THE THEREMIN

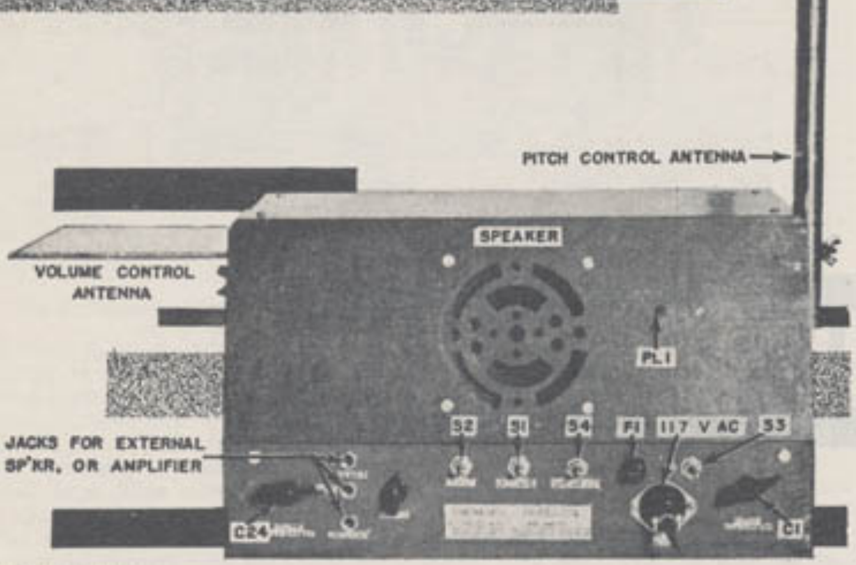


Fig. 1. Over-all view of the home-built Theremin. The cabinet is made of ½-inch plywood. The speaker panel is constructed of ¼-inch Masonite. The antennas are mounted with through bolts and wing nuts.

By popular request—another Theremin article. This new design incorporates many refinements that provide greater operational stability—it is easy to build.

SHORTLY after vacuum-tube radios were first put into production, experimenters began to look for other uses for vacuum-tube circuits. One of the early developments was a unique musical instrument, played by the free movement of the performer's hands in the space surrounding the instrument. This device, named the "Theremin" after its inventor, Leon Theramine, attracted widespread attention. Today, Theremin music is still quite popular, despite the fact that no new instruments have been built commercially for about twenty-five years.

Musically, the Theremin is capable of a great deal of individualism and expression. The pitch is controlled by varying the distance between one hand and a control rod. Volume is similarly controlled with the other hand. There are no keys or "notes" on the Theremin. The position of the performer's hands is the only factor that determines the pitch and volume of the sound.

As an electronic instrument using up-to-date circuits and tubes, a Theremin may be constructed at a very nominal cost, and give completely satisfactory performance. In the instrument about to be described, the tone is produced by two radio-frequency oscillators beating at an audible frequency. The addition of hand capacity to the pitch control antenna lowers the frequency of one of the r.f. oscillators, and the pitch of the beat frequency is correspondingly changed. The outputs of the two r.f. oscillators (V_1 and V_2 in Fig. 3) are mixed, and the r.f. components of the resultant signal removed by means of a diode detector.

In the volume control circuit, the addition of hand capacity to the volume control antenna causes a change in the frequency of a third oscillator, V_3. The output of this oscillator is fed through a series of tuned circuits, T_4 and T_5, and then rectified. The rectified voltage is used as grid bias to control the gain of a variable mu amplifier tube. A change in the oscillator frequency will vary the grid bias and, therefore, the output of the amplifier. The output of this amplifier is fed directly into the power amplifier and from there into a loudspeaker.

The variable pitch oscillator uses the triode section of V_1 and its frequency is determined by two tuned circuits, L_1-C_1, and L_2-C_4. L_1 is a variable coil of high inductance, and has only its distributed capacity and a small variable condenser C_1 across it. Therefore, the resonant frequency of this tuned circuit will be appreciably lowered by a slight addition of hand capacity. On the other hand, L_2 has much less inductance and is tuned to resonance by a large fixed condenser C_4. The two coils are coupled so that the tube oscillates at the average of their resonant frequencies. This pitch control oscillator is extremely sensitive to changes in hand capacity, but because of the low impedance of L_2-C_4, changes in input capacitance of the tube have no effect on it. Naturally, this stability is an extremely desirable feature in an electronic musical instrument.

The pentode part of V_1 acts as a buffer amplifier to further isolate the oscillator from extraneous disturbances. The output frequency is about two hundred kilocycles.

Except for the absence of an antenna coil, the operation of the fixed oscillator V_2 is identical with that of the variable oscillator. The outputs of the two oscillators are fed through isolating condensers into three r.f. transformers, which pass or reject harmonics produced by the oscillators. These high frequency harmonics produce corresponding overtones in the beat note and, by controlling these harmonics, distinctive qualities of tone may be produced by the instrument.

The volume control oscillator is identical to the pitch control oscillator, except for the tuned circuit values. The output is passed through two conventional i.f. transformers, T_4 and T_5, and then rectified by the crystal diode, *Rect.*$_1$. When the transformers are tuned to the same frequency as the oscillator, a maximum voltage difference of about eighty volts exists across R_{13}. The oscillator frequency is then raised to a point where the voltage across R_{13} is about one half maximum, or forty volts. This provides operation on that portion of the sensitivity curve that results in the greatest change in voltage across R_{13} for a given slight variation in the oscillator frequency. To take advantage of this maximum sensitivity, the positive end of R_{13} is placed at a point on the voltage divider R_{10}-R_{11} which is about forty volts above ground. Therefore, the negative end of R_{13} is at zero volts in relation to ground. With a slight addition of hand capacity to the volume control antenna, the junction of R_{14} and R_{13} will become negative in relation to ground. This negative voltage is used as grid bias to control the gain of the pentode section of V_3. The amplifier will be completely cut off when the grid bias exceeds minus ten volts. R_{14} and C_{11} make up a time constant which eliminates clicks and pops resulting from sudden hand movements. The diode connected across C_{11} prevents the grid bias from accidentally going positive. The sensitivity of this volume control is such that the amplifier is completely cut off when the hand is a few inches from the antenna, and full volume is obtained with the hand about eighteen inches from the antenna. R_9 is used to set maximum volume.

The power supply uses a gas-type voltage regulator to supply the oscillators and the control amplifier, thereby adding to the over-all stability of the instrument.

As a musical instrument, the Theremin should be as compact and portable as possible. However, a distance of at least eighteen inches should separate the two antennas. The unit pictured is built on a 17 x 7 x 3 inch chassis and the antennas are mounted on the wooden housing, one on each end (see Fig. 1). The pitch control antenna is made of a sixteen-inch length of one-inch brass pipe, and the volume control antenna is made of a 5 x 7 inch sheet of sheet brass. C_1 and C_{24} are used to "tune up" the instrument and should be placed on a convenient part of the panel. The unit must be adequately ventilated to prevent an extreme temperature rise that might otherwise result in frequency drift. It is recommended that R_{21} and R_{22} be mounted above the chassis, to prevent heating of the oscillator components. T_2, T_3, T_4, and T_5 are all conventional broadcast i.f. transformers and may be either of the shielded or unshielded type. If unshielded transformers are used, they should be mounted under the chassis and holes drilled for adjusting the trimmer condensers (see Figs. 4 and 5). Placement of parts is not critical, since the oscillators work at low frequencies, and all circuits are of fairly low impedance. The oscillator coils should be carefully constructed however, since these are the "heart" of the instrument. In constructing the pitch control coil assembly (L_1, L_2, L_3) a ring with an outside diameter of 1½ inches and inside diameter of 13/16 inch is cut from ¾ inch wood. On

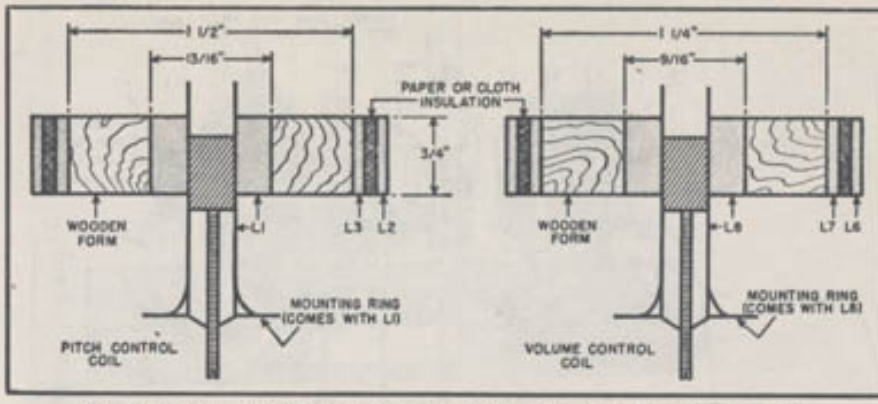
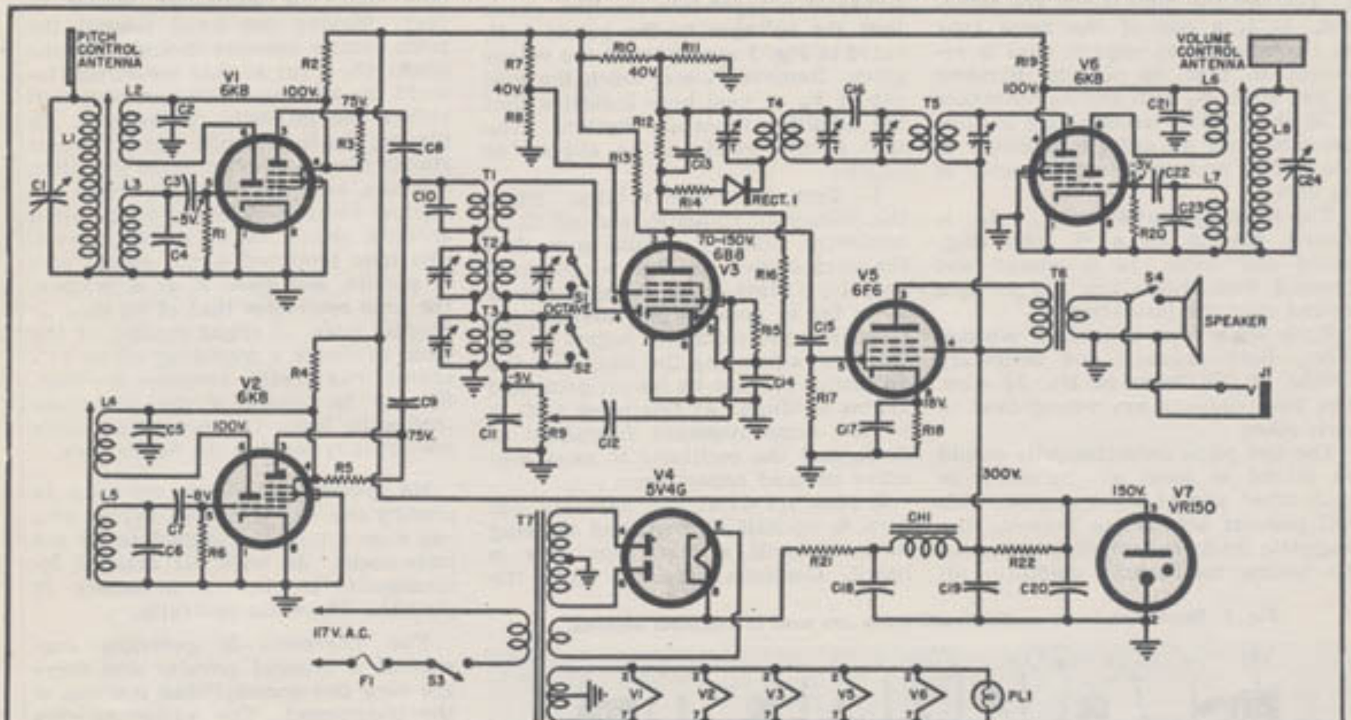


Fig. 2. Cross-sectional details of control coils. Dimensions should be exact.

Fig. 3. Complete schematic diagram for the Theremin. All voltage readings shown were taken with 20,000 ohms-per-volt meter.



R_1, R_6, R_{13}, R_{20}—100,000 ohm, ½ w. res.
R_2, R_4, R_{19}—4700 ohm, 1 w. res.
R_3, R_5, R_{11}—10,000 ohm, ½ w. res.
R_7, R_{12}—47,000 ohm, ½ w. res.
R_8—22,000 ohm, ½ w. res.
R_9—250,000 ohm pot
R_{10}—330,000 ohm, ½ w. res.
R_{14}, R_{17}—470,000 ohm, ½ w. res.
R_{15}—4.7 megohm, ½ w. res.
R_{16}—1 megohm, ½ w. res.
R_{18}—470 ohm, 2 w. res.
R_{21}—300 ohm, 10 w. wirewound res.
R_{22}—3000 ohm, 10 w. wirewound res.
C_1, C_{24}—15 μμfd. var. cond.
C_4, C_6—.1 μfd., 400 v. cond.
C_2, C_5, C_{11}, C_{21}, C_{22}—250 μμfd. mica cond.
C_8, C_9—.005 μfd., mica cond.
C_3, C_7, C_{13}—50 μμfd., mica cond.
C_{10}—750 μμfd., mica cond.
C_{12}—.001 μfd., 400 v. cond.
C_{14}, C_{23}—.05 μfd., 400 v. cond.
C_{15}—.01 μfd., 400 v. cond.
C_{17}—20 μfd., 25 v. elec. cond.
C_{18}, C_{19}, C_{20}—20 μfd., 450 v. elec. cond.
C_{16}—.002 μfd., mica cond.
J_1—Jack for external speaker (optional)
L_1—TV horizontal osc. coil (Stanwyck LHO 2)
L_2—40 t. #30 c.c. wire wound over L_3 (see text)
L_3—60 t. #30 c.c. wire on 1½" form (see text)
L_4—30 t. #30 c.c. wire wound over L_5
L_5—85 t. #30 c.c. wire wound on ⅜" slug-tuned coil form
L_6—20 t. #30 c.c. wire wound over L_7 (see text)
L_7—40 t. #30 c.c. wire on 1¼" form (see text)
L_8—TV horizontal osc. coil (Stanwyck LHO 2 modified per text)
PL_1—6.3 volt pilot light
Spkr.—6" loudspeaker
Rect.$_1$—1N34 germanium diode
S_1—S.p.s.t. switch (second harmonic, octave)
S_2—S.p.s.t. switch (third harmonic)
S_3—S.p.s.t. power switch
S_4—S.p.s.t. speaker switch (see text)
F_1—2 amp fuse
CH_1—10 hy., 100 ma. filter choke
T_1—R.f. transformer (see text)
T_2, T_3, T_4, T_5—465 kc. broadcast i.f. trans. with trimmers (see text)
T_6—Audio output trans., 7000 ohm pri. impedance; Sec. impedance to match speaker voice coil
T_7—Power trans. 325-0-325 v. @ 100 ma.; 5 v. @ 2 amps; 6.3 v. c.t. @ 3 amps
V_1, V_2, V_6—6K8 tube
V_3—6B8 tube
V_4—5V4G tube
V_5—6F6 tube
V_7—VR150 tube

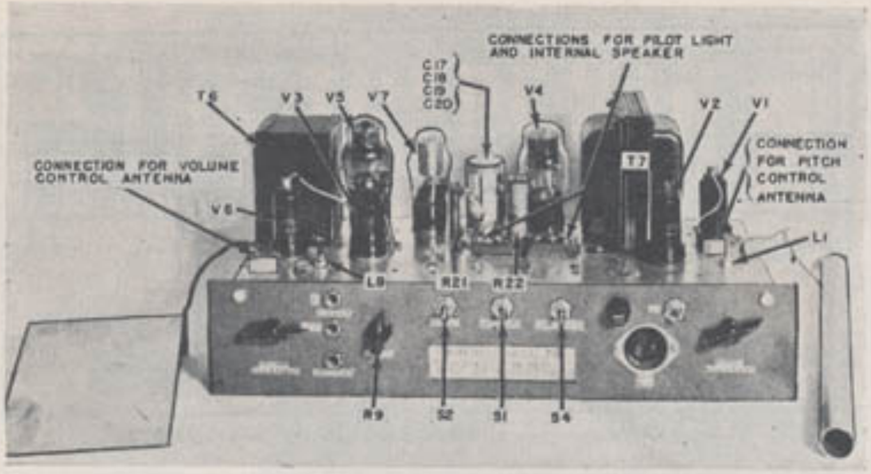


Fig. 4. Top chassis view of the Theremin. Antennas should be widely separated.

this form, L_3 is wound. A layer of insulation is placed over L_3 and L_2 is wound over the insulation. L_1 is then placed in the hole in the coil form (see Fig. 2). With L_1 in place, the entire assembly is coated with cement or coil dope. This assembly is seen in the upper right hand corner of Fig. 5.

The same procedure is followed for the volume control coil assembly (L_6, L_7, L_8), but the dimensions are different. L_8 is a coil of the same type as L_1, except that enough wire is removed so that its outside diameter is just under 9/16 inch and its resistance is 30 ohms. The wooden ring for this assembly has an outside diameter of 1¼ inches and an inside diameter of 9/16 inch.

The fixed oscillator coil (L_4, L_5) is wound directly on a 3/8 inch slug-tuned coil form. L_5 is wound and covered with insulation. L_4 is then wound over the insulation.

T_1 is wound on a 7/8 inch wooden form. Both primary and secondary consist of 250 turns of No. 30 wire. The two windings are wound next to each other.

The two pitch oscillator coils should be placed at least six inches from each other and at right angles. This will prevent interaction between the magnetic fields surrounding the coils. To insure mechanical stability, all leads going to these coils should be solid rather than stranded wire. The antenna connections are brought out to connectors on the top of the chassis. The loudspeaker and pilot light are also connected in this fashion.

To adjust the Theremin, use a voltmeter with an internal resistance of at least 20,000 ohms-per-volt. After the wiring has been checked and the instrument plugged into the line, check that the voltages at the points indicated in Fig. 3 approximate the values given. Remove V_6 and touch the grid cap of V_5. A loud hum indicates that the amplifier tubes are working. The unit is now ready to be aligned as follows:

1. Turn R_9 to zero volume. Place the voltmeter across R_1 and set C_1 to minimum capacity. Make sure that the pitch control antenna is connected properly. Start with the slug out of L_1 as far as possible and advance the slug until the voltmeter begins to dip. Continue advancing the slug until the voltmeter reaches its lowest point and begins to climb. At this point L_1-C_1 is at the same resonant frequency as L_2-C_4, and the oscillator is most sensitive to hand capacitance.

2. Now set C_1 at half capacity and turn R_9 up half way. Adjust the slug in L_4-L_5 until a loud beat note is heard. Continue adjusting until the two oscillators are zero-beating.

3. Set C_1 for an audible note. Close S_2 and open S_1. Tighten the trimmers on T_2 until a marked change in tone quality is heard. T_2 is now tuned to the second harmonic (octave) of the fundamental and may be shorted out by simply closing S_1.

4. Close S_1 and open open S_2. Loosen the trimmers on T_3 until a change in tone quality is heard. T_3 is now tuned to the third harmonic of the fundamental and may be shorted out by closing S_2. With both S_1 and S_2 open, the resultant tone will contain both second and third harmonics.

5. Place V_6 in its socket and allow it to warm up. Set C_{24} at minimum capacity and connect the volume control antenna. Place the voltmeter across R_{20} and adjust L_6 until the voltmeter shows the greatest dip. V_6 is now oscillating at about 500 kc.

6. Now set C_{24} at maximum capacity and place the voltmeter across R_{19}. Adjust T_4 and T_5 trimmers for maximum voltage.

The unit is now ready to play. The chassis and antennas are mounted in the cabinet. C_1 is set for the lowest note that the performer wishes to play. Moving the hand toward the pitch control antenna should raise the pitch. C_{24} is set so that movement toward the volume control antenna will reduce the intensity of the tone. In playing the instrument, the performer stands about two feet from the pitch antenna, and about 1½ feet from the volume antenna. The top of the pitch antenna should be at shoulder level. The tone produced is not unlike that of a cello, and when S_1 or S_2 is open, the tone resembles that of an oboe or English horn. A slight shaking of the hand produces a quivering effect (vibrato) that greatly enriches the tone. S_4 may be opened if the performer wishes to leave the power on while not actually playing the instrument.

No special techniques are used in playing the Theremin and anyone who can hum a tune is a candidate for the instrument. As with all musical instruments, practice is necessary to play the Theremin skillfully.

The Theremin is generally considered a musical novelty and there are very few accomplished masters of the instrument. The writer believes that the scarcity of instruments rather than any great difficulty in learning to play is responsible for this situation. The instrument herein described, in the writer's opinion, is the equal of any in existence, and incorporates added features that make it superior to any that he has seen or heard. Construction of the instrument should present no great trouble to anyone with some knowledge of electronic circuits and construction techniques. Beside the satisfaction of having built a musical instrument, the constructor will enjoy the distinction of being able to "pull music from the air." —30—

Fig. 5. Underchassis view. Short, stiff leads are used in oscillator sections.