BUILD AN

Autoranging Digital Capacitance Meter

BY DAVID H. DAGE

Autoranges from 1 pF to 1 µF and from 1 µF to 4000 µF. Updates readings automatically.

THE DIGITAL-READOUT capacitance meter described here is a most useful instrument when one has to determine values of unmarked capacitors or those with unknown codes, or when checking the tolerances of marked components. Its autorange function greatly simplifies what would ordinarily be a measurement chore without this feature. Moreover, the meter's accuracy of over 1% (dependent on the tolerances of a few passive components) from 1 pF to 4000 µF enhances its utility. The project is easy on the budget, too, as low-cost 7400 series logic and 555 timer IC's are used throughout.

To operate, simply turn on the unit, connect a capacitor to the test terminals, and read the digital value displayed for any capacitor up to 1 µF. Switching a mode switch from nF to µF extends the autorange function to 4000 µF and beyond, limited only by the leakage characteristics of the test capacitor.

How it Works. Traditionally, capacitance has been measured on an ac bridge by balancing known components against the reactance of an unknown capacitance at a given, fixed frequency. However, instruments are now appearing which employ a different method to determine capacitance—they measure time. Here's how.

Mathematically, the voltage across a capacitor discharging through a resistor in a simple RC network can be expressed by the equation:

$$V_C = V_O(1 - e^{-t/RC})$$

where V_O is the voltage across the capacitor when fully charged, R the resistance in ohms, C the capacitance in farads, t the time in seconds, and e the exponential constant or base for natural logarithms (approximately equal to 2.718). If we let a capacitor that has charged to a known voltage discharge through a fixed, stable resistance to some given voltage, the discharge time will be directly proportional to the component's capacitance, which then can be readily determined.

The meter described here employs this method of measurement, which readily lends itself to use with a digital readout and eliminates null adjustments. As shown in Fig. 1, the capacitance to be measured is charged through R_A and R_B. When the voltage across the capacitor equals V_{REF}, comparator A sets the flip-flop, turning on the transistor. The capacitor then discharges through R_A until the voltage across it drops to one-half V_{REF}. At this point, comparator B resets the flip-flop, which in turn cuts off the transistor. The capacitor then starts to charge up to V_{REF}, and the cycle is repeated.

A reference oscillator output at a fixed frequency is gated by the flip-flop output signal. The gated reference pulses are counted by a digital counter, decoded, and displayed directly as capacitance. The two comparators, flip-flop, transistor, reference voltage sources, and an output driver are all contained in one package—the common 555 timer IC.

The meter's autorange circuit functions during a single capacitor discharge cycle. If the three-decade counter overflows, the reference frequency input is automatically divided by ten. Simultaneously, the decimal point in the digital display is shifted one position to the right. If necessary, the process is repeated once

Interior photo of prototype.

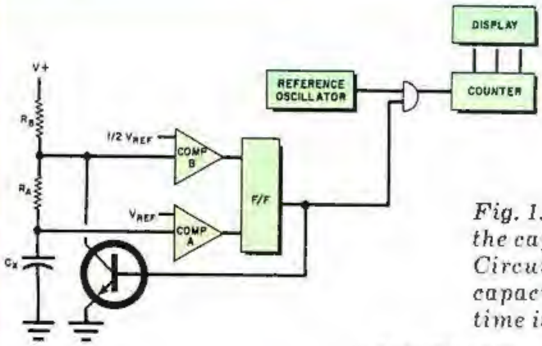


Fig. 1. Block diagram of the capacitance meter. Circuit determines unknown capacitance by measuring time it takes to discharge.

PARTS LIST

C1—4000-μF, 16-V electrolytic capacitor
C2,C4,C8 through C16, C23—0.01-μF disc ceramic capacitor
C3—0.0033-μF, 10% Mylar capacitor
C5—0.1μF disc ceramic capacitor
C6,C17—4.7-μF, 16-volt tantalum capacitor
C7—220-μF, 16-volt electrolytic capacitor
C18—0.01-μF, 5% polystyrene capacitor
C19—820-pF, 5% polystyrene capacitor
C20—470-pF, 5% polystyrene capacitor
C21—220-pF, 5% polystyrene capacitor
C22—0.005-μF, 10% Mylar capacitor
D1,D2—1N4002 silicon diode
D3 through D5—1N4154 or HEP R0600 silicon fast-recovery diode
DIS1 through DIS3—DL707 common-anode, seven-segment LED display
F1, F2—¼-ampere fast-blow fuse
IC1,IC2,IC3,IC17,IC18,IC19—7490 decade counter
IC4,IC15—7404 hex inverter
IC5—74125 Tri-State quad buffer
IC6,IC20—555 timer
IC7,IC8,IC22—7400 quad Two-input NAND-gate
IC9,IC10,IC11—7447 BCD to seven-segment decoder/driver
IC12,IC13—7474 dual D edge-triggered flip-flop
IC14,IC21—74121 monostable multivibrator
IC16—7493 4-bit binary counter
IC23—LM309K 5-volt regulator
L1—13-μH inductor
LED1, LED2—20-mA light emitting diode
R1—100,000-ohm pc mount trimmer potentiometer
R2—1-megohm, 1% tolerance, 50 ppm/°C metal film resistor
R3—100-ohm pc mount trimmer potentiometer
R4—1000-ohm, 1% tolerance, 50 ppm/°C metal film resistor
R10—25,000-ohm, panel mount linear taper potentiometer
The following are ¼-watt, 5% tolerance carbon composition resistors.
R5—1000 ohms
R6, R7—100,000 ohms
R8, R9—1500 ohms
R11,R12,R13—100 ohms
R14, R15—3300 ohms
R16 through R20—470 ohms
R2:1, R1:2, R3:3, R5:4, R4:6, R7:5, R6:7 (one set for each of three decades)—330 ohms
S1—3-pole, 3-position rotary switch
T1—16-volt center-tapped transformer
Misc.—Suitable enclosure, banana jacks or binding posts for C_X terminals, printed circuit board, fuseholders, knobs, hook-up wire, IC sockets or Molex Soldercons, hardware, solder, etc.
Note—The following items are available from Dage Scientific Instruments, Box 1054, Livermore, CA 94550: CM-6 complete kit of parts, including tested IC's, cabinet, hardware, miscellaneous items, calibration capacitor, and assembly manual, $69.95 in U.S. and Canada. CM-6B partial kit includes etched and drilled double-sided pc board, 13-μH inductor, polystyrene capacitors (C18 through C21), calibration capacitor, and assembly manual for $20 in U.S. and Canada. U.S. residents add $1 postage and handling, Canadians add $2. Californians add sales tax.

or twice, resulting in four automatically selected ranges. Additional overflow pulses are displayed by two LED's located to the left of the display.

Circuit Details. Refer to the appropriate schematic (Figs. 2 through 6) for the following detailed circuit description. Free-running 555 timer *IC20* (Fig. 2) is the basic capacitance measuring circuit, comprising the comparators, reference voltages, flip-flop, and discharge transistor described previously. The timer's discharge period is used to measure the component under test. When MODE switch *S1* is in the nF position, the discharge period is determined by *R1*, *R2*, and C_X. In the μF position, the interval is determined by *R3*, *R4*, and C_X.

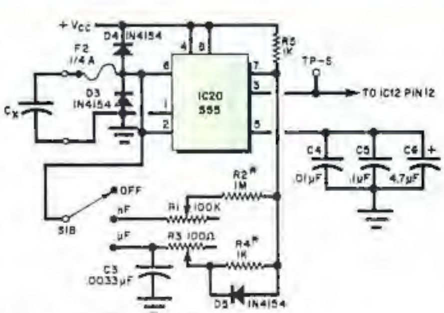


Fig. 2. Input stage has free-running 555 timer.

A second free-running 555 timer, *IC6* Fig. 3), is employed in an autocycling circuit which automatically updates the capacitance measurement. The reference frequency (about 1.4 MHz) is supplied by a Colpitts oscillator made up of IC4, L1, and *C18* through *C21*. Signals from the reference oscillator and timers *IC6* and *IC20* are combined by dual-D flip-flops *IC12* and *IC13*. One half of *IC12* synchronizes the output of *IC20* with the 1.4-MHz reference frequency, providing dual-phase (Q and $\bar{Q}$) outputs. The other half of *IC12* and *IC13* select one discharge pulse from *IC20* after the output of autocycle timer *IC6* goes high. The flip-flops disable *IC6* until the discharge pulse is completed.

The reference oscillator output is gated by *IC7* so that it passes to the counting stages during one discharge period of C_X per measuring interval. Monostable multivibrator *IC14*, when triggered by

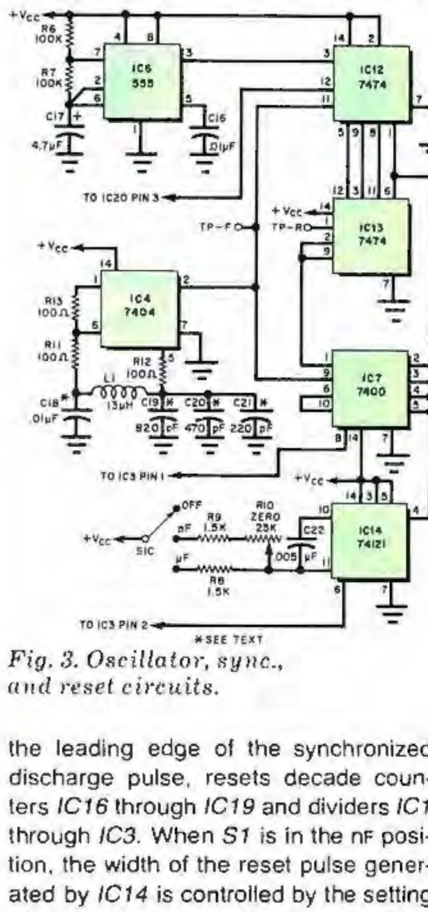


Fig. 3. Oscillator, sync., and reset circuits.

the leading edge of the synchronized discharge pulse, resets decade counters *IC16* through *IC19* and dividers *IC1* through *IC3*. When *S1* is in the nF position, the width of the reset pulse generated by *IC14* is controlled by the setting of ZERO trimmer potentiometer *R10*. This allows the user to keep stray capacitance out of the measurement.

The gated reference signal is divided by decade counters *IC1*, *IC2* and *IC3*. Output signals from these counters, at 1/1000th, 1/100th, and one-tenth the input frequency, are applied to Tri-State logic switch *IC5* (Fig. 5), which passes the appropriate pulse train to decade counter *IC19*. Overflow pulses from this BCD decade counter are applied to counter *IC18*, whose overflow pulses in turn are counted by *IC17*. Binary coded decimal outputs from these three decade counters are decoded by *IC9*, *IC10*

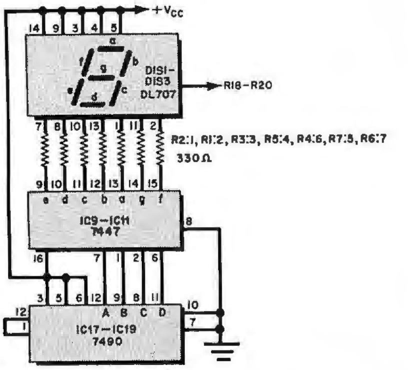


Fig. 4. Display and drivers.

and *IC11* (Fig. 4), which also drive seven-segment displays *DIS1*, *DIS2*, and *DIS3*. Current limiting for each display is performed by resistors *R2:1*, *R1:2*, *R3:3*, *R5:4*, *R4:6*, *R7:5*, and *R6:7*. (This method of identifying the resistors is discussed in the Construction section of the article.)

Now we'll examine the capacitance meter's autorange circuitry (Fig. 5). Overflow pulses from the last BCD decade counter (*IC17*) are applied to 4-bit binary counter *IC16*. This IC has four weighted binary outputs, A, B, C, and D, which are inverted by *IC15*. Lines A, $\bar{A}$, B, and $\bar{B}$ are decoded by the NAND gates in *IC8* to provide control signals for the Tri-State logic switches in *IC5* and selection of the proper display decimal point. Outputs C and $\bar{C}$ either sink or block current from overrange indicators *LED1* and *LED2*.

Assume that counters *IC17* through *IC19* have counted 999 pulses and the display reads ".999." Upon receipt of the next pulse, the decimal point is shifted one position to the right and the display reads "0.00." Tri-State switch *IC5* then passes the ÷10 reference output of *IC3* to decade counters *IC17* through *IC19*. One-shot *IC21* and *IC22* then produce a pulse which advances the most significant counter and (leftmost) display by one so that the displays now read "1.00." If necessary, this process is repeated once or twice, resulting in an autorange function of 1000:1. After the third counting sequence, the overflow pulses cycle the two overrange LED's to indicate a count of 1000 pulses.

The 7400 series IC's require +5 volts, which is provided by the projects's power supply (Fig. 6). Transformer *T1* reduces the line voltage to a convenient value. The low-voltage ac is rectified by *D1* and *D2* into pulsating dc and smoothed by *C1*. A regulated dc output at +5 volts is provided by *IC23*. Although the regulator IC can provide a 1-ampere output, the capacitance meter circuitry requires only about 700 mA.

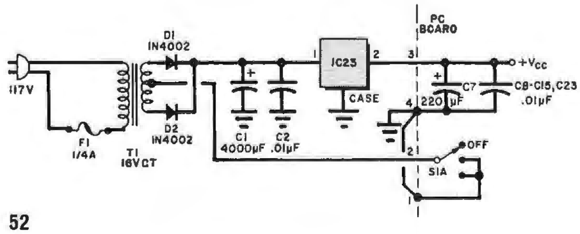


Fig. 6. Power supply circuit has a voltage regulator IC.

Construction. For the most part, the circuit is not critical and any assembly technique can be used to reproduce it. However, the measuring circuit comprising *IC20* and its associated components is critical, and should be properly shielded and decoupled from the other stages. Etching and drilling and parts placement guides for a suitable printed circuit board are shown in Figs. 7 and 8.

The pc board holds all components of the capacitance meter, less those in the power supply. It is a double-sided board on which many connections must be made between the top and bottom foil patterns. If you cannot make plated through holes, you must use wire feedthroughs to make the necessary connections. Component leads must be soldered on both sides of the board when pads are available.

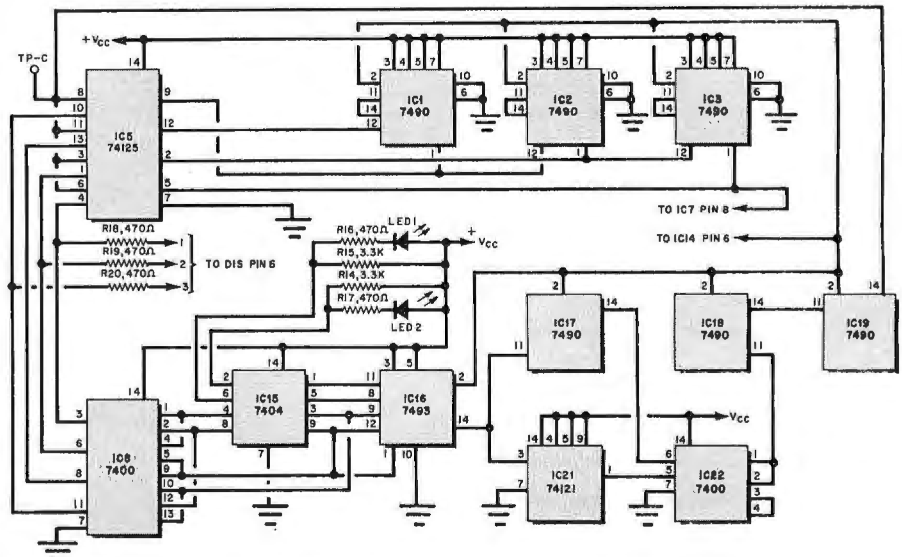


Fig. 5. Schematic of meter's autorange circuit.

Sockets or Molex Soldercons should be used to hold the integrated circuit and display packages. However, it is impossible to solder leads to pads on the component side of the board when they are under an IC socket. Because of this, all feed-through pads are accessible to the sides of the sockets. Molex Soldercons present no problem, as they can be soldered on both sides of the board. The 42 feedthrough points are identified by circles on the component placement guide (Fig. 8).

Sockets or Molex Solercons are mandatory for the LED displays and decoder/drivers. By cutting a socket lengthwise or using Molex Soldercons on the outside pin rows, as shown in Fig. 9A, a trough is provided under the displays and decoder/drivers into which the current-limiting resistors are placed. Numbering the holes from the center both up and down will allow quick resistor placement. For example, the leads of *R2:1* occupy the second hole up and the first hole down. (See Fig. 9B.) Use small, ¼-watt resistors and, where necessary, insulate leads with sleeving.

The critical components on the board are *L1*, *C18* through *C21*, which determine the frequency of the reference oscillator, and *R1* through *R4* which with *IC20* form the basic capacitance measuring circuit.

High-quality polystyrene capacitors and metal-film fixed resistors with temperature coefficients of less than 50 ppm/°C should be used. These components, together with *IC20*, will determine the long-term accuracy of the meter and measurement error as a function of temperature. If high-quality components are used and the meter is properly calibrated, its accuracy will be at least 1% at room temperature.

Checkout and Calibration. A properly functioning unit will respond as follows, and should then be calibrated. Rotate *R1*, *R3*, and *R10* fully counterclock-

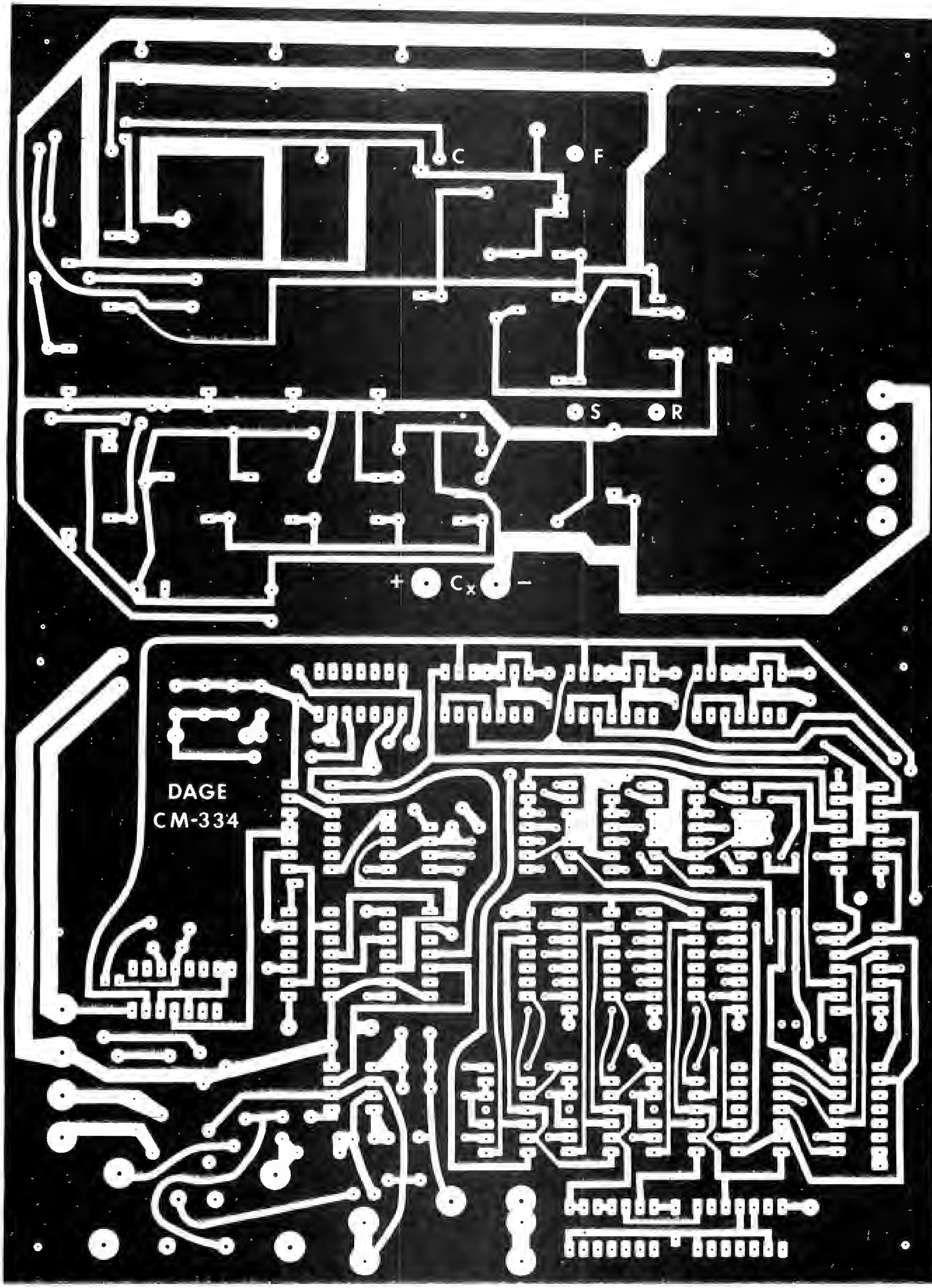


Fig. 7. Actual-size etching and drilling guides for the double-sided pc board.

wise, set *S1* to the nF position and apply power to the project. The display will light and within 2 seconds will reset to ".000." Rotate ZERO potentiometer *R10* fully clockwise. The display will indicate a few picofarads (.003 to .030 nF). Slowly rotate the ZERO potentiometer counterclockwise until the display reads ".001." Rotate the control slightly counterclockwise until it reads ".000."

Connect a reference capacitor with a known value of 0.68-µF to the C_X terminals of the meter. The display will count up for about one-half second and stop at some value which is not critical at this

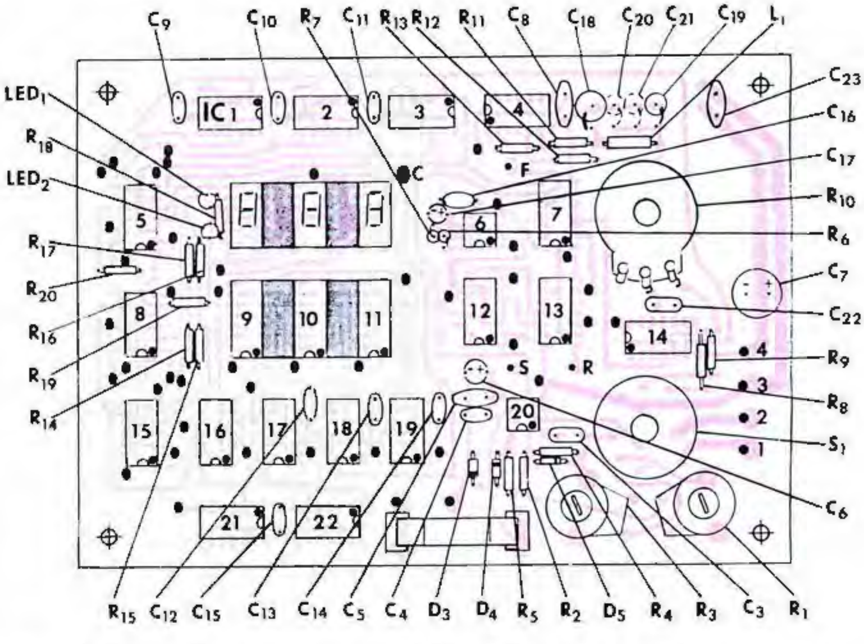


Fig. 8. Component placement guide. Numbered circles are feedthroughs.

time. Place *S1* in the μF position. The display will read a similar value, but will not appear to flicker. Finally, place a 5000-to-8000-μF capacitor across the C_X terminals. Within a few seconds, the display will advance and the overrange LED's will cycle top on only, bottom on only, both on, both off, and repeat the sequence. The meter is now ready for calibration.

The most direct method of calibration is to measure a reference capacitor whose value is about 0.7 μF. A precision capacitor will be very expensive, so if you have access to a precision (0.1% or better) capacitance bridge, measure the value of a good-quality Mylar capacitor on it. If the capacitor is used at approximately the same temperature as the bridge environment, it will be a suitable reference component.

The 0.7-μF capacitor will be used as a reference for both the nF and μF switch positions. Setting one point for each position is all that is required, as absolute linearity is provided by the project circuitry. The reference oscillator's mean output frequency is designed to be slightly high when only *C18* and *C19* are included in the circuit. If trimmer potentiometers *R1* and *R3* cannot be adjusted to bring the display reading into agreement with the value of the reference component, install *C20* and/or *C21*. Calibration is now a matter of merely connecting the reference capacitor to the C_X terminals, placing *S1* in the μF position, and adjusting *R3* until the display matches the value of the reference component. Then, *S1* should be placed in the nF position and *R1* adjusted for the same displayed capacitance.

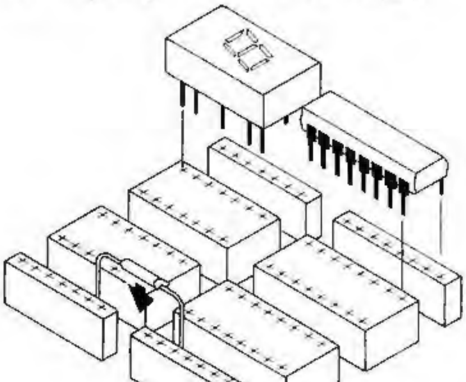
Using the Meter. Apply power to the project by placing *S1* in the nF position. Zero the display by slowly rotating the shaft of *R10* counterclockwise until the display reads, ".001," advancing the control slightly more until a ".000" reading is obtained. Once zeroed, no further adjustments are necessary. The μF position does not require zeroing.

Connect the capacitor to be measured across the C_X terminals. Polarized capacitors must be oriented positive to positive, negative to negative. Do *not* connect charged capacitors to the project. Although the input circuitry is protected with clamping diodes and a fuse, charged capacitors might damage the project.

Capacitance is displayed in either nF or μF, depending on the setting of *S1*. Values greater than 1000 nF should be read in the μF position. Capacitance greater than 1000 μF is determined by observing the overrange LED's to the left of the display. Because these two LED's cycle every ⅔ second, they are easily observed. If the top LED glows, 1000 μF is indicated; if the bottom LED glows, 2000 μF; if both, 3000 μF.

This sequence will then repeat, with two dark LED's representing 4000 μF; the top LED glowing, 5000 μF; the bottom LED, 6000 μF; both on, 7000 μF; both dark, 8000 μF; and so on until the cycling stops. Values up to several thousand microfarads can be measured. The upper limit is determined mainly by capacitor leakage, and to a lesser extent by your patience! Capacitors, with high leakage will never charge to V_{REF}, and thus will not trigger the discharge cycle.

When using the capacitance meter with *S1* in the nF position, treat the reading as if it were in picofarads if the decimal point is to the left. That is, ".084" should be read as 84 pF, and ".003" as 3 pF. With a little experience, you will quickly become familiar with the autorange function and the behavior of the overrange LED's. ◇



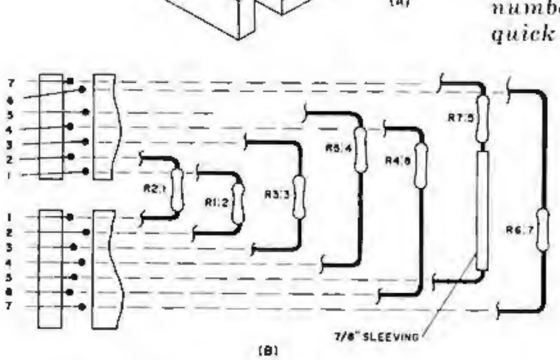


Fig. 9. A trough is provided for the current-limiting resistors as shown in (A). Diagram at (B) shows how numbering the holes allows quick resistor placement.