An Audible ac/dc Voltmeter

Sounds a tone whose frequency is proportional to the voltage being measured

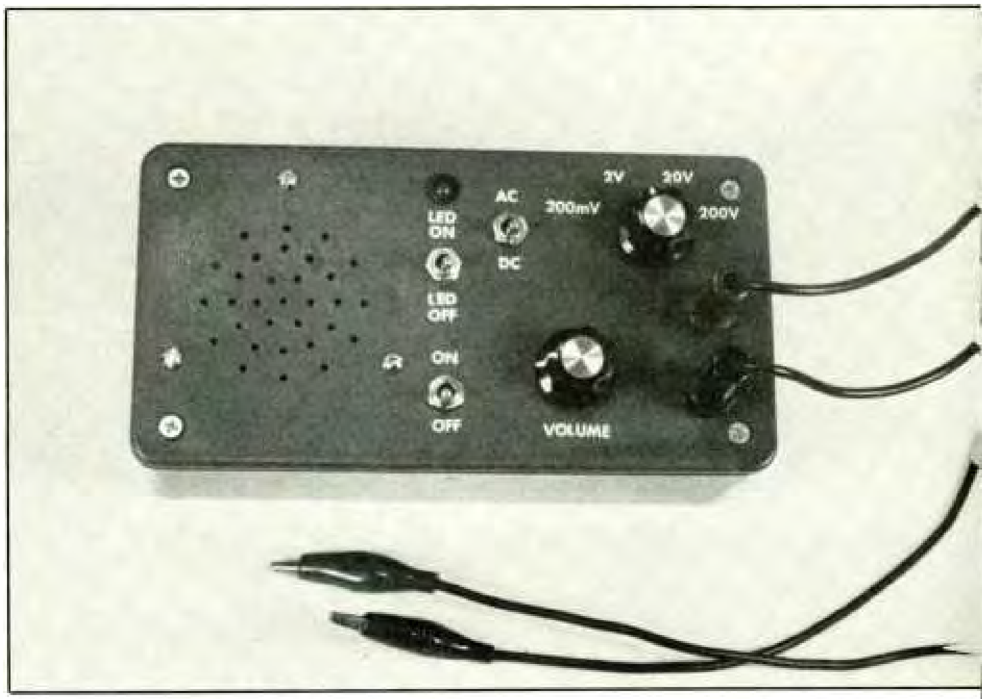
By Jan Axelson & Jim Hughes

The "Voltone" audible voltmeter presented here can extend your voltage-measuring capabilities. It enables you to listen to a tone whose frequency is proportional to the measured voltage instead of viewing a display.

This feature is very useful when you wish to monitor a circuit device to learn if it's the cause of an intermittent problem. It's also an efficient instrument for tuning a resonant circuit to maximum or minimum output, checking voltages quickly on a crowded circuit board, and other instances where it's not necessary to observe a meter's display.

Both ac and dc measurements can be made, and a tricolor light-emitting diode tells you whether the voltage being measured is positive, negative or ac. You can use the project by itself or connect it in parallel with a digital voltmeter or multimeter for visual as well as audible indications. For convenience, the project is powered by a battery.

Four input ranges are provided: 200 millivolts and 2, 20 and 200 volts. Input impedance is a constant 10 megohms. The audio output ranges from around 800 Hz at 0 volt to around 1,800 Hz at full-scale. With most users being able to distinguish a just few Hertz difference in frequency, "resolution" can be less than 1 millivolt on the project's lowest range.



About the Circuit

As shown in the schematic diagram in Fig. 1, the Voltone is built around just three integrated circuits: an LF411 operational amplifier (*IC1*), which serves as an input amplifier; an LM324 quad operational amplifier (*IC2*), which provides a polarity indicator, rectifier, biasing circuit and power amplifier; and a 556 function generator (*IC3*), which generates a tone that can be heard through the speaker.

Batteries *B1* and *B2* provide separate +9 volts and −9 volts to power the circuitry. The voltage being measured connects to the circuit across jacks *J1* and *J2*. Plugs *P1* and *P2* provide a means for connecting the Voltone in parallel with a digital voltmeter or multimeter (DVM or DMM). The contacts of switch *S2A* must be open when making ac measurements to allow capacitor *C1* to filter out any dc offset voltage that might be present in the input signal.

RANGE SELECT switch *S3* allows you to select an input signal from the voltage divider made up of resistors *R1* through *R4*. With *S3* set to position 1—the 200-millivolt range—the entire input voltage is fed to *IC1*. Positions 2, 3 and 4 (2-volt, 20-volt and 200-volt ranges) provide successive division so that $\frac{1}{10}$th, $\frac{1}{100}$th and $\frac{1}{1,000}$th of the input signal voltage is fed into *IC1*. With *S3* selecting the appropriate range, the voltage at *R5* is always 200 millivolts or less.

Resistor *R5* and diodes *D1* and *D2* help to protect the Voltone from damage due to user error. The diodes

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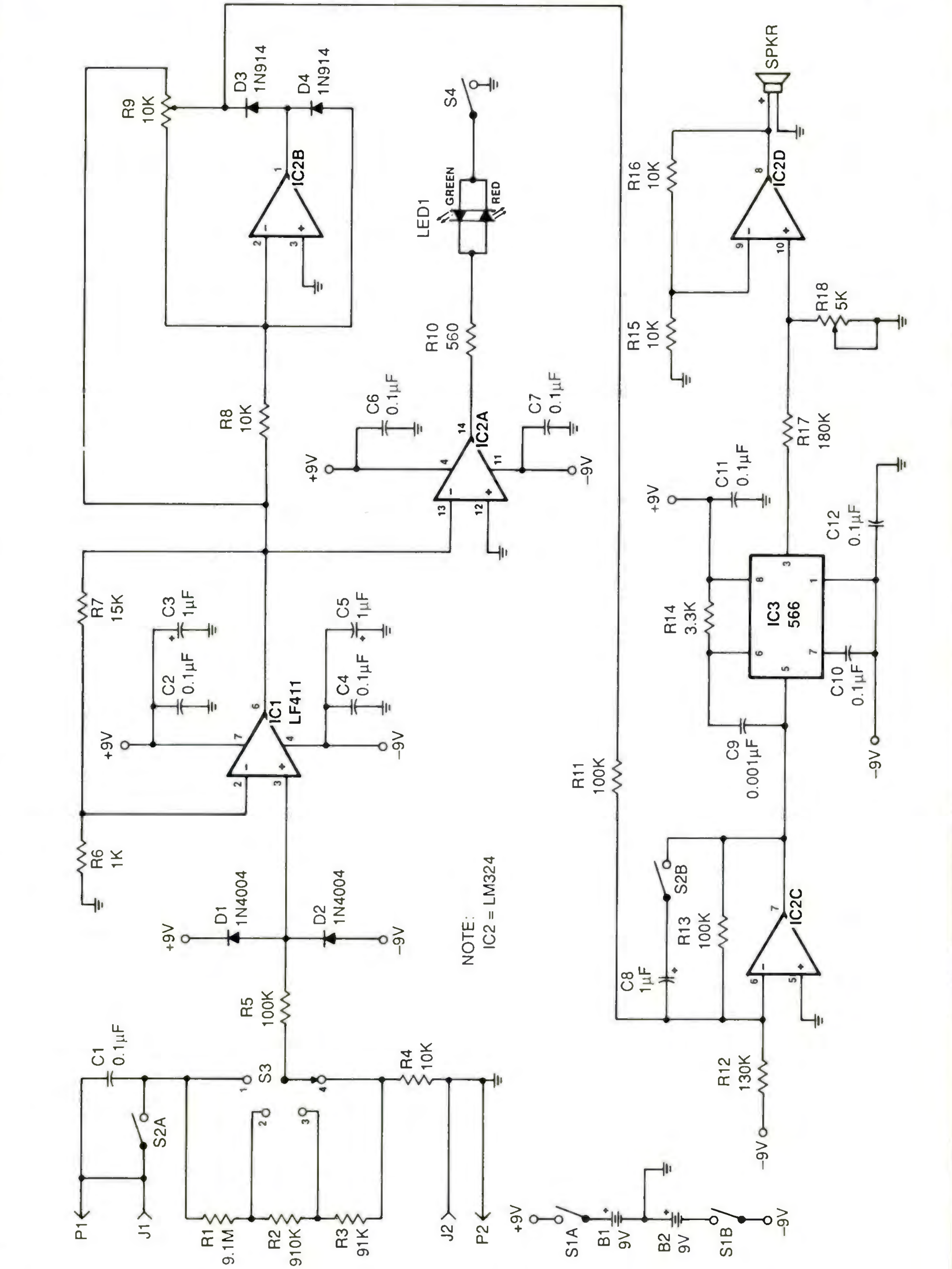

Fig. 1. Complete schematic diagram of the Audible Voltmeter.

PARTS LIST

Semiconductors
D1,D2—1N4004 or similar 400-PIV rectifier diode
D3,D4—1N914 or similar signal diode
LED1—Tricolor light-emitting diode with two leads (see text)
IC1—LF411 JFET-input operational amplifier
IC2—LM324 quad operational amplifier
IC3—566 function generator
Capacitors
C1—0.1-μF, 250-volt polyester film
C2,C4,C6,C7,C10,C11,C12—0.1-μF, 25-volt ceramic
C3,C5,C8—1-μF, 25-volt electrolytic
C9—0.001-μF, 25-volt ceramic
Resistors ¼-watt, 10% tolerance)
R1—9.1 megohms
R2—910,000 ohms
R3—91,000 ohms
R4,R8,R15,R16—10,000 ohms
R5,R11,R13—100,000 ohms
R6—1,000 ohms
R7—15,000 ohms
R9—10,000-ohm potentiometer
R10—560 ohms
R12—130,000 ohms
R14—3,300 ohms
R17—180,000 ohms
R18—5,000-ohm, audio-taper, panel-mount potentiometer
Miscellaneous
B1,B2—9-volt battery
J1,J2—banana jack
P1,P2—banana plug
S1—Miniature dpst toggle or slide switch
S2—Miniature dpdt toggle or slide switch
S3—Miniature 4pst panel-mount rotary switch
S4—Miniature spst toggle or slide switch
SPKR—8-ohm speaker
Printed-circuit board or perforated board with holes on 0.1-inch centers and suitable soldering or Wire Wrap hardware; sockets for ICs; suitable enclosure; 9-volt battery holders (2); battery snaps (2); panel-mount LED holder: pointer-type control knobs (2); 8-inch length of shielded cable; labeling kit and clear acrylic spray; ½-inch spacers; machine hardware; hookup wire; solder; etc.

clamp pin 3 of *IC1* to 9 volts if a large, overrange input is applied, and *R5* limits the input current to a safe value.

An LF411 op amp was chosen for *IC1* because of its high-impedance JFET inputs. Resistors *R6* and *R7* set the gain of *IC1* to 15, giving an output at pin 6 of 3 volts for a 200-millivolt (full-scale) input. Figure 2 shows several signals measured at different points in the Voltone. (A) and (B) show the response of *IC1* to an ac input.

Since the output tone gives no indication of the polarity of the measured signal, a visual indicator is provided. Operational amplifier *IC2A* is configured as a comparator whose output drives tricolor *LED1*, which consists of red and green LEDs connected in reverse parallel inside the same package.

The control input of *IC2A* at pin 13 is proportional to the Voltone's input, and the reference input at pin 12 is grounded. If pin 13 goes positive, the output at pin 14 goes negative and lights the green element inside *LED1*. If pin 13 is negative, pin 14 goes positive and the red LED element lights. With ac signals, both LEDs are on alternately, resulting in a yellow glow, which accounts for the third color in the "tricolor" LED.

Resistor *R10* limits LED current to a safe value. Switch *S4* allows the LED to be turned off, to save on battery power.

Op amp *IC2B* functions as a full-wave rectifier to produce a positive voltage that is proportional to inputs of either polarity. Gain of the circuit is set at 0.7 by adjusting potentiometer *R9* so that 70 percent of its resistance lies between its wiper and pin 2 of *IC2B*.

Operation of the circuit varies for positive and negative inputs. When the input at *R8* is positive, *D4* provides a feedback path for the op amp and *D3* is off. The output of the rectifier, which is controlled by the setting of *R9*, equals $0.7V_{in}$.

For negative inputs, *D4* is off and feedback current flows through *D3* and part of *R9* (between *D3* and pin 2 of *IC2B*). Now the output of the rectifier is $-0.7V_{in}$.

For both positive and negative inputs, the cathode of *D3* is at a positive voltage that is directly proportional to the input. Figure 2(C) illustrates this.

Op amp *IC2C* adds a bias voltage to the rectifier's output, to provide the proper control voltages for voltage-controlled oscillator (vco) *IC3*. The frequency of the vco's output signal at pin 3 varies with the magnitude of the voltage at its pin 5 control input. For proper operation, this potential must be between 75 percent of the total supply voltage and V+, or in this case, between +6.75 and +9 volts.

To provide the control voltage, op amp *IC2C* is configured to operate as an inverting summing amplifier. The current through *R13* is the sum of *R12*'s current (which generates the bias voltage) and *R11*'s current (which varies according to the measured voltage). The result is that the output at pin 7 varies from +7 to +5 volts as the rectifier's output varies from 0 to 2 volts. These levels are safely within the range required.

For ac measurements, switch *S2B* is closed to connect capacitor *C8* in parallel with resistor *R13*. This causes the signal on pin 7 of *IC2C* to be a dc voltage that is proportional to the ac input.

At *IC3*, the values of *R14* and *C10* determine the frequency range of the output. With the values specified, the output at pin 3 oscillates at around 800 Hz with an input of 5 volts and at around 1,800 Hz with an input of 7 volts. Figures 2(D) and 2(E) show a control input to *IC3* and

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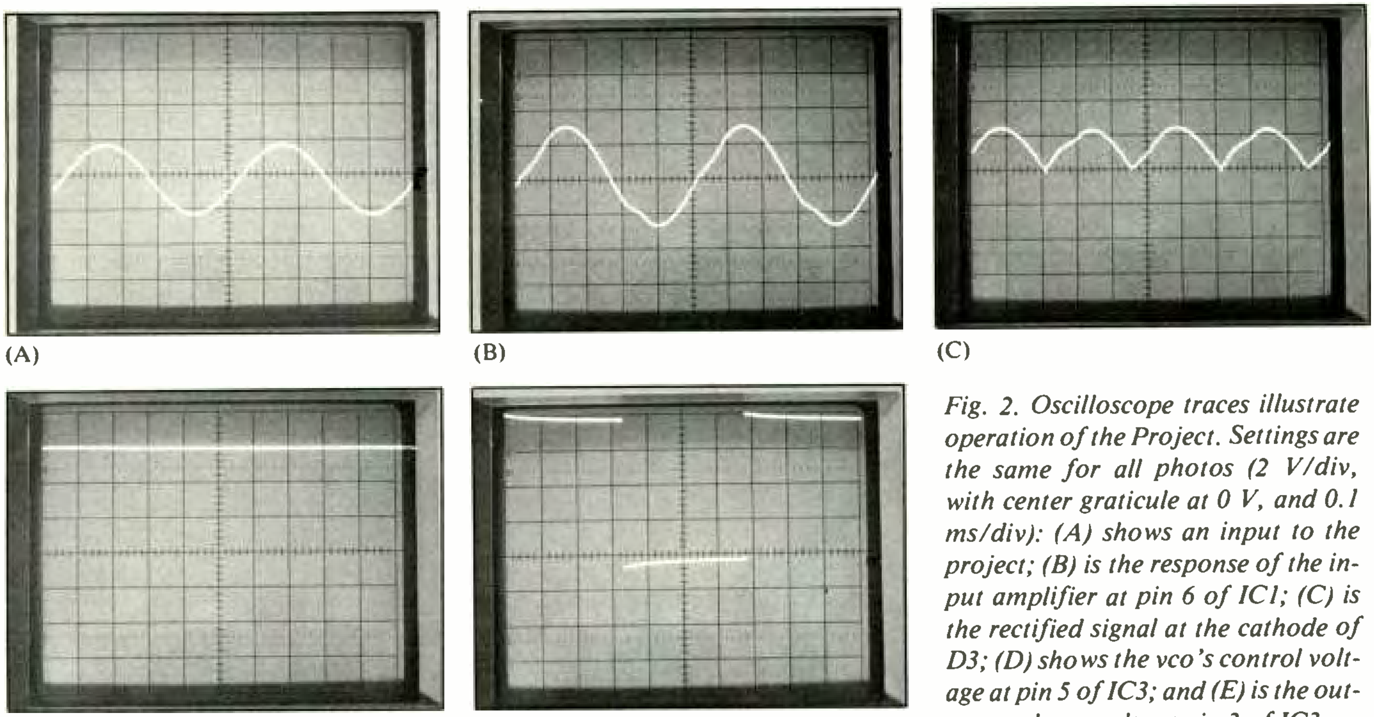

(A) (B) (C) (D) (E)

Fig. 2. Oscilloscope traces illustrate operation of the Project. Settings are the same for all photos (2 V/div, with center graticule at 0 V, and 0.1 ms/div): (A) shows an input to the project; (B) is the response of the input amplifier at pin 6 of IC1; (C) is the rectified signal at the cathode of D3; (D) shows the vco's control voltage at pin 5 of IC3; and (E) is the output that results at pin 3 of IC3.

Fig. 2(E) shows the output that results. Capacitor *C9* prevents unwanted high-frequency oscillations.

Power-amplifier stage *IC2D* drives speaker *SPKR*. Resistor *R17* and potentiometer *R18* divide the input to *IC2D*, with *R18* serving as the project's VOLUME control. Resistors *R15* and *R16* give the amplifier a gain of one. Finally, *C2* through *C7*, *C11* and *C12* serve as bypass capacitors.

Construction

Component values for the Voltone are not super-critical, though changes in values from those specified in the Parts List may alter the exact response of the circuitry. If necessary, you can change the value of *R7* to match the input ranges of your DVM or DMM. For instance, for a meter that uses 300-mV and 3-, 30- and 300-volt scales, change *R7*'s value to 10,000 ohms. Sockets are recommended for all ICs. Also, when selecting the *LED1* device use the two-lead tricolor variety that contains two LEDs that are wired in reverse parallel, rather than the three-lead type in which the cathodes of two LEDs are wired together.

Shown in Fig. 3 is the actual-size etching-and-drilling guide to use for fabricating the printed-circuit board on which you will mount and wire together the project's components. While drilling the component-lead holes in the board, also drill 5/32-inch mounting holes in the corners near where *C12* and *R12* will mount and below where *C2* and *C3* will mount (see Fig. 4). Alternatively, you can wire the circuit on perforated board that has holes on 0.1-inch centers using suitable Wire Wrap or soldering hardware and a point-to-point wiring technique.

Refer to Fig. 4 for wiring details for the pc-board version of the project. (Note: Use Fig. 4 as a rough guide to component layout if you are using perforated board, but refer back to Fig. 1 for wiring details.) Begin wiring the board by installing and soldering into place the IC sockets and resistors.

Before installing trimmer potentiometer *R9*, connect an ohmmeter between its center and either outer lugs and adjust it for a 7,000/3,000-ohm split. Without disturbing the setting, install the trimmer so that the 7,000-ohm section is between pin 2 of *IC2* and *D3*. Next, install and solder into place the capacitors and diodes, observing proper orientation for *D1* through *D4*, *C3*, *C5* and *C8*. Do *not* install the ICs in the sockets until after preliminary voltage checks have been made and you are sure the circuit has been correctly wired.

Strip 1/4 inch of insulation from both ends of nine 6-inch-long hookup wires. If you are using stranded hookup wire, tightly twist together the fine conductors at both ends of all wires and sparingly tin with solder. Plug one end of these wires into all unoccupied holes in the board and solder into place. The other ends will be connected later, after the circuit-board assembly has been mounted in place inside its enclosure.

You can use any type of enclosure that will accommodate all elements of the project without interference

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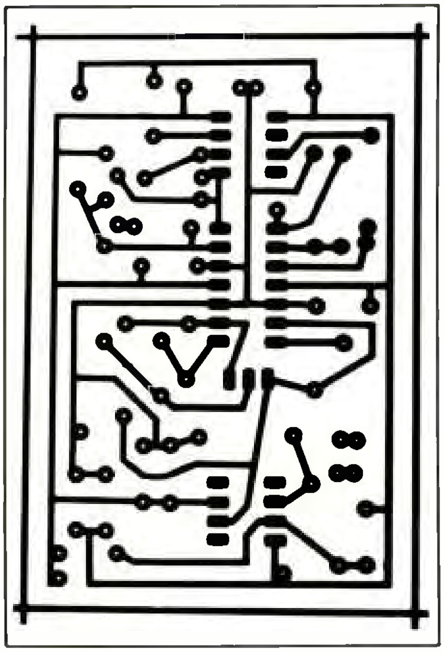

Fig. 3. Use this actual-size etching-and-drilling guide to fabricate a printed-circuit board for the project.

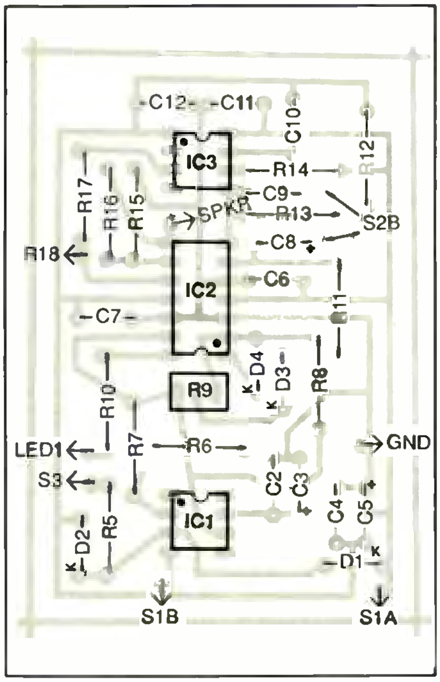

Fig. 4. Wire the printed-circuit board as shown here.

with each other and has adequate panel space on which to mount the LED, switches, potentiometer, speaker and connectors. A suitable enclosure is the all-plastic project box shown in the lead photo.

Prepare the enclosure by drilling mounting holes for *S1* through *S4*, *R18*, *J1*, *J2* and the holders for *LED1* and the batteries. You can mount the speaker either with machine hardware or a bead of silicone adhesive. If you do the former, drill three holes spaced in the front panel equidistant from each other for mounting screws around the the speaker (see Fig. 5). Whichever mounting method you choose, make a pattern of small holes in the panel where the speaker will be mounted to permit the sound to escape.

Temporarily mount the controls on the front panel and place on the shaft of the potentiometer a pointer-type control knob to determine where to put the identifying legends. Mark the panel as needed. Then remove and set aside the controls. Use a dry-transfer lettering kit to label the panel. Spray over the entire surface of the panel two or more light coats of clear acrylic to protect the legends from abrasion. Allow each coat to dry before spraying on the next. If you use a tape labeler, you can forego the protective acrylic spray.

With the front panel machined, machine the remainder of the project box. Drill holes in the floor for mounting the circuit-board assembly and the two holders for the batteries. Then drill mounting holes for banana jacks *P1* and *P2*. Figure 5 shows a suggested layout for the components inside the enclosure. If possible, space the holes for *P1* and *P2* so the Voltone accessory can plug directly into your DVM or DMM, as shown in the photo on the cover. Otherwise, use a pair of test leads that exit the project box and are terminated in banana plugs. If you have more than one meter with which you wish to use the accessory and their jack spacings are different, you might want to go the latter route.

Trim to length and crimp the leads of resistors *R1* through *R4* directly to the lugs on rotary switch *S3*. Then to minimize noise pickup by the high-impedance input, make the connection from *S3* to *R5* with shielded cable. Carefully cut and remove about ½ inch of the outer plastic jacket from one end of a length of shielded cable, trim away the exposed shield (only one end of the shield will be grounded), and remove ¼ inch of insulation from the center conductor. Tightly twist together the fine wires in this conductor and sparingly tin with solder.

Remove from the other end of this coaxial cable ¾ inch of outer plastic jacket. If the shield is made of braided wire, separate it back to what remains of the outer jacket, tightly twist together all conductors and sparingly tin with solder. Strip ¼ inch of insulation from the center conductor at this end of the cable, twist together the exposed wires and tin them with solder.

Plug the center conductor at the end of the cable from which you trimmed the shield into the hole labeled S3 on the circuit-board assembly and solder into place. Loop the shield at the other end of the cable around the lead of *R4* that is not connected to any lug on *S3* and solder the connection. Trim off any excess shield wire. Arrange things so that the shield cannot touch any other parts of the circuit when *S3* is installed on the panel. If necessary, insulate it with electrical tape. Crimp and solder this conductor to the lug on *S3* that goes to the rotor contact.

Mount the circuit-board assembly on the floor of the enclosure with three ½-inch spacers and 4-40 × ¾-inch machine hardware. Mount the battery clips in place with suitable hardware. Twist together the red-insulated wire from one battery snap connector and the black-insulated wire from the other battery connector.

Mount the speaker, LED, switches,

potentiometer and banana jacks in their respective locations on the front panel of the enclosure. If you are using silicone adhesive to secure the speaker in place, wait until the project has been completely assembled to mount the speaker.

Crimp and solder the red/black-insulated pair of battery connector leads to the solder lug on banana jack *J2*. Do *not* solder the connection. Next, crimp and solder the remaining red-and black-insulated battery connector leads to contact of *S1A* and *S1B*, respectively. Referring to Fig. 4, identify the wire coming from the hole in the circuit board labeled S1A (lower right); crimp the free end of this wire to the other *S1A* lug and solder the connection. Do the same with the *S1B* wire and lug.

Now, referring to Fig. 1 and Fig. 4, crimp and solder the free ends of the remaining wires coming from the circuit-board assembly to the lugs of the potentiometer and switches. Then wire into the circuit the LED and banana jacks. Make all ground (GND) connections at *J2*, soldering this multiple connection only after all wires have been connected to it. Use Fig. 1 as a wiring guide.

Wire *S2* so that for dc inputs, *S2A* is closed and *S2B* is open, while for ac inputs the reverse is true. Mount *C1* on *S2A*. Before wiring *LED1*, determine which end is which by connecting it across a 9-volt battery in series with a 560-ohm resistor. If it lights red, plug the positive lead of the LED into specified hole near *R10* on the circuit board and solder the connection. If it glows green, solder the *negative* lead into the specified hole. In either case, crimp and solder the remaining LED lead to one lug of *S4*, and connect a hookup wire from the other *S4* lug to the *J2* lug. Similarly, use hookup wires to connect the speaker into the circuit, as specified in Fig. 1.

With all wiring complete and the ICs still not installed in their sockets, double-check your work to ascertain that all components are installed in the right places and in the correct orientation where required and that all wiring is properly executed.

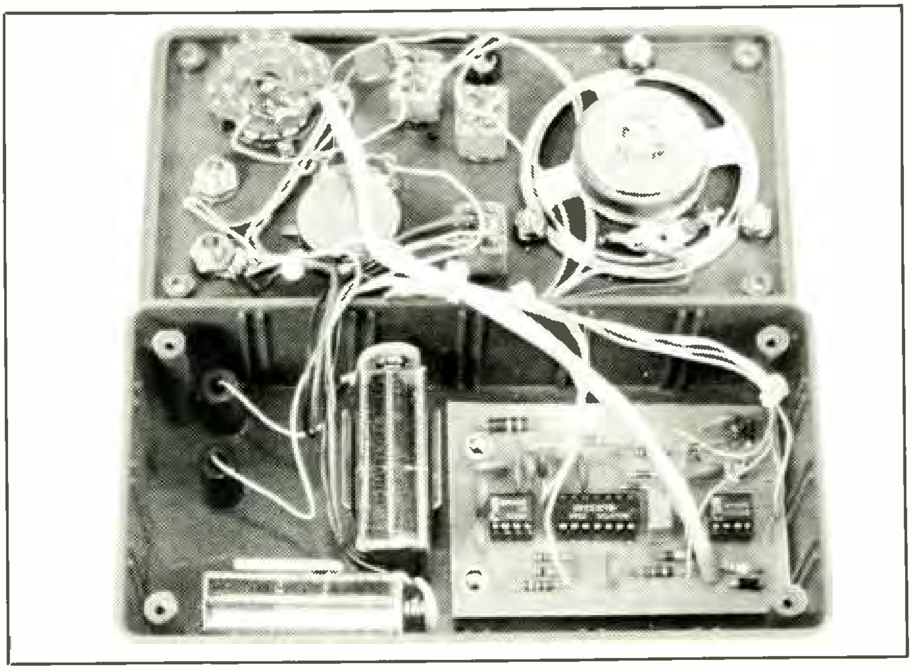

Fig. 5. Circuit board, batteries and plugs for connecting to a DVM or DMM mount on the floor of the enclosure. Front-panel controls and the speaker mount on the enclosure's cover panel.

A few plastic cable ties or some waxed lacing cord will help keep things neat. Use electrical tape or pieces of non-conductive foam to insulate any parts that may short together when the cover is put on.

Checkout & Use

Before conducting an operational check, perform voltage checks to make sure the battery supply has been wired into the circuit properly. Clip the common lead of a dc voltmeter or multimeter set to the dc volts function to the lug on *J2*. Snap fresh 9-volt batteries into the connectors and set POWER switch *S1* to ON. Touch the meter's "hot" probe to pin 7 of the *IC1*, pin 4 of the *IC2* and pin 8 of the *IC3* sockets. In all three cases, you should obtain a reading of approximately +9 volts. Then touch the probe to pin 4 of the *IC1*, pin 11 of the *IC2* and pin 7 of the *IC3* sockets. This time, the reading should be −9 volts in all three cases.

If you do not obtain the correct reading at any one of the points specified above, set *S1* to OFF and remove the batteries from the circuit. Rectify the problem before proceeding.

Once the proper readings have been obtained, plug the ICs into their respective sockets. Observe proper orientation and make sure that no pins overhang the sockets or fold under between the ICs and sockets.

Operation of the project can most easily be checked with it connected in parallel with a DVM or DMM, the latter set to dc volts, via *P1* and *P2*. Push these banana plugs into the input jacks on your DVM or DMM and plug the meter's test leads into *J1* and *J2* on the project. You'll also need a variable voltage source, which can be as simple as a potentiometer connected across a battery and the "output" taken between the wiper and either of the other two lugs on the potentiometer.

This project is used in much the same manner as you would use any other voltmeter. That is, set the input scale to a value greater than the voltage you expect to measure, and connect the signal to be measured to the input jacks via the meter's test leads. A low-frequency tone indicates a low voltage, while a high-frequency tone indicates a higher voltage. So, when using the instrument for peaking or nulling purposes, a rising tone tells you that the input voltage is increasing, and a falling tone means it's decreasing.

To begin operational checkout, set both your DVM or DMM and the project to the 200-millivolt scale for dc volts. Set the project's VOLUME control to minimum, and turn on both units.

Adjust the variable voltage source you're using for a 0-volt output and connect your meter probes to measure it. Turn up the volume, and you should hear a tone—at a frequency of about 800 Hz.

Slowly increasing the output of the voltage source should make the project emit a tone that rises in frequency until the input reaches approximately 200 millivolts, at which point it will hold constant at a frequency of around 1,800 Hz. The exact frequencies heard aren't critical, and the cut-off voltage may be somewhat higher than 200 millivolts. What's important is that the frequency varies throughout the full input range.

On the 2-volt range, you should hear the same frequency range as you adjust the variable voltage source for an input that ranges from 0 to 2 volts. The 20-volt and 200-volt ranges operate similarly. With *S2* set to AC, you can measure ac signals independently of any dc offset.

Using the project in parallel with a DVM or DMM increases the loading effect on the circuit being measured (compared to using just one meter). In most cases, however, the effect will still be negligible.

For audible-only measurements, unplug the DVM or DMM and use the project by itself. The LED polarity indicator tells you if *J1* is more positive (red), more negative (green), or ac (yellow) with respect to *J2*.

If the frequency remains constant as you adjust the measured voltage, either the voltage being measured is constant, or the magnitude of the input voltage is too large for the range selected. You'll soon learn to recognize your meter's maximum frequency, which lets you know it's time to change ranges. ME