BUILD THIS SINGLE CHIP DVM

A 4½-digit voltmeter is usually pretty expensive—but it doesn't have to be when you build it yourself!

ANTHONY J. CARISTI

A DIGITAL VOLTMETER, OR DVM, IS probably the first test instrument that most electronics enthusiasts buy, because it's a necessary instrument. Moreover, they don't cost much these days. However, one voltmeter is often not enough; a second voltmeter, allowing simultaneous measurements, is always handy.

Our DVM project fills the need for a second voltmeter that can be made at low cost. But, although our DVM is inexpensive to build, it has a full 4½-digit display. That allows measurement resolution of 10 microvolts on its most sensitive range, which is not possible with 3½-digit meters.

The input resistance of the voltmeter is about 11 megohms, which is comparable to that of commercial DVM's. Calibration of the instrument is very easy; it's accomplished by adjusting a single potentiometer.

An additional feature of this DVM is a continuity function that allows the instrument to locate opens or shorts in circuit wiring. Continuity is indicated not only by a CONTINUITY flag on the display, but also by the digital readout which gives an approximate indication of the resistance between the test leads. Also, an audio tone is automatically generated when the test leads are placed across a conductive path.

The circuit is relatively simple, containing just one IC and a handful of other components. There are four DC voltage ranges: 200 millivolts, 2 volts, 20 volts, and 200 volts full scale. The current draw by the circuit is only 1 milliamp from a 9-volt battery, which permits several hundred hours of operation from a fresh alkaline battery. A LOW BATTERY indicator is automatically energized when the battery nears the end of its useful life.

The circuit

The heart of this digital voltmeter is IC1, a Maxim ICL7129A 4½-digit A/D converter with LCD driver (see the schematic diagram in Fig. 1). The chip has a ±20,000-count resolution, features high input impedance, and auto polarity indication. Only one active external component is required for voltage measurement: D1, a Harris 1.2-volt bandgap reference.

Power to IC1 is provided by 9-volt battery B1 that is connected to pins 23 and 24 of IC1 through POWER switch S1. The battery also drives the external reference voltage circuit composed of R6–R9 and D1. About 1.2 volts is developed across D1, and potentiometer R8 is adjusted during instrument calibration so that the voltage differential between pins 34 and 35 is set to 1 volt.

The dual-slope conversion technique of IC1 requires an oscillator circuit; in this DVM it's a 120-kHz crystal, XTAL1, and its associated components. A 120-kHz crystal allows maximum normal-mode rejection at 60 hertz, the standard U.S. power-line frequency. For countries where 50-hertz power-line frequencies are common, a 100-kHz crystal should be used.

The DVM chip, IC1, is designed to accommodate an RC oscillator instead of a crystal, as shown in Fig. 2. However, for 10-microvolt resolution, provided by the DVM's most sensitive range, a crystal oscillator is recommended.

The input voltage to IC1 is fed to pins 32 and 33. The test leads of the instrument, connected to J1 and J2, drive a voltage divider composed of R1–R4. The values of those resistors are chosen so that each step of RANGE switch S2-a results in a 10:1 reduction in the voltage presented to pin 33 of IC1. Components R11 and C5 form a low-pass filter to attenuate any noise or AC component appearing across J1 and J2. That helps by providing a more stable DC voltage reading.

Pin 37 of IC1, the digital input control terminal, sets the full-scale sensitivity of the A/D converter. When pin 37 of IC1 is connected to pin 36, digital common, the full-scale sensitivity is 200 millivolts. With a high-level logic input at pin 37, full-scale sensitivity is 2 volts. Switches S2-a and S2-b allow

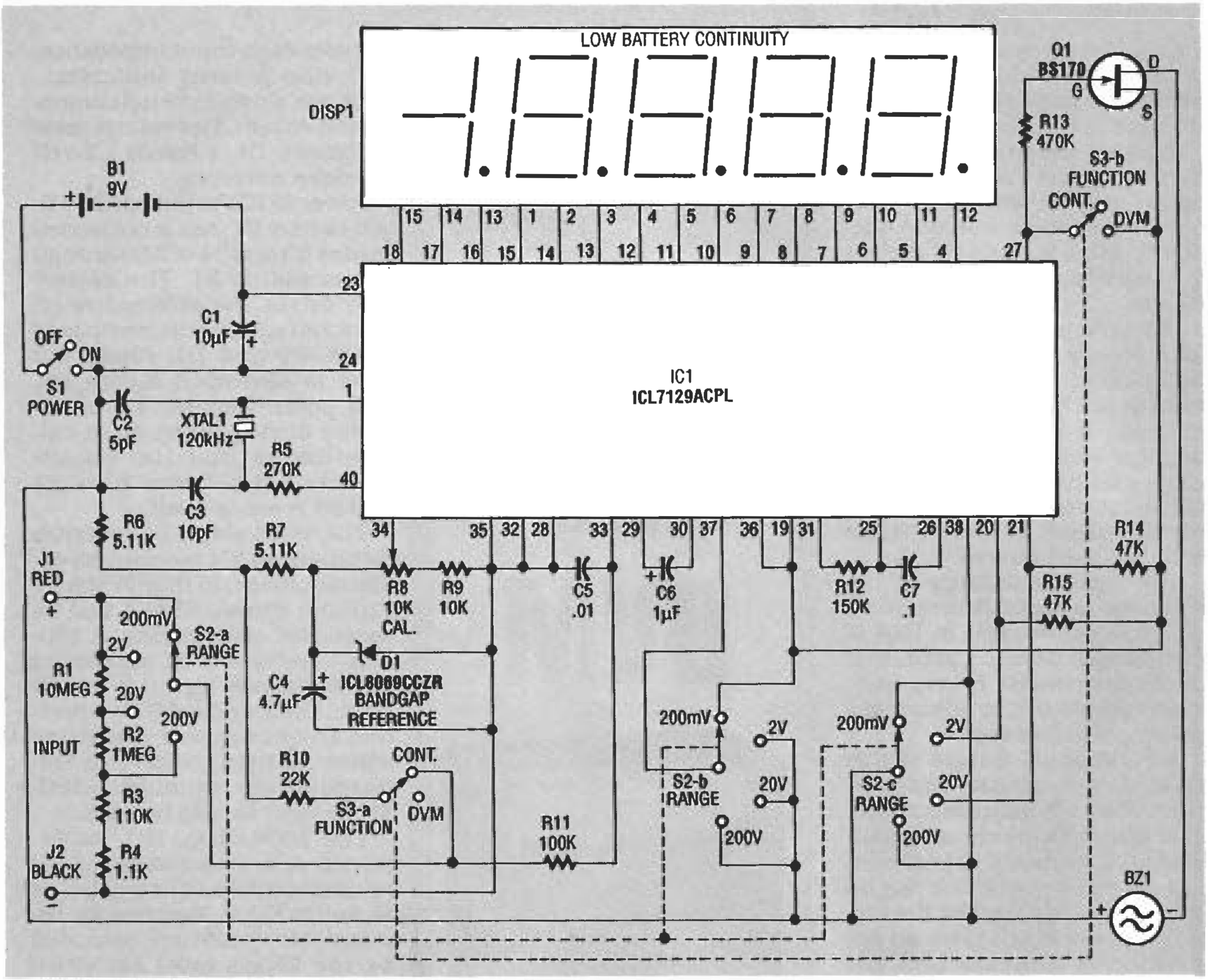


FIG. 1—THE HEART OF THE CIRCUIT is IC1, a Maxim ICL7129A 4½-digit A/D converter with a built-in LCD driver,

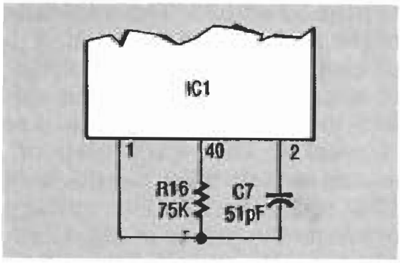


FIG. 2—THIS RC OSCILLATOR can replace the crystal. The PC board is designed to accommodate either circuit. However, the crystal is recommended for highest accuracy.

the voltmeter to be set to any one of the four full-scale ranges.

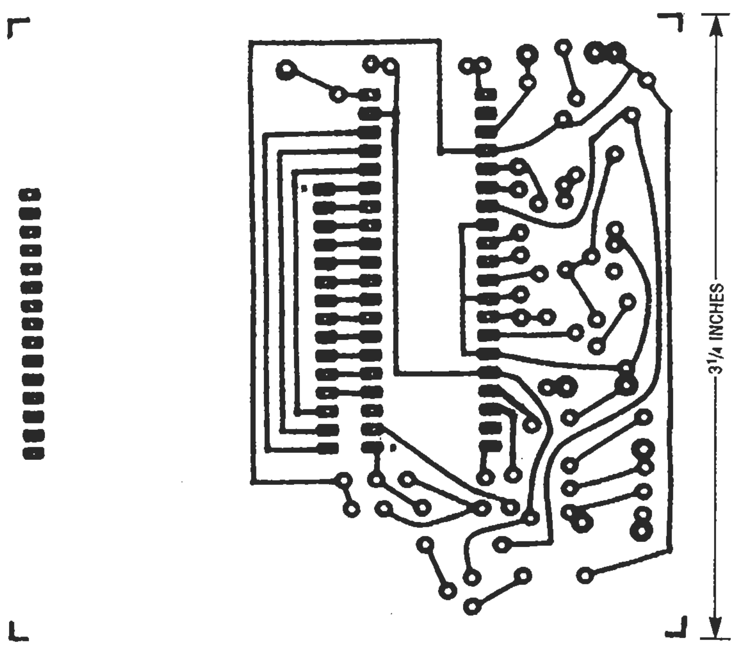
Switch S2-c controls the display's decimal point. A logic high presented to any one of the decimal-point control inputs (pins 38, 20, and 21) activates the appropriate decimal point on the display. The most sensitive range of the instrument displays millivolts, while the other ranges indicate volts.

A built-in comparator within IC1, with a threshold voltage of 200 millivolts, monitors the analog voltage applied to pins 32 and 33 from input terminals J1 and J2. When the voltage is less than the threshold level, the CONTINUITY flag of the display is activated. At the same time, pin 27 goes high, which allows an audio-tone circuit to be activated on the DVM.

Resistor R10 keeps pin 33 of IC1 above 2 volts when the instrument is used as a continuity checker and the test leads are open. That causes the display to go to overrange, and extinguishes the continuity flag. Pin 27 goes low, and the tone circuit (Q1 and BZ1) is held dormant.

When the test leads are shorted together or connected across a low resistance, the voltage across pins 32 and 33 falls to less than 200 millivolts. That activates the continuity flag and sounds the buzzer. At the same time, the reduced voltage appearing across pins 32 and 33 provides a relative indication of the resistance between the test leads.

Switch S3-b defeats the continuity function during voltage measurement by pulling pin 27 (the input/output control) low. That also ensures that Q1 is cut off, silencing the buzzer. A 4½-digit tri-multiplexing liquid crystal display (LCD) module (DISP1) allows control of all 37 segments, including the CONTINUITY and LOW BATTERY flags, with just 15 connections from IC1. That is accomplished by separating the various elements of the display into three sections. Three backplane ter-



FOIL PATTERN for the DVM circuit.

PARTS LIST

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

R1—10 megohms, 1% metal-film
R2—1 megohm, 1% metal-film
R3—110,000 ohms, 1% metal-film
R4—1100 ohms
R5—270,000 ohms (crystal oscillator circuit only)
R6, R7—5110 ohms, 1% metal-film
R8—10,000 ohms, PC-mount potentiometer
R9—10,000 ohms, 1% metal-film
R10—22,000 ohms
R11—100,000 ohms
R12—150,000 ohms
R13—470,000 ohms
R14, R15—47,000 ohms
R16—75,000 ohms (RC oscillator circuit only)

Capacitors

C1—10 µF, 16-volts, axial electrolytic
C2—5 pF, 50-volts, ceramic disc (crystal oscillator circuit only)
C3—10 pF, 50 volts, ceramic disc (crystal oscillator circuit only)
C4—4.7 µF, 10 volts, axial electrolytic
C5—0.01 µF, 50 volts, ceramic disc
C6—1 µF, 10 volts, radial electrolytic
C7—51 pF, 50 volts, ceramic disc (RC oscillator circuit only)

Semiconductors

IC1—ICL7129ACPL A/D converter/LCD driver (Maxim)
D1—ICL8069CCZR 1.2-volt bandgap reference (Harris Semiconductor)
Q1—BS170 FET transistor

Other components

S1—SPST slide or toggle switch
S2—3P4T non-shorting rotary switch
S3—DPDT slide or toggle switch
DISP1—353R3R03GHZ1 4½-digit triplexed LCD module (LXD)
BZ1—piezo buzzer (Radio Shack 273-074 or equivalent)
J1, J2—Banana jacks (1 red, 1 black)
B1—9-volt battery
XTAL1—120-kHz crystal (for crystal oscillator circuit only)

Miscellaneous: Test leads with banana plugs, 9-volt battery connector and mounting clip, enclosure, wire, 1.5-volt test battery, test voltmeter for calibration

Note: The following parts are available from A. Caristi, 69 White Pond Road, Waldwick, NJ 07463:

- **Etched and drilled PC board—$12.75**
- **IC1—$25.50**
- **D1—$3.75**
- **DISP1—$24.95**
- **Set of six 1% metal-film resistors—$6.25**
- **Q1—$2.25**

Please add $4.00 postage and handling.

minals are used for the tri-multiplexing scheme. (Ordinary LCD displays contain just one backplane terminal.)

The segments of the display are in three groups, each controlled by its own backplane square-wave voltage. Driver IC1 generates the backplane signals that cause the appropriate elements of the display to be activated in sequence. The process takes place at such high speeds that all three sections of the display appear to have constant illumination. The LOW BATTERY indicator of the display is automatically energized when the supply voltage between pins 23 and 24 of IC1 falls below 7.2 volts.

Construction

The voltmeter circuit is constructed on a single-sided PC board. We've provided a foil pattern if you wish to make your own. However, the circuit layout is not critical, so it can be hard-wired on perforated construction board.

Figure 3 is the parts-placement diagram. Be sure to use a socket for IC1—it is well worth the slight additional cost, and permits easy IC removal should that ever be necessary. Do not insert the IC in its socket at this time.

Be sure to use the specified 1% metal-film resistors for R1, R2, and R3; the accuracy and stability of the voltmeter depend on the accuracy and stability of their values. Ordinary carbon resistors are temperature-sensitive and should not be used in this DVM.

Although a crystal oscillator is preferred, the alternate RC oscillator circuit (shown in Fig. 2) can be accommodated on the PC board using the extra pad on pin 2 of IC1. The existing pads on pins 1 and 40 can be used to mount R16 and C7 of the RC oscillator circuit.

The bandgap reference, D1, is packaged in a three-terminal transistor package. Only two of the terminals are active—the third is unused. Position it on the board as shown in Fig. 3.

The LCD module is packaged like an IC with 15 pins on each

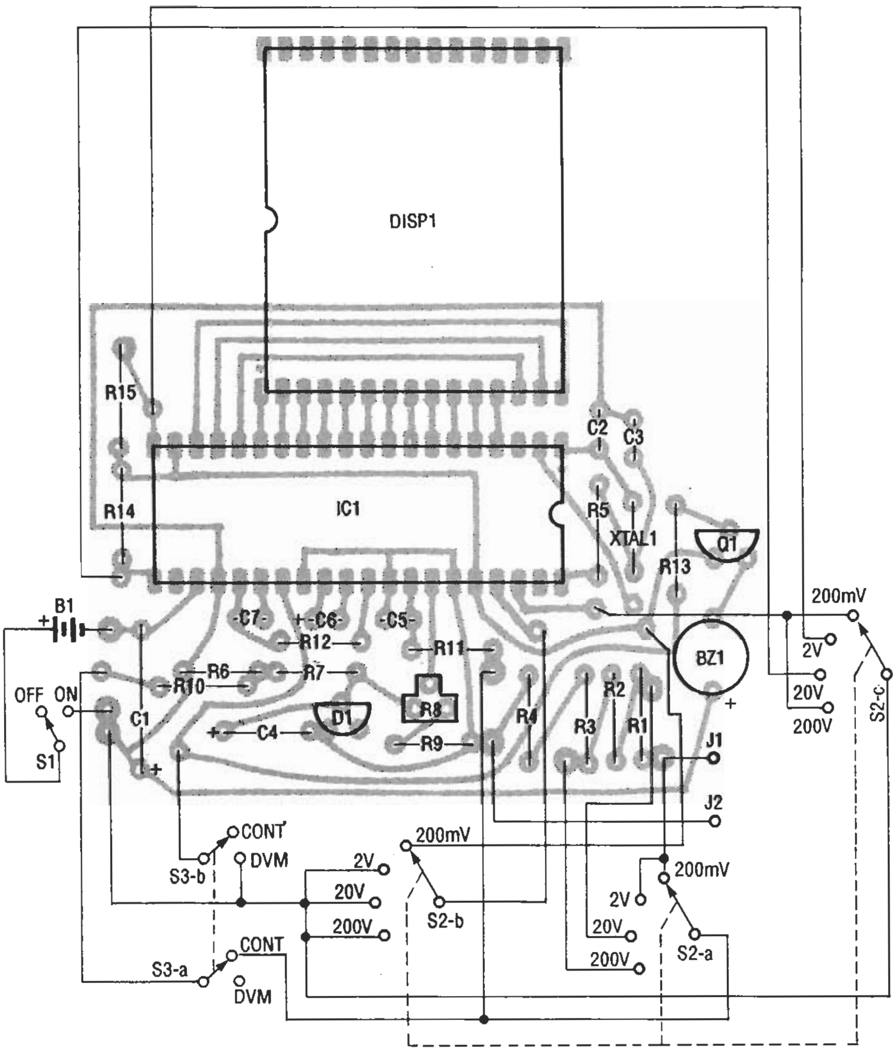


FIG. 3—PARTS-PLACEMENT DIAGRAM. Install a socket for IC1, and make two 15-pin SIP sockets for the LCD module from a 40-pin DIP socket.

side. However, only pins 1–15 (the row near the decimal points) are active. The other row of pins is used only for mounting. The module, which is fragile, can be directly soldered onto the PC board, but it is recommended that you make a socket for it by carefully cutting apart a 40-pin DIP socket to form two 15-pin SIP sockets. Note that the module is brittle, and can be fractured if excessive force is used during handling.

All of the switches and jacks are connected to the PC board with appropriate lengths of insulated wire. Refer to the Parts-Placement diagram as a wiring guide. Be sure to use stranded 24- or 26-AWG wire, as solid wire has a propensity to break. Make the connections to S2 first. Note that S2 has three poles with four contacts each. Observe which pole terminal of the switch belongs to which set of four contacts. If you're in doubt, check with an ohmmeter to be sure. A wiring error here will require a lot of troubleshooting later. Next, make the connections to S1 and S2. Finally, install the 9-volt battery connector, observing proper polarity.

When the PC board is completely assembled, examine it thoroughly for opens, shorts, and cold solder joints before proceeding with the checkout.

Checkout procedure

The calibration of the instrument requires a DC voltmeter with an input resistance of at least 10 megohms. A 1.5-volt battery will be handy as a voltage source to calibrate the circuit. Prepare a set of test leads consisting of two banana plugs and lengths of red and black flexible wire. Insert the plugs into jacks J1 and J2, and short the ends of the wires together. Set FUNCTION switch S3 to "DVM" and RANGE switch S2 to 200 millivolts. Insert a fresh battery to power the DVM, and turn S1 on.

The normal display should be 00.00. The reading might flicker between 00.00 and 00.01. Rotate the range switch to the other three positions. A normal indication is .0000, 0.000, and 00.00 for the 2-, 20-, and 200-volt ranges, respectively. Again, the least significant digit might flicker between 0 and 1. The minus sign might also appear intermittently.

If the display does not operate as described, troubleshoot the problem before proceeding. If the display is totally blank, measure the terminal voltage of the battery across C1 to be sure that it is delivering at least 7 volts to the circuit and the polarity is correct. Verify that IC1, C1, and D1 are properly oriented in the board. Also check all electrolytic capacitors to be sure they are installed correctly. Examine the board for any open circuits or short circuits. Resolder any solder joints that don't appear smooth and bright.

To verify that the oscillator circuit is operating, examine the wave shape at pin 40 of IC1 with an oscilloscope, using digital ground (pin 36) as the reference. A normal indication is a 5-volt peak-to-peak square wave at a frequency of about 120 kHz.

If the oscillator waveform is absent, check XTAL1 and its associated components. If a substitute crystal is not available, XTAL1, C2, C3, and R5 can be temporarily removed from the board and replaced with the RC oscillator circuit of Fig. 2. That will verify that the on-chip oscillator circuit within IC1 is operating correctly.

If the only problems are with the decimal-point display, check the wiring between S2-c and pin 38 of IC1. If the circuit seems to be working, but some

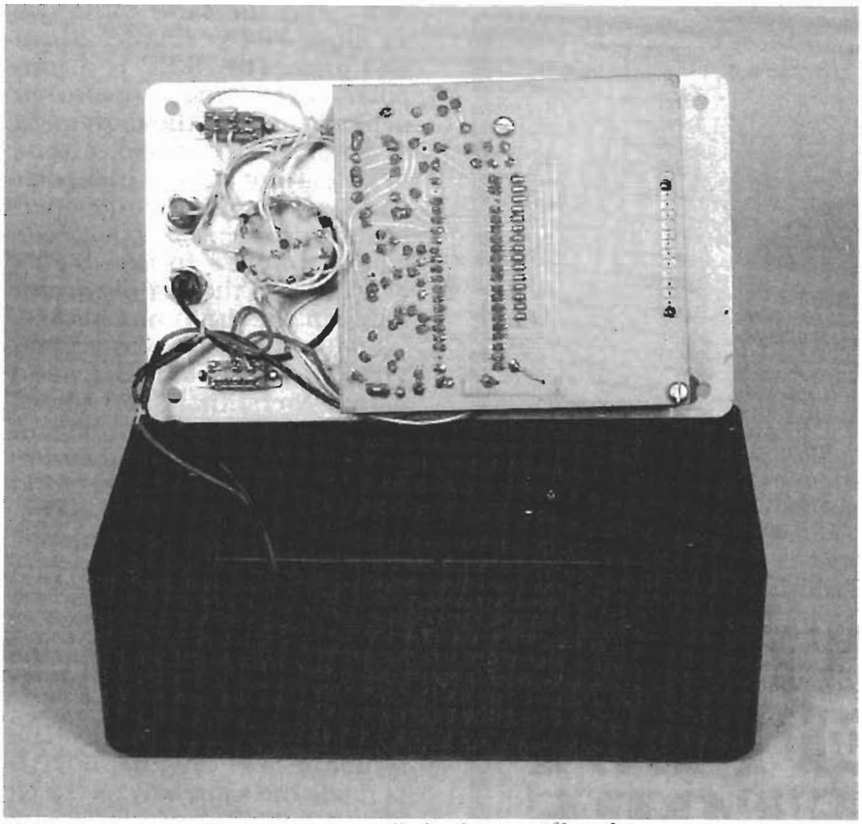


FIG. 4—THE DVM BOARD fits in a small plastic or metal enclosure.

of the digits are not fully illuminated, check the connections between DISP1 and IC1. Once the circuit is operating properly, proceed with calibration.

Calibration

Set R8 to mid-position, and the RANGE switch to the 2-volt scale. Connect a separate digital voltmeter and the test leads of this DVM across the 1.5-volt test cell, and compare the readings of the two voltmeters. Carefully adjust R8 to obtain a reading that is as close to the test voltmeter as possible. Check the reading with the polarity of the cell reversed to verify the operation of the minus sign.

Rotate the RANGE switch to the 20- and 200-volt range, and ascertain that the voltage display is still correct. Set the RANGE switch to 200 millivolts, and verify that the DVM goes into overrange with only a "1" displayed.

If the readings do not track within about 1% for the 2-, 20- and 200-volt positions of S2, measure the values of R1, R2, R3, and R4 to be sure they are correct. If the readings are off by a factor of 10, check the wiring to S2-a, S2-b, and pins 36 and 37 of IC1.

Remove the 1.5-volt test battery and short the meter leads together. Set the FUNCTION switch to "continuity" and the RANGE switch to the 2-volt scale. The CONTINUITY indicator should be activated, and the piezoelectric buzzer should emit a tone. Disconnect the leads; the audio tone and CONTINUITY indicator should be extinguished, and the display should go off scale.

If the piezoelectric buzzer does not work, check the orientation of Q1 and the buzzer. Check the wiring to S3-b, and try a new transistor.

Final assembly

The entire DVM assembly easily fits in a small plastic or metal enclosure. Figure 4 shows the author's completed prototype. Before drilling holes in the enclosure for the control switches and jacks, determine the location for the LCD cutout by holding the board assembly next to the panel and measuring and marking carefully. A 1- × 2-inch opening is suitable for the display module specified in the Parts List from LXD, Inc. of Beachwood, Ohio.

Once the LCD cutout has been made, locate the mounting holes for the PC board. Carefully drill both the board and front panel to accommodate the mounting hardware. Four machine screws, spacers, and nuts are recommended. Be sure the spacers are long enough to prevent the LCD module from contacting the front panel so that no stress will be put on the display.

With the board assembly temporarily mounted to the front panel, determine the desired location of switches S1, S2, and S3, and jacks. J1 and J2; the jacks should be spaced ¾-inch apart to accommodate a standard dual banana plug. Remove the PC board assembly before proceeding with the mechanical work on the panel. Remember to install a mounting clip for the 9-volt battery inside the case so it will not contact any of the DVM circuitry.

Using the DVM

Your new instrument works like any other DVM. When using the continuity function, the RANGE switch must be set to the 2-volt scale. The display will indicate about .0000 for a dead short between test leads, and will provide a relative reading for resistances up to 100K. Note that the continuity function is not calibrated, and can be used for relative resistance readings only.

When the battery is near the end of its service life, the LOW BATTERY indicator of the display will be activated. Replace the battery at that time with a new one, and be sure to turn off the instrument when it's not in use.

As with many other digital voltmeters, this meter will continue to operate for some time in the low-battery condition, its accuracy will be affected, and you will not be able to trust the displayed value. That situation can be inconvenient when you are measuring low voltages; it becomes dangerous when you measure high voltages. Ω