A High-Performance Audible Continuity Tester

A stand-alone instrument that tests circuits and components for continuity down to 50 milliohms

By Adolph A. Mangieri

Most continuity testers have a relatively high resistance at which they trip, severely limiting their utility in many critical testing applications. With a trip threshold of 200 ohms, for example, *any* resistance less than this value will show up as a good indication, which would make just about any switch, relay or wire that is not an open circuit test good. So to be truly useful, a continuity tester should be able to tell you when a device or circuit has too much resistance, even if "too much" is less than 10 ohms, to adequately do its job. The continuity tester should have a trip point that can be adjusted to between, say, 50 milliohms and 10 ohms, as the high-performance continuity tester to be described does.

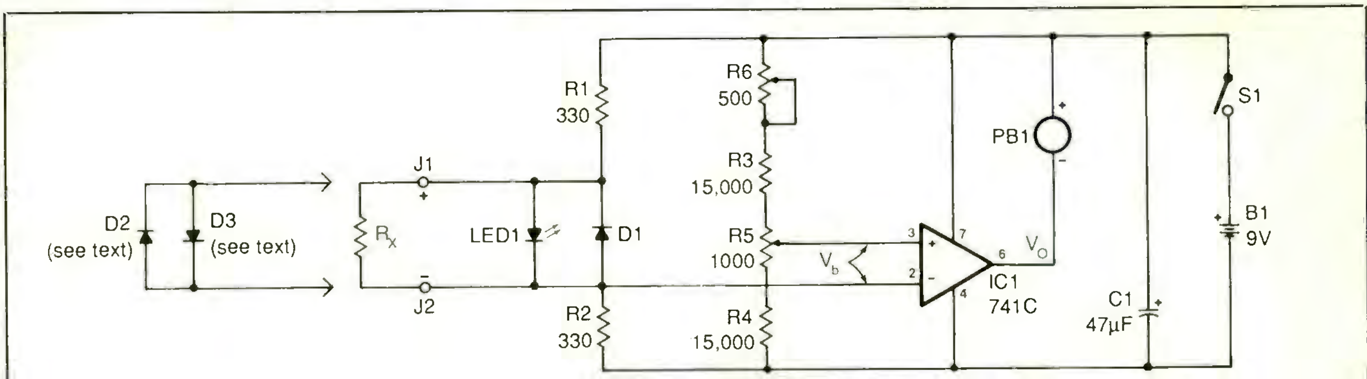
Our tester has a piezo-buzzer that sounds when continuity measures between 0 and 10 ohms. For general-purpose testing, a 10-ohm trip threshold would be selected. For more critical tests, the project would be preset against a 50- or 100-milliohm resistor to detect resistance differences of as little as 10 or 15 milliohms. A LED indicator is used when testing circuits whose resistance is greater than 10 ohms.

Only a 0.25-volt test potential is imposed on the circuit under test, making this continuity tester safe to use on digital circuits. For maximum versatility, the tester can be used as a low-range ohmmeter (you read resistance directly its dial) and as a good/bad indicator for a variety of solid-state devices.

About the Circuit

Shown in Fig. 1 is the complete schematic diagram of the High-Performance Audible Continuity Tester. Resistors *R1* and *R2* make up two arms of a dc Wheatstone bridge, with resistor R_x in the *R1* arm representing the circuit or device under test. The other two arms of the bridge are made up of potentiometers *R5* and *R6* and resistors *R3* and *R4*. Potentiometer *R6* is used to set the threshold from 0 to 10 ohms on a calibrated dial, while potentiometer *R5* balances the bridge circuit.

Operational amplifier *IC1* senses the output voltage from the bridge circuit, V_b, via input pins 2 and 3. In this configuration, the *IC1* op amp is operated in the open-loop condition as a very-high-gain voltage comparator with a dc open-loop gain in excess



PARTS LIST

Semiconductors
D1—1N4001 rectifier diode
D2,D3—1-ampere Schottky barrier diode (Radio Shack Cat. No. 276-1165 or equivalent)
IC1—741C operational amplifier
LED1—Red T-1¾ light-emitting diode
Capacitors
C1—47-µF, 15-volt electrolytic
Resistors (½-watt, 1% tolerance)
R1,R2—220 ohms
R3,R4—15,000 ohms
R5—1,000-ohm trimmer potentiometer
R6—500-ohm, linear-taper panel-mount potentiometer
Miscellaneous
B1—9-volt transistor battery
J1,J2—5-way binding post (one red, one black)
PB1—Piezoelectric buzzer (Radio Shack Cat. No. 273-065 or similar)
S1—Spst toggle or slide switch
Suitable enclosure; printed-circuit board or perforated board with holes on 0.1-inch centers and suitable soldering or Wire Wrap hardware; DIP socket for IC1; snap-on connector and clip for B1; pointer-type control knob for R6; machine hardware; hookup wire; solder; etc.

Fig. 1. Complete schematic diagram of high-performance continuity tester.

of 100,000. Hence, a fraction of a 1-millivolt difference at pins 2 and 3 of *IC1* is sufficient to swing output voltage V_o at pin 6 from low to high or high to low, depending on the polarity of input V_b.

If R_x is an open circuit, pin 3 of *IC1* will be positive with respect to pin 2, causing Vo to go high and silence piezoelectric buzzer *PB1*. Conversely, if R_x is less than the value set by *R6*, input pin 3 goes negative with respect to pin 2, causing V_o to go low and sound *PB1*.

Light-emitting diode *LED1* serves as an on/off indicator, test-current indicator and visual continuity indicator. It also limits the open-circuit test potential to 2 volts.

When plugged into *J1* and *J2*, Schottky barrier diodes *D2* and *D3* further limit the open-circuit test potential to 0.25 volt. Rectifier diode *D1* provides circuit protection. The short-circuit test current passed through R_x is approximately 12 milliamperes.

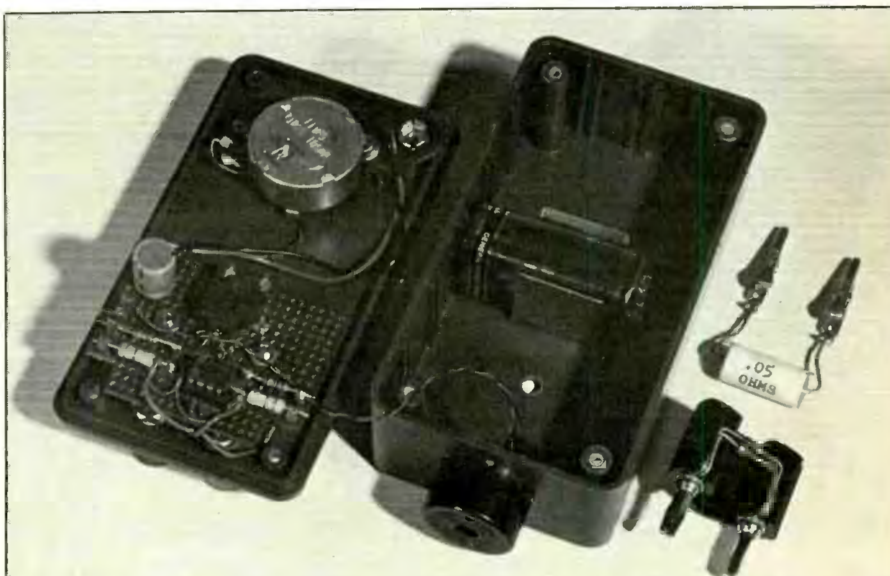


Fig. 2. All components can be mounted and wired on perforated board that then mounts on front panel of enclosure.

In designing the project, the range of R_x covered by *R6* was calculated using the formula $R_x = (R1 \times R6)/(R3 + 0.5R5)$. With the component values specified, R_x is 10.6 ohms. The range covered by *R6* would be doubled to nominally 20 ohms if this potentiometer's 1,000-ohm value or halved to 5 ohms if the potentiometer's value is 250 ohms.

Sensitivity of the bridge circuit to small differences in R_x is determined by the amount of current in arms *R1* and *R2*. The greater the current, the higher the sensitivity.

Values for *R1* and *R2* were chosen as a compromise between loading of battery *B1* and bridge sensitivity. Making *R1* and *R2* larger in value to reduce battery drain reduces sensitivity because *R1* becomes appreciably larger than R_X. Contrariwise, making *R1* and *R2* appreciably lower in value than 330 ohms increases bridge sensitivity but places a greater drain on *B1*. Keep this in mind if you decide to make circuit changes.

Construction

Figure 2 shows how the high-performance continuity tester can be assembled in a small plastic enclosure with all circuitry except the piezo buzzer and battery in its holder mounted on the lid. Component layout and wiring are not critical, permitting you to use any assembly technique that suits you. You can use perforated board with holes on 0.1-inch centers and suitable soldering or Wire Wrap hardware as shown or a printed-circuit board on which to mount the components, which is then mounted to the enclosure's lid.

Fabricate the pc board using the actual-size etching-and-drilling guide shown in Fig. 3. Then install the components on it exactly as shown in Fig. 4. Use a socket for *IC1* and make sure that *C1* and *D1* are properly polarized before soldering their leads to the copper pads. Do *not* install the IC in the socket until after initial checkout has been performed. You can use an ohmmeter to select matched pairs of 5-percent-tolerance resistors for *R1* through *R4*.

Next, trim ¼ inch of insulation from both ends of eight 5-inch hookup wires. Plug one end into the LED1, B1-, S1 and R6 holes and solder them into place.

When machining the enclosure's lid, drill two mounting holes for *J1* and *J2* exactly ¾ inch apart to accommodate a double banana-jack assembly. Then drill the holes in which to mount *LED1* in a panel clip and POWER switch *S1* and potentiometer *R6*. Mount the LED, switch and pot in their respective holes.

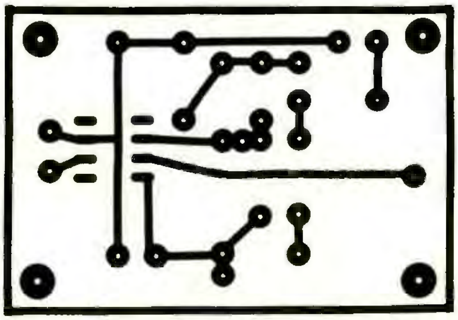


Fig. 3. Actual-size etching-and-drilling guide for making printed-circuit board that can be used instead of using perforated board.

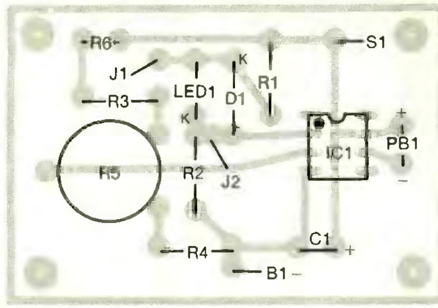


Fig. 4. Wiring guide for printed-circuit board. Be sure to use a DIP socket for IC1 and observe proper component orientations.

Wire potentiometer *R6* so that its resistance increases with clockwise rotation of the shaft. File a flat on the shaft of this pot so that its knob pointer falls at about the 7 o'clock position with the control shaft set fully counterclockwise. Set *R6* fully counterclockwise and place a small dot on the panel at the pointer location to serve as the minimum reference mark.

Install two 40-volt, 1-ampere Schottky rectifier diodes in parallel with each other and back-to-back on a double banana plug. This "accessory" can plug either way into the *J1/J2* assembly. It is used to limit the open-circuit test potential to 0.25 volt for digital circuit tests.

Carefully check the polarities of *C1*, *J1*, *J2* and *PB1* before applying power to the circuit. Connect a voltmeter, set to its lowest dc voltage range, from *J2* (common lead) to the wiper lug of *R5* or to pin 3 of the *IC1* socket. Set *R6* to its fully counterclockwise position. Set POWER switch *S1* to ON and verify that *LED1* lights. Connect a jumper wire across *J1* and *J2* and adjust *R5* over its entire range. The polarity of V_b should change from + to − and vice-versa.

If you used 1-percent resistors in the bridge circuit, potentiometer *R5* will be near its mid-point setting when the bridge is at null setting. If you cannot null the bridge circuit, check the resistors here for possible mismatch caused by soldering heat.

Power down the circuit and install *IC1* in its socket, taking care to properly orient it as shown. Make sure that no pins overhang the socket or fold under between IC and socket.

Use an ohmmeter to set *R6* to about 25 ohms and mark a temporary 0-ohm index on the project's panel. Connect a short, heavy U—shaped jumper wire across *J1* and *J2* and adjust the setting of bridge BALANCE control *R5* just to the point where the buzzer sounds.

Advance the setting of *R6* from its fully counterclockwise reference mark until the buzzer sounds and note whether this corresponds with the 0-ohm index. If not, trim the *R5* setting slightly and recheck.

Connect a 10-ohm resistance across *J1* and *J2* and advance *R6*'s setting until the buzzer sounds. If the value of *R6* is too low, maximum range may be 8 or 9 ohms.

To calibrate the BALANCE dial, you need six 1-ohm and two 5-ohm resistors to make up all the values between 0.5 and 10 ohms in 0.5-ohm increments. Two 1-ohm resistors in parallel make up a 0.5-ohm resistor.

With *J1* and *J2* shorted together, advance the setting of *R6* until the buzzer just sounds and mark and label this as the 0-ohm index. Connect resistors ranging from 1 to 10 ohms across *J1* and *J2* and mark off on the panel the 1-ohm intervals. Then, using the 0.5-ohm resistance you prepared in series with the 1-ohm resistors, label the 0.5-ohm intervals.

Remove the pointer knob from the potentiometer and label the control panel as shown in the lead photo. You can use a dry-transfer lettering kit for this. When the panel is ready, spray onto it two or three *light* coats of clear acrylic to protect the lettering. Wait until each coat completely dries before spraying on the next. Then replace the knob on the potentiometer's shaft and double check that the pointer index properly lines up with the counterclockwise reference mark.

The resistance per foot of solid copper wire is as follows:

Wire Gauge	Milliohms/foot
12	1.62
14	2.56
16	4.10
18	6.51
20	10.4
22	16.5
24	26.2
26	41.5
28	66.2
30	105
32	167

Armed with this information, fabricate a 50-milliohm and a 100-milliohm resistor, using suitable lengths of wire wound onto larger-value (100-ohm or greater) 1- or 2-watt carbon resistors. For example, a 6-inch length of 30-gauge wrap wire is 50 milliohms, which is close enough for our purposes.

Connect the 50-milliohm resistor across *J1* and *J2*. With the buzzer sounding, very slowly rotate the control knob on *R6* counterclockwise until the sound from the buzzer ceases. Replace the resistor with the heavy wire jumper. If you have not overshot the first setting, the buzzer should sound, indicating that the resolution of the tester is well under 50 milliohms.

If you cannot obtain the above result, try again using the 100-milliohm resistor instead of the 50-milliohm one. If even this fails to give you the proper response, the problem is low open-loop gain of the particular 741 op amp being used. You will then have to change chips until you have one with sufficient open-loop gain. When you replace an op amp, it may be necessary to touch up the setting of *R5* to reset the 0-ohm index.

Make a pair of test leads with phone tips at one end and collet-type test-probe handles at the other end. The collet accepts steel phono needles that easily bite into copper pads and terminals. Check your spare-parts box for old computer cable connectors that have machined female pins. You may be able to chuck the pin in the probe collet and use the probe to make contact with the top ends of Wire Wrap posts.

Make another pair of test leads, this time terminating one end in heavy-bite alligator clips and the other end with phone tips. Jumper-wire the two jaws of the alligator clips with copper braid to assure low-resistance connections.

Using the Tester

For general-purpose tests, merely set the dial to a resistance threshold of your choice, from 0.25 ohm to 10 ohms, and proceed with your tests. The buzzer will sound when the resistance of the circuit or component under test is equal to or less than the value set on the dial. If the buzzer does not sound and *LED1* is off, indicating test current flow, you can adjust the setting of *R6* until the buzzer does sound and read off the indicated resistance from the tester's BALANCE dial.

Switch and relay contacts usually have contact resistances of 2 to 10 milliohms or so when new. The small reed relay may have up to 100 or even 200 milliohms of contact resistance. Used toggle, slide and microswitches often exhibit much higher contact resistance, the result of contact wear and oxidation.

To test switches, flip their toggles or sliders back and forth a number of times to burnish their contacts, removing oxidation. Then set the tester's dial well up-scale, say, to 5 ohms. Make connections to the switch and rotate the control knob on *R6* counterclockwise until the buzzer stops sounding. If the dial is at or very near the 0 index, the switch is in good condition. Many of the used switches I have tested gave resistance readings of as much as 0.5 ohm (500 milliohms), 3 ohms and even 5 ohms. Slide switches can often be restored with a shot of lubricating cleaner spray.

When the resistance of a circuit is expected to be extremely low, do the following. Give the project a 30-second warm-up to stabilize the very small drift of *IC1*. Short together the test leads and adjust the dial setting counterclockwise to the point where the buzzer just sounds. Proceed with your test. In this case, you will be working at considerably lower than 100-milliohm thresholds, possibly as low as 50 milliohms or less.

If the above procedure cuts things just a bit too close, use the following procedure. Short the test leads through the nominally 50- or 100-milliohm resistor you made earlier. Adjust the tester's dial just the the point where the buzzer sounds. The actual resistance threshold is equal to the value of the calibrating resistor plus just a bit more. This gives you more leeway than does the preceding mode of operation.

You can also do the above the other way around. With the calibrating resistor connected to the test leads, adjust the project's dial to the point where the buzzer just stops sounding. Then remove the calibrating resistor and short together the tester's leads and verify that the buzzer sounds to be sure you have not overshot the adjustment. This sets the threshold to a point somewhat less than the value of the calibrating resistor.

Multiple-conductor ribbon cables, DIP jumpers and similar devices are tested by comparing the lines while looking for differences in resistance. You decide how close you want to cut this test.

For an example of how to use the tester, assume you are testing a 36-inch IDC ribbon cable made up of 28-gauge conductors. Armed with conductor length and gauge and the information given above, you know that the conductors should have a resistance that is close to 200 milliohms. The two IDC contact pins at the ends of the conductor may add 40 milliohms of resistance at worst.

Make connections to the IDC socket pins of any line selected as a standard for comparison. Use two wrap-post pins, preferably gold plated, to make connections. Adjust the setting of *R6* clockwise until the buzzer sounds. Check two additional lines. If the buzzer sounds, the three lines are typical; so you can proceed with testing. If the buzzer does not sound, the first selected line may be defective. Select another line as the standard for comparison and proceed in a similar manner.

A cable that passes this test is in excellent condition. If you want more leeway, nudge *R6* a bit more upscale, or calibrate the first line with your 100-milliohm test resistor temporarily inserted in series with it. Checking an IDC cable suspected of causing computer crashes, I found that the resistance of one line was 0.5 ohm greater than the others. This difference would be of little concern with a low-current signal line. However, as luck would have it, the defective conductor run was the 5-volt power-supply line. When you find a suspicious line, test it several times and flex the cable at each connector

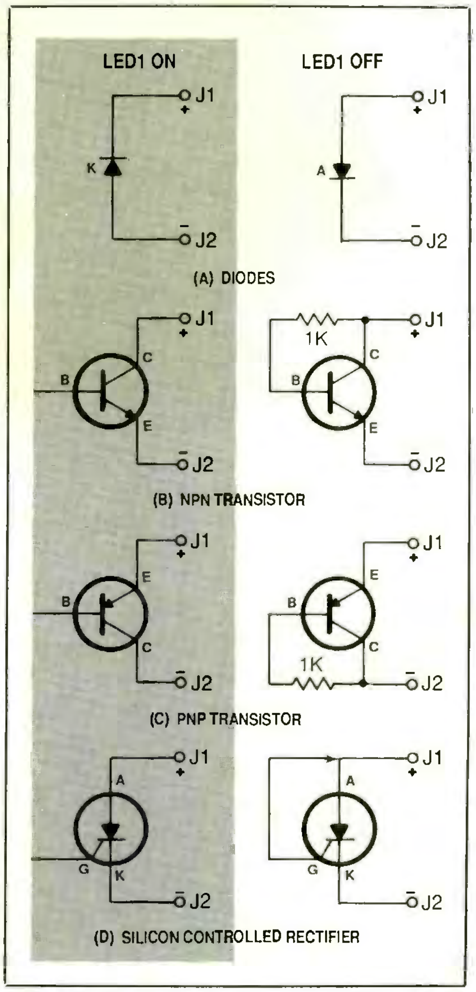


Fig. 5 Connection arrangements to use when testing various types of semiconductor devices.

to identify which connector is causing the problem.

To assist in cable testing, dedicate a male or female socket with all pins connected together at one end and probe each line at the other end. Ribbon cables and DIP jumper cables have the same wire gauge on all lines, but some bundled cables may have several wire gauges and several socket pin sizes that you must take into account when making tests on them.

When you test populated circuit-board assemblies, insert the *D2/D3* Schottky diode voltage limiter into *J1* and *J2*. For good indications, *LED1* should remain off when the tester is used in this manner. Perform your tests with no power applied to the circuit-board assembly. The low 0.25-volt test potential and 12-milliampere test current should not damage any ICs in the circuit, regardless of test lead polarity. Integrated circuits can typically withstand up to 0.6 volt of reverse bias current. If there is any doubt about this, check the device's specifications.

You can also use this continuity tester to measure resistances of up to 10 ohms. When it is used in this manner, adjust *R6* to the threshold point and read the value indicated on the control's dial. Another way you can use the tester is as a visual continuity tester in which *LED1* is off when the resistance between *J1* and *J2* is less than about 100 ohms or so. Use this mode to check continuity of audio transformers and the like.

Using the connection arrangements shown in Fig. 5, the continuity tester handily performs basic good/bad tests on a wide variety of semiconductor devices. If the device being checked fails the test, it has little or no chance of meeting its published specifications. If it passes the test, the device has a very good chance of meeting its specifications.

To check diodes and rectifiers, bridge the device across *J1* and *J2* in both directions, as shown in Fig. 5(A). With cathode K connected to *J1* (+) and anode A connected to *J2* (−), *LED1* should be on to indicate that the diode is blocking the flow of current. Reversing the device's connections to the jack, the LED should be off, indicating that the diode is conducting.

If *LED1* is on when the diode is connected across the jacks in both directions, the diode is either open or consists of multiple diodes in series with each other. If the LED remains off when the diode is connected across the jacks in both directions, it is shorted.

When checking a light-emitting diode, the LED should emit some light (though it may be faint and difficult to see) with its anode connected to *J1* and its cathode connected to *J2*.

Figures 5(B) and 5(C) show connections for checking small- and medium-power npn and pnp bipolar transistors. When using the tester to check bipolar transistors, check first with base lead B floating or disconnected. If the transistor is good, the LED should light, indicating that the transistor is off and is not shorted. Connecting a 1,000-ohm resistor from base B to collector C should cause *LED1* to turn off, indicating that the transistor has switched on and is amplifying.

Check photodiodes and transistors as you would any ordinary diode and transistor. The only exception is that you should use a flashlight to switch on the device under test.

Figure 5(D) shows how to check low- and medium-current silicon controlled rectifiers (SCRs). With gate lead G not connected to anode A, *LED1* should be on to indicate that the SCR is blocking the flow of current. If the LED is off, try opening and closing *S1* on the continuity tester. With the SCR in the blocking mode, momentarily touch gate lead G to anode lead A; the LED should switch off, indicating that the SCR has switched on and is conducting current as it should.

With high-current SCRs, the device may not switch off when the gate lead is removed from the anode lead. This is because the test current is less than the SCR's holding current. With very-low-current SCRs, the device may switch on just by touching its gate lead. A high-current SCR that needs more than about 12 milliamperes of gate turn-on current will not switch on and, thus, cannot be properly tested with this tester.

The tester should rarely require any servicing, apart from occasionally replacing the battery when its output voltage under load drops to about 6 volts. Occasionally check the 0-ohm index with *J1* and *J2* shorted together, and adjust *R5* as needed. **ME**