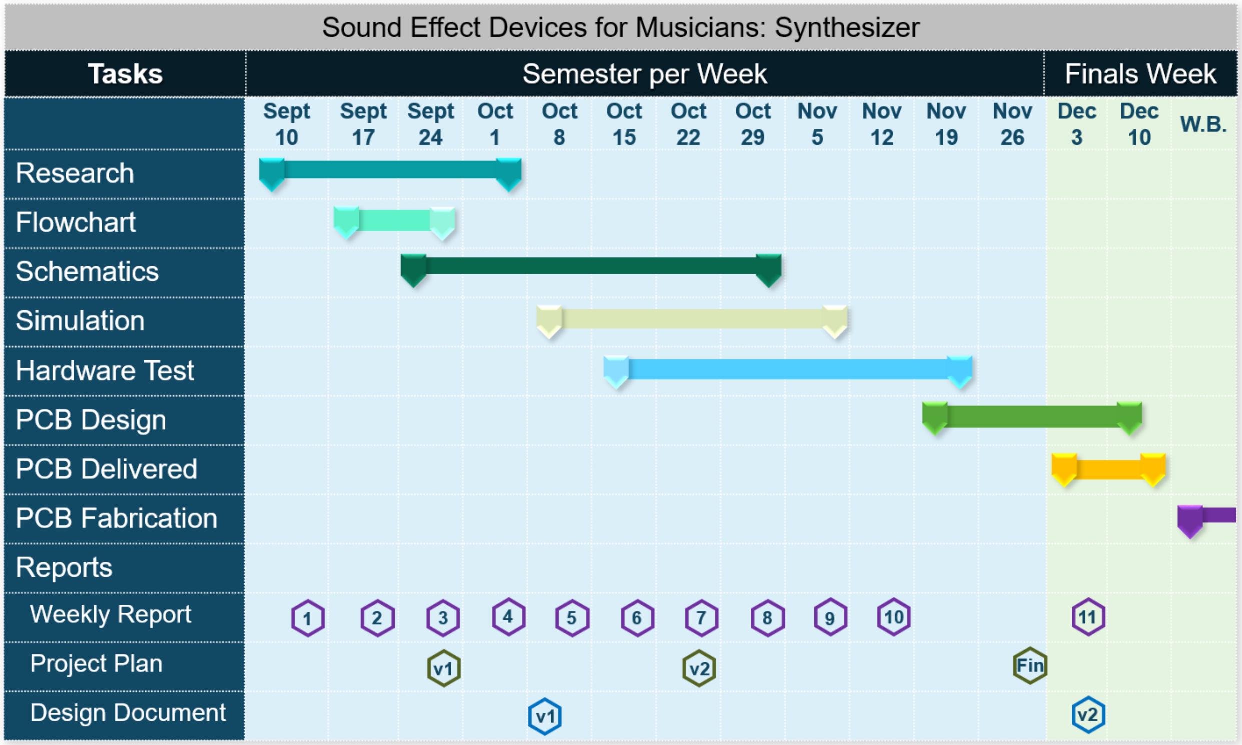

Figure **1**

Figure 2

Closure Materials

As a team, we will have challenges, but we have a good approach to eliminate potential issues. Part of this approach is splitting up the project into modules and assigning each member to take charge of a specific module, as we discussed in our project tracking procedure. Everyone on our team has experience in some aspect relating to music, from playing instruments, to playing gigs, to just being fascinated and wanting to learn more about the music industry. These experiences are the reason we all chose this project. The current equipment in today's world is very expensive. We want to take the knowledge we gained from our classes and combine it with our experiences with music to create an inexpensive synthesizer that will revolutionize the way musicians make music.

References

Ray Wilson. *Make: Analog Synthesizers.* Sebastopol, CA: Maker Media, 2013.