A Simple Theremin Project

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What is a Theremin?

The theremin is an electronic musical instrument without any moving parts. It is played by moving one's hands near antennas, of which there are usually two: one to control the pitch, and another to control the volume. The theremin player's hands are capacitively coupled to the device, so the theremin does not even have to be touched to be played.

Lev Termen, a Russian physicist, invented and built the first theremin in 1919. He came to the United States in the 1920's to promote his new invention, and while in the country he changed his name to the apparently less ethnic name Leon Theremin, hence the name of his invention. On an interesting side note, Leon Theremin was taken back to the U.S.S.R. by force in 1938. After a stay in a prison camp, Theremin worked for the KGB making electronic "bugs" for spying purposes, as well of a host of other radio frequency devices. He eventually was able to return to the U.S.

The theremin produces an eerie tone that changes pitch with the movement of the player's hand. The hallmark of the theremin sound is the glissando effect that occurs as the tone is changed. Many classic sci-fi movies from the mid-50's, like *The Day the Earth Stood Still*, used theremins to create creepy "space noises". The theremin has also been used by many famous rock bands. Jimmy Page played a pitch-only theremin in the Led Zeppelin sound *A Whole Lotta Love*. A common misconception (that I only recently discovered for myself) is that a theremin was used in the Beach Boys song *Good Vibrations*. Apparently, a device called a Tannerin was used instead; the Tannerin was designed to sound like a theremin, but it is actually a mechanical controller for a frequency generator, so it is played and works totally differently. A list of bands that use theremins, as well as links to articles and theremin schematics, can be found at the interesting website: *http://www.thereminworld.com*.

How does a Theremin work?

A theremin operates by using dual oscillator circuits in the radio frequency domain. The oscillators signals are combined in a mixer to produce an average frequency, modulated by a beat frequency. The following simple trigonometric relation shows the principle involved. Consider two oscillators at nearly the same frequency ω, with one frequency being slightly different by an amount $\delta\omega$. The sum of these two signals becomes:

$$\cos(\omega + \delta\omega) + \cos(\omega) = 2\cos\left(\frac{\delta\omega}{2}\right)\cos\left(\omega + \frac{\delta\omega}{2}\right).$$

The first cosine term on the right hand side is the beat frequency modulation. In a thermin, this beat

frequency is in the audible range (20 Hz to 20 KHz). The radio frequency average of the two signals is rolled off in a low-pass filter, leaving only the beat frequency to be sent to an amplifier for our listening pleasure. A similar circuit is also often used to control the volume of the theremin's output.

The two oscillator circuits are designed to run at approximately the same frequency, with some means of tuning the circuits. On of the oscillators is attached to an antenna, with is usually a long metal wire or a metal plate. This antenna forms on half of a capacitor, with the player's hands acting as the other half. The motion of the player's hands corresponds to a few picofarads change in capacitance, typically. This change in capacitance alters the oscillator's frequency output, creating the $\delta\omega$ shown in the above equation. Note that the player is sufficiently coupled to the instrument via the earth ground so that this control works. Also note that by having the oscillators run at high frequencies, small changes in their relative frequencies correspond to beat frequencies that cover the whole audio range, in principle.

My Theremin design.

I had originally intended to create a tube theremin, but it proved exceedingly difficult to find the old-style variable inductor coils used in the schematics I was able to find. Realizing that I would miss several labs when I went to visit potential graduate schools, I decided to find a simple design for a theremin that I could conceivably build in the time I had. I eventually found a design for a pitch-control only theremin that used simple CMOS inverters and ran on a 9-volt battery (Arthur Harrison's Minimum Theremin design). This design did not have the fidelity or stability of more complicated designs, but it had the advantage of being feasible.

The theremin uses standard CMOS inverter oscillator circuits (I was able to find similar designs in *The Art of Electronics*), as well as using the CMOS inverters to act as buffers, amplifiers, and a mixer, eliminating the need for lots of transistors or op-amps. The design used two IC's, each with six inverters (hex inverters). Two IC's were used so that the oscillator circuits could be physically separated on the circuit board, to reduce coupling between them. These oscillators run at a rather atypical 73 KHz (much lower than most of the other theremin designs I looked at). Consequently, my theremin does not have a large variation in pitch, but it is still able to cover about three octaves, from 200 Hz to 1600 Hz. There is a trimmer pot (RV1) on the first oscillator to calibrate the it so that both oscillators can be tuned to the same frequency when the player's hand is far from the plate. There is also a second potentiometer to adjust frequencies when the theremin is placed in its housing. For my antenna, I simply used a piece of scrap aluminum that I found in the lab, attached to a long wire. Sections C1 and C2 of the hex interverters are used to buffer the oscillators from the rest of the circuit. The two signals are combined in section F of the hex inverter, and the combined signal is then fed through the low-pass filter made by R6 and C5, which has a roll-off frequency of $\sim$4.5 KHz. Finally, there is a small amplification stage which boosts the signal enough that the theremin can drive headphones.

My theremin has an interestingly noisy sound: a pleasant, mild distortion that sounds much better than

the dull, pure tone I was expecting. There is a range of about eighteen inches of hand placement above the antenna where the theremin works, and as the hand gets closer to the plate, it becomes more sensitive to hand displacements. It is also remarkably sensitive to changes in the electric field around it. Waving your hand around the circuit board with change the frequency somewhat. It's even more fun to touch various parts of the circuit itself; this will cause all sorts of interesting noises, some even have a vibrato-like effect. While I do not think my theremin could be used for professional music, it does have great potential for generating novel tones.

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