Theremin, a Musical Instrument

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Objective

To build an analog musical instrument device that employs precise tuning to control frequency in pitch and volume.

Important Aspects
- Oscillators (Pitch and Volume)
- Amplifiers
- Resonant Frequency Matching with Antenna
- Attenuation
- Mixer

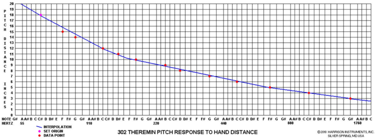
Project Description

- A musical instrument first built by a Russian physicist and musician Leon Theremin
- Playable with absolutely no physical contact; uses electromagnetic field around each antenna
- As hand gets closer to the pitch antenna (straight), the pitch rises; the closer to the volume antenna (loop), the smaller the volume.
- Mechanism: hand acts like the ground side of a variable capacitor with the antenna; when far away, capacitance is about 1 pF (almost negligible). Hand waving in the EM field causes variation of around 2 to 4 pF, which is converted to a frequency change of 2 to 4 kHz.
- Frequency range by choice of L and C:

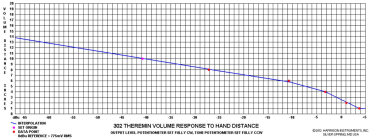
$$f_{resonant} = \frac{1}{2\pi\sqrt{LC}}$$

$$\frac{df}{dC} = \frac{1}{4\pi\sqrt{LC**3}} = -\sqrt{\frac{L}{2C}} f_{resonant}$$

Response to Hand Distance



(a) Pitch (Dist. vs. Hz)



(b) Volume (Dist. vs. -dB)

Figure: Oscillator Output for Hand Distance

src: http://harrisoninstruments.com/302/302_*description.html*

High Level Overview

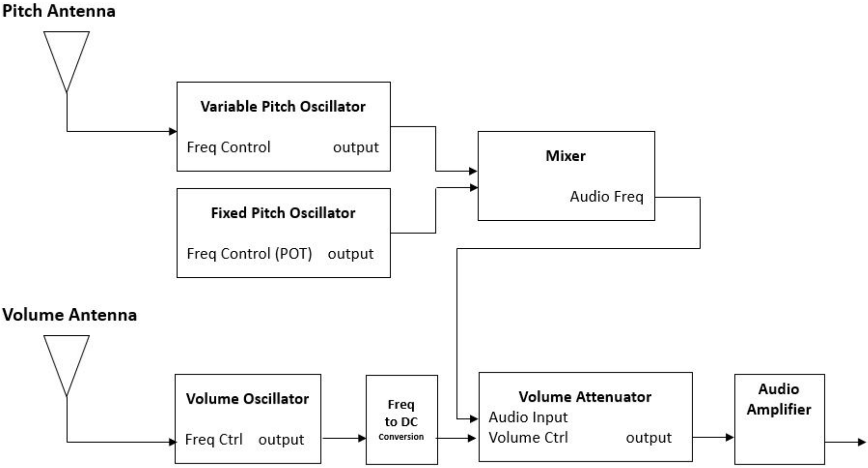
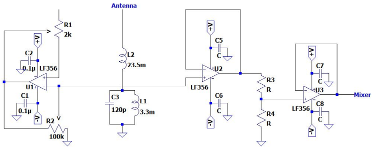


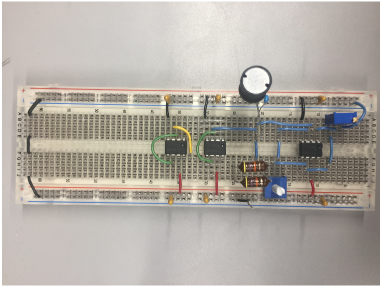
Figure: High-Level Block Diagram

1. Variable Pitch Oscillator

- The variable pitch oscillator is meant to be mixed with the fixed pitch oscillator. This oscillator is based on the resonant frequency of the antenna. In order to achieve a circuit that produces a noticeable amplitude, an LC tank is necessary with a feedback system to assure that the system produces correct output. When testing this module of the circuit, there were varying degrees of success depending on the way the circuit was constructed.



(a) Schematic

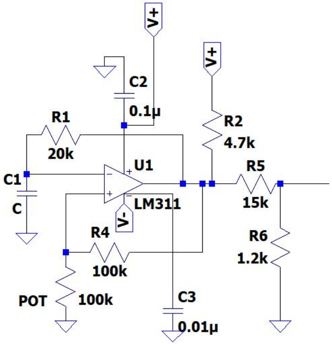


(b) Circuit

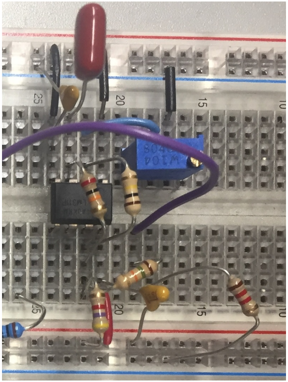
Figure: Variable Pitch Oscillator

2. Fixed Pitch Oscillator

- The fixed pitch oscillator is meant to be mixed with the sinusoidal pitch antenna input so that the wave of frequency at the difference of the two inputs is obtained. To achieve a sinusoidal wave at the difference frequency, the fixed pitch oscillator should create a square wave form, which is obtained by a relaxation oscillator. The output level is adjusted by voltage divider.



(a) Schematic

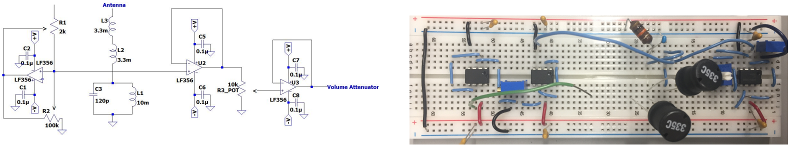


(b) Circuit

Figure: Fixed Pitch Oscillator

3. Volume Oscillator

- The volume oscillator is very similar to variable pitch oscillator in design since it requires the use of an LC tank and feedback system to function correctly but there was a slight difference in the circuit which was the choice of inductors and capacitors to match the impedance of the antenna. Since the volume antenna was different in shape and size when compared to the pitch antenna these values were modified.

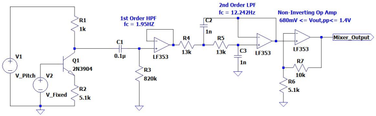


(a) Schematic (b) Circuit

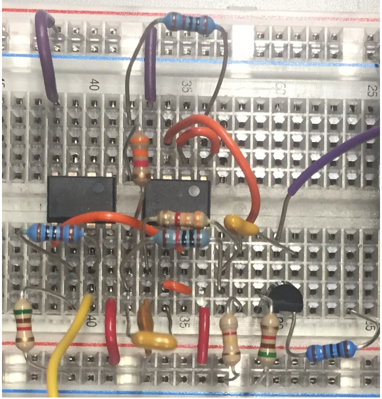
Figure: Volume Oscillator

4. Mixer

- Assuming the pitch antenna gives the expected sinusoidal form of input, the mixer is tested with a function generator (square wave) and a generated sine wave from the oscilloscope as inputs. The mixing of square wave at around 159 kHz and sine wave of around 160.2 kHz gave the difference signal at the frequency of around 1.2 to 1.3 kHz range, as expected. The difference in frequency is often called "beat frequency."



(a) Schematic



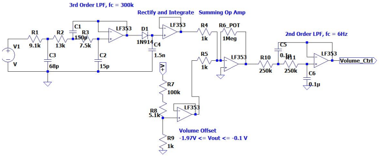
(b) Circuit

Figure: Mixer

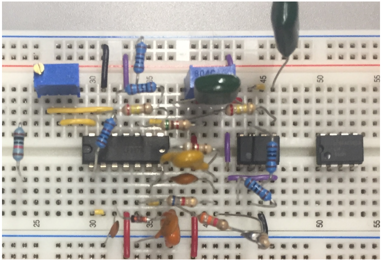
4. Mixer

5. Frequency to DC Conversion

- This frequency to DC conversion stage is intended to control the level of volume attenuation through JFET in the attenuator circuit. This is achieved in two stages: passing the variable frequency signal through LPF to attenuate the signal, and then passing through a peak detector circuit, which produces a corresponding DC voltage from its attenuated magnitude, finally resulting in a variable DC voltage from a variable frequency signal.



(a) Schematic



(b) Circuit

Figure: Freq to DC Conversion

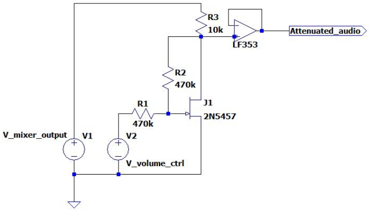
5. Frequency to DC Conversion

6. Volume Attenuator

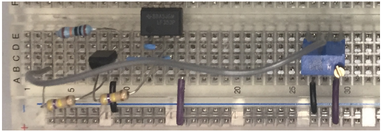
- The volume attenuator was designed to take in the DC voltage value from the previous stage as the control for the JFET and the output of the mixer to produce a signal with lower voltage. Simply put, the n-channel JFET performs as a resistor, whose resistance value is varied by the control DC voltage from previous stage. The output audio signal is the result of voltage division as follows:

$$V_{audio} = \frac{R_{JFET}}{R_{JFET} + R_3} V_{mixer.output}$$

This exploits the property of JFET:
$V_{control}$ = 0 V: smallest resistance at drain, most attenuation
$V_{control}$ = <0 V: larger resistance at drain, less attenuation



(a) Schematic



(b) Circuit

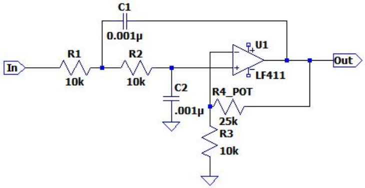
Figure: Volume Attenuator

6. Volume Attenuator

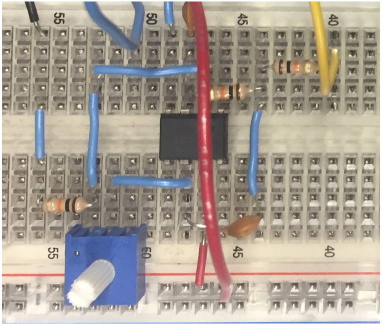
7. Audio Amplifier

- A simple amplifier with LF411 performed well enough for the purpose of increasing mV to V range for audibility. This second order, non-inverting low pass filter is intended to give gain greater than 1, and its high enough input impedance to act as an ideal op amp.

$$Gain = 1 + \frac{R4_{POT}}{R3} > 0$$



(a) Schematic



(b) Circuit

Figure: Volume Attenuator

Resonant Frequency Matching

- In testing variable pitch oscillator functionality with the antenna, the resonant frequency was experimentally chosen to be 253 kHz, with L = 3.3 mH, C = 120 pF, which at some point the pitch antenna was able to produce. The purpose of matching the frequency from the antenna at resonance is to mitigate producing of sound when there is no change in capacitance from the antenna. For volume oscillator, $f_{resonant} =$ 459 kHz, with L = 1 mH, C = 120 pF. (values based on references).

For pitch:

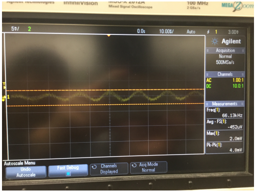
- Hand closer: capacitance increases, frequency decreases, causing beat frequency

For volume:

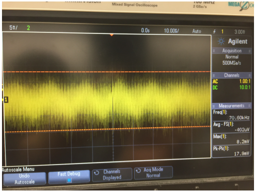
- Hand closer: capacitance increases, frequency decreases, out of resonance, decreases voltage across inductor in LC tank, lowers volume control DC voltage, attenuates the amplitude.

Closer Look at Oscillators with Antenna

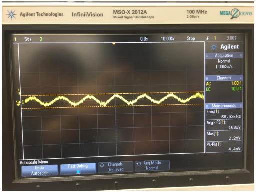
Although unsuccessful at tuning the frequency of the antenna, we were able to point out that the amplitude of signal from the antenna was too low to work with (around 2 mV).



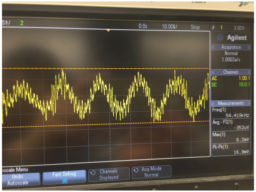
(a) Pitch - Hand at far distance



(b) Pitch - Hand at near distance



(c) Pitch - Hand at far distance (Single Capture)



(d) Pitch - Hand at near distance (Single Capture)

Closer Look at Oscillators with Antenna

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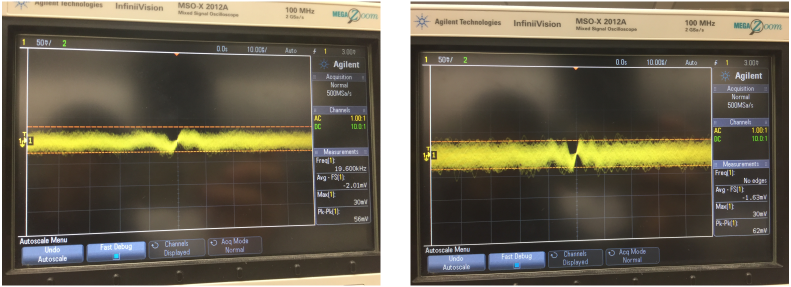

(a) Volume - Hand at far distance

(b) Volume - Hand at near distance

Figure: Volume Oscillator

Overall Results

- Experimentally configuring antenna to produce a sinusoidal input at the oscillators was tough, provided that antennas behaved poorly under certain circumstances
- Working with analog signals with other interfering parameters (noise, nonlinearity, etc.) were somewhat hard to overcome

Challenges

- Working with antenna (with unknown specifications)
- Integration of modular circuits
- Integration of DC and AC components

Future Work

- Obtain a better functioning antenna that gives constant input signal
- Attempts at different designs of pitch/volume oscillators for improved sinusoidal wave to mixer input

Questions?