

Build the EM Theremin

This classic electronic instrument gives good vibrations and excitations.

By Robert Moog



ost electronic musical instruments are sonic chameleons that try to sound like a wide variety of other things. Howinstrument that makes no

apologies for its single, immediately recognizable sound: the theremin. This monophonic instrument has added its distinctive, melodic character to the scores of many horror and suspense movies and made its pop debut on the Beach Boys' "Good Vibrations." It has also appeared on many concert stages, including Carnegie Hall.

The theremin was named after its inventor, Russian physicist and musician Leon Theremin, who developed the instrument in the 1920s. Unlike most musical instruments, the theremin is played with absolutely no physical contact. Players wave their hands in the air near two antennas. As one hand gets closer to the straight vertical tube (called the *pitch antenna*), the pitch rises; as the other hand gets closer to the horizontal tubular loop (called the volume antenna), the volume decreases. Because the theremin's pitch and volume are intimately tied to the play-

er's hand motions, the tone has a vibrant, wavering quality, not unlike a human voice or a violin.

Among the requests for DIY projects ever, there is one electronic that EM receives, by far the most common is a do-it-yourself theremin. The instrument presented here is an authentic theremin, with antenna response it is reasonably easy to build. It uses currently available components and

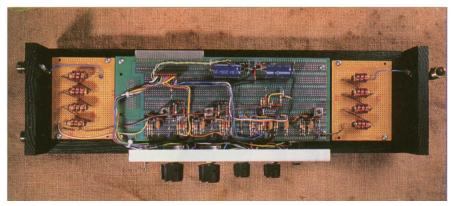
materials that you can buy at your local hardware store or from mail-order electronic-parts distributors. If you know how to read a schematic diagram, solder, and use a voltmeter, and if vou're comfortable with basic home tools, you should be able to build and adjust this theremin.

OVERVIEW

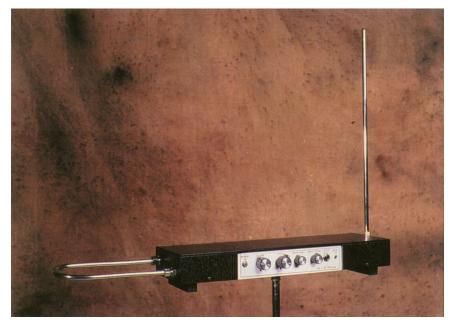
When you bring your hand near a theremin antenna, you are actually forming a variable capacitor: the antenna is one "plate" and your hand is the other. With the high frequencies and very low currents used by the instrument, your hand is effectively grounded by being attached to your body, so the antenna and your hand form a variable capacitor to ground. This variable capacitance is called hand capacitance. You increase the hand capacitance by bringing your hand nearer to the antenna. During normal operation, the hand capacitance is less than one picofarad, which is a very small capacitance indeed!

Each antenna forms a resonant circuit with a group of inductors collectively called an antenna coil. In this design, the resonant frequencies are about 260 kHz for the pitch antenna and about 450 kHz for the volume antenna. At or near the resonant frequency, a tiny change in hand capacitance results in a larger change in the impedance of the antenna circuit as a whole.

Refer to **Figure 1**, the functional block diagram, and Figure 2, the schematic diagram of the entire circuit. The variablecharacteristics, pitch range, and tone pitch oscillator (VPO), fixed-pitch oscillator color that closely emulate Leon (FPO), and detector sections form a beat-Theremin's original designs. However, frequency oscillator. Q1, Q2, and their associated components constitute the VPO, the frequency of which is set



The theremin's main circuitry is mounted on a single prototyping board, and the two antenna circuits are mounted on their own smaller boards.



The EM theremin closely emulates Leon Theremin's original design, although it is housed in a smaller cabinet.

frequency by about 3 kHz.

nents form the FPO, the frequency of components). hand is away from the pitch antenna. is about 0 dBm (0.8V RMS). The difference, or beat, frequency is hand near the pitch antenna, the used frequency of the audio waveform goes from 0 to about 3 kHz (3½ octaves above middle C).

Q5 and its associated components constitute the *pitch-tuning circuit*. This circuit presents a variable active impedance that is used to make fine adjustments to the FPO frequency while the instrument is being played. Frontpanel potentiometer P1 adjusts the current through Q5, thereby changing its active impedance.

Q6, Q7, and their associated components form the volume oscillator. Its frequency is set slightly higher than the resonant frequency of the volumeantenna circuit by adjusting L11. As the player brings a hand near the volume antenna, the resonant frequency of the volume-antenna circuit is lowered, and

slightly higher than the resonant fre- the DC voltage appearing at the juncquency of the pitch-antenna circuit (es- tion of D1 and C12 is reduced. The retablished by adjusting L5). As a player sulting current flowing through R14 is brings a hand near the pitch antenna, amplified and level-shifted by the VCA the changing impedance of the pitch processor section (U3-B and associated antenna circuit lowers the VPO components) and then fed through R30 to control the gain of the voltage-Q3, Q4, and their associated compo- controlled amplifier (U3-A and associated The amplitude-conwhich is set equal to the VPO frequen- trolled audio output is then fed to cy (by adjusting L6) when the player's front-panel jack J1. The maximum level

Q8 and its associated components extracted by the detector and appears constitute the volume-tuning circuit, as an audio waveform at the junction of which is nearly identical to the R23 and R24. As the player brings a pitchtuning circuit. Potentiometer P2 is to make fine adjustments to the volume-oscillator frequency during performance.

The audio waveform is applied to pin 3 of U3-A at a level high enough to clip it. This has the effect of reshaping the waveform from a skewed sine to a quasirectangular wave, which is very similar to the waveform of Professor Theremin's original instruments. P3 varies the input resistance of U3-A, which influences the amount by which the audio waveform is clipped. P4 shifts the bias at the input of U3-A, which changes the waveform width and therefore the output's harmonic spectrum. C24 and C26 roll off the high-frequency harmonics to produce a pleasant, cello-like tonal balance.

ANTENNAS

Making the antennas can be tricky. They should be metallic, rugged, attractively finished, capable of being rigidly mounted, and easy to fabricate by a home hobbyist. I have found that 3/8-inch soft copper tubing of the sort that plumbers use with bathroom sinks works well. You can buy preplated, straight, short pieces at your local builders' supply or hardware store. You can also purchase a simple tubing bender that will allow you to bend the volume antenna by hand without collapsing the tubing. You'll also need a tubing cutter or hacksaw to cut the tubing to length.

The finished pitch antenna is a straight, vertical tube eighteen inches long and 3/8 inch in diameter, and the finished volume antenna is a horizontal, hairpin loop with a total length of nine inches. The ends of the volume

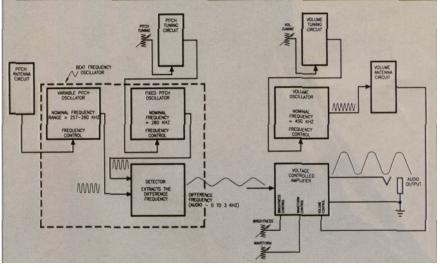


FIG. 1: This functional block diagram reveals how the theremin works.

inches, center to center.

I suggest you make the antennas longer than necessary and then cut them to length after they're formed and stiffened (discussed shortly). Start with this configuration is more sensitive to a straight, 24- or 36-inch length of tubing for each antenna. To form the volume antenna, slip the tubing bender over the tube. Then, starting ,at the midpoint of the tube, bend it into a semicircular curve. Hold the tube in both hands and push into the curve with your thumbs while pulling down with your other fingers. Doublecheck to make sure that the two ends of the volume antenna are parallel and are the correct distance apart.

Copper tubing has one drawback: because copper is soft enough to bend by hand, it is easy to put unwanted kinks in the tubing after it has been formed. You can stiffen the antennas by filling them with polyester resin (the liquid plus-hardener type used to repair car bodies) after you've formed them. This

so be sure you have plenty of time and you're at peace with the world.

The pitch antenna is straight because changing hand position when the hand is farther away and less sensitive when the hand is close. The change in hand capacitance is extremely small when the hand is far away, and the change in pitch as a function of distance must be as uniform as possible.

The volume antenna is looped because this configuration is less sensitive when the hand is far away and more sensitive when the hand is close. This gives you greater control over the low end of the dynamic range and lets you articulate notes by quickly dipping your left hand into the loop (more in a moment)

The two antennas are perpendicular to each other to minimize the interaction between them. For example, as you move your left hand tip and down

antenna should be separated by $3\frac{1}{4}$ is not particularly difficult, but the po- above the volume antenna, its motion is tential for making a mess is significant, parallel to the pitch antenna, which causes little or no change in pitch.

CABINET

The entire cabinet is made of wood. Except for the front panel, large metal cabinet parts should not be used, as they may add unnecessary capacitance to the antennas. My materials of choice are hardwood plywood for the top and solid hardwood for the rest of the cabinet because they are rugged, easy to shape accurately, and can be attractively finished.

The enclosure consists of a base and cover (see Fig. 3). The cover should fit snugly over the base. You may fasten pieces the together with anv combination of nails, wood screws, and wood glue, depending on how you like to put cabinets together. After the cabinet parts have been assembled, sand them down well and finish them with the wood finish of your choice, except metallic paint.

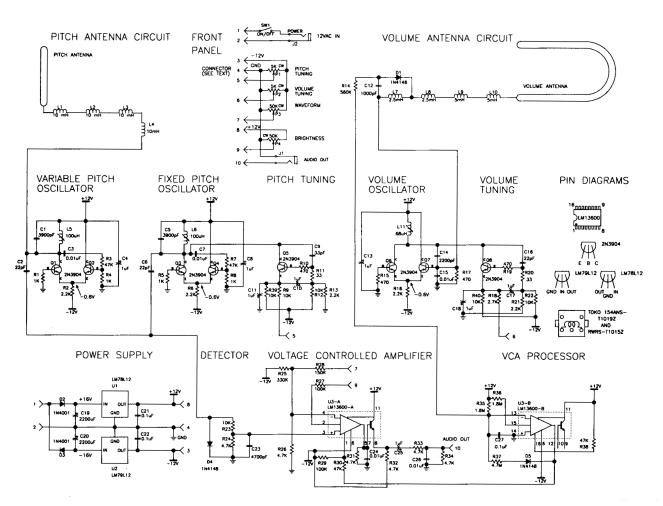


FIG. 2: The schematic for the EM theremin.

The antenna sockets are regular you use an insulated, 1/4-inch jack for sort used to assemble computer I/O tube-to-pipe connectors that you can get J1 to avoid a ground loop between the circuits provides the space, connection when you buy the copper tubing for the audio and power grounds. antennas. The volume-antenna sockets are straight 3/8-inch-tube-to-3/8inch-male-pipe connectors, whereas the pitch-antenna socket is a right-angle, 3/8-inch-tube-to-3/8-inch-male-pipe elbow. Drill 3/8-inch holes for these fittings; then screw them in by hand. If you can't screw the 3/8-inch pipe threads into the wood by hand, don't force it by using a pipe wrench: you may split the wood. Instead, enlarge the hole slightly with a large round file or a 3/8-inch pipe tap.

Once you're sure you can screw in the pipe fittings by hand, unscrew them. put a small amount of epoxy on the threads, and reinsert them by hand. Before the epoxy hardens, verify that the pitch-antenna socket is vertical by inserting the pitch antenna into the socket and adjusting the position of the socket as necessary.

Two 4/4-inch X 3/4-inch blocks and one microphone-stand mounting flange are attached to the bottom of the enclosure. This lets you set the finished unit on a microphone stand (preferred) or on a wood (*not* metal) table when you play it.

FRONT PANEL

The front panel should be made of 1/16-inch sheet aluminum. It should be about nine inches long and should have bends at the top and bottom for mounting and stiffening. You can either cut and bend the panel yourself or have your local sheet-metal shop do it for you. Alternatively, you can buy a blank, single-space (1U) rack panel, which is 1³/₄ inches high by nineteen inches wide, cut it to length with a hacksaw, and attach the panel to the base from the front instead of from the bottom. However, that will leave a 1/4-inch gap between the top of the panel and the enclosure cover.

Four rotary potentiometers, one 1/4-inch phone jack, one 1/8-inch minijack, and one toggle switch are mounted on the front panel. The two tuning pots should be located in the left part of the panel so your hand is as far from the pitch antenna as possible when You tune the antennas. Use high-quality, full-size rotary pots and large-diameter knobs for PI and P2, P3 and P4 are less critical; these pots can be miniature, and the knobs can be small. I suggest

Eight single-conductor wires and one shielded wire connect the front-panel components to the main circuit board, I suggest you use a connector for these wires so Von can unplug the panel if board. Prototyping boards often have provisions for mounting a DB15 or DB25 connector.

MAIN CIRCUIT BOARD

All circuitry (except the antenna circuits and front-panel components) is mounted on one circuit board (see Fig. 4). A plug-in prototyping board of the

provisions, and solidity you need. Radio Shack's prototyping board (catalog #276-1598) provides ample space for all the circuitry with extra room to try your own modifications.

The theremin's power is supplied by a you need to work on the main circuit ± 12 VAC wall wart, which is widely available (see sidebar "Where to Get Parts and Materials"). The AC voltage is converted into DC by two voltage regulators (UT, U2, and associated components). Keep the power-supply circuit components as close together as possible, and keep connections as short as you can. Be *really* sure that

THEREMIN: AN ELECTRONIC ODYSSEY

Leon Theremin lived a long, productive, and amazingly diverse life. He developed the theremin during the 1920s, a time when most people had never even heard of radio! He came from Russia to New York City in 1927 and instantly became the darling of

the cultural elite. He set up a laboratory and studio in midtown Manhattan, where he developed new instruments and tutored a long string of students. His greatest protege was Clara Rockmore, a young Russian musician who was originally trained as a classical violinist.

Professor Theremin's tenure in the United States came to an abrupt end one day in 1938, when he was taken back to Russia by Soviet agents under circumstances that are still not fully known. For decades after Theremin disappeared, nobody in the West knew of his whereabouts. Some publications even reported that Theremin had died in a Soviet prison during the Second World War. Fortunately, the rumors of his demise were premature; Theremin actually survived until 1993.

A few years ago, documentary filmmaker Steven Martin (not the comic actor) became interested in Theremin's story. He interviewed people who had known Theremin,

located old newsreels and home movies, and dug deep into the life of this amazing man. The result is a film entitled Theremin: An Electronic Oddessy. If you haven't already seen this movie, watch for it at your neighborhood cinema.



Clara Rockmore was Leon Theremin's greatest protege

An amazing array of people appear in the film, including Brian Wilson of the Beach Boys (talking about the use of theremin in "Good Vibrations"), Clara Rockmore, Jerry Lewis, and Todd Rundgren (do ing an on-camera imitation of the theremin). In addition, I discuss the technical side of theremins at several points in the film. But most important. the true story of Leon Theremin is told in a way you won't forget. -Robert Moog

that C20 and C22 are very close to U2. The negative side of C19 and the positive side of C20 should be connected together with a very short lead, and the grounded side of J2 should also be connected to this lead. The voltage regulators are less likely to oscillate if the connections are kept as short as possible.

Be sure to separate the VPO from the FPO by a couple of inches. These oscillators are already lightly coupled through C2 and C6, so they tend to synchronize at low beat frequencies (which is desirable). Placing the oscillator circuits close together increases the coupling, which may result in an excessive tendency to synchronize. In addition, place C4, C8, and C13 very close to the oscillator circuits with which they are associated to maximize the decoupling.

After the main board is assembled and checked, brush the solder side with a small wire brush and inspect for unwanted solder bridges, wiring mistakes, and weak solder joints. Then set the board in the middle of the cabinet base in preparation for final test and tuning.

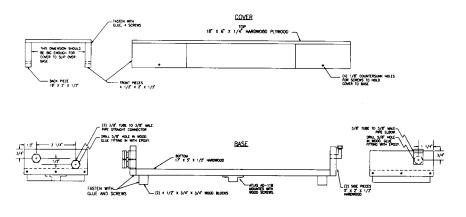


FIG. 3: Fabricating the cabinet requires some basic woodworking skills.

ANTENNA CIRCUIT BOARDS

antenna circuit board (see Fig. 4). Po- connected to the beginning of the next. sition the inductors so they are each terminal is distinct: one emerges close to the pitch-antenna socket.

from the center of the coil and the The inductors and other antenna-cir- other emerges from the outer layer of cuit components are mounted on two the coil. Arbitrarily select one terminal separate, small circuit boards with lit- as the beginning and the other as the tle or no copper circuit pattern. LI end, and connect the inductors in sethrough L4 are mounted on the pitch- ries so the end of one inductor is Position the board on the base next to parallel to one another and about one the pitch antenna. The free end of L4 inch apart, center to center. The should be close to the main circuit inductors are not polarized per se, but board, and the free end of Ll should be



Connect a short wire from the free end pitch-antenna circuit, position the nect the junction of L7 and C12 to the of LI to the pitch-antenna socket using inductors so they are parallel to one junction of C14 and C15, and connect a heavy soldering iron or by drilling another, about an inch apart, and con- the free end of R14 to pin 13 of U3. and tapping a hole for a 4-40 thread nected so the windings are end to beand then mounting a solder lug.

are mounted on the volume-antenna connect the free end of L10 to the volcircuit board (see Fig. 4). As with the ume-antenna socket. In addition, con-

nd then mounting a solder lug. ginning. Position the board near the L7 through L10, DI, C12, and R14 volume antenna, and install wires to

CHECKING IT OUT

After you've assembled and cleaned the main board, take a deep breath and check all your connections again. Look

Integrated CircuitsPotentiometersU1LM7811.12 12V positive regulatorU2LM7811.12 12V positive regulatorU3LM1360ON dual operational transcondance amplifier (National Semiconductor)TransistorsP3 P4O1-082N3904 NPNDindesNameD1, D4, D51N4148 signal diodeD1, D4, D51N4148 signal diodeD1, D4, D51N4148 signal diodeD1, D4, D51N4148 signal diodeD1, D51N4148 signal diodeD1, D4, D51N4148 signal diodeD2, D31M4001 power diodeC1, C53,900 pF/50V, 5%, polypropuler or polystyreneC4, C6, C1622 pF/50V, 5%, polypropuler or polystyreneC3, C7, C15, C260.01 µF/50V, 10%, polypester c13, C17, C8, C22C1, C22, C270.11 µF/35V tantalum electrolyticC142,200 µF/35V, sim, polyperopuler or polystyreneC19, C22, C270.11 µF/35V atamalum electrolyticC21, C22, C270.11 µF/35V atamalum electrolyticC22, C2, C270.11 µF/35V atamalum electrolyticC21, C22, C270.11 µF/35V atamalum 	PARTS LIST			
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Transistors Q1-Q8 $R1, R4, R5, R8$ $1 LQ$ Q1-Q82N3904 NPN $R2, R6, R13, R16, R21$ $2.2 k\Omega$ $R3, R7, R30, R3847 k\OmegaDidesD1, D4, D51N4148 signal diodeR2, R39, R4010 k\OmegaD2, D31N4001 power diodeR1, R20, R33, R4010 k\OmegaCapacitorsC1, C53,900 pF/50V, 5\%, polypropyleneor polystyreneR11, R2033\OmegaCapacitorsC2 C6, C 162.2 pF/50V, 5\%, polypropyleneor polystyreneR14560 k\OmegaC3, C7, C15, C260.01 \mu F/50V, 10\%, polysterR24 R26, R314.7 k\OmegaC3, C7, C15, C260.01 \mu F/50V, 10\%, polysterR25330 k\OmegaC4, C8, C10, C111.0 \mu F/35V tantalumR35, R361.8 M\OmegaC121.00 \mu F/50V, 10\%, polysterR25330 k\OmegaC121.00 \mu F/50V, 10\%, ceramicR27R22C142.200 \mu F/50V, 5\%, NPO (zerotemperature coefficient) ceramicR35, R361.8 M\OmegaC121.00 \mu F/50V, 10\%, ceramicSWithSPST miniature power switchC121.000 \mu F/50V, 10\%, ceramicSWithSPST miniature power switchC142.200 \mu F/S0V, 10\%, ceramicJ1Insulated ¼-inch phone jack(Switchcraft N-1 11 or equivalent)C21, C22, C270.1 \mu F/S0V ceramicJ1Insulated ¼-inch phone jack(Switchcraft N-1 11 or equivalent)C21, C22, C270.1 \mu F/S0V, 10\%, ceramicJ2J5 mm phone jack (SwitchcraftM1 or equivalent)L5, L6100 \mu FI, i-Q, variable inductor(Toko RWRS-11018Z)$		(National Semiconductor)		
Transistors Q1-Q8 $R1, R4, R5, R8$ $1 LQ$ Q1-Q82N3904 NPN $R2, R6, R13, R16, R21$ $2.2 k\Omega$ $R3, R7, R30, R3847 k\OmegaDidesD1, D4, D51N4148 signal diodeR2, R39, R4010 k\OmegaD2, D31N4001 power diodeR1, R20, R33, R4010 k\OmegaCapacitorsC1, C53,900 pF/50V, 5\%, polypropyleneor polystyreneR11, R2033\OmegaCapacitorsC2 C6, C 162.2 pF/50V, 5\%, polypropyleneor polystyreneR14560 k\OmegaC3, C7, C15, C260.01 \mu F/50V, 10\%, polysterR24 R26, R314.7 k\OmegaC3, C7, C15, C260.01 \mu F/50V, 10\%, polysterR25330 k\OmegaC4, C8, C10, C111.0 \mu F/35V tantalumR35, R361.8 M\OmegaC121.00 \mu F/50V, 10\%, polysterR25330 k\OmegaC121.00 \mu F/50V, 10\%, ceramicR27R22C142.200 \mu F/50V, 5\%, NPO (zerotemperature coefficient) ceramicR35, R361.8 M\OmegaC121.00 \mu F/50V, 10\%, ceramicSWithSPST miniature power switchC121.000 \mu F/50V, 10\%, ceramicSWithSPST miniature power switchC142.200 \mu F/S0V, 10\%, ceramicJ1Insulated ¼-inch phone jack(Switchcraft N-1 11 or equivalent)C21, C22, C270.1 \mu F/S0V ceramicJ1Insulated ¼-inch phone jack(Switchcraft N-1 11 or equivalent)C21, C22, C270.1 \mu F/S0V, 10\%, ceramicJ2J5 mm phone jack (SwitchcraftM1 or equivalent)L5, L6100 \mu FI, i-Q, variable inductor(Toko RWRS-11018Z)$			Resistors (%W, 5%, metal or carbon film)	
Q1-Q8 2N3904 NPN R2, R6, R13, R16, R21 22 kG Diodes R3, R7, R30, R38 47 kG D1, D4, D5 1N4148 signal diode R9, R12, R22 10 kG D2, D3 1N4001 power diode R10, R15, R17, R19 470G Capacitors 0 kD p50V, 5%, polypropylene R10, R15, R17, R19 470G C1, C5 3.900 pF/S0V, 5%, polypropylene R12, R22 10 kG C2 C6, C 16 22 pF/S0V, 5%, NPO (zero R18 2.7 kG C3, C7, C15, C26 0.01 µF/S0V infaitum R27, R29 100 kG C3, C7, C15, C26 0.01 µF/S0V infaitum R38, R36 1.8 MQ C3, C7, C15, C26 0.01 µF/S0V infaitum R35, R36 1.8 MQ C3, C17, C18, C25 1.0 µF/S5V intaitum R35, R36 1.8 MQ C19, C20 2.200 µF/S0V, 5%, NPO (zero R37 4.7 MQ C21, C22, C27 0.1 µF/S0V atamitum R35, R36 1.8 MQ C23 4.700 pF/S0V, 10%, ceramic J1 Insulated ¼-inch phone jack C3, C2, C27 0.1 µF/S0V atamitum S75 J1 <	Transistors		• • • •	
DiodesR3, R7, R30, R38 47 kQ D1, D4, D51N4148 signal diodeR3, R7, R30, R38 47 kQ D2, D31N4001 power diodeR10, R15, R17, R19 470 Q Capacitors1N4001 power diodeR14560 kQC1, C53,900 pF/50V, 5%, polypropylene or polystyrene or polystyrene (C2, C6, C16 22 pF/50V , 5%, NPO (zero temperature coefficient) ceramic R24, R26, R31 4.7 kQ C3, C7, C15, C260.01 μ /F/30V, 10%, polyester temperature coefficient) ceramic R32, R33, R34 4.7 kQ C4, C8, C10, C111.0 μ F/35V tantalum temperature coefficient) ceramic temperature coefficient) ceramic ro polystyrene C12 83μ F/30V, 5%, NPO (zero temperature coefficient) ceramic response temperature coefficient) ceramic ro polystyrene or polystyrene (J. U. M. Miler #6306)Insulated W-inch phone jack (Switchcraft N-1 11 or equiv		2N3904 NPN		
Diodes D1, D4, D5 1N4148 signal diode 1N4001 power diode R9, R12, R22 10 kΩ Capacitors C1, C5 3,900 pF/50V, 5%, polypropylene or polystyrene C1, C5 3,900 pF/50V, 5%, polypropylene or polystyrene or polystyrene 7, KΩ 7, KΩ C2 C6, C 16 22 pF/50V, 5%, NPO (zero temperature coefficient) ceramic C3, C7, C15, C26 0.01 µF/50V, 10%, polyester R24, R26, R31 4,7 KΩ C3, C7, C15, C26 0.01 µF/50V, 10%, polyester R24, R26, R31 4,7 KΩ C4, C3, C10, C11 1.0 µF/35V tantalum remperature coefficient) ceramic C13, C17, C18, C25 1.0 µF/35V tantalum respective coefficient) ceramic C14 7, R36 1.8 MΩ C9 33 µF/50V, 5%, polypropylene rop olystyrene Switch R37 4,7 MΩ C1, C22 1.0 µF/35V tantalum respective coefficient) ceramic C14 2,200 µF/35V, s%, polypropylene rop olystyrene Switch SW1 SPST miniature power switch C19, C20 2,200 µF/35V aluminum electrolytic J1 Insulated ¼-inch phone jack (J. W. Miller #6306) J2 C21, C22, C27 0.1 µF/50V, 10%, ceramic (J. W. Miller #6306) J2 3.5 mm phone jack (Switchcraft 41 or equivalent) C24 3.300 pF/50V, 10%, ceramic (T0ko RWRS-T10152) J2 3.5 mm phone jack (Switchcraft 41 or equivalent)				
D1, D4, D51N4148 signal diodeR23, R39, R4010 kΩD2, D31N4001 power diodeR10, R15, R17, R19470ΩCapacitorsR11, R2033ΩC 1, C53,900 pF/50V, 5%, polypropyleneR14560 kΩC 2 C6, C 16R17, R1910 kΩC 2 C6, C 16R18C 4, C8, C10, C11R27, R29100 kΩC 3, C7, C15, C26R18C 4, C8, C10, C11R35, R361.8 MΩC 3, C7, C15, C26R35, R361.8 MΩC 3, C7, C15, C26R35, R361.8 MΩC 3, C7, C15, C26R374.7 KQC 4, C8, C10, C11R35, R361.8 MΩC 3, C7, C15, C26R374.7 MΩC 9R374.7 MΩC 14SPST miniature power switchC12SWitchC14SPST miniature power switchC23C24, C22, C27C19, C20C21, C22, C27<	Diodos			10 kΩ
D1, D1, D2, D3In Hold signal dodeR10, R15, R17, R19 4702 D2, D31N4001 power diodeR11, R20 332 Capacitors 332 C1, C53,900 pF/50V, 5%, polypropylene or polystyreneR14560 kΩC2 C6, C 1622 pF/50V, 5%, NPO (zero temperature coefficient) ceramicR14560 kΩC3, C7, C15, C260.01 µF/50V, 10%, polyester temperature coefficient) ceramicR25330 kΩC4, C8, C10, C1110 µF/35V tantalumR35, R361.8 MΩC331 µF/50V, 5%, polypropylene or polystyreneR35, R361.8 MΩC12.200 µF/30V, 10%, ceramicSwitchC142.200 µF/30V, 5%, polypropylene or polystyreneSwitchC19, C202.200 µF/35V atuminum electrolyticSwitchC21, C22, C270.1 µF/50V, 10%, ceramicSwitchC234,700 µF/50V, 10%, ceramicJ1Insulated ¼-inch phone jackC243,300 µF/50V, 10%, ceramicJ1Insulated ¼-inch phone jackC31, L22, C270.1 µF/50V, 10%, ceramicJ23.5 mm phone jack (Switchcraft N-1 11 or equivalent)J2J2 miniature power switchJ23.5 mm phone jack (Switchcraft N-1 11 or equivalent)L1, L2, L3, L410 mH, 3-section, RIF choke (J, W. Miller #6306)In 6-pin IC socket for U3L5, L6100 PH, hi-Q, variable inductor (Toko RWRS-T1015Z)Two samal knobs for PC and P2L9, L105 mH, 3-section, RF choke (J, W. Miller #6304)Two samal knobs for P2 and P4L1168 µH, hi-Q, variable		1N/11/8 signal diado	R23, R39, R40	10 kΩ
Capacitors C1, C53.900 pF/50V, 5%, polypropylene or polystyreneR11, R20330C2 C6, C 1622 pF/50V, 5%, PPO (zero temperature coefficient) ceramicR27, R29100 kΩC3, C7, C15, C260.01 μ F/50V, 10%, polyesterR32, R33, R344.7 kΩC4, C8, C10, C111.0 μ F/35V tantalumR35, R361.8 MΩC933 μ F/50V, 5%, NPO (zero temperature coefficient) ceramicR38, R361.8 MΩC1(1.000 pF/50V, 10%, ceramicR374.7 MΩC12,200 μ F/50V, 5%, NPO (zero temperature coefficient) ceramicSwitchC142,200 pF/50V, 5%, polypropylene or polystyreneSwitchC19, C202,200 μ F/50V, 10%, ceramicSwitchC21, C22, C270.1 μ F/50V ceramicSwitchC21, C22, C270.1 μ F/50V, 10%, ceramicJ1C243,300 pF/50V, 10%, ceramicJ2C34,700 pF/50V, 10%, ceramicJ2C34,700 pF/50V, 10%, ceramicJ2C34,700 pF/50V, 10%, ceramicJ2C34,700 pF/50V, 10%, ceramicJ2C43,300 pF/50V, 10%, ceramicJ2C34,700 pF/50V, 10%, ceramicJ2C35, mH, 3-section, RIF choke (J. W. Miller #6306)I6-pin IC socket for U3L5, L6100 pH, hi-Q, variable inductor (Toko RWRS-T1015Z)Connectorse with at least ten conductors for connections between the main circuit board and front panelL9, L105 mH, 3-section, RF choke (J. W. Miller #6302)Two small knobs for PC and P2L9, L105 mH, 3		-		470Ω
Clip C5 $3,900 \text{ pF/50V}$, 5%, polypropylene or polystyrene C2 C6, C 16R18 $2.7 \text{ k}\Omega$ R27, R29C2 C6, C 16 22 pF/50V , 5%, NPO (zero temperature coefficient) ceramic C4, C8, C10, C11 $1.0 \mu \text{ µF/35V}$ tantalum R24, R26, R31 $4.7 \text{ k}\Omega$ R24, R26, R31C3, C7, C15, C26 $0.01 \mu \mu \text{ µF/35V}$ tantalum C3 $1.0 \mu \mu \text{ µF/35V}$ tantalum R24, R26, R31 $4.7 \text{ k}\Omega$ R25C4, C8, C10, C11 $1.0 \mu \mu \text{ µF/35V}$ tantalum C9 $1.0 \mu \mu \text{ µF/35V}$ tantalum R35, R36 $1.8 \text{ M}\Omega$ R37C12 $1.000 \mu \text{ µF/35V}$ tantalum electrolyticR37 $4.7 \text{ M}\Omega$ C14 $2.200 \mu \text{ Pf/50V}$, 5%, polypropylene or polystyrene C21, C22, C27 $Switch$ Switch SW1C19, C20 $2.200 \mu \text{ Pf/50V}$, 6%, oplypropylene or polystyreneSwitch SW1SPST miniature power switchC14 $2.200 \mu \text{ Pf/50V}$, 10%, ceramic C21, C22, C27 $0.1 \mu \text{ µF/50V}$, ceramic C21, C22, C27 $0.1 \mu \text{ µF/50V}$, ceramic C21, C22, C27 $0.1 \mu \text{ µF/50V}$, 10%, ceramic C21, C22, C27 $0.1 \mu \text{ µF/50V}$, 10%, ceramic C21, C22, C27 $0.1 \mu \text{ µF/50V}$, 10%, ceramic 	D2, D3	IN4001 power diode		33Ω
C I, C53,900 pF/50V, 5%, polypropylene or polystyreneR18 2.7 K0 C2 C6, C 1622 pF/50V, 5%, NPO (zero temperature coefficient) ceramicR27, R29100 kΩC3, C7, C15, C260.01 µF/50V, 10%, polyesterR24R26, R314.7 kQC4, C8, C10, C1110 µF/35V tantalumR25330 kΩC13, C17, C18, C251.0 µF/35V tantalumR35, R361.8 MΩC142.200 µF/50V, 5%, NPO (zero temperature coefficient) ceramicR374.7 MΩC142.200 µF/50V, 10%, ceramicSwitchC142.200 µF/50V, 10%, ceramicSwitchC142.200 µF/50V, 10%, ceramicSwitchC19, C202.200 µF/50V, 10%, ceramicJ1C21, C22, C270.1 µF/50V ceramicSwitchC234,700 pF/50V, 10%, ceramicJ1C243,300 pF/50V, 10%, ceramicJ2C324,700 pF/50V, 10%, ceramicJ2C3410 mH, 3-section, RIF choke (J. W. Miller #6306)J2L5, L6100 pH, hi-Q, variable inductor (Toko RWRS-T10152)Toko RKRS-T10152)L7, L82.5 mH, 3-section, RF choke (J. W. Miller #6302)Section RF choke (J. W. Miller #6304)L1168 µH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two small knobs for P2 and P4L1168 µH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two cal-to k3-inch x 3/8-inch straight copper tubes for antennasTube bender for volume antenna A tlas AD-11 B microphone-stand mounting flange -10-inch x 4-inch prototyping circuit board	Canacitora		R14	560 kΩ
or polystyreneR27, R29100 k0C2 C6, C 1622 pF/50V, 5%, NPO (zeroR24 R26, R314.7 kΩC3, C7, C15, C260.01 μ F/35V, 10%, polyesterR25330 kΩC4, C8, C10, C111.0 μ F/35V tantalumR35, R361.8 MΩC13, C17, C18, C251.0 μ F/35V tantalumR35, R361.8 MΩC23.3 μ F/30V, 5%, NPO (zeroR374.7 MΩC9temperature coefficient) ceramicR374.7 MΩC121,000 pF/50V, 10%, ceramicSwitchC142.200 μ F/35V aluminumSPST miniature power switchC19, C202.200 μ F/35V aluminumSwitchC21, C22, C270.1 μ F/50V, 10%, ceramicJ1C234,700 pF/50V, 10%, ceramicJ1C243,300 pF/50V, 10%, ceramicJ1C3410 mH, 3-section, RIF chokeJ1L1, L2, L3, L410 mH, 3-section, RIF choke.L1, L2, L3, L410 mH, 3-section, RIF choke.L7, L82.5 mH, 3-section, RIF choke.L7, L82.5 mH, 3-section, RIF choke.L9, L105 mH, 3-section, RF choke.L1168 μ H, hi-Q, variable inductor (Toko T54ANS-T1019Z)Two large knobs for P3 and P4L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Tube bender for volume antennaL1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Tube bender for volume antennaL1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two large knobs for P3 and P4L1168 μ H, h	•	2.000 pE/EQV = 5% polypropylopo	R18	
C2 C6, C 1622 pF/50V, 5%, NPO (zero temperature coefficient) ceramic 0.01 μ F/35V tantalumR32, R33, R344.7 kΩ R25C3, C7, C15, C260.01 μ F/35V tantalumR32, R33, R344.7 kΩC3, C7, C15, C251.0 μ F/35V tantalumR35, R361.8 MΩC3, C17, C18, C251.0 μ F/35V tantalumR35, R361.8 MΩC933 μ F/50V, 5%, NPO (zero temperature coefficient) ceramicR374.7 KΩC121.000 pF/50V, 10%, ceramicR374.7 MΩC142.200 pF/50V, 5%, polypropylene or polystyreneSwitchC142.200 µF/35V aluminum electrolyticSwitchC234.700 pF/50V, 10%, ceramicJ1Insulated ¼-inch phone jack (Switchcraft N-1 11 or equivalent)C243.300 pF/50V, 10%, ceramicJ23.5 mm phone jack (Switchcraft 41 or equivalent)L1, L2, L3, L410 mH, 3-section, RIF choke (J. W. Miller #6306)Parts Not on SchematicL7, L82.5 mH, 3-section, RIF choke (J. W. Miller #6302)·16-pin IC socket for U3L9, L105 mH, 3-section, RIF choke (J. W. Miller #6304)··L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)·Two samit knobs for P2 and P2L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)·Two samit knobs for P3 and P4L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)·Tube bender for volume antenna ·L1061 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)·Two samit knobs for P3 and P4L10<	01,00		R27, R29	100 kΩ
R32, R344.7 kGC3, C7, C15, C260.01 μ F/50V, 10%, polyester330 kGC4, C3, C10, C111.0 μ F/35V tantalumR25330 kGC13, C17, C18, C251.0 μ F/35V tantalumR374.7 MGC933 μ F/50V, 5%, NPO (zeroR374.7 MGC121.00 μ F/35V tantalumR374.7 MGC13, C17, C18, C251.0 μ F/35V tantalumR374.7 MGC142.200 μ F/35V tantalumR374.7 MGC142.200 μ F/35V tantalumR374.7 MGC142.200 μ F/35V, 10%, ceramicSwitchC19, C202.200 μ F/35V, 10%, ceramicSwitchC21, C22, C270.1 μ F/35V no%, polypropyleneJ1Insulated ¼-inch phone jackC234,700 μ F/50V, 10%, ceramicJ1Insulated ¼-inch phone jack (Switchcraft h^{-1} 1 11 or equivalent)C243,300 μ F/35V, 10%, ceramicJ1Insulated ¼-inch phone jack (Switchcraft h^{-1} 1 1 or equivalent)L1, L2, L3, L410 mH, 3-section, RIF choke (J. W. Miller #6304)Parts Not on SchematicL7, L82.5 mH, 3-section, RIF choke (J. W. Miller #6304)16-pin IC socket for U3L9, L105 mH, 3-section, RF choke (J. W. Miller #6304)11L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)17 wo large knobs for PC and P2L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)17 wo large knobs for PC and P2L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)17 wo large knobs for PC and P2L	C2 C6 C 16		R24 R26, R31	4.7 kΩ
C3, C7, C15, C26 C4, C8, C10, C11 C13, C17, C18, C25 C9 C12 C12 C12 C14 C13, C27 C14 C14 C14 C2, C20 C14 C14 C14 C2, C20 C15, C20 C15, C26 C14 C21, C22, C27 C14 C21, C22, C27 C14 C21, C22, C27 C14 C21, C22, C27 C14 C21, C22, C27 C14 C224 C21, C22, C27 C14 C21, C22, C27 C14 C224 C21, C22, C27 C14 C23 C24 C24 C24 C25 C10 C24 C25 C10 C24 C25 C24 C25 C27 C24 C27 C27 C24 C24 C27 C24 C27 C27 C24 C27 C27 C27 C27 C27 C24 C27 C27 C24 C27 C24 C27 C24 C27 C27 C27 C27 C27 C27 C27 C27	02 00, 0 10		R32, R33, R34	4.7 kΩ
C4, C6, C10, C111.0 μ F/35V tantalumR28150 kQC13, C17, Cl8, C251.0 μ F/35V tantalumR35, R361.8 MQC933 μ F/50V, 5%, NPO (zero temperature coefficient) ceramicR374.7 MQC121,000 pF/50V, 10%, ceramicSwitchC142,200 pF/50V, 5%, polypropylene or polystyreneSwitchC19, C202,200 μ F/35V aluminum electrolyticSwitchC21, C22, C270.1 μ F/50V ceramicJ1C234,700 pF/50V, 10%, ceramicJ1C243,300 pF/50V, 10%, ceramicJ2C344,700 pF/50V, 10%, ceramicJ2C43,300 pF/50V, 10%, ceramicJ2C43,300 pF/50V, 10%, ceramicJ2C5, L6100 pH, hi-Q, variable inductor (Toko RWRS-T1015Z)Parts Not on SchematicL7, L82.5 mH, 3-section, RIF choke (J. W. Miller #6302)Naller #6304)L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two large knobs for P2 and P4 (J. W. Miller #6304)L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two large knobs for P3 and P4 (J. W. Aliner #6304)L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two large knobs for P3 and P4 (J. W. Aliner #6304)L1050 mH, 3-section, RF choke (J. W. Miller #6304)Two large knobs for P3 and P4 (J. W. Aliner #6304)L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two large knobs for P3 and P4 (J. W. Aliner #6304)L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two large kno	C3 C7 C15 C26	• •	R25	330 kΩ
C13, C17, Cl8, C251.0 μ F/35V tantalumR35, R361.8 MΩC933 μ F/50V, 5%, NPO (zero temperature coefficient) ceramicR374.7 MΩC121,000 pF/50V, 10%, ceramicSwitchC142,200 pF/50V, 5%, polypropylene or polystyreneSwitchC19, C202,200 μ F/35V aluminum electrolyticSwitchC21, C22, C270.1 μ F/50V ceramicJ1C234,700 pF/50V, 10%, ceramicJ1C243,300 pF/50V, 10%, ceramicJ2C243,300 pF/50V, 10%, ceramicJ2C243,300 pF/50V, 10%, ceramicJ2C34,700 pF/50V, 10%, ceramicJ2C43,300 pF/50V, 10%, ceramicJ2C43,300 pF/50V, 10%, ceramicJ2C43,300 pF/50V, 10%, ceramicJ2C5, L6100 pH, hi-Q, variable inductor (Toko RWRS-T1015Z)Connector set with at least ten conductors for connections between the main circuit board and front panelL7, L82.5 mH, 3-section, RIF choke (J. W. Miller #6302)Wall-wart transformer to provide 12 to 15 ILIAC with at least 200 mA (Cui-Stack DPA120020-P1-SZ)L105 mH, 3-section, RF choke (J. W. Miller #6304)Two large knobs for PC and P2L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two saml knobs for P3 and P4L1168 μ H, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two bender for volume antenna attennas.Tube bender for volume antenna attennas.Tube bender for volume antenna attennas			R28	150 kΩ
C933 μF/50V, 5%, NPO (zero temperature coefficient) ceramic 0 polystyreneR374.7 MΩC121,000 pF/50V, 10%, ceramic or polystyreneSwitchC142,200 pF/50V, 5%, polypropylene or polystyreneSwitchC19, C202,200 µF/35V aluminum electrolyticSwitchC21, C22, C270.1 µF/50V ceramic (23)J1C234,700 pF/50V, 10%, ceramic (24)J1C243.300 pF/50V, 10%, ceramic (24)J2C243.300 pF/50V, 10%, ceramic (J. W. Miller #6306)L5, L6100 pH, hi-Q, variable inductor (Toko RWRS-T10152)L7, L82.5 mH, 3-section, RIF choke (J. W. Miller #6302)L9, L105 mH, 3-section, RF choke (J. W. Miller #6304)L1168 µH, hi-Q, variable inductor (Toko 154ANS-T1019Z)L1168 µH, hi-Q, variabl		•	R35, R36	1.8 MΩ
temperature coefficient) ceramicC121,000 pF/50V, 10%, ceramicC142,200 pF/50V, 5%, polypropylene or polystyreneC19, C202,200 µF/35V aluminum electrolyticC19, C202,200 µF/35V aluminum electrolyticC21, C22, C270,1 µF/50V ceramicC234,700 pF/50V, 10%, ceramicC243,300 pF/50V, 10%, ceramicC243,300 pF/50V, 10%, ceramicL1, L2, L3, L410 mH, 3-section, RIF choke (J. W. Miller #6306)L5, L6100 pH, hi-Q, variable inductor (Toko RWRS-T1015Z)L7, L82.5 mH, 3-section, RIF choke (J. W. Miller #6302)L9, L105 mH, 3-section, RF choke (J. W. Miller #6304)L1168 µH, hi-Q, variable inductor (Toko 154ANS-T1019Z)L1168 µ			R37	4.7 ΜΩ
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electrolyticConnectorsC21, C22, C270.1 μF/5OV ceramicJ1Insulated ¼-inch phone jack (Switchcraft N-1 11 or equivalent)C234,700 pF/50V, 10%, ceramicJ1Insulated ¼-inch phone jack (Switchcraft N-1 11 or equivalent)C243,300 pF/50V, 10%, ceramicJ23.5 mm phone jack (Switchcraft 41 or equivalent)InductorsJ2S.5 mm phone jack (Switchcraft 41 or equivalent)L1, L2, L3, L410 mH, 3-section, RIF choke (J. W. Miller #6306)Connector set with at least ten conductors for connections between the main circuit board and front panelL7, L82.5 mH, 3-section, RIF choke (J. W. Miller #6302)Connector set with at least ten conductors for connections between the main circuit board and front panelL9, L105 mH, 3-section, RIF choke (J. W. Miller #6304)Wall-wart transformer to provide 12 to 15 ILIAC with at least 200 mA (Cui-Stack DPA120020-P1-SZ)L1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two small knobs for P3 and P4L1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Tube bender for volume antenna Atlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board	C19. C20			
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InductorsParts Not on SchematicL1, L2, L3, L410 mH, 3-section, RIF choke (J. W. Miller #6306)9L5, L6100 pH, hi-Q, variable inductor (Toko RWRS-T1015Z)16-pin IC socket for U3L7, L82.5 mH, 3-section, RIF choke (J. W. Miller #6302)9L9, L105 mH, 3-section, RF choke (J. W. Miller #6304)9L1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two 24- to 36-inch x 3/8-inch straight copper tubes for antennasL1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Tube bender for volume antenna Atlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board			J2	
 L1, L2, L3, L4 L0 mH, 3-section, RIF choke (J. W. Miller #6306) L5, L6 L7, L8 L7, L8 L9, L10 L11 Connector set with at least ten conductors for connections (J. W. Miller #6302) L9, L10 Connector set with at least ten conductors for connections (J. W. Miller #6302) L9, L10 Connector set with at least ten conductors for connections (J. W. Miller #6304) L11 Connector set with at least ten conductors for connections between the main circuit board and front panel Wall-wart transformer to provide 12 to 15 ILIAC with at least 200 mA (Cui-Stack DPA120020-P1-SZ) Two large knobs for PC and P2 Two small knobs for P3 and P4 Two 24- to 36-inch x 3/8-inch straight copper tubes for antennas Tube bender for volume antenna Atlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board 				41 or equivalent)
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L5, L6100 pH, hi-Q, variable inductor (Toko RWRS-T1015Z)between the main circuit board and front panelL7, L82.5 mH, 3-section, RIF choke (J. W. M i ller #6302)Wall-wart transformer to provide 12 to 15 ILIAC with at least 200 mA (Cui-Stack DPA120020-P1-SZ)L9, L105 mH, 3-section, RF choke (J. W. Miller #6304)Two large knobs for PC and P2L1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two 24- to 36-inch x 3/8-inch straight copper tubes for antennasL1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Tube bender for volume antennaAtlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board	L1, L2, L3, L4	10 mH, 3-section, RIF choke	16-pin IC socket for U3	
 (Toko RWRS-T1015Z) L7, L8 L9, L10 L11 Charlen (J, W, Miller #6304) L11 Charlen (J, W, Miller #6304) L11 Charlen (J, W, Miller #6304) Charlen (J, W, Miller (J, W, W, Miller #6304) Charlen (J, W, W, M, Millen (J, W, W,		(J. W. Miller #6306)	Connector set with at least ten conductors for connections	
L7, L82.5 mH, 3-section, RIF choke (J. W. M i ller #6302)200 mA (Cui-Stack DPA120020-P1-SZ)L9, L105 mH, 3-section, RF choke (J. W. Miller #6304)Two large knobs for PC and P2L1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two 24- to 36-inch x 3/8-inch straight copper tubes for antennasL1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Tube bender for volume antennaAtlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board				
 (J. W. M i ller #6302) L9, L10 5 mH, 3-section, RF choke (J. W. Miller #6304) L11 68 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z) Two large knobs for PC and P2 Two small knobs for P3 and P4 Two 24- to 36-inch x 3/8-inch straight copper tubes for antennas Tube bender for volume antenna Atlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board 		,	 Wall-wart transform 	ner to provide 12 to 15 ILIAC with at least
L9, L105 mH, 3-section, RF choke (J. W. Miller #6304)Two small knobs for P3 and P4L1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Two 24- to 36-inch x 3/8-inch straight copper tubes for antennasL1168 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z)Tube bender for volume antennaAtlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board	L7, L8		200 mA (Cui-Stack DPA120020-P1-SZ)	
 (J. W. Miller #6304) L11 68 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z) Two sinial kitos for 10 and 14 Two 24- to 36-inch x 3/8-inch straight copper tubes for antennas Tube bender for volume antenna Atlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board 			 Two large knobs fo 	r PC and P2
 L11 68 μH, hi-Q, variable inductor (Toko 154ANS-T1019Z) Carter of the L+ to on more x or more x o	L9, L10	, ,		
 (Toko 154ANS-T1019Z) Tube bender for volume antenna Atlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board 			 antennas Tube bender for volume antenna Atlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board 	
 Atlas AD-11 B microphone-stand mounting flange 10-inch x 4-inch prototyping circuit board 	L11			
 10-inch x 4-inch prototyping circuit board 		(Toko 154ANS-T1019Z)		
Two A inch v 2 inch prototyping boards for the antenno				
Two 4-inch x 3-inch prototyping boards for the antenna			Two 4-inch x 3-inch	n prototyping boards for the antenna
circuits			circuits	

tions, etc. Then connect the front panel detector, measure the DC voltage connect pin 12 of U3 to ground. (This to the main board, plug in the power across R24. If it's -0.5V or so, the should turn on the VCA.) Connect supply, and turn the power switch on.

Use a voltmeter to check the voltages everything until you find the problem.

you don't read any voltage at all, the is in good shape.

for shorts, mistakes, missing connec- oscillator is not working. To check the detector is working.

Temporarily connect a pair of across R34. You should hear a someat the inputs and outputs of U1 and U2 headphones or a small powered speaker what louder tone. Now, disconnect the (see Fig. 2). Then check the DC across R24. Turn the tuning slugs in L5 temporary ground connection to pin voltages at the collectors of Q1 through and L6 counterclockwise until the tops 12 of U3, and connect that pin to -12V. Q8 (they should all be about +12V); the of the slugs hit the shield cans. Be The audio across R34 should disappear. emitters of Q1 through Q4, Q6, and Q7 *careful. Do not force the slugs farther*. If it does, the VCA is working properly. (about 0.6V); and the emitters of Q5 than they want to go! Turn L5 exactly and Q8 (about -2.6V). If you don't two turns clockwise. Then turn L6 ground, you can also check the Brightobserve all these readings, check clockwise slowly until you hear a high- ness and Waveform controls (P3 and pitched whistle. Keep turning until the P4). Use the Pitch Tuning control (PI) Next, verify that all three oscillators tone is in the mid range (about I kHz). to set the tone's pitch to approximately are working. Read the AC voltages Now, turn P1 in either direction. You middle C. Then turn the Brightness and across L5, L6, and L1 I. If you read should hear the pitch change markedly. Waveform controls. The Brightness about 10 VAC, then the corresponding If you observe all these things, then the control should change the sound from oscillator is producing a waveform. If entire beat-frequency oscillator circuit muted to bright, and the Waveform

To check the VCA, temporarily headphones or monitor amp your While pin 12 of U3 is connected to control should change the sound

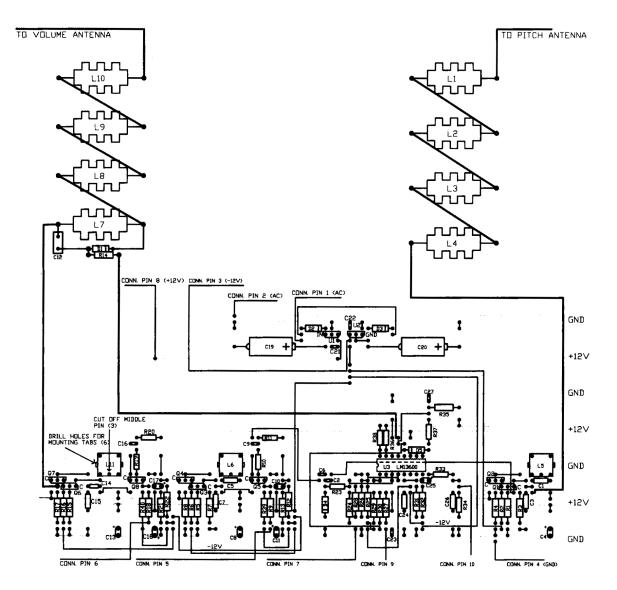


FIG. 4: The position of certain components is critical to minimize unwanted oscillations and capacitances

from "reedy" (narrow waveform) to $3 \text{ kHz} (3 \frac{1}{2} \text{ octaves above middle C}).$ "full" (wider waveform). After you have checked all of these controls, remove the temporary connection to pin 12 of U3.

TUNING

Before tuning, clean off your workbench and move aside any large, conductive objects such as desk lamps and test gear. Leave a clear space of two or three feet around your work area. Place the cabinet base in the middle of the cleared space, put the pitch antenna in place, and connect the pitch-antenna circuit board between the antenna and the main board. On the main board, temporarily connect pin 12 of U3 to ground and connect the instrument's audio output to headphones or a monitor amplifier. Now follow these steps to adjust L5 and L6:

1. Set PI (the Pitch Tuning control) to its middle position.

2. Grasp and hold the pitch antenna with one hand. With the other hand, adjust L6 until the beat frequency is zero, Then carefully turn L6 counter*clockwise* until you hear a pitch of about

3. Let go of the pitch antenna. Slowly retract your hand from the vicinity of the antenna. You should hear the pitch

go down.

zero when you've retracted your hand completely and stepped back, the inductance of L5 is set too high. Advance the slug in L5 clockwise by a small amount, perhaps 1/10 turn or so, and

4. If the pitch does not go down to repeat steps 2 and 3.

WHERE TO GET PARTS AND MATERIALS

Most of the electronic parts for this project can be purchased from DigiKey individual parts are available from Big (tel. 800/344-4539 or 218/681-6674; fax Briar, Inc. (tel. 800/948-1990 or 218/681-3380: Web www.diaikev.com). Other include Allied (tel. 800/433-5700 or assembled and tested circuit board (with 817/595-3500; fax 817/595-6404; BBS antenna circuits), completely fabricated 800/433-5003; Web http://www.allied. front panel and antennas, and precut avnet.com), Mouser (tel. 800/346-6873 or 817/483-4422; fax 817/483-0931), and Newark (tel. 800/463-9275 or 312/ 784-5100; fax 312/907-5378). Radio Shack is a good place to shop for prototyping boards. You should be able to get wood for the cabinet and all the kit is \$229, including shipping within the materials to make the antennas at your United States. local hardware superstore.

A complete kit and many of the http:// 704/251-0090; fax 704/254-6233; email suppliers bigbriar@aol.com). The kit includes an cabinet parts. Also included are The Complete Theremin Video starring Lydia Kavina. Clara Rockmore's The Art of the Theremin CD. and Bob Mood's detailed and illustrated booklet on theremin technology and history. The price of the

5. If the pitch goes to zero and then from the volume antenna and the begins to ascend as you retract your volume begins to decrease noticeably hand, the inductance of L5 is set too when your left hand is brought within the instrument with your right shoulder low. Turn the slug in L5 counterclock- ten to twelve inches of the volume about 24 inches from the pitch antenna. wise by a small amount, and repeat antenna. Then set PI so the frequency is Relax your wrists. Think of a note and steps 2 and 3.

retract your hand, the inductance of L5 becomes apparent when you bring your until the theremin pitch coincides with is set far too low. Turn the slug in L5 right hand within 18 to 24 inches of the the pitch you're humming. Now hold counterclockwise approximately quarter-turn and repeat steps 2 and 3.

is to find the settings at which the fre- some practice. You can start by follow- of practice will work wonders.

quency (a) is zero when you've stepped away from the theremin, (b) begins to ascend when your body is about two feet from the pitch antenna, and (c) reaches about 3 kHz when your hand touches the pitch antenna. Tap lightly on L5 and L6 as you converge on the proper settings, which will stabilize the tuning-slug positions.

This completes the tuning of the pitch oscillators. In performance, the exact tuning is established by adjusting the pitch-tuning control (P1).

Now, remove the temporary ground connection to pin 12 of U3. Connect a voltmeter from pin 12 of U3 to ground, install the volume antenna, and connect the volume-antenna circuit card between the antenna and the main board. Follow these steps to adjust L11:

1. Set P2 to its mid position.

2. Carefully turn the slug in L11 counterclockwise until it is out as far as it will go. The meter should read about -12V.

3. Slowly turn the slug *clockwise*. At some point, you will see the voltage begin to rise from -12V. Stop when the voltage passes through 0 and becomes positive, At this point, bringing your hand near the volume antenna lowers the voltage; the meter should read about -12V when your hand is two or three inches from the volume antenna.

This completes the tuning of the volume oscillator. In performance, the exact volume is established by adjusting the volume-tuning control (P2).

PLAYING THE THEREMIN

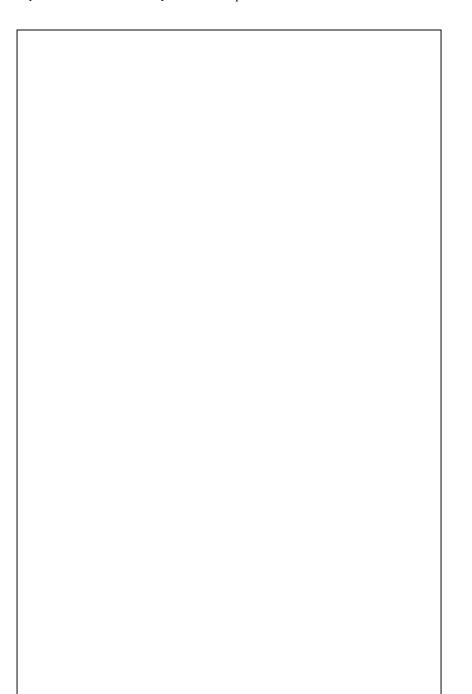
You are now ready to try your theremin. Place the instrument (with antennas installed) on a microphone stand that is set about 40 inches high. Connect a small monitor amplifier and speaker to J I and the 12 VAC wall-wart power adapter to J2. Turn on SW1 and touch the pitch antenna. Set P2 so the tone is loud when your left hand is well away

zero when your right hand is well away hum it to yourself. Then move your 6. If the pitch jumps abruptly as you from the pitch antenna and the tone right hand toward the pitch antenna a pitch antenna. Your instrument is now the note. This is not as easy as it ready to play.

Eventually, you will converge on the As with any expressive musical to learn. At first, you will find it proper settings for L5 and L6. The idea instrument, playing the theremin takes difficult to stand still, but a few hours

ing these simple exercises:

1. Stand slightly left of the center of sounds, but it's an important technique



2. Hum two different notes, one after the other. Find the first note on the theremin, hold it, and then slowly glide to the second note.

3. Repeat the above exercise, but bring your left hand near the volume antenna while your right hand glides from one note to the next. Move the left hand slowly at first and then more rapidly as you learn to move your left hand independently of your right hand. This exercise teaches you to "feel" where the notes are and to impart expressive dynamics.

4. While playing a note, introduce vibrato by moving your right hand back and forth from your wrist several times a second. Concentrate on making the vibrato even and steady.

These exercises address the basic skills of theremin playing: finding notes, playing intervals, articulating notes, and introducing vibrato. With these basic skills, you can play slow melodies. Practicing regular scales and arpeggios will increase your proficiency. Focus on accuracy of pitch and precise control of dynamics.

Once you've mastered the basic moves, it's time to develop your own style. Pay particular attention to shaping envelopes and dynamics with vour left hand. The left hand can also be used to articulate discrete notes by momentarily dipping into the volume antenna as the right hand quickly moves from one pitch to another. Try combining audible glides and discrete pitch changes within a musical phrase. In addition, avoid constant vibrato in the right hand. Instead, impart expressive nuance by shaping the amount and rate of vibrato. These considerations are important components of theremin musicianship.

The theremin presented here is designed to meet the needs of musicians who wish to explore the artistic resources of this unique instrument. Build your instrument carefully, and it will provide many years of reliable service. Practice with diligence, and you will provide enjoyable music for yourself and your audiences. Finally, be sure to give an occasional thought to the spirit of Leon Theremin, to whom we owe so much.

Robert Moog was a pioneer in the early development of commercial synthesizers and currently serves as Grand Poobah of Big Briar, Inc.