

# Theremin

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Section 6

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## **Introduction**

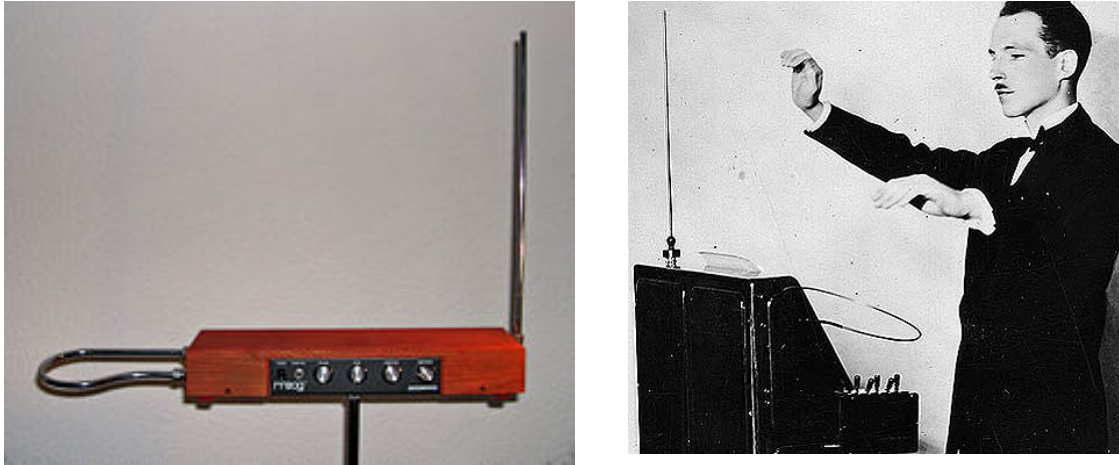
The theremin, invented in 1919 in the Soviet Union, is considered one of the first fully developed electronic musical instruments. It was named after its creator, the physicist Lev Sergeyevich Termen, or Leon Theremin. (History Lesson) This instrument gets its recognition from the uniqueness and originality behind it. The original basic structure consists of a wooden box fitted with two radio-frequency oscillators and two metal antennas, a vertical rod on the instrument's right and a horizontal ring on its left. The vertical antenna controls the pitch and the horizontal controls the volume. It's unique because of the ability to play this instrument without any physical contact. Just by waving a hand in front of each antenna, a player can produce many different sounds and tones. The theremin has been incorporated in music anywhere from the early orchestra to popular music of today. (Columbia Electronic Encyclopedia)

## **History**

Theremin's invention began the emergence of electronic music. In 1915 Lee De Forest invented the oscillator, which revolutionized the radio industry. In turn Theremin used this new technology to revolutionize the music industry. He travelled all through Russia demonstrating his device on the invite of Lenin. In 1926 he arrived in Europe where audiences especially in Germany, France, and England praised him. Critics claimed his instrument as a transformation of the world of music. (Glettler) This excitement and his sensational performances commenced Theremin's international recognition. In 1927, he made his way to the US. To promote his instrument he trained many musicians in his New York studio to be able to play the theremin in order to bring

it into the public eye. His best student Clara Rockmore has been considered the best thereminist ever with unparalleled precision by developing her own aerial fingering techniques. Theremin ended up selling his patent rights to the Radio Corporation of America. From 1927 to 1931 they manufactured and sold 500 instruments. He abruptly left in 1938 under the Soviets demand. While in solitude he worked in a special lab under the Internal Affairs department of the Soviet Union. After his release he was given the Stalin Prize in 1947. Many compared this prize to the Nobel Prize of the USSR. He received his award for his espionage devices that could eadrop on US embassies. (Glinsky) “Some of the bugging devices were so advanced that the U.S. did not discuss them until 1960, over ten years since their discovery.” (Mattis) He did not return to the United States until 1991. Two years later he died right after an American documentary premiered about his life, “Theremin, An Electronic Odyssey” (TVOX) His musical device had left his legacy and imprint across the globe.

This musical instruments commercial downfall was due to its best feature, complete freedom. Many compared it to “singing with someone else’s voice” and could not master it. However others took note of this and attempted many of their musical aspirations. Its unique eerie and haunting sounds are difficult to replicate. This device has been involved across the board in the entertainment industry from its background music in “The Bride of Frankenstein” to its use in Led Zeppelin’s songs.



*Figure 1. Modern Day Theremin vs. Original theremin*

## **Components of the Theremin**

### *LC Circuit Tank*

The simplest form of sound is just a wave produced by something oscillating. This motion can be described as a function of sine. How fast an object takes to complete one full cycle of oscillation, from its starting point and back again, with respect to time is its frequency. This movement, or vibration, is characterized as simple harmonic motion. (SHM) In nonelectric musical instruments there are objects that perform SHM. For example, the strings on a piano or the air inside a flute are the vibrating objects. (Berg) Well in electrical instruments, an electric oscillator replaces these objects. This is a device that generates electric currents or voltages in this motion by nonmechanical means.

An LC circuit tank acts as the electric oscillator in a theremin. This type of circuit consists of an inductor (L) and a capacitor (C). An inductor is an electric component, usually a coil, that when current passes through it produces a magnetic field. And a

conductor is a device used to store an electric charge. At certain frequencies the combination of the two produces a “resonant” circuit that outputs a resonant frequency. (Zhu) This is when the inductance and capacitance reactances are equal and cancel. This only leaves the resistance of the circuit to oppose the flow of current. (Skeldon)

The LC circuit tank can be described using figure 1 below. The capacitor stores its energy as static voltage and the inductor stores its energy in the form of an electromagnetic field. The capacitor is charged up by a voltage supply by moving the switch to A. Once fully charged the circuit switches back to B where the capacitor begins to discharge causing all the energy to be stored as the electromagnetic field. As soon as there is no more voltage to maintain a current, the magnetic field begins to collapse. This induces an emf keeping the current flowing back to the original direction. This process theoretically continues back and forth producing a sinusoidal voltage. (Glettler) This action mimics the physical motion of oscillation.

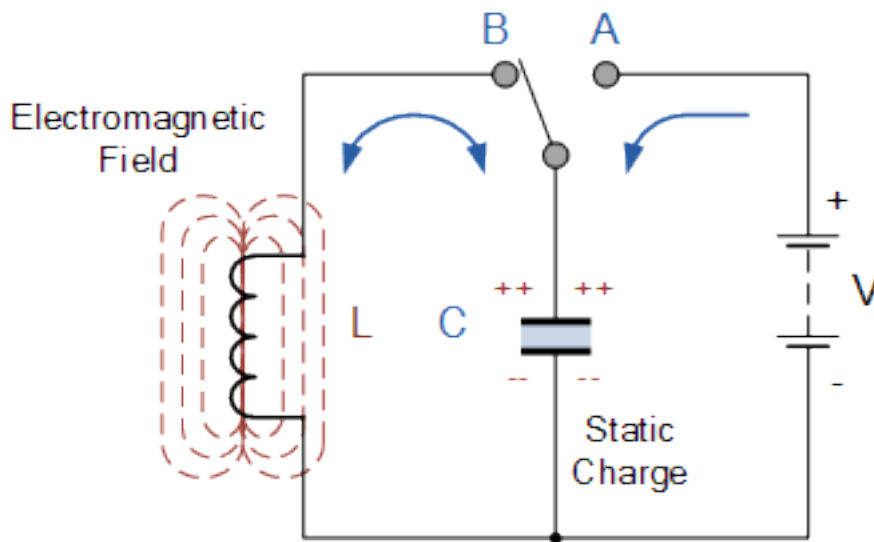


Figure 2. Representation of the LC Circuit (Storr)

## *Vacuum Tubes*

LC tank circuits need to be “recharged” sometimes. This is because resistance exists in the inductor, capacitor, and the wires. In the original design of the theremin, vacuum tubes were used to keep the LC tank circuit oscillating. Versions of this invention were matured and patented by Lee De Forest in 1907. The tube is said to have started the revolution of electronics. (History Lesson) A vacuum tube is basically a heated cathode, plate, and a grid. Electric potential is applied to both the cathode and plate. When the plate is more positive, electrons jump from the cathode to the plate. This acceleration of the electrons form an electric current. However this current can only go one direction. The effect of the grid allows the tube to operate both as a current switch and a voltage controlled current amplifier. (Simonton) The vacuum tube, or valve, is replaced today by transistors.

## *Capacitance*

The resonant frequency of an LC oscillator can be mathematically expressed by the equation  $f_r = \frac{1}{2\pi\sqrt{LC}}$ . (Glettler) In order to change the frequency of an LC oscillator, then one of its variables needs to change. Among the capacitance or the inductance, capacitance is the easiest to change. As we learned earlier in the semester the capacitance depends on both the distance between the conductors and the area of their surface. The human body and the antenna are the conductors in the theremin’s case. The movement of the theremin player’s hand near the antenna changes the capacitance therefore it stands to reason it changes the resonant frequency also. However this change does not make a very significant effect. The change of capacitance can result in as little as a few picofarads.

With that said for a device to be feasible, the oscillator frequency must be arranged to operate upwards of 500kHz. At this higher frequency even just a 1% change in the capacitance can change the resonant frequency by around 5kHz. (Skeldon) This could be a very significant change in the musical scale.

### *Beat Frequency Oscillators and Heterodyning*

In most of the unelaborate versions of the theremins at least one or more beat frequency oscillators (BFO) are used. A beat frequency oscillator is used to produce a variable frequency produced by two different radio frequency oscillators that are generating their own resonant frequencies. The LC tank circuits are used as the RF oscillators. This type of method is helpful with harmonic operation because of its stability and its ability to reduce undesired interference (Fritz). A BFO has mainly two different radio frequency oscillators where one is a fixed frequency and the other one has a variable frequency (Hageman). The outputs of the two different oscillators may be expressed mathematically as  $A_1 \sin \omega_1 t$  and  $A_2 \sin \omega_2 t$ . This beat frequency oscillator action is a type of heterodyne mixture, just a mixture of local frequencies converted to a fixed intermediate frequency. This fixed frequency can be considered the output voltage  $V_{out}$  given by the equation  $V_{out} = A_1 A_2 \sin \omega_1 t \sin \omega_2 t$ . (Skeldon) By using a low pass filter, a filter that passes frequencies below a certain value and attenuates frequencies above that value, helps reduce the equation to  $V_{out} = \frac{A_1 A_2}{2} \cos (\omega_1 - \omega_2) t$  by only leaving the Fourier component. (Skeldon) This whole process can be easily visualized by figure 3.

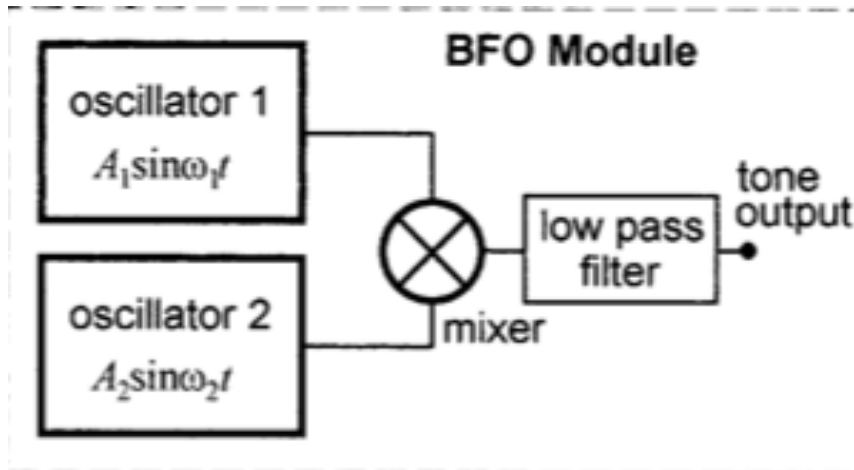


Figure 3. Module of the Beat Frequency Oscillator System (Skeldon 946)

### Original Analog Theremin Design

Now that we understand the main components of the theremin we can look at the whole design of the original schematic of the U.S. patent in 1928. In figure 4 is the edited schematic for Leon Theremin's original design. It illustrates the complete system for producing the musical sounds and tones and in the actual patent it describes each characteristic thereof. (Theremin US)

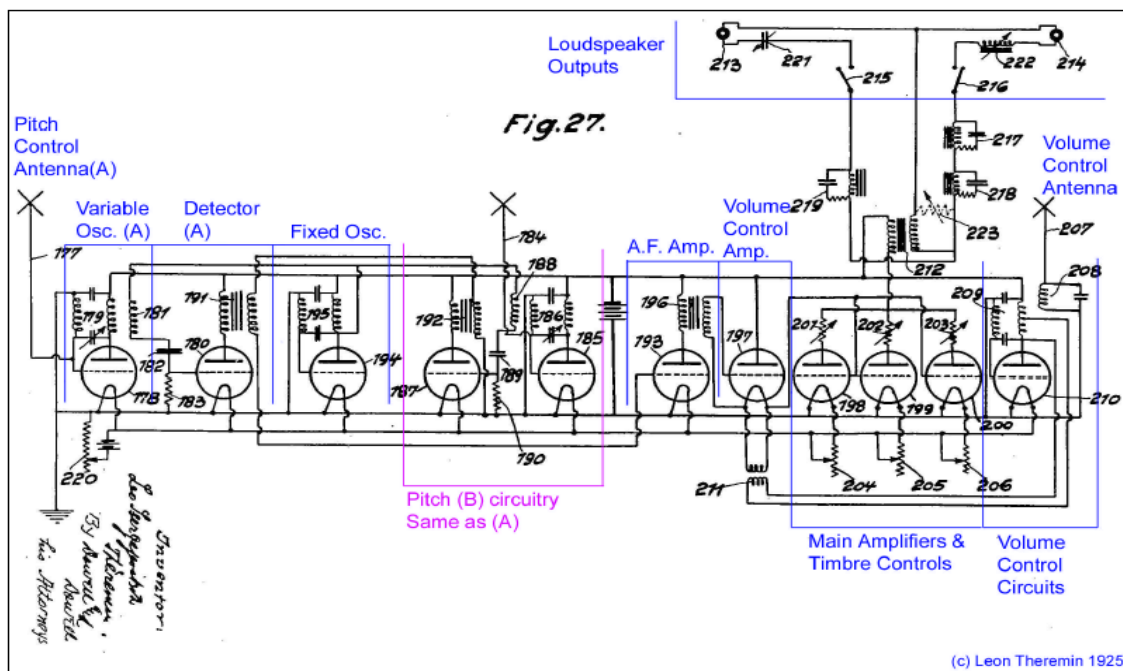
On the left side of the figure is the pitch control circuits section. There are 2 LC tank oscillators on this side. Earlier we discussed how usually in a beat frequency oscillator there are two resonant frequency oscillators, where one has a fixed frequency and the other has a variable frequency. The LC tank oscillator closest to the antenna is the variable oscillator. The frequency of this oscillator depends on the player's hand. Two sections over is where the fixed LC oscillator is where the frequency is the same. These two signals are mixed, which is the previously described process of heterodyning. The heterodyning signal is then picked up by the detector located in between the two oscillators. There is also another identical pitch control section in the middle of the



figure. These two pitch control detectors send the frequency output to the first stage amplifier. (Glettler 9)

On the right side of the figure is where the volume circuits section is located. This is the same beat frequency oscillator design as the right. It goes through the heterodyning mixing process from the LC oscillator pairs and produces a resonant frequency, however the amplitude produced is more important. The amplitude varies in response to the small changes in the antenna capacitance. (Skeldon 950) Theremin describes this LC tank circuit as an “absorption” system rather than another oscillator. (Theremin) The farther away the hand is to the volume control antenna then the lower the amplitude of the output signal. This signal controls the second stage amplifier which is the volume control amplifier. The rest of the design show the loudspeakers and the main amplifiers. (Glettler 10) A simpler model to describe this whole design can be seen in figure 5.

Figure 4. Original Patent Design (Theremin)



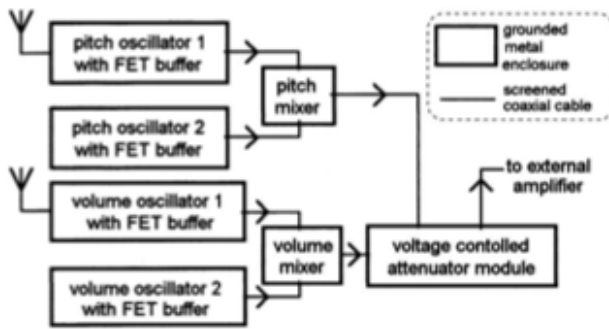


Figure 5. Model of Theremin design

## Conclusion

The design described in this paper is just the analog version of the theremin. Unfortunately trying to replicate the original theremin can be very difficult and expensive. Many of the original components aren't used in everyday life now so that is where the project becomes a little pricey. With today's modern day technology, many different modified versions of the theremin do exist though. The range of size and complexity is very broad from anywhere to digital designs to optical designs.

Instead beat frequency oscillators digital designs use CMOS oscillators. These produce different DC levels. One varies with the distance between the pitch antenna and the hand and the other with volume antenna. The advantages behind this design are that the DC levels are able to control a filter involving voltages. This makes the sound much higher quality (Skeldon).

Optical designs are different because it creates the audio frequency directly instead of operating a circuit to do so. However to do this it is useless to change the capacitance. The resistance has to change by using photocells. These are light dependent resistors. This theremin depends on the amount of light from the photocells rather than the distance from the antennas.

As simple of an instrument the theremin was, it started a revolution not only in the world of music, but in the world of science also. From the early 1920's when it made its way across nightclubs and orchestras to the horror and sci fi movies in the 1960's. This instrument was a cornerstone for many things. Theremin's technology behind his invention opened many doors for other scientists as well.

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