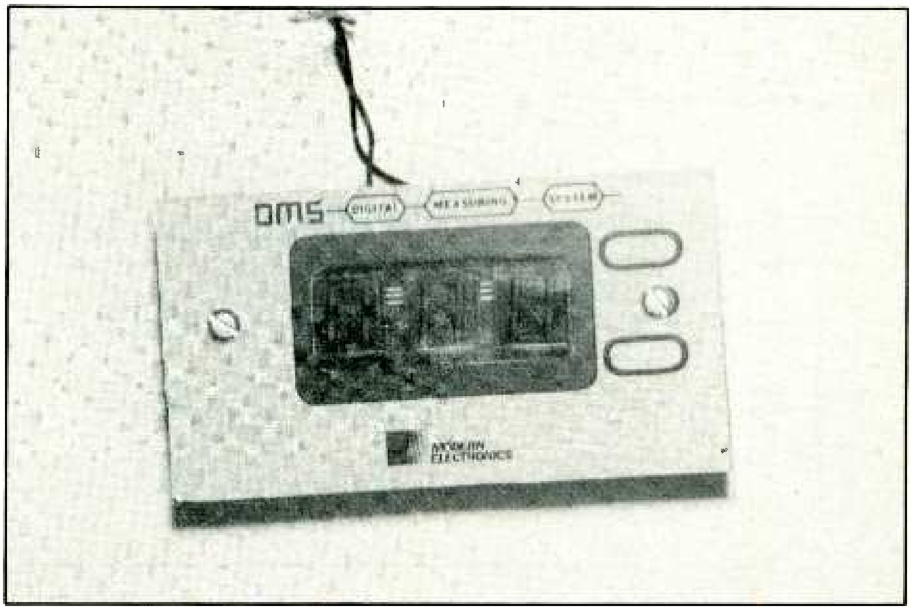
A Digital Measuring System

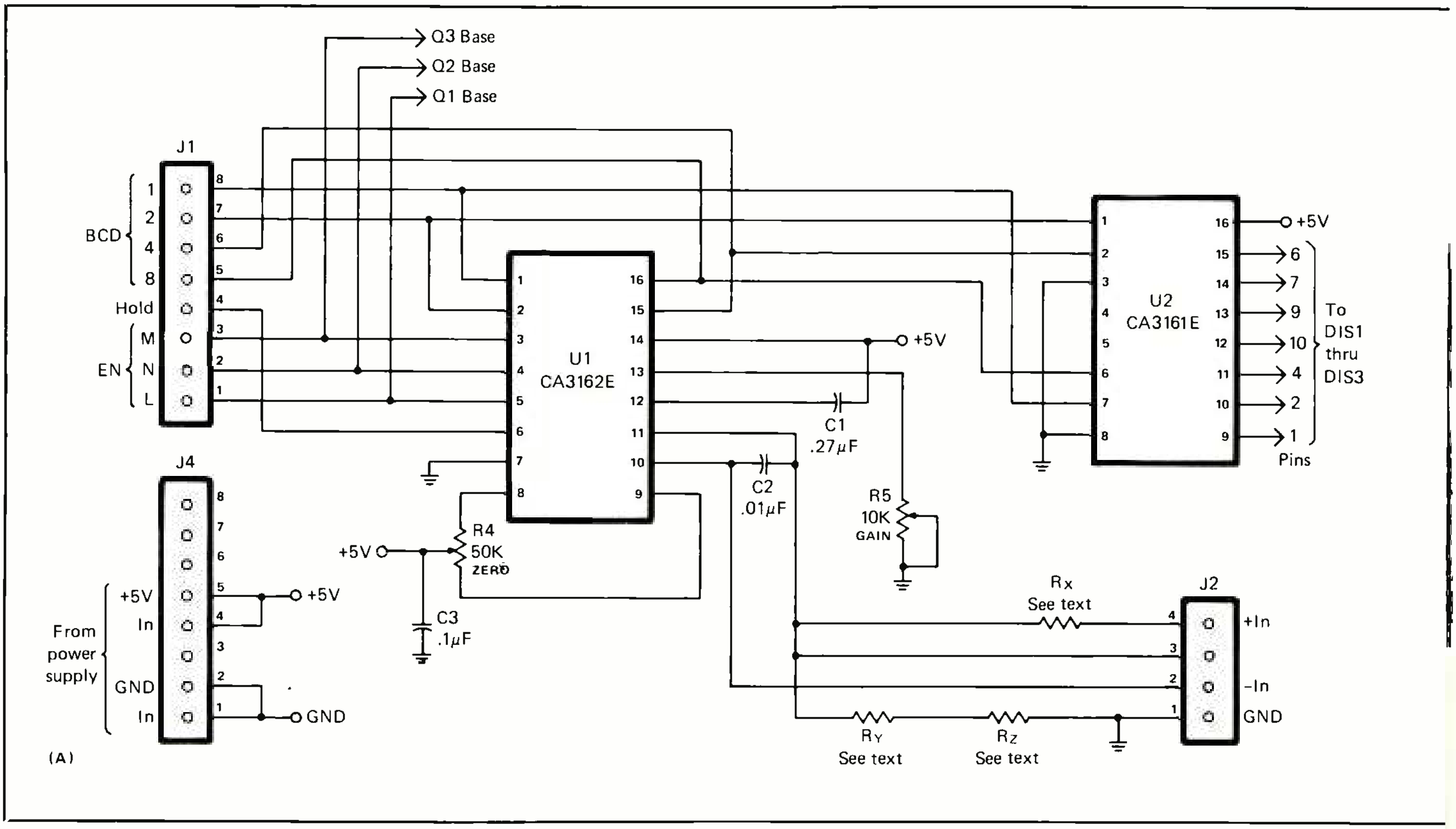
This compact element serves as the basic building block for a wide variety of add-on measuring modules

By Charles R. Ball



Most modern electronic instruments have gone "digital." You see this in multimeters, frequency counters, tachometers, weight scales, thermometers, and just about every other instrument designed to measure the magnitude of a particular physical parameter.

Common to all digital instruments are the numeric display and its decoding and driving circuitry. With commercial measuring instruments, every time you purchase a particular one, you are duplicating the display/decoder/driver systems—for which you pay a hefty premium, usually more than half the purchase price. In this



article, we describe how to build a highly accurate, low-cost 3-digit panel meter that serves as the basic building block for a wide range of specialty add-on function modules like a DMM, tachometer thermometer, etc.

The Digital Measuring System features single-polarity supply operation, 999-mV full-scale sensitivity, 0.1% accuracy, and a multiplexed BCD (binary-coded-decimal) output. It also has variable update, display hold, over/under-range indicators, a floating input, and negative readings to −99 mV. (See the Table for a complete list of Technical Specifications.)

This is an ideal building block for a variety of digital measuring systems that can be used in the shop, home, car, boat or industry. Add-on modules can later be used to allow the system to measure voltage/current/resistance, temperature, pressure, revolutions per minute and more.

This month, we tell you how to build the DMS and the power supply that goes with it and the add-on modules. Next month, we will tell you how to build a tachometer module for measuring rotational speed, and in the future other useful modules will be described as they are developed.

About the Circuit

At the heart of the DMS is an analog-to-digital (A/D) converter, shown as *U1* in Fig. 1. This integrated circuit is an ultrastable differential-input, dual-slope A/D converter designed specifically for digital numeric systems. Internal details of the complex A/D converter chip are given in Fig. 2.

A voltage applied to the input of the

PANEL METER PARTS LIST

Semiconductors
DIS1,DIS2,DIS3—FND507 LED numeric display
Q1,Q2,Q3—2N2222 transistor
U1—CA3162E A/D converter
U2—CA3161E BCD-to-7-segment decoder/driver

Capacitors
C1—0.27-μF, 100-volt metallized Mylar or polystyrene
C2—0.01-μF, 12-volt disc
C3—0.1-μF, 12-volt disc

Resistors (all ¼-watt, 10% tolerance)
R1,R2,R3—56 ohms
Rx,Ry,Rz—See text
R4—50,000-ohm trimmer potentiometer (Bourne No. 3352H-1-503 or similar—see text)
R5—10,000-ohm trimmer potentiometer (Bourne No. 3352H-1-103 or similar—see text)

Miscellaneous
Printed circuit board; headers (AP Products No. 929974-36; cut to lengths needed); IC sockets (2); Molex Soldercons; spacers; machine hardware; hookup wire; solder; etc.

Note: The following items are available from BALL, P.O. Box 1022, Snellville, GA 30278-1022; Double-sided pc board No. DPMR-PC for $9.95; CA3162E and CA3161E, No. DPMR-IC, for $11.00; complete kit of parts (less headers) for decoder/driver/display, No. DPMR-K, for $27.95; power supply pc board, No. DPMRPS-PC, for $6.95. Headers and terminal board are available from Digi-Key, P.O. Box 677 Thief River Falls, MN 56701.

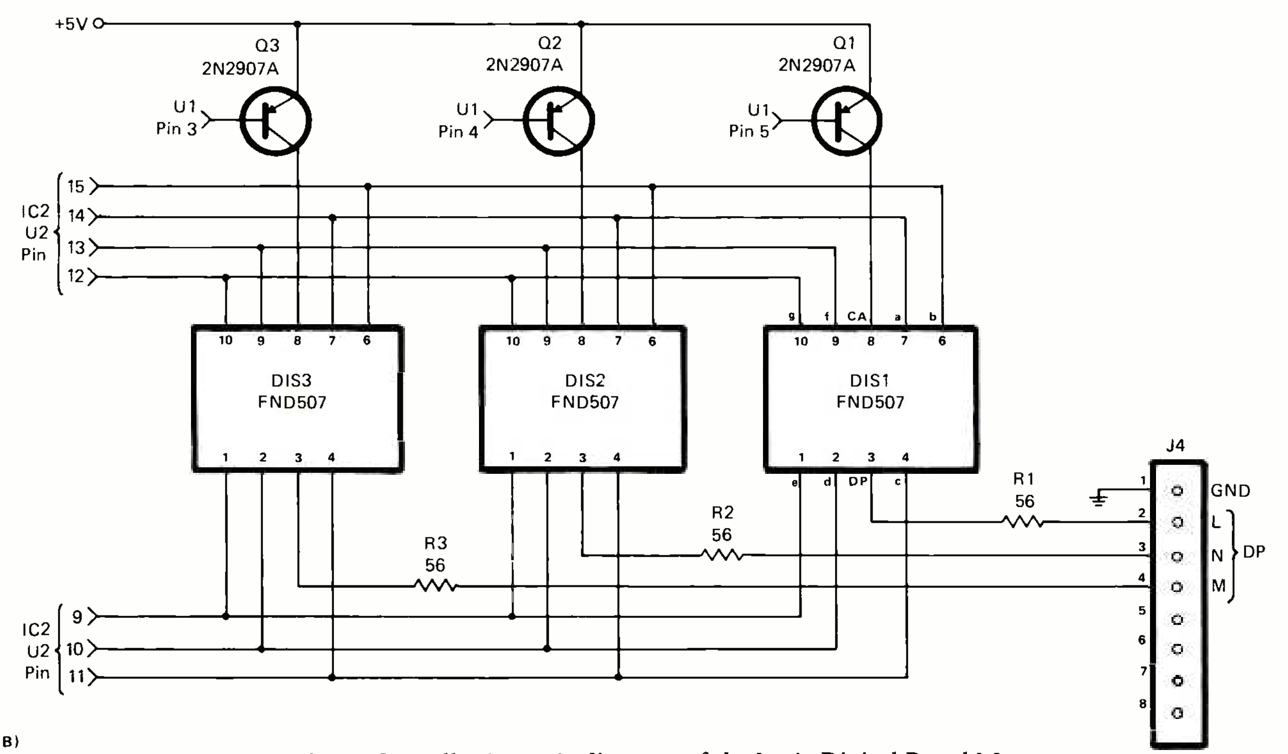


Fig. 1. Overall schematic diagram of the basic Digital Panel Meter.

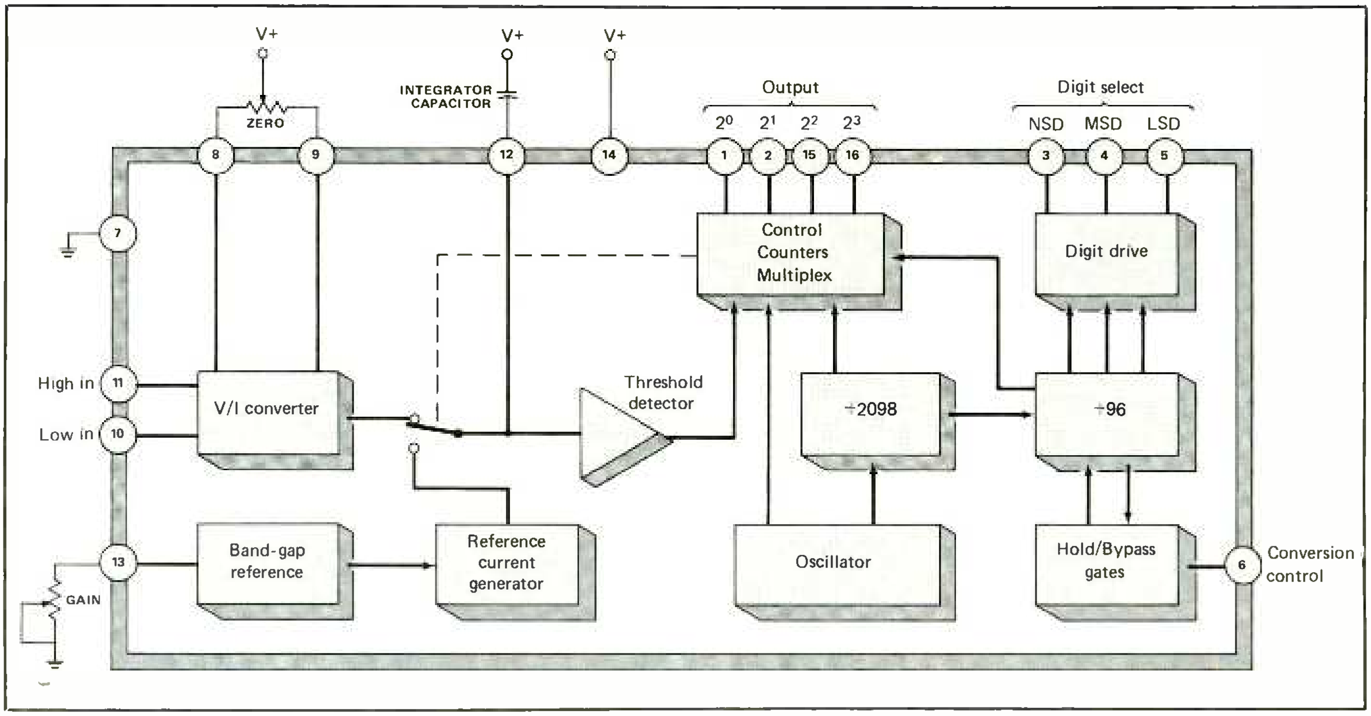


Fig. 2. Block diagram of internal circuit details of the A/D converter chip used in this project.

D/A converter is converted to a current that charges the integrator capacitor (*C1* in Fig. 1) over a predetermined number of clock periods. The integrator capacitor is then connected to a different and opposite polarity current source.

The number of clock periods required to restore the integrator capacitor to the original charge is a direct function of the applied voltage. When the comparator (threshold detector) senses restoration, the number of clock periods is latched into the counter and multiplexed into the display decoder/driver chip via Output pins 1, 2, 15 and 16. The Digit Drive block sequences the three digits on one at a time at a fast enough rate that the eye sees all digits on simultaneously, via pins 3, 4 and 5.

Timing and the multiplex rate inside the A/D converter are derived from a 786-kHz ring oscillator. The multiplex rate is 384 Hz. Two conversion rates —4 and 96 Hz—and display hold are available with the A/D converter's pin 6 option. A/D conversion time is approximately 5 milliseconds.

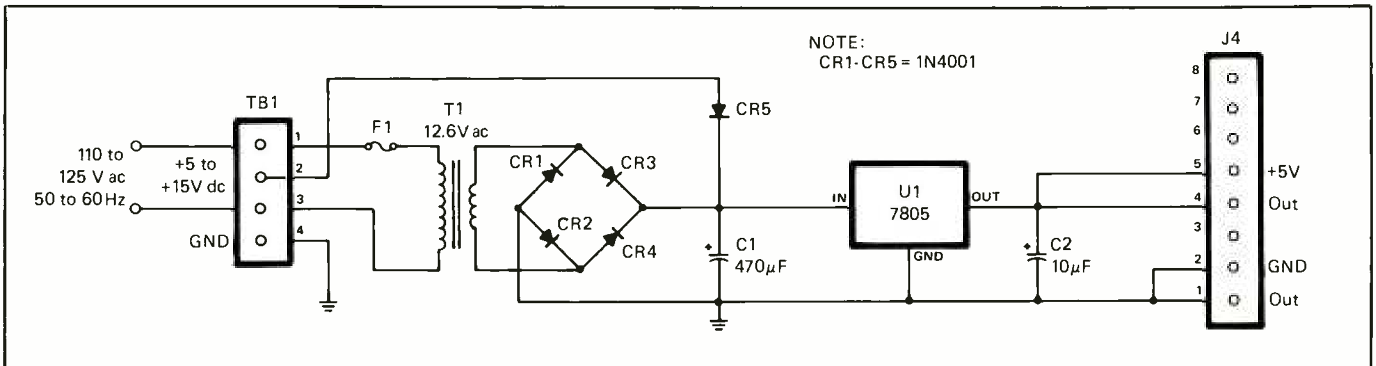
Returning to Fig. 1, we see that dc voltages are scaled to the proper level by resistive networks and are applied to the input of *U1*. The A/D converter then determines the value of the applied signal, scales it and multiplexes the information in BCD format. This information is then processed by BCD-to-7-segment decoder/driver *U2* to provide segment signals for the displays. Digit-enable is provided by transistors *Q1, Q2* and *Q3* that turn on LED numeric displays *DIS1, DIS2* and *DIS3,* respectively.

Although only a single-polarity power supply is required for proper operation, the DMS can still measure negative potentials down to −99 mV. Any potential more negative that −99 mV will cause the display numerals to disappear and be replaced by the three horizontal dashes (---) that indicate an underrange condition. Likewise, any potential greater than +999 mV causes EEE to appear in the display, this time indicating an overrange condition.

Shown in Fig. 3 is the power supply for the DMS system. When this power supply is plugged into the DMS (all header blocks, identified by "J" numbers in all circuits and modules, in this series directly mate with each other to eliminate as much point-to-

Technical Specifications Table

Input voltage level	
Normal	−99 to +999 mV
Maximum	+15 V
Input impedance	80 to 100 megohms
Accuracy at 25 C	±1%, ±1 count
Temperature coefficient	
Zero	10 μV/°C
Gain	0.005 °C to 125 °C
Power supply output	+5 V dc, 200 mA



POWER SUPPLY PARTS LIST

C1—470-µF, 25-volt electrolytic capacitor
C2—10-µF, 10-volt tantalum capacitor
CR1 thru CR5—1N4001 rectifier diode
T1—12-volt, 300-mA transformer
TB1—4-position terminal board (OK Industries No. TS-4)
U1—7805 +5-volt regulator
Misc—Printed-circuit board; machine hardware; hookup wire; solder; etc.
Note: See Panel Meter Parts List for sources of parts.

Fig. 3. Schematic diagram of project's regulated 5-volt power supply.

point wiring as possible), +5V and GND are automatically connected through *J4*. Ac power-line voltage or + 12 volts can serve as the source for this supply.

Construction

If you wish to obtain a very compact project and make it possible for the DMS and power-supply modules (as well as any future modules that might be forthcoming) to mesh together, the only practical way to assemble the circuitry is on printed-circuit boards.

Shown in Fig. 4 are the actual-size etching-and-drilling guides for the DMS board. Note that two guides are required for each board—one for the top and the other for the bottom. The actual-size etching-and-drilling guide for the single-sided power supply board is shown in Fig. 5.

You can fabricate your own pc boards from Figs. 4 and 5 if you wish. Unless you are very experienced in fabricating pc boards, especially the difficult double-sided DMS board that requires careful attention to registering the two sides, you might wish to purchase ready-to-wire boards from the source given in the Note at the end of the Parts List.

When wiring the DMS board, refer to the components placement/orientation diagram in Fig. 6. Except for the ICs and displays, install the components on the DMS board exactly as shown, paying particular attention to the basing of the transistors. Then install the headers in the *J1* through *J5* locations on the noncomponent side of the board.

Next, install sockets in the *U1* and *U2* locations and Molex Soldercons in

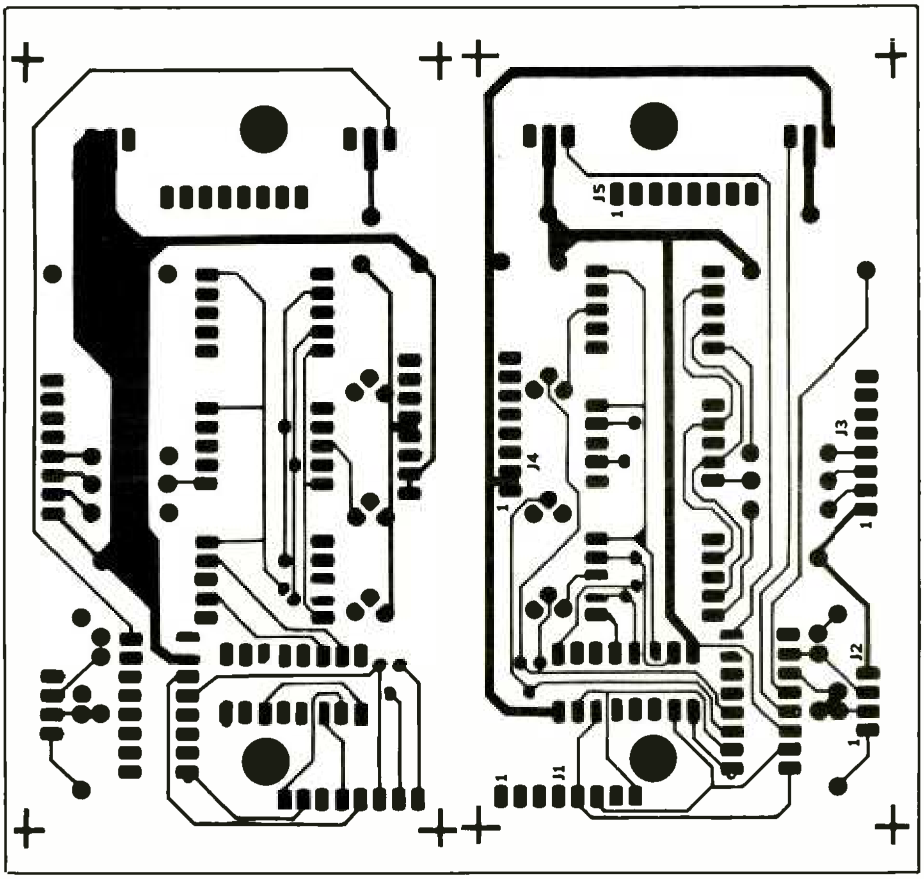


Fig. 4. Actual size etching-and-drilling guides for the top and bottom of the DMS printed-circuit board.

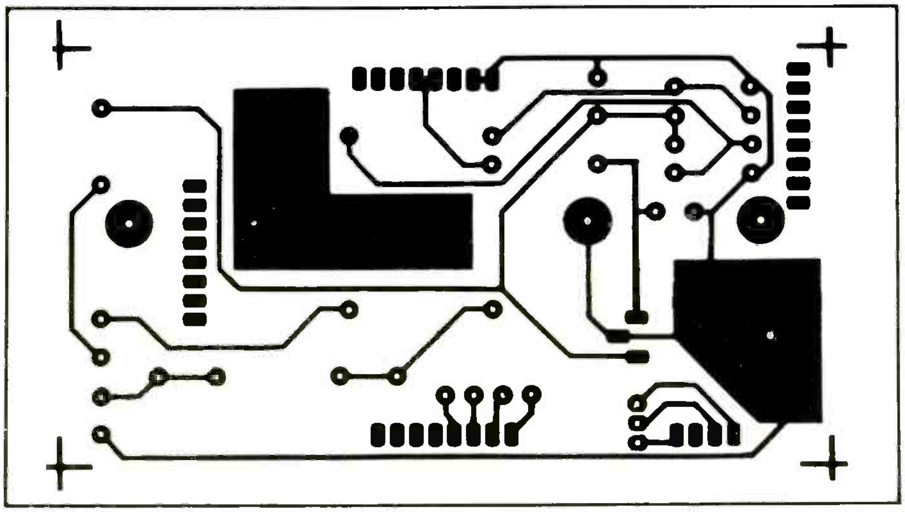


Fig. 5. Actual-size etching-and-drilling guide for the 5-volt power supply.

the *DIS1, DIS2* and *DIS3* locations. Do *not* install the ICs in their respective sockets just yet.

You can install trimmer controls *R4* and *R5* on either side of the board, depending on your preferences and needs. Decide which is better for your needs before installation. Note that several mounting holes are provided for the trimmer controls. This allows you to select from a wide variety of trimmer potentiometers. For easy adjustment and greater stability, you might want to consider replacing the pc-type trimmers specified in the Parts List with multi-turn precision wire-wound trimmers.

For fixed decimal point operation, you need install only one 56-ohm dropping resistor in the appropriate location (*R1, R2* or *R3*) and ground the associated DP lead on the display.

Note at this time that there are no resistors in the R_x, R_y and R_z locations. These locations will be used later under calibration and use.

After soldering is completed, carefully clean away any rosin flux from the board with alcohol or flux solvent. This is necessary because the DMS's 80- to 100-megohm input impedance is easily affected by stray high-resistance paths.

When the board assembly is clean, use standard handling procedures for MOS devices and install *U1* and *U2* in their respective sockets. Then install the displays in their Molex Soldercon socket pins. Pay careful attention to orientation.

Wiring of the power supply board, as per the components placement/orientation guide in Fig. 7, is simple and straightforward, and no special precautions are necessary. Just keep in mind that the *J1* through *J5* headers are to be mounted on the component side of the board with the long pins protruding through the solder side. For safety, place piece of plastic IC carrier (not the conductive type) over the fuse and fuse clips to prevent accidental electrical shocks. If operation is required from only a +12-volt source, you can eliminate *T1, CR1* through *CR4* and *F1*.

Calibration

You need the regulated a 5-volt dc power supply shown in Fig. 3 and either a millivolt reference source or two 100,000-ohm, 1% tolerance resistors and a 1.35-volt mercury cell to calibrate the DMS. If you have the millivolt reference, set if for an output of 650 mV. However, if a millivolt reference is not available, breadboard the circuit shown in Fig. 8 to obtain the required 650-mV reference voltage across R_b.

Before starting calibration, temporarily solder a 100,000-ohm, ¼-watt resistor in the R_z location on the board. Leave this resistor standing about ½" above the board's surface, since it may have to be removed later.

Using the header arrangement, plug together the 5-volt power supply and DMS boards. Secure the two boards together and/or to a panel with spacers and machine hardware via the mounting holes provided, as shown in the lead photo. Turn on the power and observe that a random number, "---" or "EEE" appears in the display.

Carefully adjust the ZERO trimmer control to obtain a reading of exactly 000. Connect the negative side of the millivolt reference source or the Fig. 8 circuit to −IN and the positive side to +IN on the DMS board. Now careful-

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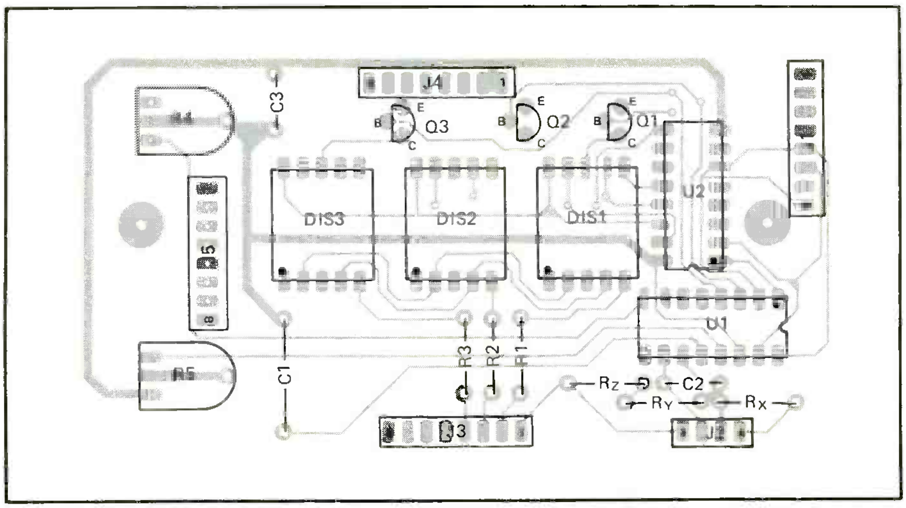


Fig. 6. Components placement/orientation guide for the DMS board.

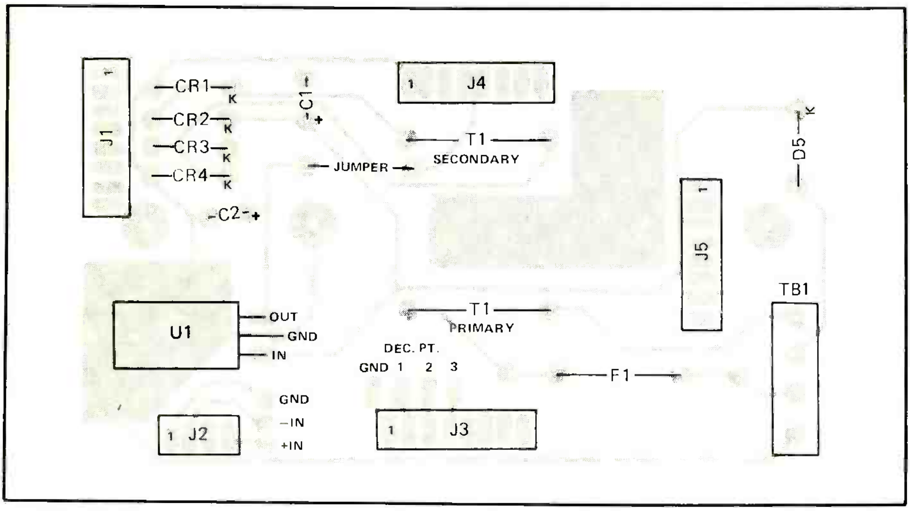


Fig. 7. Components placement/orientation guide for power-supply board.

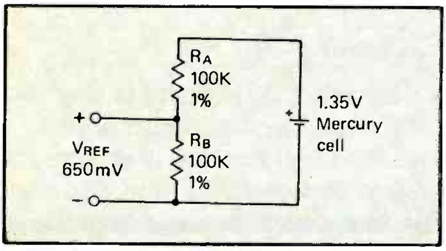


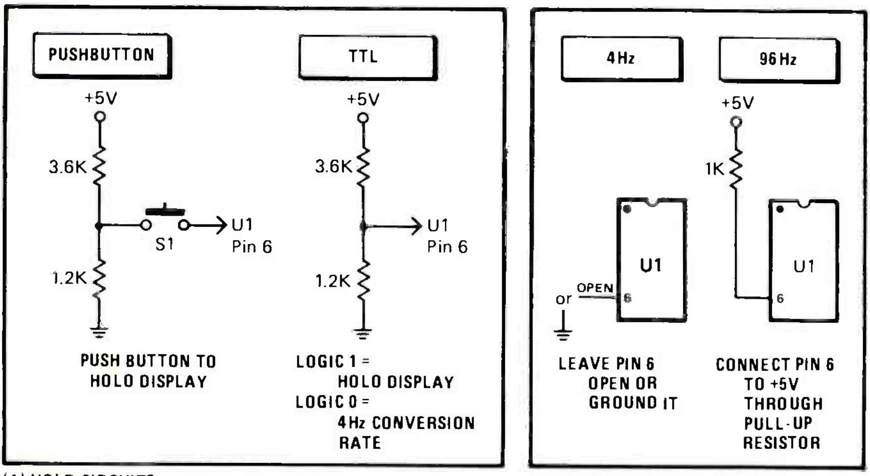
Fig. 8. Millivolt source for calibration can be assembled with two 100k resistors and 1.35-V mercury cell.

ly adjust the the GAIN trimmer for a reading or exactly 650 in the display.

Recheck the 000 reading and readjust if necessary. If you must readjust the ZERO control, reconnect the millivolt source and check the 650 reading. Repeat the GAIN and ZERO adjustments as necessary until no change is observed in the display. Then secure the trimmers with RTV or similar adhesive to prevent vibration from causing the DMS from drifting out of calibration.

The DMS is now calibrated for a +999- to −99-mV full-scale range.

In cases where the −IN terminal will not be grounded (floating input), the 100,000-ohm resistor at R_z should remain in place to provide bias feedback. On the other hand, if the −IN terminal is to be grounded, replace this resistor with a jumper wire. Positions R_x and R_y can be used for an on-board scaling network.



(A) HOLD CIRCUITS

(B) CONVERSION RATE CIRCUITS

Fig. 9. Hold (A) and conversion (B) circuits.

Pin 6 of *U1* provides the display-hold function when biased at +1.2 volts. Several simple circuits for controlling the hold function and programming conversion rates are shown in Fig. 9. The Fig. 9A circuits provide for pushbutton or TTL control of the hold feature; those in Fig. 9B show methods of controlling update rates.

A multiplexed BCD output is available at *J1* (from pins 1, 2, 15 and 16 of *U1*) on the DMS board.

In Closing

As you can see from the foregoing, the Digital Measuring System's panel meter and companion 5-volt power supply serve as a solid foundation on which to build a multipurpose test and measuring instrument. Add-on function modules simply plug into the system via "buses" accessed through headers common to all circuit-board assemblies in the system. **ME**