Design Document

Theremixer

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Team 15, TA: Zhen Qin

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1 Introduction

1.1 Objective

The Theremin is an extremely unique musical instrument first patented in 1928. By using relative positioning to control oscillators, users are able to operate the theremin by simply waving their hands. After learning more about the instrument, we wanted to bring a classical instrument into a modern light, creating the Theremixer DJ Theremin. Our proposed solution brings new avenues to express musical creativity. The Thermixer will be a stand alone DJ controller fully capable of altering music settings such as: bass, treble, midrange, and volume. Users will be able to modify these settings through their perceived hand movements by the theremin antennae. The primary objective of our project is to provide users a novel way to mix music. In today's day and age, DJ mixers have consisted of robust systems that have a high cost and a large learning curve. But, we hope to create a simplistic mixer that can actually allow users to mix music with ease.

1.2 Background

For thousands of years, music has been the foundation of helping people reach new heights. Music has allowed people to break boundaries, smash ceilings, and set records. There are hundreds of different music instruments across various cultures and regions. One such instrument is the theremin, known for its ingenuity in utilizing gestures between two antennas to control the output music. The theremin is named after its inventor Leon Theremin who received a patent for the device in 1928. The theremin has been recreated multiple times over the last 90 years in order to adapt to more modern technical abilities. Some recent adaptations of the theremin include digital theremins, including MIDI controller theremins which output MIDI signals rather than line level audio in order to provide easy use for live music playing and production. The theremixer is an effort to utilize a traditional instrument with mixing capabilities found in modern DJ hardware using hand gestures.

1.3 High-Level Requirements

- The output signal from the function oscillator will have a peak value 1 V AC ±10% with a frequency range of 282-288 kHz ±10%.
- The output signal from the magnitude oscillator will have a peak value of 1 V AC ±10% with a frequency range of 440-460 kHz ±10%.
- Our DSP chip will increase and decrease the bass, treble, mid, and volume levels, as described in section 2.3.4, of the imported song based on the output signals of the function and magnitude oscillators.

2 Design

2.1 Block Diagram

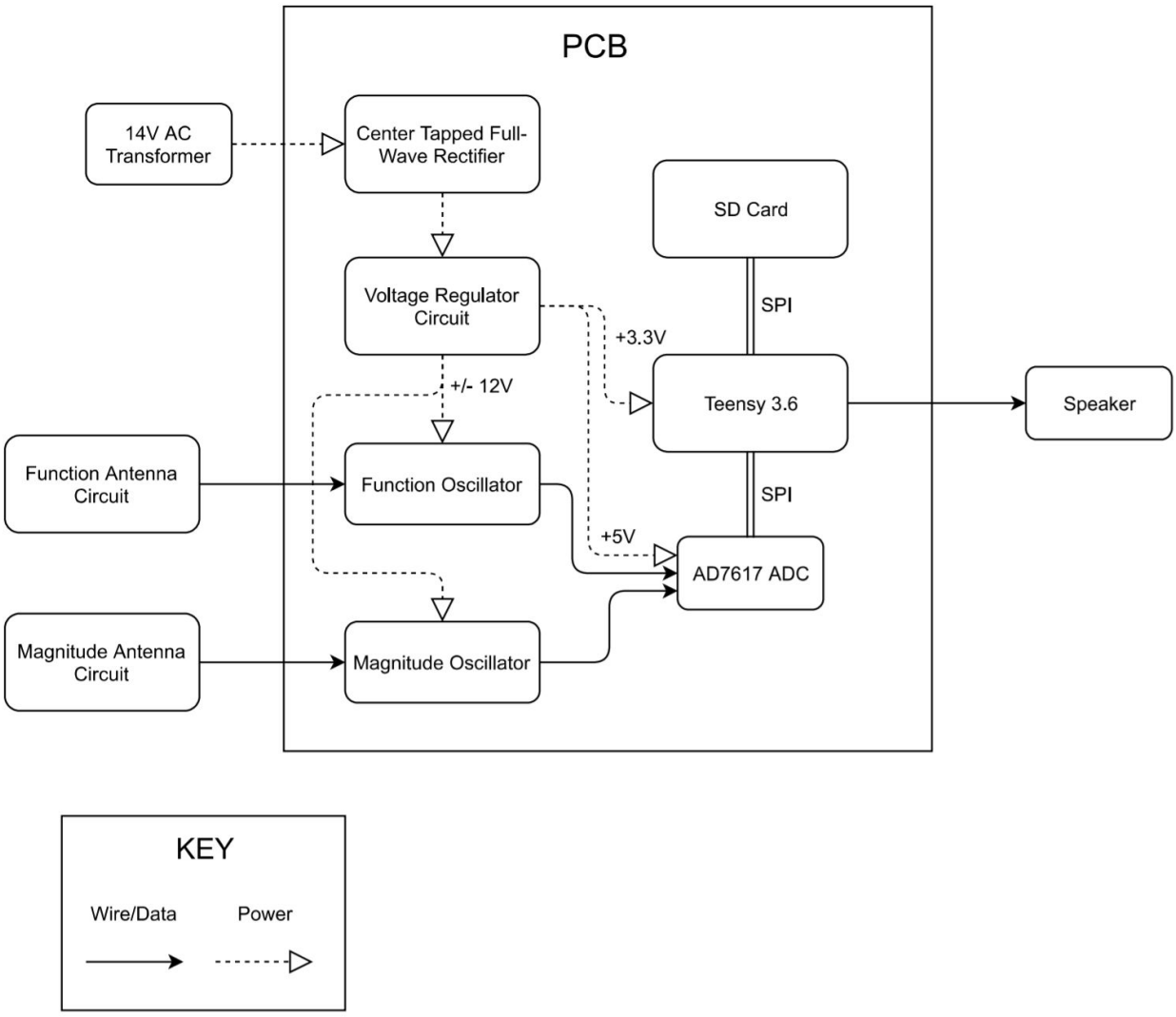


Figure 1: Block Diagram

2.2 Physical Design

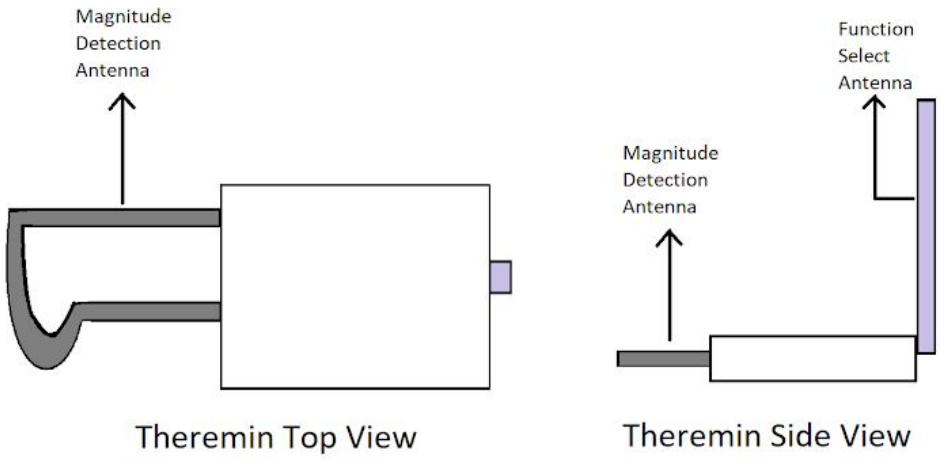


Figure 2: Theremin Physical Design

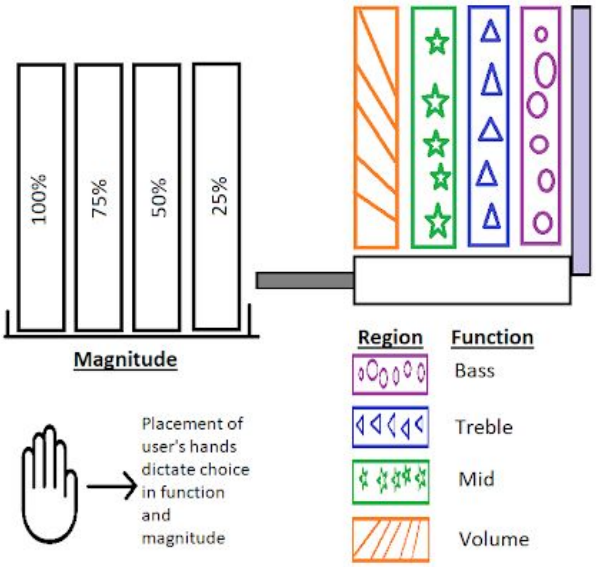


Figure 3: Function - Physical Design Relationship

We plan to make the Theremixer look similar to a traditional Theremin. All of our hardware and interface components will be in a compact housing. The housing will be designed to provide a user interface through switches, and dials. Two antennas will protrude from our housing to allow user control of function select and magnitude value. Our design is subject to constraints based on our hardware and spacing decisions.

2.3 Functional Overview & Block Requirements/Verifications

2.3.1 Power Supply Submodule

14 Volt AC Transformer

We will use a Hammond Manufacturing's 14V AC transformer (BPD2EE) to convert the input voltage to be used by the voltage rectifier.

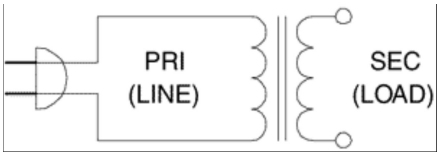


Figure 4: 14 Volt AC Transformer Schematic

Requirement	Verification
• Provide 14V AC ±5% at 60 Hz to voltage rectifier.	1. Use specification sheet to confirm rating. 2. Measure output of transformer (input of voltage rectifier) using oscilloscope while connected to power supply circuit. 3. Verify from the waveform that the transformer is providing 14V ±5% AC at 60 Hz.

Center-Tapped Full-Wave Voltage Rectifier

The center-tapped full wave voltage rectifier will be used to convert the half cycles of the 14V AC signal into a pulsating DC signal with current flow in a single direction into the voltage regulator circuit using two d1N4001 diodes. The output of the voltage rectifier is the voltage regulator.

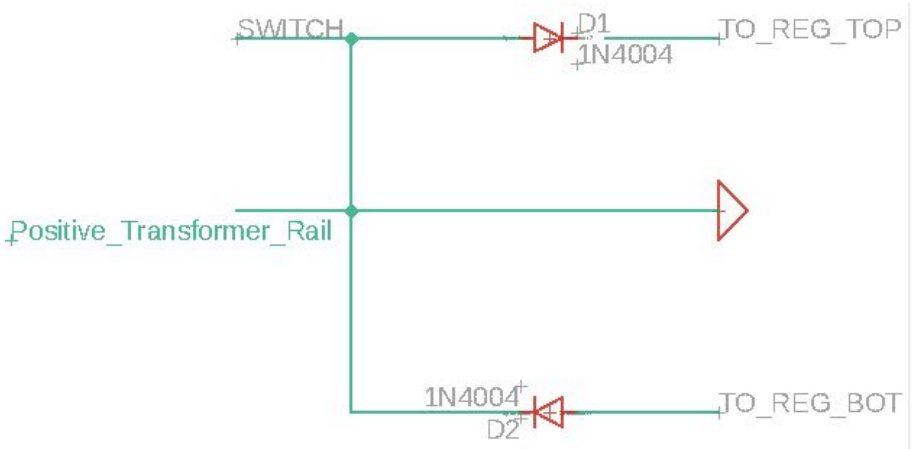


Figure 5: Center-Tapped Full-Wave Voltage Rectifier Schematic

Requirement	Verification
• Provide 14V DC ±5% at 60 Hz to voltage regulator.	1. Use specification sheet to confirm rating. 2. Measure voltage output of full wave rectifier using oscilloscope while connected to power supply circuit. 3. Verify from the waveform that the voltage regulator is providing 14V ±5% DC at 60 Hz.

Voltage Regulator Circuit

This circuit will use the LM7912 and LM7812, 3-Terminal Negative Regulators, to power the main board components through positive and negative voltage rails. These rails will be used to power the circuit as shown in the block diagram.

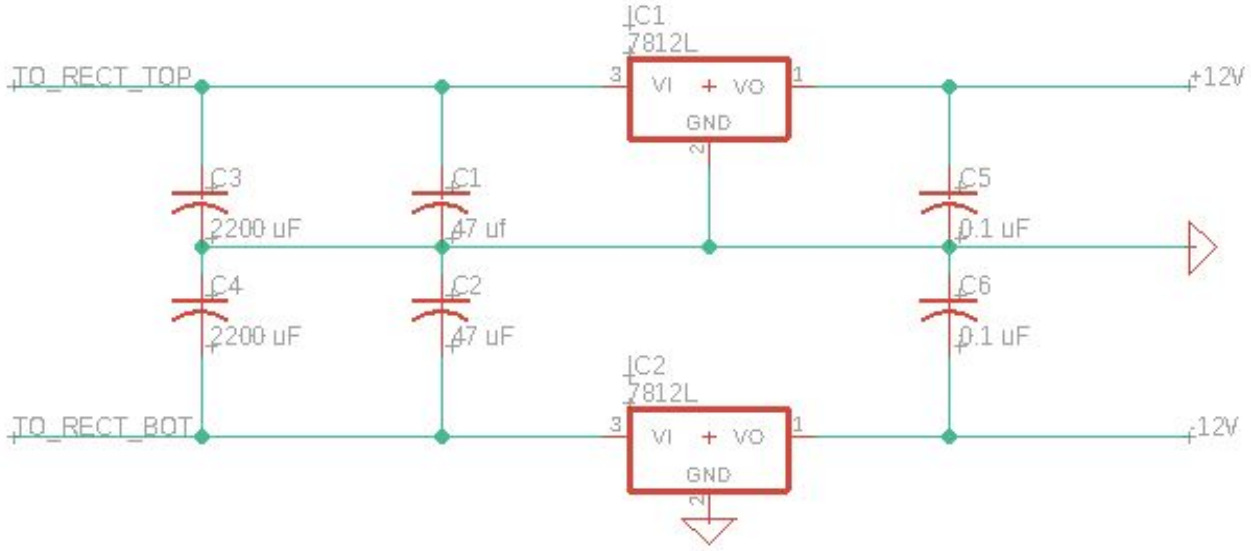


Figure 6: Voltage Regulator Circuit Schematic

Requirement	Verification
• Provide ±12V ±5% to the positive and negative power rails.	1. Measure the output voltage at the positive rail using a multimeter. 2. Verify that the positive rail provides +12V ±5%. 3. Measure the output voltage at the negative rail using a multimeter. 4. Verify that the negative rail provides -12V ±5%.

2.3.2 Magnitude Detection Submodule

Magnitude Detection Antenna Circuit

Our magnitude detection antenna will consist of a wire soldered onto a ¾ inch copper plated tube connected to 2 5 mH inductors and one 5 mH inductor in series. We also will use a 1N4148 and a 1000 pF capacitor to help regulate the output.

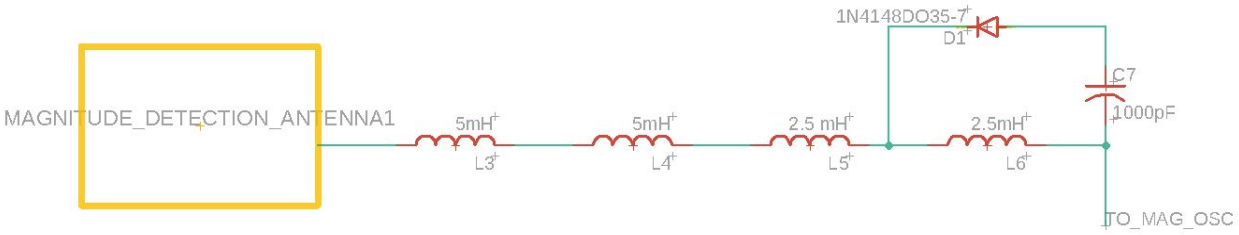


Figure 7: Magnitude Detection Antenna Circuit Schematic

Requirement	Verification
• Antenna effective capacitance of 10-15 pF ±10% . • Capacitance increase of 0.8 pF ±10% when a hand approaches the antenna (wire and tube).	1. Measure the effective capacitance of the antenna using a vector network analyzer, while your hand is far from the antenna. 2. Verify that the total capacitance is in the range of 10-15 pF ±10%. 3. Measure the effective capacitance of the antenna using a vector network analyzer, while your hand is near the antenna. 4. Verify that the total capacitance has increased by 0.8 pF ±10%.

Magnitude Detection Oscillator

The magnitude detection oscillator will create a sinusoidal waveform with varying frequencies based on hand positioning near the volume antenna.

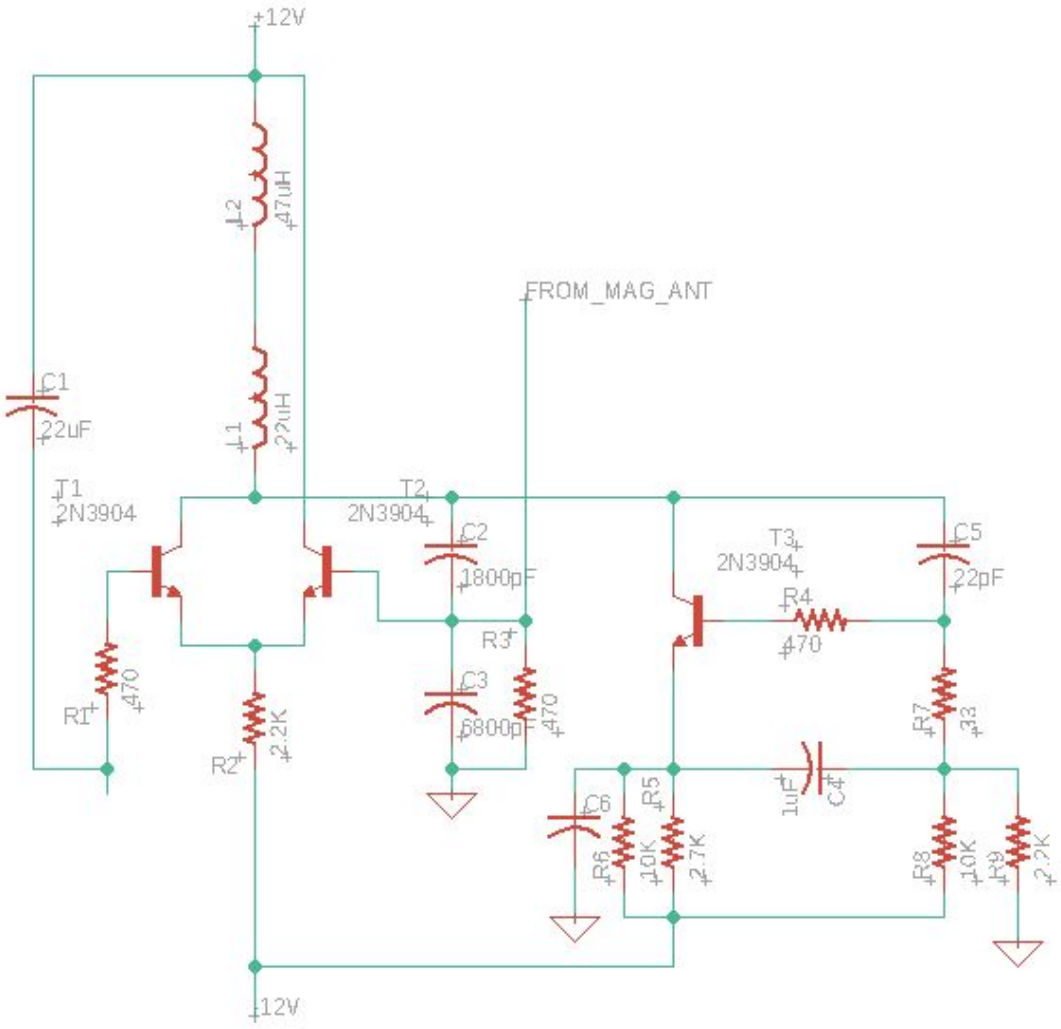


Figure 8: Magnitude Detection Oscillator Schematic

Requirement	Verification

• Maintain a baseline frequency of 450 kHz ±10%.
• Be responsive to hand movements.
  ○ When a hand approaches the antenna the variable frequency should be 440 kHz ±10%.
  ○ When a hand is away from the antenna the variable frequency should be 460 kHz ±10%.
	1. Using an oscilloscope, measure the frequency of the waveform when a hand is far from the antenna.
	2. Verify that the frequency is near 460 kHz ±10%.
	3. Using an oscilloscope, measure the frequency of the waveform when a hand is near the antenna.
	4. Verify that the frequency is near 440 kHz ±10%.

2.3.3 Function Select Submodule

Function Select Antenna Circuit

Our function select antenna will consist of a wire soldered onto a ¾ inch copper plated tube connected to four 10 mH inductors in series.

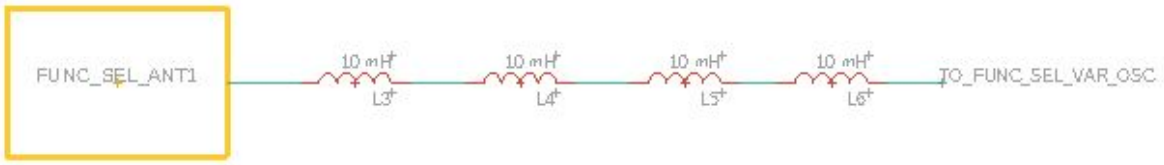


Figure 9: Function Select Antenna Circuit Schematic

Requirement	Verification
• Antenna effective capacitance of 10-15 pF ±10% . • Capacitance increase of 0.8 pF ±10% when a hand approaches the antenna (wire and tube).	1. Measure the effective capacitance of the antenna using a vector network analyzer, while your hand is far from the antenna. 2. Verify that the total capacitance is in the range of 10-15 pF ±10%. 3. Measure the effective capacitance of the antenna using a vector network analyzer, while your hand is near the antenna. 4. Verify that the total capacitance has increased by 0.8 pF ±10%.

Variable Function Select Oscillator

The function select antenna circuit will feed into this oscillator to create the sinusoidal pitch waveform. This waveform will be sensitive to hand positioning near the pitch antenna.

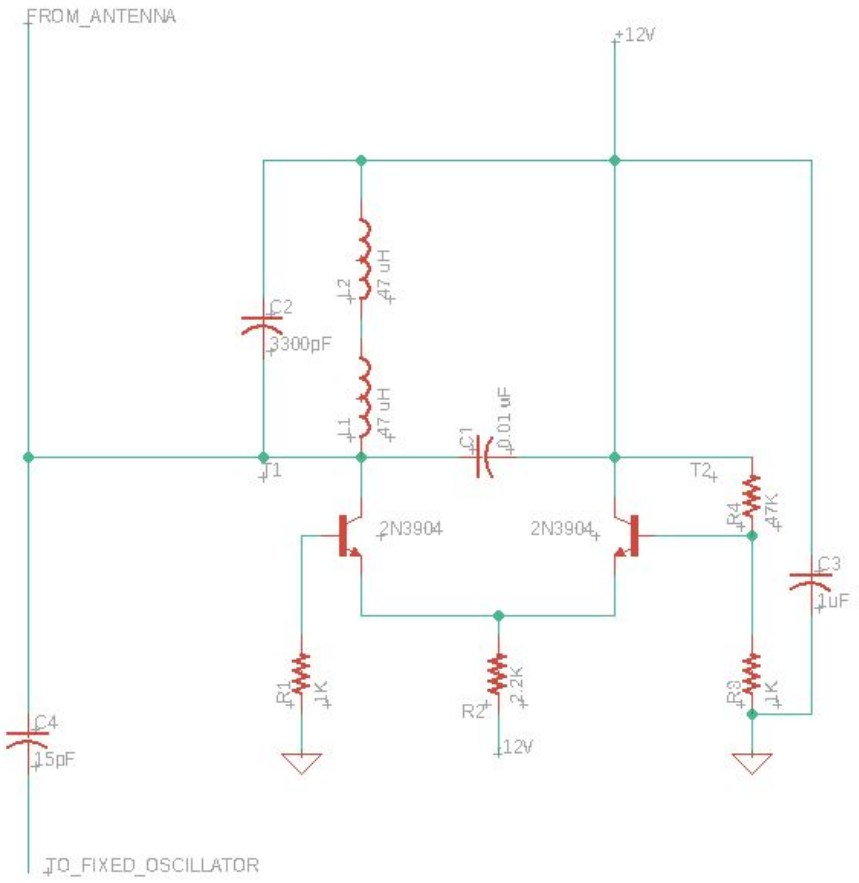


Figure 10: Variable Function Select Oscillator Schematic

Requirement	Verification

• Maintain a baseline frequency of 260 kHz ±10%.
• Be responsive to hand movements.
  ○ When a hand approaches the antenna the variable frequency should be 263 kHz ±10%.
  ○ When a hand is away from the antenna the variable frequency should be 257 kHz ±10%.
	1. Using an oscilloscope, measure the frequency of the waveform when a hand is far from the antenna.
	2. Verify that the frequency is near 257 kHz ±10%.
	3. Using an oscilloscope, measure the frequency of the waveform when a hand is near the antenna.
	4. Verify that the frequency is near 263 kHz ±10%.

Fixed Function Select Oscillator

The fixed function select oscillator will create a steady sinusoidal waveform of a resonant frequency 260 kHz. Its waveform will be used to compare with the variable function select oscillator by the detector.

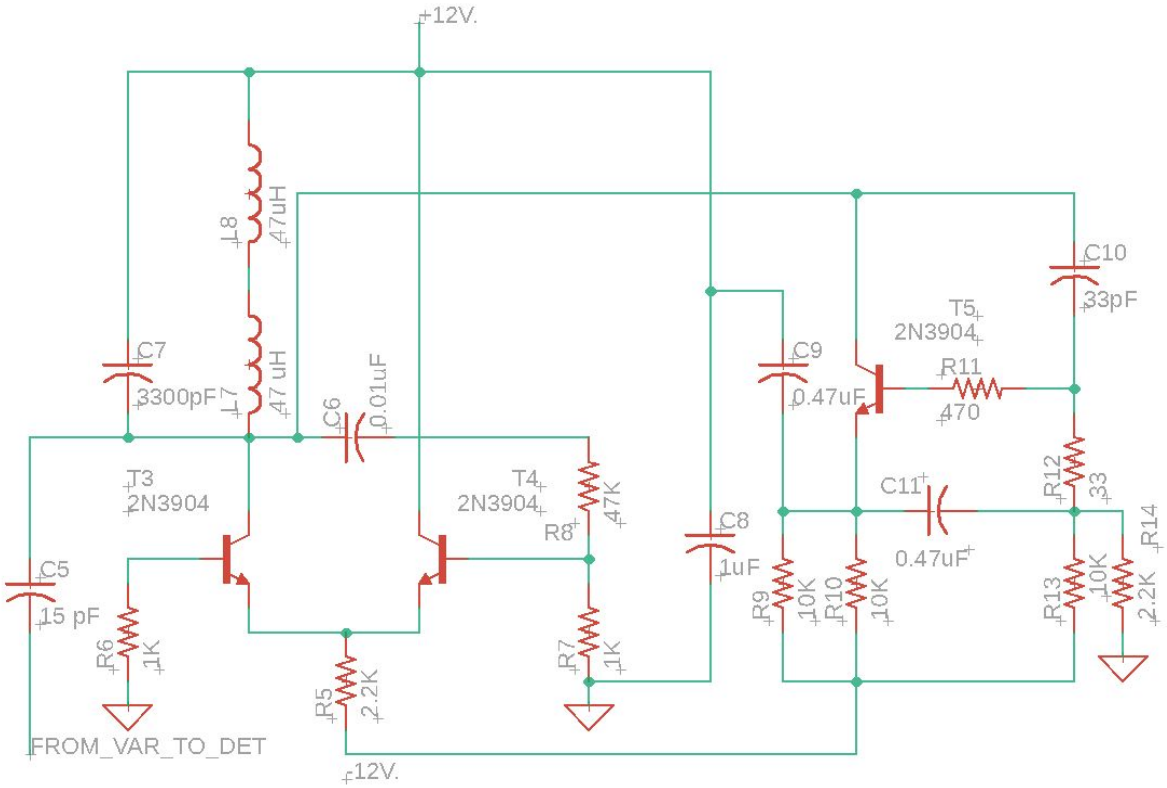


Figure 11: Fixed Function Select Oscillator Schematic

Requirement	Verification
• Maintain a resonant frequency of 260 kHz ±10% that is unaltered by hand movements.	1. Using an oscilloscope, measure the frequency of the waveform when a hand is far from the antenna. 2. Verify that the frequency is near 260 kHz ±10%. 3. Using an oscilloscope, measure the frequency of the waveform when a hand is near the antenna. 4. Verify that the frequency is near 260 kHz ±10%.

Detector

Using a 1N4148 diode, the detector circuit will heterodyne the signal from the fixed function select oscillator and the variable function select oscillator and output the difference between these two signals.

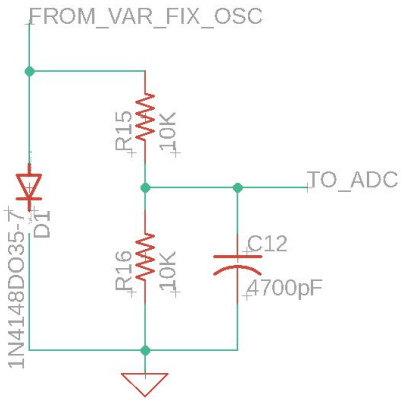


Figure 12: Detector Schematic

Requirement	Verification

• Differentiate the fixed function select oscillator waveform and variable function select oscillator waveform.
  ○ Output a sinusoidal waveform with a frequency of 3kHz ±10% when a hand approaches the function select antenna.
  ○ Output a sinusoidal waveform with a frequency approaching 0kHz ±10% when a hand moves away from the antenna.
	1. Using an oscilloscope, measure the frequency of the waveform when a hand is far from the antenna.
	2. Verify that the frequency is 3 kHz ±10%.
	3. Using an oscilloscope, measure the frequency of the waveform when a hand is near the antenna.
	4. Verify that the frequency is near 0 kHz +10%.

2.3.4 Integrated Circuits

Analog-to-Digital Converter (ADC)

We will use the Analog Devices AD7617 as our analog to digital converter. It will be used to convert the analog signals from both antenna circuits into digital signals to be processed by the Teensy microcontroller. The AD7617 will communicate to the Tennsy microcontroller via SPI protocol. The analog to digital converter has a maximum sample rate of 1 MSPS and so it should be able to detect both oscillators' frequencies.

Requirement	Verification
• Properly sample both oscillator signals with a sample rate of at least 600 kSPS.	1. Verify from the specification sheet that the AD7617 has a sampling frequency of 1 MSPS. This is much higher than the required sample rate of at least 600 kSPS.

Teensy 3.6 Microcontroller

The Teensy 3.6 will be used as our microcontroller to adjust the bass, mid, treble, and volume settings of a song on an SD card. Two inputs of the Teensy 3.6 will be the sampled waveforms from the function select and magnitude detection circuits through the ADC. The third input will be an audio signal from the WAV file. The mixed WAV file will output to our speaker. We will take a buffer-centric approach with a 40ms buffer to apply these filters.

Bass Boosting

To increase the bass of the song, we will apply a low pass filter to amplify or attenuate frequencies of 0-250 Hz and not affect frequencies greater than 250 Hz. To apply the filter we will multiply the FFT of the song with the transfer function of one of two FIR low pass filters. The coefficients will result in a slightly boosted or attenuated bass range (depending on if magnitude is high or low) and 0 dB gain elsewhere, and the filtered output will be scaled further based on the magnitude.

Requirement	Verification
• Amplify or attenuate frequencies of 0-250Hz. • Filter does not affect frequencies greater than 250 Hz.	1. Load test audio file 2. Use NVIDIA spectrogram analysis program to verify that frequencies above 250 Hz are not affected and 0-250 Hz have been amplified. It will be easily visible because only the 0-250 Hz frequencies will have a nominal amplitude.

Treble Boosting

To increase the treble of the song, we will apply a band pass filter to amplify or attenuate frequencies of 2000-6000 Hz. It will not affect frequencies greater than 6000 Hz and less than 2000 Hz, as frequencies greater than 6000 Hz are generally very sensitive to this method of scaling and can result in unpleasant sounds. To apply the filter we will multiply the FFT of the song with the transfer function of one of two FIR bandpass filters. The coefficients will result in a slightly boosted or attenuated treble range (depending on if magnitude is high or low) and 0 dB gain elsewhere, and the filtered output will be scaled further based on the magnitude.

Requirement	Verification
• Amplify and attenuate frequencies of 2000-6000 Hz. • Filter does not affect frequencies greater than 6000 Hz and less than 2000 Hz.	1. Load test audio file 2. Use NVIDIA spectrogram analysis program to verify that frequencies above 6000 Hz and below 2000 Hz have been filtered out. Also verify that the frequencies between 2000-6000 have been amplified. It will be easily visible because only the 2000-6000

	Hz frequencies will have a nominal amplitude.

Mid Boosting

To increase the midrange of the song, we will apply a bandpass filter to amplify or attenuate frequencies of 250-2000 Hz. It not affect frequencies greater than 2000 Hz and less than 250 Hz. To apply the filter we will multiply the FFT of the song with the transfer function of one of two FIR low pass filters. The coefficients will result in a slightly boosted or attenuated midrange (depending on if magnitude is high or low) and 0 dB gain elsewhere, and the filtered output will be scaled further based on the magnitude.

Requirement	Verification
• Amplify or attenuate frequencies of 250-2000 Hz. • Filter does not affect frequencies outside of the 250-2000 Hz range more than 0.5 dB.	1. Load test audio file 2. Use NVIDIA spectrogram analysis program to verify that frequencies above 2000 Hz and below 250 Hz are not affected by more than 0.5 dB. Also verify that the frequencies between 250 and 2000 have been amplified. It will be easily visible because only the 250-2000 Hz frequencies will have a nominal amplitude.

Volume Boosting

The teensy microcontroller will also have control of adjusting the volume output of the song being mixed. It will have the capability of increasing the volume from 50% to 100%. This capability can be quantified as a 3-dB increase and decrease from the baseline volume.

Requirement	Verification
• Apply a 3-dB increase to the baseline volume. • Apply a 3-dB decrease to the baseline volume.	1. Using a multimeter, measure the voltage amplitude of the output from the teensy before a volume increase or decrease is applied. 2. Apply a 3-dB increase by moving your right hand away from the function select antenna and left hand towards the magnitude detection antenna. 3. Measure the effective gain and calculate the dB gain using 20log(Vout/Vin) 4. Verify the increase is 3-dB 5. Apply a 3-dB decrease to the volume by moving your hand away from the function select antenna and left hand away from the magnitude detection antenna. 6. Measure the effective gain and calculate

	the dB gain using 20log(Vout/Vin) 7. Verify the decrease is -3-dB

Software Control Flow

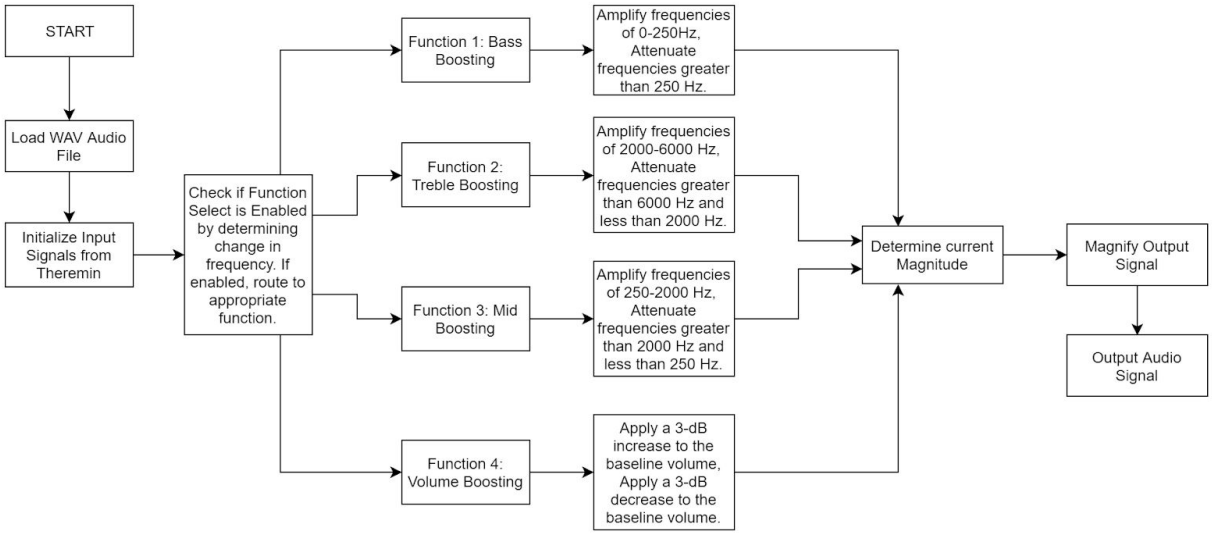


Figure 13: Software Flowchart

2.4 Tolerance Analysis

In order to understand acceptable tolerance levels for the antenna, it is vital to realize that the surroundings of the theremin will significantly impact it. Although we can't control the nuances of the environment, it is important to understand the tolerance levels of subcomponents of the antennas and how how they impact the output signals.

The magnitude detection and function select oscillator circuits are of most importance in our tolerance analysis. Unfortunately, currently we are unable to calculate the theoretical effective impedance of our circuits due to the complexity of the etherwave design. Our plan to conduct tolerance analysis is to first measure the effective capacitance of our antenna connected to the theremin. Once we have a baseline capacitance and resistance of our design, we will be able to use the tolerances of the individual subcomponents to find the risk designated to our component choices.

We have also included tuning circuits attached to each of the oscillators to adjust the effective capacitance of each antenna. Using these tuning circuits, we will be sure to meet our oscillator requirements. The tuning portion of the function select oscillator portion will allow us to maintain a 3 kHz frequency signal when a user's hand is away from the function select antenna. To ensure

that our magnitude detection antenna is functional, the tuning portion of the magnitude detection oscillator circuit will be used to adjust the frequency range to 440-460 kHz.

3 Cost & Schedule

3.1 Costs

3.1.1 Development

Team Members (3) * Hourly Rate ($50) * Hours per Week (12) * Total Weeks (16) * 2.5 = $72,000

3.2.2 Parts & Materials

Part Name	Part Number	Manufacturer	Unit Cost ($)	Quantity	Total Cost ($)
AC Transformer	BPD2EE	Hammond Manufacturing	$17.58	1	$17.58
Teensy 3.6	TEENSY36	PJRC	$29.25	1	$29.25
NPN Transistor	2N3904	OnSemi	$0.07	8	$0.56
Voltage Regulator	LM78L12	Texas Instruments	$0.79	1	$0.79
Voltage Regulator	LM79L12	Texas Instruments	$0.79	1	$0.79
Power Supply Diode	1N4001	ComChip Technology	$0.17	2	$0.34
Detector / Oscillator Diode	1N4148	ON Semiconductor	$0.10	2	$0.20
ADC Chip	AD7617	Analog Devices	$24.40	1	$24.40
10 mH Inductor	74404086103	Wurth Electronics, Inc	$0.65	4	$1.30
47 uH Inductor	74404065233	Wurth Electronics, Inc	$0.67	5	$1.34
5 mH inductor	74404023433	Wurth Electronics, Inc	$0.55	2	$1.10

2.5 mH Inductors	74404076811	Wurth Electronics, Inc	$0.52	2	$1.04
3300 pF Capacitor	GRM2165C1H332JA01D	Murate Electronics	$0.87	2	$1.74
15 pF Capacitor	CL05C150JB5NNNC	Samsung Electro Mechanics	$0.35	2	$0.70
1000 pF ceramic Capacitor	GRM033R71E102KA01D	Murate Electronics	$0.72	2	$1.44
22 uF tantalum Capacitor	GRM027R1E102KA01D	Murate Electronics	$0.76	1	$1.52
1800 pF film Capacitor	GRM076F76E00KA01D	Murate Electronics	$0.80	1	$1.60
2200 uF Aluminum Electrolytic Capacitor	GRM897T6F2155LA01D	Murate Electronics	$0.56	2	$1.02
0.1 uF Ceramic Capacitor	GRM762F8T200MA01D	Murate Electronics	$0.42	2	$0.84
Copper Plated Tubing for Antennas	----	ECE Shop	$7.05	2	$14.10
				TOTAL:	**$101.65**

3.2 Schedule

Week	Akhil	Karthik	Shiv
01/14/19 - 02/04/19	● Conduct research for project proposal ● Create project proposal	● Conduct research for project proposal ● Create project proposal	● Conduct research for project proposal ● Create project proposal
02/11/19	● Work on design document ● Complete eagle	● Work on design document ● Complete eagle	● Work on design document ● Complete eagle

	assignment	assignment	assignment
02/18/19	● Complete Design Document ● Order Parts	● Complete Design Document ● Order Parts	● Complete Design Document ● Order Parts
02/25/19	● Build filter prototype on Teensy microcontroller	● Complete PCB Design ● Build Magnitude Detection ● Conduct Antenna Impedance Testing	● Complete PCB Design ● Build Function Select Antenna ● Conduct Antenna Impedance Testing
03/04/19	● Complete Soldering Assignment ● Complete Teamwork Evaluation I ● Build software prototype to utilize multiple inputs for choosing filters	● Complete Soldering Assignment ● Antenna Oscillator Testing & Calibration ● Complete Teamwork Evaluation I	● Complete Soldering Assignment ● Antenna Oscillator Testing & Calibration ● Complete Teamwork Evaluation I
03/11/19	● Test and calibrate filters using simulated inputs	● Construct housing design and submit to ECE shop ● Connect and test Theremixer hardware subsystem	● Construct housing design and submit to ECE shop
03/18/19	**SPRING BREAK**		
03/25/19	● Connect and test Theremixer hardware subsystem ● Submit individual progress reports	● Connect and test Theremixer hardware subsystem ● Submit individual progress reports	● Connect and test Theremixer hardware subsystem ● Submit individual progress reports
04/01/19	● Test and interface all hardware and software components	● Test and interface all hardware and software components	● Test and interface all hardware and software components

04/08/19	• Develop project demonstration • Further verification and calibration	• Develop project demonstration • Further verification and calibration	• Develop project demonstration • Further verification and calibration
04/15/19	• Work on final paper and presentation	• Work on final paper and presentation	• Work on final paper and presentation
04/22/19	• Work on final paper and presentation	• Work on final paper and presentation	• Work on final paper and presentation
04/29/19	• Finalize and submit the final paper, presentation, lab notebook, lab checkout, and Teamwork Evaluation II	• Finalize and submit the final paper, presentation, lab notebook, lab checkout, and Teamwork Evaluation II	• Finalize and submit the final paper, presentation, lab notebook, lab checkout, and Teamwork Evaluation II

4 Ethics & Safety

4.1 Risk Analysis

The volume and pitch antennae are significant risks to the successful completion of this project. Circuit calibration to ensure a variable output voltage of 0.5-1 VAC under a range of 0-3 kHz is is vital for a functioning theremin. We will need to include volume and pitch tuning circuits to guarantee proper audio output from the theremin. Another potential risk to the successful completion of our project is output latency from the theremin to the mixing program. There must be low latency for users to have full control of the mixer so that gestures on the theremin will have immediate reactions to the music output to the speakers. The volume antenna will include a volume oscillator and volume tuning circuit. The pitch antenna will include a variable pitch oscillator, a fixed pitch oscillator, and a pitch tuning circuit. For successful completion, it will be necessary that these circuits are calibrated to produce a desirable output. Proper calibration will ensure that substantial hand movements from the user will create varying output voltages from 0.5-1 VAC with a frequency range of 0-3 kHz. Another significant risk of our project is the proper design of the microcontroller. This is because the microcontroller is vital for the extension of the traditional theremin to a theremin that can mix music. It is essential that we build a microcontroller that can an analog input from the theremin, read a WAV file from a USB or SD card, and output a video signal to a monitor and audio signal to a speaker.

4.2 Ethics

There are several ethical and safety matters to consider throughout the development of our project. Firstly, the IEEE Code of Ethics #5 states that the goal is “to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems” [1]. Our project encompasses replicating a traditional theremin design to develop an alternative operation of mixing music using output from the theremin. This aligns closely with the IEEE Code of Ethics #5 because we want to help individuals understand alternative uses of traditional technologies in the modern day. We also hope to accept honest criticism of our work throughout the semester to help guide our project and make fixes where necessary in accordance with IEEE of Ethics #7[1]. Another critical foundation of our project is to work closely with each other to develop professionally, and always uphold the IEEE Code of Ethics. The Code of Ethics is not only a statement of what to do on paper, but also the framework for an engineer’s mindset to always be solution oriented while upholding certain principles.

The theremin we hope to construct would be a modern replication of the traditional theremin. We are going to be building a theremin that is an adaption of an Etherwave Theremin that has been developed my Moog Music previously [2]. Fortunately, Moog Music has published various open-source information to help guide the design of the theremin [3]. We hope to use this design as a foundation for further developing a modern theremin and provide an alternative use with music mixing. Additionally, another ethical point to concern is developing a platform to alter precreated music. Although the music is the property of artists, we will follow similar practices as those DJs in today’s day and age who mix music at clubs. We hope to access the music we play legally through a streaming service or through purchase of music albums. Overall, our project does not pose any significant ethical concerns that might impact its success. This is primarily due to the fact that we are taking a traditional design and making a modern use of it.

4.3 Safety

There are some safety concerns in relation to our project. Our project has power component that has a very low probability of being hazardous since it is only being used to power our theremin and circuit. In order to prevent any problems with power, we will always build stable connections in our circuit and ensure that connections are made properly. Also, it’s important to note that we will be working in an electronics lab, and as a result there are several lab-specific safety risks to mitigate. We need to ensure that we use line voltage from the walls safely, and also ensure that no other metal components are close to the antennas while we are testing. Essentially, the successful testing of the theremin requires isolated space to prevent any other material from

interacting with the theremin. We will mitigate these risks by using the techniques we have learned in the lab training, and also always be aware of our surroundings. Another safety concern we might face will be during the design of the housing. This is because we need to properly construct a wooden housing with knobs, power inlet, and other components with proper spacing to allow for a fully functional theremin music mixer. In order to be safe, we will always use best practices in the lab and verify our design before constructing it.

5 References

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