6.101 Final Project Proposal - Theremin

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Introduction

The theremin is a unique and uncommon instrument that is played by measuring the distance from two antennas that control pitch and volume to the musicians hands. Using the theremin does not actually involve touching it, making it fun and interesting to watch and play. The theremin is also a completely analog device and should give us some good experience with oscillators, amplifiers, and signal processing. In fact, the capacitive sensing techniques used to control the theremin have many practical applications such as cell phone touch screens.

The theremin can also be made very modular by dividing it into functional blocks such as the pitch antenna, volume antenna, voltage controlled amplifier, voltage controlled oscillator, and power supply. These blocks can all be designed and tested in parallel by different members of our team. If we can complete these parts to make a basic theremin, we plan on trying to extend the project by doing things such as optimizing the linearity and range of the antenna controls and adding pitch visualizations to aid in tuning and playing.

Theremin Circuit Block Overview

The purpose of a Theremin is to let a user control the pitch and volume of an audio output by moving their hands closer and farther from two antennas. One antenna controls the pitch of the audio, moving your hand closer to the antenna increases the pitch. The other controls the volume, moving your hand closer to the antenna decreases the volume.

The distance to the hands can be detected because the antennas are capacitively coupled to the player so moving your hands around changes the capacitance which is then used to change the frequency of oscillators inside of the instrument. For the pitch, the frequency difference between an oscillator that varies with antenna capacitance and a fixed reference oscillator is taken by a heterodyning circuit. This produces an audio signal in the frequency range of 0-3KHz. The volume antenna uses a similar variable frequency oscillator; however, instead of a heterodyning circuit, the signal is passed through a bandpass filter and an amplitude detecting circuit. This generates a DC value that can be used to control a voltage controlled amplifier, thereby controlling the volume of the audio signal. The audio signal is passed into a speaker to play the tone. We have also included a visualizer which will display the musical note being produced to aid in tuning and playing the instrument.

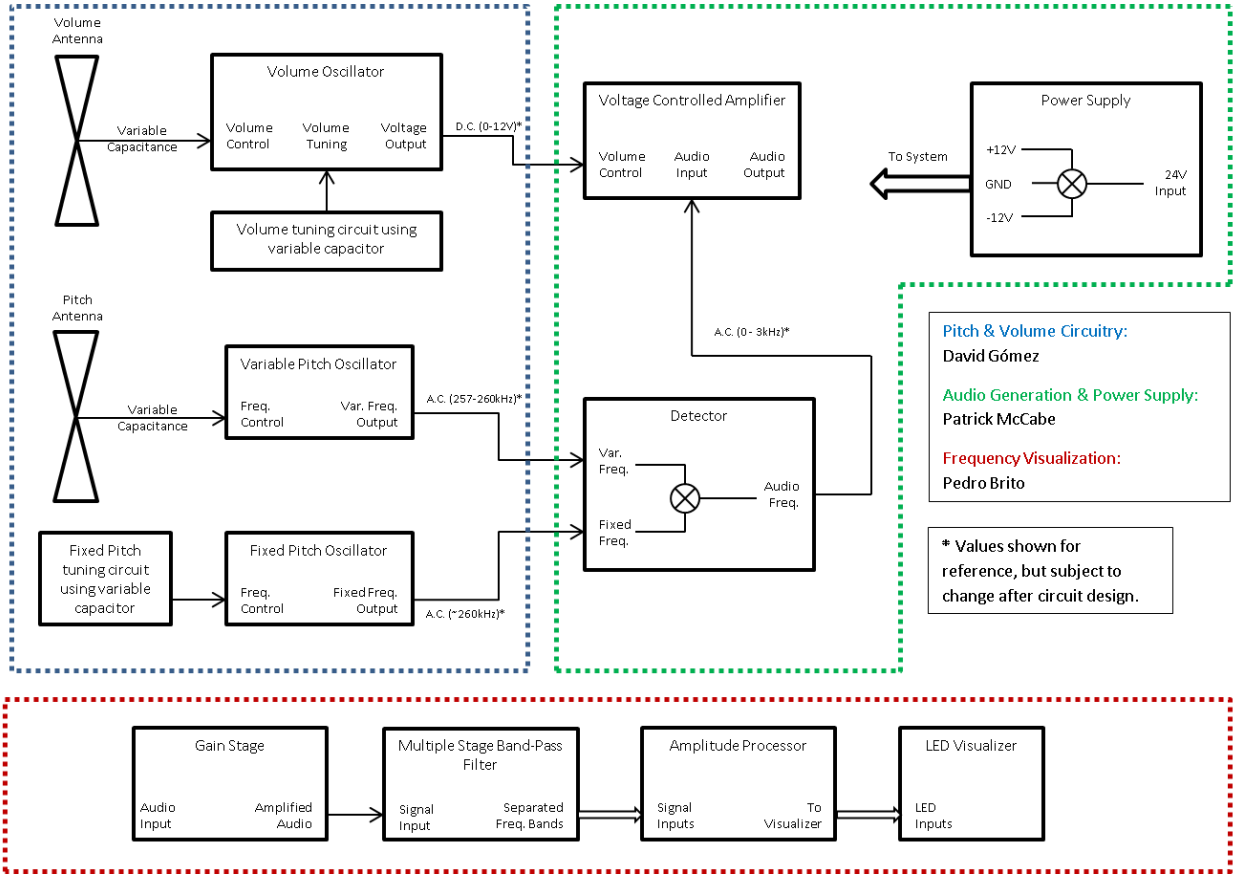

Figure 1: Block Diagram

Theremin Circuit Block Descriptions

Pitch Circuitry (Responsible Engineer - David)

Variable Pitch Oscillator (VPO): This is an LC sine wave oscillator whose oscillation frequency is varied based on the capacitance between the pitch antenna and the player's hand. As the capacitance increases, equating to a hand is moving closer to the antenna, the frequency of this oscillator will also decrease. The center frequency of this oscillator is set at a large value compared to the frequency of human hearing (around 260 KHz). This is done to increase the range of frequency change that the small change in capacitance creates. This center frequency will be chosen to give the instrument a 0-3KHz audio range.

Our oscillator will use two LC resonant tanks, one fixed parallel inductor and capacitor and another series inductor and antenna capacitance. These LC values will be chosen to give the proper resonant frequency while an opamp giving the system positive feedback will be tuned to ensure the system satisfied the Barkhausen criteria to sustain oscillations.

Fixed Pitch Oscillator (FPO): This will be a square wave oscillator which will consist of a schmitt trigger in a feedback loop with an integrator. The center frequency is selected to match the

center frequency of the variable pitch oscillator when the hand is not near it. This is done such that the mixer circuitry can take the difference between the FPO and the VPO - resulting in just the 0-3KHz audio.

Pitch Tuning: The pitch tuning circuitry will allow the FPO to be tuned as environmental differences could change the capacitance to ground of the pitch antenna, leading to the wrong musical notes being produced. Since the audio frequency produced is the difference between the two oscillator frequencies, changing the FPO frequency will change the range of notes produced. Pitch tuning will be implement through variable capacitors in parallel with the resonant tank capacitors.

Pitch Antenna: The pitch antenna forms one side of a variable capacitor with the other side being the player's hand. This controls the VPO's frequency. The pitch antenna is made from a aluminum tube.

All the pitch circuitry can be tested by using an oscilloscope to take frequency readings of the outputs to ensure the FPO produces a ~260KHz square wave and the VPO produces a sine wave that changes between ~260KHz to 257KHz with changing antenna capacitance.

Volume Circuitry (Responsible Engineer - David)

Variable Volume Oscillator (VVO): This is an oscillator whose frequency is controlled by the distance of the player's hand to the volume antenna. The center frequency, will be in the 450KHz range) of this oscillator is large so that there is a decent range of frequency change created by the small change in capacitance that the player's hand introduces. This oscillator will have the same topology as the VPO but with a higher center frequency.

Volume Tuning: The volume tuning circuitry allows the player to adjust the center frequency of the VVO so that when a player's hand is very close the the volume antenna the theremin is silent. This tuning circuitry is important since environmental changes could move the center frequency of the VVO into an unplayable range. This will be implemented by a variable capacitor in parallel with the resonant tank capacitance.

Volume Antenna: The volume antenna forms one side of a variable capacitor with the other side being the player's hand. This controls the VVO's frequency. The volume antenna is a loop made from an aluminum tube. The loop is horizontal to the pitch antenna to minimize the effect of the pitch hand moving on the volume antenna's capacitance and vice versa. The loop shape allows a player to quickly mute the theremin by sticking their hand into the loop.

Similar to the pitch circuitry, the volume circuitry can be easily tested with an oscilloscope to ensure that the VVO produces a ~450KHz sinewave when no hand is near the antenna and that this frequency decreases by a large amount when a hand is very close to the antenna. The exact value of frequency decrease will determine how we set up the voltage controlled amplifier to completely kill the volume when the hand is very close.

Audio Generation (Responsible Engineer - Patrick)

Mixer Block: This block of the theremin circuitry generates frequencies in an audible range from the FPO and VPO (which are at high, inaudible frequencies of ~260KHz) by extracting the difference in frequency between them. This can be done by first mixing the signals together to create a signal that is the FPO output signal multiplied by the VPO output signal. This multiplication creates a signal that has many different frequency components, one of them being the difference between the FPO and the VPO. This signal processing technique is called heterodyning. The difference frequency, in the range 0-3KHz, can be extracted simply by low pass filtering the mixer output. The fixed oscillator signal can be a square wave to make the multiplication process simple. In this setup, the fixed oscillator's output is used to gate the variable oscillator's output, which is the same as a multiplication. That signal can then be passed through a Sallen-Key low pass filter to extract the FPO - VPO frequency. This circuit will be built on a breadboard using opamps, bjts, and passive components. Both of the input signals to this block are ~3VPP. The output will be 0.89VPP, which is the line-level standard for consumer electronics. The power consumption of this block is very low at ~5ma.

The mixer circuitry can be tested using two function generators and an oscilloscope. One function generate will be used to emulate the sinusoidal output from the VPO and the other will emulate the square wave output from the FPO.

DC Volume Control Signal Generation: The frequency output of the VVO has to be changed to a DC voltage so that it can be routed to the voltage controlled amplifier. This is done through a bandpass filter and an amplitude detector circuit. The bandpass filter is centered near the VVO's center frequency (~450KHz). When the player moves their hand by the volume antenna the VVO's frequency changes. This attenuates the signal outputted from the bandpass filter. This signal then goes through an amplitude detector to create a DC voltage level that can be used to control a voltage controlled amplifier - thus controlling the volume of the instrument. The bandpass filter can be implemented with a Sallen-Key topology. The amplitude detector can be made from a rectifier and averaging circuit. This block will consume a few milliamps of current. This block can be tested using a function generator to emulate the output of the VVO and measuring the output signal on the oscilloscope.

Voltage Controlled Amplifier (VCA): The name of this block is a little misleading. In reality, this block acts as a voltage controlled attenuator. The voltage controlled amplifier will take the audio output from the mixer (0-3KHz), which is at maximum amplitude per the line level standard, and and attenuate the signal based on a control voltage. This will allow our theremin to have volume control. The amount the signal is attenuated will be dependent on the DC voltage that the volume antenna circuit will generate based on the distance between the player's hand and the volume antenna. The final output will be in the range specified by the line level standard, which is 0VPP to 0.894VPP, and will have a frequency of 0-3KHz. The circuit will provide an output impedance of 100-600 ohms to match the standard. This circuit will use a chopper circuit topology that chops the incoming signal with a varying duty cycle square to produce an

attenuated signal. This block can be tested by using a function generator to emulate the audio input and a function generator to emulate the DC control voltage.

Power Supply (Responsible Engineer - Patrick)

Power Supply: Since the power supply is not a critical design component of the Theremin we will make ours as simple and reliable as possible by using a 24VAC wall wart to do the conversion from 120VAC. We will then use 12v Linear regulators and convert the 24VAC into +12VDC and -12VDC. This power supply will be able to supply 300ma of current. We may also elect to simply use benchtop power supplies.

Frequency Visualization and Calibrator (Responsible Engineer - Pedro)

The Frequency Visualizer serves to give the player a clear representation of what frequency he's playing and at what intensity. This is done by having a range of LED columns for different frequency bands, as shown in Fig. 1. Each column then has a row of LED's that lights up incrementally as the volume increases. A calibrating row is also added, which responds to a very narrow frequency range around the standard tuning frequency A440.

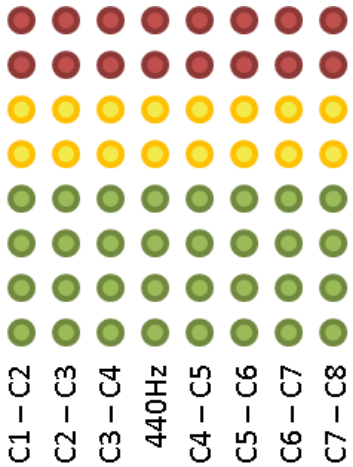

Fig. 1 - Frequency Visualizer with Tuning Column

The visualizer has four main stages: a gain stage, a band-pass filter stage, an amplitude detection stage, and a visualization stage.

Gain Stage

The gain stage serves to adjust the sensitivity of the visualizer amplitude representation and to amplify the audio input if necessary. This can be done by implementing a non-inverting op-amp circuit with a variable resistor in the feedback path. It also gives the benefit of having a high input impedance into the visualizer circuit.

Band-Pass Filtering Stage

In order to be able to visualize each separate frequency range they first have to be detected from the audio input. This is done by having a band-pass filter for each frequency range of interest. A band-pass filter is in essence a combination of low-pass and high-pass filters set such that only -the frequencies of interest are returned (in the visualizer's case, from the low cut-off to the high cut-off of each bandpass).

Amplitude Detection Stage

The amplitude detection stage receives the output from each band-pass filter and analyzes each one individually. In other words, there's an amplitude detection module for each band-pass filter. It's purpose is to detect how strong the signal is and determine how many LED's to turn on. This can be done by using astable configured opamps which turn respective LED's after certain thresholds.

LED Visualization Stage

This stage goes hand to hand with the output detection stage, since it essential receives all of the processed signals from the amplitude detection stage and sends it tp the corresponding LED.

Testing

Each block of the visualizer was inherently chosen so that none is dependent on the other for testing. Every stage can be tested by connecting a frequency generator to every input and checking that the output behavior is as expected.

Timeline

Weeks-> Members || V	April 04	April 11	April 18	April 25	May 02
All	Order/make antennas Order power supply		Integration	Integration/testing/refining	DONE!
David	Make FPO with Tuning	Make/test VPO with antenna	Design/make stretch goal component		
Patrick	Mixer	VCA / Power	Design/make		

		supply	stretch goal component		
Pedro	Working Schematic on LTSpice	Gain Stage Band-Pass	Amp. Proc. Visualization	Integration	

Conclusion

The theremin is a very old instrument and many designs exist; however, many of them use obsolete components or don't take advantage of modern techniques. By the end of this project we will achieve a modernized version of the theremin which utilizes higher precision components and techniques, such as op-amp based oscillators. Another distinction of our theremin is the addition of visualization. This will enable the user to tune it easily and have a clear visualization of what range he's playing in, something that normally requires a user to have perfect pitch to do.

One of the greatest challenges of this project is getting the circuit to behave smoothly with the antennas. The capacitance change from the antennas is not only very small, but also changes in a nonlinear fashion as does the resonant frequency of the oscillator. To further complicate matters, pitch is perceived exponentially so getting a response that makes sense will be hard. Throughout the course we have gained a broad knowledge on most of the theremin's components and behaviors, so we are confident that we have what it takes to carry on with the project and take on the challenges it poses.