Affordable Analog Synthesizer

Design Document

ECE 445 Design Document
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1. Introduction

1.1 Problem and Solution

To further understand the purpose that the project holds, our team did research on the interest in music synthesizers in the market. Music synthesizers are extremely expensive at market value and for most people, it is not reasonable to own a music synthesizer due to the high cost. As many people are interested in creating music, or using synths but may not have the budget to own one, the objective of the project is to create an affordable analog synthesizer. Also, According to Technavio, “the music synthesizers market is poised to grow by USD 62.90 million during 2021-2025, progressing at a CAGR of over 2% during the forecast period” [1]. Being able to create an affordable model holds values with the growth in market and demand for music synthesizers, as well as documentation for the homemade solution that we make.

In order to solve the demand for an affordable music synthesizer, creating the synthesizer from scratch and utilizing a cost analysis to obtain cheaper parts will help in implementing an effective and cost effective approach.

2 Visual Aid

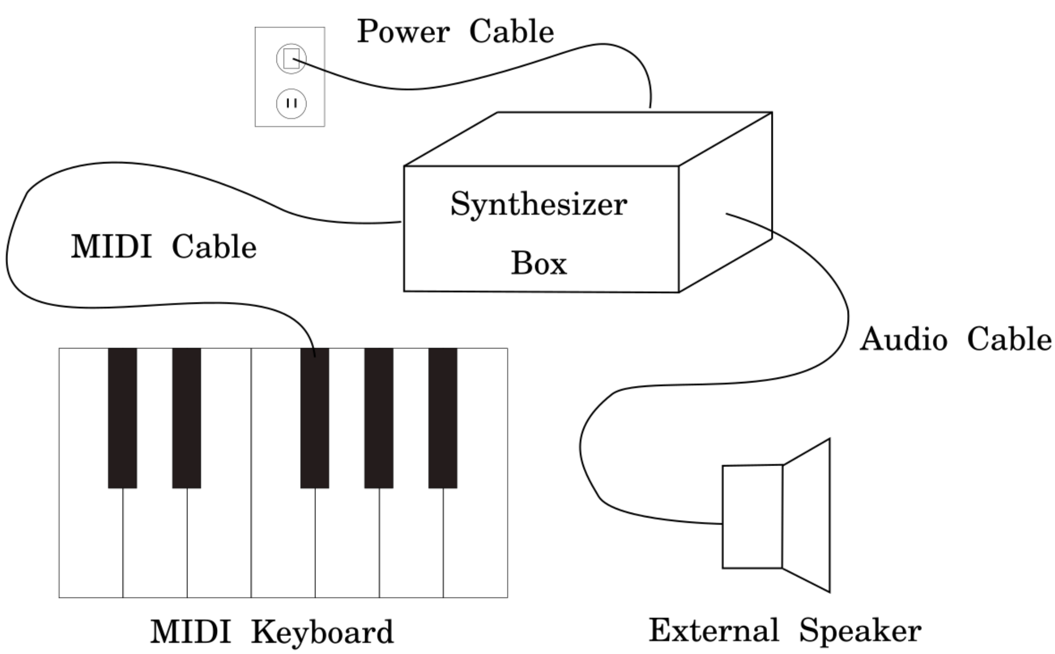

Figure 2.1: Physical Design

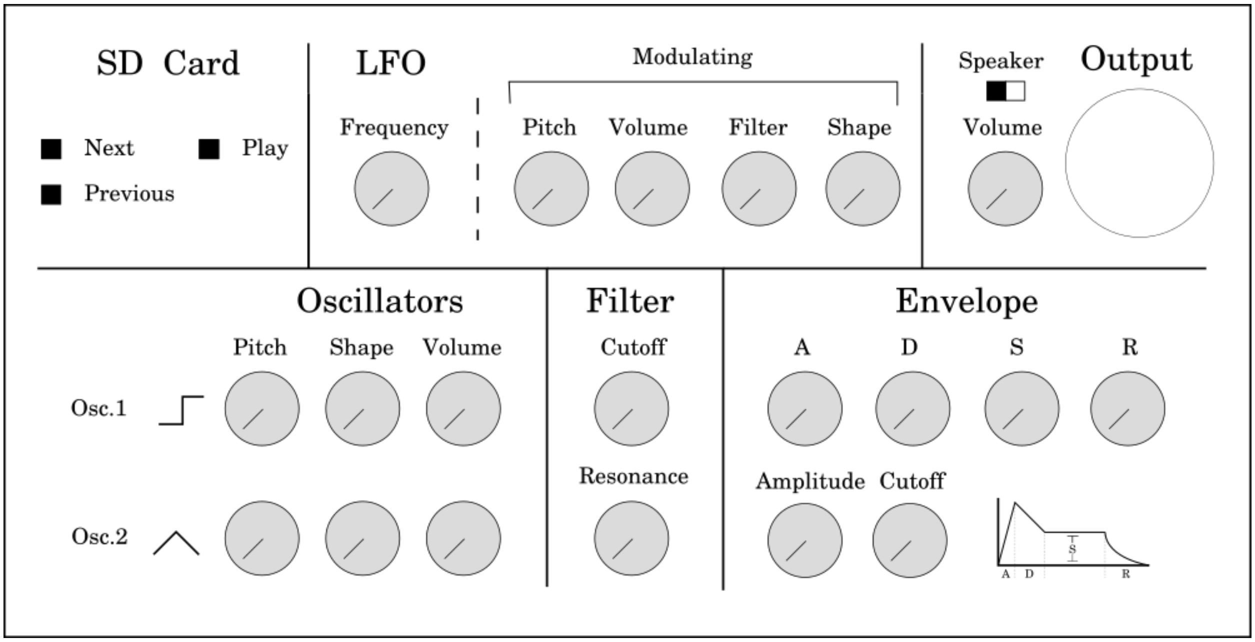

Figure 2.2: Front Panel of Synthesizer

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3 High-Level Requirements

1. Recreate well known synth sounds used in popular songs. Some examples of sounds would be the synthesizer parts of Cinema Show, On the Run, and Lunar Sea.
2. The synthesizer will be able to produce the correct pitches for at least 24 consecutive keys, or two octaves, from the MIDI keyboard.
3. Have the ability to read key inputs from a file on an SD card and play them back through the synthesizer as if they were notes being played on the keyboard. Also, the SD card can have multiple files, and the file being played can be cycled through.

4 Block Diagram

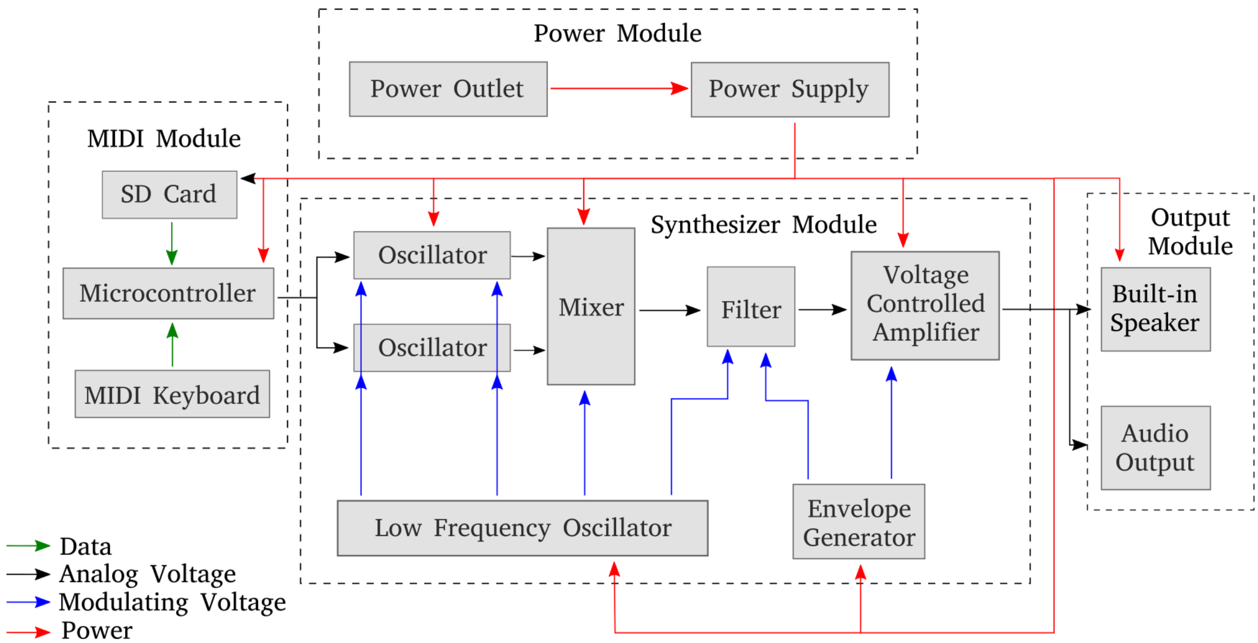

Figure 4.1: Block Diagram

5 Requirement and Verification

MIDI Subsystem

The microcontroller which will be denoted as the midi subsystem we are choosing to use a . The use of this board will connect to an external Midi Keyboard.

Requirement	Verification
1. Microcontroller can produce an analog voltage in the range from 0-5V that acts as the input to the voltage controlled oscillator.	Probe the voltage-controlled oscillator's input voltage, which is connected to the microcontroller's PWM output through a filter. Write test code to loop through every key in the keyboard and check that the voltage level

	matches what is expected for the given key press.
2. Needs to be able to take in keyboard inputs from the MIDI keyboard and output 24 unique key notes(one note at a time)	Write code to connect each key to a specific voltage that will be outputted to the synthesizer module.
3. Ability to switch between reading input from the SD card or the midi keyboard	Test the switch that will be used utilizing the SD card input as well as checking that the switches output is the correct output. Will make the switch= 1 to be for the keyboard and switch =0 signal for the SD card.
4. Ability to switch between playing audio output through the in built speakers and the externally connected speakers.	Test that the switch that is responsible for switching audio output correctly switches between the external speakers and in built speakers when toggled.

Inputs: power supply
Outputs: voltage to the oscillators

Synthesizer Subsystem

add schematics here

Requirement	Verification
1. Two voltage-controlled oscillators, with a voltage input in the range of 0-5V. The first oscillator produces a square wave with an adjustable duty cycle, and the second oscillator produces a sawtooth wave.	a) Hook the output of the oscillator #1 to an oscilloscope and speaker. Then vary the voltage input between 0 and 5 volts. Make sure that the output is a clean square wave, and also that the frequency increases exponentially when voltage increases linearly. b) Do the same for oscillator #2 and check that the output is a sawtooth wave.
2. A mixer combines the outputs of the two oscillators into any ratio.	a) Turn the mixer potentiometer knob and view its output on the oscilloscope while both oscillators are working. Verify that the oscilloscope shows a square wave at one extreme and a sawtooth wave at the other extreme.
3. Low-pass filter with controllable cutoff and resonance. The cutoff is	a) Verify that the voltage controlled cutoff works: Connect the input of the filter to a

voltage-controlled within a range of 0 to 5 volts. Resonance is not voltage controlled; it is controlled simply by a variable resistor which adjusts the feedback into the filter.	function generator's square wave. View the output of the filter on an oscilloscope. Use a power supply as an input to the control voltage, sweep the cutoff, and make sure the resulting square wave becomes smoother as the cutoff decreases. b) Now keep the voltage fixed and vary the resonance to the filter. Check to see that the resonance appears on the oscilloscope. On the oscilloscope, resonance appears as ripples after steep transitions.
4. The envelope generator creates an envelope that is used to modulate the sound's amplitude as well as the cutoff frequency of the filter. The degree to which it affects the filter is controllable with a potentiometer. The envelope first increases during the attack phase, then decreases during the decay, then stays at a constant sustain level, and then drops to 0 during the release phase.	a) Connect the output of the envelope generator to the oscilloscope and program the microcontroller to set the trigger signal every few seconds. View the envelope on the oscilloscope and make sure it has distinct phases for the attack, decay, sustain and release. Turn the attack potentiometer and verify that the attack time increases. Similarly verify the decay and release increase when those knobs are turned. Verify that the sustain level increases as the sustain knob is turned.
5. The voltage controlled amplifier has two inputs, the audio signal coming from the filter as well as the amplitude envelope from the envelope generator. The envelope controls the gain of the amplifier.	a) View the output of the amplifier with an oscilloscope. Set the control voltage with a power supply and use the audio output from the other parts of the synth as the other input. Verify that the audio signal being sent to the amplifiers is viewable on the oscilloscope connected to the output of the VCA. b) Change the control voltage with the power supply. Check that as voltage increases the amplitude on the oscilloscope increases and as voltage decreases the amplitude decreases.
6. The low frequency oscillator will generate a triangle wave from about 1Hz to 20Hz. It's output will be in the range from -2V to 2V. It can be used to modulate other parameters of the synthesizer in varying amounts set by knobs on the front panel.	a) Verify that the waveform is a triangle wave with the oscilloscope and that its frequency changes as the potentiometer is changed. b) Connect the synthesizer output to a speaker. Verify that for each knob (volume, pitch, filter cutoff, square wave duty cycle), turning it increases the modulation of that particular sound. Also check with the the oscilloscope.

Power Subsystem

Requirement	Verification

6 Plots

Below is a simulation of the VCO (schematic in Fig 7.1). It produces a sawtooth wave, which can also be used to generate a square wave using a comparator. The duty cycle of the square wave can be controlled by setting the threshold voltage of the comparator.

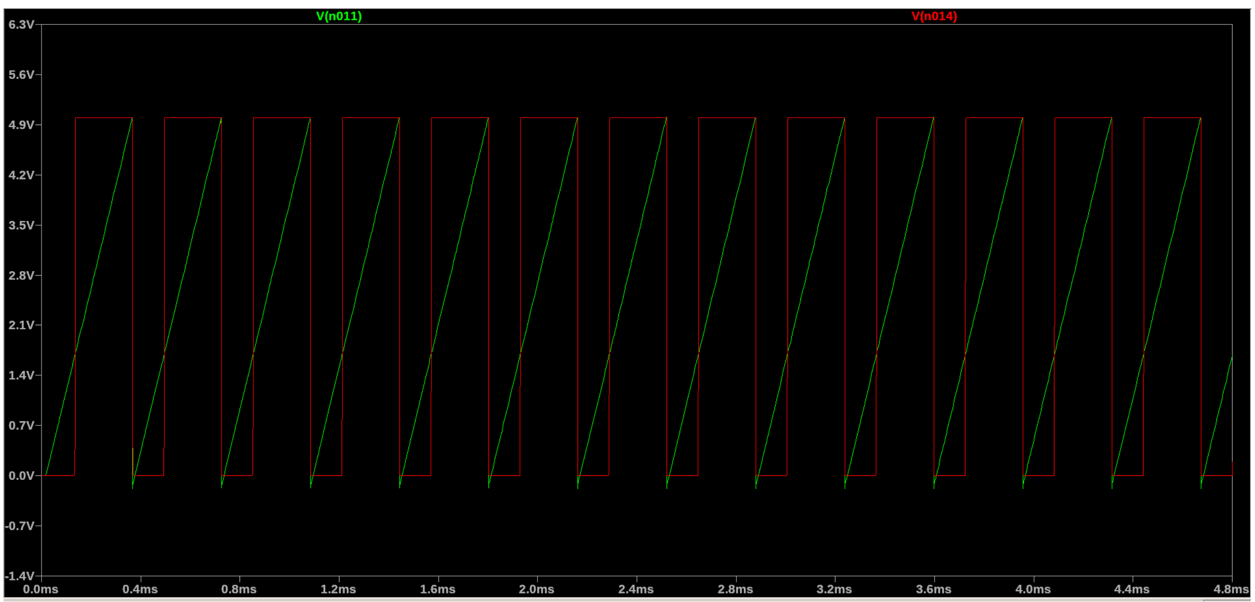

Figure 6.1: Sawtooth and Square Waves

7 Circuit Schematics

This design for this voltage-controlled oscillator was based on a lecture by Aaron Lanterman at Georgia Tech [4] and the book *Musical Applications of Microprocessors* [5]. It consists of an integrator with a constant current input to generate a ramp up. When a threshold of 5V is reached, a comparator turns on, turning on a JFET which allows the capacitor to discharge quickly back down to 0V. The input current to the integrator is created by a pair of BJTs. The current has an exponential relationship with the control voltage, which is ideal for musical applications.

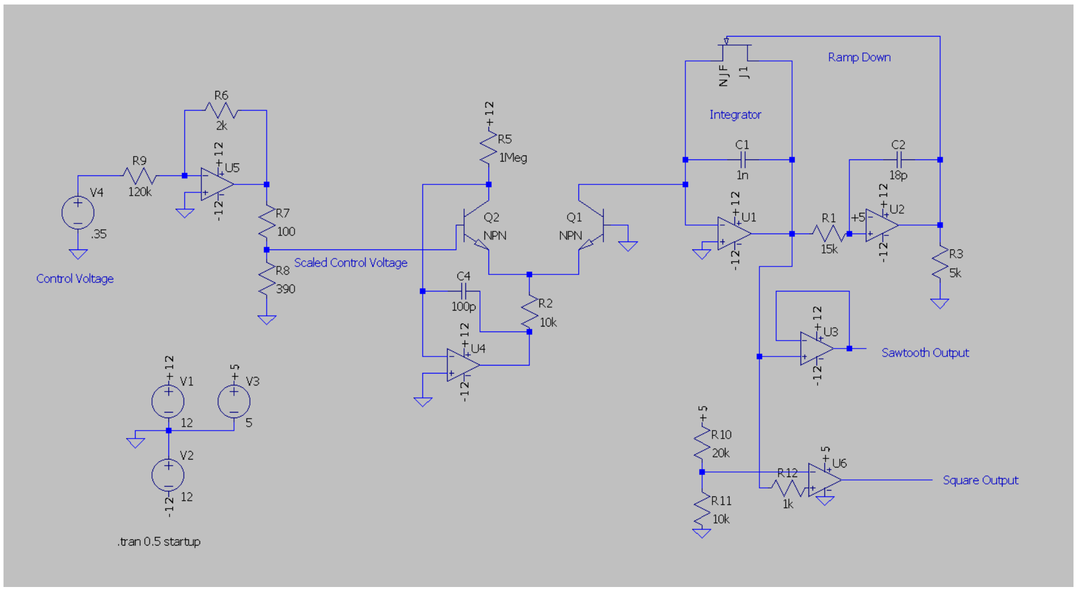

Figure 7.1: VCO

For the voltage-controlled filter, we will use the Moog ladder filter [3]. This was patented in 1969 and so the patent is now expired. The control voltage changes the bias current to all the transistors, which effectively changes their small-signal resistance, changing the cutoff of the filter. This part is still a work in progress.

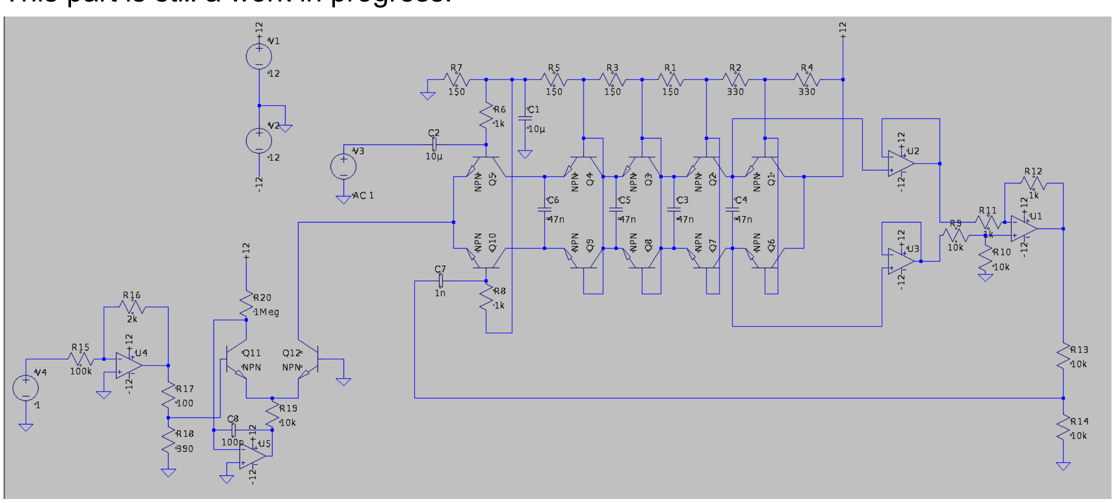

Figure 7.2: Moog Ladder Filter

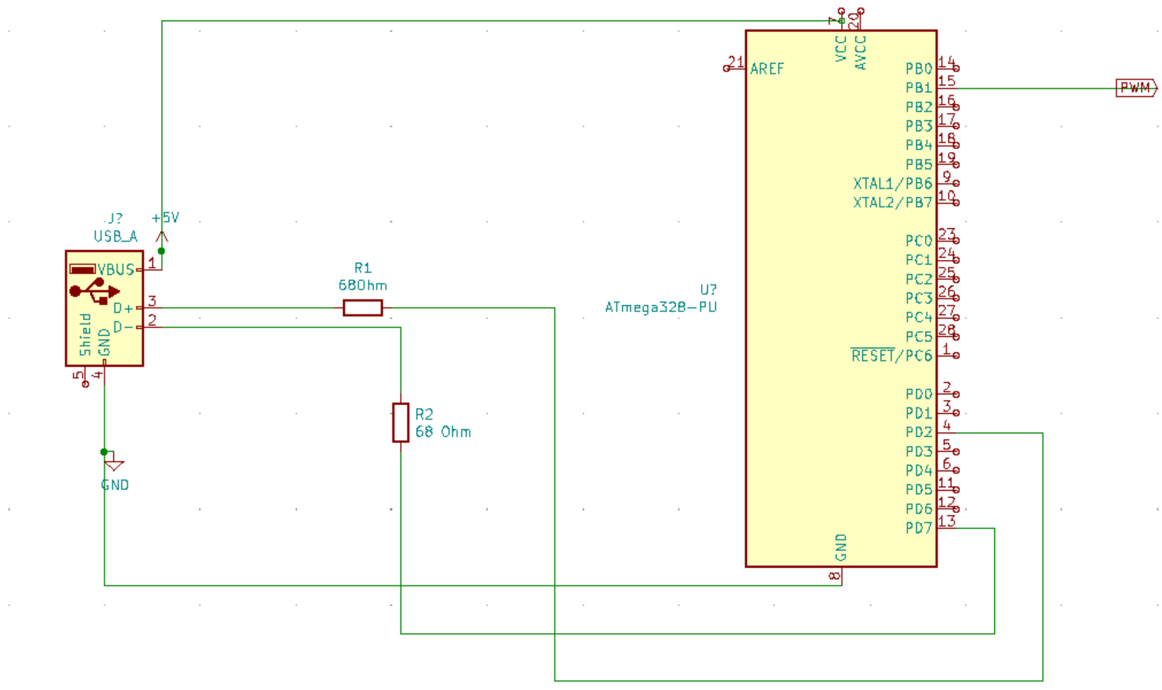

Figure 7.2: Microcontroller

Tolerance Analysis

The power supply should provide a stable positive and negative 12V to the circuits. It is important that there is very little noise in the power because this would ultimately affect the sound in an undesirable way. We are aiming for a tolerance of 0.5V on the supply voltages.

Ethics and Safety

4.1 **Ethical Issues**

- Our project is not very original, and many books and other resources exist to explain the circuits in synthesizers. Schematics of many old synthesizers can be found easily online. Some particular circuits have also been patented, though most of these patents are old and have expired, such as the patent for the Moog ladder filter [3]. If we use any designs from some reference material, patent or schematic, we will need to first make sure that we can legally use it and then reference where it came from.

- The synthesizer produces sounds and could be used to play loud noises of any frequency by connecting the audio output to large speakers and the user can potentially cause a lot of noise pollution.
- The synthesizer could be used to play frequencies that are not in the human hearing range and if misused in the wild it could cause problems to animals and birds around.
- The synthesizer relies on an external powercost so it does rely on electricity and can hence contribute to green-house emissions if it is not using electricity produced through a clean manner.

4.2 **Safety Concerns**

- Exposing one's ears and mind to very irritating and loud sounds.
- Shocks from the synthesizer subsystem in case the synthesizer gets wet.
- In case of water damage, if the synthesizer power source is still plugged in, there could be a fire due to a short circuit.

5. Citations

[1] "IEEE Code of Ethics", ieee.org, 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 15- Sep- 2021].

[2] Grainger College of Engineering, "2018-2019 Illini Success Survey Outcomes* UNDERGRADUATE STUDENTS," https://ecs.engineering.illinois.edu/files/2020/04/UG-ECE-2018-2019.pdf. [Online]. Available: https://ecs.engineering.illinois.edu/files/2020/04/UG-ECE-2018-2019.pdf. [Accessed: 22-Sep-2021].

[3] R. A. Moog, " Electronic high-pass and low-pass filters employing the base to emitter diode resistance of bipolar transistors," United States Patent 3475623A, Oct. 28, 1969.

[4] A. Lanterman, "Exponential Voltage-to-Current Conversion & Tempco Resistors," in *ECE4450 (Analog Circuits for Music)*, 5-Apr-2021.

[5] H. Chamberlin and H. Chamberlin, "Basic Analog Modules," in *Musical applications of microprocessors*, Indianapolis, Indiana: Hayden, 1987, pp. 177–220.