105

3½ digit DVM

Using the 3½-digit-A/D-converter LD 110/111 and a minimum of external components, it is possible to construct a universal digital voltmeter. The accuracy of the meter is approx. 0.05% + 1 digit. The scale of the meter runs from −2 V . . . +2 V and by means of additional voltage dividers can be extended as required.

The polarity of the measured voltage is indicated by the sign in front of the highest digit. When the range of the meter is exceeded all 7 segments will flash on and off (over-range indication). If no voltage is present at the input then the meter automatically indicates 0 V (auto-zeroing). The circuit board is designed for use with Hewlett-Packard 7-segment displays 5082-7730/5082-7732 or 5082-7750/5082-7752, although other pin-compatible common-anode displays may also be used.

The input resistance of the circuit is greater than 1 M, and the input current is approx. 4 pA.

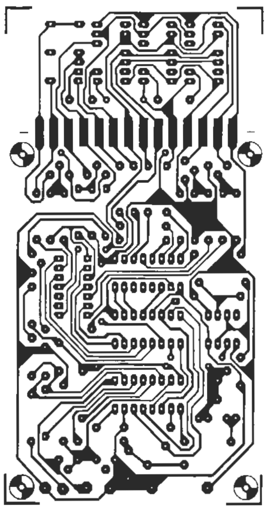
The reference voltage is produced by the FET-constant current source T6 and a transistor which is reverse biased and used as a zener diode*.

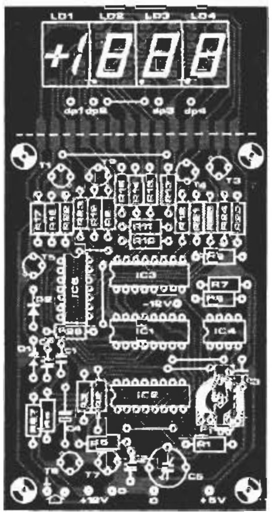
Construction and calibration

It is recommended that the meter is used with a stabilised voltage supply. A cermet trimmer should be used for potentiometer P1. After applying the supply voltage, the input should be short-circuited. Zero adjustment is then carried out using trimmer capacitor C5. Finally the meter is calibrated by means of P1 against a standard voltage. The decimal points of the displays are brought out separately. It should be noted that the series resistors in the cathode connections are not shown on the printed circuit board and should be added as required.

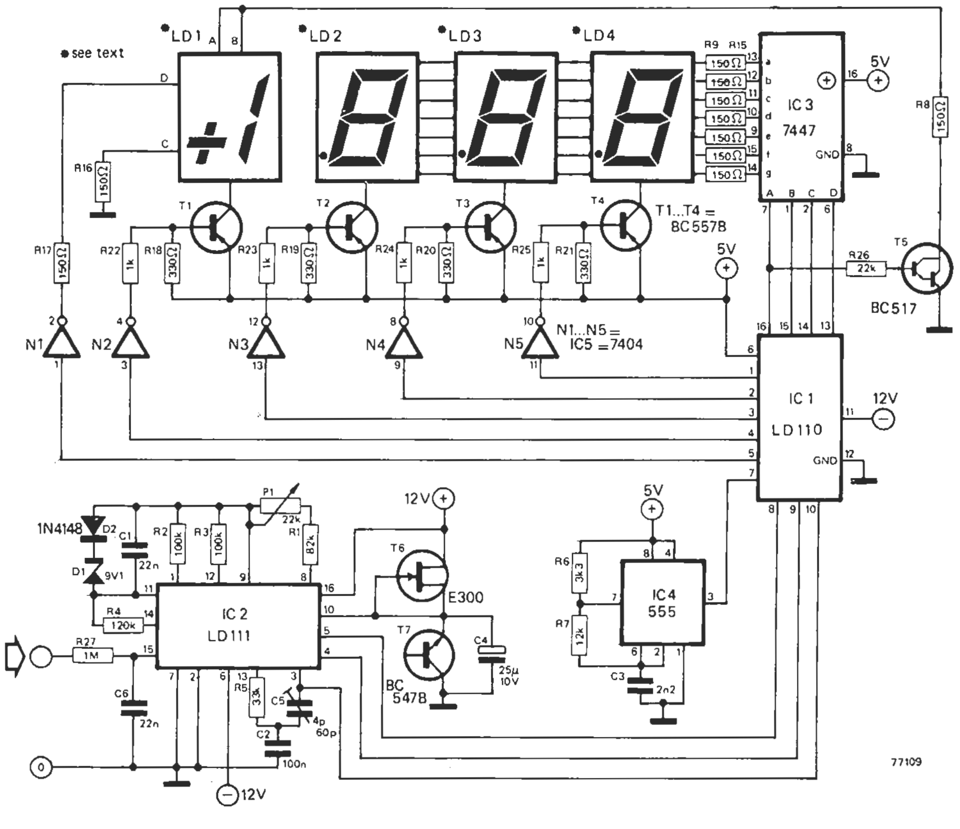
(Siliconix Application)

*Note that for optimum performance T6 and T7 ought to be selected types. A simpler solution is to use a 1 k resistor instead of T6 and a 5V6 voltage reference diode instead of T7.





Owing to space limitations, the p.c. board (EPS 77109) and component layout are reproduced here reduced to 50% of the original size.



2½-digit DVM uses quad Norton op amp

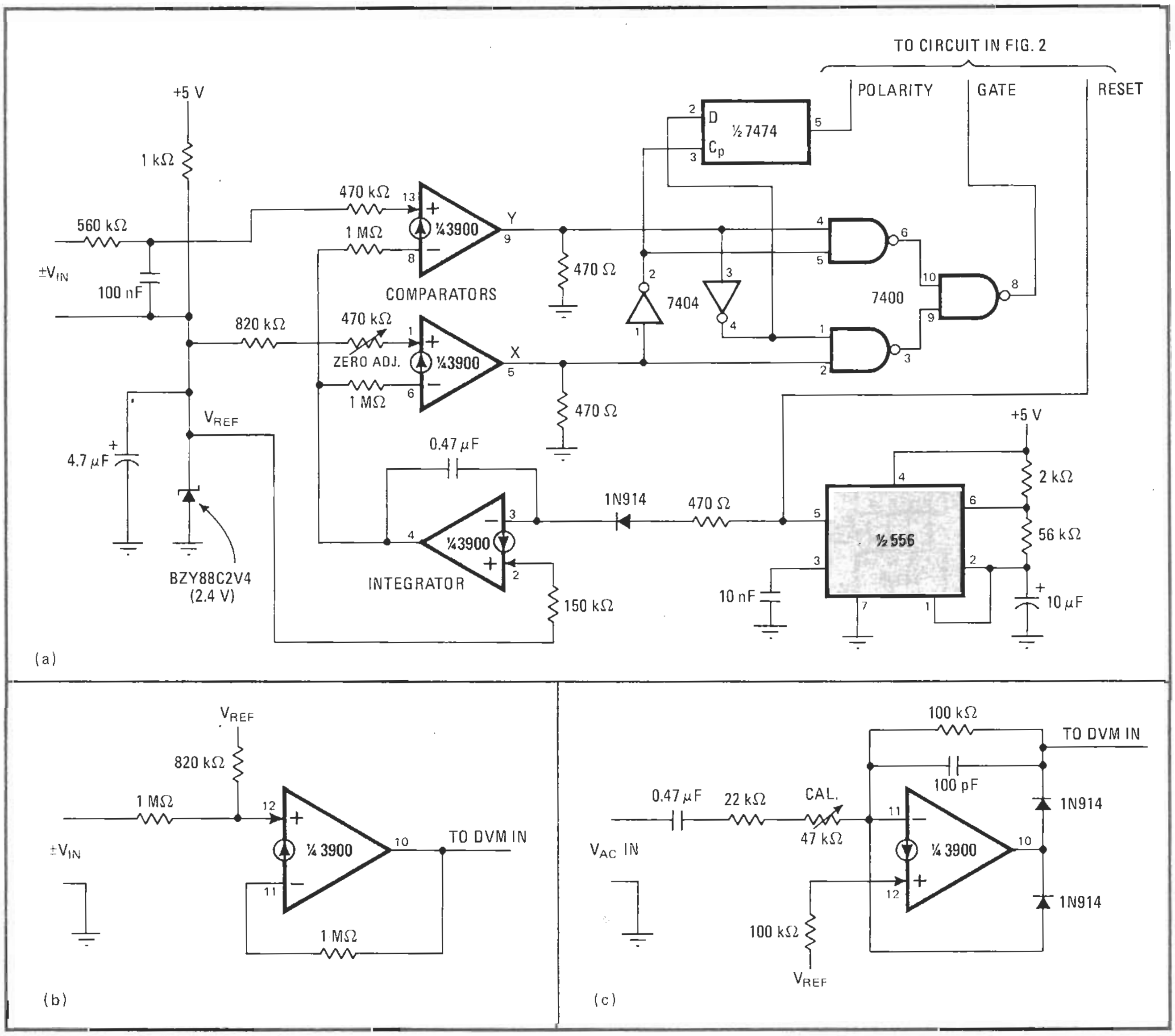
by Erdal Musoglu
Medical Computing Center, Free University of Brussels, Belgium

A compact digital voltmeter can be built inexpensively around a quad Norton operational amplifier (LM3900). It has a 2½-digit display with polarity indication and a 1-megohm input impedance, is accurate to within 1%, and is powered by a single 5-volt supply. The basic scale is chosen as ±1.99 V.

The voltage to be measured determines how long a counting circuit stays on. The display shows how many clock pulses were counted during that period. The measurement is repeated two and one-half times per second.

The measuring circuit for the DVM is shown in Fig. 1(a). One half of a 556 dual timer, used as a reset flip-flop, generates a 2.5-hertz square wave that drives the ¼ LM3900 connected as an integrator. (This is why the DVM makes a measurement every 400 milliseconds.) When the output of the reset flip-flop is $+V_{CC}$, the integrator is reset. But when the output goes to 0, a positive ramp is generated by integration of current entering the integrator's noninverting terminal. This current is driven through the 150-kilohm resistor by the 2.4-V reference voltage V_{ref} across the zener diode. Each positive ramp at the output of the integrator has an amplitude of more than 4 V and lasts 200 ms.

Two other Norton op amps are used as comparators. The dc input voltage to be measured is applied between V_{ref} and the noninverting terminal of one of the comparators after filtering. The noninverting terminal of the other comparator is connected to the reference point via a variable resistor that is adjusted so that there is no



1. Measurement. Basic circuit for digital voltmeter (a) uses 2.5-Hz reset flip-flop to cycle integrator and comparators to generate gate pulse with duration proportional to voltage being measured. Gate pulse, polarity signal, and reset output are fed to counter and display portions of DVM in Fig. 2. If input voltage is referenced to ground, input stage (b) is used. For ac voltage measurement, converter (c) is added to circuit.

output gate pulse when $V_{in} = 0$. The inverting terminals of the comparators are driven by the integrator.

The outputs from the two comparators, X and Y, are applied to an exclusive-OR circuit. The XOR output is used to gate on the counter in the counting and display circuit, as shown in Fig. 2(a). The time that the gate is on is directly proportional to the amplitude of V_{in}. The XOR circuit is realized here using three NANDs and two inverters, for reasons of economy. Polarity information for the display circuit requires only one half of a 7474 dual D-type flip-flop.

The arrangement in Fig. 2(a) optimizes the package count for the counter, display, and clock of the complete DVM. Here the other half of the 556 timer is used as the clock generator. The nominal clock frequency is 2 kilohertz, and the meter can be calibrated with the 22-kΩ variable resistor that modifies this frequency.

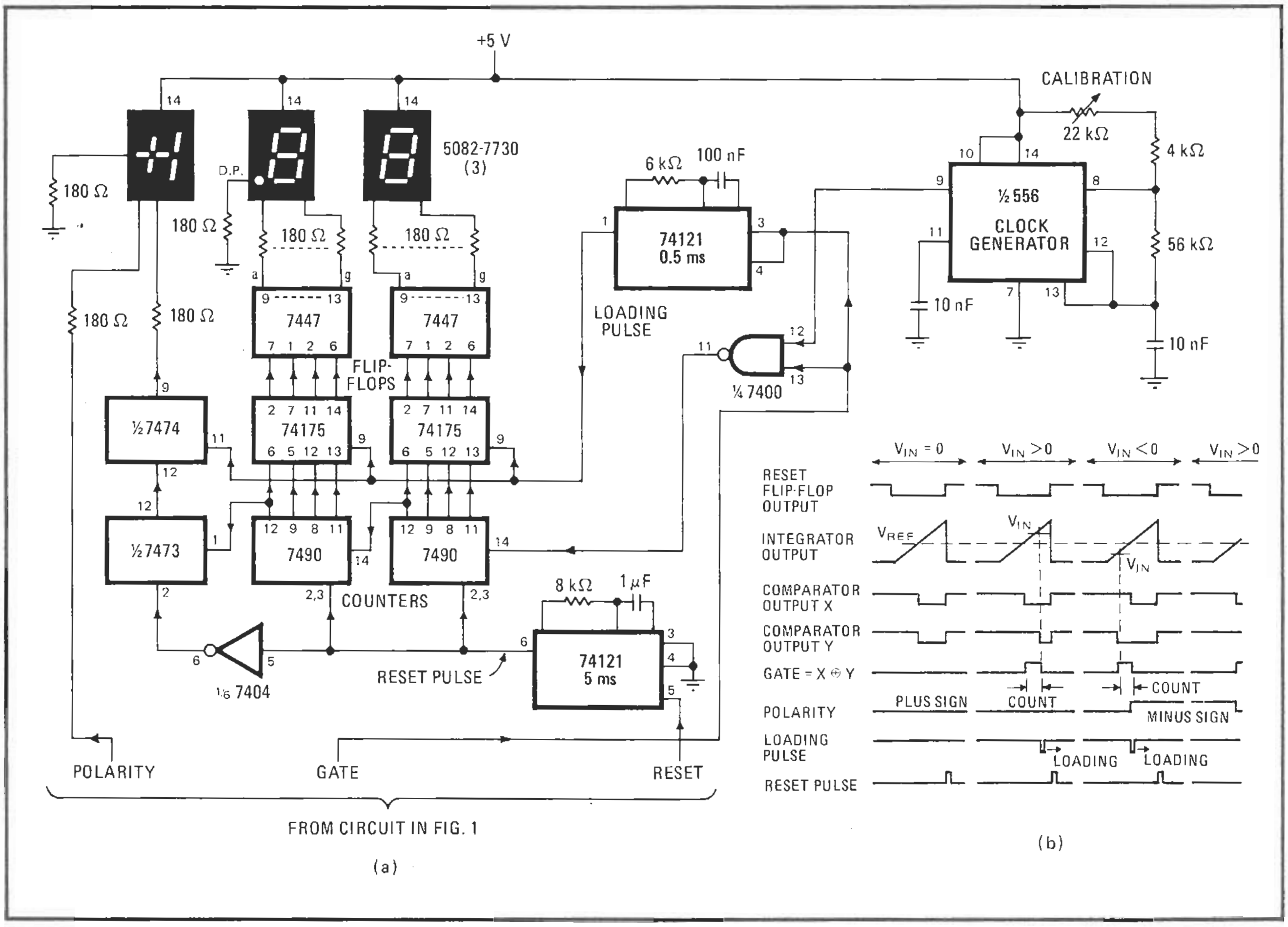
Two one-shots, which have output pulses lasting 0.5 ms and 5 ms, respectively, are used for loading from and resetting the counters. The reset one-shot is activated by the leading edge of the reset flip-flop output that comes in from the circuit of Fig. 1(a), so the counters are reset immediately after the ramp ends. Because the reset time is quite long (5 ms), any spurious gate outputs that occur during the fall of the ramp are ignored by the counter circuits; the fall time of the integrator is less than 2 ms for the circuit of Fig. 1(a).

The total accuracy and stability of the DVM depend on the frequency stability of the clock generator and on the stability of the ramp's slope. If stable external components (e.g. polycarbonate capacitors and metal-film resistors) are used in these circuits, the least significant digit is in error by only ±1, so accuracy within 1% is obtained. Note that the frequency stability of the reset generator does not affect the accuracy or the stability of the DVM. To avoid error due to the bias current of the Norton amplifier, the source impedance must be less than 20 kΩ even though the input impedance of the DVM is 1 MΩ.

If ground-referenced signals are to be measured, the fourth Norton amplifier of the LM3900 package can be used as shown in Fig. 1(b). In this case, however, it is advisable to divide the input voltage by two—for example, by using a 2-MΩ resistor at the input of the circuit of Fig. 1(b) instead of 1 MΩ—and to have a nominal clock frequency of 4 kHz for better linearity.

The fourth amplifier of the package can also be connected as an ac-to-dc converter, as shown in Fig. 1(c), for measurement of ac voltages. ☐

Engineer's Notebook is a regular feature in Electronics. We invite readers to submit original design shortcuts, calculation aids, measurement and test techniques, and other ideas for saving engineering time or cost. We'll pay $50 for each item published.



2. Display. In counter and display portion of digital-voltmeter circuit (a), clock pulses are counted by decade counters during gate pulse. After gate pulse, total count is loaded into D-type flip-flops that drive seven-segment displays via decoder-drivers. Counters are reset by 5-ms pulse from one-shot every 2.5 seconds for new measurement. Timing diagram (b) summarizes operation of DVM.

Time-shared DVM displays two inputs simultaneously

by Barry Harvey
Siliconix Inc., Santa Clara, Calif.

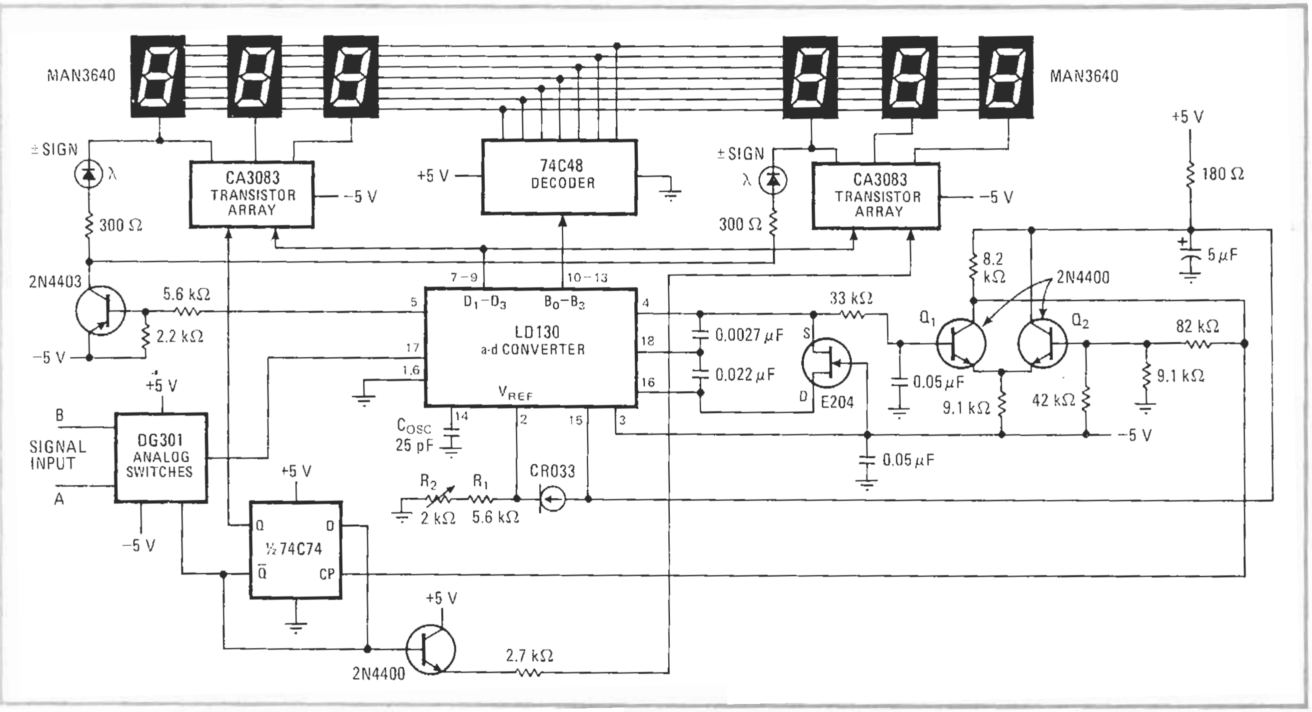
Two voltages can be measured and displayed simultaneously with one voltmeter if the voltmeter is built around a time-sharing circuit containing a fast-sampling analog-to-digital converter. The converter is united with an input-signal multiplexing network, and the system elicits a normally flicker-free response from a light-emitting-diode display, while saving the cost of the additional voltmeter and other parts that would be needed for two separate measuring units.

As implied by the figure, this circuit accomplishes two major tasks; it controls the rates at which analog signals and two banks of LEDs are sampled, and it determines the strobe rate of each LED in the banks.

The LD130 ±3-digit a-d converter was selected for its relatively fast sampling speed of up to 60 samples per second. The sampling rate of this complementary-metal-oxide-semiconductor device is controlled by external capacitor C_{osc} in conjunction with the internal oscillator circuitry of the device. Its output drives transistor pair Q_1 and Q_2, which in turn drive the sampling and multiplexing circuits through the 74C74 D flip-flop. The output of the flip-flop switches 30 times per second; the analog input signals are multiplexed at this rate through the DG301 analog switch, and one of two banks of LEDs is selected through the CA3083 transistor array. Each bank contains three MAN3640 displays.

The LD130 periodically samples each signal input and converts it into a digital output. Each display and its segments are driven through a strobe sequence; $D_1 - D_3$ determine which digit in each bank is enabled, lines $B_0 - B_3$ of the converter supply binary-coded-decimal information to the seven segments of each LED through the 74C48 decoder/driver, and the 74C74 determines which bank is chosen. The strobe rate for the LEDs is 384 times per sampling period.

Although the measurements are performed 30 times per second per channel, fast enough so that flickering would not usually be detectable, flutter of the least significant digit may occur when the LD130 is sampling



Two voltmeters in one. If the input signals can be sampled at rates of 60 times per second or greater, they can be measured, then observed simultaneously at acceptable flicker rates. Key to circuit operation is use of fast-sampling analog-to-digital converter.

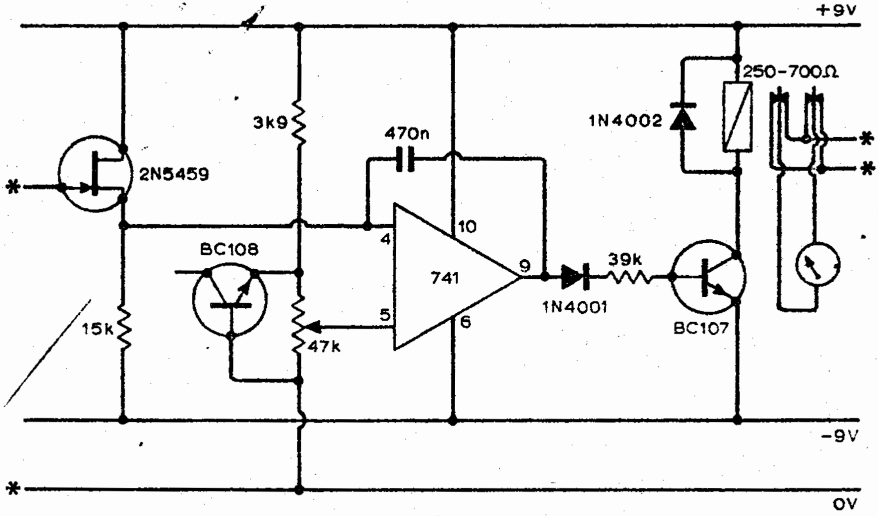
the input signals, because of the ±1-count effect inherent in counter operation. However, in applications where the output is observed only occasionally, it will not bother the eye, and in any case, a full three-digit reading is discernible.

To calibrate the converter, a reference of approximately 2 volts is required at the V_{ref} terminal, and this is easily furnished by the 330-microampere constant-current diode CR033 and resistors R_1 and R_2. R_2 is adjusted to null the output for no-signal conditions. □

Auto polarity switching for voltmeters

This circuit converts most high-impedance voltmeters to auto reverse-polarity switching. To prevent meter shunting an f.e.t. is used as the input element, the comparator is referenced to a zener-stabilized voltage, and a cheap silicon planar transistor is used as the zener for economy. Feedback is arranged in the comparator to provide fast switching. The relay can also be used to switch polarity indicators.

Hans Wedemeyer,
Vanse, Norway.



* to meter amplifier output

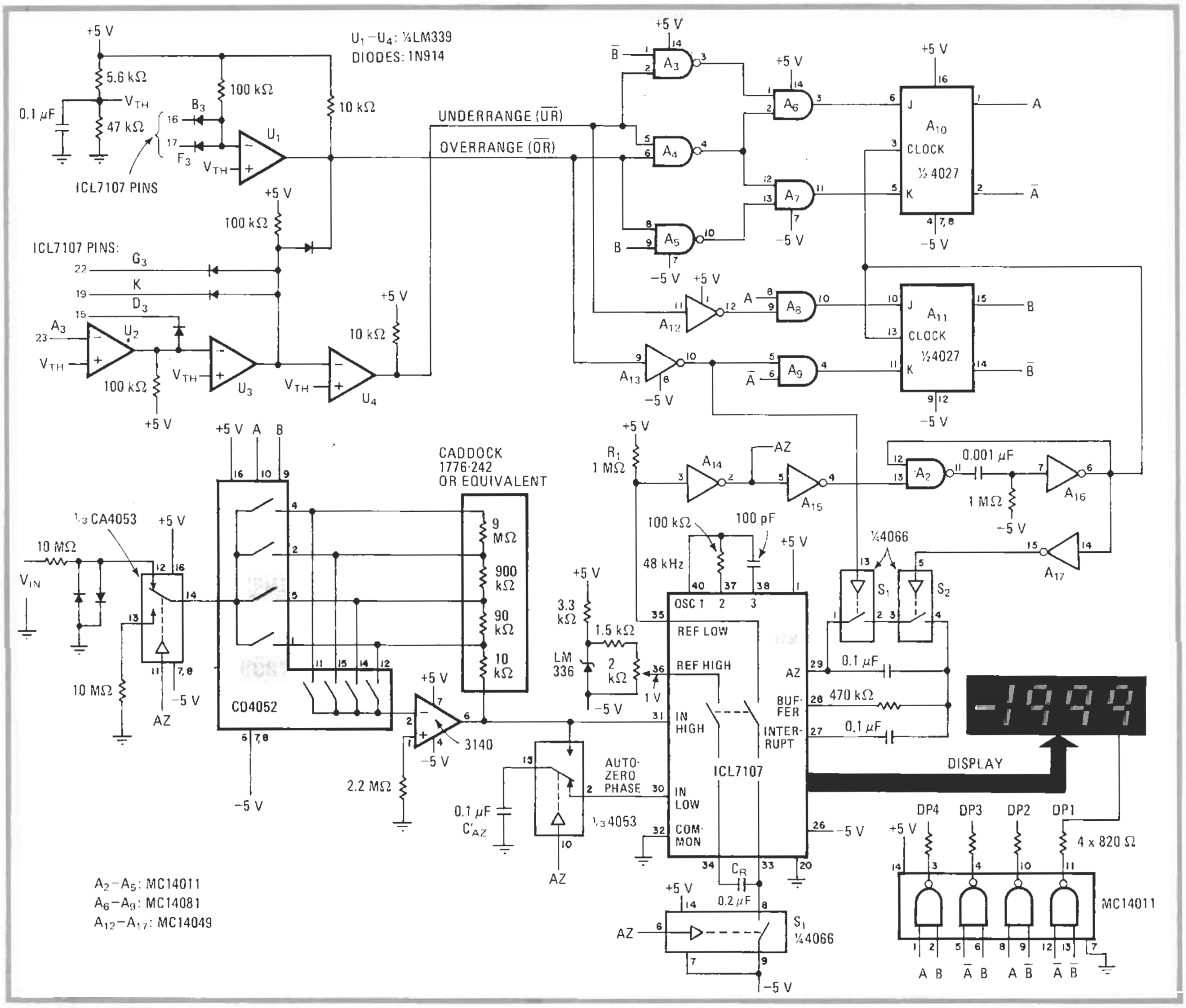
Low-cost autoranger scales DVM over four decades

by L. Y. Hung
Boston, Mass.

Autoranging capability can be added to a digital voltmeter with this circuit, which costs less than $25. Built around a dual-slope integrating analog-to-digital converter to ensure greatest measurement accuracy, the unit scales a 3½-digit voltmeter over a range of four decades (±1 to ±1,000 volts dc) without the need for complex feedback circuitry.

In operation (see figure), signals to the input are applied to the ICL7107 a-d converter through the range switch formed by the 4052 multiplexer and the attenuator that includes the CA3140 comparator and its accompanying decade resistor network. During each 333-millisecond measurement cycle, the converter proceeds to eliminate the error caused by the comparator's offset (autozero phase), stores the input voltage (integrating phase), and displays the difference, in terms of a voltage, between the integration time and the time required to discharge a reference potential from capacitor C_R (display phase). The autorange circuit (A_3–A_{13}) that follows tracks both underrange and overrange conditions with the aid of a suitable detection circuit. It generates the appropriate signals for controlling the range switch and thus the gain of the attenuation network.

The autorange circuit determines underflow or overflow at the initial portion of the autozero phase. During this time, the voltage on pin 35 of the converter drops momentarily. The drop switches gate A_{14} and thereby closes switch S_1, an action that brings pin 35 to logic 0 and completes the charging cycle for C_R. The rising edge of the AZ signal that clocks the range switch is delayed about 1 millisecond by A_2 and A_{16}, providing sufficient time to stabilize the display and to check for the underrange and overrange conditions.



Searching. DVM autorange circuit uses A_3–A_{14} to detect underflow and overflow conditions by examining the output state of ICL7107 a-d converter, then sets gain of input attenuator network over four decades through 4052 range switch. Circuit cost is under $25.

The range switch is an up-down counter. It will count down one state if an overrange signal is present and up one state if an underrange condition exists, over the binary range 00 to 11. The discharge path provided by switches S_2–S_3 reduces the residual charge on C_{AZ} during the de-integrating phase; otherwise continuous rocking between two adjacent scales may occur.

As for underrange and overrange detection, only one quad comparator need be connected to the ICL7107, as shown at the upper left. Both signals are derived from the converter's seven-segment outputs. Underranging occurs if the displayed number is less than 200; for overrange, the number must be greater than 1,999.

A blank display on digit 3 indicates the overrange condition. A blank output on digit 4 and either a 1 or a 0 on digit 3 signifies underrange. In equation form:

$$\overline{UR} = \overline{\overline{OV} \cdot G_3 \cdot \overline{K} \cdot (\overline{A}_3 + D_3)}$$

where A_3, D_3, and G_3 are the display segments of digit 3 and K is the converter's thousands multiplier. ☐

Pulse-width meter displays values digitally

by Paul Galuzzi
Beverly, Mass.

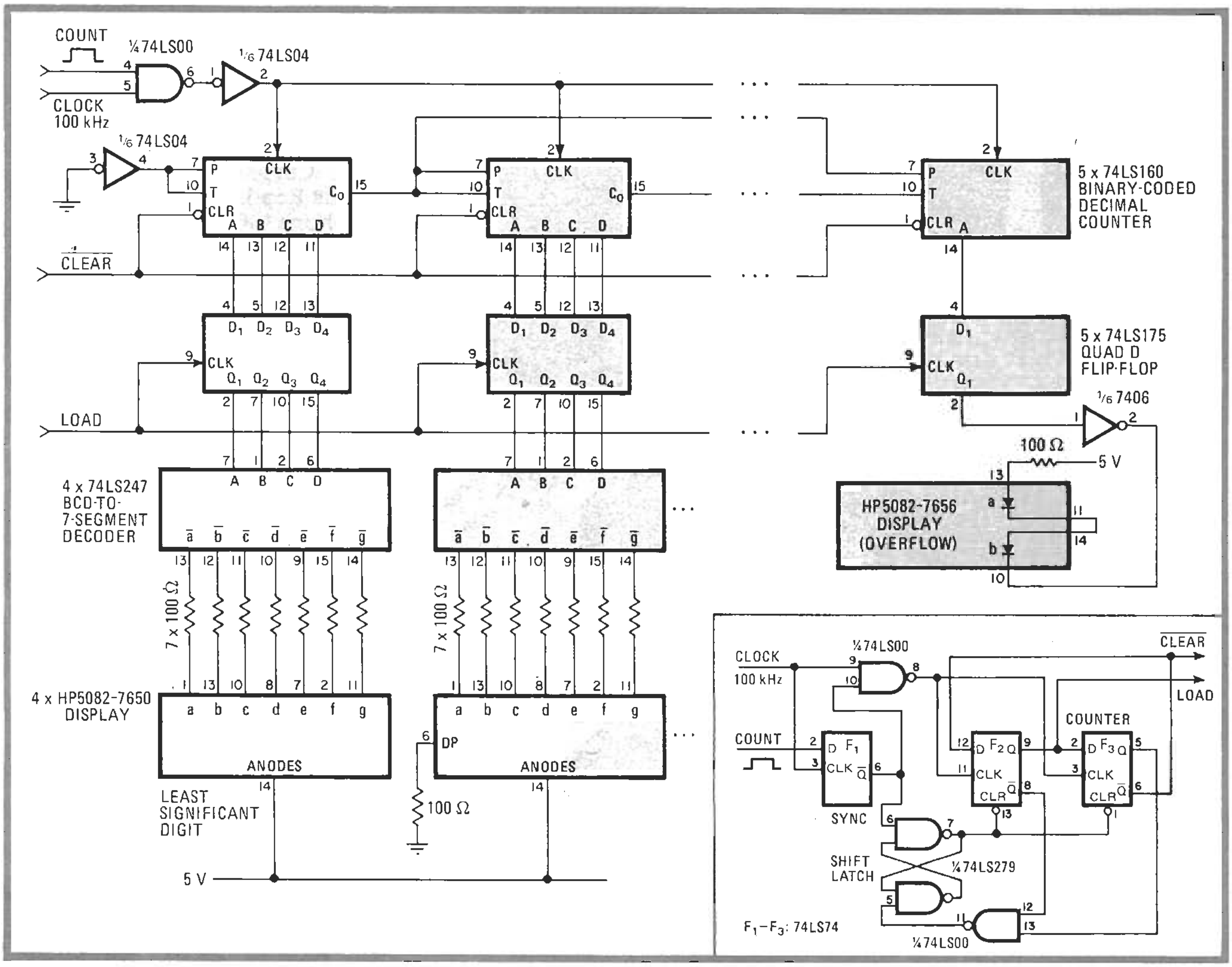
Built only with standard logic elements and solid-state displays, this meter provides digital readout of pulse width, a widely sought-after feature in instruments of this type. Measurement accuracy is one part in 10,000.

As the figure shows, this circuit is relatively straightforward, being made from several cascaded binary-coded decimal counters, flip-flops, BCD-to-seven-segment decoders, and the corresponding displays. In operation, the pulse (count) to be measured gates in the 100-kilohertz system clock, which steps the 74LS160 counter bank. After the count pulse goes to logic 0, the load pulse transfers the BCD data to the 74LS175 flip-flops that serve as a storage register.

At this time, the BCD data, whose value is directly proportional to the width of the count pulse, is decoded by the 74LS247 chips and displayed. A clear pulse then resets the counter bank, and the measurement cycle repeats.

The circuitry for generating the clear and load pulses is shown in the right-hand inset. As shown, sync flip-flop F_1 is enabled by the inverted count signal, thereby gating the 100-kHz system clock so that flip-flops F_2 and F_3 can shift through a two-stage cycle. Thus, the load and clear pulses are generated in sequence after the falling edge of the pulse whose width must be measured.

With the 100-kHz clock, the meter will display 100.00, its full-scale reading, for a pulse width of 100 milliseconds. Pulses as small as 10 μs in width can be measured accurately with the given clock rate, and more narrow pulses can be detected if the clock frequency is made proportionally higher. ☐



Count time. Digital meter measures pulse width by counting number of 100-kHz system clock cycles during time that pulse is present. Solid-state displays provide direct readout of time in milliseconds. Measurement accuracy is 1 part in 10^4 over range of 10 μs to 100 ms.

INTERSIL

A046
Building a Battery Operated Auto Ranging DVM with the ICL7106

INTRODUCTION

In the field of DVM design, three areas are being addressed with vigor: size, power dissipation, and novelty. The handheld portable multimeter has gained in popularity since low power dissipation devices enabled battery operation, LSI A/D converters reduced IC count, and novelties such as conductance, automatic range scaling, and calculating were included to entice the user.

This application note describes a technique for auto-ranging a battery operated DVM suitable for panel meter applications. Also, circuit ideas will be presented for conductance and resistance measurement, 9 volt battery and 5 volt supply operations, and current measurement.

SECTION ONE: AUTO RANGING CIRCUITRY

The control signals necessary for auto-ranging are over-range, under-range, and clock. The over-range and under-range inputs control the direction of a scale shift, becoming active at the completion of an invalid conversion and remaining active until a valid conversion occurs. The clock input controls the timing of a scale shift. This signal should occur only once per conversion cycle, during a time window which will not upset an ongoing conversion and must be disabled after valid conversions.

In the circuit of Figure 1, inverted over-range ($\overline{O/R}$) and under-range ($\overline{U/R}$) are generated by detecting the display

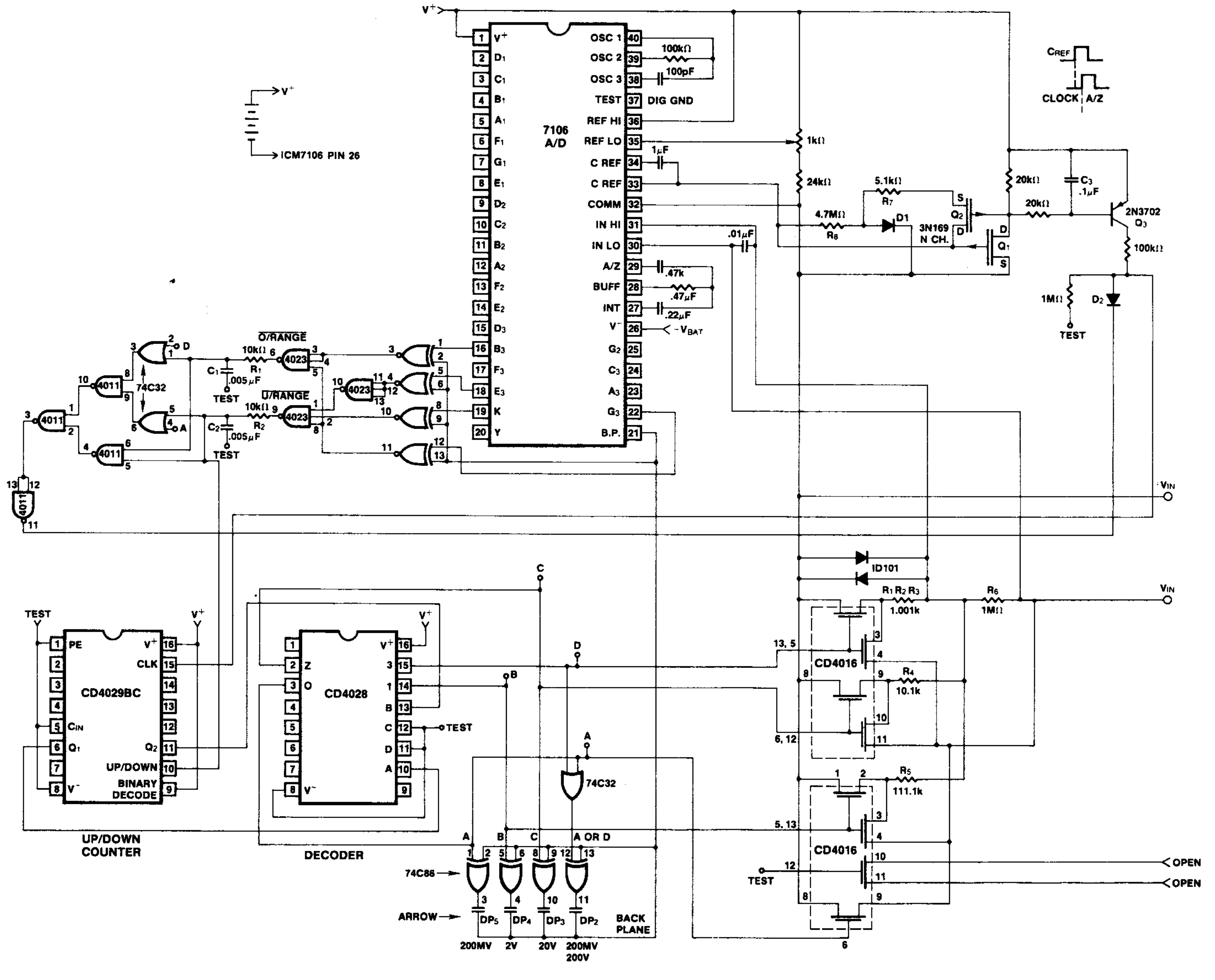


Figure 1: Auto Ranging Circuitry

reading. The 7106 turns the most significant digit on and blanks the rest to indicate an over-range. An under-range occurs if the display reads less than 0100. R_1C_1 and R_2C_2 are required to deglitch $\overline{O/R}$ and $\overline{U/R}$.

The next step in the logic disables $\overline{O/R}$ and $\overline{U/R}$ prior to shifting into non-existent ranges. $\overline{O/R}$ is disabled when in the 200 volt range, while $\overline{U/R}$ is disabled when in the 200mV range.

The next level of gating disables the clock if the conditions are as described above and a valid conversion state exists. Clock is enabled only when a range shift is called for and there exists a valid range to shift into.

The 4029 is a four bit up/down counter, used as a register to hold the present state and as a counter to shift the scale as directed by the control inputs. The 4028 is a BCD to decimal decoder interfacing the 4029 and ladder switches. An additional exclusive OR gate package is added to drive the appropriate decimal point.

SECTION 2: INPUT DIVIDER NETWORK

A simplified drawing of the divider network is shown in Figure 2. This configuration was chosen for simplicity and implementation using analog switches. The low leakage ID101's are used for input protection, and the second set of switches to IN LO reduces the net error due to switch resistance. This can be seen by calculating IN HI and IN LO voltages for the two equivalent circuits.

For equivalent circuit A,

$$V_{MEAS} = V_{IN\ HI} = \left(\frac{R_S + R/K}{R_S + R + R/K}\right) V_{IN} \qquad (1)$$

where R_S = switch resistance, R = input resistance (1MΩ), and 1 + K is the desired divider ratio.

Ideally V_{INHI} should be

$$V_{IDEAL} = \left(\frac{R/K}{R/K + R}\right) V_{IN} = \left(\frac{1}{1+K}\right) V_{IN} \qquad (2)$$

Therefore the percent error is

$$\left[\frac{\text{Ideal} - \text{actual}}{\text{ideal}}\right] 100, \qquad (3)$$

$$\text{or} \left(1-(1+K)\ \frac{R_S + R/K}{R_S + R/K + R}\right) 100 \qquad (4)$$

The worst case error occurs at (1+K) = 1000. For this example, the error due to a 1kΩ switch resistance is 99.7%.

IN HI for equivalent circuit B is the same as EQ (1) above. However, IN LO for circuit B is

$$\left(\frac{R_S}{R_S + R + R/K}\right) V_{IN}, \qquad (5)$$

and combining EQ (1) and (5)

$$V_{MEAS} = V_{INHI} - V_{INLO} = \left(\frac{R/K}{R_S + R + R/K}\right) V_{IN} \qquad (6)$$

The percent error is equal to

$$\left(1 -(1+K)\ \frac{R/K}{R + R_S + R/K}\right) 100 \qquad (7)$$

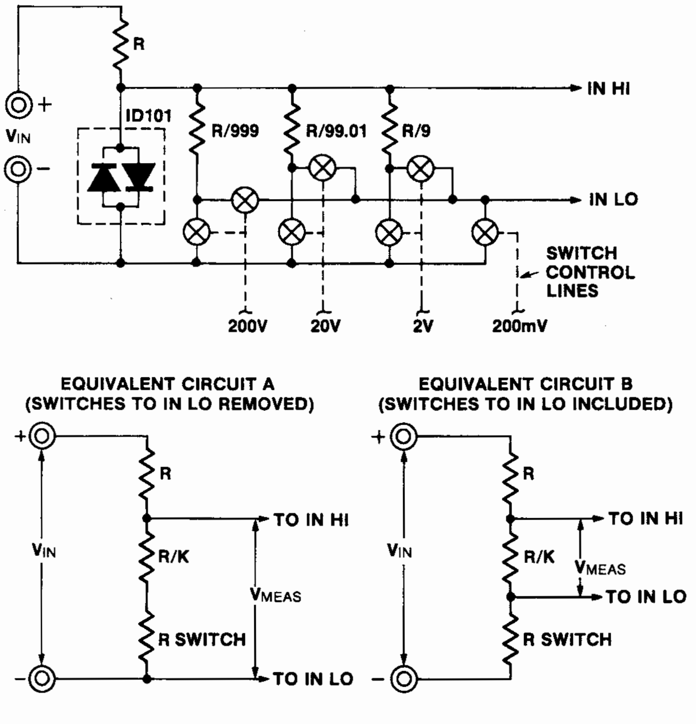


Figure 2: Input Divider Network

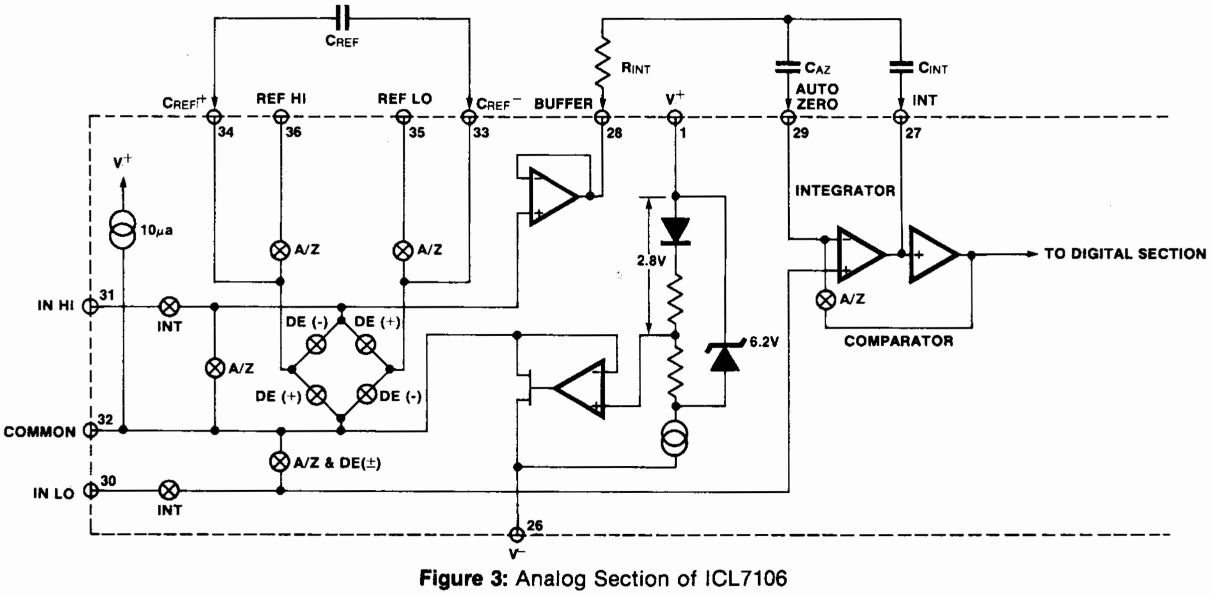


Figure 3: Analog Section of ICL7106

Using the same values for R_S, (1+K), and R, the worst case error is 0.1%. This error can be further improved if lower $r_{DS(on)}$ switches are used. From the results calculated above, the worst case conversion error due to switch resistance will be one count of the least significant digit for a full scale input, and a slight adjustment to R itself will correct the remaining error on all scales.

SECTION 3: RANGING CLOCK CIRCUIT

Two N-channel MOSFET's, a PNP transistor and a handful of passive components combine to generate the clock signal used to gate the auto-ranging logic. A closer look at the inner workings of the ICL7106 will help clarify the discussion of this circuit. The analog section of the ICL7106 is shown in Figure 3.

It can be shown that C_{REF} low (pin 33 of ICL7106) will sit at $-V_{REF}$ for DE+ and at common for DE−, with DE+ designating the deintegrate phase for a positive input signal and DE− referring to a negative input signal. During the auto-zero phase, C_{REF} low is tied to an external reference through pin 35, which in Figure 1 is V_{REF} below the positive supply. The net result is that C_{REF} low is above COMMON during auto-zero, is left to float during signal integrate, and is at or below COMMON during deintegrate. R_8 and D_1 are added externally to pull C_{REF} to COMMON during integrate, with Q_2 and R_1 included to speed this action. The signal at C_{REF} low is now a square wave that is high during auto-zero and low at all other times. Q_1 and Q_3 amplify and level shift this waveform for logic level compatability. This clock signal is gated through D_2 and controls the timing of the auto-ranging circuitry. C_3 is added to delay the clock, eliminating disparity with $\overline{O/R}$ and $\overline{U/R}$ (see Figure 4 for timing diagram).

SECTION 4: SUPPLY REQUIREMENTS

The circuit of Figure 1 operates on a standard 9V transistor battery. CMOS logic and a CMOS A/D converter (ICL7106) are used to extend battery life; the approximate power drain for this circuit is 8mW. The circuit of Figure 5 can also be added to detect low supply voltage.

The circuit of Figure 6 can be used to generate ±5 volts from a single 5 volt supply. The ICL7660 is a voltage converter which takes a 5 volt input and produces a −5 volt output.

With respect to common mode signals, the circuit of Figure 1 will have infinite common mode handling capability if operated from a floating nine volt battery. However if powered by a fixed supply such as in Figure 6, the common mode capability of the converter will be limited to approximately ±2 volts, if COMMON is disconnected from $-V_{IN}$.

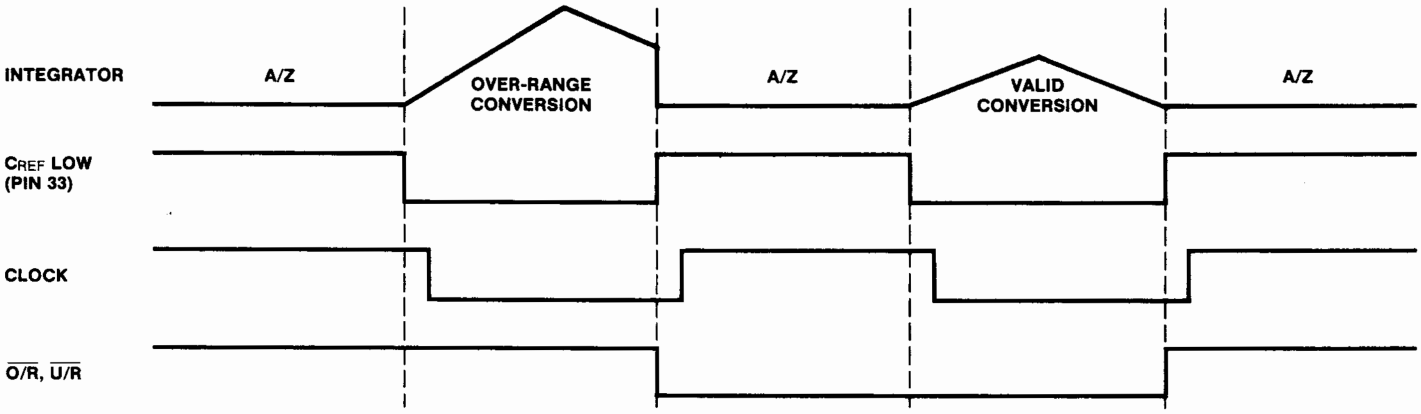


Figure 4: Timing Diagram

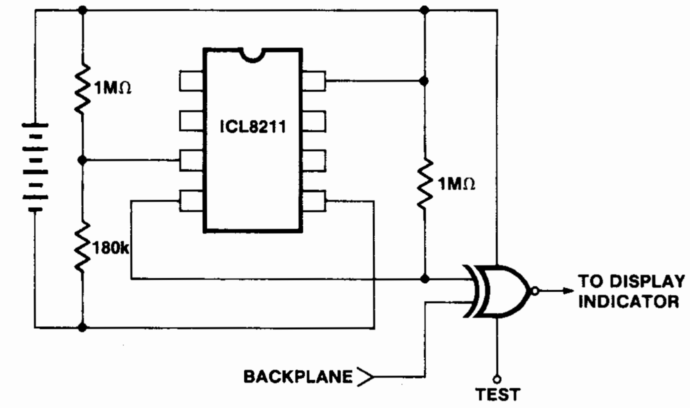


Figure 5: Low Voltage Detector

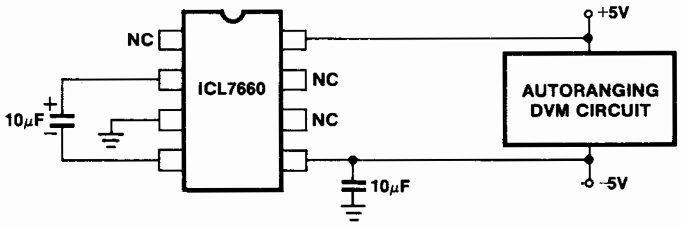


Figure 6: Generating ±5 volts from +5 volts.

SECTION 5: RESISTANCE, TRANSCONDUCTANCE AND CURRENT CIRCUITS

The purpose of this section is to show the simplicity of measuring transconductance (1/R) and resistance with the ICL7106. The circuit of Figure 7 requires only one precision resistor per decade range of interest. The conversion output is described by the formula

$$\left(\frac{R_X}{R_{STD}}\right)1000$$

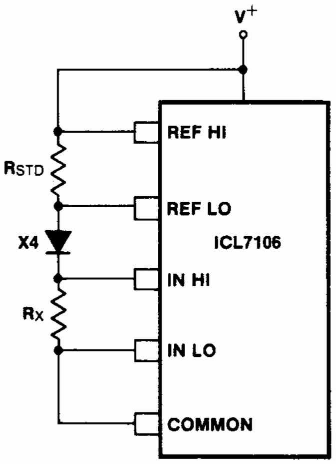


Figure 7: Transconductance and Resistance Measurement

For transconductance measurement, merely switch R_{STD} and R_X. This scheme makes the measurement of large resistors, in conductance form, convenient and easy. This is also convenient for leakage measurements.

A simple current meter can be built using the circuit of Figure 8. The low leakage of the ICL7106 (10pA/max) makes possible the measurement of currents in the mid pico-Amp range. However, the switch leakage current will limit the accuracy of the resistor network and may degrade converter resolution.

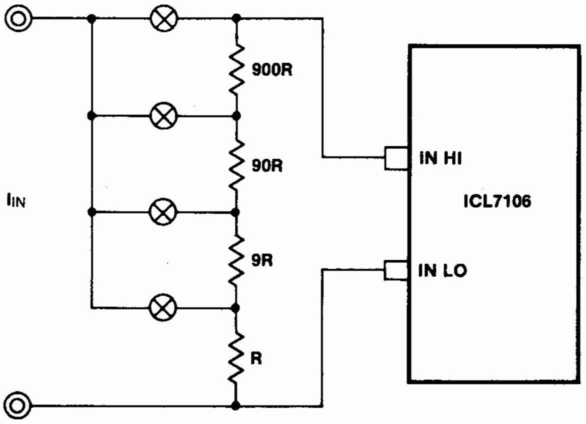


Figure 8: Current Meter

SECTION 6: USING THE ICL7126 AND ICL7107

With a few modifications the circuit of figure 1 can easily be adapted for use with either the low power 7126 or the 7107. Using the 7126 simply requires a change in the values of the integrating and auto-zero components. Refer to the ICL7126 data sheet for details.

The ICL7107 is an LED version of the ICL7106, and is a bit trickier to use in this application. First the overrange/underrange logic must be changed slightly. Simply replace the quad exclusive-NOR with an LM339; connect the outputs, as before, to the 4023 triple 3-input NAND. Second, the 7107 requires +5V and −5V rather than the +9V battery used in figure 1. If battery operation is desired, the negative supply can be derived from 4 Ni-cad cells in series and an ICL7660. (See figure 9.) Note that both supplies float with respect to the input terminals. (Logic supplies are V^+ and DIG. GND.)

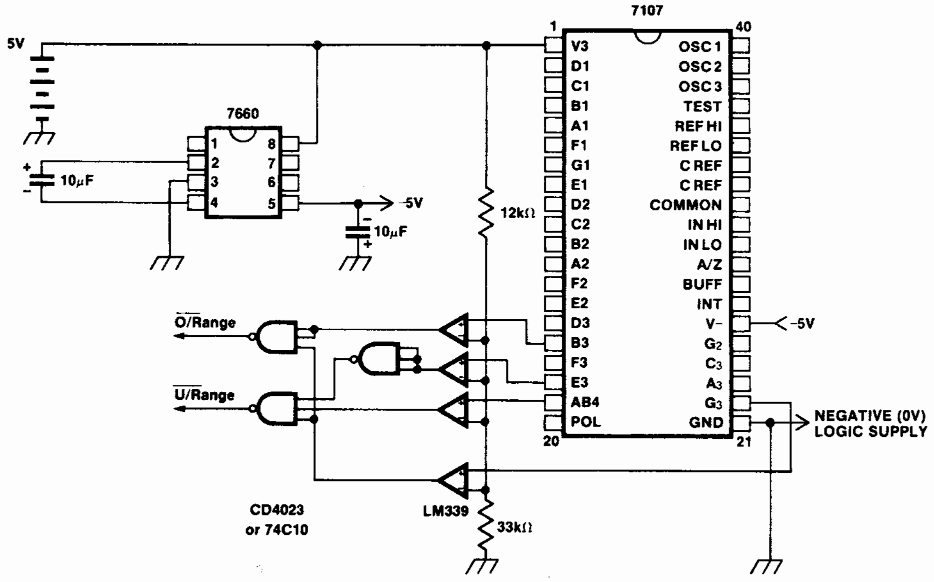


Figure 9: Circuit for developing Underrange and Overrange signals from 7107 outputs. The LM339 is required to ensure logic compatibility with heavy display loading.

CONCLUSIONS

The circuits described above were built and tested as drawn. The accuracy error of the converter was ±0.2% on all ranges. scale change between adjacent ranges required approximately 250 ms, a zero input yielded a true zero reading and full-scale roll over error was ≤ one count.

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10710 N. Tantau Avenue, Cupertino, CA 95014 U.S.A. Tel: (408) 996-5000. TWX: 910-338-0171
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Tel: 0256-57361. TLX: 847227 INTRSL G
Liaison Office, 217, Bureaux de la Colline, de St. Cloud, Batiment D, 92213 Saint-Cloud, Cedex, France,
Tel: (1) 602-57-11, TLX: Datelem 204280F
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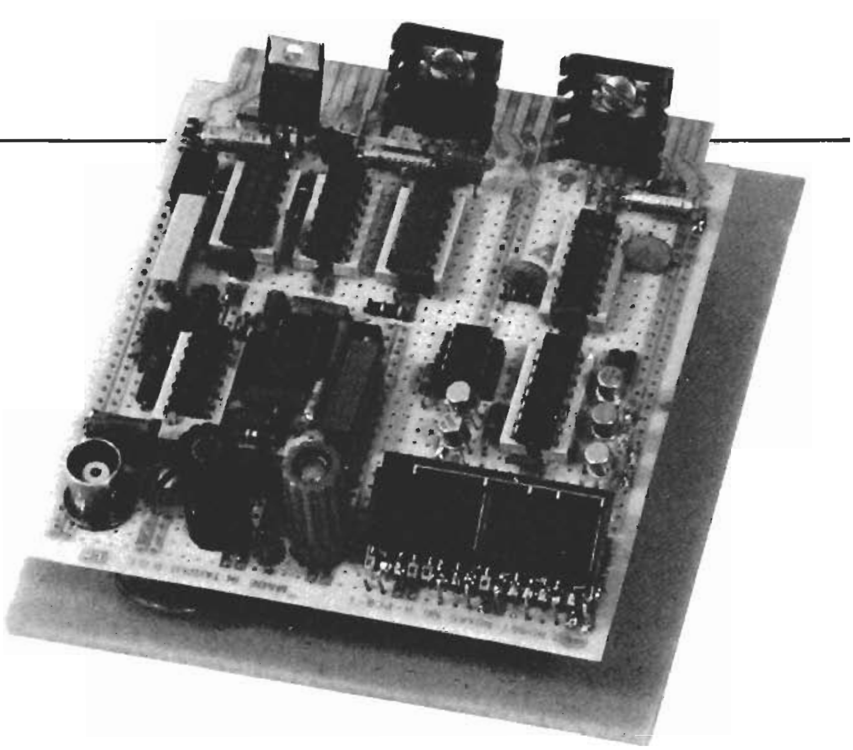
Two Compact DVM's



Equip your bench power-supply with its own digital voltmeter. LSI circuits make the project simple and inexpensive.

CLEMENT S. PEPPER

THE POWER SUPPLY I USE ON MY BENCH has five outputs, two of which are variable over a range of ±25 volts. I found having to connect a voltmeter to either of those two merely to set a voltage or to make a status check to be a bother, and was thinking of adding an analog panel meter with selector switching, when I stopped to ask myself why I wanted to do a dumb thing like that. High performance linear and digital IC's now available make a built-in *digital* voltmeter practical at about the same cost as a high quality panel meter. All the semiconductors and the 4-digit display, for example, can be purchased for less than twenty-five dollars.

The circuit I designed performed so well that I modified it and made a general-purpose DVM for use on the bench. It is quite compact, so it can be close to the work at hand while taking up little space.

At the heart of both versions is the LM331 precision voltage-to-frequency converter. That device, along with the MM740925 (a 4-digit counter with multiplexed 7-segment output drivers) and the NSB3881 4-digit common-cathode multiplexed LED display, contributes to the high performance and compact construction of the DVM's. All three IC's are made by the National Semiconductor Corporation.

LM331 V-to-F converter

The LM331 is a monolithic circuit designed for voltage-to-frequency or frequency-to-voltage conversion. Figure 1 shows the LM331 in simplified block-diagram form, along with the external resistors and capacitors needed for stand-alone V–F operation. The principal parts of the device are a switched current-source, an input comparator, and a one-shot timer.

The switched current-source establishes a positive reference voltage, V_X, as one input to the comparator, and a positive input-voltage, V_{IN}, as the second. If V_{IN} exceeds V_X, the comparator will trigger the one-shot. The one-shot then turns on the output transistor and the switched current-source for a time, t, equal to $1.1R_tC_t$. During that time, current i provides a fixed charge Q, equal to i_{Xt}, to capacitor C_L. That will normally raise V_X to a higher level than V_{IN}. At the end of the timing period, current i will turn off, and the timer will reset itself. Since there is then no current flowing from pin 1, capacitor C_L is gradually discharged by resistance R_L until V_X falls to the level of V_{IN}, Then the cycle will repeat.

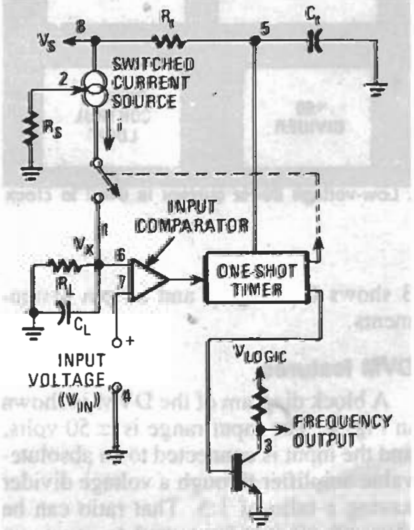


FIG. 1—SIMPLIFIED BLOCK DIAGRAM of voltage-to-frequency converter showing LM331 with external components

The output device is an open-collector transistor, a real convenience in translating between the 15-volt supply for the converter and the 5-volt one for the display. The output is a train of negative-going pulses that is input directly to the counter's clock input for counting and count display. The output frequency is given by the equation:

$$F_{OUT} = V_{IN}/2.09 \times R_S/R_{IN} \times 1/R_tC_t$$

The current flowing into C_L is $i_{AVE} = i \times (1.1R_tC_t) \times F_{OUT}$, and the current flowing from C_L is exactly V_X/R_L, which, in turn, is very nearly equal to V_{IN}/R_L. If V_{IN} is doubled, F_{OUT} will also double to maintain that balance. The converter can provide an output that is proportional to its input voltage over a broad range of frequencies. The voltage-to-frequency linearity in a circuit having values very nearly the same as those in the two versions of the DVM described here, is specified by National as ± 0.14% worst-case over the range of 10 Hz to 11 kHz.

MM74C925 4-digit counter

The MM74C925, shown in Fig. 2, is a CMOS device containing a 4-digit decade counter, an internal latch, NPN output sourcing drivers for a 7-segment display, and internal multiplexing circuitry with four multiplexing outputs. It has its own free-running oscillator; no external clock is required for digit strobing. The counters advance on the negative edge of the incoming clock signal. A high on the RESET input will reset the counter to zero. A high on the LATCH ENABLE input allows data to flow through the counters without being latched; a low latches the number in the counters. The display can be driven

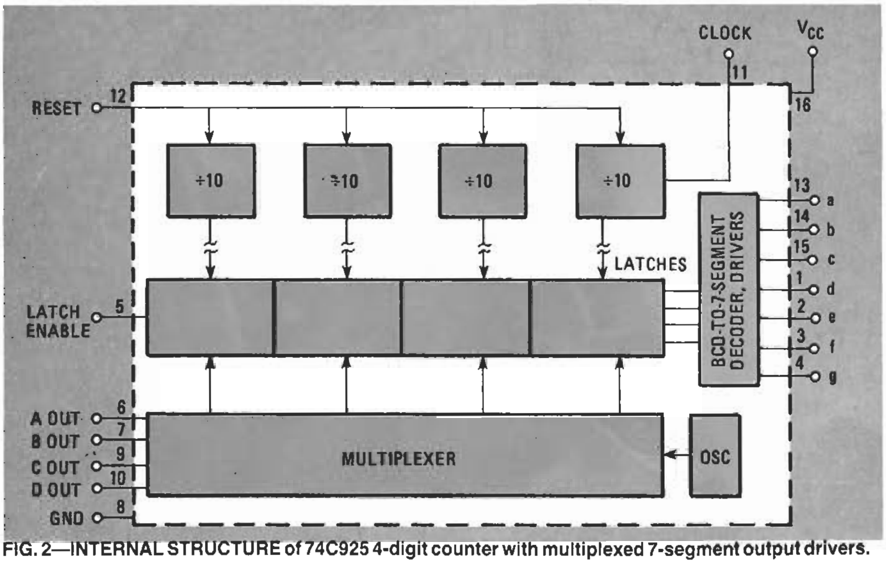


FIG. 2—INTERNAL STRUCTURE of 74C925 4-digit counter with multiplexed 7-segment output drivers.

PIN	FUNCTION	PIN	FUNCTION
1	NC	9	NC
2	ANODE e	10	COMMON CATHODE DIGIT 3
3	COMMON CATHODE DIGIT 1	11	ANODE b
4	NC	12	ANODE a
5	NC	13	ANODE f
6	COMMON CATHODE DIGIT 2	14	COMMON CATHODE DIGIT 4
7	ANODE d	15	ANODE DP
8	ANODE g	16	ANODE c

FIG. 3—NATIONAL SEMICONDUCTOR NSB3881 4-digit LED display.

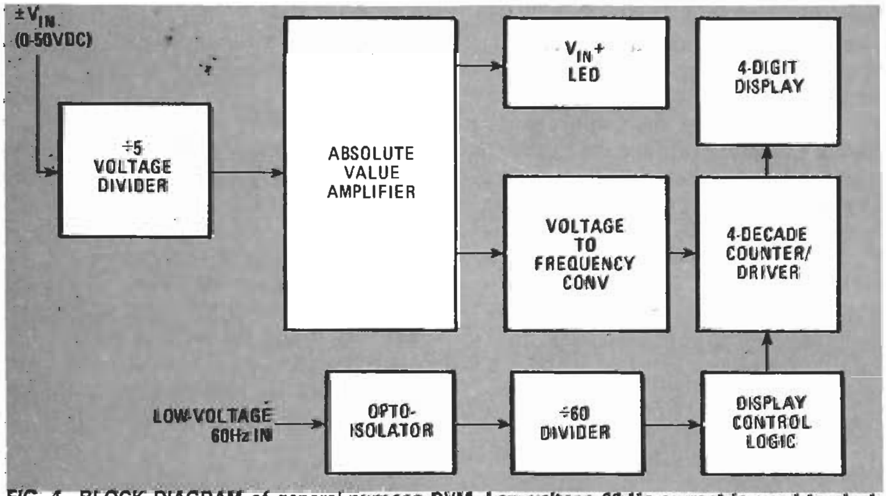


FIG. 4—BLOCK DIAGRAM of general-purpose DVM. Low-voltage 60-Hz current is used to clock display control-logic.

PARTS LIST— GENERAL PURPOSE DVM

All resistors 1%, ¼ watt unless otherwise specified

R1—1 megohm
R2—20,000 ohms, multi-turn trimmer potentiometer
R3—250,000 ohms
R4—200,000 ohms
R5, R6, R8, R12—10,000 ohms
R7, R11—5000 ohms
R9—1000 ohms, multi-turn trimmer potentiometer
R10—4750 ohms
R13, R15—100,000 ohms
R14—47 ohms, 5%
R16—5620 ohms
R17—10,000 ohms, 5%
R18—10,000 ohms, multi-turn trimmer potentiometer
R19—6800 ohms
R20, R23, R36—1000 ohms, 5%
R21—220 ohms, 5%
R22—see Table 1
R24-R26, R35—3300 ohms, 5%
R27-R34—82 ohms, 5%

Capacitors

C1, C3, C5, C7-C10—0.1µF, ceramic disc
C2—1000 pF, ceramic disc
C4—1µF, Mylar or tantalum
C6, C11-C13—0.01µF, ceramic disc

Semiconductors

IC1—TL084C quad biFET op-amp
IC2—LM311N (or -H) voltage comparator
IC3—LM331N precision voltage-to-frequency converter
IC4—74121 monostable multivibrator
IC5—7492 divide-by-12 ripple counter
IC6—7490 divide-by-10 ripple counter
IC7—74123 dual monostable multivibrator
IC8—74C925 CMOS 4-digit counter w/multiplexed digit and segment drivers
IC9—MCT2E opto-coupler
DISP1—NSB3881 4-digit, 7-segment LED display
LED1—jumbo red LED
Q1—2N2907
Q2-Q5—2N2222
D1, D2—1N914

Miscellaneous: regulated power supply, perforated construction board, IC sockets, hardware, etc.

without external segment-current-limiting resistors, but they should be used to minimize power dissipation and chip heating.

NSB3881 4-digit LED display

The NSB3881 is one of a family of multidigit LED-displays mounted on a small PC card, which greatly simplifies assembly and wiring. The individual digits are prematched for brightness and are mounted so as to be end stackable. Figure 3 shows the display and its pin assignments.

DVM features

A block diagram of the DVM is shown in Fig. 4. The input range is ±50 volts, and the input is connected to an absolute-value amplifier through a voltage divider having a ratio of 1:5. That ratio can be changed—it just happened to meet my needs. The one strict requirement is that the maximum voltage to be measured result in a V_{IN} to the voltage-to-frequency converter of no more than ten volts. That will keep the maximum signal within the linear operating range of the operational amplifier.

The output of the absolute-value amplifier is always postive, regardless of the polarity of the input voltage. That's necessary because of the input requirements of the LM331. An output is also taken from pin 7 of the amplifier (IC1-b) to light an LED and provide a visible indication of the polarity of the input. When the LED is lit, the voltage is positive; when it's dark, it's negative.

The 60-Hz line current serves as the clock source for the display. Division by 60 provides a one-second timebase. (The

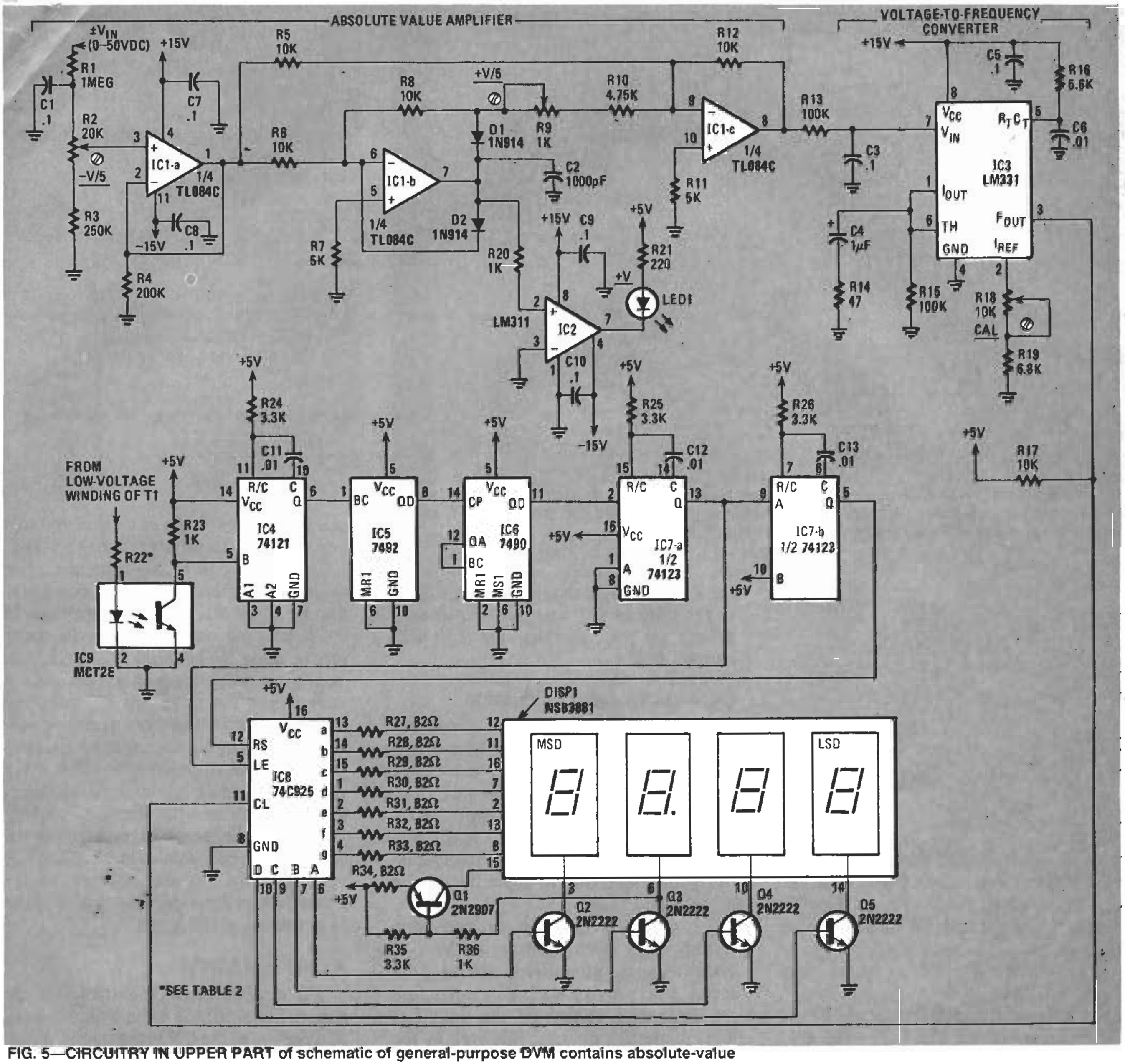


FIG. 5—CIRCUITRY IN UPPER PART of schematic of general-purpose DVM contains absolute-value amplifier and V–F converter. Lower section is for timing and display.

equation for F_{OUT} assumes a one-second timebase.) However, any clock frequency can be used, provided that F_{OUT} stays the same. The easiest component to change to compensate for a different timebase is R_S.

A schematic of the general-purpose voltmeter circuit is shown in Fig. 5. The TL084C quad bi-FET op-amp is used primarily because its very low bias currents allow the use of high-value resistors for the input divider.

Figure 6 helps to explain how the absolute-value amplifier section works. When V_{IN} goes negative, the output of the first amplifier goes positive by the amount of one diode-voltage-drop (about 0.7 volt), shutting off the upper diode and bypassing the amplifier by virtue of the lower diode connected to the input. The second amplifier inverts V_{IN} to provide a positive output equal in amplitude to the negative input. When V_{IN} is positive, both amplifiers invert, but the output of the first is $-2V_{IN}$ which, when summed with V_{IN} at the input to the second, results in an actual input equal to $-V_{IN}$, and thus an output of V_{IN}.

Referring once more to Fig. 5, the second amplifier, IC1-b, is connected to the non-inverting input of a LM311 comparator. Whenever V_{IN} is positive, that input is negative and the LED lights. The three trimmer potentiometers should be preset to approximately midpoint for R2 and R9 and to about 6000 ohms for R18. The National data book suggests that C4 be a Mylar capacitor, but I used a tantalum with no apparent problems. If you are looking for accuracy on the order of one percent or so, and good long-time stability, you should use cermet trimmers and metal-film resistors throughout the amplifier and converter circuits.

As shown in Fig. 7, an opto-coupler is used to extract a clock signal from the low-voltage winding of the transformer used by the power supply that will be monitored. Table 1 will help you select a

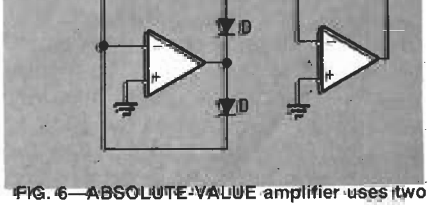


FIG. 6—ABSOLUTE-VALUE amplifier uses two diodes to "decide" whether input voltage is positive or negative.

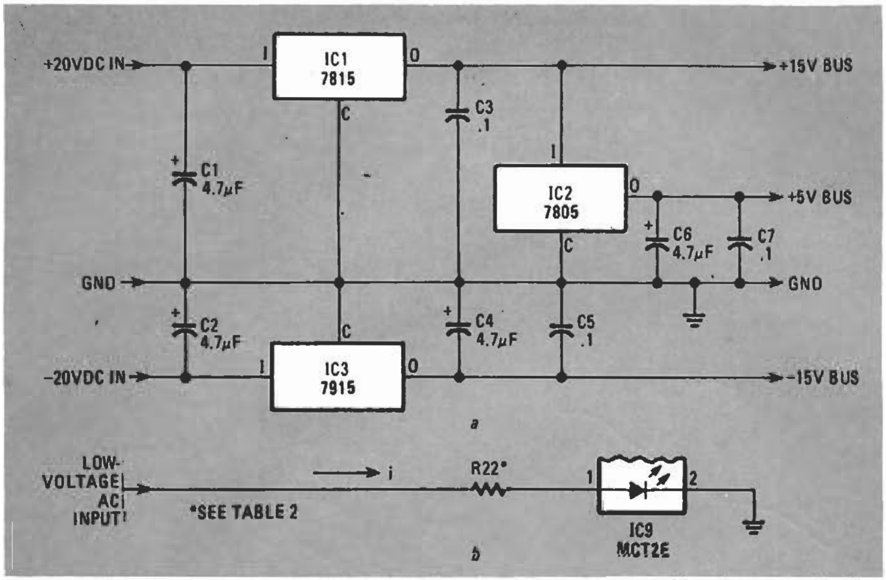


FIG. 7—POWER IS TAKEN from power supply being metered. Regulators provide voltages required by meter circuits. Two positive regulators require heatsinks. Resistor R22 and opto-coupler IC9 also appear in Fig. 5 and serve same functions as R20 and IC14 in Fig. 11.

PARTS LIST—REGULATOR SECTION

All resistors 1%, ¼ watt unless otherwise specified
R22—see Table 1

Capacitors
C1, C2, C4, C6—4.7μF, 25 volts, tantalum
C3, C5, C7—0.1μF, ceramic disc

Semiconductors
IC1—7815 15-volt positive regulator
IC2—7805 5-volt positive regulator
IC3—7915 15-volt negative regulator
IC9—MCT2E

Miscellaneous: heatsinks for positive regulators

TABLE 1

V_{rms}	R22 (R20) (I_{rms}=20mA)
7	270Ω
10	390Ω
13	560Ω
16	680Ω
19	820Ω
22	1000Ω
25	1200Ω

suitable value of R22 for your transformer. Power for the meter circuit itself can also be obtained from within the power supply; ± 18-20 volts DC will do the job nicely.

The 60-Hz divider is quite conventional. When you build the circuit, keep in mind the fact that the 7490 and 7492 power pins are 5 and 10, rather than the more common 14 and 7 for V_{CC} and ground, respectively. The leading edge of the output of the 7490 triggers IC7-a, a 74123 dual monostable-multivbrator. The output pulse, which has a duration of about ten microseconds, latches data from the 74C925 counter (IC8) for display updating. Its trailing edge triggers IC7-b to reset the counter.

The 74C925 is capable of driving the display directly—that is, without current-limiting resitors—but then you must heatsink the counter, and you may have a power-supply problem as well. The 82-ohm current-limiting resistors provide more-than-adequate brightness for good readability on a well-lighted bench. The 2N2907 transistor is used to turn on the second-digit decimal point. The counter does not feature leading-zero blanking, and I didn't think it worth the effort to include it. If you do wish to blank the leading zero, add logic to detect when segments "a–f" are at a logic-high, and segment "g" and pins 7, 9, and 10 of IC 8 are low. The logic should inhibit the drive to the base of Q2 whenever those conditions are met, and the first digit will remain dark.

Construction and calibration

Construction can be quite compact if reasonable care is taken to prevent shorts and solder bridges. There are two things you should do to avoid oscillations: Connect 0.1-μF ceramic capacitors fairly close to the amplifier's "+" and "–" DC-power pins, and take care to separate the input and output circuits of the amplifiers.

I usually combine construction and testing. That is, I construct a block of circuitry, such as the analog portion of the meter, and then stop to check it out before proceeding. I assembled the amplifier and comparator circuits, followed by the voltage-to-frequency converter, the timebase, and the display.

It's a good idea to assemble the amplifier circuit, then stop to test and adjust it, before connecting it to the LM331. The reason is that the voltage-to-frequency converter will respond to positive voltages only, but should there be a defect in the amplifier wiring you could input a negative voltage. (That's because the initial step in the test-and-adjustment procedure is to connect a negative voltage to the input.) With a calibrated meter connected to pin 8 of the TLO84CN, apply a known negative voltage to the input of the meter you built. You should read a positive voltage equal to one-fifth the input. Adjust R2 to obtain that value.

Next, replace the negative voltage with a positive one of a similar amplitude and adjust R9 for the correct reading—again one-fifth the value of the input voltage. There is a somewhat larger error for a positive input than for a negative one, so you may want to make the adjustment using an input voltage of a value you will be measuring frequently (I used 15 volts).

The third—and final—adjustment has to be made after assembly is complete. Simply adjust R18 so your display shows the same input-voltage as does the meter you're using for calibration. Again, you may wish to perform that step with a voltage you use often. At 1½ volts my completed meter displayed a positive voltage that exceeded its negative counterpart by about 30 millivolts. That error approached zero at my calibration value; then the positive error increased slightly more than the negative as I continued upward. Overall, with an input span of 20 volts, the positive and negative values tracked my calibration meter within about two percent of full scale.

A dual-input DVM

The longish rectangle to the left of the banana plug in Fig. 8 is the 4-digit display of a version of the DVM that monitors my power supply's variable outputs (the jacks between the two knobs). That version features two inputs—one for a positive voltage, the other for a negative one. Because the range of the supply is about 27 volts, I designed the meter circuit to span 30 volts. I constructed the circuit in three sections, as can be seen in Fig. 9, so I could tuck it all into the cramped space available inside the supply.

A function diagram of that meter is shown in Fig. 10. An inverting amplifier is required for the negative input; a non-inverting one for the positive, so that each provides a positive source for the voltage-to-frequency converter. Connection to the converter is made through a solid-state analog switch controlled by measurement logic derived from the one-second timing logic. The control logic for the display differs somewhat from that of the general purpose DVM, but the remainder of the circuitry is the same.

A schematic of the dual-voltage meter is shown in Fig. 11. A general-purpose

PARTS LIST—DUAL-INPUT DVM

All resistors 1%, ¼ watt unless otherwise specified
R1, R3—20,000 ohms
R2, R4-R6—10,000 ohms
R7, R19—10,000 ohms, multi-turn trimmer potentiometer
R8—8200 ohms, 5%
R9, R10—5600 ohms, 5%
R11, R17—100,000 ohms
R12—47 ohms, 5%
R13—4700 ohms, 5%
R14, R16—10,000 ohms, 5%
R15—5600 ohms
R18—220 ohms, 5%
R20—see Table 1
R21, R34—1000 ohms, 5%
R22-R24, R33—3300 ohms, 5%
R25-R32—180 ohms, 5%

Capacitors
C1, C5, C10-C12—0.01µF, ceramic disc
C2, C4, C6-C9—0.1µF, ceramic disc
C3—1µF, Mylar or tantalum

Semiconductors
IC1, IC2—741 op-amp
IC3—4016 CMOS quad bilateral switch
IC4—7407 hex buffer, open collector
IC5—LM331N precision voltage-to-frequency converter
IC6—74121 monostable multivibrator
IC7—7492 divide-by-12 ripple counter
IC8—7490 divide-by-10 ripple counter
IC9—7474 dual D flip-flop
IC10—7408 quad 2-input NAND gate
IC11—7432 quad 2-input OR gate
IC12—74123 dual monostable multivibrator
IC13—74C925 CMOS 4-digit counter with multiplexed digit and segment drivers
IC14—MCT2E opto-coupler
DISP1—NSB3881 4-digit, 7-segment LED display
Q1, Q3-Q6—2N2222
Q2—2N2907

Miscellaneous: regulated power supply, perforated construction board, IC sockets, hardware, etc.

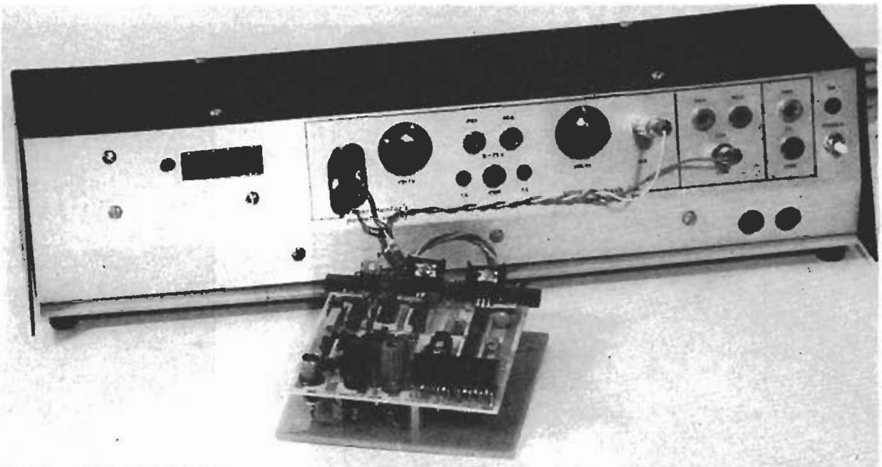


FIG. 8—DISPLAY OF DUAL-INPUT DVM can be seen at left of power supply. General purpose DVM is in foreground.

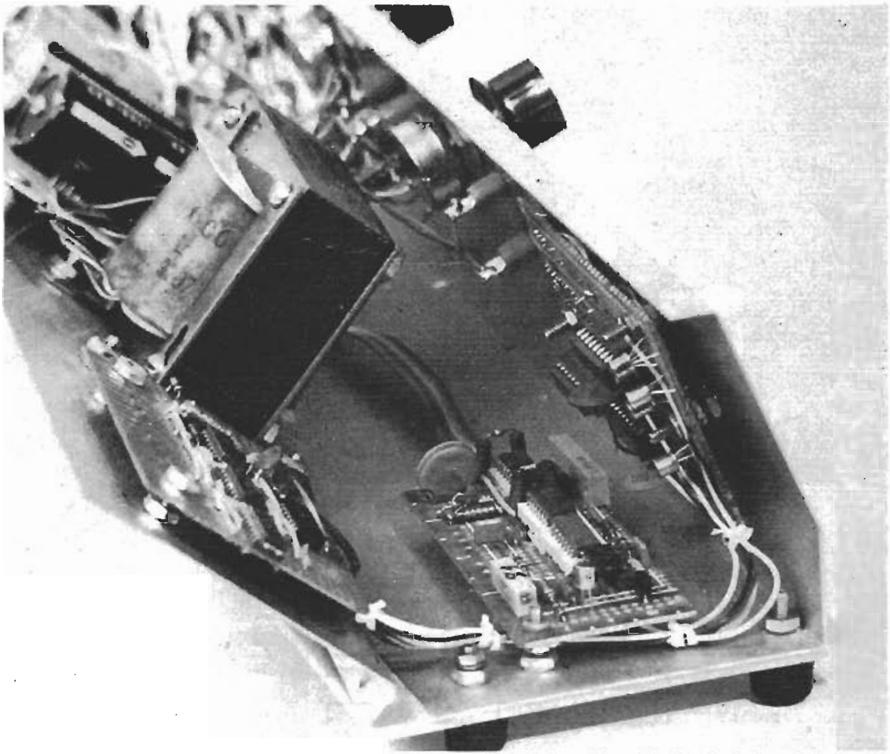


FIG. 9—DUAL-INPUT DVM was built in three sections to fit in tight cabinet. Timing logic is on left-hand board; amplifiers, switching, and V-F converter on center one, and display and display logic on front-panel-mounted board at right.

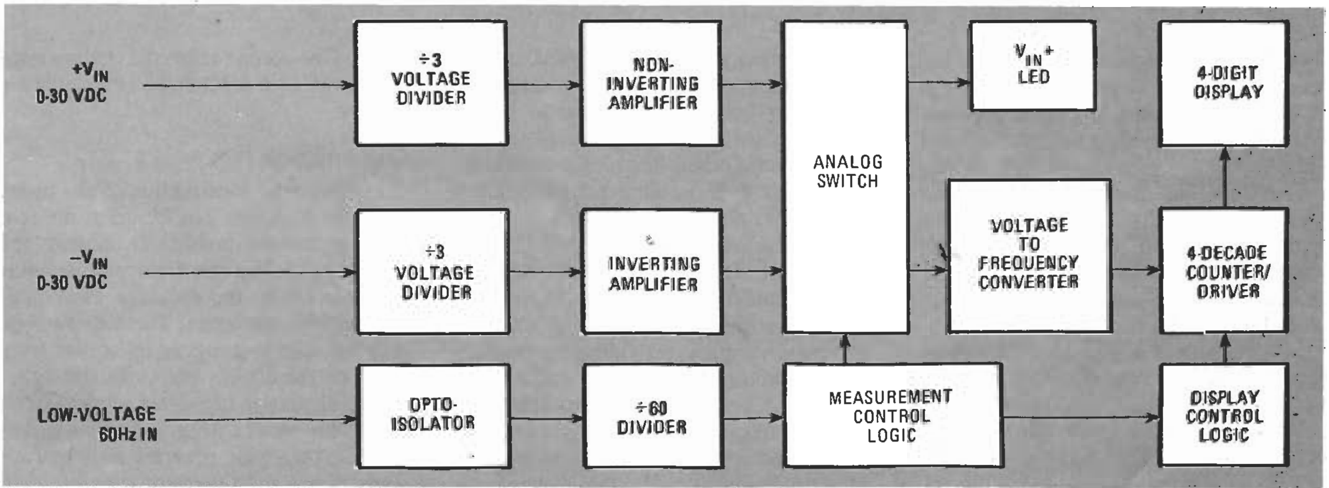


FIG. 10—BLOCK DIAGRAM of dual-input DVM. Timing and display circuits are essentially the same as those in general-purpose meter.

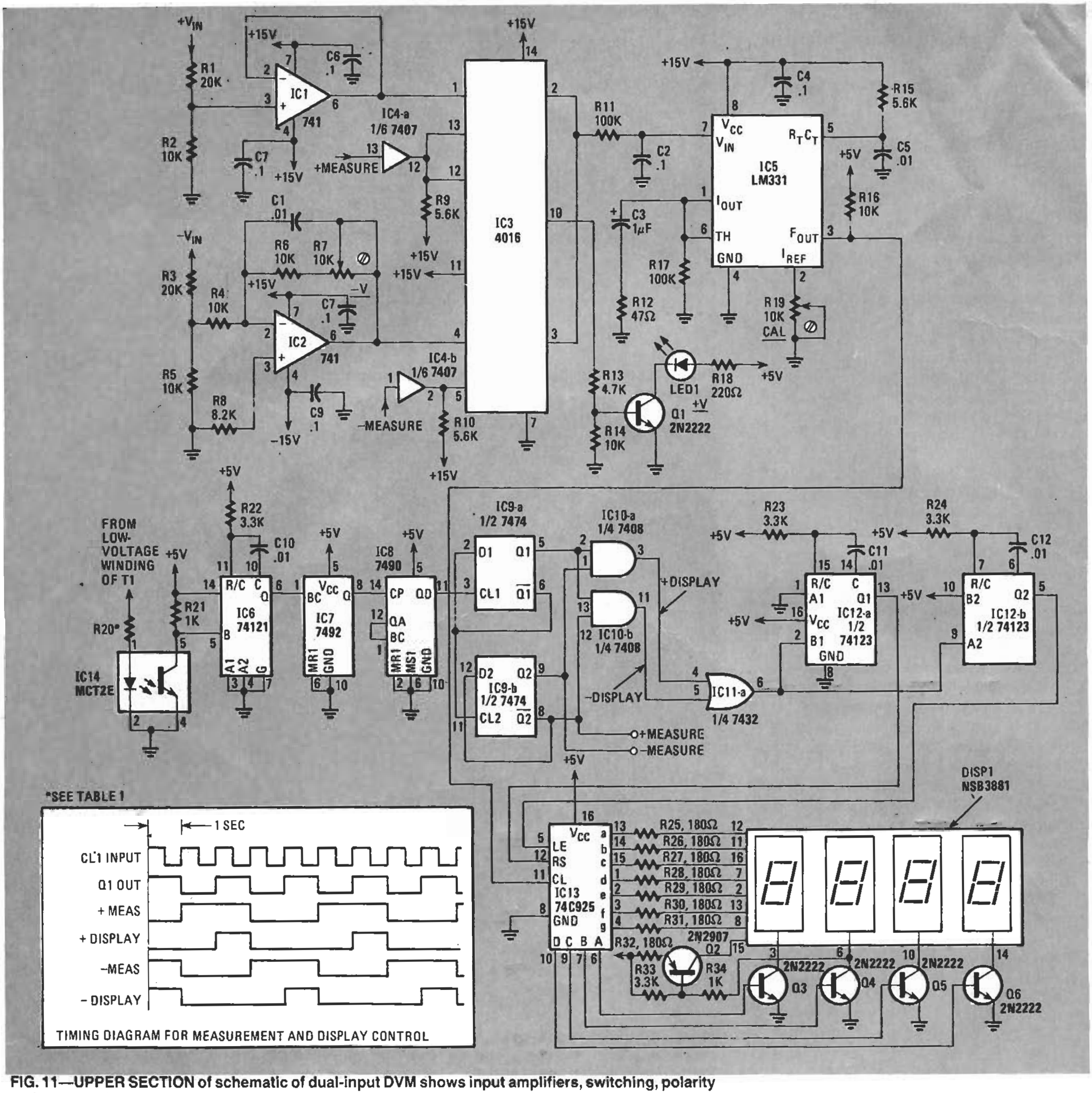


FIG. 11—UPPER SECTION of schematic of dual-input DVM shows input amplifiers, switching, polarity indicator, and V–F converter. Lower section shows timing and display circuits.

DVM requires a high input-resistance not necessary here, so I used less resistance in the divider, permitting use of the popular, low-cost 741 op-amp instead of the TL084C.

The TTL IC's used in the timer logic operate from 5 volts. A section of a 7407 open-collector buffer, IC4-a, provides translation to 15 volts for control of the 4016 quad CMOS switch. The switch is controlled by the + MEASURE and − MEASURE outputs of IC9-b, a 7474 flip-flop. The section of the 4016 used to drive the front-panel POLARITY LED is also controlled by the MEASURE output of the 7474.

A timing diagram is included in Fig. 11 as an aid in following the logic timing. A complication arises in this DVM in that the voltage presented the voltage-to-frequency converter can change by as much as ten volts in going from one source to the other. There is a time constant in the V–F circuitry that will cause a large error unless it is dealt with. My way around that was to allow the LM331 two seconds of measure time, then take only the last half of that time for display.

While at first glance it may appear that the display logic is providing the counter with a simultaneous LATCH and RESET. That, however, really isn't so. The 7432 (IC11-a) triggers IC12-a with the leading edge of its output to reset only the counter (and not the latch) while the display continues to show the currently-latched count. One second later, the trailing edge triggers IC12-b to latch the new count for display.

Construction

I tailored the construction of this meter to fit the location. The board at the rear (seen at the left in Fig. 9) contains the timing logic. The one in the middle holds the two 741's, the measure switching, and the V–F converter. The display logic and the display snuggle up to the front panel so the display can poke through.

The display is supported on the circuit board only by its wiring—short lengths of No. 22 bus wire (quarter-watt resistor leads). Each short piece of wire has a 90°

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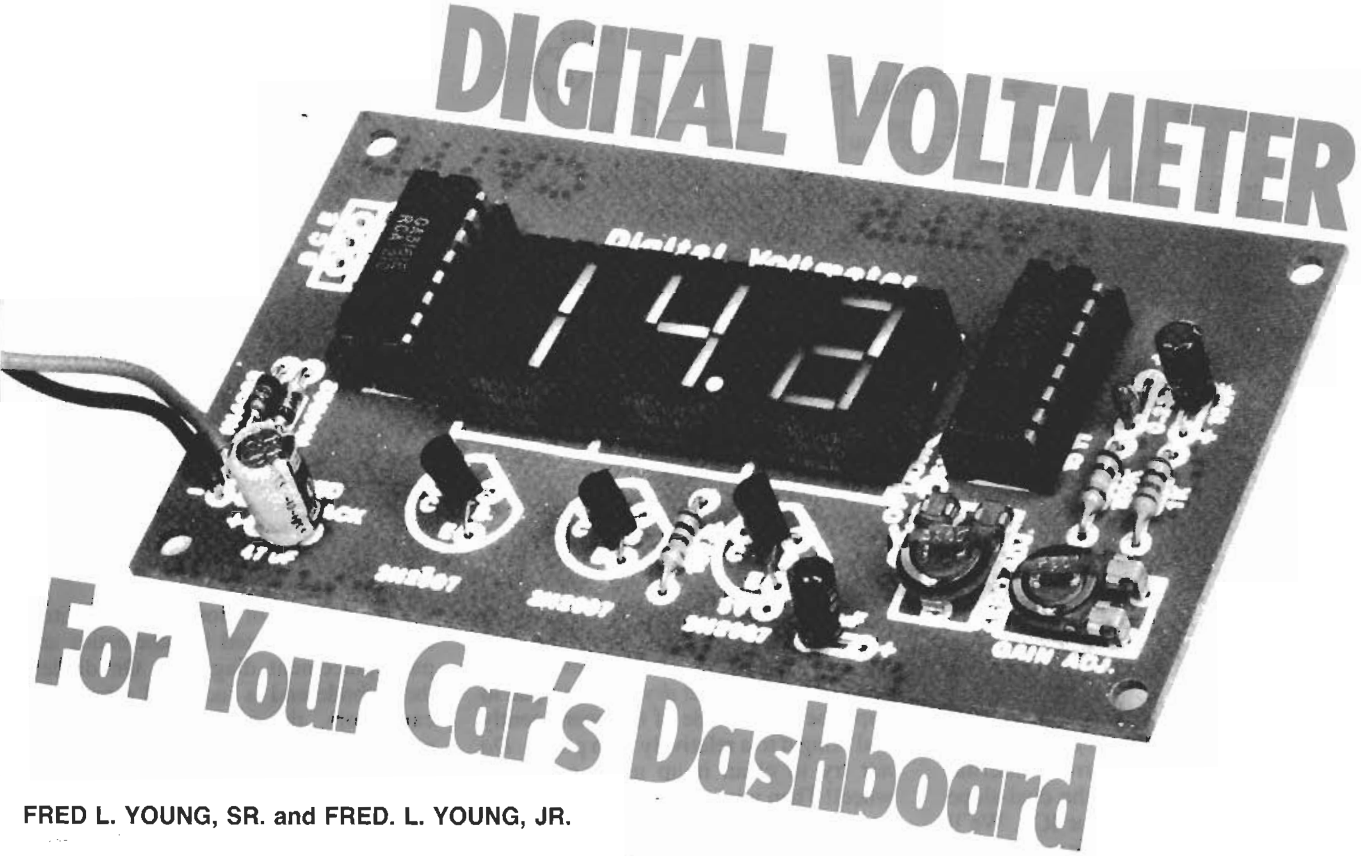


DIGITAL VOLTMETER For Your Car's Dashboard

FRED L. YOUNG, SR. and FRED. L. YOUNG, JR.

Keep an eye on the condition of your car's electrical system with this 3-digit digital voltmeter. Even if you're just a beginner in electronics, you can easily assemble it.

MOST CARS THESE DAYS DON'T HAVE gauges or meters on their dashboards—they have "idiot lights" instead. They're great for telling you when something has gone wrong, but they do very little to warn you when something is *about to* go wrong. What's more, even if you are one of the lucky ones and your car does have gauges, their accuracy is not the best. A device with a digital readout would be much more satisfactory in many cases and easier to read as well.

The digital voltmeter described here can be installed in your car (or boat, or truck) to give you constant and accurate (to a tenth of a volt) information about the state of your battery. It is equally useful in electrically powered vehicles like golf carts and electric service-trucks (fork-lifts, baggage carts, etc.). While most of the latter do have meters, this voltmeter will prove to be more accurate.

The meter is very simple to build—it has only three IC's, three capacitors, five resistors, three transistors (and, of course, three LED's)—and for that reason makes an excellent project for the electronics novice who wants to "get his feet wet." Because it may be your first project, we'll go into the details of construction a little more deeply than we usually do in **Radio-Electronics**.

How it works

Figure 1 is a schematic of the entire voltmeter. The LM340T-5 regulator, IC1, has an output of five volts, which is ideal for the other two IC's in the circuit and for the LED displays. The input to the regulator is protected by diodes D1 and D2, and by a 47 μF capacitor, C1. Those components minimize positive- or negative-going voltage spikes that may be caused by switching inductive devices like the windshield wipers, air conditioning, electric windows, etc., on or off. A 10 μF capacitor, C2, at IC1's output damps any noise or transients that may appear on the five-volt output line and makes the regulator a very stable voltage source, which is critical for accurate readings.

The heart of the voltmeter circuit is IC2, a CA3162E dual-slope, dual-speed, A/D (*A*nalog-to-*D*igital) converter that reads the battery voltage and converts it into a BCD (*B*inary-*C*oded *D*ecimal) digital number. That number appears at pins 2, 1, 15, and 16 of the IC and is fed to pins 7, 1, 2, and 6, respectively, of IC3, a CA3161E BCD 7-segment decoder/driver that drives the three FND507 seven-segment LED numeric displays (DISP1–DISP3).

The CA3161E deserves a little further attention. It performs several functions that, in the past, would have required the circuit to contain a number of additional components. For one thing, it limits the current that is drawn by the displays. Without current-limiting, the LED's would tend to overheat and burn out and, in the past, current-limiting resistors would have been required to prevent that from happening; the CA3161E eliminates the need for them. That IC also allows the displays to be multiplexed; that means that only one LED is on at a time—although they're switched on and off so rapidly through driver transistors Q1–Q3 that they all seem to be on simultaneously. Multiplexing the displays saves a lot of power, and the total current needed to operate the voltmeter is 160 mA or less.

The maximum voltage differential allowed between the input pins on IC2—pins 10 and 11—is 999 mV. Therefore, resistors R1 and R2, whose values have the ratio 100:1, are used to form an attenuation network with a factor of 100. If 13.8 volts are applied to the attenuator network, the voltage difference between the pin 10 (which is grounded) and that at pin 11 (the input pin) will be, according to Ohm's law, 136.6 mV. What we want it to be, though, is 138.0 mV. That differ-

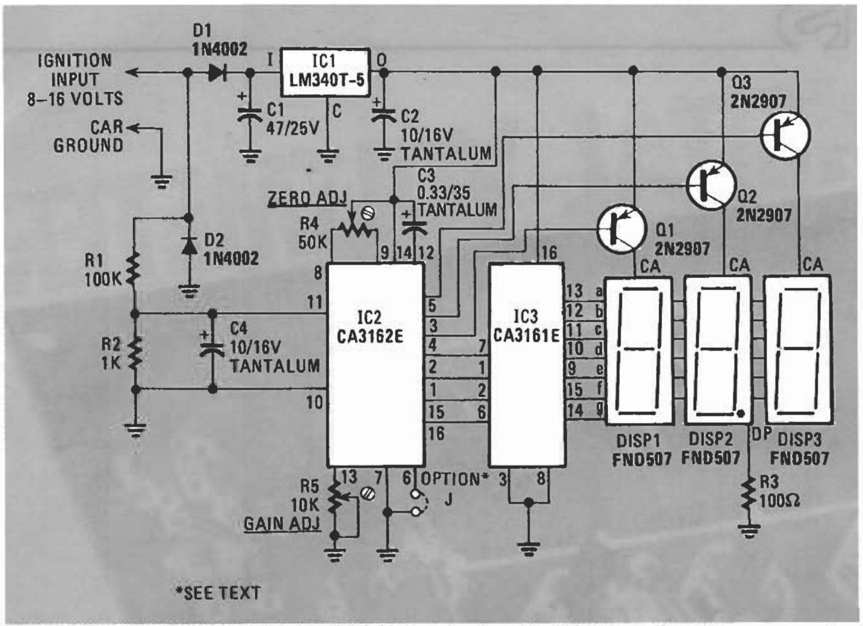


FIG. 1—NOTE THE POINTS MARKED "OPTION" at pins 6 and 7 of IC2; they allow the sampling rate of the converter A/D to be changed. See the text for details.

ence is compensated for by the GAIN ADJUST potentiometer, R5.

The ZERO ADJUST potentiometer, R4, is used—together with a 0.33 μF capacitor, C3—to generate the correct internal ramp-voltage (needed for the dual-slope A/D conversion process) for IC2. We'll discuss the adjustment of both potentiometers later.

Finally, there are two different conversion rates (the rate at which the A/D converter samples the analog input and changes it to digital form) available from IC2. Tying its pin 6 to five volts will produce a conversion rate of 96 (samples) per second. That speed, though, will cause the last digit of the display to become a blur, so we use the other conversion rate—four samples-per-second—by tying pin 6 to ground. The point at which the choice of conversion rates is made is marked "OPTION" in the schematic.

Construction tips

The voltmeter is so easy to build that the process really needs little description. Instead, we'll assume that this is the first circuit you've ever put together, and give you lots of helpful information. Even if you're an experienced constructor, you may find something of interest here, so don't skip this section!

While an etched and drilled circuit board is available from the source indicated in the Parts List, you may decide to go all the way and make your own (the foil pattern is reproduced in Fig. 2). Techniques for making your own PC boards were discussed in detail in the December 1982–February 1983 issues of **Radio-Electronics**. If the board's foil traces are naked copper, there is the possibility that some oxidation may have taken place if the board was not used immediately, and the copper may be difficult to solder to. If that's the case (or even as a preventative measure) use a clean *dry* scouring pad to wipe the copper side of the board gently and bring it to a relatively high polish. *Do not* try to clean it up using a buffing wheel! Then wipe it off with a soft cloth. It should then be as solderable as a board that's just been produced.

The choice of a soldering iron is very important. It should be low power—about 27 watts—and should be used sparingly. Keep it in contact with the points to be soldered only long enough to do the job; if you apply too much heat to a PC board the foil is apt to separate from the board. Use as fine a tip as you can get—that not only keeps heat-buildup down, but lessens the possibility of your creating solder blobs and bridges between adjacent foil points that were meant to be isolated. A fine (thin) rosin-core solder will also help keep your work neat. Use only as much solder as is needed to "wet" the connection; don't make big blobs.

A final word about soldering: keep the tip of the iron clean. A clean tip is a requirement for precision soldering. As your work progresses, solder will usually accumulate on the tip of the iron and it is important that you start soldering with a clean tip, and that you stop the buildup of solder on the tip before it gets started. A damp (not sopping wet) sponge makes a good tip cleaner. Place it out of the way on a plate where you can lightly wipe the tip against it frequently. Wipe the tip whenever you are about to put the iron down after using the it, or at intervals if you are soldering something like a series of IC pins. And, of course, wipe the tip well at the end of your work session.

Many components—like IC's, LED's, diodes, transistors, and tantalum or aluminum electrolytic capacitors—are polarized. That means that they will work properly only if they are installed in the circuit so that the correct pins or leads go to the appropriate points.

The polarities of diodes and capacitors are clearly indicated in schematics and parts-placement diagrams. On diodes, the cathode end is indicated a band; on capacitors, the positive lead may be marked with a dot on the body of the capacitor, or in another fashion. The September 1982 and November 1982 issues of **Radio-Electronics** contained a lot of valuable information on the various types of electronic components; you might want to take a look at them.

Integrated circuits like the ones used in the voltmeter come in DIP (*D*ual *In*-line *P*in) packages. The pin-1 end of the IC may be marked with a notch, a dot (usually placed next to pin 1), or both. Many IC sockets—which you should use, by the way, in case you have to remove an IC for some reason—also have their pin-1 ends marked, even though the sockets themselves are not polarized. Those markings help you to remember which way the IC is to be installed.

Finally, a word of caution about IC's. Many of them—including the CA3161E

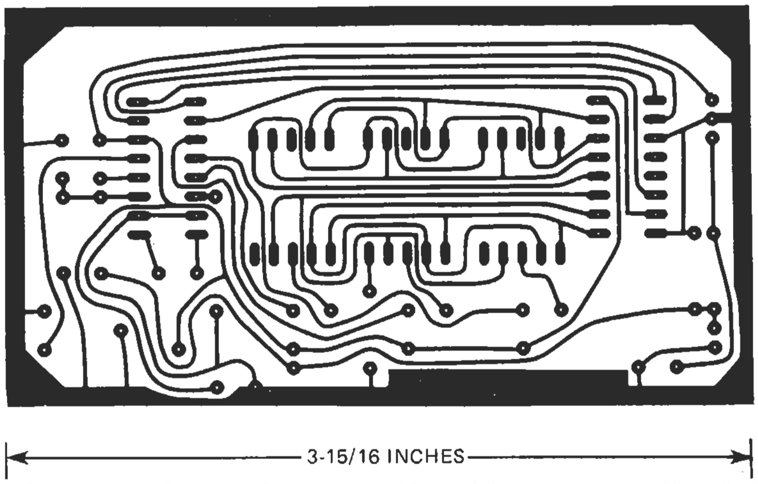


FIG. 2—FOIL PATTERN FOR ETCHING the voltmeter PC-board. A ready-to-use board is available from the supplier indicated in the Parts List.

and CA3162E—can be damaged by static electricity. Do not wear clothing made of synthetic fibers when working with such devices (although, once they've been installed on the PC board, they're relatively safe from harm and you can pretty much wear what you like). If static electricity is a problem for you, handle the IC's under humid conditions. A good solution to the problem is to steam up your bathroom by running the hot water in the shower for a few minutes and then installing the IC's in their sockets in that room while the air is still damp. That trick is especially useful in winter.

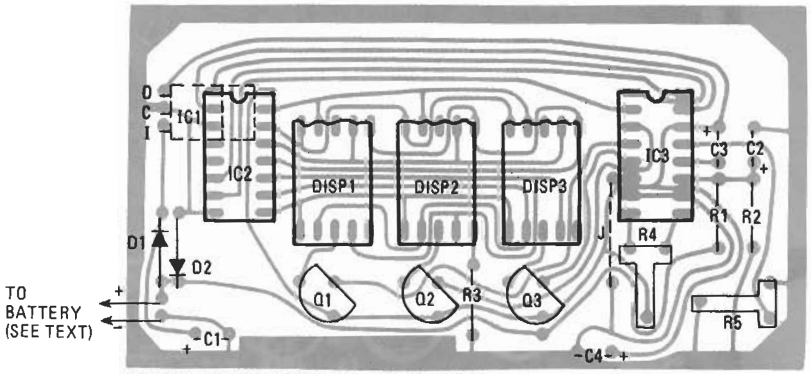


FIG. 3—NOTE THE RIDGES AT THE TOPS of the display LED's. The devices must be installed with the ridges in that position.

Construction

A red plastic filter will make the displays of the voltmeter easier to read under difficult lighting conditions. Use a piece of plastic ⅛-inch thick and a little larger than the PC board. Drill a hole in each corner of the PC board, and drill matching holes in the plastic. To avoid cracking the fragile material, drill small pilot-holes first, and then carefully enlarge them. Be careful not to scratch the plastic. Then set the plastic aside temporarily and, with the advice just given in mind, proceed to "stuff" the PC board.

Use Fig. 3, the parts-placement diagram, to guide you. Install the IC sockets first, and then the resistors, diodes, and capacitors. Don't forget the "OPTION" jumper, which can be a piece of leftover resistor lead. Save the larger parts, like the potentiometers, for last. The 47 μF capacitor, C1, can be mounted on the foil side of the board if you wish to conserve height between the plastic filter and the voltmeter board.

When you install the LED's, which can be soldered directly to the board, be certain that you mount them with the side with the ridges at the top (if you look closely, you'll be able to see the decimal point of the display at the lower right). Solder only two pins, at opposite corners of each device, first. That will allow you to reposition the displays easily if you find that they're in at an angle.

The five-volt regulator, IC1, should be mounted on the foil side of the board as shown in Fig. 4. Bend the leads carefully as shown so they arch backwards. The reason for installing the regulator on the back of the board is, again, to conserve height.

Connect about three feet each of red and black 22-gauge wire to the "IGNITION" and "GROUND" pads of the board, respectively. That will prevent confusion later on in connecting the voltmeter to the vehicle.

Finally, *do not* install IC1 and IC2 in their sockets until you have carefully inspected the board for poor solder-connections, solder bridges, proper component-orientation, and anything else that you might conceivably have done wrong (*anyone*—even you—can make a mistake). Then verify that the supply voltages to the IC sockets are correct. If you temporarily connect the red and black wires to a 12-volt-DC source, you should measure five volts at pin 14 of the socket for IC2 and at pin 16 of the socket for IC3. Pins 7 and 8, respectively,

PARTS LIST

All resistors 5%, ¼ watt unless otherwise indicated

R1—100,000 ohms
R2—1000 ohms
R3—100 ohms
R4—50,000 ohms, trimmer potentiometer
R5—10,000 ohms, trimmer potentiometer

Capacitors

C1—47 μF, 25 volts, electrolytic (axial leads)
C2, C4—10 μF, 16 volts, tantalum or electrolytic (axial leads)
C3—0.33 μF, 35 volts, tantalum

Semiconductors

IC1—LM340T-5 (7805) five-volt regulator, tab type
IC2—CA3162E dual-speed, dual-slope A/D converter
IC3—CA3161E BCD 7-segment LED decoder/driver
Q1-Q3—2N2907 or similar PNP transistor
DISP1-DISP3—FND507 or FND510 7-segment LED
D1, D2—1N4002

Miscellaneous: PC board, IC sockets, wire, red plastic filter, mounting hardware, etc.

The following are available from Digital World, PO Box 5508, Augusta, GA 30906: PC board only, $7.50; PC board with schematic, $8.50; CA3161E and CA3162E, $12.00; PC board with all three IC's and with IC sockets, $20.00; kit of all parts (no filter, chassis or solder) $30.00. The prices of the *first two items only* include postage and handling costs within the continental U.S. and Canada. For all other items add $2.00 within the continental U.S.; $3.00 all other U.S., APO, and FPO. Canadians please use $U.S. postal money order. Other countries write for prices and shipping costs. Please allow 4-6 weeks for delivery.

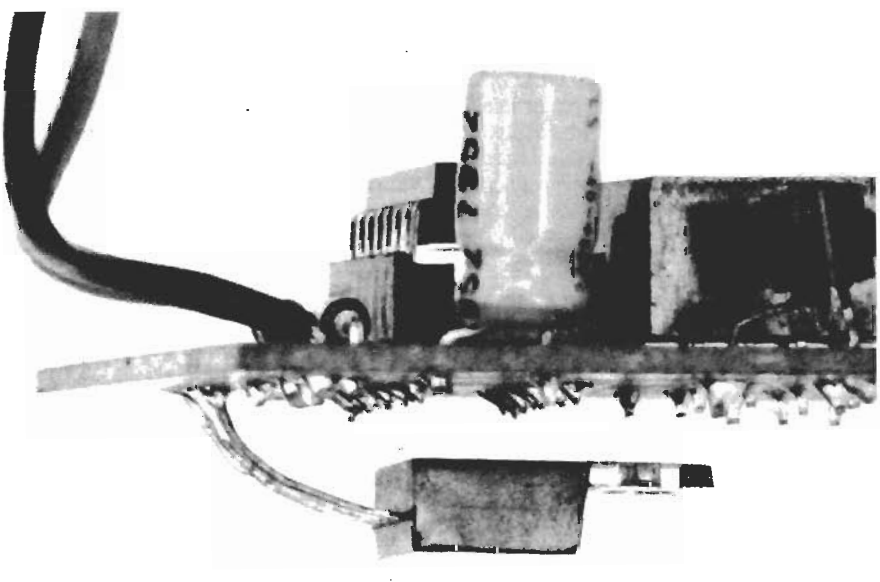


FIG. 4—THE FIVE-VOLT regulator is mounted on the bottom of the PC board, exactly as shown.

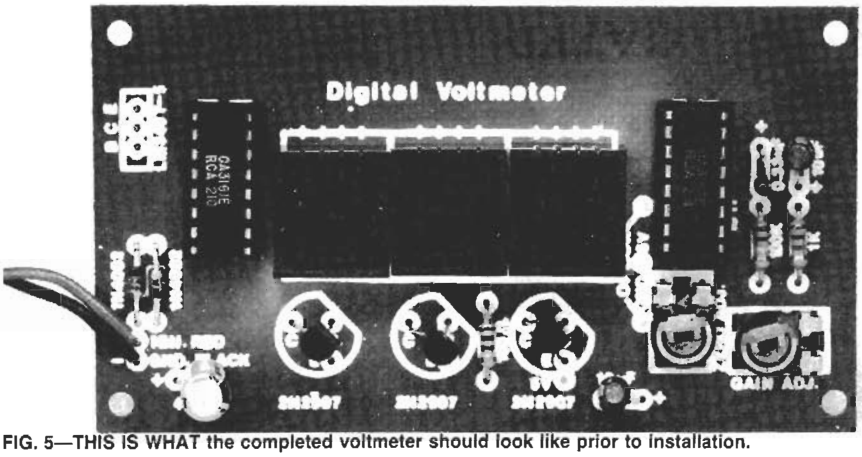


FIG. 5—THIS IS WHAT the completed voltmeter should look like prior to installation.

of those sockets should be at ground potential; you should measure no voltage there.

If your voltage readings are correct, you can disconnect the board from its temporary power supply and install the two remaining IC's. If your measurements differed from those indicated, recheck the board carefully for errors. The completed board should look similar to the one shown in Fig. 5, assuming, of course, that you used the same types of capacitors and other parts.

Calibration

Connect a known, accurate, voltage source to the red and black input wires of the voltmeter. If you already have an accurate meter, connect it in parallel with the one you're calibrating to act as a double check. The calibration voltage should be between 10 and 16 volts; 13.8 volts is recommended. Do not attempt to use a source of less than 10 volts, for it may result in inaccuracies.

To set the ZERO ADJUST trimmer potentiometer, R4, temporarily ground pins 10 and 11 of IC2 to the ground foil of the PC board. Then, very carefully adjust the pot until the display reads "00.0." (You'll need a very fine screwdriver—and some patience—for this.) You can then unground the two IC pins.

Adjust the GAIN ADJUST trimmer potentiometer, R5, until the display indicates the exact value of the calibration voltage being applied. That's all there is to it.

Troubleshooting

If the voltmeter did not light up for the calibration procedure, first make sure that potentiometer R4 is centered. If there is still no response, double check your work once again for solder bridges, unsoldered connections, components installed incorrectly, etc. *Carefully* remove the IC's from their sockets and make sure that none of their pins were bent under.

If the displays are dim, check the emitter and collector leads of transistors Q1–Q3; you might have mistakenly inserted the transistors backwards.

If a digit seems to be trying to display two numbers at the same time, its driver transistor may be defective.

If, after you've installed the meter, it doesn't work, make certain that the red and black wires are properly connected to the "tie in" point and to ground, respectively.

Installation

The first step in installing the meter is to mount the plastic filter in front of it. That can be done using ¾-inch spacers, or by making spacers using 1½-inch bolts and nuts. If you use the latter method, insert a bolt through the plastic and put a nut on the reverse side. Then put a second nut on the bolt, allowing ¾-inch of space between it and the first nut. Do that at all four corners of the plastic. Next, insert the bolts through the holes drilled in the PC board, and secure them with four more nuts. Securing the plastic at all four corners gives the assembly greater strength and minimizes the potential for the plastic's cracking from vibration.

The voltmeter does not require a special cabinet or chassis. It can be mounted in a recess in the dashboard of the vehicle and the edges of the mounting hole covered with a frame, or bezel. For a touch of class, the displays can be mounted on a separate board (a duplicate of the voltmeter board will do quite nicely) and "remoted" from the meter itself. In that case you'll need a 14-conductor ribbon cable to connect the two boards.

The black wire should be securely connected to the vehicle's chassis ground. The red wire should go to a point in the vehicle's electrical system that is active only when the ignition switch is turned on; a good place for that connection is at the same fuse terminal to which the radio is connected.

Now that your voltmeter is installed and working, what voltages should you expect to read? You're probably thinking that the answer is 12 volts. Wrong! Actually, it should be about 12.6 volts. When you're driving, and the battery is being charged, expect to read about 13.8 volts. Any readings above 17 volts or below 11 volts (such as when cranking the starter) indicate trouble!

A possible problem

It is possible that the display-multiplexing circuit will interfere with the operation of an AM radio (especially if the meter and the radio are connected to the same point) by generating some radio-frequency interference that will cause the radio to "whine."

Some radios are more sensitive to that problem than others. There are several solutions to that problem, should it occur.

First, try using a "tie in" point other than the one used by the radio. Just remember that it should be active only when the ignition switch is on.

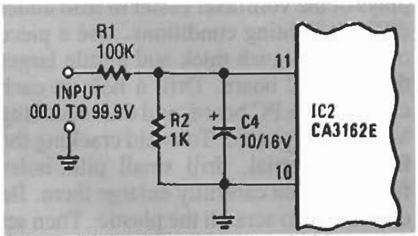


FIG. 6—USING RESISTOR R1 as the input allows you to measure up to 99.9 volts. See the text for precautions.

You can also try moving the meter away from the radio (or vice versa).

Finally, you can try shielding the voltmeter circuit in a metal box. That is usually very effective.

If you decided to "remote" the display from the rest of the meter circuit, wrap the connecting ribbon cable in aluminum foil, and connect the foil to ground. That is almost a "must" in applications where the two units will be separate.

Use with higher voltages

The voltmeter can be used to measure voltages up to 99.9 volts *provided that two conditions are met.*

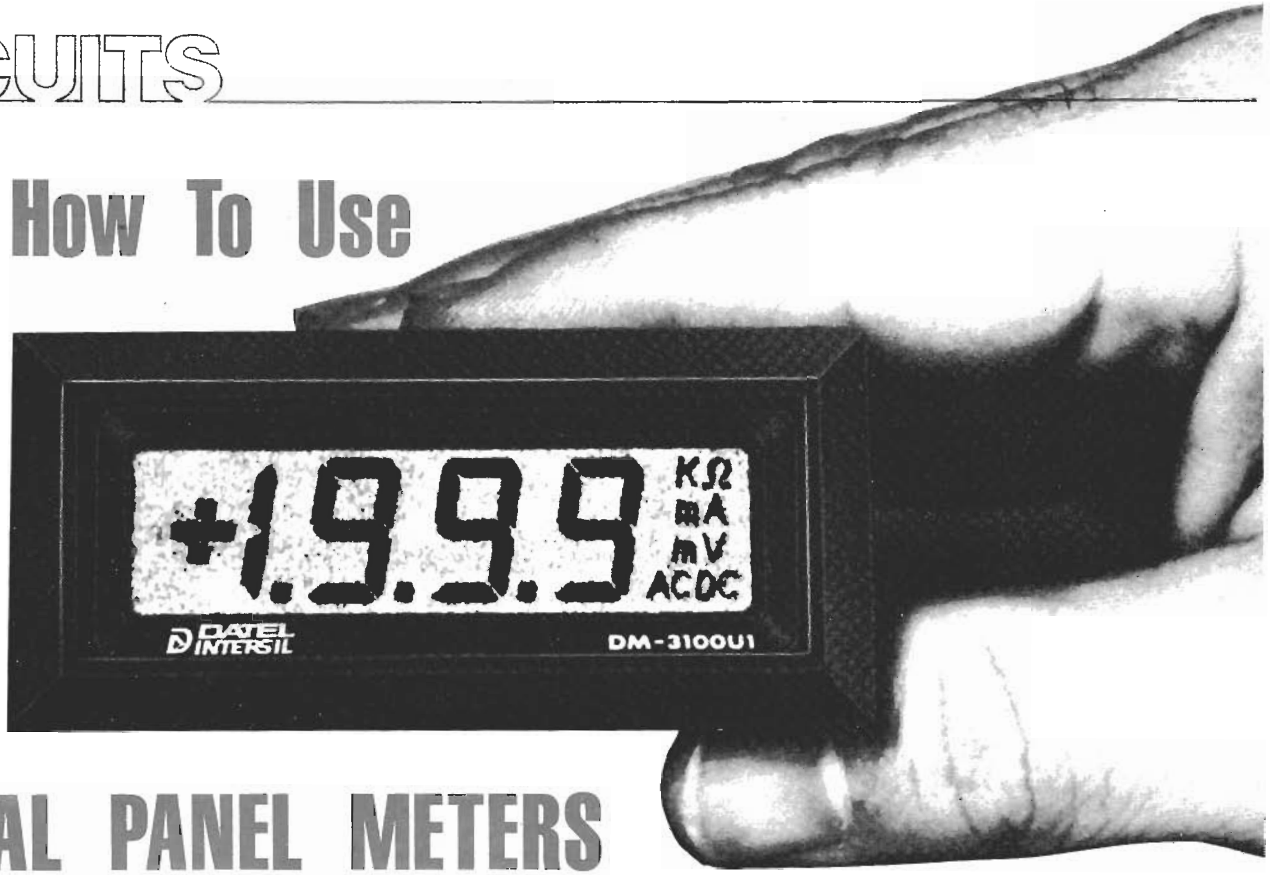
First, the supply voltage to the board must be between 8 and 16 volts. Any lower, and the regulator will not function properly; any higher and it will quickly self-destruct.

Second, the end of the 100K resistor (R1) connected to D2 should be disconnected from that diode, and the voltage being measured applied to the circuit through that resistor. This is shown in Fig. 6.

A last word of advice: Even though your new meter will almost certainly be more accurate than the old indicator you were using, don't get rid of the old one! Keep it in place to monitor the functioning of the meter you built, and to act as a backup just in case something should go wrong.

If you follow the instructions given here, you will not only have learned something about electronics construction-techniques, but you will also have built yourself a very useful measurement instrument. **R-E**

How To Use DIGITAL PANEL METERS



Modern digital panel meters can easily be used to measure voltage, current, resistance, capacitance, frequency, temperature—and a whole lot more.

RAY MARSTON

TAKE A LOOK AT THE TEST-EQUIPMENT market these days and you're sure to notice one thing—just about every VOM, or any other type of meter for that matter, uses a digital display. It's really not all that surprising considering the advantages that digital displays offer in the way of easy readability and better resolution.

But what about your own projects? There's really no reason not to use a digital display in any application that requires measuring an analog quantity such as voltage, resistance, current, temperature, or what have you. That's especially true now that easy-to-use digital panel meters are available from a number of manufacturers. In this article, we are going to take a look at those devices, and how to use them in a variety of applications.

Most digital panel meters combine an analog-to-digital (A/D) converter IC, a 3½ digit LCD or LED readout, a voltage reference, and a few other components, into a compact module that costs little more than a good-quality moving-coil meter. As supplied, the meters typically have an input range of +1.999-to −1.999-volts DC, 1-mV resolution, and a typical calibrated accuracy of 0.1% ±1 digit. They can easily be used to read any desired voltage, current, or resistance range, however, by connecting the appropriate external circuitry.

Several companies manufacture digital panel meters. The meter we'll be looking at here is the DM-3100U1 from Datel-Intersil (11 Cabot Boulevard, Mansfield, MA 02048). Generally, however, digital panel meters differ only in details of their internal circuitry and displays, and in the number and notations of their user-available terminals. As such, our discussion, and the circuits we'll present, can be easily generalized and applied to almost any of the other units on the market.

The DM-3100U1

Figure 1 shows a block diagram of our device. The pinout of its rear card-edge connector is shown in Fig. 2. The device normally operates on +5 volts DC and typically draws just 12 mA; power can be provided by either alkaline batteries or an inexpensive 5-volt regulated DC supply. Also, if an external reference (more on that later) is not required for a particular application, the meter can be simply powered from a 9-volt alkaline battery.

The heart of this particular meter is an LSI circuit that includes a dual-slope A/D converter and the necessary 7-segment-display drivers all in one unit. In essence, that IC automatically compares the relative values of an input voltage and a reference voltage, and uses the ratio of the two to generate the readout.

To ensure maximum versatility, provision has been made to allow for the use of an external reference when the meter is in the +5-volt mode. That reference is connected between pins B1, REFERENCE IN, and A15, EXT. REF. LOW. The panel meter also has a built-in internal reference available at pin A1, REFERENCE OUT. That reference is approximately +1 volt above the ANALOG RETURN input, pin B2. To use the internal reference, pins A1 and B1 are simply jumpered together. When we look at some sample applications for the device, we will show examples using both the internal and an external reference.

Before you use any digital panel meter in a project it is a good idea to know a bit about it. While we have already touched upon several important points, there are a few more that bear mentioning.

As supplied, and when configured as shown in Fig. 3, the meter has a full-scale input range of −1.999- to +1.99-volts DC. Claimed accuracy at 25°C is ± 0.1% of reading, ± 1 count. The resolution is 1 mV. The calibration can be adjusted using a multiturn screwdriver potentiometer,

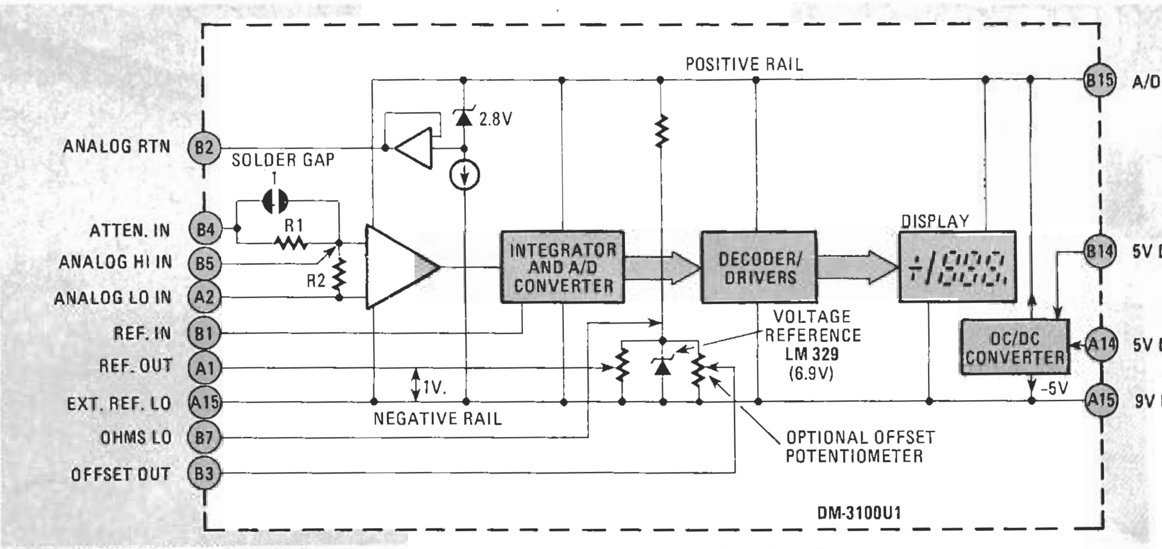


FIG. 1—SIMPLIFIED BLOCK DIAGRAM of the DM-3100U1 digital panel meter from Datel-Intersil.

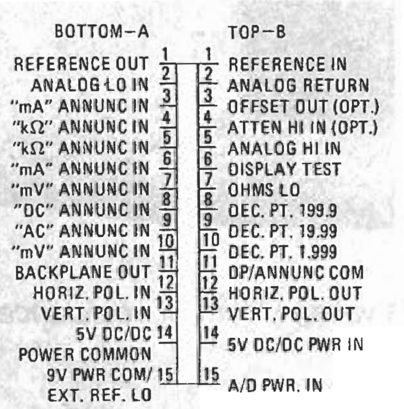
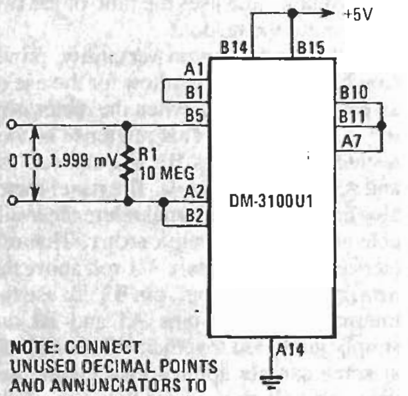


FIG. 2—PINOUT of the unit's rear card-edge connector. The pinout is shown here with the unit tilted on its side.



NOTE: CONNECT UNUSED DECIMAL POINTS AND ANNUNCIATORS TO A11 (BACKPLANE OUT)

FIG. 3—WHEN THE PANEL METER is configured as shown, it will measure DC voltages from +1.999 to −1.999. The 10-megohm resistor across the meter's input is included to ensure proper auto-zeroing. It is otherwise optional and need not be included.

and the recommended recalibration-period is 90 days.

Differential input signals are applied to ANALOG HI and ANALOG LO, pins B5 and A2 respectively. To prevent the voltages at those inputs from exceeding the common-mode voltage range—$+V_S - 0.5$ volts to $-V_S + 1$ volt, where $+V_S$ is the positive rail (pin B15) and $-V_S$ is the negative rail (pin A15)—they must be externally tied to ANALOG RETURN, or POWER COMMON (A14) if the device is +5-volt powered.

Three decimal points (pins B8–B10), the vertical and horizontal portions of the polarity indicator (pins A13, B13, A12, and B12), and a variety of function annunciators (pins A3-A10) are available to the user. To select a decimal point or a function annunciator, simply connect it to DECIMAL POINT COMMON, pin B11. All unused decimal points and function annunciators should be connected to BACKPLANE OUT, pin A11.

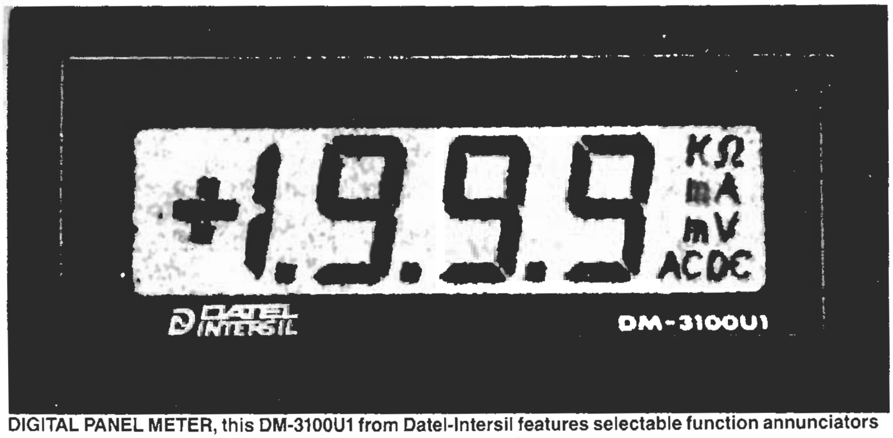
There are two points we should mention concerning the function annunciators. First of all, they are only display labels. The meter cannot measure resistance, current, or AC without the appropriate user-added circuitry. We'll be looking at some of that circuitry shortly. Second, you'll notice in Fig. 2 that some of the annunciators are identified with one of the letters underlined. When those annunciators are selected, only the underlined portion is displayed.

Turning to the polarity indicator, for normal auto-polarity operation, pins A12 and B12, as well as pins A13 and B13, are jumpered together. For reverse-polarity sensing, pins A12 and B13 are jumpered together (no other connections). If the polarity sign is not wanted, the unused pins are again connected to BACKPLANE OUT, pin A11.

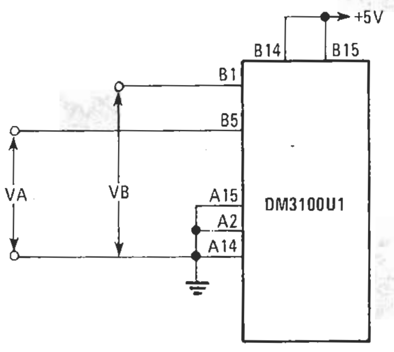
The meter uses a 3½-digit LCD readout. The readout is not backlighted, so sufficient room light is required. The digits themselves are ½-inch high. Overrange is indicated by a blanked display with the exception of the leftmost digit (1) and the polarity indicator. The sampling rate as supplied is 3 conversions-per-second, but that can be changed by the user to up to 20 conversions-per-second.

The DM-3100U1's input impedance is rated at 100 megohms minimum, and its input bias current is rated at 5-pA typical, 50-pA maximum. Those last two factors are significant because they mean that the meter will not load down any sensitive circuitry that is connected to its inputs.

Physically, the panel meter measures a compact 2.53 × 3.25 × 0.94 inches and weighs 5 ounces. It can be mounted in any

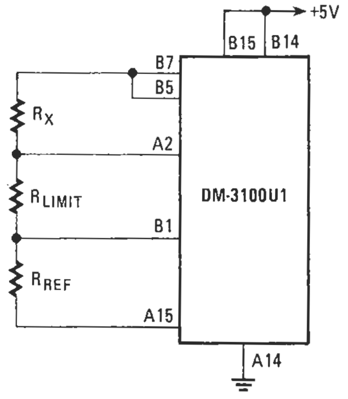


DIGITAL PANEL METER, this DM-3100U1 from Datel-Intersil features selectable function annunciators and decimal points, as well as auto-polarity and auto-zeroing.



NOTE: INPUT = ± 500mV MAX.

FIG. 4—A SIMPLE RATIOMETRIC VOLTMETER. When the inputs are identical, the meter will read 1000.



RANGE (FULL SCALE)	R_{LIMIT}	R_{REF}
19.99 MEG	22 MEG	10 MEG
1.999 MEG	3.6 MEG	1 MEG
199.9 K	360 K	100 K
19.99 K	36 K	10 K
1.999 K	6.2 K	1 K

FIG. 5—A RATIOMETRIC ohmmeter. The limiting resistor is included to constrain the voltage through the resistor series to 100 mV maximum.

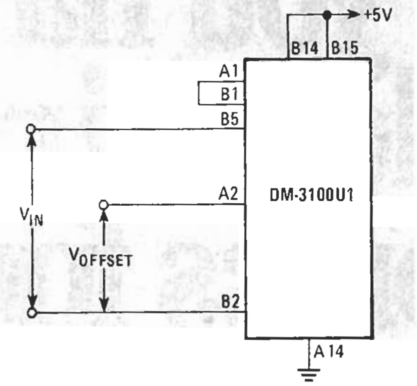


FIG. 6—APPLYING AN OFFSET voltage. This configuration is useful in applications where scaling is required.

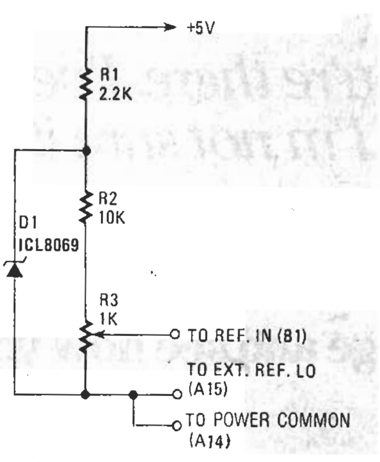


FIG. 7—A 100 MV external standard. The heart of this circuit is a 1.2-volt band-gap reference.

position and has a claimed operating temperature range of 0°C to 50°C.

Applications

Figure 3 shows how to configure the meter to act as a simple voltmeter. As shown in the figure, the meter can handle inputs from −1.999-volts DC to +1.999-volts DC. For simplicity, we've kept the interconnections to a minimum. In this, as well as the remaining examples we'll look at, it is assumed that the polarity sign has been set up for auto-polarity readings as described earlier. Note that the v annunciator and the appropriate decimal point have been connected to pin B11; although not shown, all other annunciators and decimal points should be connected to BACKPLANE OUT, pin A11. In the remaining examples the annunciator and decimal- point connections will be eliminated for clarity. The 10-megohm resistor connected across the input terminals is included to insure proper auto-zeroing. It is optional and can be omitted if you desire.

Figure 4 shows how to set up the panel meter so that it acts as a simple ratiometric voltmeter. In that configuration, when two input voltages (V_A and V_B) are identical, the meter will read 1000.

It's relatively simple to configure the DM-3100U1 to act as a precision ohmmeter. Such a circuit is shown in Fig. 5.

The circuit takes advantage of the meter's ratiometric measuring capabilities. An external reference resistor—whose resistance, accuracy, and drift with temperature is known—is connected in series with the unknown resistance and a current limiting resistor. You'll recognize the fact that the series resistors form a voltage divider. The voltage to the three, a regulated 6.9 volts, is supplied via the OHMS LO output, pin B7; note that that pin is used only in resistance-measuring applications. The voltage drop across R_X and R_{REF} is compared by the meter and the result is used to calculate the resistance of the unknown. The current-limiting resistor is selected to keep the current though the series combination to a maximum of 1 mA; it serves no other function in the circuit. The values for R_{REF} and R_{LIMIT} for different ranges of R_X are also shown in Fig. 5.

Finally, Fig. 6 shows how an offset voltage can be applied to the basic "DVM" circuit so that the display reads zero when the input voltage and the offset voltage are identical. That can be useful in a number of applications. Consider, for instance, a temperature-sensing application in which the sensor is scaled to produce an output of 1mV/°K. In other words, that sensor will produce an output of 273.2 mV at 0°C and 373.2 mV at 100°C. By feeding the output of the sensor between pins B5 and B2, and applying a 273.2 mV offset voltage between A2 and B2, the meter can be made to give a direct reading of temperature in degrees Centigrade.

DC voltage and current meters

As was mentioned earlier, provision has been made in the panel meter we are

TABLE 1—SUPPLIERS

In addition to the manufacturer mentioned in the article, digital panel meters are available from a wide variety of sources. Some of those sources are listed below.

Ametek
2 Station Square
Paoli, PA 19301

Analog Devices
PO Box 280
Norwood, MA 02062

Analogic Corporation
Audubon Rd.
Wakefield, MA 01880

API Instruments
1601 Trapelo Rd.
Waltham, MA 02254

Ballantine Labs
90 Fanny Rd.
Boonton, NJ 07005

Data Precision Corporation
Electronics Ave.
Danvers, MA 01923

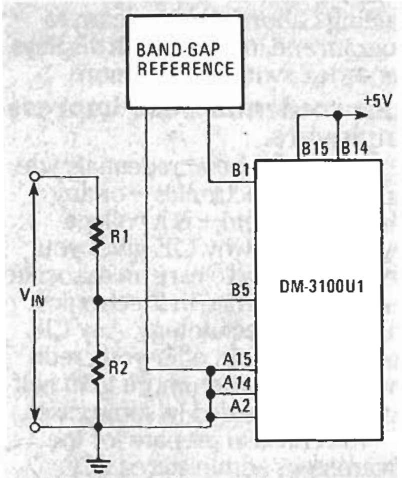
Fluke Manufacturing Company
Box C9090
Everett, WA 98206

Non-Linear Systems
533 Stevens Ave.
Solana Beach, CA 92075

Sigma Instruments
170 Pearl St.
Braintree, MA 02184

Simpson Electric Company
853 Dundee Ave.
Elgin, IL 60120

Weston Instruments
614 Frelinghuysen Ave.
Newark, NJ 07114



R1	R2	$V_{FULL SCALE}$
0	10 MEG	199.9mV
9 MEG*	1 MEG	1.999mV
9.9 MEG*	100K	19.99V
10 MEG	10K	199.9V
10 MEG	1K	1.999kV

*SEE TEXT

FIG. 8—THE VOLTMETER'S input range can be expanded easily using a simple voltage divider.

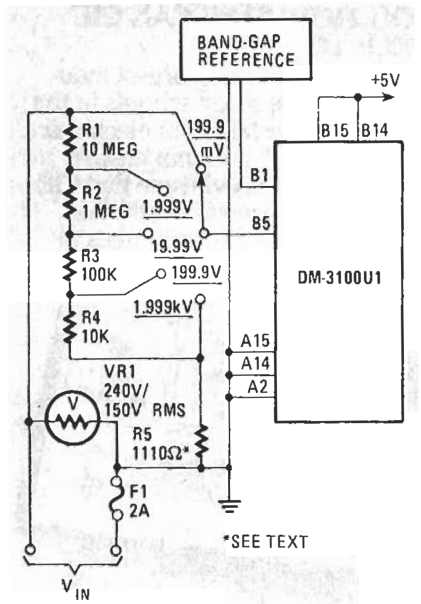


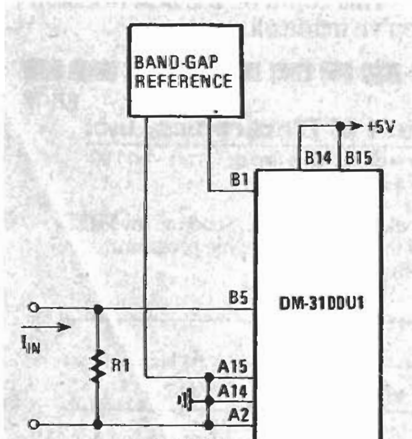
FIG. 10—A FIVE-RANGE switchable voltmeter. The varistor is included to prevent damage to the panel meter from excessive input voltages.

using to allow the use of an external reference of from +100 mV to +2 volts, referred to $-V_S$. In several of the following examples we will make use of that feature. The external reference that we've chosen to use is shown in Fig. 7. The output of that circuit, which is built around a 1.2-volt band-gap reference (an Intersil ICL8069 is used here, although any similar device may be substituted), is a stable 100 mV.

The DVM module is supplied ready-calibrated to give a full-scale reading of ±1.999-volts DC. It is relatively simple, however, to add external circuitry that will extend that range. Consider, for example, the circuit shown in Fig. 8. It uses a simple voltage divider and an external 100-mV reference to allow the meter to measure voltages from 199.9 mV to 1.999 kilovolts full-scale over five ranges. Appropriate values for R1 and R2 are given for each range in the table in Fig. 8.

One note about the resistors before we go on. Some of the values may be difficult to obtain. If you can not find the appropriate resistances, simply combine two standard-valued units in series.

The DM-3100U1 can also be made to act as a DC current meter by wiring a suitable shunt resistor across the input terminals, as shown in Figure 9. Once again, the values for R1, the shunt resistor, are given in the table in the figure.



R1	I_{IN} (FULL SCALE)
100Ω	1.999mA
10Ω	19.99mA
1Ω	199.9mA

FIG. 9—MEASURING CURRENT with the DM-3100U1.

It is a simple matter at this point to take one of the circuits we've discussed and add the appropriate switching for range selection. That's what we've done in Fig. 10, a five-range voltmeter. Note that in multi-range applications the circuit should be provided with some form of overload protection. That has been taken care of in this circuit by fuse F1 and by a placing a voltage-dependent resistor (varistor) across the divider. That varistor ensures that the voltage to the meter does not exceed the meter's rating (250 volts DC, 175 volts rms continuous). Also note that on the 1.999-KV range the maximum input is therefore limited to 240.

Ohmmeter

The easiest way to use a digital panel meter as an ohmmeter is to use it in the ratiometric configuration shown in Fig. 5. That technique has two major advantages. First, it is very stable and inherently self-calibrating, the meter reading being equal to R_X/R_{REF}. Secondly, very low test voltages are generated across R_X, the maximum voltage being constrained to 100 mV by the presence of R_{LIMIT}.

As with the voltmeter and ammeter, it's relatively easy to set up a multi-range ohmmeter by expanding upon the basic circuit. Such a multi-range circuit is shown in Fig. 11.

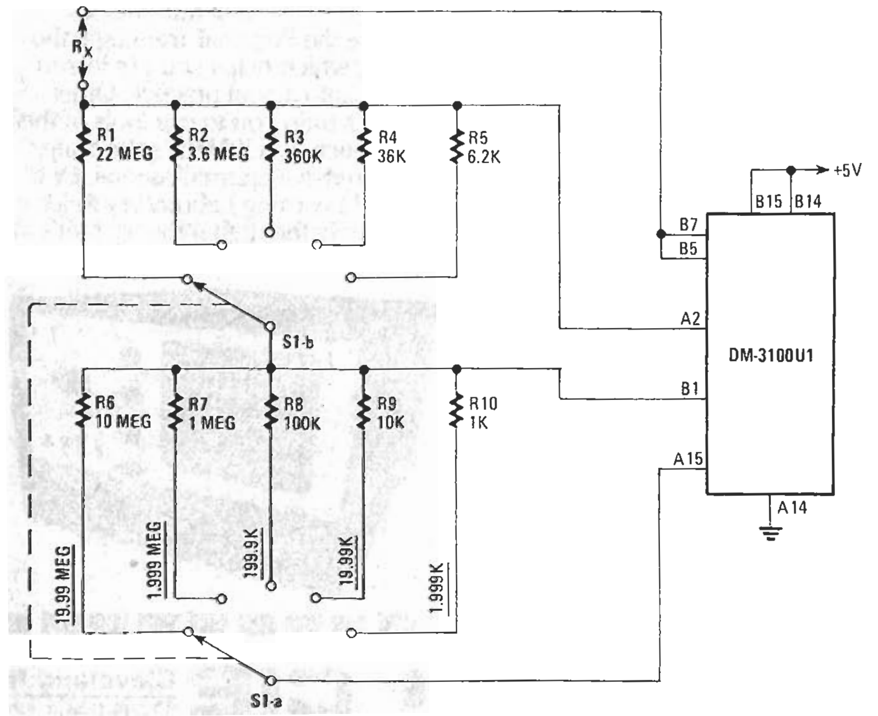
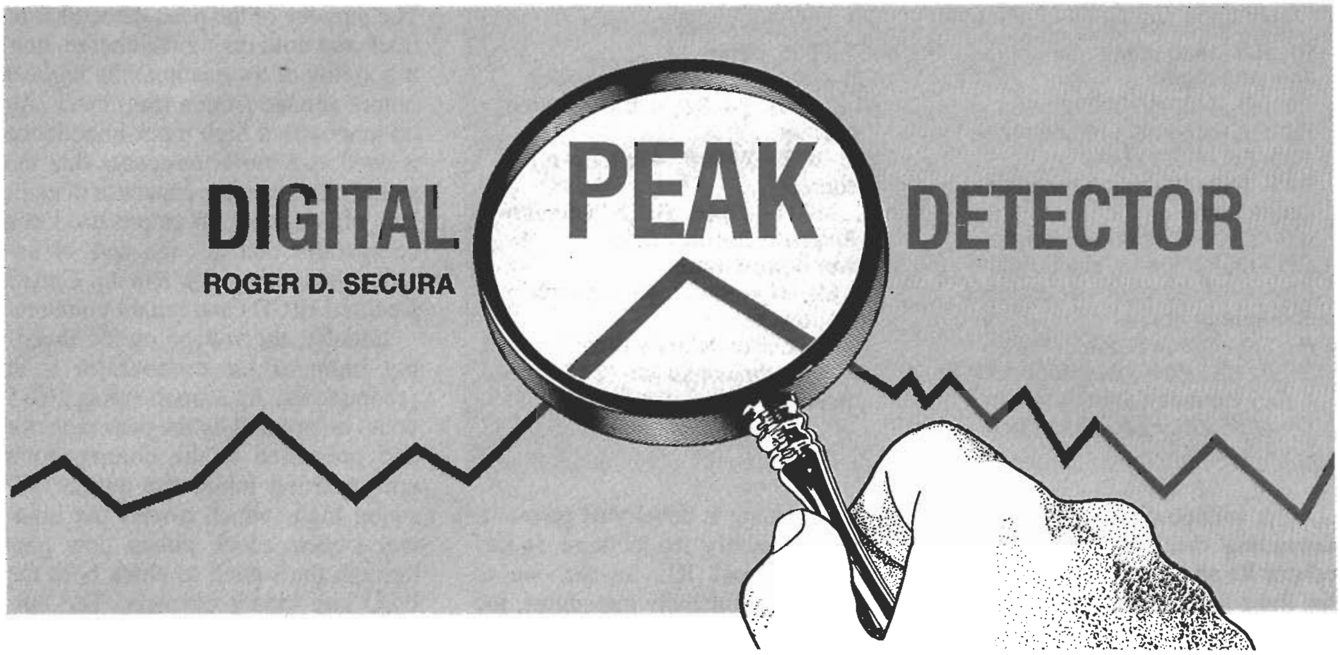


FIG. 11—THE RATIOMETRIC OHMMETER from Fig. 5 is expanded here to a five-range switch-selectable circuit.

There is still much more that can be done with a digital panel meter. We will look at some of those applications next time when we continue this article. **R-E**

DIGITAL PEAK DETECTOR

ROGER D. SECURA



When you need to know the hottest, the fastest, the highest, or the absolute most, you need to build our peak detector.

WHAT'S THE TOP WIND SPEED DURING A hurricane? What about that jumbo jet on final approach, flying 1000-feet over your home: Is the noise pollution higher than that allowed by law? How hot does beach-sand get under a blazing summer sun?

To answer those questions, you have to measure the relevant physical parameter, store the maximum event, and then display the result. To sense the relevant parameter, you need a *transducer*. To track and hold the maximum event, you need a *peak detector*. And to record the result, you need a *digital display*. Such a peak-detecting device should continuously track, hold, and display the maximum level of any physical parameter; for example, speed, loudness, temperature, pressure, position, flow rate, force, light intensity, and so on—you name it.

Transducers

Getting the world of electronics to communicate with the physical world is like trying to mix oil with water—an almost impossible task, unless you have the right emulsifier. We know that emulsifiers work with oil and water, but what works with physical quantities and electronics? You can't shake them up in a bottle. To get them to mix you need a transducer. And their are literally hundreds of different types of transducers; each type mixing a specific physical parameter with electricity.

A transducer outputs an electrical signal that is proportional to the magnitude of the physical event it's detecting; an output can be a series of digital pulses, an analog voltage, a varying frequency, or a change in current or resistance.

An example of a practical transducer is a *L*ight *D*ependent *R*esistor or LDR, which is a resistor whose resistance changes in proportion to the amount of light striking its surface. (Cadmium-sulfide photocells are the most common LDR's.) But our peak detector can sense only voltage within the 0 to 5-volt range; it can't sense resistance at all! What's needed is a method to convert the LDR's resistance to an equivalent voltage. A typical LDR might have a light-to-dark resistance range of 100 ohms to 500,000 ohms. A circuit must be designed that transforms that resistance range into a voltage range between 0 to 5 volts. That conversion process is called signal conditioning.

As shown in Fig. 1, to condition the

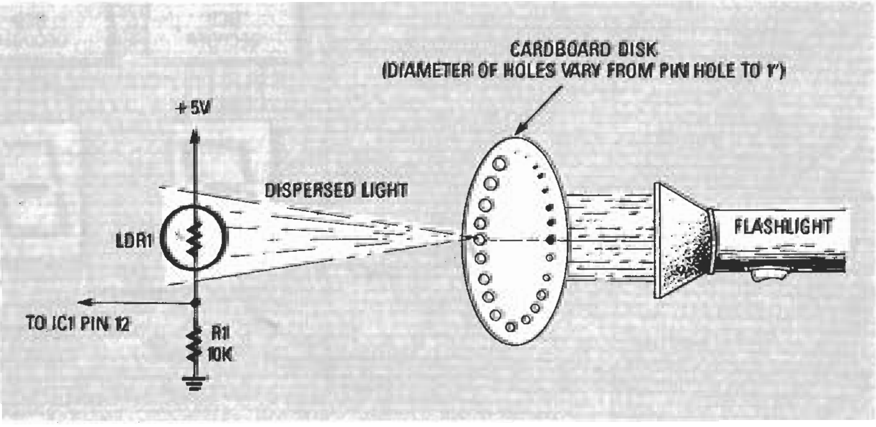


FIG. 1—THE *L*IGHT *D*EPENDENT *R*ESISTOR (LDR1) IS A TRANSDUCER **whose resistance changes in proportion to amount of light falling on its surface.**

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted)
R1, R7—1000 ohms
R2—100 ohms
R8, R9, R42—10,000 ohms
R3–R6, R10–R19—10,000 ohms, 1%
R20–R40—330 ohms
R41—250,000-ohm potentiometer
Capacitors
C1—22µF, 16 volts, electrolytic
C2—10µF, 16 volts, electrolytic
C3—.01µF, 50 volts, ceramic disc
Semiconductors
D1, D2—1N914 Diode
DISP1–DISP3—7 Segment LED Display (common anode)
Q1—2N3906, PNP Transistor
Q2—2N3904, NPN Transistor
IC1—LM324, Quad Op-amp
IC2—555, Timer
IC3—4066, Quad Bilateral Switch
IC4, IC5—74193, 4-bit up-down counter
IC6–IC8—74190, 4-bit up-down counter
IC9–IC11—7446, BCD-to-Seven-Segment Decoder/Driver
Other components
S1, S2—Normally-open momentary-on push button
S3—6 position rotary switch
LDR1—cadmium-sulfide (CdS) photocell

LDR, a voltage divider is formed by connecting the LDR in series with resistor R1 and a 5-volt source. When the light source is maximum, the LDR appears as a low resistance, allowing almost the entire 5 volts to be developed across R1. When the light source is minimum (dark), the LDR has its highest resistance, so almost all the voltage is developed across it, and practically no voltage is developed across R1. So far, we've taken a light-intensity transducer, the LDR, and conditioned its changing resistance to be compatible with the our peak detector's input requirement of 0 to 5-volts. Shortly, we'll see how to calibrate our transducer.

How it works

Figure 2 shows a block diagram of our digital-readout peak-detector. The purpose of the peak detector is to track and hold (using the charge-storing ability of a capacitor) the highest output voltage from a transducer. An op-amp with a high input-impedance is used as a buffer to ensure that the stored charge on the capacitor doesn't leak off. Another op-amp is used as a comparator that has the task of enabling/disabling the *B*inary *C*oded *D*ecimal (BCD) and binary counters.

Initially, the voltage on the inverting input of the comparator is at ground level. As a small voltage (0–5 volts) is captured by the peak detector and presented to the comparator's non-inverting input, the output will swing high, which asserts the bilateral switch; clock pulses now pass through the switch to clock both the BCD and binary counters. The outputs of the binary counters are connected to a R2R ladder network, which functions as a digital-to-analog converter. As the binary count increases, the R2R ladder voltage also

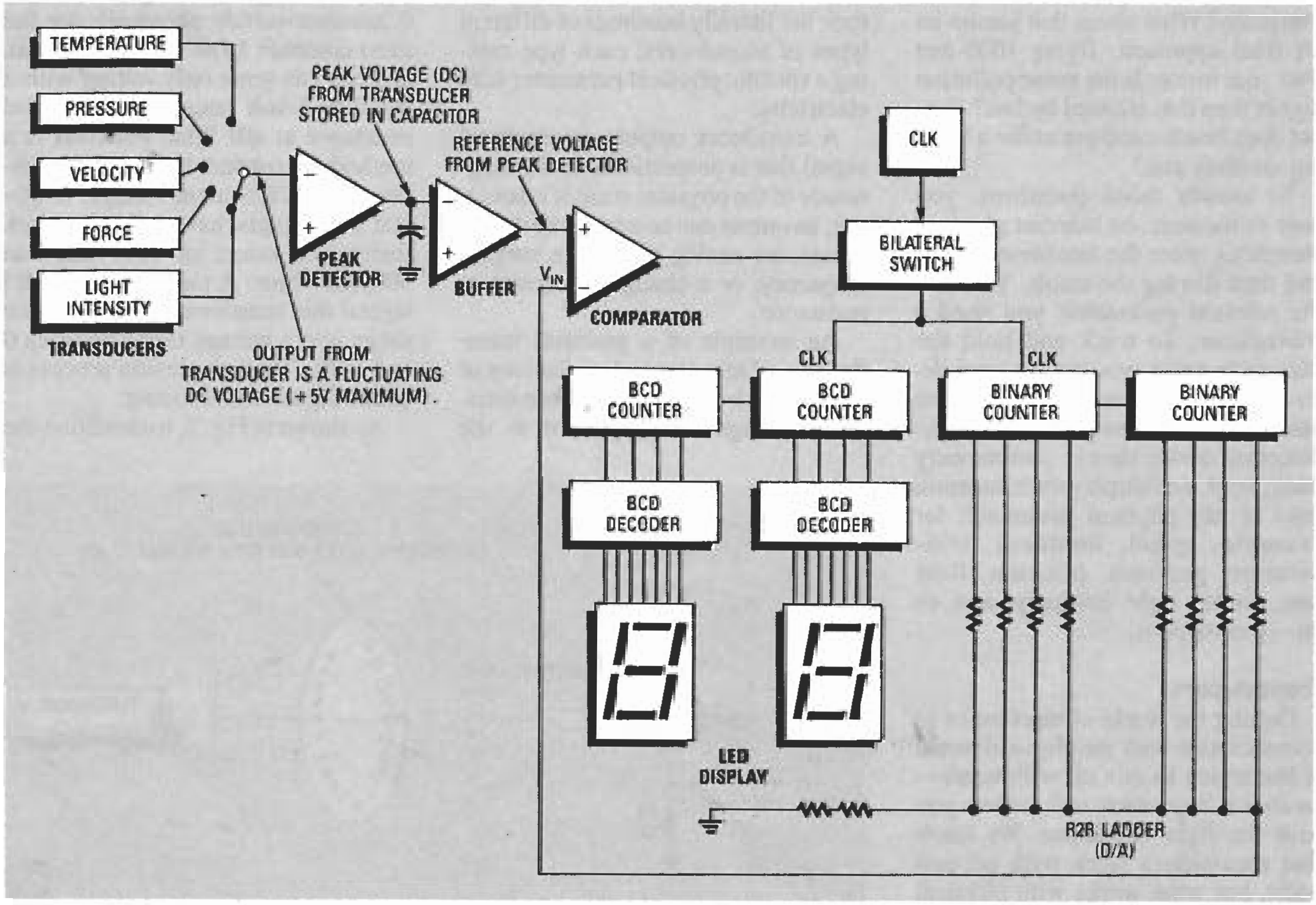


FIG. 2—THE TRANSDUCER, PEAK DETECTOR, AND DISPLAY are the main components of a digital-readout peak-detector.

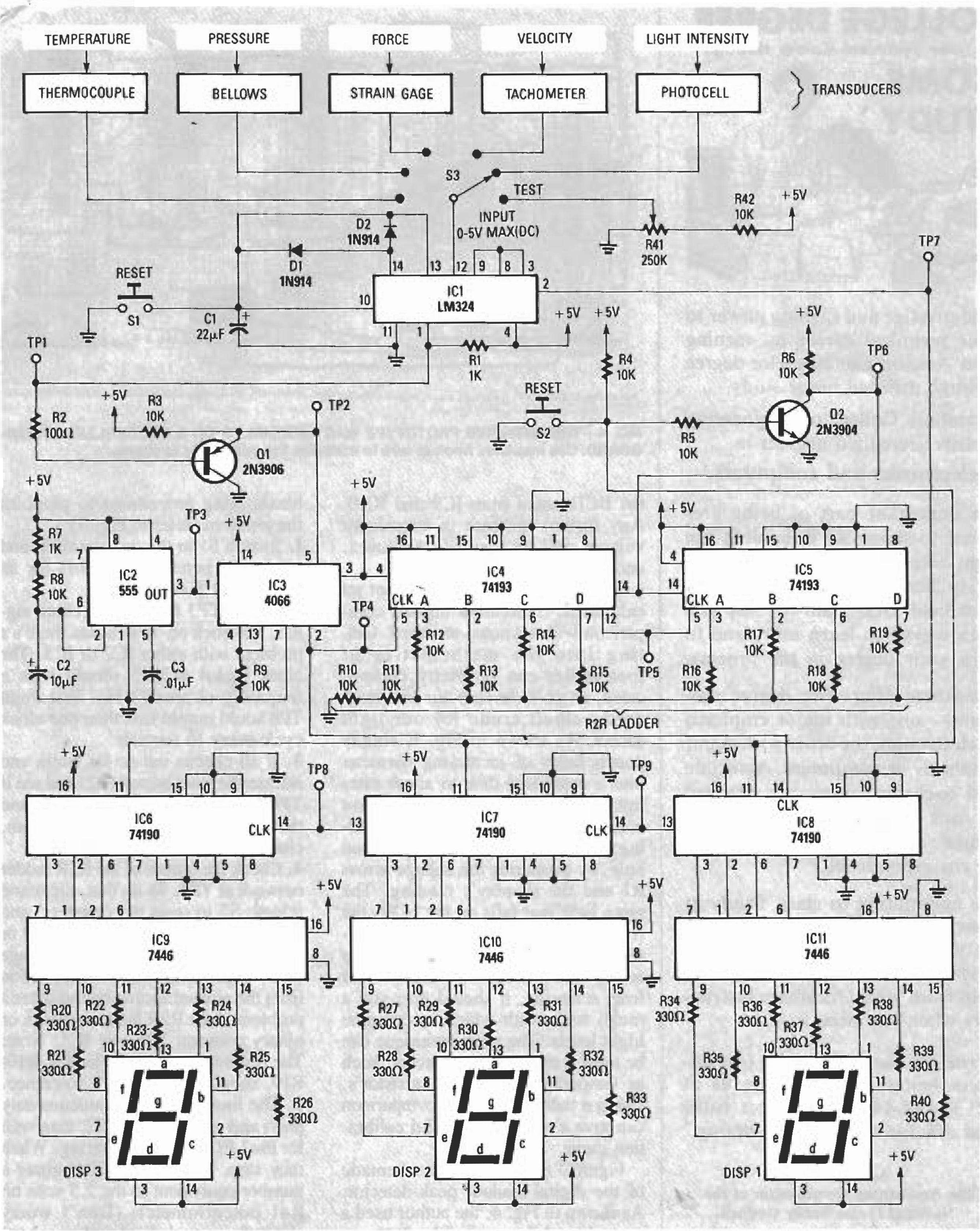


FIG. 3—THE CIRCUITRY CONSISTS OF COMMON TTL, CMOS, AND OP-AMP IC'S. When switch S3 is in the test position, varying R41 simulates a transducer's voltage output.

increases until it reaches a point slightly above the voltage of the peak detector; at that instant, the comparator output swings low, which disables the bilateral switch and stops the counters.

If everything functions properly, the number displayed on the 7-segment LED's will represent a value equivalent to the transducer's output. Note that the display's reading is not an actual voltage reading, but simply

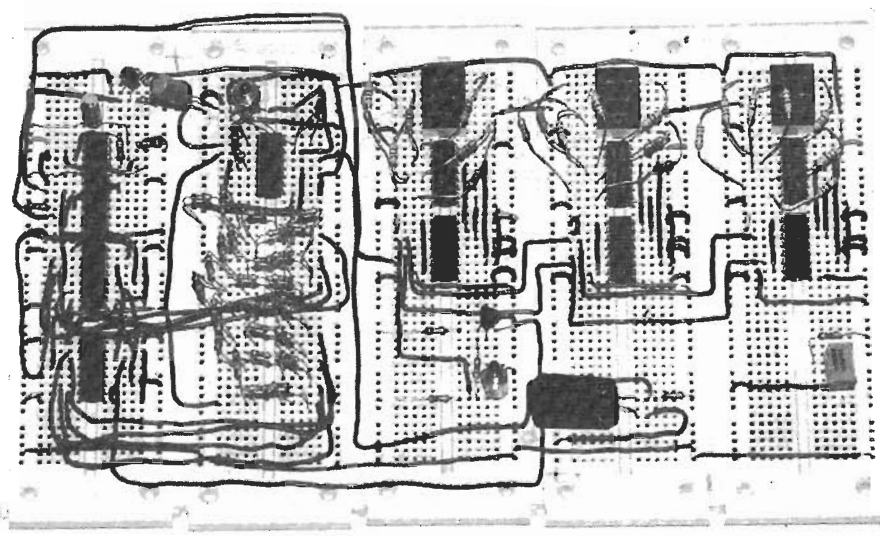


FIG. 4—THE AUTHOR'S PROTOTYPE WAS ASSEMBLED ON A SOLDERLESS BREADBOARD. Use insulated hookup wire to minimize the possibility of shorts.

the BCD count from IC9 and IC10. Any further increase in transducer voltage will be tracked, displayed, and maintained.

Of course, the transducer is not yet calibrated. Calibration implies comparison with a known standard. Getting into the mathematics of footcandles can be pretty complicated, so we'll develop our own standard—albeit crude for our light sensor. As shown in Fig. 1, simply punch holes of increasing diameter into a cardboard disk to allow extra light to pass through each successive hole; then chart the light intensity falling on the LDR, for each punched hole, by measuring the voltage across R1 and the display's reading. The more light that falls on the LDR, the lower its resistance and, consequently, the greater the voltage drop across R1. Although that method is far from scientific, it should give you a rough scale with which to compare lilght levels. The same technique can be used with other transducers, such as temperature-dependent resistor's. Using a thermometer for comparison can give a more meaningful calibration curve.

Figure 3 is the complete schematic of the digital-readout peak-detector. As shown in Fig. 4, the author used a proto-board for assembly, but you may just as easily use a prototype PC-board and wire-wrap all connections.

Testing

If your circuit fails to respond after construction, use the following troubleshooting procedures to pinpoint the problem (refer to Fig. 3):

1. Switch S1 to the test position, and adjust the potentiometer R41 for an output of 2.5 volts.

2. Check TP3 for a 30-Hz clock signal. No clock on TP4 means there's a problem with either IC2 or IC3. The clock signal at TP5 should have a frequency of about 1 Hz. Test Point TP8 sould output less than one clock cycle every 16 seconds.

3. If all checks out so far, press and release the reset button (S2) and see if TP6 goes from a low to a high, and then back to low. If there's a problem, check Q2 and associated circuitry.

4. Check the output of the R2R ladder network at TP7. To do that, press and release S2 to reset the counters, and watch TP7 (using an oscilloscope or meter) for a slow rising DC voltage (+5-volts maximum). Any deviation from the normal ascension indicates a problem in the R2R ladder network or binary counters IC4 and IC5. Note: The resistors in the R2R ladder, R10-R19, should be within 1% tolerance.

5. The final test is to simultaneously press and release S1 and S2, then wait for the LED's to stop counting. When they stop, the display will register a number equivalent to the 2.5 volts on R41 potentiometer. (Don't worry about the actual displayed number.) Repeat that procedure a few times. The same number should re-appear on each test. Next, turn the test potentiometer R41 up to three volts. The LED's should start counting up to some number and then stop. **R-E**