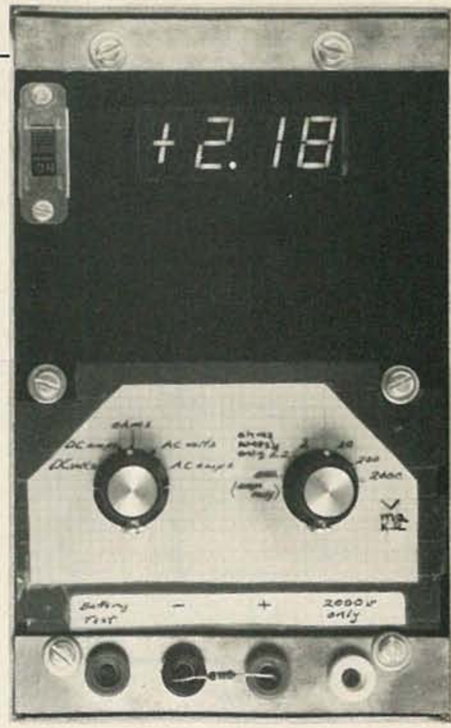
BUILD THIS

3½ Digit DMM



Want to design and build your own DMM? If so, this developmental prototype is a good place to start. You can add features and select an enclosure and layout to meet your needs.

CARSON CHEN*

HERE'S HOW AN ACCURATE, INEXPENSIVE 3½ digit DMM can be built. The DMM is designed around a single 3½ digit DVM IC that performs the analog-to-digital conversion function. The specifications of the DMM are shown in Table 1.

Referring to the schematic in Fig. 1, (see page 62) the basic building block of the multimeter is the ADD3501 analog-to-digital converter using a pulse-modulation technique. A 2-volt reference voltage tapped off the LM336 2.5-volt precision reference diode allows for a 1mV resolution. Additional ADD3501 support circuitry consists of an NSB5388 LED display, a DS75492 digit driver, an RA08 resistor array and an LM340 to regulate the V_{CC} supply voltage.

DC voltage measurement: Depending upon the range selected, the positive or negative DC voltage to be measured is applied to the + and − meter probes and, where applicable, attenuated so that the maximum voltage per range equates to 2 volts full-scale and applied across the ADD3501 $V_{IN}+$ $V_{IN}-$ pins (pins 13 and 12 respectively). The ADD3501 then performs a pulse-modulation analog-to-digital conversion and digitally displays the numerical equivalent of the analog input voltage.

DC current measurement: In the DC current mode, the meter probes are placed in series with the current to be measured. On any range, the DMM places a known resistance in series with the current to develop a 2-volt full-scale voltage drop. (This voltage drop may be reduced to 200 mV; refer to the last section of this article). The equivalent drop across the current measuring resistor is then converted and displayed by the ADD3501.

Resistance Measurement: As in all multimeters, a current source develops a voltage drop across the unknown resistor being measured. In this case the resistor to be measured is placed across the + and − meter probes and, depending upon the range selected, a constant current is forced through the resistor developing, at maximum, 2 volts full-scale. This voltage is applied to the $V_{IN}+$ and $V_{IN}-$ pins of the ADD3501 and converted to its proper digital equivalent displayed as ohms. The current source is designed around two of the op-amps in the LM346 (IC2-a and IC2-b) and transistors Q1 and Q2.

Isolating the current source and analyzing the circuit in Fig. 2, we see that resistor R_X sets the desired current for a chosen resistance measurement range. It is essential to note that varying resistor values placed at R_X must not alter the constant current through R_X. If this occurs, erroneous resistance readings will be displayed. To eliminate any non-constant current conditions, op-amp IC2-b and transistor Q2 function as follows:

To establish a constant-current source, a constant voltage drop must be maintained across load resistor, R_L. The closed-loop operation of IC2-b trys to maintain a zero differential input voltage. With V_A applied to the non-inverting input, point A is forced to V_A+V_{BE} so that the voltage of point B would equal V_A. Thus a constant voltage potential is maintained across R_L. With V_A constant at point B, the current source remains constant, and varying R_X has no effect on the current source, provided that $R_X \times I_{SOURCE}$ is not greater than V_A-V_{BE}, so that transistor Q2 is saturated. This non-linear condition however will not be noticed since $R_X \times I_{SOURCE} \geq 2V$ will force the ADD3501 to display +OFL. (See Fig. 3.)

A change in the V_{CC} supply voltage is

TABLE 1—SPECIFICATIONS

DC Volts:	Accuracy better than ±1%
	Ranges: 2 volts, 20 volts, 200 volts, 2 kV.
	Input impedance: greater than 10 megohms on 2-volt range; 10 megohms on 20-volt to 2-kV ranges.
AC RMS Volts:	Accuracy better than ±1%
	Ranges: 2 volts, 20 volts, 200 volts, 2kV (40 Hz to 8 kHz, sinewave)
DC Amps:	Accuracy better than ±1%
	Ranges: 200 μA, 2 mA, 20 mA, 2 amps
AC RMS Amps:	Accuracy better than ±1%
	Ranges: 20 μA, 2 mA, 20 mA, 2 amps
Ohms:	Accuracy better than ±1%
	Ranges: 200, 2000, 20,000, 200,000 ohms, 2 megohms

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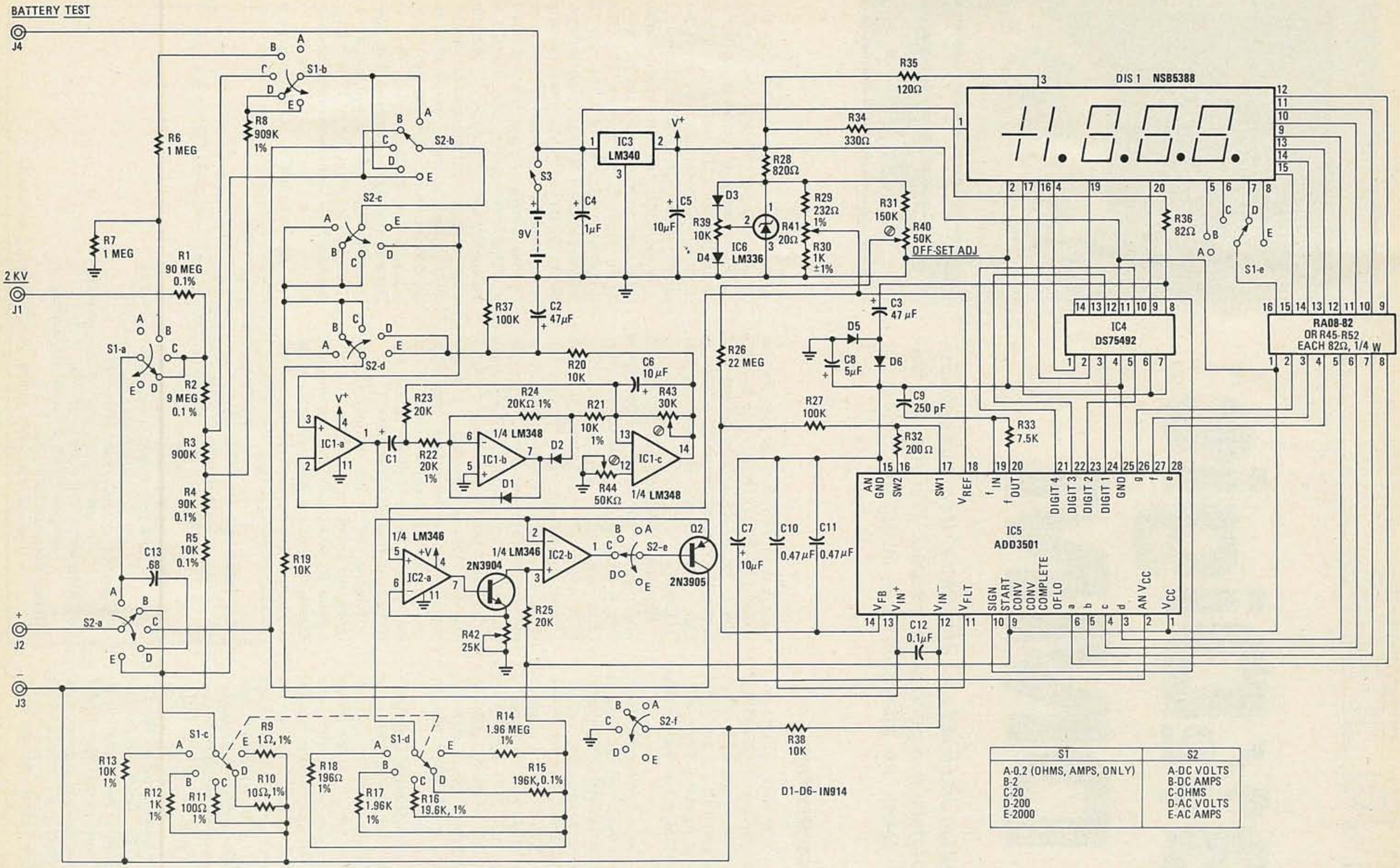

FIG. 1—SCHEMATIC of the low-cost digital multimeter. The component-count is low for an instrument of its versatility.

PARTS LIST

Resistors ¼ watt, 5% unless otherwise specified

R1—90 megohms, 0.1%
R2—9 megohms, 0.1%
R3—900,000 ohms, 0.1%
R4—90,000 ohms, 0.1%
R5—10,000 ohms, 0.1%
R6, R7—1 megohms
R8—909,000 ohms, 1%
R9—1.0 ohms, 1%
R10—10 ohms, 1%
R11—100 ohms, 1%
R12—1000 ohms, 1%
R13—10,000 ohms, 1%
R14—1.96 megohm, 1%
R15, 196,000 ohms, 1%
R16—19,600 ohms, 1%
R17—1960 ohms, 1%
R18—196 ohms, 1%
R19, R20, R38—10,000 ohms
R21—10,000 ohms, 1%
R22, R23, R24—20,000 ohms, 1%
R25—20,000 ohms
R26—22 megohms,
R27, R37—100,000 ohms
R28—820 ohms
R29—232 ohms, 1%
R30-1000 ohms
R31—150,000 ohms
R32—200 ohms
R33—7500 ohms
R34—330 ohms
R35—120 ohms
R36—82 ohms
R39—10,000 Ohms, 10-turn trimmer pot
R40, R44—50,000 Ohms, 10-turn trimmer pot
R41—20,000 ohms, 10-turn trimmer pot
R42—25,000 ohms, 10-turn trimmer pot
R43—30,000 ohms, 10-turn trimmer pot
R45—R52—RA08-82 resistor array (National) or eight—82 ohms, ¼ watt

Capacitors

C1, C2, C3—47 μF, 15 volts, electrolytic
C4—1 μF
C5, C6, C6—10 μf, 15 volts, electrolytic
C8—5 μF, 15 volts, electrolytic
C9—250 pF
C10, C11—0.47 μF
C12—0.1 μF

Semiconductors

D1—D6—1N914
Q1—2N3904
Q2—2N3905
DIS1—NSB5388 3½-digit LED display
IC1—LM346 quad op-amp
IC2—LM348 quad op-amp
IC3—LM340 5-volt regulator
IC4—DS75492 (National) MOS to LED hex-digit driver
IC5—ADD3501 3½-digit digital voltmeter
IC6—LM336 2.5-volt Zener reference source
S1—rotary switch, 5 circuits, 5 positions
S2—rotary switch, 6 circuits, 5 positions
S3—SPST miniature slide switch
Miscellaneous hardware including case, stand-off bushings, hookup wire, IC sockets, etc.

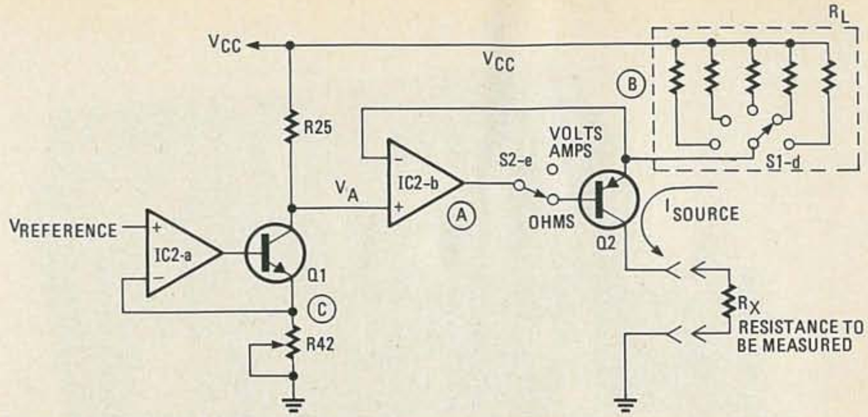

FIG. 2—FUNCTIONAL DIAGRAM of the constant-current source. The op-amps are part of a quad device.

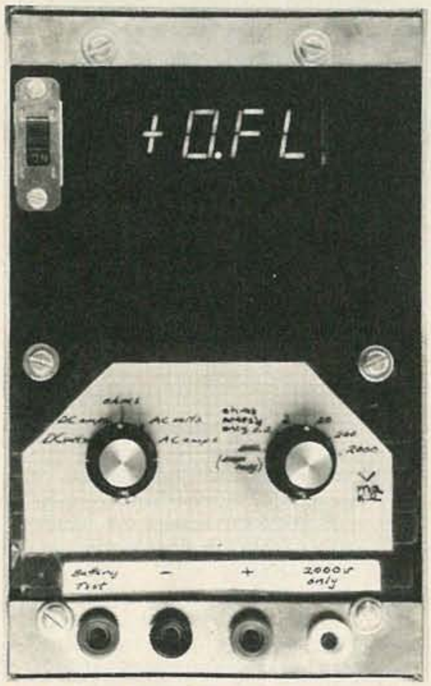

FIG. 3—THIS DISPLAY on the readout can not be mistaken for anything other than overflow.

another condition that may affect the constant-current source and must be corrected for within the circuit. A constant-current sink is established when amplifier IC2-a forces point C to the non-inverting input voltage V_{ref}. With V_{ref} held constant at point C, the current through R25 is roughly equal to the current through R42. (See equation 1.) This allows V_A to vary directly proportional to any fluctuations in supply voltage.

$$V_A = V_{CC} - [(V_{ref}/R42)\alpha]R25 \qquad (1)$$

If V_{CC} drops by V_X, V_A drops by V_X and sustains the desired voltage across R_L. Reference voltage V_{ref} is taken from the LM336 and remains constant throughout the ADD3501 supply voltage range. Note that the base of Q2 must be left connected to IC2-b during the AC current or voltage measurements. In these modes the R_X terminals (and the collector–ground) are open circuited. This allows the Q2 emitterbase junction to act as a forward-biased diode pulling the V− supply to ground through IC2-b. This problem is eliminated by the opening switch (S2-e) connecting Q2 to IC2-b.

AC voltage measurement: The AC voltage is measured using the AC-to-DC converter shown in Fig. 4. The voltage attenuator has a source impedence on any range of 1 megohm. Amplifier IC1-a is connected as a voltage-follower lowering the source impedence driving IC1-b to a few hundred ohms. The small DC offset voltage is decoupled through C1.

The AC/DC converter, IC1-b and IC1-c, can best be understood by following the signal path for negative and then for positive inputs. For negative signals, the output of IC1-b is clamped to +0.7 volt by diode D1 and disconnected from the summing point of IC1-c by D2. Amplifier IC1-c then functions as a simple unity-gain inverter with input resistor R23 and feedback resistor R43 giving a positive-going output.

For positive inputs, IC1-b operates as a normal amplifier connected to the summing point of IC1-c through resistor R21. Amplifier IC1-b then acts as a simple unity gain inverter with input resistor R22 and feedback resistor R24. The gain accuracy of IC1-b is not affected by diode D2 since it is inside the feedback loop. Positive current enters the summing point of IC1-c through R23 and negative current is drawn from the summing point through R21. Since the voltage across R23 and R21 are equal and

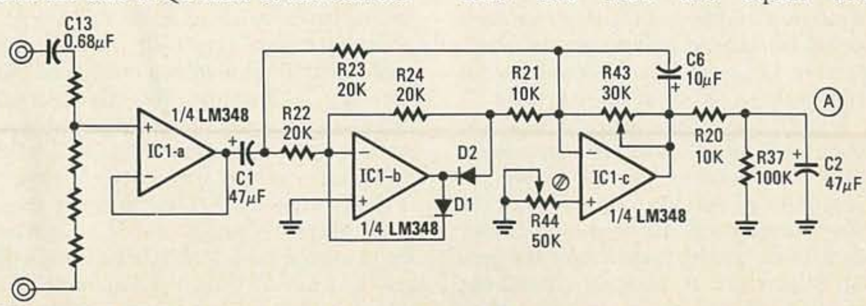

FIG. 4—THE AC/DC CONVERTER is designed around three op-amps and a few other components.

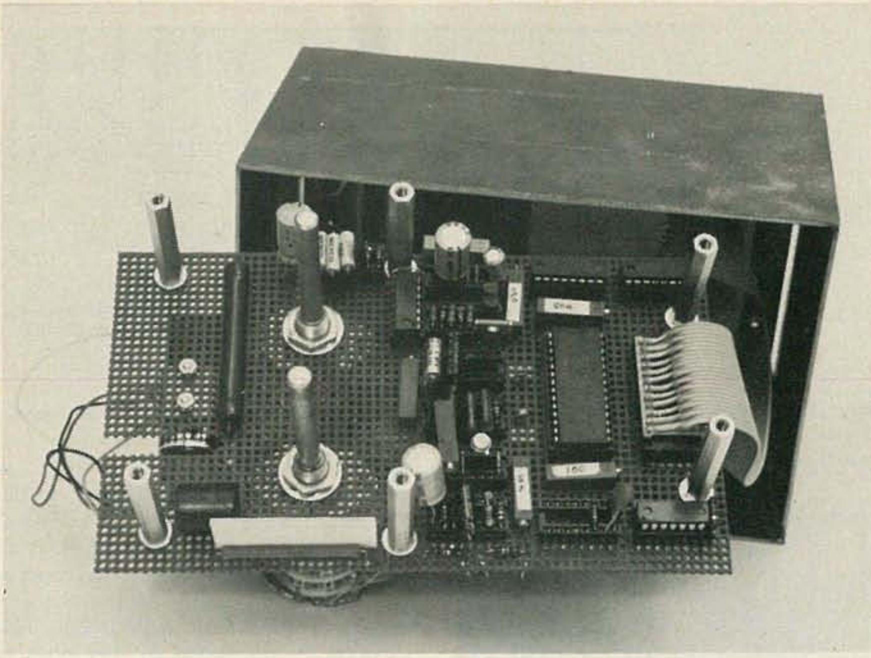

FIG. 5—INTERIOR VIEW of the DMM. Perforated board is used for the chassis. Wiring is point-to-point. Precision resistors in the voltage divider, current shunts and ohmmeter circuits are plugged into IC sockets.

opposite, and R21 is one-half the value of R23, the net input current at the summing point is equal to and opposite from the current through R23. Thus amplifier IC1-c operates as a summing inverter with unity gain, again giving a positive output. The circuit then becomes an averaging filter with C6 connected across R43. Trimmer resistor R44 is used to minimize output errors due to input offset currents.

AC current measurement: To measure AC current, the meter circuit is configured as in the DC current measurement setup. Again, IC1-a through IC1-c (see Fig. 4) performs the AC to DC conversion with the final DC voltage at point A being fed to and converted by the ADD3501.

Construction

The digital multimeter described here was developed as a prototype to prove the suitability of the ADD3501 for use in an inexpensive electronic test instrument. The circuit is simple and the component-count relatively low so point-to-point wiring or wirewrap on perforated board can be used. An interior view is in Fig. 5. Note that all V_{CC} connections should be made to a single point and all grounds should be made to a single ground point. Be sure to connect an 0.1-μF capacitor from each V_{CC} IC terminal to ground.

It cannot be overly stressed as to the importance of maintaining single-point ground connections for the amplifiers. Ground-loop resistances coupled with the offset currents and AC response can play absolute havoc with system linearity, gain and display flicker. Similarly, flickering occurs if precautions are not taken when considering the layout of analog, high-switching-current and digital ground-loop paths of the ADD3501.

Calibration

Calibration of the digital multimeter is performed as follows:

1. Adjust R40 until the cathode of the precision zener reference diode (LM336) equals 2.49-volts. This adjusts the diode's temperature coefficient.
2. Set the meter to measure 2 volts DC. Short the + and − probe inputs of the meter and adjust R45 until the display reads 0000.
3. Now, apply 1.995 volts DC across the + and − probe inputs and adjust R41 until the display reads 1.995.
4. Set up the meter for resistance on the 2-megohm range. Select a precision resistor whose value is a little lower than 2 megohms and adjust R42 until the appropriate value is displayed.
5. Apply a known 1.995-volt RMS sinewave signal to the meter and adjust R43 until the display reads the same.

(Calibrating the DMM to three decimal places will be difficult for many readers. You can do it if you have access to a 4½- digit DMM. A friendly TV service technician or a lab technician in a local electronics plant may help you with the calibration. If, at first, you don't need the accuracy offered by this instrument, there are a couple of schemes that you can use to get all the precision you'll need for ordinary servicing and experiments.

Calibration on the DC range is relatively simple. A rough calibration can be made using a fresh flashlight cell that will give 1.54 to 1.55 volts. For a more precise reference, you can use a 1.35-volt mercury cell. Most of these supply 1.354 volts ± 2 mV. Note that 1.4 volt mercury cells are available but they are not suitable for use as voltage standards. Among the several 1.35-volt mercury cells that are available are Mallory RM12R, Burgess HG12R and Eveready E12N. The "N" and "R" suffixes indicate types suitable for instrument voltage references and high-temperature applications. If the type 12 is not available, try to get a 42, 400, 401 or 625 with the "N" or "R" suffix.

(If your scope has AC/DC coupling you can use it and your DC reference to arrive at a reasonably accurate AC reference source. Connect the DC reference cell across the vertical input and adjust the vertical attenuator for deflection to a convenient reference point above the zero reference line. Without changing the attenuator setting, switch the scope to AC and connect an adjustable AC source to the scope input. Adjust the applied voltage so its uppermost peak rests on the same reference line as the DC voltage.

(The effective or RMS value of the AC voltage equals 0.707 times the peak value indicated on the scope. For example, when a 1.35-volt cell is the DC reference, the equivalent RMS voltage giving the same deflection is 1.35 × 0.707 or 0.954 volt.—*Editor*).

Final note

The digital multimeter described here was specifically developed with accuracy and minimal cost in mind. For a more elaborate multimeter, improvements to the basic circuit of Fig. 1 can be made in the following areas.

1. Increase the volts mode to include a 200 mV full-scale range. (Refer to the ADD3501 data sheet).
2. Decrease the full-scale current measurement load voltage from 2 volts to 200 mV.
3. Provide true-RMS mesurement capability.

The first two categories may be satisfied by dividing down the ADD3501 feedback loop by a ratio of 10 to 1, thus scaling down the full-scale 2-volt input requirement to 200 millivolts. This not only allows 200 mV impressed across the $V_{IN}+$ and $V_{IN}-$ inputs to display a full-scale reading but also implies that the maximum voltage dropped across the current-measuring resistance is also 200 millivolts.

Note, of course, that the values of the current-measurement resistor array must be scaled down by a factor of 10 to 1. Also note that a 200 mV full-scale input implies a resolution of 100μV. At these low input levels, offset currents may effect linearity and gain of the AC/DC converter and some clever circuitry may be required to eliminate such problems. A true RMS meter can be made by replacing the AC to DC converter with LH0091, a true RMS-to-DC converter, and appropriate interface circuitry. **R-E**