

A SOLID-STATE THEREMIN

Here is a project for which we have had many requests over the past years. It is the Theremin, an instrument with a reputation bordering on the mythical. Most people know that it can be used to produce weird sound effects for science fiction films and the like, but few have seen one and fewer still have been close enough to try one. In this article, construction of a Theremin is described in detail.

By Leo Simpson

Invented by a Russian named Leon Theremin, in the early days of radio, the instrument is very simple in its principle of operation. Its sound output is controlled in pitch and loudness by the effects of hand capacitance. The player merely waves his hands near two "antennas" to produce the weird sound effects—and music!

The control functions of the instrument consist of two fairly distinct sections: (1) one of the player's hands, one antenna or capacitance plate and the associated circuitry to produce the desired note or audio frequency; (2) the player's other hand, a second capacitance plate and more circuitry to control the loudness of the sound produced. Over and above these sections, there is the amplifier system, the loudspeaker and the power supply, of which more will be said later.

Basically, the audio tone or musical note is produced by heterodyning two radio frequency oscillators to produce an audible "beat" or difference frequency. Most readers will have heard a similar kind of whistle, produced when an oscillating radio receiver is turned across the carrier frequency of an incoming station. By

carefully manipulating the receiver dial, it is possible to produce a beat ranging from a high frequency whistle to a low frequency growl.

As might be expected, the two oscillators in a Theremin, used to produce the audible beat, must be set up so that they can operate very close together in frequency, without too obvious a tendency to "pull" one another or to lock together.

One oscillator must be designed so that its frequency will change readily when a hand is brought close to a capacitance plate which is part of its circuitry. The other oscillator should not exhibit this effect and, in practice, is pre-set so that it oscillates on the same frequency as the "variable" oscillator when the latter's natural frequency is not being disturbed. With both oscillators on the same frequency, there is "zero beat" and no audible note is heard from the loudspeaker system.

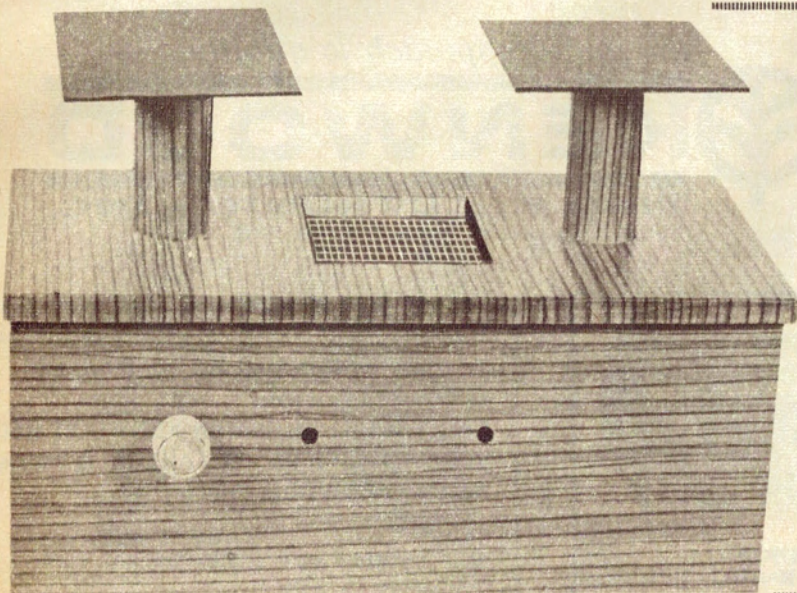
When a hand is brought near the capacitance plate, the frequency of the variable oscillator changes and a beat note is produced. With suitable design, the beat note can be changed from near zero frequency to the limit of

audibility. In part the art of playing a Theremin is in being able to move the hand with sufficient control and subtlety to produce a desired sequence of musical notes. Moving the hand from one position to the next must inevitably produce a gliding tone, or glissando effect, while a slight tremble — intentional or otherwise — will produce vibrato.

For the instrument to have any potential appeal at all, it is essential that the player have adequate control over loudness, not only to give the required emphasis to the melody notes but also to control the glissando effect first mentioned. Control could be obtained with a foot—or hand-operated potentiometer but this would be completely out of keeping with the Theremin idea. Hence the need to adapt hand capacity effects to control loudness as well as pitch and, later in the article, we shall see how this can be done.

Ideally, both the pitch and volume control effects should be as progressive as possible, with pitch and loudness changing smoothly and linearly with movement of the hands within a fairly large "active" distance from the respective plates.

Unfortunately for the present requirement, capacitance varies inversely with the distance between hand and plate, so that the closer the hand is to the plate, the greater is the capacitance change for a given small change in distance. It is quite difficult to counter this effect in a practical kind of instrument and, as a result, the player must be able to position his hands quite accurately and often quite close to the surface of the respective plates to obtain just the right pitch and the right volume level.

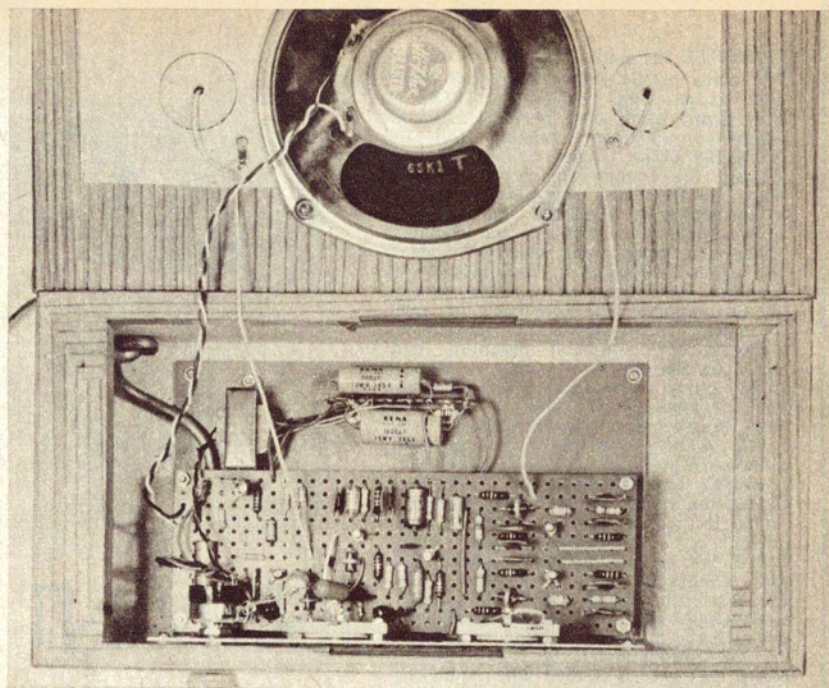


At left is a player's eye view of the prototype Theremin. It is played by waving the hands near the two raised plates. The plate on the left controls the pitch while that on the right controls the loudness. The two holes in the panel are screwdriver access holes for initial setting of pitch and loudness. The loudspeaker is installed under the lid but could be fitted in a separate cabinet if desired. The volume control knob is used to set the overall loudness to a suitable listening level. At right is the circuit diagram of the complete instrument. The numbers in brackets after the semiconductor type numbers are the key to their lead connection diagrams.

tance of the volume antenna (plate). A portion of the signal across the tuned circuit is coupled to a diode via another 4.7pF capacitor. The DC voltage so derived is amplified by a PNP transistor, T5, and applied to the gate of the FET.

The level of the audio tone being reproduced should increase when a hand is brought near the volume antenna. Initially, the volume oscillator is adjusted, by means of a 100pF rotary ceramic trimmer capacitor, to give a minimum loudness of the audio tone. This involves tuning the oscillator so that its frequency coincides with the resonant frequency of the tuned circuit. As a result, the voltage derived from the diode will be at a maximum so that T5 is forward biased and, consequently, turned on. The gate of the FET is taken toward the positive supply rail and the drain-source resistance held to a low value.

A view of the layout inside the cabinet. The mains cord should be clamped to the chassis (this has been obscured) and knotted as shown, to reduce strain.



shunting a large portion of the beat note signal to the positive supply.

When a hand is brought near the volume antenna the hand capacitance in the tuned circuit changes the resonant frequency so that the DC derived from the diode decreases. This progressively carries T5 toward cut-off so that the drain source resistance of the FET increases, and thus more of the audio tone signal is fed to the following amplifier. At this point, a particular characteristic of the FET becomes apparent.

For small voltages of either polarity (or AC) applied between drain and source electrodes, the FET behaves as a resistor which can be varied in linear fashion by a voltage applied between source and gate. From zero to about minus 4 volts between source and gate, the relationship between gate-source voltage and drain-source resistance may be relatively linear but this is no longer true as the gate-source voltage approaches the "pinch-off" voltage of the FET. In this region the relationship becomes very non-linear, a small increase in gate-source voltage resulting in very large change of drain-source resistance; i.e., the FET is turned off over a small voltage range.

The above means that, in a certain region near the volume antenna, a small hand movement will result in a large change in loudness so that it tends to act almost as a switch. To reduce this effect, a 33K resistor is connected between collector and emitter of T5. When the transistor is turned off, the 33K and the 10K collector load resistor form a voltage divider which limits the FET gate-source voltage to about minus 6 volts. This has the effect of making the volume control action more progressive but it does reduce the available range of the control.

Note that it is not possible for the volume control circuitry to give zero sound output, since the minimum resistance of the FET is typically 300 ohms and it cannot shunt all the signal to the positive supply.

To sum up, then, we see that the pitch of the Theremin is controlled by beating two RF oscillators together, one of which is sensitive to hand capacitance. The resulting beat note can be varied over the whole of the audible range. The loudness of the beat note is controlled by a third oscillator feeding a tuned circuit which has its reso-

nant frequency shifted by hand capacitance. A DC voltage, derived from the tuned circuit, is used to vary the drain-source resistance of a FET, which is part of a voltage divider to which the beat note signal is applied. Having grasped this, the rest of the Theremin is straightforward.

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PARTS LIST

- 1 chassis (see text).
- 1 miniature power transformer, with centre-tapped 12.6 volt secondary.
- 1 piece of matrix board, 9 x 3 inches.
- 1 8-terminal tagstrip.
- 4 330uH RF chokes.
- 1 100K(log) potentiometer (mains switch optional).
- 2 100pF Ducon TDB rotary ceramic trimmers.
- 1 15-ohm loudspeaker.
- 1 knob.

SEMICONDUCTORS

- 3 BF115 or similar silicon NPN RF transistor.
- 2 BC108, 2N3565 or similar silicon NPN transistor.
- 1 2N3638 or similar silicon PNP transistor.
- 1 BC178, 2N3638A, AY1110 or similar high gain PNP transistor.
- 1 AC127/128 complementary germanium pairs (with flag heat-sinks).
- 1 2N5459 N-channel FET.
- 1 OA91 or similar diode.
- 2 EM401, AD4001, 1N3193 or similar power diode.

The layout is not really critical but the wiring diagram should be followed fairly closely for best results.

All the RF chokes are 330uH, honeycomb wound on a ferrite former by Aegis Manufacturing Co. Pty. Ltd., and available from most component suppliers. All the 0.1uF capacitors in the RF portion of the circuit are low voltage ceramic discs rated at 25 volts working; a lower rating may be used, if available. Mica or polystyrene capacitors may be substituted, if they are on hand.

Electrolytic capacitors shown on the circuit diagram and in the parts list are specified with the minimum suitable voltage rating currently available. As always, higher voltage units may be used if size is not a problem. old electrolytics should not be used, as their capacitance may have decreased and leakage and power factor will be increased.

The AC127/128 output transistor pair should be fitted flag heatsinks, (Miniwatt part No. 56200) which are normally supplied with each complementary pair. Under normal conditions the transistors will be cold to the touch.

A simple chassis was used in the prototype, made from a piece of 22 gauge aluminium 9½ x 8½ inches bent so that it has a 3 inch flange to accommodate the volume potentiometer and two trimmer capacitors. The matrix board is mounted on the chassis so that it is spaced above it by a distance of one inch, by 1/8-inch screws and nuts. The chassis reduced the tendency of the two pitch oscillators to lock.

The rotary ceramic trimmers are type TDB, made by Ducon division

RESISTORS

- (½ or ¼ watt unless specified)
- 1 x 820K, 3 x 560K, 1 x 330K, 3 x 150K, 2 x 100K, 4 x 33K, 2 x 10K, 1 x 1.5K, 7 x 1K, 1 x 470 ohms, 1 x 220 ohms, 1 x 100 ohms, 1 x 22 ohms, 2 x 1 ohm/½ watt.

CAPACITORS

- 1 x 1000uF/12VW electrolytic.
- 1 x 500uF/10VW electrolytic.
- 1 x 320uF/6VW electrolytic.
- 1 x 250uF/6VW electrolytic.
- 1 x 25uF/6VW electrolytic.
- 8 x 0.1uF/25VW ceramic disc (see text).
- 2 x 0.1uF polyester or ceramic.
- 2 x 0.01uF polyester or ceramic.
- 1 x .0022uF polyester or ceramic.
- 1 x .001uF polystyrene or ceramic.
- 2 x 330pF polystyrene or ceramic.
- 1 x 100pF polystyrene or ceramic.
- 1 x 47pF polystyrene or ceramic.
- 2 x 4.7pF ceramic.

MISCELLANEOUS

Timber for cabinet, contact covering, sheet metal for pitch and volume plates, 3-core mains flex and power plug, hook-up wire, mains cord clamp, screws, nuts, solder, etc.

of the Plessey Components Group and are available from most component suppliers. These trimmers were used since they are fully adjustable and do not lose their ability to be adjusted, as do compression trimmers. The trimmers are adjusted by a screwdriver, through an access hole in the chassis and cabinet. They are spaced off the chassis by the thickness of one nut to ensure that the rotor has sufficient clearance. When wiring the trimmer for the pitch oscillator, connect the rotor terminal (terminal going to centre of ceramic former) to the positive supply rail, as in the circuit diagram. If it is connected in contrary fashion, it will be impossible to "zero" the pitch oscillator because of the capacitance of the screwdriver blade.

To take advantage of the wide frequency range available, a speaker with a good frequency response should ideally be used. If an economy speaker is used it should have as large a diameter as is practical. For this reason we used a 6-inch diameter speaker which enables a conveniently sized cabinet to be obtained.

An exploded diagram illustrates the method of assembly of the cabinet and gives the major dimensions of a cabinet suitable for a six-inch diameter speaker. If desired, the output of the amplifier can be fed to an external speaker system. If this is done, be sure to connect the speaker with a two-pin plug and socket to reduce the possibility of shorting the output of the amplifier which would almost certainly be damaged.

Antennas or plates associated with the pitch and volume controls may be any reasonable size and shape. We made two rectangular plates 6 x 4½in.

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BC 108 .. 60c BC 148 .. 50c
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12, TS13) .. 50c
AF 116 .. 65c OC 445 .. 50c
BSY 28 .. 50c (BCY30) .. 30c
OC 440K .. 50c OC 469 .. 50c
(BCY33) .. 50c (BCY34) .. 50c
OC 440 .. 50c TS3 (AF185) .. 25c
(BCY430) .. 50c 25C92 .. 50c
OC 470 .. 50c 2G526 .. 50c
(BCY34) .. 50c 2N 1613 .. 50c
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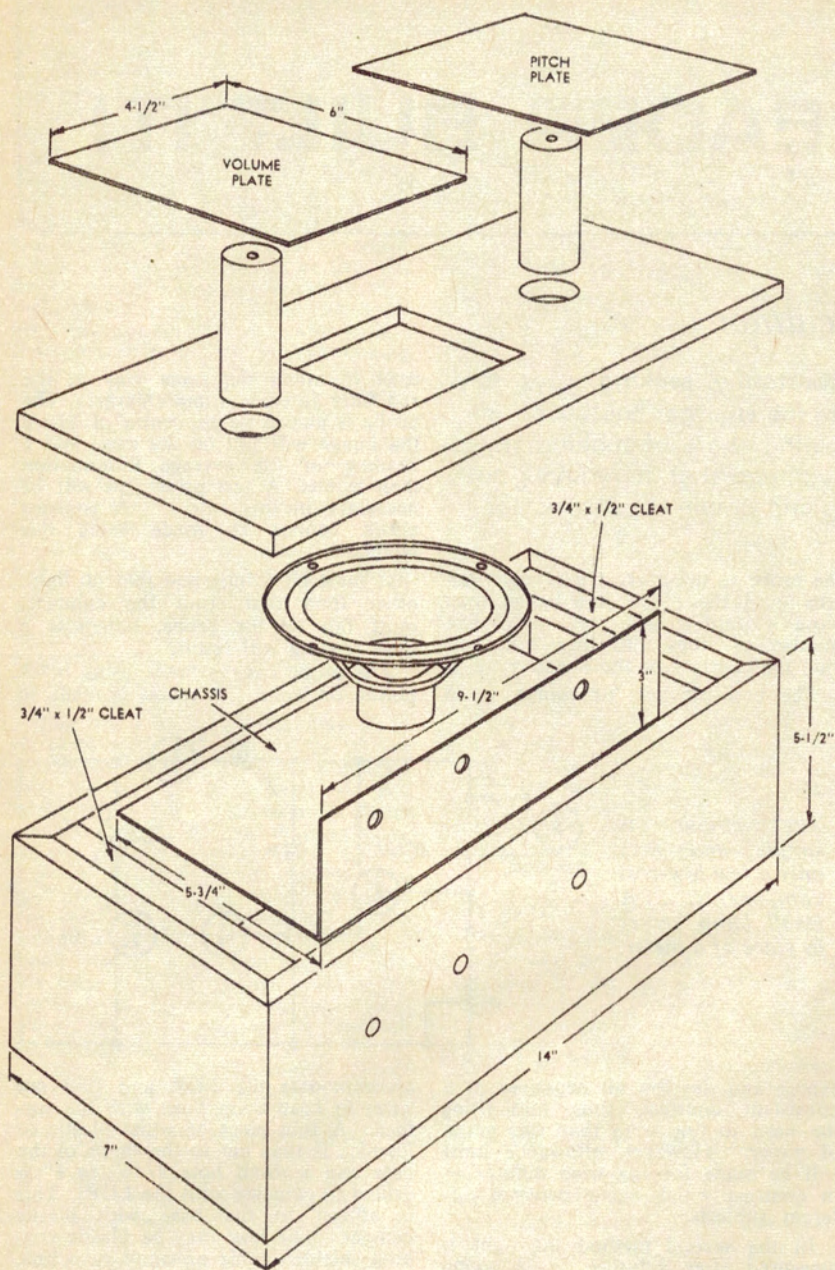
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The above diagram shows the major details of a cabinet suitable for a six-inch diameter speaker.

and these were mounted above the lid by two 1-3/8-inch dowels. These were drilled right through to take a piece of hookup wire for connection in the circuit. The method of mounting the plates, however, is non-critical and readers may use whatever method is convenient. Note that the plates should not be too close together, otherwise the controls will interact.

Finally, we covered the plates with black vynex to contrast with the simulated wood of the cabinet. Contact adhesive is suitable for sticking the material to the plates.

SETTING UP: First, adjust the pitch control trimmer for an audible note. Set the volume control potentiometer for a suitable level. Then adjust the volume control trimmer for minimum loudness. Note that it is not possible for the volume trimmer to

completely turn off the sound, for the reason already explained. Finally, with your hand close the volume plate, adjust the pitch trimmer for zero pitch. These adjustments will have to be repeated each time the unit is set up in a different position.

You will find the theremin capable of an endless variety of sounds. Low grunts and growls can be produced by a quick, sweeping motion of the hands. Similarly, one can obtain wails and squeaks in the high range. To produce a vibrato effect, hold the "volume hand" in a fixed position and flutter the "pitch hand" at the desired rate. Similarly, to create a "tremolo" effect, hold the "pitch hand" in a fixed position and flutter the "volume hand." Do not practice these effects in the vicinity of someone with a headache!

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