BUILD A

MULTIPLE-CHOICE DIGITAL MULTIMETER

BY JOHN T. BAILEY

A 3½-digit meter with either LED or LCD displays, plus a variety of options including a temperature probe

THE introduction of two new 3½-digit A/D converter ICs by Intersil now makes it possible for you to build a low-cost state-of-the-art digital multimeter with a variety of options. Here are details on building an instrument with a choice of LED or LCD display. Included are instructions for several options, such as an ac precision rectifier, an ohms converter, ac and dc current modifications, and a temperature probe. With such a choice available, you can mix and match according to your needs and desires. By changing some component values, you can even modify the basic ranges.

The basic DMM described in this article can measure ac and dc voltages in five ranges from 200 mV full-scale to 2000 volts full-scale; ac and dc currents from 200 μA to 2 amperes; resistance from 2000 ohms to 20 megohms; and temperature from 0° C to 100° C(32° F to 212° F). Simple modifications can extend the basic ranges to 200 ohms, 20 μA, and 20 amperes, all full-scale.

There are two versions of the new Intersil A/D converter. The ICL7107 is designed to directly drive 3½ digits of conventional seven-segment light-emitting diode display, while the ICL7106 can directly drive 3½ digits of seven-segment liquid-crystal display. Both chips contain a precision dual-slope converter, BCD-to-seven-segment decoding, display drivers, clock, and reference. Only 10 passive components are required to turn either chip into a 200-mV or a 2-volt full-scale dc meter. The basic meter also features automatic zeroing and polarity indication.

About the Circuit. The basic circuit for the LCD version is shown in Fig. 1, while the circuit for the LED version is shown in Fig. 2. Both circuits feature the same 3½-digit display capability. Since both chips have a noise level of about 15 μV, the associated display should be quite stable. With the inputs shorted, the display should indicate 000, with no rollover of the last digit.

With the component values shown, both circuits have full-scale displays of 200.0. To change this to 2.000, change *C2* to 0.047-μF, *R2* to 470,000 ohms, and *R4* to 25,000 ohms.

The decimal points in the LED display (Fig. 2) are driven by switching a 150-ohm resistor from ground to the decimal point in the desired decade.

LCD displays, such as that shown in Fig. 1, are driven by a symmetrical square wave applied to the backplane. Each digit segment is then turned on by applying an identical waveform (but reverse-phase) to it. For this reason, the decimal points of the LCD display are driven by inverting the backplane signal using NOR gate *IC4*. (LCD displays can be permanently damaged by prolonged application of a dc voltage. Any dc potential greater than 50 mV applied to the LCD for more than two minutes will permanently damage the display.)

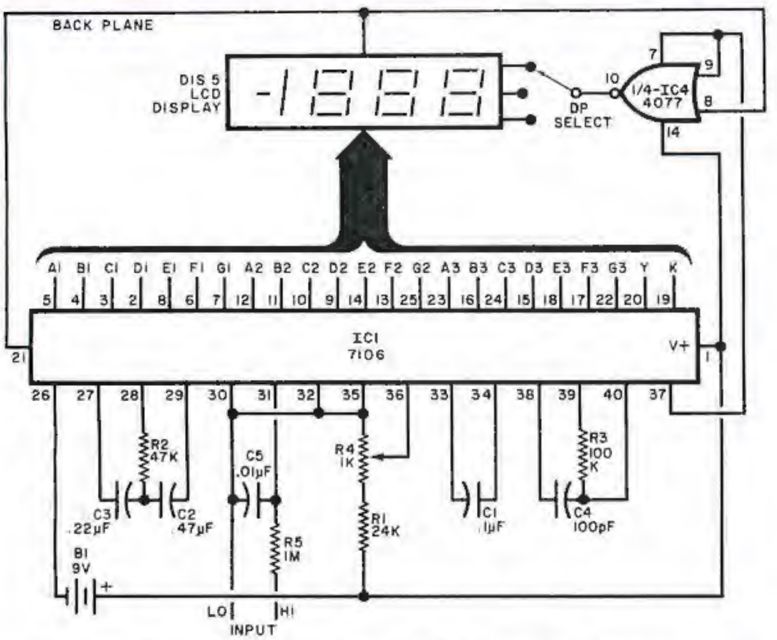


Fig. 1. As single 3½-digit A/D converter 7106 can directly drive an LCD display, using a NOR gate for decimal selection.

PARTS LIST
BASIC METER

B1—9-volt battery (not in kit)
C1—0.1-μF Mylar or polypropylene
C2—0.47-50-μF Mylar or polypropylene
C3—0.22-μF polypropylene
C4—100-to-200-pF disc
C5—0.01-μF disc
DIS1 thru DIS3—Common-anode 7-segment light-emitting diode display*
DIS4—Common-anode ±1 light-emitting diode display*
DIS5—3½-digit liquid-crystal display (Hamlin No. 3902 or similar)**
IC1—7107* or 7106** A/D converter (Intersil)
IC4—4077 NOR gate**
R1—24,000-ohm, ¼-watt, 5% resistor
R2—47,000-ohm, ¼-watt, 5% resistor
R3—100,000-ohm, ¼-watt, 5% resistor
R4—1000-ohm, 10-turn potentiometer
R5—1-megohm, ¼-watt, resistor
R11—150-ohm, ½-watt, 10% resistor
Misc.—Battery holder (not in kit); printed-circuit board; 40-pin and 14-pin** IC socket; 14-pin sockets for LED displays (4).
*These items required for LED version only.
**These items required for LCD version only.

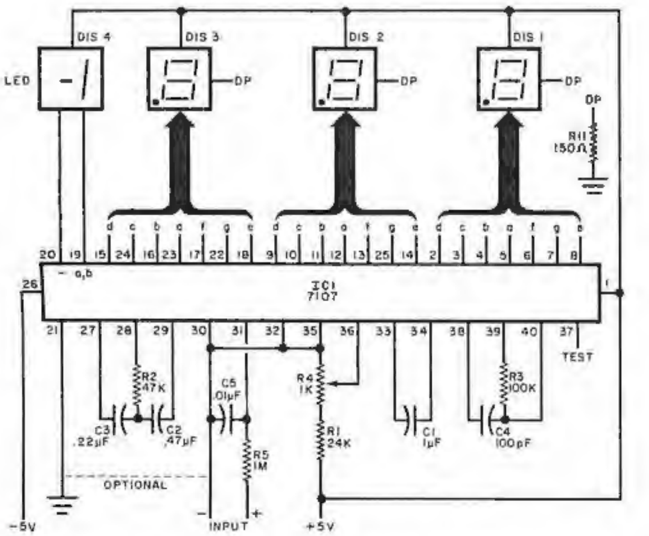


Fig. 2. The LED circuit, using a 7107 is similar to that in Fig. 1. Decimal point is selected through R11 to ground.

Construction. The actual-size etching-and-drilling and component-placement guides for the LCD version of the meter are shown in Fig. 3. Similar guides for the LED version are shown in Fig. 4. Note that the board for the LED (7107) version is arranged so that the display section can be cut from the main board to permit it to be mounted at a right angle to the latter.

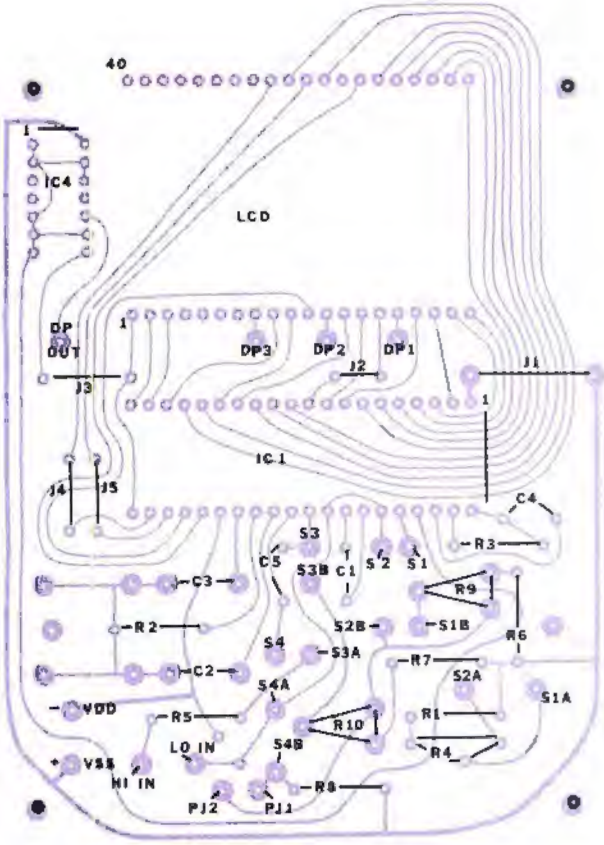
In the LCD (7106) version, the display comes with an edge connector. Mount and solder this connector to the board at the appropriate location.

The components used in the circuit are not critical in determining the accuracy of the meter. However, it is important that integrating capacitor *C3* have a low dielectric loss. Use either a polypropylene or a polystyrene capacitor. Mylar capacitors are satisfactory for reference capacitor *C1* and auto-zero capacitor *C2*.

Temperature Probe. The addition of a few components can add a temperature-measuring feature to your basic instrument. The circuit shown in Fig. 5 illustrates how this feature can be added. Note that a four-pole double-throw switch (*S1*) is used to transfer from regular DMM functions and the temperature function.

The temperature probe operates on the principle that a diode forward-biased at a constant but low forward current changes forward voltage linearly over a relatively wide range (−40° C to +150° C) at about 2 mV/°C. In Fig. 5, the emitter of a metal-cased npn transistor is used as one diode lead, while the base/collector combination is used as the other lead. The transistor's metal case makes a convenient probe tip. (A zener diode rated at less than 20 volts would work as well.)

The probe itself is fabricated from an ordinary ballpoint pen with screw-on top, a transistor sensor, shielded two-conductor cable, and a subminiature phone jack and plug. Open the pen and remove the ink cartridge, spring, and retractor mechanism. Then trim away the pen's top until its diameter is the same as that of the rim on the transistor's metal case. Slide the cable through the top and bottom of the pen and assemble the pen. Separate the cable's conductors for a distance of 2″ (50.8 mm) at the point end of the cable and trim away ¼″ (6.4 mm) of insulation from each. Twist together the fine wires in each conductor and lightly tin with solder. Slide over each conductor a 1″ (25.4-mm) length of heat-



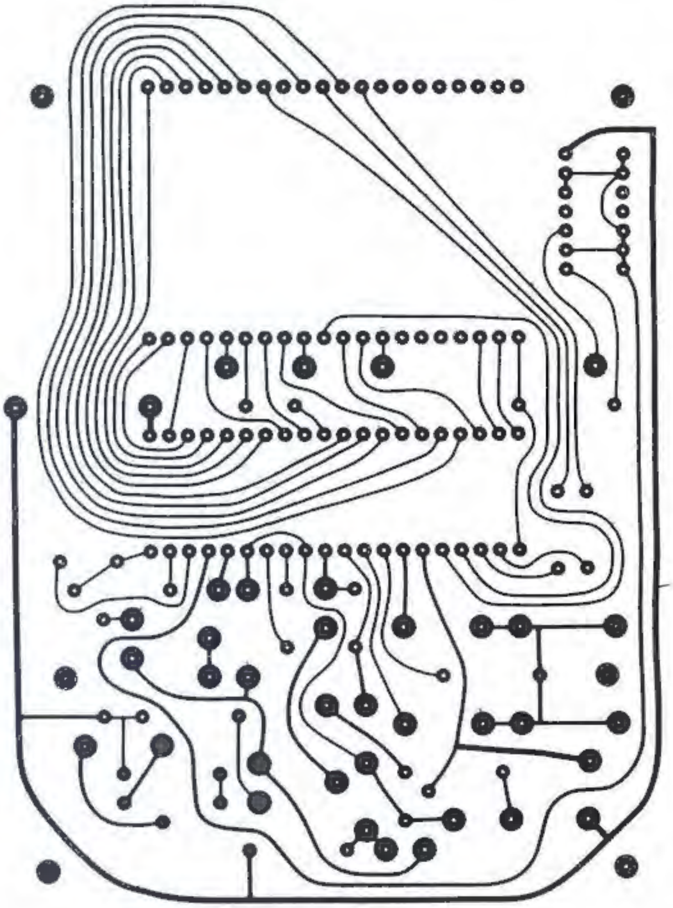
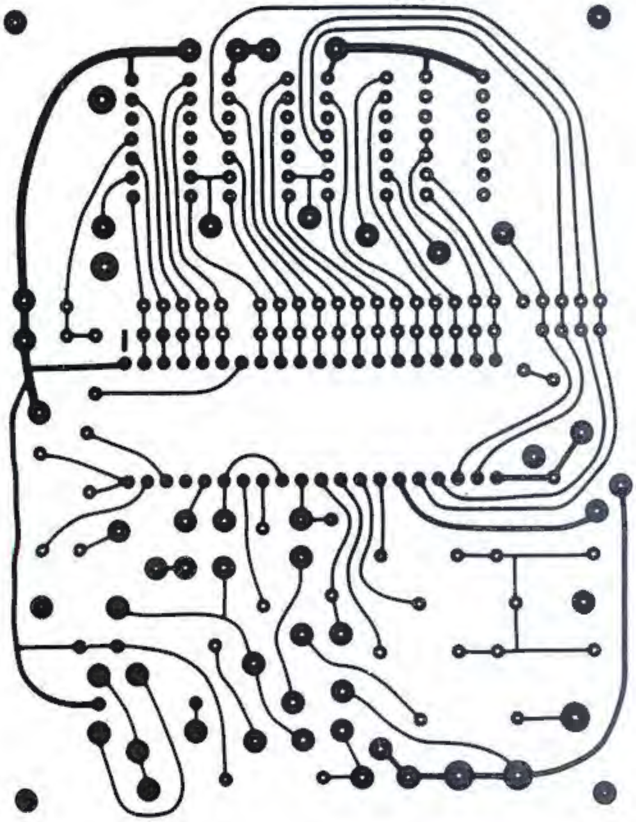


Fig. 3. Actual size etching and drilling guide for the pc board for the LCD display meter is shown at right, component placement above.



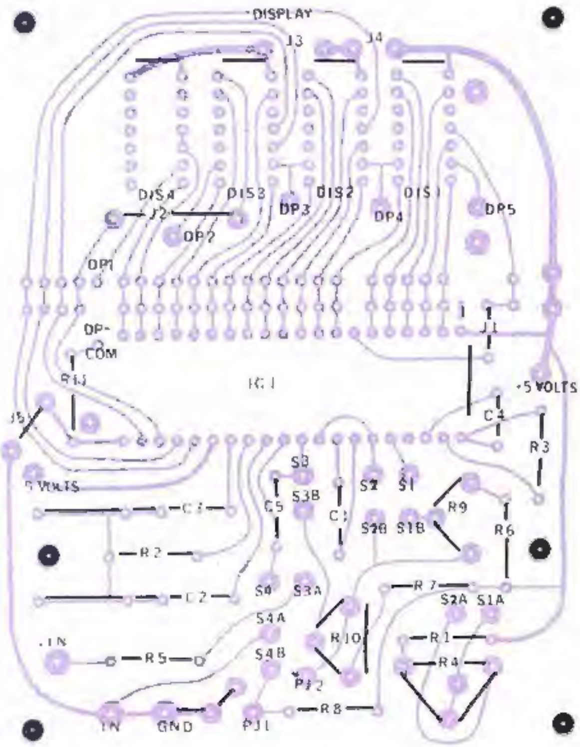


Fig. 4. Actual size etching and drilling guide for pc board for LED meter is at left, component placement above. The display can be separated from main electronics if desired.

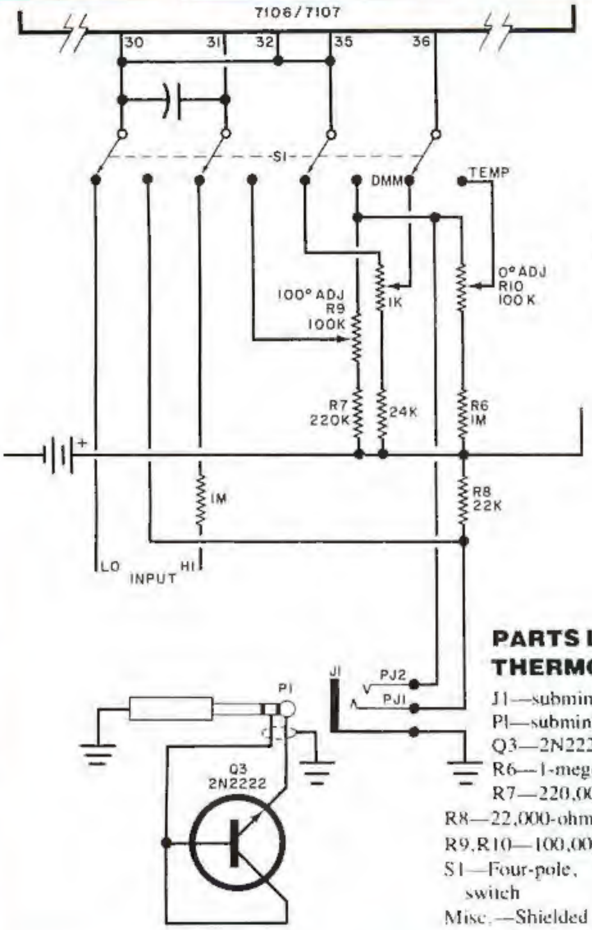


Fig. 5. By adding a switch, some passive components, and a transistor, the meter can be used as a thermometer.

PARTS LIST THERMOMETER

J1—subminiature stereo phone jack
P1—subminiature stereo phone plug
Q3—2N2222 or similar transistor
R6—1-megohm, ¼-watt, 5% resistor
R7—220,000-ohm, ¼-watt, 5% resistor
R8—22,000-ohm, ¼-watt, 5% resistor
R9,R10—100,000-ohm potentiometer
S1—Four-pole, double-throw nonshorting switch
Misc.—Shielded cable, ball-point pen, heat shrinkable tubing, solder, (not in kit).

shrinkable tubing. Then twist together the base and collector leads of the temperature-sensor transistor, trim the lead pair to ½" (12.7 mm) and solder to one of the cable's conductors. Connect the solder and transistor's emitter lead to the other cable conductor. Then slide the heat-shrinkable tubing down over the respective connections and shrink into place.

Connect and solder a subminiature phone plug to the conductors at the free end of the cable. Epoxy the bottom of the heat-sensing transistor's case to the tip of the pen body and the cable to the top of the pen where it exits the body of the pen.

DMM Circuit. The circuit shown in Fig. 6 can be used to convert the basic dc meter into a digital multimeter. Note here that two new circuits have been added. One is a constant-current source for measuring resistance (ohms converter) and the other is a precision ac rectifier for the ac converter.

As shown in Fig 7, the ohms converter employs a constant-current FET regulator (*D9*) in one leg of the *IC3* operational amplifier circuit to generate a reference voltage.

For ac measurements, the input signal from the voltage divider is fed to the

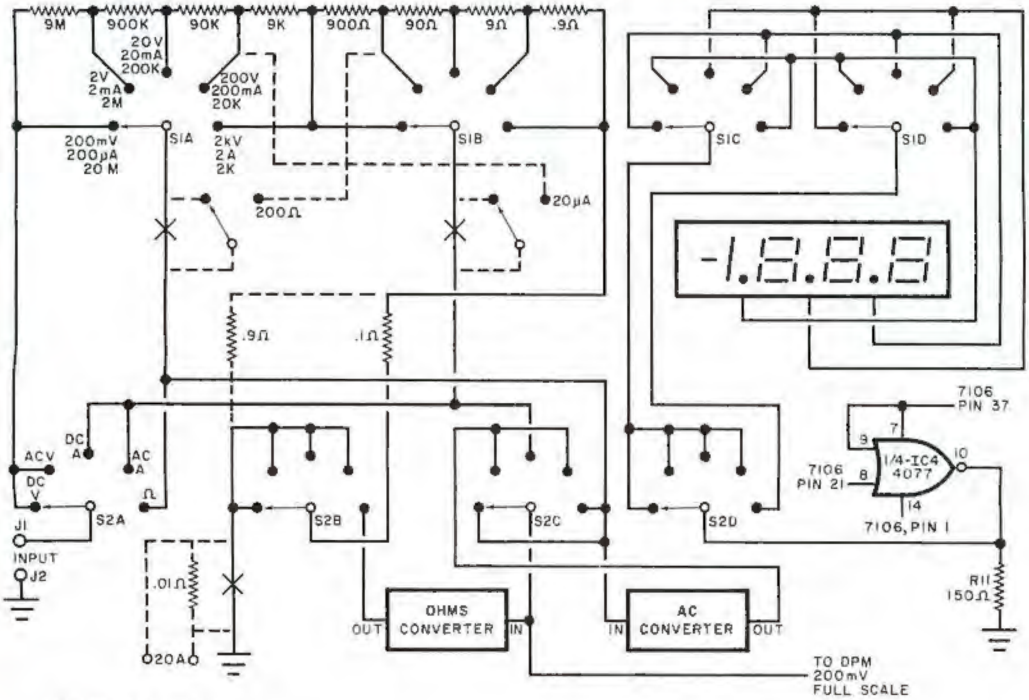
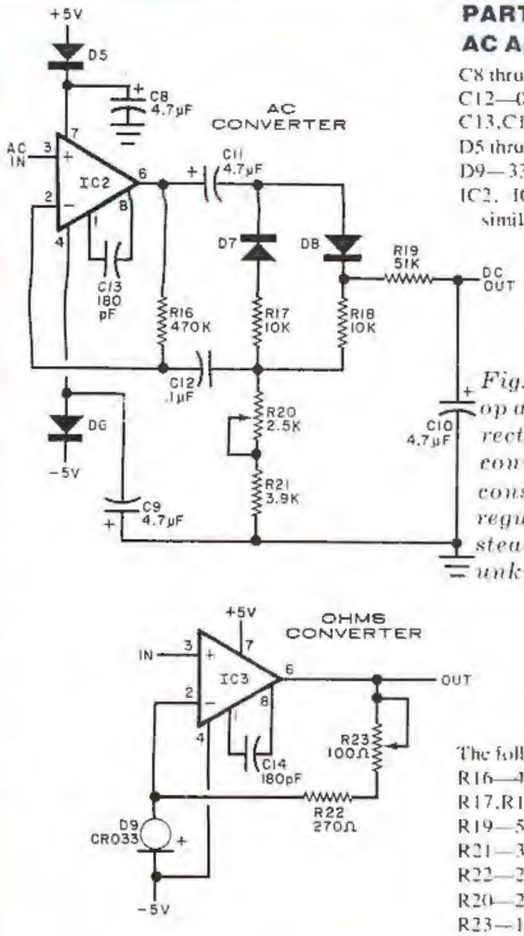


Fig. 6. Front-end switching converts the basic dc meter into a full-fledged digital multimeter. The ohms and ac converter must be added also.

PARTS LIST SCALING CIRCUIT

One each of the following 1% resistors:
9.00 to 9.09 megohms
90,000 to 90,900 ohms
9000 to 9090 ohms
900 to 909 ohms
90 to 90.9 ohms
0.9-ohm 2% resistor
0.1-ohm, 10% resistor
J1, J2—Banana jack (not in kit)
Misc.—Four-pole, five-throw switches (2); solder; hookup wire; (not it knit).



PARTS LIST
AC AND OHMS CONVERTERS

C8 thru C11—4.7- to 6-µF electrolytic
C12—0.1-µF ceramic or film
C13,C14—100-to-200-pF disc
D5 thru D8—1N914 or similar switching
D9—330-µA FET regulator
IC2, IC3—LF13471, CA3130, CA3140 or similar op-amp

Fig. 7. The ac converter uses an op amp in a basic precision rectifier circuit. The ohms converter uses a constant-current regulator (D9) to maintain steady output for measuring unknown resistances.

The following resistors are ½ or ¼ watt, 10%:
R16—470,000 ohms
R17,R18—10,000 ohms
R19—51,000 ohms
R21—3900 ohms
R22—270 ohms
R20—2500-ohm trimpot
R23—100-ohm trimpot

precision rectifier shown in Fig. 7. The dc output from the rectifier can be scaled to indicate rms voltage by adjusting *R20*. FET input op amps are used to produce the high input impedance required when the full 10 megohms of the input divider is in the circuit.

A useful power supply for the LED version of the DMM is shown in Fig. 8. This supply can operate from a 12.6-volt center-tapped transformer or from a conventional 6.3-volt transformer, both of which are shown in Fig. 8.

DMM Construction. The ac and ohms converters and power supply can be assembled on a single printed-circuit board, the etching-and-drilling and component-placement guides for which are shown in Fig. 9. If desired, the power-supply portion can be separated from the op-amp circuits.

When using the 6.3-volt transformer in the power supply, connect one output lead to point CT and the other output lead to one of the 6.3 points. This converts the power supply from full wave to half wave.

The LCD version of the instrument requires only a single 9-volt battery to drive both the logic and display. A line-powered 9-volt dc charger can be used with a 9-volt rechargeable battery in this version of the DMM.

The circuit shown in Fig. 10 can be used with the LCD DMM if you wish to use four small-sized cells to supply both the +6 and −5.6 volts required by the circuit.

Options. As shown in Fig. 6, additional ranges can be added to the instrument by switching into other points on the voltage-divider network. For example, to add a 200-ohm full-scale range to the ohms function, another switch is required to transfer the ohms input line to the 100-ohm point on the divider.

In a similar manner, the current range

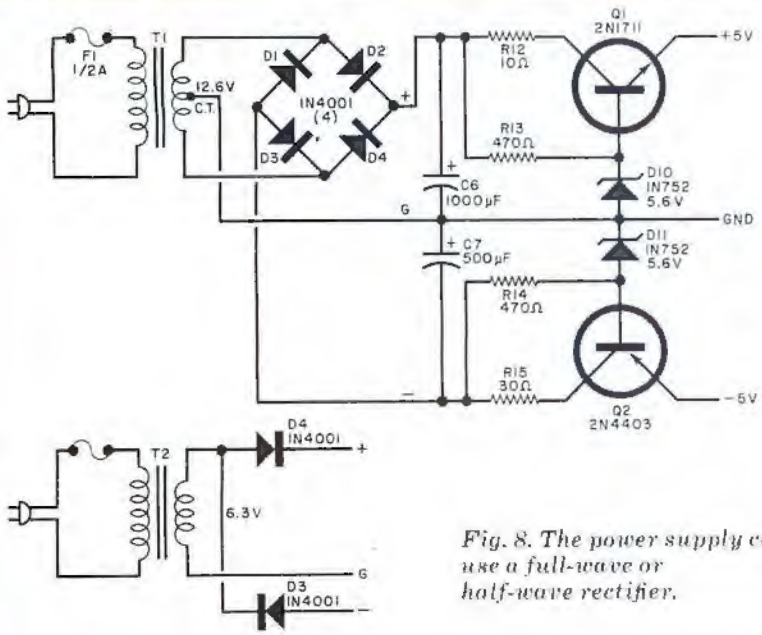
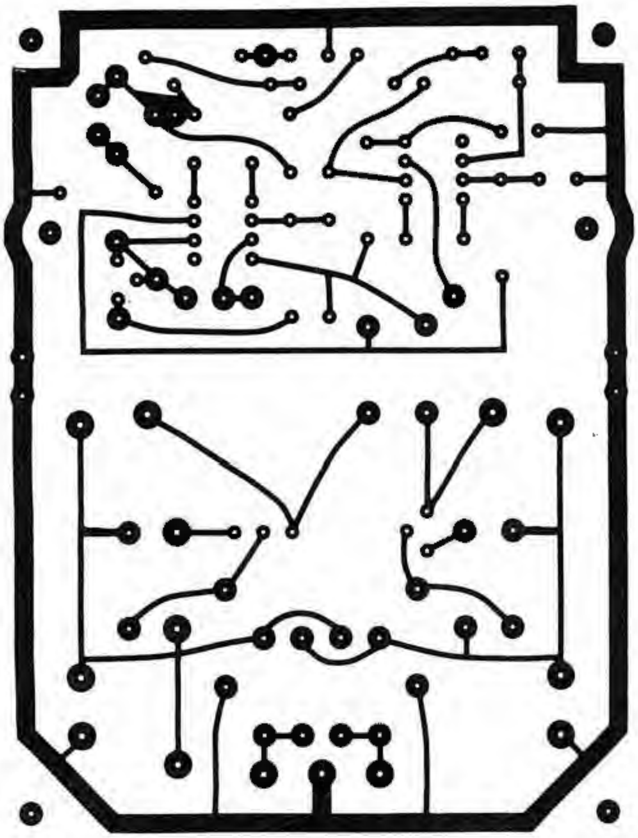


Fig. 8. The power supply can use a full-wave or half-wave rectifier.

PARTS LIST
POWER SUPPLY

C6—1000-µF (minimum), 10-volt electrolytic
C7—470-µF (minimum), 10-volt electrolytic
D1 thru D4—1N4001 rectifier or similar
D10,D11—5.1- to 6.2-volt zener (1N752 or similar)
F1—½-ampere fuse and holder (not in kit)
Q1—2N1711 or similar transistor
Q2—2N4403 or similar transistor
R12—10-ohm, 1-watt resistor
R13,R14—470-ohm, ½-watt resistor
R15—30-ohm, ½-watt resistor
Note: The following items are available from Hobb-Y-Tronics, 957 Ball Ave., Union, NJ 07083; complete kit of parts for LED version, including case, for $49.95; complete kit of parts for LCD version, including case, for $53.95. Add $1.50 for shipping and handling. Also available separately: case (specify version) for $4.95; pc board, ICs, and D9 for either version for $17.95. New Jersey residents, please add 5% sales tax. Outside continental USA, add necessary extra postage.



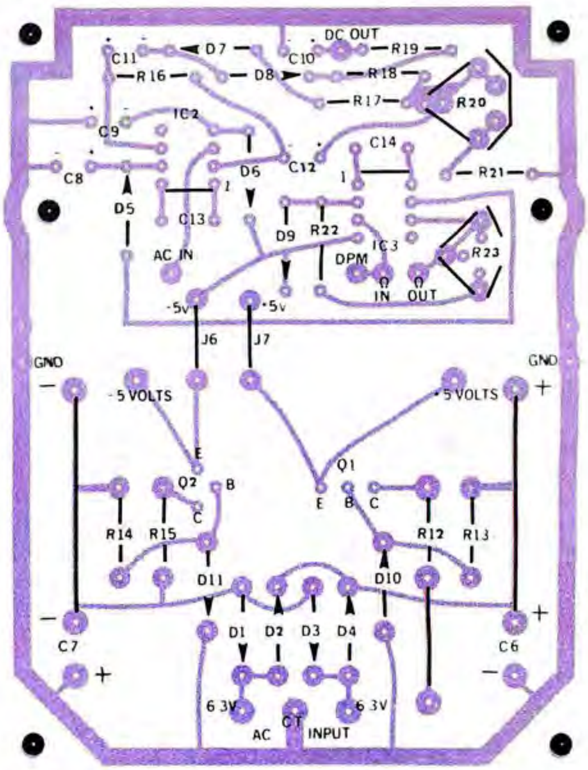


Fig. 9. Actual size etching and drilling guide for pc board for the ohms and ac converter is shown at left, components placement above. Board can be separate from power supply if desired.

can be extended downward by switching into higher points on the divider network. A high-current range can best be added by using a separate 0.01-ohm input shunt, with the shunt current feeding into the current line. The three options, with the required lead breaks, are shown in Fig. 6.

To add the 20-ampere option, use heavy-duty terminals and bus-bar wiring to minimize voltage drops and contact resistance. The 0.01-ohm resistor should have a minimum 10-watt rating. The circuit is arranged so that the current being measured does not flow through switch contacts.

The 20-μA current option increases the low-current measuring capacity.

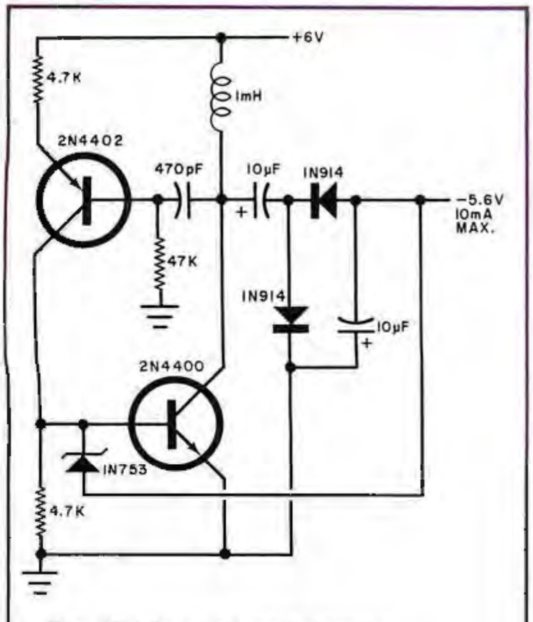


Fig. 10. This −5.6-volt supply can be used with battery supplying the LCD circuit.

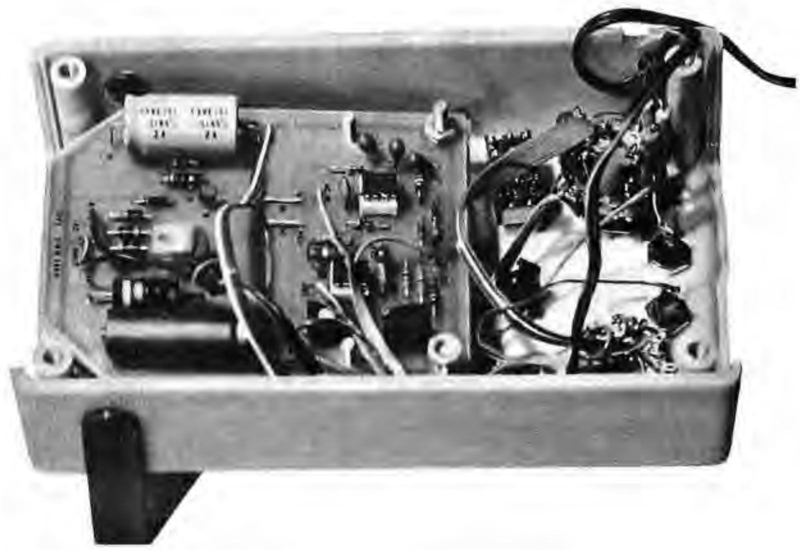


Photo shows inside of author's prototype meter. Switches on front can be arranged to suit builder.

However, it should be noted that the current shunt will be 10,000 ohms, a value that will limit current measurements to high-resistance circuits.

In the 200-ohm resistance option, when the range switch is set to 20 volts, the decimal point energized for all three options will be correct even though this option has a three-decade scale range.

Calibration. The unloaded potential of a fresh mercury cell is 1.35 volts. A voltage-divider network consisting of 0.5% or better tolerance resistors can be applied to this voltage source to arrive at almost any potential in the 150-to-200-mV range. There is no need to obtain resistors that yield exact decade voltages. Instead, you can use Ohm's law to determine what the voltage will be between any two points in a voltage divider. Let us assume you have a voltage divider made up of a precision-tolerance 500- and a 3000-ohm resistor. Using Ohm's law, the current through this series network with a mercury cell would be 1.35 volts divided by 3500 ohms, or 3.86 mA. Then the voltage dropped across the 500-ohm resistor would be 3.86 mA times 500 ohms, or 192.86 mV.

Ac calibration is achieved by setting the FUNCTION switch to AC VOLTS and the RANGE switch to the setting for which you have an accurate calibration voltage. Then adjust *R20* in the ac-converter section for the known voltage level being applied to the input, while observing the display.

The resistance ranges can be calibrated by adjusting *R23* in the ohms converter section for exactly 100 mV between pins 2 and 6 of *IC3*. An alternative method is to use a known 0.1% tolerance resistor value and adjust *R23* for a display of its value. Bear in mind, however, that the calibration will be only as good as the accuracy of the test resistor and the setting of *R23*.

Calibration of the temperature-measuring circuit is performed by immersing the probe tip in ice water and adjusting the 0° C ADJ potentiometer for a 00.0 display. Then, with the probe tip immersed in boiling water, adjust the 100° C ADJ pot for a 100.0 display. If you prefer a °F display in degrees Fahrenheit, use a 32.0 indication in ice water and 212.0 in boiling water.

Conclusion. As you can see from the foregoing, you can just about custom tailor a digital multimeter to your needs and/or desires with the new 3½-digit A/D converters. ◇