BUILD THIS THEREMIN

Build Theremax—a theremin for the 1990's!

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LAST MONTH, WE DESCRIBED THE circuitry behind Theremax. This month, we show you how to build it.

Although all of the signals in Theremax have frequencies below 1 MHz, it's important to build the unit carefully. Keep the point-to-point wiring as short as possible, and leave plenty of space between the four oscillators to minimize oscillator lock.

The easiest way to build the electronics of Theremax is to make or buy the printed-circuit board, which was presented last month. The component-placement diagram for the board is shown in Fig. 3. If you construct the circuit or just parts of it on perforated prototyping board, try to follow this layout as closely as possible since care has been taken to isolate parts of the circuit that might interact. Note in particular the use of a star ground point with traces emanating from circuit board point "G", and the grounded lands that encircle each oscillator. Make sure the metal cans of the inductors are grounded as well.

For the most part, Theremax is very forgiving of the specifics of components. For example, almost any NPN silicon transistor will work in place of the 2N4124s specified—2N3904s or 2N2222s will be fine. Even the inductor values are not very critical, and you will find that most suppliers carry IF transformers and local-oscillator coils that can be made to work in the circuit, probably without even changing the operating points of the transistors. Make sure the "cans" you use have a tapped primary (you may have to reverse the ends of the primary to get the tap closer to the collector end) and a secondary (polarity doesn't matter here).

Do not substitute silicon diodes for the germanium types used in the ring modulators. The forward voltage drop of silicon diodes makes them inappropriate here. The other critical components are the ceramic disc capacitors used in the tank circuits. These must be NPO types to minimize oscillator drift with changes in ambient temperature.

Connect the front-panel controls and jacks to the lettered pads on the circuit board with No. 22 AWG stranded wire, as shown in Fig. 4. Note that you must mount some of the fixed resistors between solder lugs on the panel controls, as shown. Mount the LEDs by twisting their cathode leads to their current-limiting resistors and soldering. Mount the front panel to the lectern case from the inside; the controls are exposed though a hole that's routed-out in the front of the case.

The shapes of the case pieces have been kept as simple as possible. (See Fig. 5.) Assemble the case with simple butt joints, countersunk screws, and glue. (See Fig. 6.) The case for the prototype was cut from clear white pine and finished with walnut-tinted tung oil. If you start from scratch, you may choose other materials and configurations. If you decide on a metal case, make sure that the antennas are insulated from it.

Form the antennas from No. 6 AWG copper buss bar—the kind that power companies use for ground connections. This material was chosen for its malleability and ease of fabrication. Reformable antennas can be easily shaped for experimental purposes. For example, zig-zag pitch antennas might give a different means of obtaining vibrato—you could hold the pitch hand vertical while running it up and down, rather than waving it closer to the antenna. You can form the volume antenna from a length of the buss rod and bend it in any appealing, roughly loopish pattern. While the specific shapes that you choose for the anten-

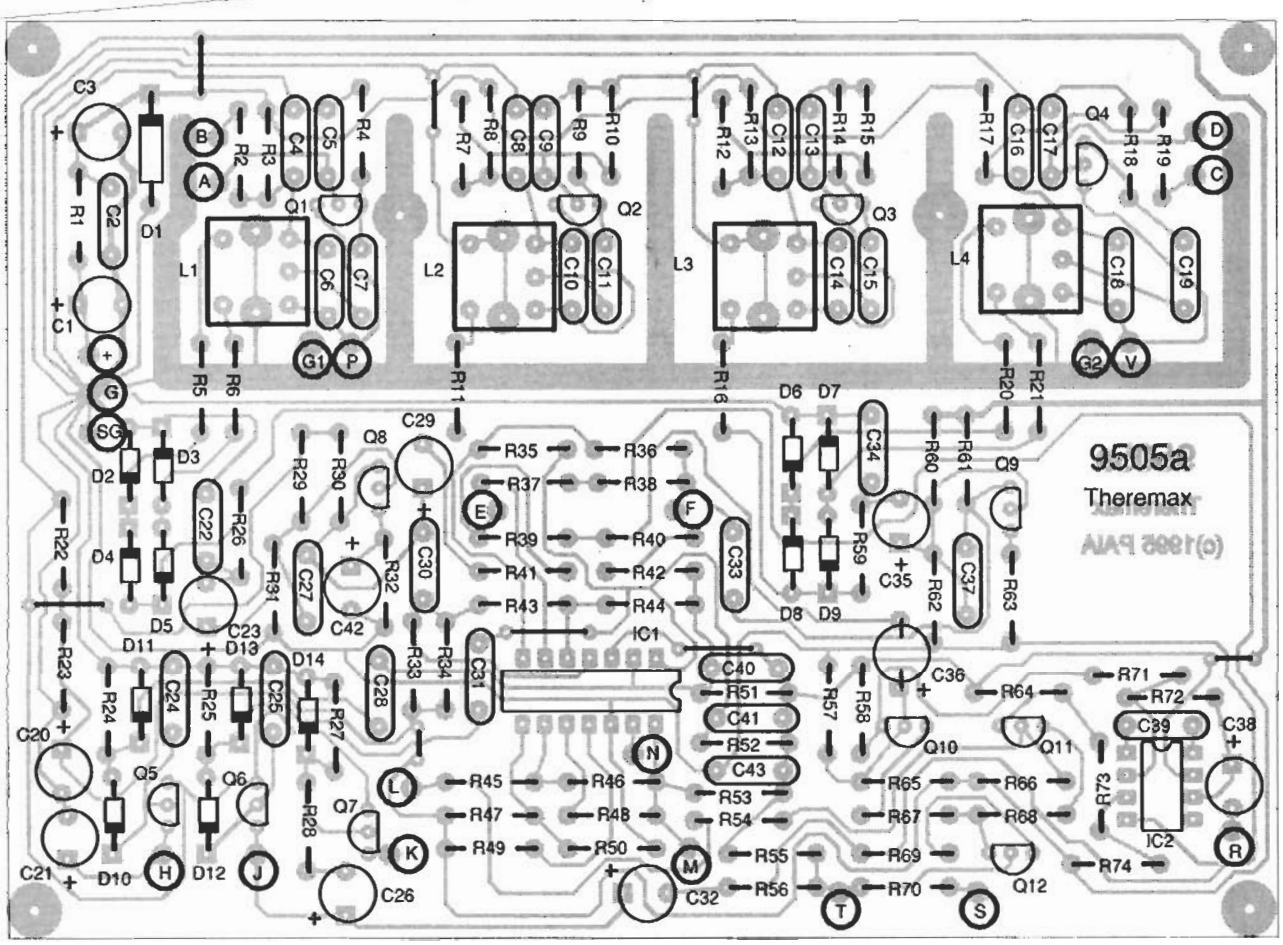


FIG. 3—PARTS-PLACEMENT DIAGRAM for the Theremax circuit board. The lettered pads connect to off-board components.

nas are pretty much up to you, be sure to keep them at right angles to one another to minimize interactions between them.

Mount the antennas to the case by passing them through 3/16-inch holes drilled in the end panels. Secure them to the back of the case with large washers, wing nuts and No. 8 flat-head screws that pass through loops bent at the end of the buss rod, as shown in Fig. 7. Make the connection to the antennas with RG-174/U coaxial cable. Ground the shield only on the circuit-board end.

Make the bottom of the case from metal to form a ground plane that cuts down on any interactions between the pitch and volume sections. Mount the circuit board to the bottom plate with standoffs and 4-40 hardware. (See Fig. 8.)

Testing and tuning

After examining your work carefully—looking for solder bridges, incorrectly placed or oriented parts and so on—it's time to power up. Plug the power adapter into a wall outlet and turn on the power switch, S1. You should immediately see the POWER LED light. If you don't, stop. Re-examine your work, and find out why.

Begin testing and initial tuning by setting the front-panel controls so that the PITCH TRIM and VOL TRIM controls are at about the midpoint of their range. Set the PITCH CV, TIMBRE and VELOCITY controls fully counterclockwise, and rotate the VOLUME control clockwise to its maximum setting. Connect the audio output of Theremax to the input of a hi-fi, instrument, or general-purpose amplifier.

Verify the operation of the oscillators and set the heterodyning pairs to the same frequency. With an oscilloscope, look at the voltage of the emitters of the oscillator transistors (Q1 to Q4) and observe the 500-kHz to 900-kHz sine waves with amplitudes of about 250 millivolts peak-to-peak, and DC offsets from ground at about a volt. As the slugs of heterodyning pairs of oscillators are adjusted, the beat frequencies—0 to 10 kHz, 0.5 volts peak-to-peak sine waves—can be seen at the collectors of the amplifier transistors Q8 or Q9. They'll have a typical DC offset of 5 to 6 volts above ground. First turn the slugs of L2 and L3 clockwise until you feel resistance (don't try to "tighten" them), then back them out about a half turn. Now adjust L1 while watching Q8's collector. At some point in the rotation of the slug, you will see a sine wave that builds in amplitude while decreasing in frequency, then goes to zero before once again increasing in pitch. The zero (null) point is your target. Do the same thing with L4 while watching for zero beat at the collector of Q9.

Continued on page 69

THEREMIN

continued from page 44

If you don't have an oscilloscope, a pocket AM radio can be pressed into service to verify that the oscillators are working and set to appropriate frequencies. Start by setting the radio to some quiet point between 650 and 750 kHz, and placing it as close as possible to the modulator diodes D2 to D5. Set the radio to fairly high volume and adjust the tuning slug of L2 up and down. At some point, you should hear a click or chirp as the frequency of the oscillator passes through the frequency set on the radio dial. Tune the slug very slowly back toward where you heard the chirp and you will hear "whines"—faint whistles, feedthrough from adjacent stations and so on—as you get closer to the setting of the radio. As you turn further, you should reach a null where the previous whines are replaced by the hiss of white noise (there's no modulation so the only audible signal for the radio to detect is the noise of the transistors in the oscillators, which is fairly faint). When you have turned too far, you will begin to hear the same "whines" that you heard approaching the null. Leave the slug set as close to the null as possible; it doesn't have to be exact.

Now adjust the slug of L1. At some point you will hear a loud chirp as the oscillator you are adjusting passes through the common frequencies of the local oscillator and the radio. Slowly adjust back to the chirp and you should hear a very loud, pure tone descending in pitch as you approach the null. Leave the slug set for as close to null as possible and verify that the front-panel PITCH TRIM control can be used to set an exact null. Leave the control set so that a low-pitch tone can be heard.

To adjust the volume oscillator pair, set the radio dial to a quiet spot between 900 and 1000 kHz, and adjust L3 in the same way that you previously adjusted L2. When L3 has been set close to the frequency of the radio, adjust L4 for zero beat of the heterodyne signal as you did with L1. Verify that the VOL TRIM potentiometer provides a vernier control of the frequency.

At this point, you should be able to start listening to Theremax through an amplifier connected to the audio output. With the volume control of the amplifier advanced slightly, bring your right hand up to the volume antenna—you should hear a tone swell in the amplifier's speaker. If you don't hear a tone, check to make sure that there is still some audible signal being produced by the pitch oscillators. If that's not the problem, check the rest of the audio signal and control path. Read the volume control-voltage at the emitter of Q6 to make sure that it goes from about 0 to 6 volts as your hand approaches the volume antenna. If that's OK, check the differential pair, Q10 and Q11 and its control current source Q12. Finally, check the output stage IC2. If there's no volume CV, check the amp Q9 as described earlier, and the output of the Schmitt trigger,

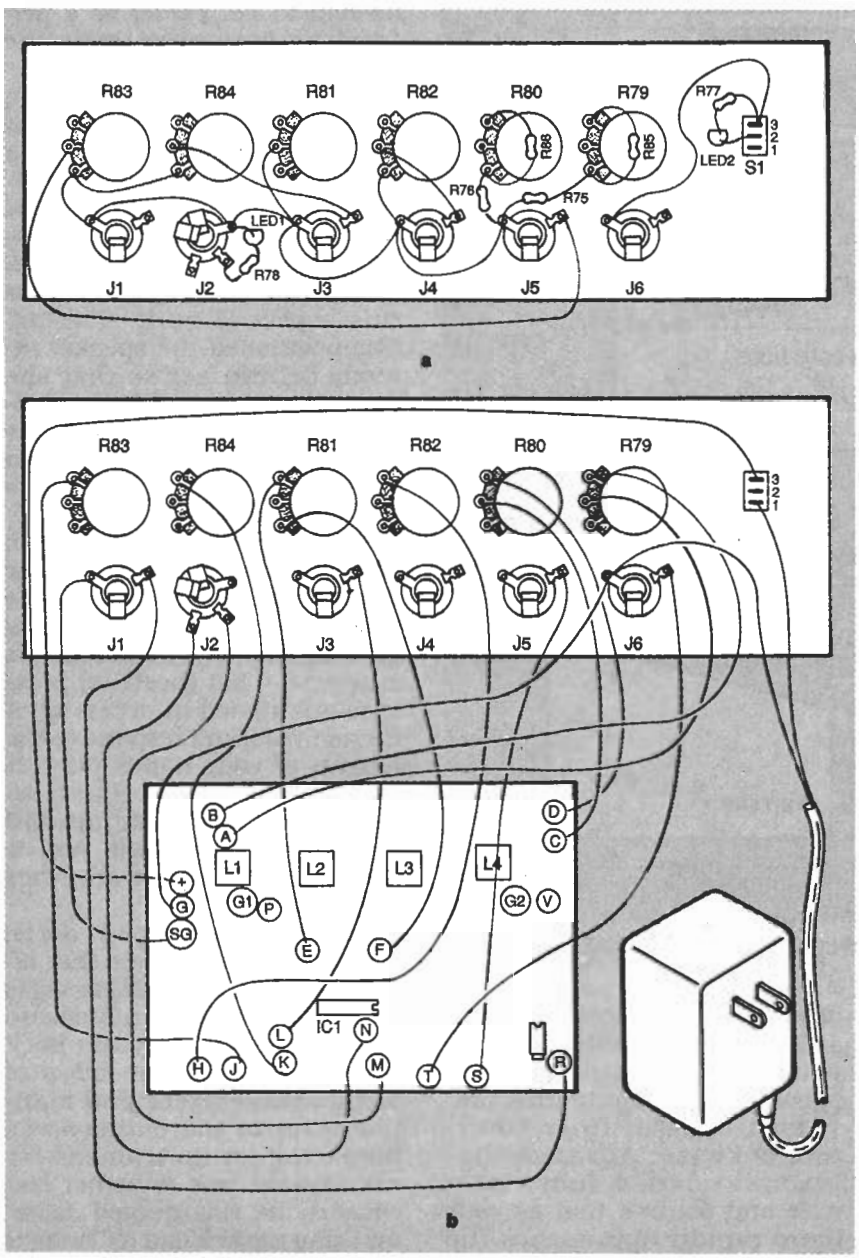


FIG. 4—OFF-BOARD WIRING for Theremax. Some fixed resistors and LEDs mount directly to the front-panel controls and jacks.

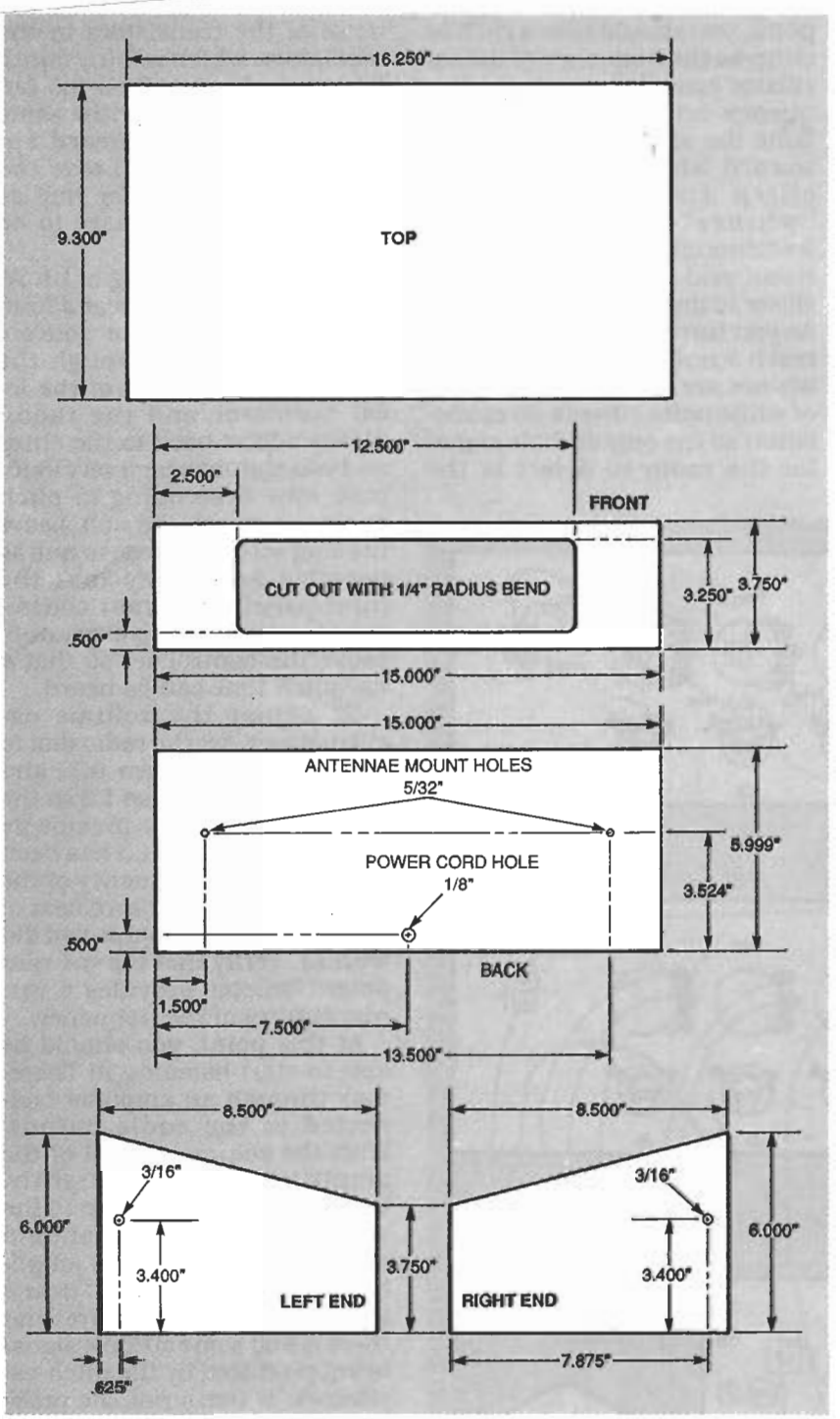


FIG. 5—THEREMAX'S CASE IS EASY TO BUILD from ½-inch thick white pine.

IC1-b at pin 1, where there should be a rail-to-rail square wave at the heterodyne frequency of the volume pair. If this signal is present, make sure the components of the differentiator/integrator (R25, C25, C31, D12 and D13) are in proper order.

With a tone audible, rotate the TIMBRE control clockwise and observe that the tone gets considerably more "sharp edged" as you fade from sine wave to square wave output. Turn the TIMBRE control fully counterclockwise. Advance the VELOCITY CONTROL fully clockwise and observe that as your hand rapidly approaches the volume antenna, the GATE/TRIG LED comes on. Also notice that the character of the sound now changes as your hand approaches the volume antenna, getting "fuller" when your hand approaches rapidly, and settling to a purer tone when you slow down, stop or withdraw.

Playing Theremax

Playing the theremin is an art that can't be taught in a few paragraphs. Still much can be learned by observing the playing style of Clara Rockmore. Clara's background was as a concert violinist, but a palsy in her hands that developed at a young age appeared to have put an end to her career as a performing musician until she started playing the theremin.

In many pictures of Clara taken over more than a 30-year span she is seen in front of a huge free-standing loudspeaker. This was not just for the theatrical effect of the apparent glory behind her head, though in some of the photos this aspect is quite striking. She positioned the speaker directly behind her so that she could hear the note she was getting ready to play before it was loud enough for the audience to hear, performing pitch corrections in that last split second.

Reviews and other accounts of performances remark on her motionless, trance-like stance while playing, only her hands dancing back and forth over the antennae. That theatrical presence was rooted in necessity: A theremin doesn't respond to the motion of your hands only; it responds to body motion as well. If you're moving around while playing, you will find it more difficult to hit an exact pitch.

Clara had developed "aerial fingering" techniques that allowed her to play rapid passages with legato and even staccato articulation. A few years back when Bob Moog—the father of Moog synthesizers and manufacturer of theremins—was preparing an instrument for use in what was to be her last concert, he was quoted as remarking that he had to "hang it on the edge" to please Mrs. Rockmore. In the interest of

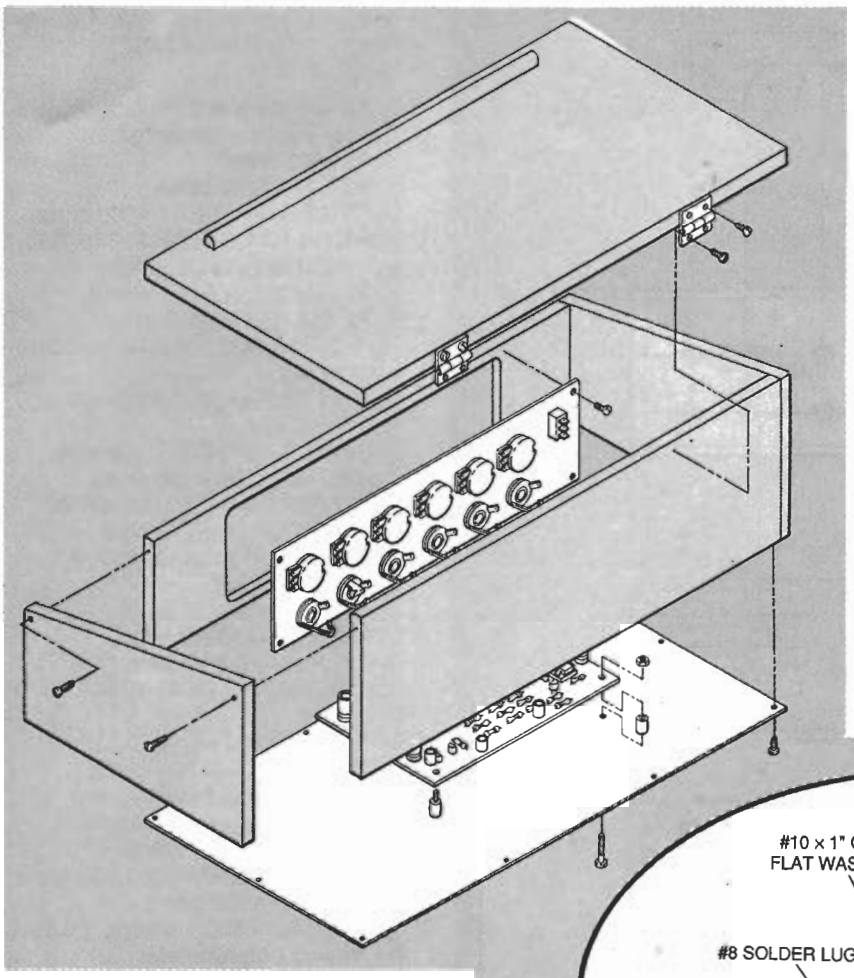


FIG. 6—ASSEMBLE THE CASE as shown here.

ease of playing, Theremax is designed to be somewhat less sensitive. However, substituting smaller capacitors in the tank of the oscillators will take its sensitivity up to this concert-level performance. But if you make these changes, be warned that you'll also need concert level skills to handle them.

For maximum sensitivity to hand gestures, the PITCH TRIM control should be clockwise from null so that the heterodyne frequency is two octaves below middle C (64 Hz or so). When tuned this way, the maximum range of about six octaves will correspond to an 18-24 inch range of hand motion. Only the rare performer will be able to use more than three or four octaves, because the last couple require that the hand be very close to the antenna.

Volume on the original theremins was increased by moving the hand away from the antenna. If you want to play Theremax this way, you should null the VOLUME TRIM control for minimum volume with your hand an inch or so from the antenna. Playing may seem more intuitive if you reverse this, so that volume increases as you move closer. To accomplish that, just null the volume trim with your hand removed. Either way, volume must be nulled completely for the velocity feature to work properly.

Closing the contacts of a SPST switch plugged into the MUTE jack turns the audio output off completely. You may find that a foot switch—either momentary or push-on, push-off—makes playing easier. This switch closure could also be an open collector transistor output from other equipment, such as the "S" triggers used in some

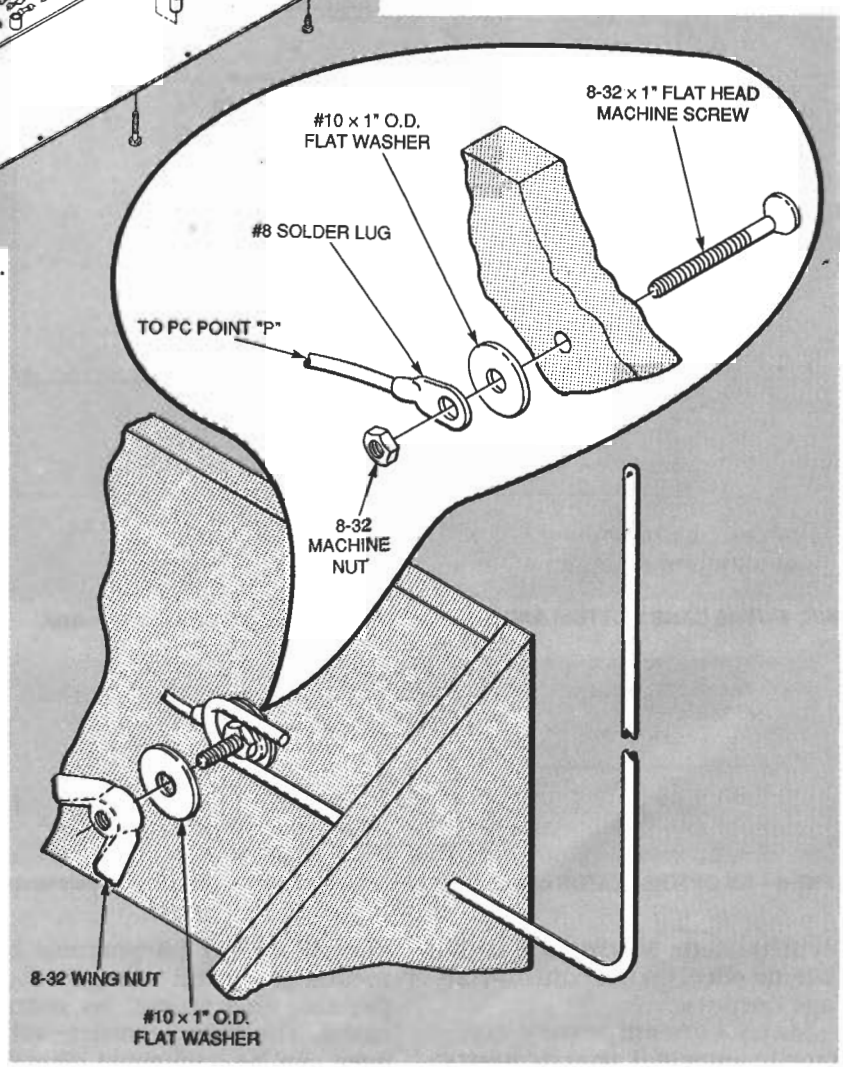


FIG. 7—FORM A LOOP at the ends of the antennas for mounting.

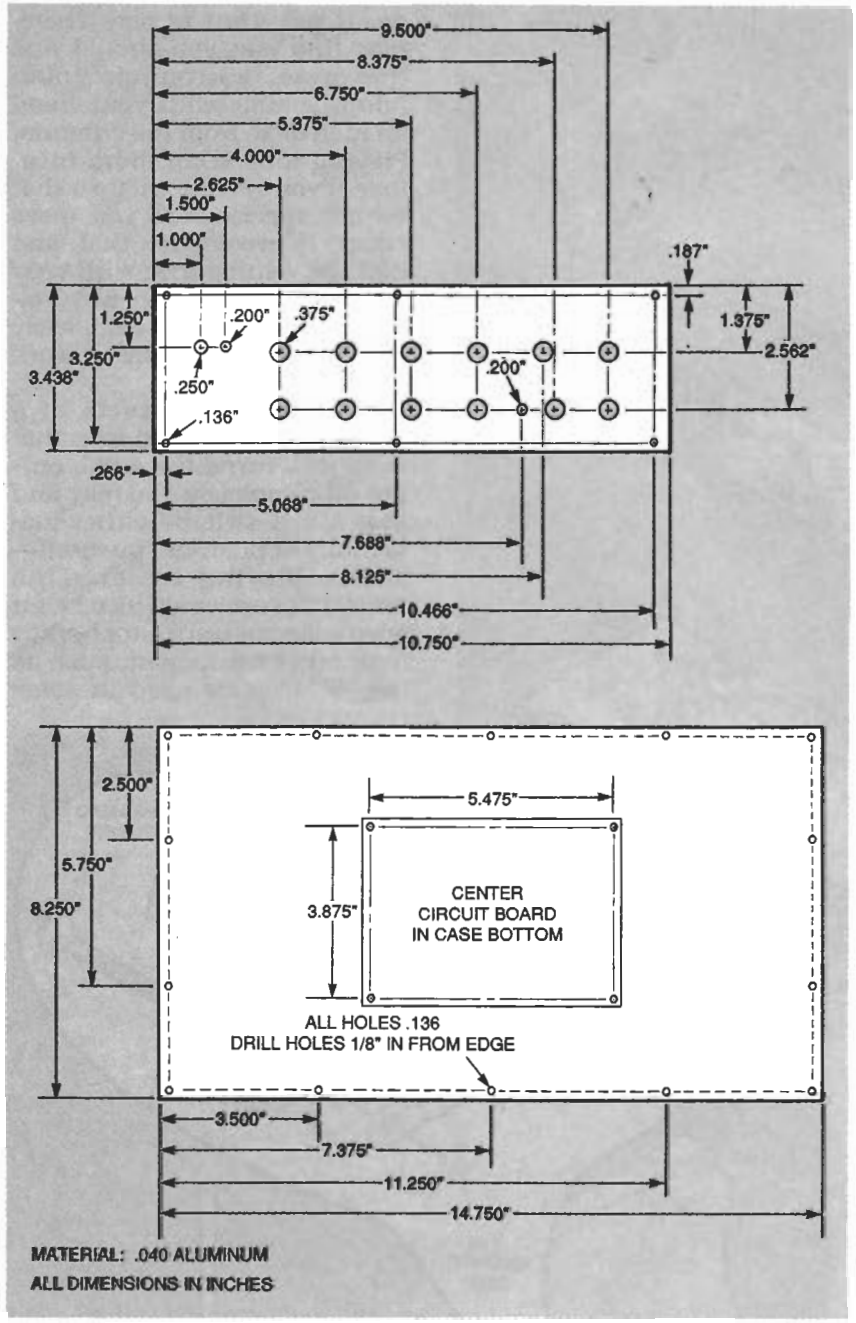


FIG. 8—THE CASE BOTTOM AND THE FRONT PANEL should be made of metal.

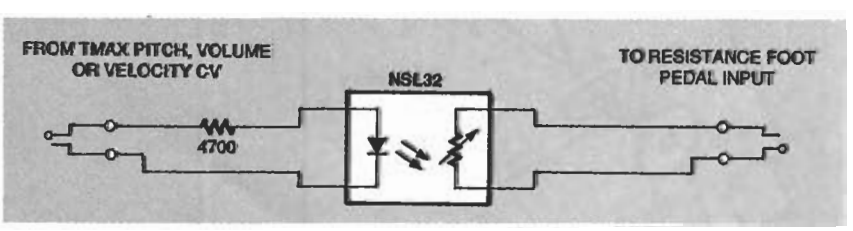


FIG. 9—AN OPTOISOLATOR can convert Theremax's control voltages to a resistance.

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.

R1—100 ohms
R2,R19—3300 ohms
R3,R8,R13,R17,R69—680 ohms
R4,R9,R14,R18,R48,R49,R61, R65,R66—56,000 ohms
R5,R6,R20,R21—47 ohms
R7,R12,R53—3900 ohms
R10,R15,R22,R23,R56—1000 ohms
R11,R16,R41,R50,R70—10,000 ohms
R24,R25,R54,R57—1 megohm
R26,R45,R59—4700 ohms
R27,R29,R60—470,000 ohms
R28,R67,R68—470 ohms
R30,R33,R34,R36,R37,R38—47,000 ohms
R31,R62—39,000 ohms
R32,R63—330 ohms
R35,R46—10 megohms
R39,R40,R55,R58,R64—22,000 ohms
R42—220,000 ohms
R43,R77,R78—2200 ohms
R44—4.7 megohms
R47—68,000 ohms
R51,R52—15,000 ohms
R71,R72,R73,R74—100,000 ohms
R75,R76—1500 ohms
R79,R80—1000 ohms, panel-mount potentiometer
R81,R82,R83,R84—10,000 ohms, panel-mount potentiometer
R85,R86—270 ohms

Capacitors

C1,C20,C42—100 µF, 10 volts, electrolytic
C2,C4,C8,C12,C16,C33,C43—0.01 µF, ceramic disc
C3—1000 µF, 10 volts, electrolytic
C5,C9,C13,C17,C39—100 pF, ceramic disc
C6,C10—100 pF, NPO, ceramic disc
C7,C11,C15,C19,C28,C31—470 pF, ceramic disc
C14,C18 —68 pF, NPO, ceramic disc

synthesizers. Muting the audio has no effect on the control-voltage outputs.

Many contemporary electronic musical instruments have provisions for external control of key parameters by means of control voltages, foot pedals, and so on. In many cases, Theremax's control voltages can be connected directly to these inputs. The availability of both gate and open-collector switching outputs on the GATE/TRIG output, J2 makes switch-style interfacing easy. In some cases, instruments expect a variable resistance at their external control jacks. In these cases, Theremax's control voltages can be converted to a resistance using an optocoupler, as shown in Fig. 9.

In some circles, voltage-con-

C21,C26,C32—10 µF, 10 volts, electrolytic
C22,C27,C34,C37—220 pF, ceramic disc
C23,C35,C36,C38—1 µF 10V, electrolytic
C24,C25,C30—0.1 µF, Mylar
C29—4.7 µF, 10 volts, electrolytic
C40,C41—0.001 µF, ceramic disc

Semiconductors

D1—8.2 volts, 400 milliwatts, Zener diode
D2–D9—1N34A germanium diode
D10–D14—1N914 silicon diode
D15,D16—red LED
IC1—LM339 quad comparator
IC2—748 op-amp
Q1–Q12—2N4124 NPN transistor

Other components

J1,J3,J4,J5,J6—¼-inch phone jack
J2—¼-inch stereo phone jack
S1—SPST switch
P1—DC wall-mount adapter, 9 volts, 100 mA.
L1,L2,L3,L4—796 kHz. (nom.) oscillator coil
Miscellaneous: knobs, circuit board, wire, solder, hardware, case, etc

Note: The following are available from: PAiA Electronics, Inc., 3200 Teakwood Ln., Edmond, OK 73013; Tel: 405-340-6300; Fax 405-340-6378; Online: http://www.paia.com/paia:

- **Complete kit of all electronic parts including power supply, circuit board and knobs less antennae and case (#9505K): $88.75**
- **Case kit with pieces cut from white pine and drilled for assembly. Includes hardware, formed antennae, bottom plate and punched, anodized and legended control panel (#9505C): $77.25**

Please add $7.00 for shipping and handling with each order.

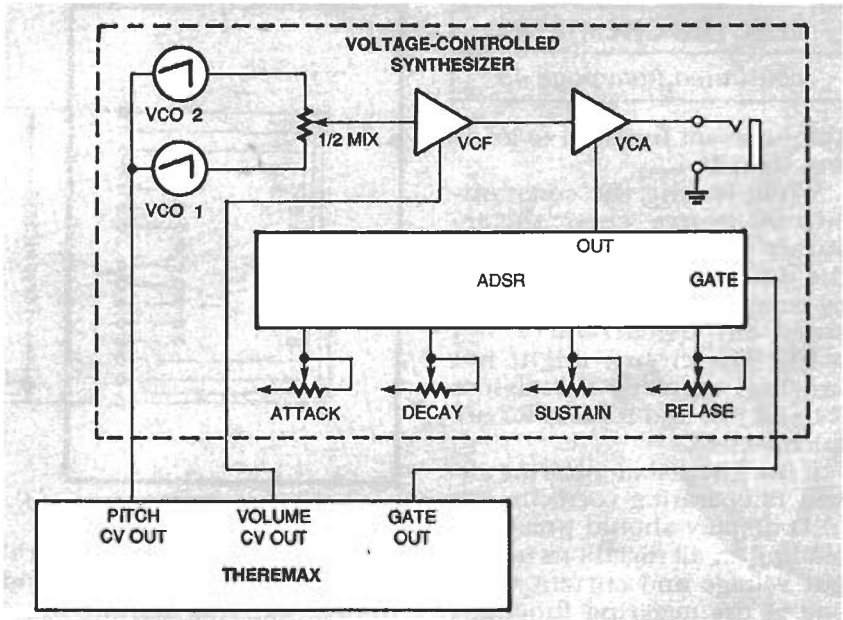


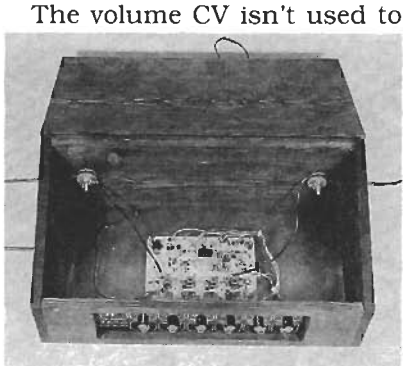
FIG. 10—VOLTAGE-CONTROLLED SYNTHESIZERS can be controlled by Theremax.

trolled analog music synthesizers, antiques that they are, have great cachet. Theremax makes a useful supplemental controller to the keyboards typically used in these instruments. Figure 10 shows only one of an unlimited number of possible "patches." The PITCH CV output sets the frequency of the synthesizer's voltage-controlled oscillators (VCOs), so that the right hand still controls pitch. VCOs will typically provide a greater selection of waveforms than just sine or square, and multiple oscillators will produce a fuller sound.

The volume CV isn't used to control volume; instead it's routed to the control-voltage input of the filter, so that the left hand now controls timbre instead.

So if volume is really timbre, how do you control volume? This is the cool part. As with most synthesizer patches, the dynamics of the sound—how fast it builds up and dies away—is controlled by an envelope generator, which here is triggered by Theremax's GATE output. The volume hand does still control volume, sort of, but now moving the hand quickly toward the antenna will trigger a sound with dynamics set by the envelope generator. And remember that the place where the hand ends the triggering move sets the timbre (VCF). You've got air drums!

Theremax's gate output and control voltages don't just respond to the gestures of a performer; they're actually general purpose people sensors and could be used to turn on or brighten lighting instruments arranged to accentuate different parts of a sculpture on the approach of an observer. Or produce kinetic art that responds to how quickly it's approached and how close a person stands. Music is just the beginning—there are a lot of possibilities. Ω



THE THEREMIN CIRCUIT BOARD mounted to the case bottom.

RESOURCES

Articles: *Keyboard* magazine, February 1994. Much of the issue is devoted to Leon Theremin and Clara Rockmore.
CD: Clara Rockmore, *The Art of the Theremin* (Delos D/CD 1014), Delos International, Inc., 2210 Wilshire Blvd., Suite 664, Santa Monica, CA 90403.
Internet: The Theremin home page, http://www.vuse.vanderbilt.edu/jbbarile/theremin.html.
Films: *Theremin: An Electronic Odyssey,* a film by Steven M. Martin.
Equipment: Theremins are also manufactured by Bob Moog's company: Big Briar, Inc., Rt. 3, Box 115A, Leicester, NC 28748.