THEREMIN

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In this project, we attempted to construct a theremin as designed by Arthur Harrison [1]. A theremin is a musical instrument that has two antennas, one to control the pitch and one to control the volume. The pitch and volume vary with the distance of the player's hand from the antenna. While both the pitch and volume circuits for our theremin are operational, they both suffer from a restricted range of usable hand distances.

I. INTRODUCTION

In 1919, the theremin was invented by a Russian physicist named Lev Termen, who later changed his name to Leon Theremin. The theremin is an instrument that is played without being touched. It has two parameters: pitch and volume, both of which are controlled by separate antennas. As a hand approaches one antenna, the pitch of the instrument becomes higher. As a hand approaches the other antenna, the volume of the instrument increases.

Although there are many theremin designs, one is the 144 Theremin by Arthur Harrison. His design consists of three major sections: a pitch circuit (FIG 1), a volume circuit (FIG 2), and a mixer/output amplifier (FIG 3).

A. Pitch Reference and Variable Oscillators

The theremin uses the heterodyne principle to generate its pitch. That is, it mixes two very similar frequencies to produce beats, which make up a third frequency, the pitch. Shown in FIG 1, the pitch processor is made of a fixed reference oscillator and a variable oscillator.

The reference oscillator, which is made of Q9 and associated parts, is claimed to have a resonant frequency in the range of 287kHz to 297kHz, depending on the value of the variable capacitor C22 [1]. In the variable oscillator, consisting of Q10 and associated parts, the interaction of the player's hand and the antenna creates a capacitance. This capacitance, which varies with the distance of the hand from the antenna, changes the frequency of the variable oscillator; thus varying the beat frequency produced. The beat frequencies are produced and passed on to the mixer/amplifier circuit at point B. Practically, the changes in capacitance provided by the hand is only a few picofarads.

B. Volume Oscillator

Like the pitch circuit, the volume circuit, shown in FIG 2, contains a fixed reference oscillator (Q1 and associated parts). When the output frequency of this oscillator is the same as the frequency of the LC circuit (L2 and C7), the combined signal has its maximum amplitude. The volume antenna creates capacitance that changes the frequency of the LC circuit, producing output signals with various amplitudes. The reference volume oscillator is claimed to have a frequency in the range of 467kHz to 508kHz, depending on the capacitance of C2 [1].

This output waveform, which appears at the source of Q2, undergoes DC restoration by diode CR1. The output from Q3 (at point A in FIG 2), which is smoothed by C8, looks like a DC signal, whose level changes with the capacitance of the hand-antenna interaction.

C. Mixer

The mixer/amplifier circuit, shown in FIG 3, combines information from the pitch and volume circuits. The pitch information, coming into the circuit at point B, and the volume information, coming into the circuit at point A, are mixed and the combined waveform is produced at the drain of Q5. The combined waveform undergoes amplification via Q6. The output stage consisting of Q7 and Q8 give the listener a signal via a phone jack.

II. CIRCUIT ASSEMBLY

Assembly was completed via a perforated board and wire wrap connections (shown in FIG 4). As placement of components is critical to the theremin due to unwanted interactions between components, the suggested circuit layout was followed. The antennas were cut from aluminum to be about 6" by 8". Although 1/16" thick aluminum was recom-

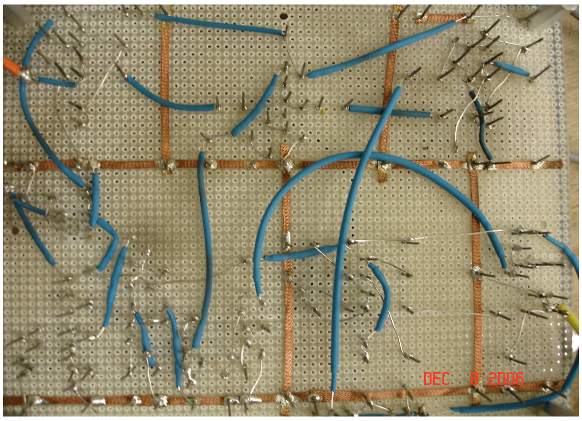

FIG. 1: *Wire wrap connections on bottom of the circuit board.*

mended, about 1/32" thick aluminum was used. An aluminum plate was also mounted below, without making contact with the components of the circuit board (spacers were used). The board and antennas were mounted on a block of wood and are pictured in FIG 5.

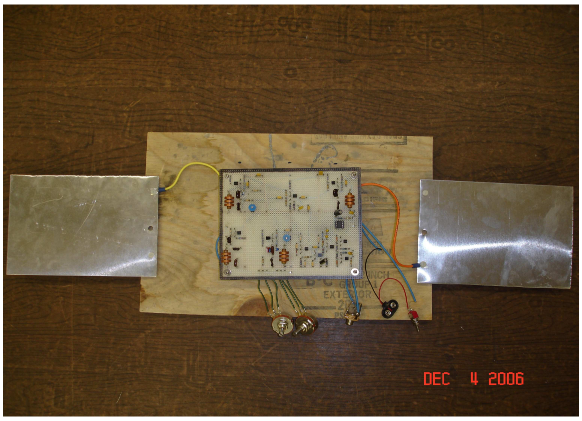

FIG. 2: *The theremin mounted on a wood base with the antennas.*

III. DEBUGGING

A. Pitch Circuit

The main challenge in getting the pitch circuit to work was matching the resonant frequencies of the reference and variable oscillators to produce a reasonable beat frequency. Theoretically, the variable capacitor (C23 in FIG 1) provides enough range to match the resonant frequencies of the reference and variable oscillators. However, this was not the case and as can been seen in FIG 6, 90pF of capacitance was added in parallel with C23 to get a suitable beat frequency.

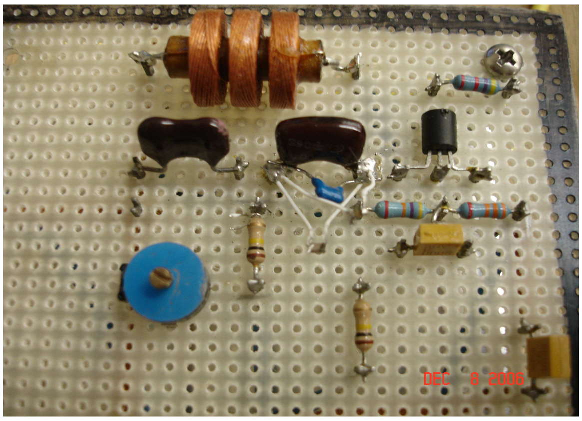

FIG. 3: *Photograph of C23 with the necessary 90pF of capacitance added in parallel.*

FIG. 4: *Photograph of an oscilloscope probe that significantly changed the frequency of the reference pitch oscillator when connected to the theremin.*

The tolerances of the capacitors used made finding the correct amount of capacitance especially difficult. Capacitance was added little by little (10pF, 5pF, and 1pF increments) to arrive at 90pF. The sensitive nature of the circuit also made debugging difficult. Because capacitances in the range of pF were used, outside influences such as oscilloscope probes had an effect on the resonant frequencies of the oscillators. Although care was taken to route probe leads away from the theremin, the very connections of the probes to the circuit board changed resonant frequencies. For example, it was determined that the connection of the probe shown in FIG 7 to the theremin changed the resonant frequency of the reference oscillator by an amount that was equivalent to adding 20pF in parallel with C23. To deal with problems such as these, the pitch circuit's final tuning was performed blind. The output of the theremin was connected to a speaker, capacitance was added in parallel with C23, and the output was tuned by ear.

B. Volume Circuit

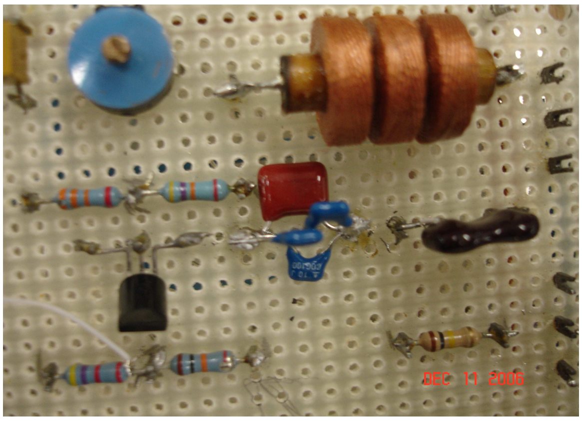

FIG. 5: *Photograph of C7 with the necessary 30pF of capacitance added in parallel.*

Like the pitch circuit, the main challenge in getting the volume circuit to work was matching the resonant frequencies of the reference oscillator and the LC oscillator, connected to the antenna. For this purpose, it was necessary to add 30pF of capacitance in parallel with C3 (FIG 2) in the reference oscillator. Because of the theremin's extreme sensitivity, the volume circuit's final tuning was performed with the aid of the oscilloscope, but without the probes connected directly to the board. Wires were soldered onto the desired points of the board and the oscilloscope probes were connected to these wires to eliminate unwanted interaction between the probes and the board. Care was taken to ensure that the probes used to perform this tuning did not perturb the board (like the one referred to in FIG 7)

IV. MEASUREMENTS

A. Pitch Circuit

The resonant frequency of the reference pitch oscillator and variable pitch oscillator were both measured via an oscilloscope to be 285kHz. This value is close to the specified range of 287kHz to 297kHz.

Measurements of the output frequency and amplitude versus distance of the hand from the pitch antenna were made and are plotted in FIG 9. The measurements were taken from point B in FIG 1 and made with an oscilloscope. Distance of the hand from the pitch antenna were measured with a tape measure.

According to its specifications, the pitch circuit's output should be 440Hz and about 800mV at a hand distance of 5 inches. When operating optimally, it should also have an operating range of about 4 octaves over a hand distance of 2 feet. According to the plots in FIG 9, the theremin has a frequency response of 600Hz and about 400mV at a hand distance of 5 inches. While the measured operating range of the theremin is about 4 octaves as specified, this occurs over a severely small range of hand distances, measured to be 4 inches.

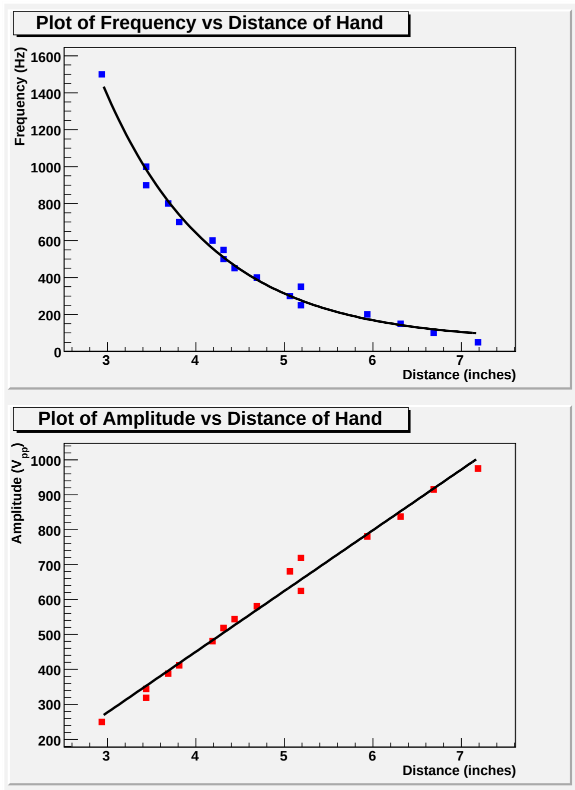

FIG. 6: *Plot of frequency vs hand distance (top) and amplitude vs hand distance (bottom). Graphs have approximate fit lines to guide the eye.*

B. Volume Circuit

While no specifications were given for the optimal operation of the volume circuit, the output was measured as a function of hand distance from the volume antenna. Measurements were made of the DC voltage at point A in FIG 2 with a multimeter. The data is plotted in FIG 10. The theremin outputs an audible sound when the voltage at point A exceeds 3.35V at a hand distance of 2.5 inches.

While the output of the volume circuit seems to have reasonable range and sensitivity as shown in FIG 10, when listening to the theremin, the volume does not vary much with hand distance. When the hand is far from the volume antenna, the theremin gives no audible output (off) and when the hand is close to the volume antenna, the theremin gives an output (on). Changes in volume are audible over only a very small range of hand distances around the on/off point.

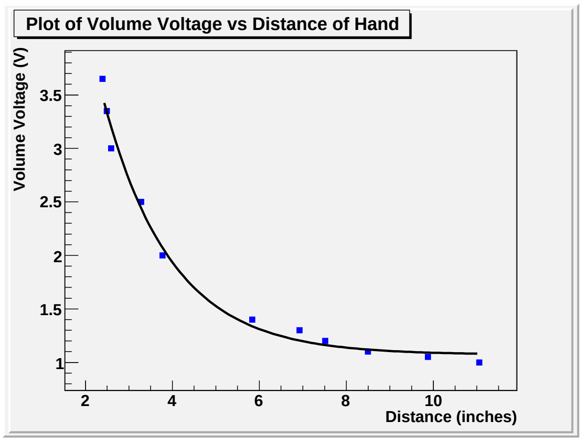

FIG. 7: *Plot of DC voltage vs hand distance with an approximate fit line to guide the eye.*

V. SUMMARY AND CONCLUSIONS

The theremin is a musical instrument whose pitch and volume are each controlled by separate antennas. Interactions between the players hands and antennas create variable capacitances, which control the pitch and volume.

The theremin as built for this project has a severely restricted range of usable hand distances for the pitch circuit. A different antenna design may help to expand this range. Often times polished commercial theremins use antennas that look similar to TV and FM radio antennas (that is, long thin rods rather than flat metal sheets).

Although the volume circuit gives a reasonably good response as a function of hand distances, when listening to the theremin, there is little audible variation in loudness other than on/off. An explanation of this could be that the linear region of JFET Q5 is very small compared to the overall range of the volume circuit's output (point A in FIG 2). Thus, for only a small range of hand distances can there be an apparent change in volume. After this brief range, Q5 goes into saturation, where it can effect little change in volume. Perhaps it should be noted that some of the later theremin versions designed by Arthur Harrison do not have a volume antenna.

The sensitivity of the circuit to the external environment and the components that were used was a large obstacle. Using a printed circuit board for the circuit would probably reduce this sensitivity and give more freedom for the placement of components. Also, providing proper test leads off of the theremin for elements such as the reference and variable pitch oscillators would prove very useful.

VI. REFERENCES

[1] Harrison, Arthur. *Art's Theremin Page. http://home.att.net/ theremin1/.*