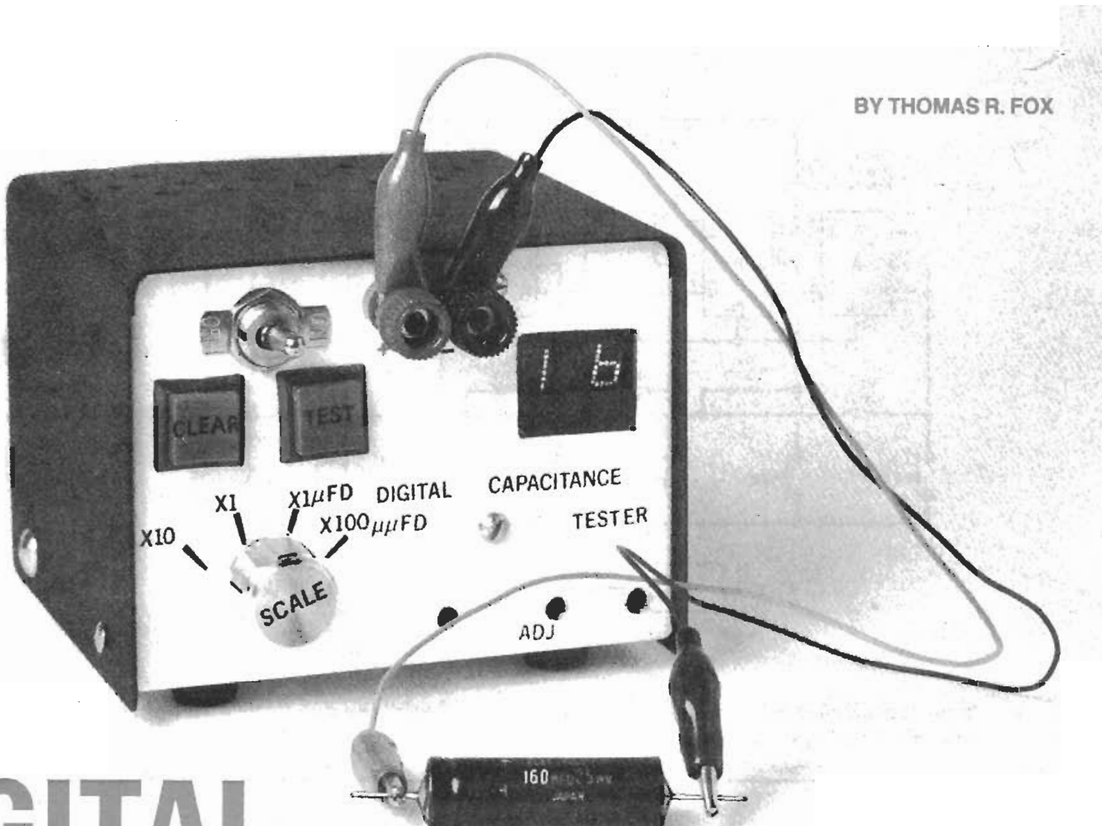
BY THOMAS R. FOX



DIGITAL CAPACITANCE METER

Provides digital display of capacitance from 100 pF to 1000 μF.

CAPACITORS are almost as numerous as resistors in many electronic circuits. Yet, while most of us have ohmmeters we can use to check resistor values readily, very few have instruments that check capacitor values. Although, in most cases, the actual capacitance value is not important, there are some circuits—time bases, oscillators, etc.—where the actual value of a capacitor can be very important.

The Digital Capacitance Meter described here is a simple, low-cost instrument that can be used in much the same manner as an ohmmeter to check the values of capacitors. It has a two-digit display and a measurement range from 100 pF to 1000 μF. To use it, you simply connect the capacitor to be measured between a pair of binding posts and press a button. The value of the capacitor is then indicated in the display. All test potentials are less than 2 volts. The instrument even has a low-battery alert (if it is battery powered); when the potential supplied by the battery falls below 4.5 volts, the display indicates 00.

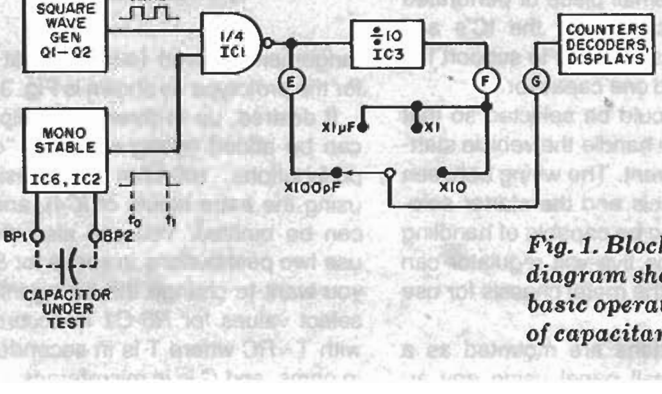


Fig. 1. Block diagram shows basic operation of capacitance meter.

Circuit Operation. The basic operation is illustrated by the block diagram shown in Fig. 1, while the complete schematic diagram is shown in Fig. 2.

Transistors *Q1* and *Q2* are arranged to form a free-running multivibrator square-wave generator that operates at about 1 kHz. The square-wave output forms one input for a two-input NAND gate (part of *IC1*), while the other gate input comes from a timer circuit consisting of *IC6* and two gates of *IC2*. The length of time that the *IC6* output is at "1" is determined by the value of the unknown capacitor connected between binding posts *BP1* and *BP2*, and the timing (range) resistor selected by one section of *S3*. With the timing resistor fixed, the time period is then proportional to the unknown capacitor value. The output of the NAND gate drops to zero only when both inputs are positive. Because the 1-kHz square waves are now gated by the timer duration, only the amount of

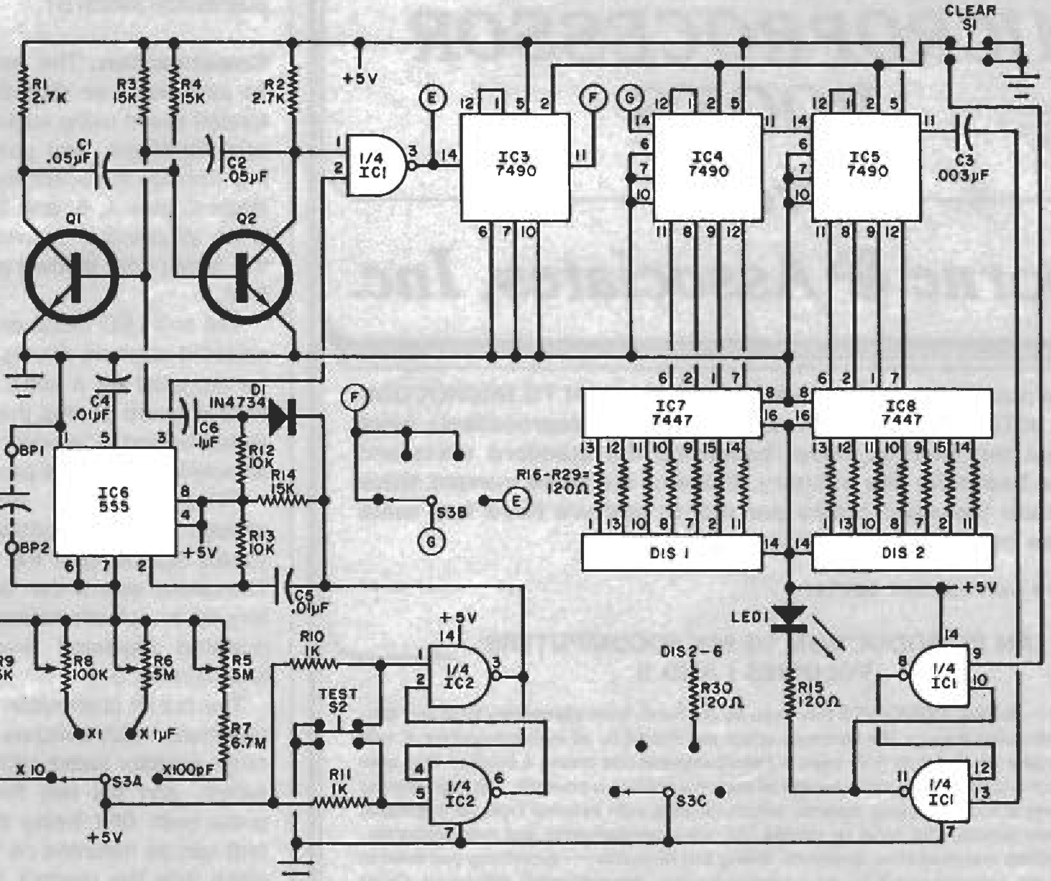


Fig. 2. Transistors Q1 and Q2 generate the 1-kHz square-wave input to IC1. The other input comes from IC6 and two gates of IC2. The output of decade counter IC3 is determined by the length of the second input.

PARTS LIST

BP1,BP2—5-way binding posts, one red, one black
C1,C2—0.05-μF Mylar or polystyrene capacitor
C3—0.003-μF capacitor
C4,C5—0.01-μF capacitor
C6—0.1-μF capacitor
D1—1N4734 diode or similar
DIS1,DIS2—Common-anode 7-segment LED (SLA-7 or similar)
IC1,IC2—7400 quad two-input NAND gate (TTL)
IC3,IC4,IC5—7490 decade counter (TTL)
IC6—555 timer
IC7,IC8—7447 BCD to 7-segment decoder (TTL)
LED1—Red LED
Q1,Q2—2N388 transistor or similar
R1,R2—2700-ohm, ¼-W resistor
R3,R4—15,000-ohm, ¼-W, 5% resistor
R5,R6—5-megohm trimmer potentiometer
R7—6.7-megohm, ¼-W resistor
R8—100,000-ohm trimmer potentiometer
R9—5000-ohm trimmer potentiometer
R10,R11—1000-ohm, ¼-W resistor
R12,R13—10,000-ohm, ¼-W resistor
R14—15,000-ohm, ¼-W resistor
R15 through R30—120-ohm, ¼-W resistor
S1,S2—spdt pushbutton switch
S3—3p4t rotary switch
Misc.—Suitable enclosure, knob (1), rubber feet (4), battery holder (if used), line cord (if used), mounting hardware, etc.

gated pulses can be counted by the following decade counter *IC3*. The output of this counter is a gated 100-Hz signal. Selector switch *S3* allows the choice of bypassing this decade counter when *S3* is in the 100-pF position.

The selected gated pulses are fed to a pair of conventional decade counter/seven-segment LED drivers, and their associated readouts. The two-digit display can handle a count up to "99", and if the 100th count is reached, the output pulse from *IC5* is coupled via *C3* to a flip-flop consisting of two gates of *IC1*. When this flip-flop operates, it turns on the OVER indicator LED. If desired, this discrete LED can be replaced by one of the colon points in the second decade

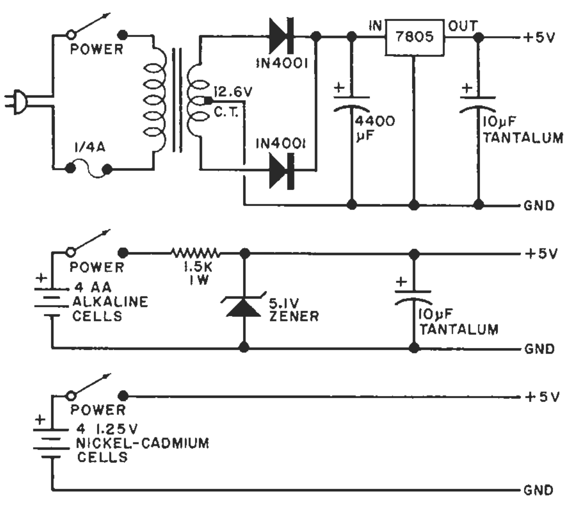


Fig. 3. Shown are three possible designs for the meter power supply.

counter. The system is reset to zero by pushbutton switch *S1*.

Construction. The basic circuit can be assembled on a small piece of perforated board using sockets for the IC's and transistors, and point-to-point wiring. Arrange the board layout so that the leads to pins 1, 6, and 7 of *IC6* are as short as possible between the IC and the front-panel binding posts *BP1* and *BP2*.

The two LED readouts, and their associated segment drivers (*IC7,IC8*) may be mounted on a separate small perforated board so that they can be positioned behind a "window" cut out of the selected chassis front panel.

Select a metal enclosure large enough to accommodate the two electronics boards, plus the power source. The power source can either be a battery set in a plastic holder, or an ac line-powered regulated 5-volt supply as shown in Fig. 3.

The CLEAR pushbutton (*S1*) and TEST pushbutton (*S2*) switches, along with the range selector switch (*S3*), power on/off switch, and the two five-way binding posts (with *BP1* being black and *BP2* red) can be mounted on the front panel along with the readout "window". The power line cord (if used) can exit via a grommetted hole on the rear.

Calibration. The ranges are 10,000 pF, 1 µF, 100 µF, and 1000 µF all full scale. For most purposes, 5% dipped silver-mica capacitors may be used for calibrating the two lower valued ranges, and 10% capacitors will suffice for the two higher ranges.

To calibrate a range, select a capacitor whose nominal value is near the middle of that range. For example, use a 5000-pF unit for the 10,000-pF range, and connect this capacitor between *BP1* and *BP2*. Turn on the tester power and note that the two displays illuminate. Depress the CLEAR pushbutton and the two readouts should indicate "00". Keep the TEST pushbutton depressed until the display comes to a rest, then adjust *R5* for the correct displayed value. The OVER indicator comes on when the unknown capacitor has a value that is larger than that selected by *S3*, so use the next higher range if this occurs.

An open capacitor will produce a "00" indication, while a "leaky" capacitor will indicate a much larger value than that marked on its case and a shorted capacitor will cause the display to keep counting without a reading even though the range switch is correct. ◇

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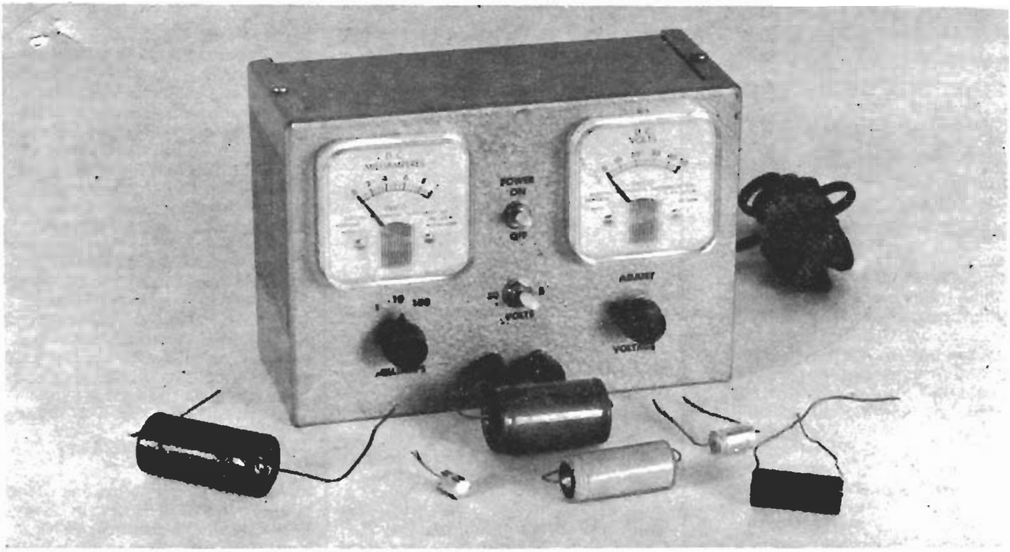
CIRCLE NO. 62 ON FREE INFORMATION CARD

Out of Tune

In "Digital Capacitance Meter" (April 1977), one end of *C3*, in Fig. 2, should be connected to pin 9 of *IC1*, not pin 13 as shown. The normally open contact of *S1* should be connected to pin 13 of *IC1*, not pin 9 as shown. Also, at the center of Fig. 3, the 1.5-k resistor should be 1.5 ohms. The second lowest range measures capacitances from 0.01 to 0.99 μF. When the switch is placed in this position, it automatically inserts a decimal point in the proper location and the display gives the capacitance directly in microfarads.



Electrolytic Leakage Checker

Leaky electrolytics change transistor bias and foul up electronic circuits.

By VICTOR KELL

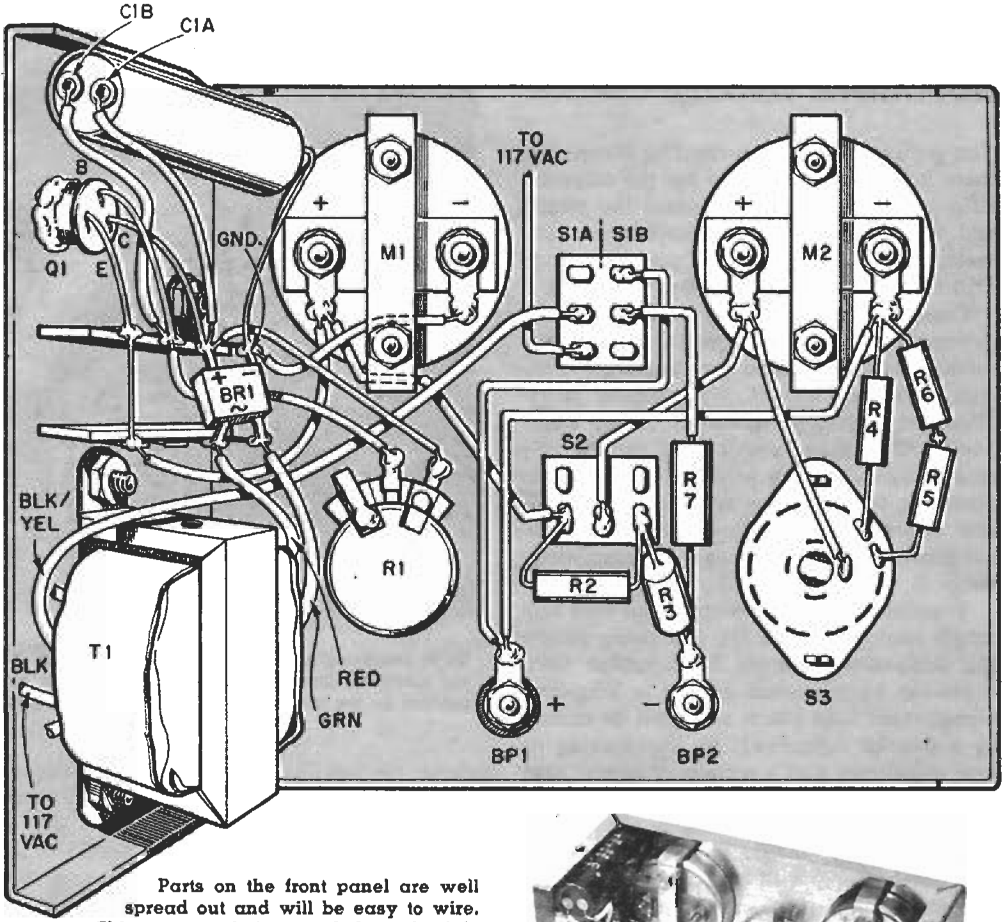
CAPACITOR problems once could be solved easily—in the days of vacuum-tube equipment, that is. Nine times out of ten the trouble was a bad electrolytic filter capacitor which gave itself away with hum from the speaker, bars in a TV picture or severe audio distortion.

But solid-state equipment is different. Because of low transistor bias currents, just a slight excess current leakage through what appears to be a good capacitor is all it takes to completely disable a circuit. The higher the transistor's gain the more prone it is to this type of failure. As examples of allowable tolerances, a 320 μa leakage current in a 1-μf coupling capacitor is sufficient cause for rejecting the capacitor. A leakage current of 600 μa rejects a 25-μf capacitor. And that big 2,000-μf transistor-amplifier output capacitor has a limit of only 10 ma maximum leakage. Admittedly, these limits often are many times greater than the leakage that will disable a solid-state circuit, but they illustrate how low the acceptable limits are.

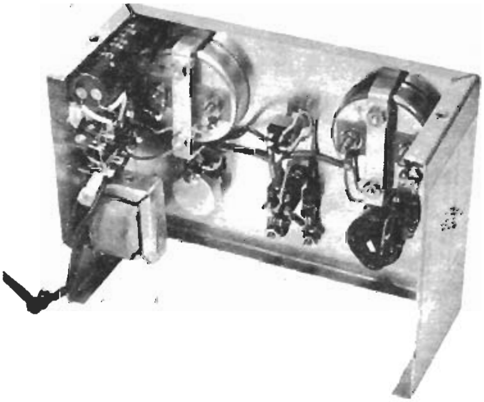
With our leakage checker you can be certain that the capacitors used for projects and service are within the test limits. The checker tests capacitors under voltage as they will be used in a circuit—from 0 to 50 VDC. And the checker can be used to troubleshoot defective capacitors in existing equipment. Finally, the checker can be used to re-form large capacitors that have been sitting on the shelf for ages, thereby avoiding the possibility of their developing high leakage current through the sudden application of full operating voltage.

As shown in the schematic, the checker consists of a transistor-regulated 0 to 50-VDC power supply, which is well filtered to prevent AC ripple from giving inaccurate indications. To provide precise voltage adjustments, and so a large variation in the adjustment of potentiometer R1 will produce a small change in test voltage, there are two output-voltage ranges. These are 0 to 5 and 0 to 50 V and are selected by range switch S2. Meter M2 indicates the leakage current of the capacitor connected to test terminals BP1 and BP2. Meter M1 indicates the test voltage. It is a 50 VDC meter and you should understand that the zero is dropped off the scale when operating on the 5 range. For example, with S2 in the 5-V position, an indication on M2 of 30 means 3 V.

To avoid getting a shock when removing



Parts on the front panel are well spread out and will be easy to wire. Things are a little crowded on the left. Leave transformer to last so it won't be in your way. Note that transistor Q1 is mounted on side of cabinet with epoxy; photo on next page shows how.



the capacitor from the binding posts, S1B shorts the capacitor under test through R7, a low-value resistor, when the checker is switched off.

Note in the schematic and photographs that M2 is provided with a 100-ma range. While no capacitor you will test will have 100-ma leakage unless it's internally shorted, the 100-ma range protects M2 against shorted capacitors and against damage when testing large value capacitors of 100 μf and higher. Large capacitors pull a very heavy surge (charge) current when the test voltage is first applied.

Construction

The tester is built on the main section of a 7 x 5 x 3-in. Minibox. The layout is not at all critical and just about any arrangement will work; the layout shown in the pictorial, however, makes for easy assembly.

Except for T1 and M1, make no substitutions as the component values are selected for the Q1 and M2 specified in the Parts List. Transformer T1 can be any type with a 40-V, 20-ma (or higher) secondary while M1 can be any 50 VDC meter. Meter M2 cannot be substituted for as meter shunts R4, R5 and R6 are selected for the internal resistance of M2. Resistor R7, the discharge resistor, can be a 1-watter between 15 and 27 ohms.

First step is to temporarily mount the meters and then mark the position for the power-supply components on the left panel.

Electrolytic Leakage Checker

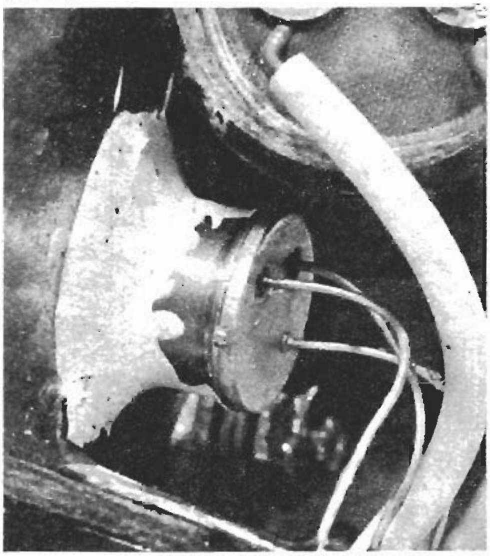
The meters must be mounted to insure that there is sufficient clearance for the terminal-strip lugs and C1. Then remove the meters and install all cabinet components. The meters may be damaged if you attempt to drill holes with them secured to the panel.

Double check S1's connections before soldering the wires to it. When the power terminals (S1A) are open the discharge terminals (S1B) are closed. When power is applied the discharge terminals (S1B) open. Meter M2's shunt switch, S3, can be any rotary type that will provide at least three positions; two positions are used for the 10- and 100-ma ranges while the unused terminal provides the 1-ma range—the basic meter range.

Transistor Q1 should be installed with full-length leads. Through Q1 can easily handle the dissipation required by capacitor tests, it should be protected against a long-term high-current load (such as would be caused by a shorted capacitor), by heat-sinking its case to cabinet. Cut a section of plastic tape about ½-in. square and coat one side with epoxy cement. Place the epoxy-coated side on the cabinet near Q1. Then coat the other side of the tape with epoxy and bend Q1 down so the top of the case is in the epoxy—the case should be resting against the tape. With a toothpick or Q-tip, spread the epoxy up the sides of Q1's case as shown in the photo. When the epoxy dries Q1 will be cemented and heat-sinked to the cabinet, yet the tape will insulate Q1 from the grounded cabinet.

Checkout

Connect a VOM or VTVM set to read greater than 50 VDC to BP1 and BP2. Set S2 to the 50-V position and S3 to the 100-ma position. Apply power by closing S1. With R1 in the off—full counterclockwise—position, both meters should indicate zero. If either meter indicates anything other than zero there is a wiring error. Slowly advance R1; both the VOM (or VTVM) and M1 should indicate an increasing voltage as R1 is advanced. Both meters should indicate the same voltage within the normal tolerance of a few volts. There should be no indication on M2 at this time. If M2 does indicate a current flow shut the checker down instantly and check for a wiring error. When R1 is full clockwise both M1 and the VOM should indicate the full test voltage of 50 V, or slightly higher depending on the particular T1 you use.



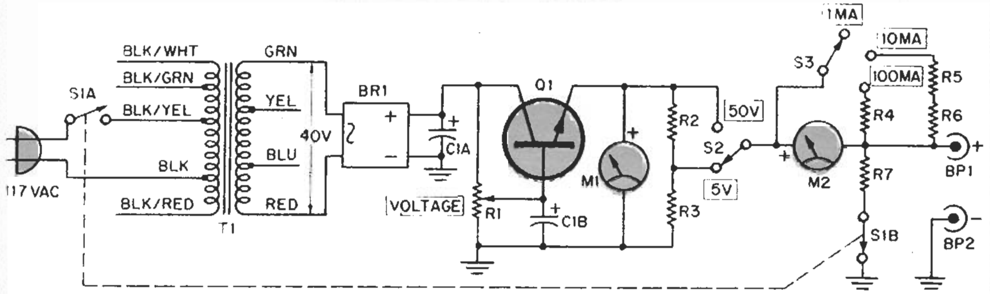
Q1 is cemented to side of cabinet with epoxy. But put electrical tape between top of transistor and cabinet so the transistor case won't be grounded.

Set R1 to off, then S1 to off. Set S2 to the 5-V range. Apply power and advance R1. The VOM and M1 should indicate a voltage range of from 0 to 5 V as R1 is advanced. Again, there should be no indication on M2.

Using the Checker

It is most important that R1 be set to off—full counterclockwise—when the checker is turned either on or off. Applying power with R1 advanced and a capacitor connected to the binding posts can destroy the capacitor if R1 is set to a higher test voltage than the capacitor's maximum rated voltage. Switching S1 to off with R1 advanced can cause excess current through Q1 and M2 because R7 is switched across BP1 and BP2 when S1 is set to off. Remember, *tests are started and completed with R1 in the off position.*

Observing polarity, connect a capacitor to BP1 and BP2. Set S1 to on and S2 to the correct voltage and S3 to the 100-ma range. Very slowly advance R1 until M1 indicates the capacitor's rated voltage. As voltage is applied M1 will indicate a relatively high current as the capacitor charges—almost 100 ma on very large capacitor. Within a few seconds M2's indication will fall sharply, showing the capacitor has reached



Capacitor under test is connected to BP1, BP2. S2 sets voltage range for test and R1 is used to get exact voltage, which is indicated on M1. M2 indicates leakage current after the capacitor charges.

PARTS LIST

BP1,BP2—Insulated binding post
BR1—Full-wave bridge rectifier: 1 A, 200 PIV (Motorola HEP-176)
C1A,C1B—20/20 μf, 150 V dual electrolytic capacitor
M1—0-50 V DC voltmeter (Emico Model RF-2¼C, Allied 52 C 6097)
M2—0-1 ma DC milliammeter (Emico Model RF-2¼C, Allied 52 C 8012)
Q1—2N2405 transistor (RCA)
Resistors: ½ watt, 10% unless otherwise indicated
R1—50,000 ohm linear-taper potentiometer
R2—4,700 ohms
R3—470 ohms
R4—10 ohms, 5%
R5—39 ohms, 5%
R6—56 ohms, 5%
R7—22 ohms, 1 watt (see text)
S1—DPDT toggle or slide switch
S2—SPDT toggle or slide switch
S3—SR triple-throw rotary switch (see text)
T1—Low-voltage rectifier transformer; secondaries: 10-20 V center tapped and 40 V center tapped @ 35 ma (Allied 54 C 4731)
Misc.—7 x 5 x 3-in. Minibox, terminal strips

full charge. Then switch S3 to the 10- or 1-ma range and note the current.

The chart shows the maximum allowable leakage current for commonly-used capacitor values in the 0 to 100-VDC range. If the capacitor under test indicates higher leakage current than the value shown, it should be rejected.

After about 20 seconds a good capacitor should settle down and the leakage current will indicate a rock-steady value. If the leakage current pulses you can safely suspect the capacitor will give trouble at a later date. Large value capacitors, however (more than 1,000 μf) have a tendency to pulse very slightly, perhaps one meter scale division, and this should be accepted as normal.

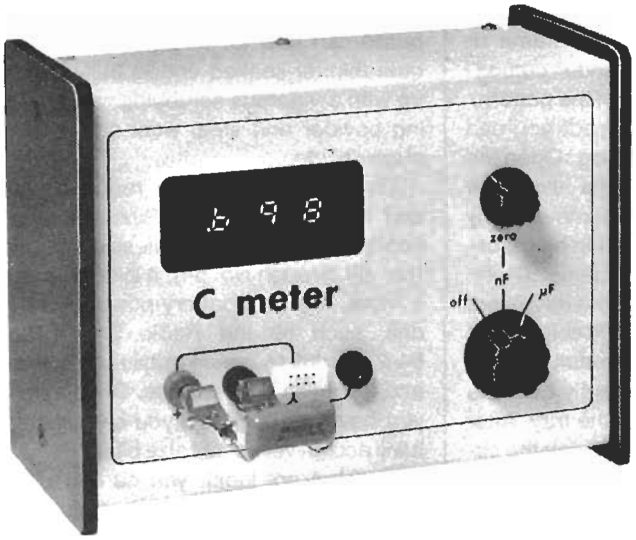
Capacitors can be re-formed by slowly increasing applied voltage over a relatively long time period. For example, assume you want to use a 50-V capacitor that has been sitting on the shelf for several years. Connect the capacitor to the binding posts and apply a low voltage, say, 5 V. When the leakage current has settled down to a constant value increase the applied voltage to 10. Again, after the leakage current maintains a constant value increase the applied voltage further, repeating the procedure until the capacitor's rated voltage is reached.

Note that it is normal for any capacitor to show a large but brief increase in leakage current whenever the applied voltage is increased—no matter how small the increase. This current surge is the capacitor charging and not leakage. For example, a 30-μf capacitor being tested at 10 V might show 0.1-ma leakage. Increasing the test voltage to 12 V can cause the M2 indication to rise sharply 1 ma, but it will quickly fall back to the true leakage value. Do not be fooled into thinking the charging-current pulse is the capacitor's leakage.

To make using the checker as easy as possible we suggest you cement a copy of the leakage chart below on the side of cabinet.

LEAKAGE-CURRENT LIMITS
(3-100 VDC)

Capacitance (μf)	Current (ma)	Capacitance (μf)	Current (ma)
1	.31	100	1.3
2	.32	125	1.55
5	.35	130	1.6
10	.4	150	1.8
20	.5	200	2.3
25	.55	250	2.3
30	.6	500	5.3
40	.7	1,000	10.0
50	.8	1,500	10.0
70	1.0	2,000	10.0
80	1.1	3,000	10.0



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:

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

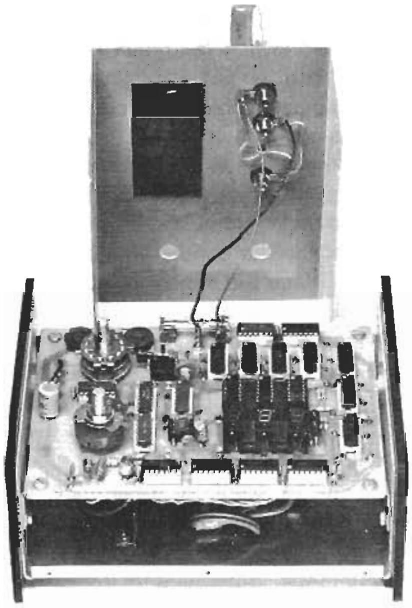
where V_O is the voltage across the capacitor when fully charged, R the resistance in ohms, C the capacitance in farads, t the time in seconds, and e the exponential constant or base for natural logarithms (approximately equal to 2.718). If we let a capacitor that has charged to a known voltage discharge 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.



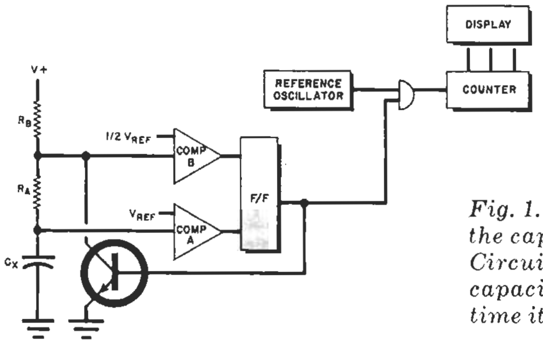


Fig. 1. Block diagram of the capacitance meter. Circuit determines unknown capacitance by measuring time it takes to discharge.

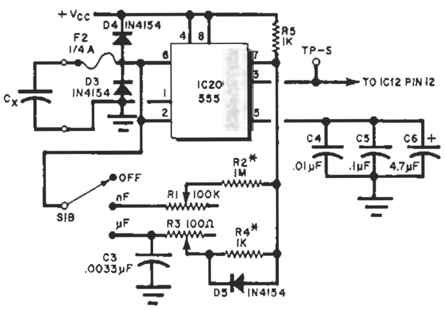
PARTS LIST

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-68 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.

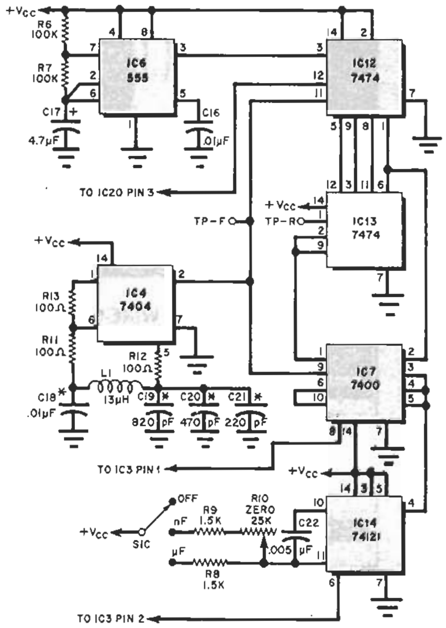


* CLOSE-TOLERANCE COMPONENTS

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 Q̄) 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 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.



*SEE TEXT

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

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*

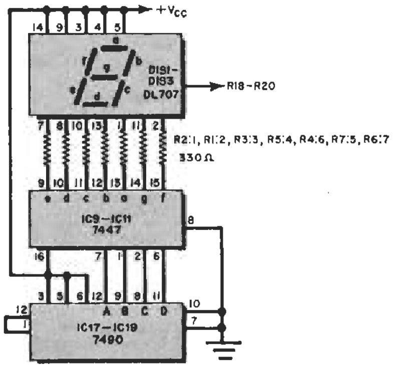


Fig. 4. Display and drivers.

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, $\overline{A}$, B, and $\overline{B}$ 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 $\overline{C}$ 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.

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.

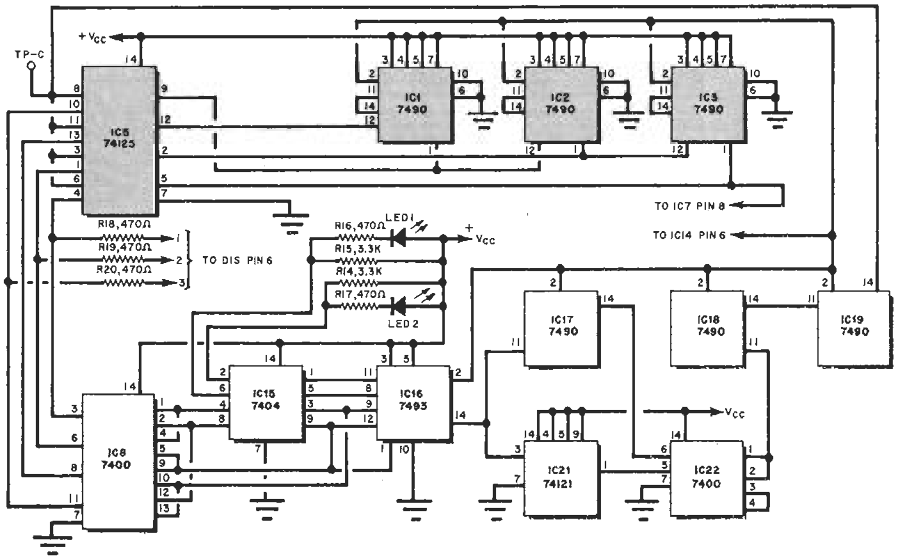


Fig. 5. Schematic of meter's autorange circuit.

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.

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).

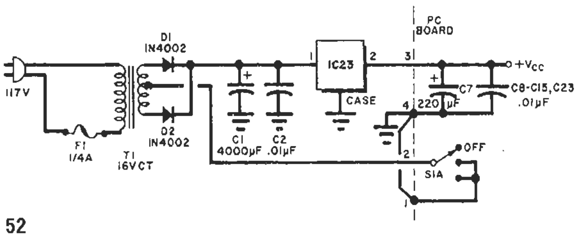


Fig. 6. Power supply circuit has a voltage regulator IC.

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-

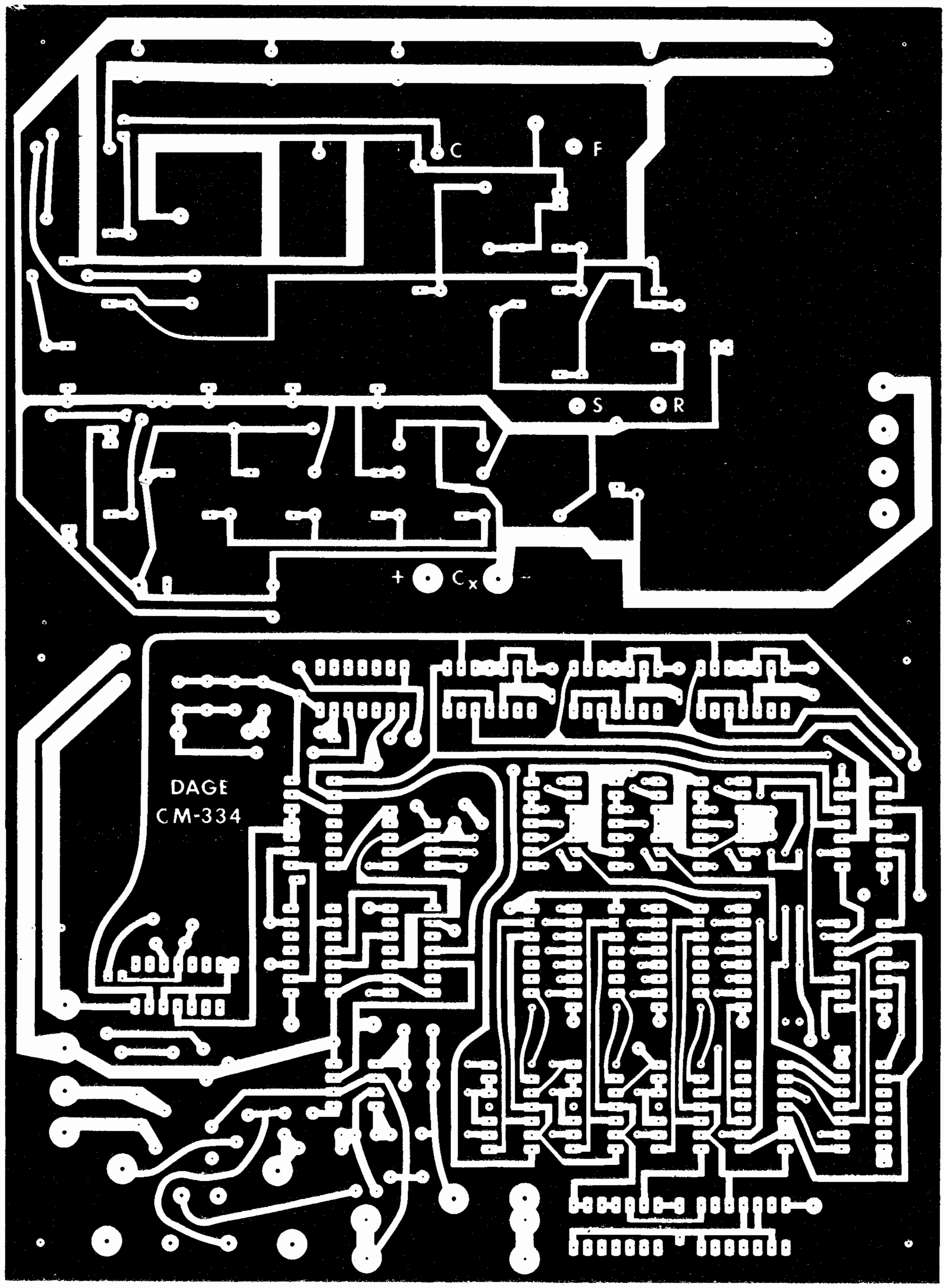


Fig. 7. Actual-size etching and drilling guides for the double-sided pc board.

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 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.

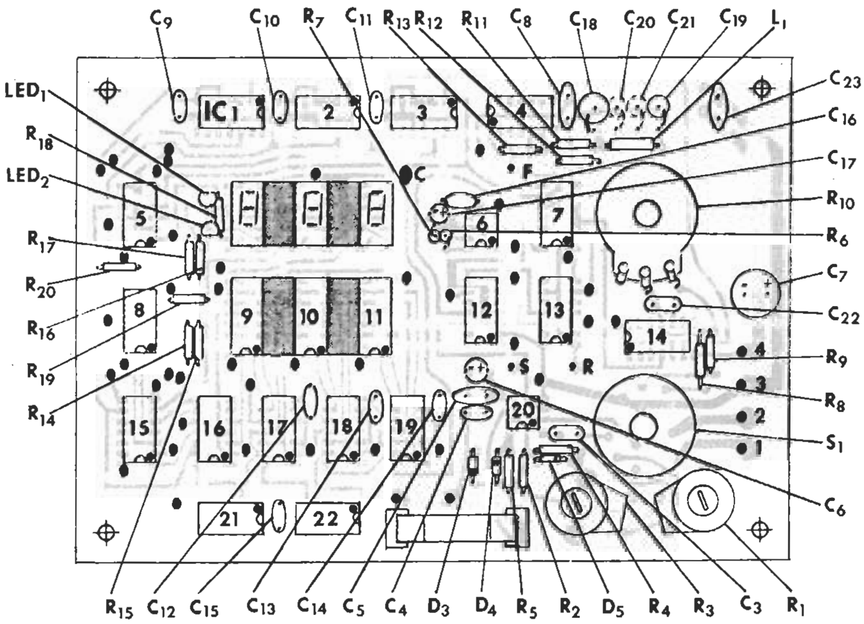


Fig. 8. Component placement guide. Numbered circles are feedthroughs.

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.

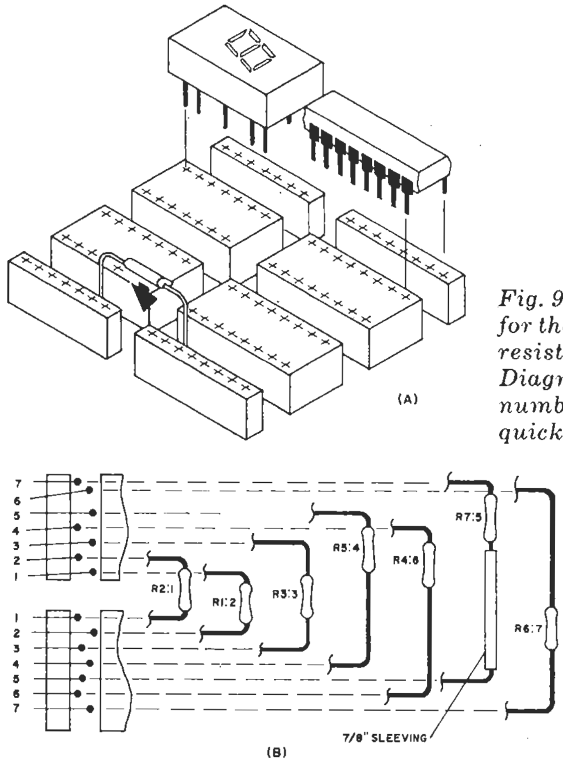


Fig. 9. A trough is provided for the current-limiting resistors as shown in (A). Diagram at (B) shows how numbering the holes allows quick resistor placement.

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.

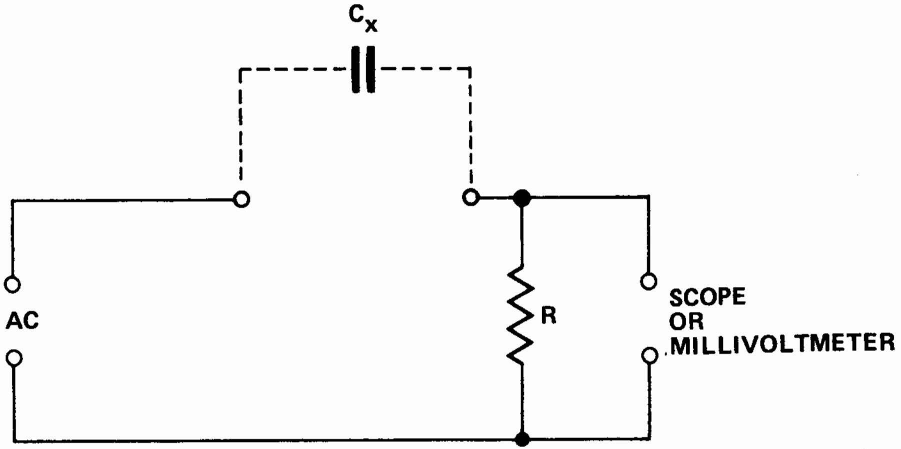
When using the capacitance meter with *S1* in the nF position, treat the reading as if it were in picofarads if the decimal point is to the left. That is, ".084" should be read as 84 pF, and ".003" as 3 pF. With a little experience, you will quickly become familiar with the autorange function and the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

Capacitance Measurement

W. Winder

Few amateurs have a reliable method for measuring small capacitors. They may have a 50 Hz bridge, but the reactance of 10 pfs. at 50 Hz is some 320 megohms, which can well be of the same order as the bridge insulation, which leads to indeterminate and incorrect results. However if one has an A.F. signal generator and a measuring oscilloscope (or a.c. millivoltmeter), one can measure down to 2 or 3 pfs. with quite as good an accuracy as more complicated methods using square wave generators and diode pumps. The following very simple circuit is all that is necessary.

As long as the reactance of the capacitor is several times larger than the resistance of R, the output voltage will be directly proportional to the capacitance of C. By supplying a 1.6 volt input signal, the mathematics are simplified, and the output measurements are as the table given below.



Capacity Range	Input Frequency	Value of R	Output
0 to 20 p	100 kHz	10 k	10 mV, per p
20 to 200 p	10 kHz	10 k	1 mV per p
200 to 2000 p	1 kHz	10 k	0.1 mV per p
2000 to 20,000 p	1 kHz	1 k	0.01 mV per p
0.02 to 0.2 µF	1 kHz	100 R	0.001 mV per p

The input wave form should be fairly good, as any harmonics present are exaggerated by the capacitor, and the shape of the output waveform can be anything but a pretty sine wave. However it has to be a poor signal generator that does this.

LR oscillator indicates inductance directly

by John Jamieson
Technical Analysis Corp., Atlanta, Ga.

Inductance measurements accurate to within ±10% may be made simply if the inductor is connected into the frequency-determining portion of this low-cost LR oscillator. Component values have been selected so that the oscillator's period, in seconds, equals 0.01 times the coil's inductance in henries, over the range from 0.5 millihenry to at least 10 H. Thus the inductance can be read directly from a period/frequency counter connected to the circuit's output.

A_1 of the TL084 operational amplifier serves as the integrator in the basic oscillator, with A_2 a Schmitt trigger having trip points at one sixth and five sixths of the supply voltage and A_3 a 1-to-20 voltage divider. A_4 derives a voltage reference equal to half the supply voltage for driving A_1, A_2, and A_3.

A_3 delivers a current into A_1 of magnitude $i_L = (1/L)\int V_L dt$, where V_L is the initially negative output voltage of A_3 and L is the inductance under consideration. As a consequence, the output of A_1 is a ramp of voltage $V_o = RV_L t/L$, where resistor R controls the gain of the stage, and t is time. Thus V_o rises linearly until A_2's trigger point is reached, whereupon it switches and brings V_L high so that V_o begins to decrease linearly. The cycle is repeated when the Schmitt's lower threshold point is reached.

Selecting the period of oscillation to fall in the area of $t = \tau/4$, it is seen that $V_o = (RV_L\tau)/(4L)$, or $L = (RV_L\tau)/(4V_o)$. Because $V_L \approx V_o/13$, then $L \approx R\tau/52$. With R adjusted so that $R/52 = 100$, $L = 100\tau$.

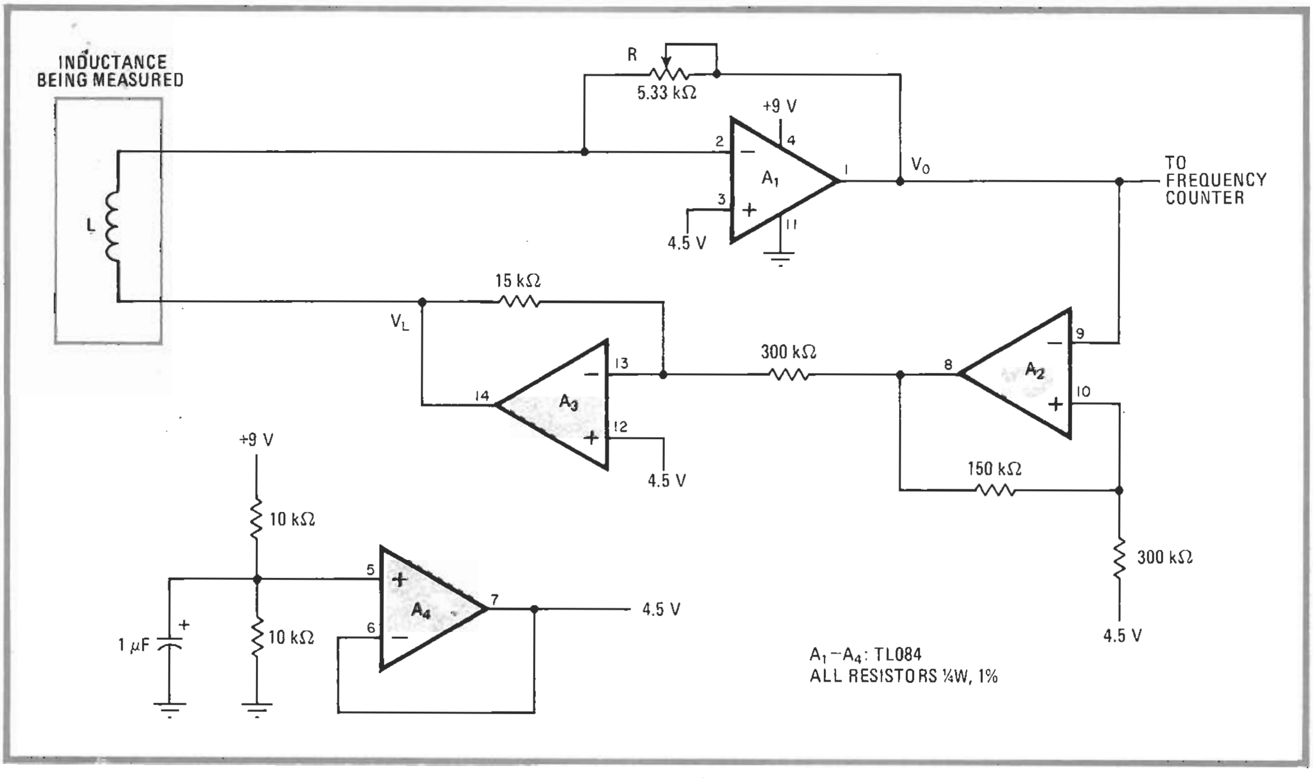
The preceding analysis assumes that the ohmic resistance of the inductor is small. For each ohm of resistance present below 10 Ω, there will be an approximate decrease of 0.1% in the accuracy of the measurement.

For inductors with considerable resistance, it will be noted that:

$$i_L = (1/L)\int V_L(1 - e^{-R_L t/L})dt$$

where R_L is the resistance of the inductor, and so it can be shown that $L = (-R_L\tau/4)\log_e(0.9975R_L)$. Thus to find the inductance, it is necessary to measure its resistance, R_L; place the inductor in the circuit; and note the frequency of oscillation, τ. L may then be calculated. □

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.



Self-measuring. Inductance of low-resistance coils is measured to within ±10% by noting frequency of LR oscillator of which the inductor is a part. Frequency counter may be used to indicate inductance directly, since period of oscillator, in seconds, is 1/100 of the inductance value in henries. Procedure is slightly modified for inductances having high impedance, most of which is ohmic for units having low hysteresis.

BY JAMES BARBARELLO AND EDWIN IRIYE

Inexpensive, accurate instrument measures inductance from 1 microhenry to 1 henry as well as capacitance

BUILD THE Reactance Measuring Set

NOW you can measure the inductance of coils and loudspeaker windings without resorting to expensive laboratory instruments. The Reactance Measuring Set (RMS) presented here will measure inductance from 1 microhenry to 1 henry, using any multimeter as a readout device. Furthermore, capacitance from 1 picofarad to 1 microfarad can be determined.

Accurate, stable, and easy to build, the RMS project uses a measurement technique based on the relationships between currents flowing through and voltages appearing across reactive components. The resulting measurements are not influenced by any effective or internal resistances of the components under test. Moreover, the RMS can be aligned without using a precision reference standard. As a bonus, it can function as a crystal-controlled frequency standard. No batteries are needed, thanks to the presence of an internal, line-powered supply.

Measuring Reactors. The voltage drop across a pure inductance is directly proportional to the rate at which the magnitude of the current flowing through it changes with time. Mathematically, this is expressed by the differential equation: $v = L\,di/dt$. If a current that has a constant rate of change flows through the inductor, the voltage drop across it will be constant. Similarly, if the waveform of the current that flows through the inductor is a triangle, the resulting voltage is a square wave.

The current that flows through a pure capacitance is directly proportional to the time rate of change of the voltage across it ($i = C\,dv/dt$). If a voltage with a constant rate of change is applied across the capacitance, a current of constant magnitude flows through it. Similarly, if the waveform of the voltage that is applied across the capacitor is a triangle, a square–wave current flows through it.

Now let's look at a block diagram of the RMS (Fig. 1). A triangle-wave voltage source is the heart of the measurement circuit. It drives both a voltage-dependent current source and a buffer/voltage-to-current converter stage. The former generates a triangle-wave current which is applied to an inductance whose value is to be determined (L_X). If a value of capacitance is to be measured, a triangle-wave voltage is applied across

the component under test (C_X). Conversion of the current through the unknown capacitance into a voltage by the latter stage means that a voltage is applied to the demodulator stage via *S3B* whether an inductance or a capacitance is being measured.

Two basic parameters of the signal generated by the triangle voltage source must be closely controlled if accurate measurements are to be obtained—its amplitude and its period. An agc stage monitors the peak-to-peak amplitude of the triangle voltage source's output and generates a control signal to suppress undesirable variations. To keep the period of the voltage source's output stable, a crystal-controlled clock and a series of frequency-divider stages are employed. The output of this portion of the RMS is a square-wave voltage whose frequency is determined by the setting of RANGE switch *S1* and which governs the frequency (and hence the period) of the triangle voltage source's output.

When the component under test is driven by the triangular test signal, a complex voltage is presented to the RMS demodulator stage. This waveform comprises a square wave, which is due to the reactive portion of the impedance of the component under test, and an added, triangle wave which is due to the resistive portion of the impedance of the component under test. (An ideal reactor contains no resistance, but practical inductors and capacitors do.) To prevent any resistive element of the component from influencing the measurement, the triangle-wave portion of the signal presented to the demodulator is averaged out.

The demodulator responds only to the square-wave portion of the signal applied to it and generates a dc output voltage. A scaling amplifier processes this voltage and presents a dc level to the output terminals of the RMS. This level, which is monitored by means of an external dc voltmeter, is scaled so that the voltage reading represents the actual value of the reactor under test.

About the Circuit. The schematic diagram of the RMS appears in Fig. 2. A quartz-crystal oscillator comprising *Q1, Q2, Q3* and their associated passive components generates a 2.0-MHz output signal. This signal is conditioned and its frequency divided by a factor of two by flip-flop *IC1B*, which provides a 1.0-MHz square wave to decade dividers *IC2* through *IC5*. One of the five decade-counter output frequencies (1 MHz, 100 kHz, 10 kHz, 1 kHz or 100 Hz) is selected by *S1A* to drive the active voltage divider comprising *R7, R18* and *Q14*. The divider is part of the agc stage.

Capacitor *C4* couples a portion of the driving signal to the triangle-wave generator comprising *Q5, Q6,* and *Q7* and their associated passive components. This circuit is a bipolar constant-current source which alternately charges and discharges the triangle-generating capacitor selected by *S1B* that is appropriate for the frequency selected by *S1A*. The triangle-wave voltage that appears across this capacitor is monitored by that portion of the agc circuit comprising *Q13, Q14, IC7* and their associated passive components.

The input signal to this portion of the

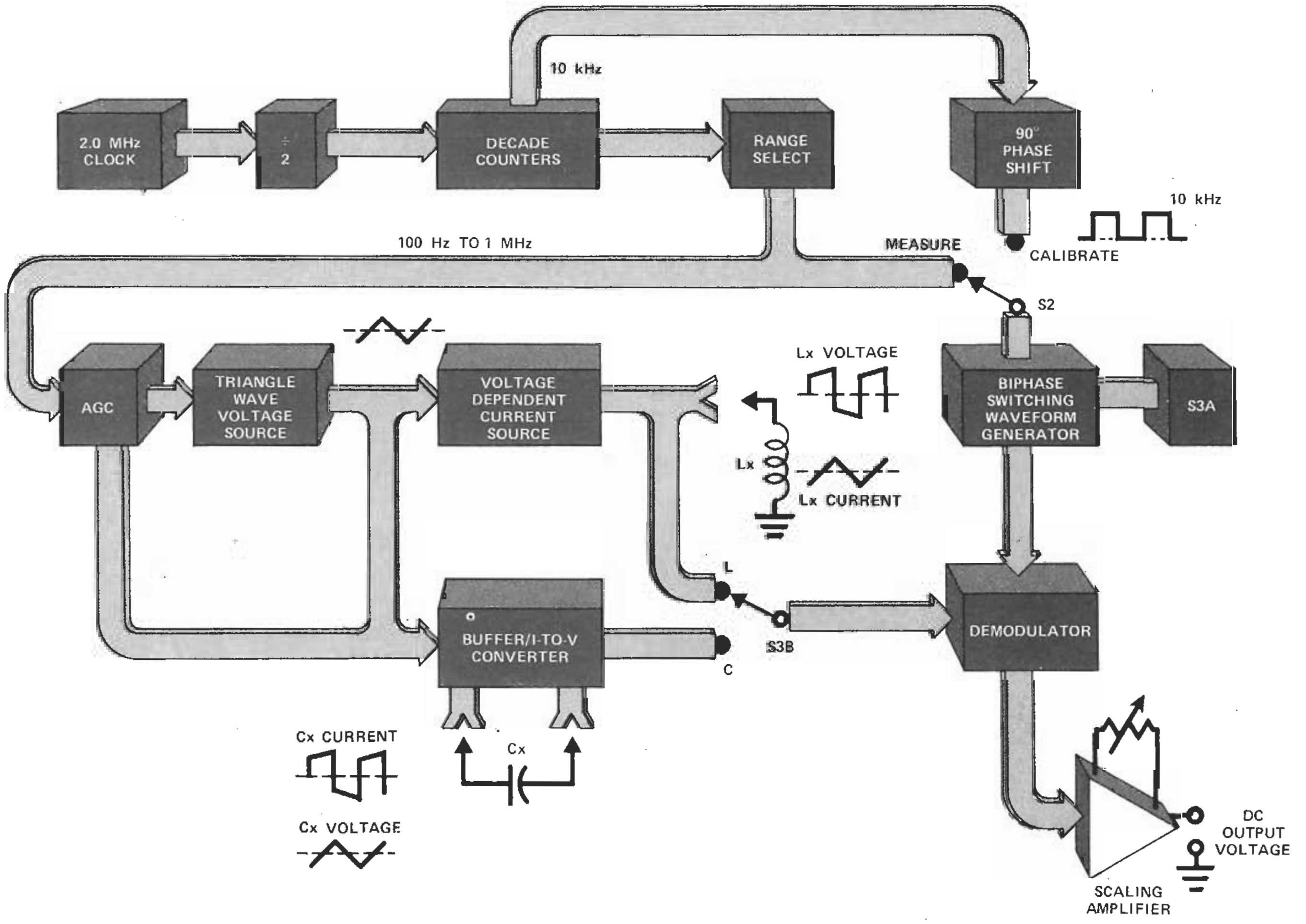


Fig. 1. Block diagram of the Reactance Measuring Set. A measurement is performed by synchronous demodulation of the square-wave voltage that appears across the component being tested.

agc stage is first buffered by *Q13* and then peak-detected by *D5* and *D6*. This detected signal is then filtered and compared by *IC7* to a reference provided by voltage divider *R21R22*. The output of *IC7* is the bias applied to the gate of *Q14* that determines the channel resistance of the FET. As a result, the amplitude of the crystal-derived square wave provided to the triangle-wave voltage source is maintained such that the amplitude of the triangle-wave voltage signal remains constant.

Owing to possible differences in device and circuit parameters, an imbalance between the charge and discharge cycles could result. This would in turn cause a net buildup in charge across the triangle generating capacitor, eventually leading to saturation. A modified phase inverter comprising *Q5, R10, R20, R24, R26,* and *C36* is utilized to prevent this. The out-of-phase (180° phase-shifted), voltage that appears at the collector of *Q5* is ac-coupled and added to the in-phase, dc-coupled voltage that appears at the emitter of *Q5*. Any tendency for the dc voltage to build up (as a result of differences between the parameters of complementary transistors *Q6* and *Q7*) will automatically change the bias of both *Q6* and *Q7* to stabilize the circuit.

The output of the triangle-wave generator drives both the voltage-controlled current source and the buffer/voltage-to-current converter. The voltage-controlled current generator comprises *Q8, Q9, Q10*, and their associated passive components, and is similar to the triangle-wave generator. It converts the voltage waveform to an out-of-phase (180° phase-shifted) current which is applied to the inductor to be measured. When the component under test is so driven, a square-wave voltage whose amplitude is directly proportional to the inductance appears across it.

The buffer/current-to-voltage converter (*Q12*, et al) is a common-base amplifier with an extremely low input impedance. From the viewpoint of a capacitor whose value is to be measured, the node *R29Q12* emitter is effectively at ground. Therefore, the magnitude of the current flowing through the capacitor under test depends only on the capacitance and the voltage waveform applied to it. The output impedance of *Q12* is very high, like that of a constant-current source, and the collector current of *Q12* is therefore a replica of the transistor's base current. This arrangement allows the capacitor to "see" an effective ground and simultaneously allows *Q12* to monitor the current flowing through the capacitor under test. The square-wave collector current of *Q12* gives rise to a corresponding square-wave voltage drop across *R34*. This square-wave voltage is buffered by *Q13* and presented to the synchronous demodulator via *S3B*.

The square-wave voltage passed by *S3B* is synchronously demodulated by *IC8*. Synchronous demodulation requires the reference signal supplied to the demodulator to be in phase with the signal from the component under test. However, the square wave generated by the buffer/current-to-voltage converter is 180° out of phase with respect to the voltage generated across an inductor under test. To compensate for this, in the inductance-measuring mode, the reference signal supplied to the demodulator is inverted by NAND gate *IC9C*. The triangle-wave voltage source provides the required 90° phase shift to ensure that the signal generated by the component under test is in phase with the reference signal.

Details of the synchronous-demodulation process follow. The square-wave voltage passed by *S3B* is simultaneously provided to two of the four bilateral switches in *IC8*. During the positive portion of the square-wave input, the signal flows from the input of bilateral switch A (pin 1) to the output of that switch (pin 2). This happens because the reference signal applied to switch A's CONTROL input (pin 13) is positive. During this interval, the phase-inverted signal applied to the CONTROL input of bilateral switch B control is negative. This causes the input-to-output channel resistance of switch B to become very high. On the negative portion of the square-wave input, switch B turns on and switch A turns off. Therefore, the negative portion of the input square wave appears at the output of switch B (pin 3). The two switch outputs are summed and scaled by *IC6*.

Calibration of the RMS does not require precision inductors and capacitors. A resistor of specific value serves as the calibrating component. Transistor *Q4* and flip-flop *IC1A* generate a 10-kHz square wave shifted 90° in phase with respect to the signal that appears at the output of counter *IC3*. During calibration, the signal generated across the calibration resistor, which is connected to the terminals to which the component under test is normally attached, and the output of *IC1A* will be in phase. This allows the demodulator to produce a specific output voltage. The calibration procedure will be described later.

Power for the circuit is provided by the supply shown schematically in Fig. 3. The power supply utilizes IC voltage regulators to produce the ±12 volts dc required by the circuit. A grounded (three-wire) line cord is used for safety purposes. The ±6.8 volts supplied to *IC8* and *IC9* are derived by zener diodes *D7* and *D8*. Because *IC8* and *IC9* must generate bipolar output voltages, this lower supply potential was selected so that the 15-volt maximum differential supply-voltage rating of the CMOS devices would not be exceeded.

Construction. Use the full-size etching-and-drilling guide shown in Fig. 4 to make a printed-circuit board, and mount all the fixed resistors shown in the parts placement guide given in Fig. 5. Next, install the diodes, transistors, ICs and jumpers and capacitors.

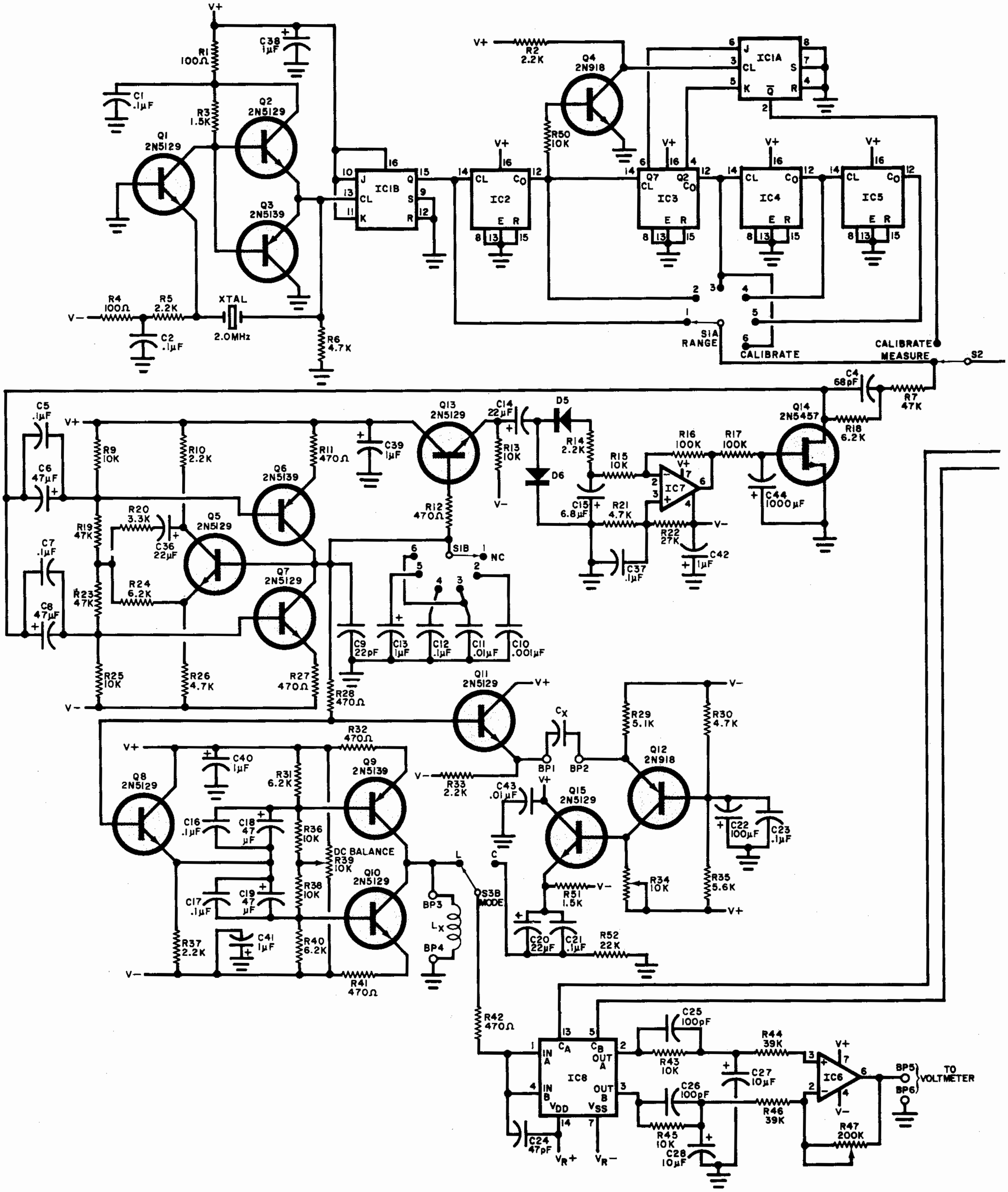
When all on-board components have been mounted, wire rotary switch *S1*. In the authors' prototype, *S1* was mounted above the board using stiff, solid-conductor wire and capacitors *C10* through *C13* to give mechanical support. We connected one lead of each capacitor to the pc board. Without shortening the leads, the free end of each capacitor was soldered to the appropriate switch lug. Next, we connected pc-board points *S1B2* through *S1B5* to the corresponding terminals of *S1* using stiff, solid-conductor wire. Wire lengths equalled lengths of the capacitor leads soldered to lugs on the opposite side of *S1* so that switch was supported securely above the pc board. Finally, we connected the rotors of *S1* to appropriate pc foil pads.

You might choose another method of mounting *S1* above the pc board. In any event, once the rotary switch has been interconnected with the board, make the necessary connections between the printed-circuit board and the remaining switches, *LED1*, and binding posts *BP1* through *BP6* using suitable lengths of stranded hookup wire. Then interconnect lugs 3 and 6 of *S1A* and *S1B*. Transformer *T1*, the fuseholder for *F1*, power switch *S4* and the line cord should be interconnected and mounted in the project enclosure so as to fit in the large pc-board cutout. Once the transformer has been mounted, the secondary leads of *T1* can be connected.

The enclosure should be machined as necessary to accept all switches and binding holes should be drilled to allow easy adjustment of trimmer potentiometers *R34, R39* and *R47* after final assembly. When all switches and binding posts have been installed and connected to the rest of the circuit, the pc board can be mounted in the enclosure using standoffs and suitable hardware.

Calibration. Begin by soldering two lengths of stranded hookup wire to the lugs of a 1000-ohm, linear-taper potentiometer so that it will act as a variable resistor. The use of a multiturn potentiometer will simplify matters, but a standard potentiometer can be employed. Utilizing a 3½-digit multimeter, adjust the potentiometer for a resistance of 856 ohms ±1%.

Taking care not to disturb the setting of the potentiometer, disconnect its leads from the meter probes and connect them to binding posts *BP3* and *BP4*. Apply power to the project, place *S1* and *S2* in their CALIBRATE positions and *S3* in its L position. Switch the multimeter to its dc-volts operating mode and connect its probes to binding posts *BP3* and *BP4*. Adjust trimmer *R39* for a meter reading of 0 volt. Next, remove the probes from *BP3* and *BP4* and connect them to *BP5* and *BP6* and adjust trim-



mer *R47* for a reading of +10 volts. This completes the calibration of the inductance-measurement function.

Fashion a capacitance-calibration network by connecting one lead of a 10-µF nonpolarized electrolytic capacitor to one side of a 2000-ohm, linear-taper potentiometer that is wired to act as a variable resistor. If a nonpolarized electrolytic capacitor is not available, use two 10-µF, 16-volt tantalum or aluminum electrolytic capacitors connected back-to-back (negative plate to negative plate) instead. Solder a short length of stranded hookup wire to the free lead of the nonpolarized capacitor and another to the uncommitted side of the potentiometer. Connect the probes of the multimeter across the potentiometer and set the meter to read resistance. Adjust the potentiometer for a reading of 1200 ohms ±1%. Remove the ohmmeter probes.

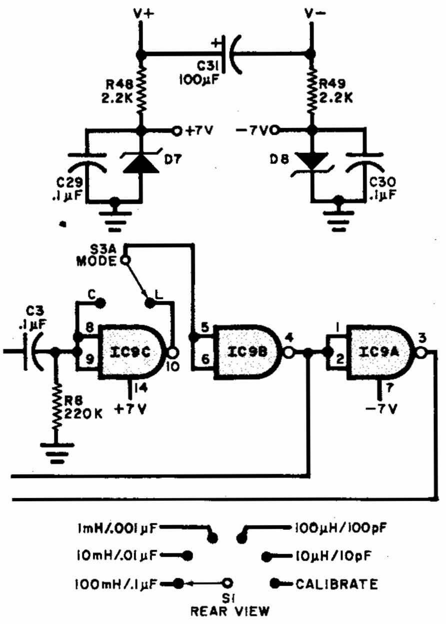
Taking care not to disturb the setting of the potentiometer, connect the leads of the capacitance-calibration network to binding posts *BP1* and *BP2*. Set the multimeter to read dc volts and connect its probes to *BP5* and *BP6*. Set the multimeter to read dc volts and connect its probes to *BP5* and *BP6*. Apply power to the project, place switch *S3* in its C position, and place *S1* and *S2* in their CALIBRATE positions. Adjust *R34* for a meter reading of +10 volts. This completes the calibration of the capacitance-measurement function.

Using the RMS. The equivalent circuit of a typical inductor (Fig. 6) contains shunt capacitance and series resistance as well as inductance. Thus, the frequency at which an inductance measurement is performed can influence the reading obtained. Therefore, it should be as close to the actual frequency the inductor will "see" in use as possible. The RMS test frequencies were chosen to meet this requirement for typical applications. Relatively low-value, air-wound coils are generally used in high-frequency applications where stability is important. Ferrite-core inductors are often employed when small size is important. They are usable from dc to approximately 100 MHz, depending on the ferrite mix employed in the manufacture of the core.

In a core inductor, the magnetic characteristics of the core, which include hysteresis and saturation, should be considered, especially if the core has high permeability. Such a component's effective inductance can be affected by the amplitude of the applied signal and any dc bias current flowing through it. Under test conditions, the peak signal voltage applied across L_X is approximately three-tenths of the project's dc output voltage. Under normal conditions, the RMS will apply no dc bias to the inductor under test and will not apply a large enough signal voltage to cause a typical core to saturate.

If inductance-value variation caused by the test signal is suspected, switch to the next higher inductance range. A large increase in measured inductance suggests that the core might have been

(Continued on page 76)



PARTS LIST

BP1 through BP6—Binding posts
C1,C2,C3,C5,C7,C16,C17,C21,C23,C29, C30,C37—0.1-µF, 50-V disc ceramic capacitor
C4—68-pF, 50-V disc ceramic capacitor
C6,C8,C18,C19—47-µF, 16-V, radial-lead electrolytic capacitor
C9—22-pF, 50-V disc ceramic capacitor
C10—0.001-µF, 50-V, 20%, Mylar or monolithic ceramic capacitor
C11,C43—0.01-µF, 50-V, 20%, Mylar or monolithic ceramic capacitor
C12—0.1-µF, 50-V, 20%, Mylar or monolithic ceramic capacitor
C13,C35,C38 through C42—1-µF, 16-V, 20% tolerance tantalum capacitor
C14,C20,C36—22-µF, 16-V, radial-lead electrolytic capacitor
C15—6.8-µF, 16-V, radial-lead electrolytic capacitor
C22—100-µF, 16-V, radial-lead electrolytic capacitor
C24—47-pF, 50-V disc ceramic capacitor
C25,C26—100-pF, 50-V disc ceramic capacitor
C27,C28—10-µF, 16-V, radial-lead electrolytic capacitor
C31—100-µF, 50-V, radial-lead electrolytic capacitor
C32,C33,C44—1000-µF, 25-V, axial-lead electrolytic capacitor
C34—10-µF, 16-V tantalum capacitor
D1 through D4—1N4001 rectifier
D5, D6—1N914 or 1N4148 silicon switching diode
D7,D8—6.8-V, 1-W zener diode (1N5235 or equivalent)
F1—½-ampere fast-blow fuse
IC1—CD4027 J-K flip-flop
IC2 through IC5—CD4017 decade counter
IC6, IC7—µA741CV operational amplifier
IC8—CD4016 quad bilateral switch
IC9—CD4011 quad 2-input NAND gate
IC10—LM340T-12 +12-volt regulator
IC11—LM320T-12 −12-volt regulator
LED1—Red light-emitting diode
Q1,Q2,Q5,Q7,Q8,Q10,Q11,Q13,Q15—2N5129 npn silicon transistor
Q3,Q6,Q9—2N5139 pnp silicon transistor
Q4,Q12—2N918 npn silicon transistor
Q14—2N5457 n-channel JFET

The following, unless otherwise specified, are ¼-W, 10%, carbon-composition fixed resistors.

R1,R4—100 Ω
R2,R5,R10,R14,R33,R37,R48,R49,R53—2.2 kΩ
R3,R51—1.5 kΩ
R6,R21,R26,R30—4.7 kΩ
R7,R19,R23—47 kΩ
R8—220 kΩ
R9,R13,R15,R25,R36,R38,R43,R45,R50—10 kΩ
R11,R12,R27,R28,R32,R41,R42—470 Ω
R16,R17—100 kΩ
R18,R24,R31,R40—6.2 kΩ
R20—3.3 kΩ
R22—27 kΩ
R29—5.1 kΩ
R34,R39—10-kΩ, linear-taper trimmer potentiometer
R35—5.6 kΩ
R44,R46—39 kΩ
R47—200-kΩ, linear-taper trimmer potentiometer
R52—22 kΩ
S1—Two-pole, six-position rotary switch
S2—Spdt toggle switch
S3—Dpdt toggle switch
S4—Spst toggle switch
T1—25.2-V, 300-mA, center-tapped step-down transformer
XTAL—2.0-MHz quartz crystal
Misc.—Printed-circuit board, IC sockets or Molex Soldercons, fuseholder, line cord, sutable enclosure, strain relief, pc standoffs, suitable hardware, hookup wire, solder, etc.

Note—The following are available from BNB Kits, 72 Cooper Avenue, West Long Branch, NJ 07764: Kit of parts including all components and etched and drilled printed-circuit board but not including enclosure, No. RMS-1, for $129.95 postpaid in U.S.; etched and drilled printed-circuit board only, No. RMS-PC, for $21.95 postpaid in U.S.A. New Jersey residents, add state sales tax.

Continued from page 71)

ehaving nonlinearly. Occasionally, it is esirable to dc bias the inductor under est. This can be done by placing a dc nilliammeter across the L_X terminals prior to connecting the inductor, and adjusting DC BALANCE potentiometer *R39*. This potentiometer controls the bias of complementary transistors *Q9* and *Q10* and allows them to provide to the inductor under test a dc bias of up to 5 mA.

To make accurate measurements of inductances less than 10 μH, it is best to use a differential technique. Wind or find a coil whose inductance is approximately 30 to 50 μH (exact value not critical). Measure its inductance and record it for reference purposes. Next, connect the low-value inductor to be

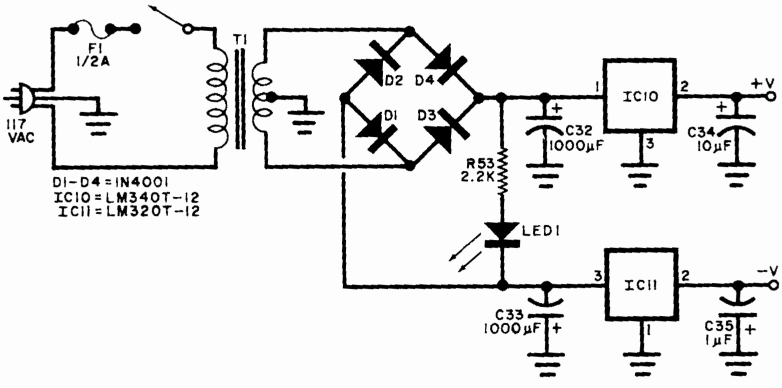


Fig. 3. Schematic diagram of the power supply which furnishes the bipolar 12 volts dc required by the circuit.

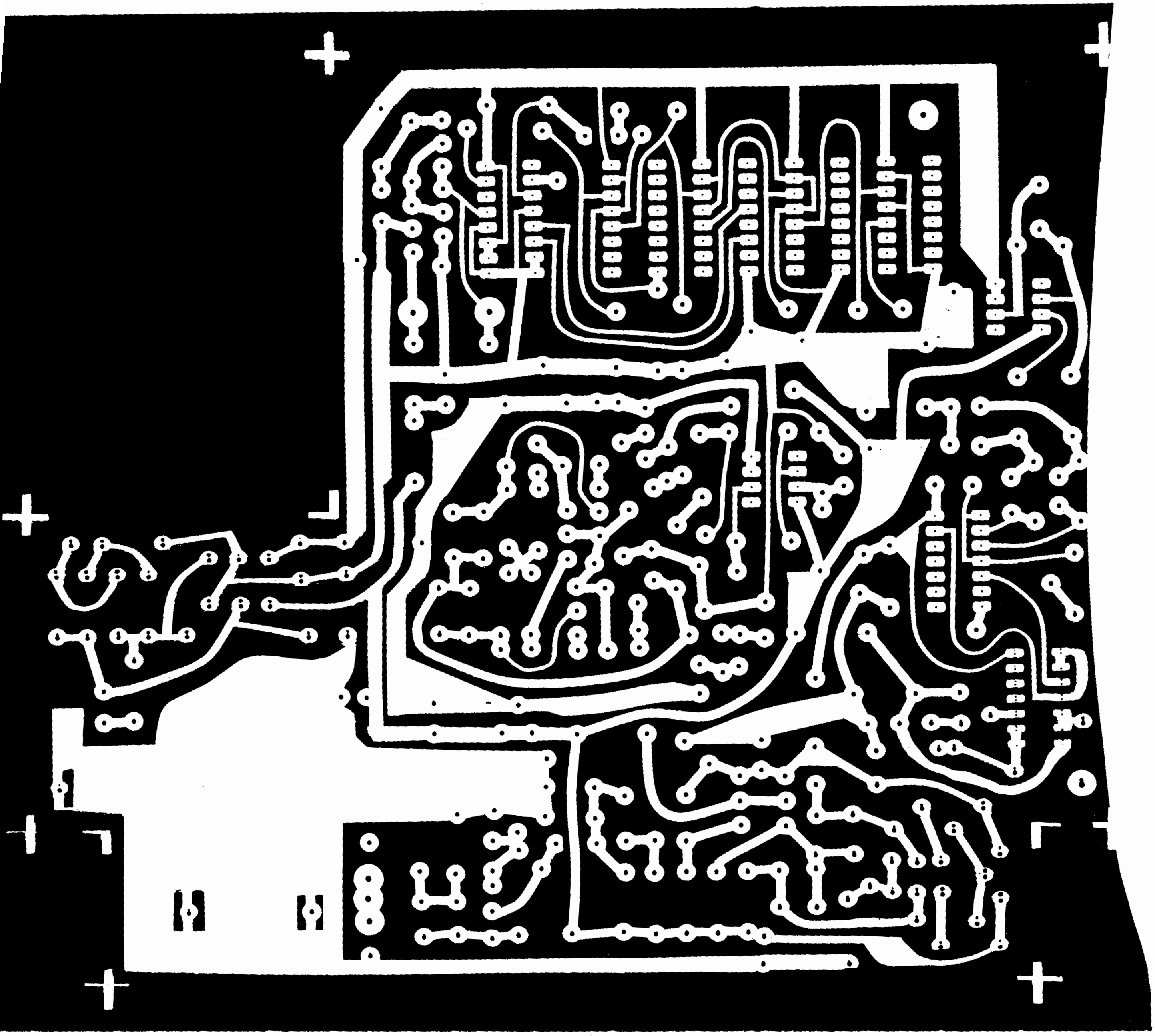


Fig. 4. Full-size etching and drilling guide of the project printed-circuit board.

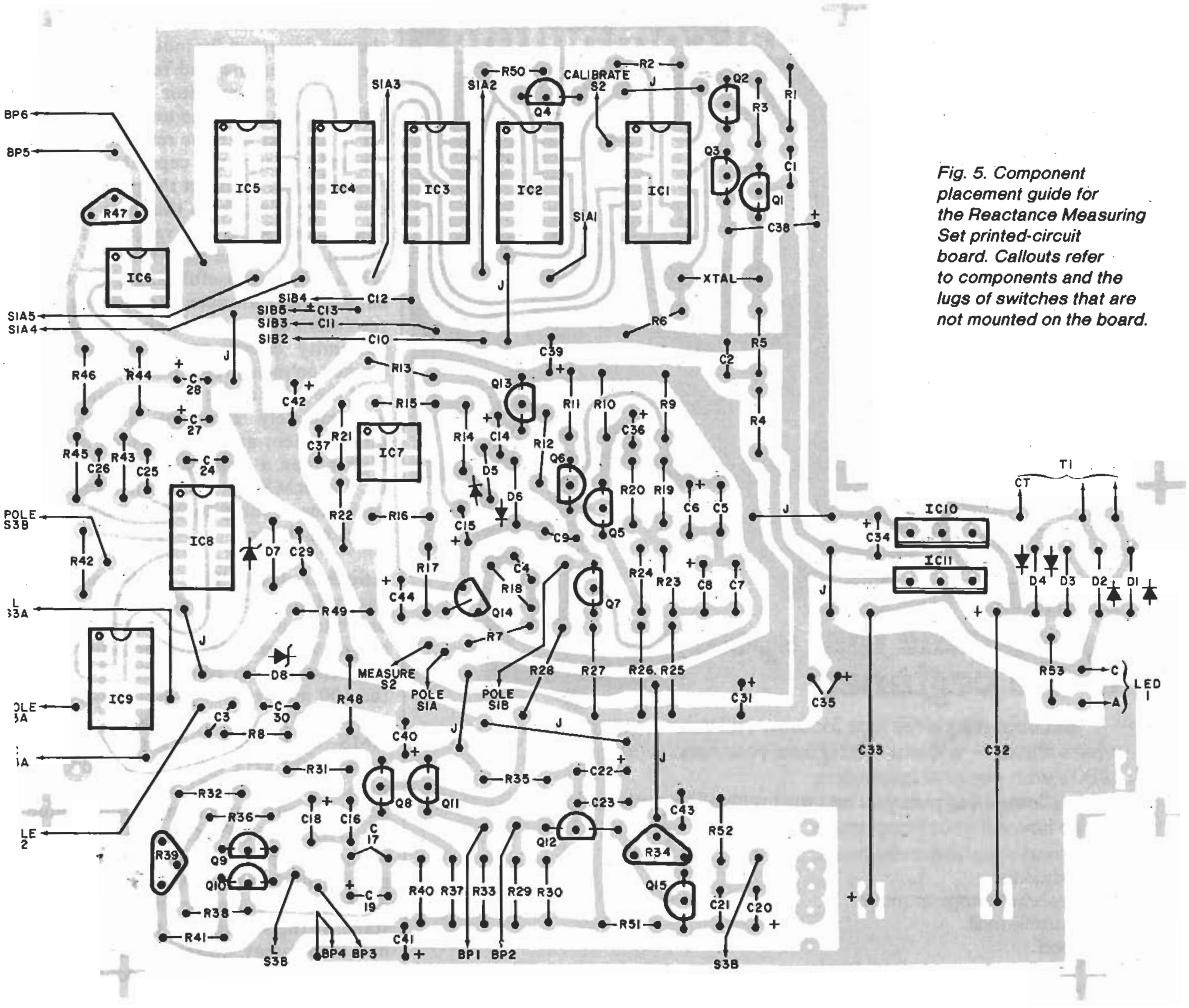


Fig. 5. Component placement guide for the Reactance Measuring Set printed-circuit board. Callouts refer to components and the lugs of switches that are not mounted on the board.

easured in series with the reference in-uctor and measure the inductance of he series combination. Subtract the re-orded inductance of the reference in-uctor from this new value. The remainder is the value of the unknown. If reasonable care is taken, this technique will yield good results and offer resolution to 0.1 μH. Keep in mind, however, that, at such low levels of inductance, the proximity of a metallic object, your body, or the effects of mutual inductance can significantly influence measured values.

The equivalent circuit of a typical capacitor is shown in Fig. 7. Although practical capacitors whose values lie within the measurement range of the RMS more closely approach the ideal than inductors do, it is worth noting two of their peculiarities.

During the charge/discharge cycle, a portion of the applied charge is retained by the dielectric. This *dielectric absorption* increases with frequency and reduces a component's effective capacitance. It is generally not separately specified but lumped with other loss components.

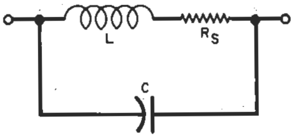


Fig. 6. The equivalent circuit of a typical inductor contains inductance, series resistance and shunt interwinding capacitance.

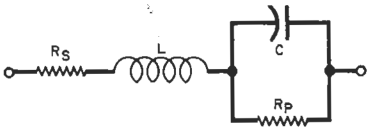


Fig. 7. The equivalent circuit of a capacitor consists of the capacitance and parallel leakage resistance in series with lead and foil-winding inductance and lead resistance.

Capacitors, too, have self-resonant frequencies. This is due to stray inductances contributed by foil windings and lead inductances. The self-resonant frequency is really a figure of merit. If the frequency at which the measurement is performed is near the self-resonant frequency, misleading data will result.

The RMS will provide sufficient accuracy for most applications. If you have an inventory of bargain-basement capacitors, you might notice that the voltmeter reading will not settle or will appear to drift. Either condition indicates that the capacitor is unstable and should be used only in the most noncritical applications. To measure small values of capacitance, the use of a differential measurement technique similar to the one described for inductors is recommended. Measure and record the value of a reference capacitor of about 30 to 50 pF. Then place the unknown capacitor in parallel with the reference capacitor and measure the capacitance of the combination. Subtract the previously recorded reading from this new reading. The remainder is the value of the unknown. Due to the good linearity of the RMS within its useful range, this method will yield an accurate reading with resolution of 0.1 pF. Keep in mind that proximity effects can have great influence on measurements.

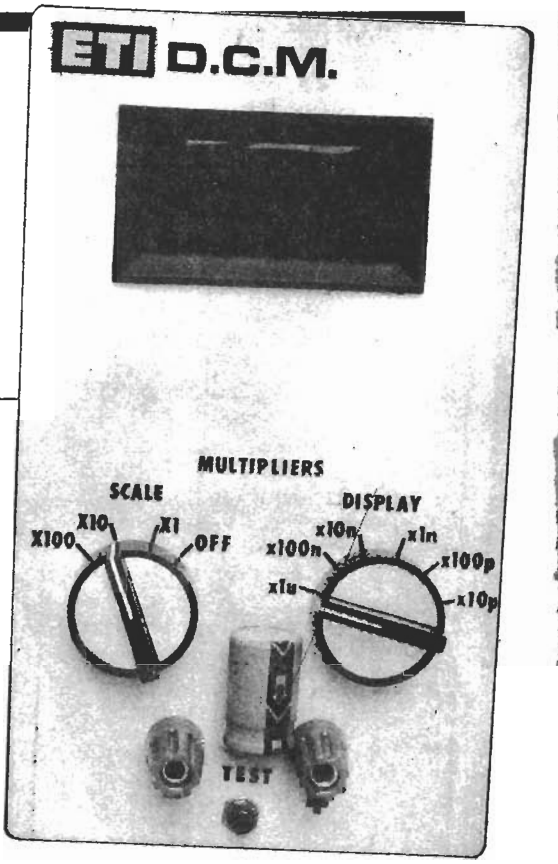
If the value of the capacitor under test is completely unknown, always start measurement at a range which is much higher than a reasonably expected value. The RMS can give a misleading capacitance reading in an extreme overrange condition.

Another Use. The RMS can be a handy frequency standard. The crystal oscillator and its associated divider stages will provide five decade-related frequencies from 100 Hz to 1 MHz (on the 100 mH/volt to 10 μH/volt ranges, respectively). For example, to use the RMS to provide marker frequencies spaced 100 kHz apart on a shortwave radio, place switch *S1* in its 100 μH/VOLT position and connect an 800-μH inductor to *BP3* and *BP4*. Couple the inductor to the r-f input stage of the receiver by placing it closer to that portion of the receiver enclosure directly above that stage. If the strength of the marker signals is too great, decrease either the value of the inductor or the coupling between it and the receiver.

Basic accuracy of the RMS is conservatively rated at ±5% of its *reading*, except on the lowest range, where the accuracy is approximately ±10% of the reading. Therefore, if a 3½-digit DVM is used with the RMS, on the project's lowest range, measurements will be resolved to the nearest 0.1 pF or 0.1 μH. Reliance should be placed, however, only on the two most significant digits displayed. The differential-measurement technique will permit resolution to 0.1 pF or 0.1 μH with the 10% accuracy of the lowest range. Accuracy could be improved if you have access to precision (±0.1%) inductors and capacitors, but, as a practical matter, such accuracy is rarely needed.

The RMS permits fast, convenient, and unambiguous measurement of inductance and capacitance over a wide range of values. Understanding its limitations and the nature of components it measures, you will find it a valuable addition to your test bench. ◇

Digital Capacitance Meter



It's fast, accurate and not too fancy. This Month's Digital Capacitance Meter is easy to build and will become one of the most used items in your workshop.

A GLANCE through an electronics catalogue soon shows that most of the cheaper multimeters do not measure capacitance. A few may measure values in the microfarad range, but not many measure in the nanofarad or picofarad ranges. This low-cost meter will, therefore, be very useful; it covers values from 100pF to 9900uF with two digit accuracy and it's cheap and easy to build. It also provides a good indication for values in the 10-100pF range but, in general, the main ranges will satisfy the requirements of most hobbyists.

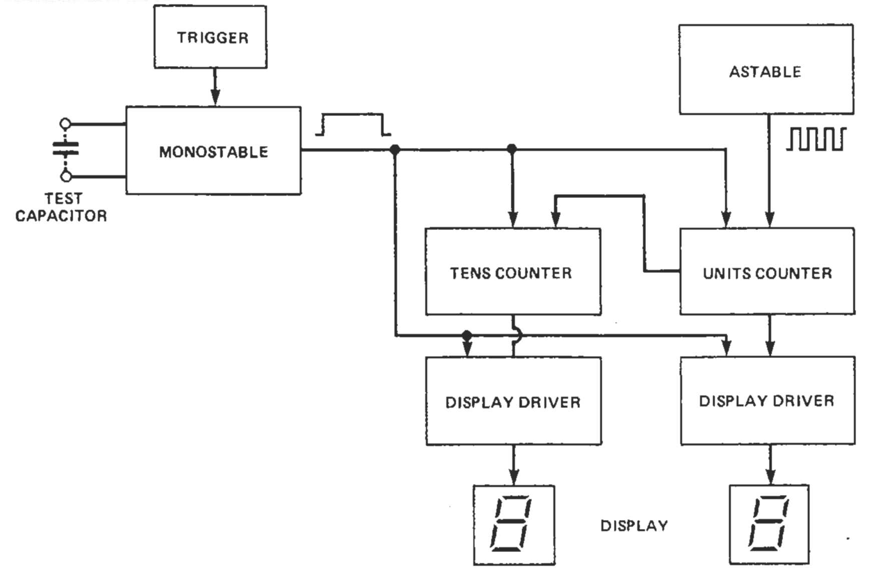
Many types of capacitors are manufactured to about 10% tolerance, yet for building filters, tuned circuits, timers and the like, it is often important to be able to know the precise value of a capacitor. Electrolytic capacitors, for example, are notorious for having very wide tolerance and for changing capacitance with age and use. Then there are all those look-alike polystyrene capacitors, which are marked in ink that seems specially prone to rub off at the first handling (their physical size is no real guide to their value, by the way). Finally, there are the bargain packs, containing an assortment of imported capacitors whose markings bear no recognisable relationship to any known classification system. When using these, the perplexing question is: "What have we here?". So, a capacitance meter is a distinct asset for these and many other circumstances.

The Circuit

The circuit uses the 556 dual timer IC in two common configurations. One half, IC1b is an astable multivibrator used to produce a square wave at either of two fixed frequencies. The pulses from the astable are counted by IC3, which contains two complete decimal counters. The first counts units and its output carries over to the second, which counts tens. The display drivers, IC4 and IC5, convert the BCD (Binary Coded Decimal) outputs from the counters to provide the outputs required for driving the 7-segment displays.

The counting action is controlled by the other half of the timer, IC1a, connected as a monostable multivibrator; when triggered, this

HOW IT WORKS



The DCM measures an unknown capacitor by counting the number of clock pulses which occur during the period of a gating pulse, produced by the monostable. The pulse is triggered by operating a push button switch (the trigger circuit ensures a clean start to the pulse) and its width is proportional of the value of the test capacitor, which is connected into the RC timing network of the monostable.

The gate pulse 'enables' the display drivers and the counters, which then begin to register pulses from the astable multivibrator. At the end of the monostable gate pulse, the display drivers are locked and a two digit number is displayed. The counters are reset to zero, ready to begin a new count.

The DCM has eight ranges, produced by changing the frequency of the astable multivibrator and by controlling the width of the monostable pulse by using different resistors in combination with the test capacitor. This is described more fully in the text.

gives a single positive pulse. As the pulse begins (rises), the counters and display drivers are 'enabled' and pulses from the astable are counted. As the pulse ends (falls), the display drivers are latched to 'hold' and the count is displayed. The counters are reset to zero at this time, ready to restart the count at the next high pulse, but the display 'holds' the count. The display is returned to zero by the enable pulse at the beginning of each run and counting begins immediately.

The length of the pulse from the monostable, IC1a, is proportional to the capacitance of the test capacitor; the greater the capacitance, the longer the pulse and, therefore, more pulses from the astable are counted. The two-figure display is read according to the format indicated by the range-setting knob.

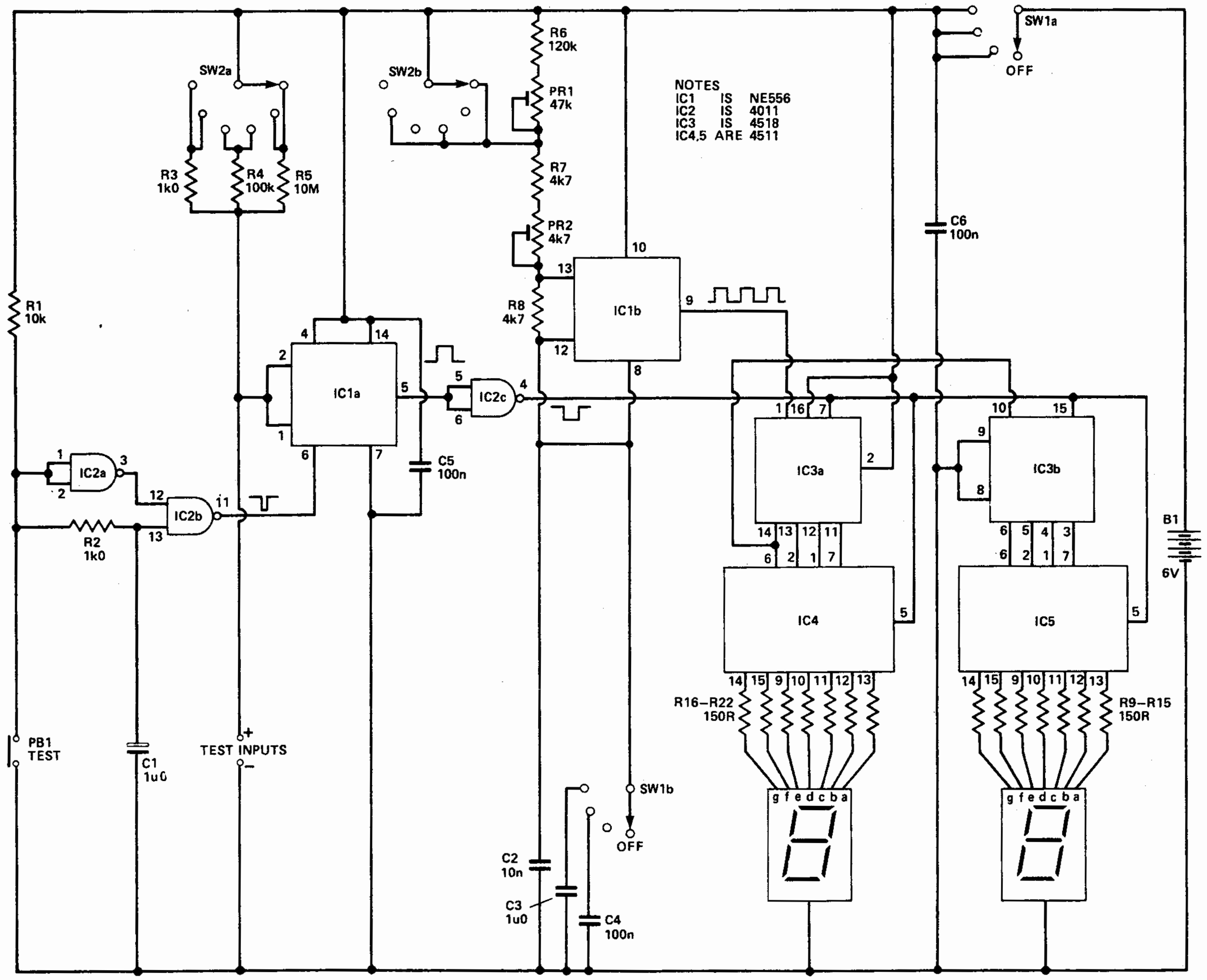
The period of the monostable is set by the test capacitor and whichever resistor, R3, R4 or R5, is selected by SW2a. The frequency of the astable, IC1b, is set by the timing capacitors C2, C3 or C4 and resistors R6, PR1, R7 and PR2. By selecting the appropriate combination of timing components, the meter provides eight decade ranges from 100pF upwards.

Construction

Most of the circuit is accommodated on the printed circuit board. It is best to begin construction with the display circuit. The two 7-segment LED displays are soldered to the board first; make sure the iron is hot and work quickly, so as not to overheat the LEDs. It is better to solder a few pins, then wait a few minutes for the heat to escape before continuing; the decimal point pins (dp) do not need to be soldered. Next, mount R9-22 (or you could use two 14-pin DIL resistor arrays, if you wish).

When you have mounted the displays and resistors, make the battery connections and test the display. Temporarily join the positive line to each of the resistors in turn and check that the correct segments light up on the display. WARNING — the current *must* go through a resistor before it goes to a segment.

The two segment-drivers, IC4 and IC5, are wired in next. The counter, IC3, completes the display section of the meter. To check its operation, connect a pulse generator to pin 1 of IC3; the displays should show a regular count up to 99, returning to 00 and repeating. If you do not



(NOTE: ON IC4 AND IC5; PIN 8 IS 0V, PINS 3,4 & 16 ARE +6V)

Fig. 1 The circuit of the Digital Capacitance Meter.

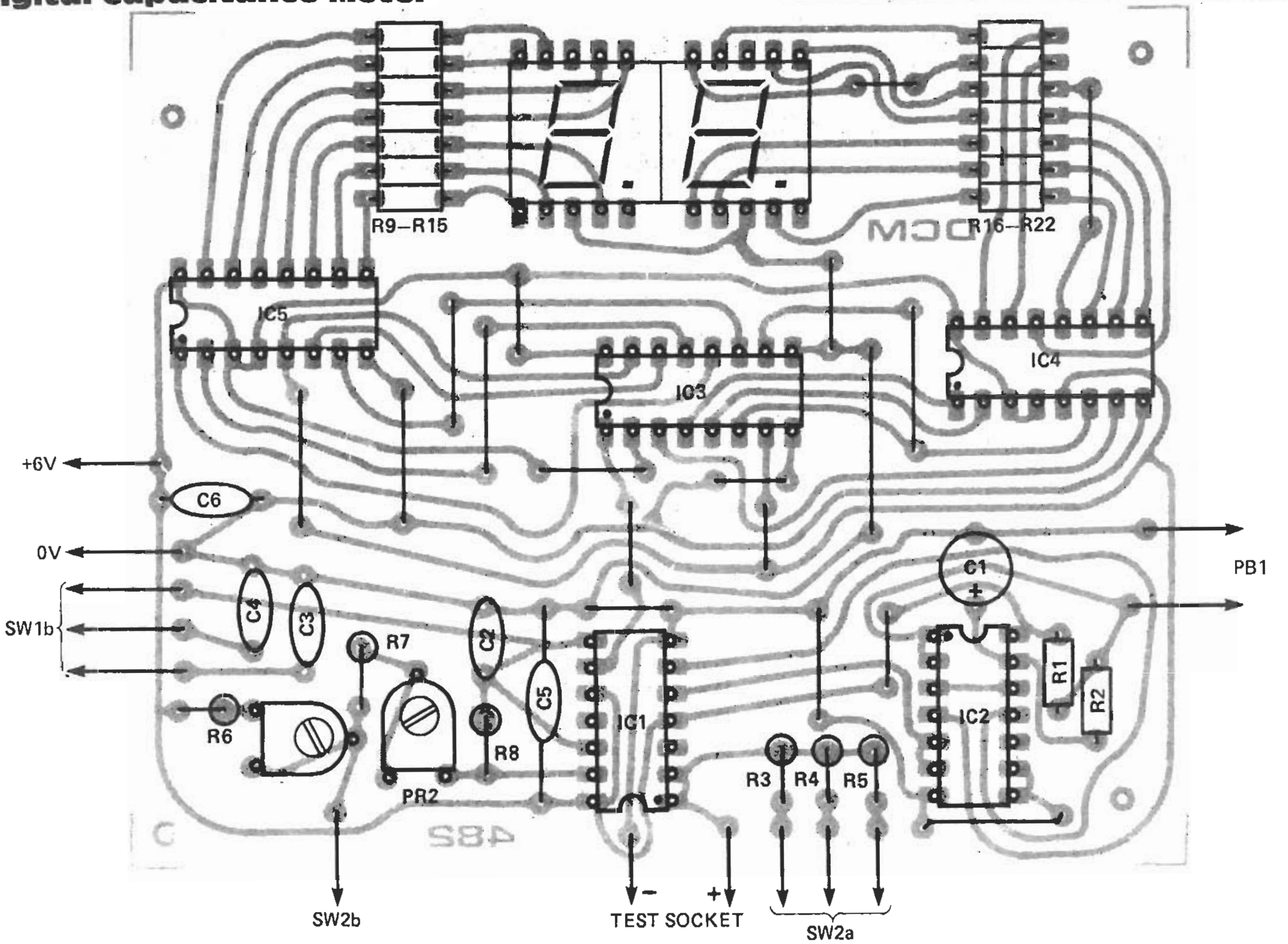
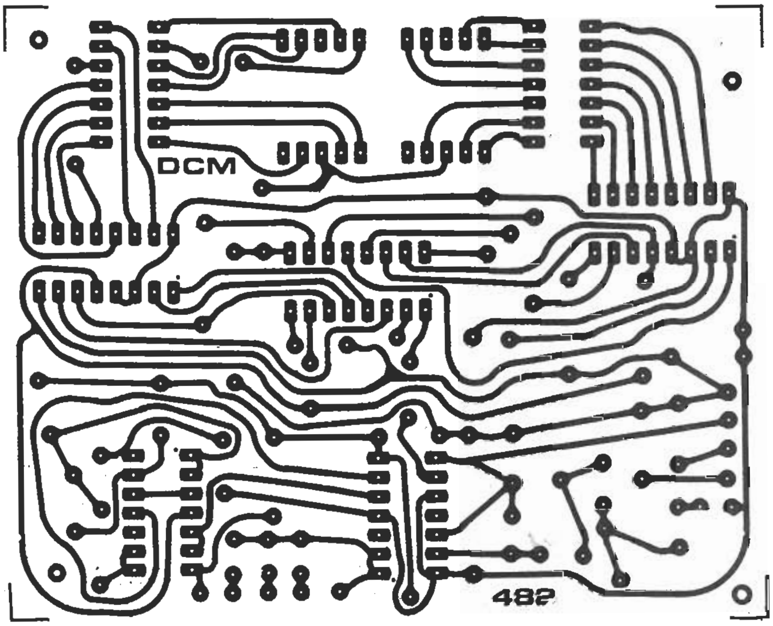


Fig. 2 The component layout; note that R9-15 and R16-22 can be either individual resistors (as shown) or 14-pin DIL resistor arrays.

have a generator, you can use the output from IC1b which, with its associated components, is the next section of the circuit to be completed.

When the pulse generator (or astable) circuit is complete, connect the power supply. When pin 4 of IC2c is taken low (to 0V), the display should count rapidly at about 1 kHz. When it is taken high, the count freezes at its current value. The rate of counting is too fast to see properly (the display will appear to show a steady '8'), but you can slow it down by temporarily wiring a large value capacitor (say, 10uF) in parallel with C2. This will let you check that the counters are working properly.

Finally, complete the monostable and trigger circuits, IC1 and IC2, and the remaining components. You will need to make off-board connections to SW2, PB1 and the capacitor test sockets before this part can be tested. It is probably best to mount the panel components and complete all the off-board wiring now. Determine the orientation of SW1 and SW2 and drill the registration holes



The foil side of the printed circuit board.

accordingly. If PB1 and the negative capacitor test socket are correctly positioned, the tag of the socket can be soldered directly to one of the lugs of PB1. The power comes from four pen-lite cells in a battery holder, which can be held in place by double-sided tape. To test the complete circuit, mount a capacitor in the test sockets; it is useful to have a pair of test leads, with 4 mm plugs at one end and crocodile clips at the other, for short-lead and otherwise 'difficult' capacitors. Remember to observe polarity, when testing electrolytic or tantalum capacitors.

You are now ready to switch on and . . . the display should immediately show a value. If nothing happens when you switch on, check that the trigger circuit, which normally has a high output (IC2b, pin 11), goes low for an instant (about 1 mS) when PB1 is pressed. The output of IC1a (pin 5) should normally be low, going high for an instant when PB1 is pressed. If you use a 100 uF test capacitor with SW2 at X1n, the output should stay high for about 10 seconds and, during this time, the display will run from 00 to 99 several times.

Calibration

IC1a is a monostable oscillator that controls the period for which the display counts pulses from IC1b. The period, t, is equal to 1.1RC, where C is the value of the test capacitor and R is the value of whichever resistor (R3 to R5) is switched into circuit. For example, if the test capacitor is 10 nF and we use R4 (100k), $t = 1.1 \times 100 \times 10^3 \times 10 \times 10^{-6} = 1.1$ mS. During this brief period the counter has to count 10 pulses from IC1b so that the display shows '10' at the end of the counting period. Now 10 pulses in 1.1 mS is equivalent to a frequency of 9.09 kHz, and this is the frequency to which IC1b is set when PR1 and R6 are short-circuited out of the timing chain by SW2b. If the test capacitor is 100 nF, the period becomes 11 mS; the display must again count 10 pulses, to show '10', so the frequency of IC2 must be reduced to 0.909 kHz by switching PR1 and R6 into circuit.

To calibrate the instrument we simply have to adjust PR1 and PR2 to give frequencies of 9.09 kHz and 0.909 kHz. The easiest method is to use an oscilloscope. Switch SW2 to position 1, bypassing PR1 and R6; monitor the output from pin 9 of IC1b and adjust PR2 until the period of the signal is 1.1 mS (9.09 kHz). Now switch SW2 to position 2 and adjust PR1 until the period is 11 mS (0.909

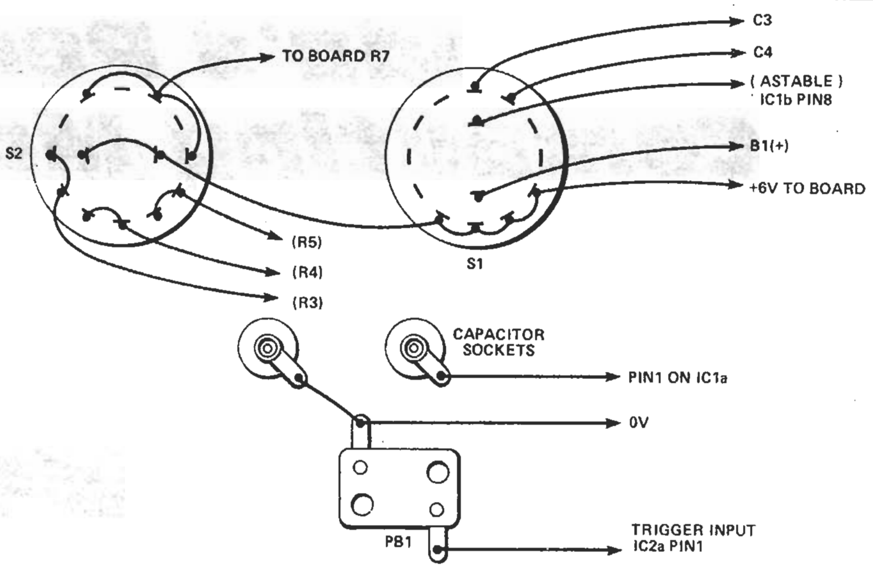


Fig. 3 Wiring diagram for the panel-mounted components. Check against the circuit to ensure all the wires go to the right place!

PARTS LIST

Resistors (all ¼ W, 5% except where specified)

R1	10k
R2	1k0
R3	1k0, 1% or 2%
R4	100k, 1% or 2%
R5	10M, 10%
R6	120k
R7,8	4k7
R9-22	150R (or two 14-pin DIL thick film resistor networks)

Potentiometers

PR1,2	47k sub-miniature horizontal trim pots.

Capacitors

C1	1u0 35V tantalum
C2	10n polyester
C3	1u0 polycarbonate
C4-6	100n polyester

Semiconductors

IC1	556 dual timer
IC2	4011B quadruple 2-input NAND
IC3	4518B dual decade counter
IC4,5	4511 7-segment decoder/ drivers

Miscellaneous

PB1	push button switch
SW1,2	2-pole 6-position rotary switches.

PCB, two 7-segment LED displays (common cathode 0.5"); ABS case 190 mm x 110 mm x 60 mm; knobs for SW1,2; 2x 14-pin, 3 x 16-pin DIL sockets; 4 mm terminal sockets (1 red, 1 blue); battery holder for 4 x AA cells; 1.0 mm terminal pins; self-adhesive feet; connecting wire; solder, etc.

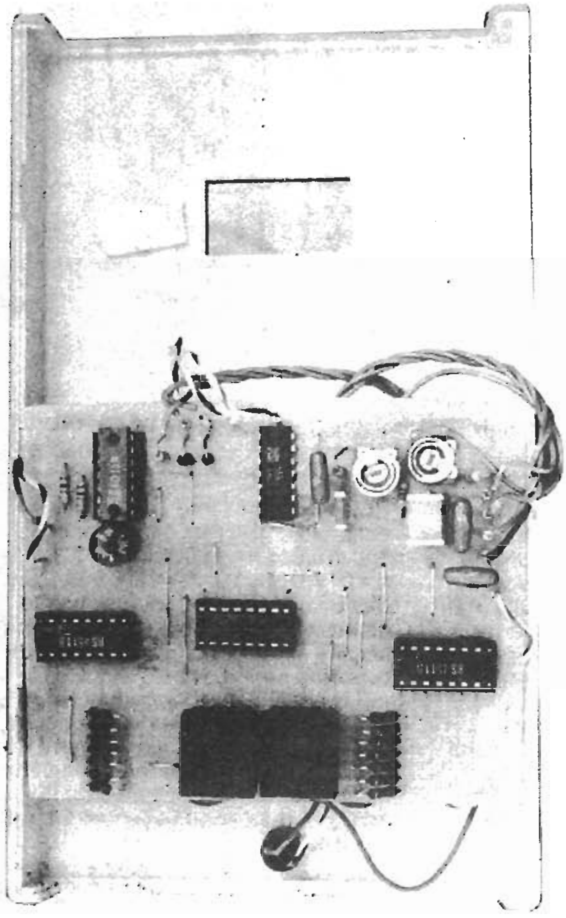


Fig. 4 Internal view of the completed DCM.

Continued on page 86

Digital Capacitance Meter

Continued from page 36

kHz) — do not re-adjust PR2 at this stage.

The astable is not calibrated for the two slow frequencies, which are used with test capacitors over 100 uF in value. Additional timing capacitors, C3 and C4, are simply added to the timing chain by switching them in via SW1. With C4 in circuit and SW2 in position 6, the frequency becomes 90.9 Hz; with C3 in, it becomes 9.09 Hz.

The accuracy of these two ranges depends on the tolerance of C3 and C4. The polyester capacitors recommended have a tolerance of 10%, which is close enough for this end of the range. You could, of course, purchase several of the same nominal value and test them (using this meter!) to find two closest to the specified values.

If you have no oscilloscope, the only method of calibration is to put a close tolerance capacitor in the test socket and adjust the astable circuit until the correct reading is obtained. It is better not to do this on the lowest range, for stray capacitance may bias the results. Use a 47 nF polyester capacitor on the X1 nF range and adjust PR2 to get a reading of '47' almost every time (you may occasionally get '46' or '48', but errors should be no greater than this). Then use a 4n7 polystyrene capacitor on the X100 pF range and adjust PR1 until '47' is obtained. The meter should then be correct for all the other ranges.

Using The Meter

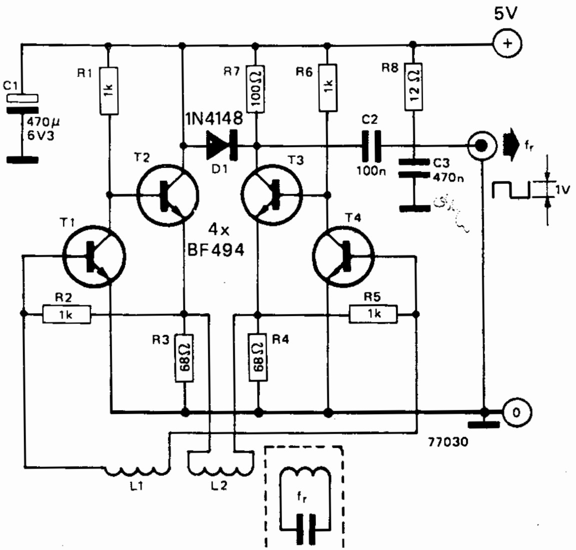
Plug the test capacitor into the socket and select the required range. If in doubt, select a range greater than the one you expect the capacitor to lie in. Switch on, and press PB1. The value will be displayed instantly (though it actually takes a few milliseconds to get there). On all ranges, the displayed figure is multiplied by the display range and the scale factor. For example, if the display switch, SW2, is set to x1u, the scale switch to X10 and the display reads '26', the value of the capacitor is 26 x 10 x 1u = 260 uF.

If the tens digit is zero, switch to the next lower range and press PB1 again. For the two highest ranges; SW2 must be in position 6 (x1u) and SW1 turned to X10 or X100, as necessary.

Switch the meter off when it is not in use, since the display consumes considerable power. In use, however, the meter works so quickly that the reading can be taken in a couple of seconds and the battery will last for many months.

103

LC resonance meter



This circuit is intended to perform the same function as a conventional grid-dip meter i.e. measurement of the resonant frequency of LC-tuned circuits. Unlike a normal grid-dip meter it is not, in itself, a complete instrument, but can be used in conjunction with a frequency counter to give a direct reading of resonant frequency.

The circuit consists of a difference amplifier comprising T1 to T4 and a pair of coils L1 and L2. These coils are wound on the same former but are spaced apart so that, when the circuit is not coupled to an LC circuit, no spontaneous oscillation occurs. When the coils are brought close to an LC circuit then oscillation will occur at the resonant frequency of the LC circuit, and this frequency can be measured by feeding the collector signal of T3 to a frequency counter. No direct connection to the LC circuit is required.

It must be stressed that this is a design idea that has not been fully developed but is printed here for the benefit of the experimenter. In consequence no constructional details are given for L1 and L2.

Millifaradometer Project

An ingenious, unusual and reliable way of measuring large-value capacitors.

By Ray Bold

THIS instrument is capable of measuring capacitors in the range 1uF to 100,000uF, and was inspired by the purchase by the author of a goody bag containing a huge number of unmarked electrolytics, and the prospect of a long tedious exercise using a bridge to measure them. A handy electromechanical counter and some development work led to the construction of a prototype instrument from which this design derives.

Construction is straightforward. The meter uses a bench supply rated at 12V DC and the full load current is in the region of 200mA.

Theory

If a capacitor, which is initially discharged, is charged from a constant current source, the voltage across it will change linearly with time. The time taken to charge to a given voltage will be dependent on the size of the capacitor and the magnitude of the charging current. Expressed mathematically,

$$CV = It$$

or

$$t = CV/I$$

If we fix V and then I, then t will be a function of C, and if we then arrange to measure t, we will also be measuring C.

In this design, a constant current of either 9uA, 90uA, 900uA or 9mA is supplied to the capacitor under test (CUT). The voltage across the capacitor is monitored by a window comparator and, while the voltage is within the limits of the window comparator, a counter operates at approximately 10Hz to give an indication of the capacitor's size. **Figures 1** and **2** help to illustrate the theory.

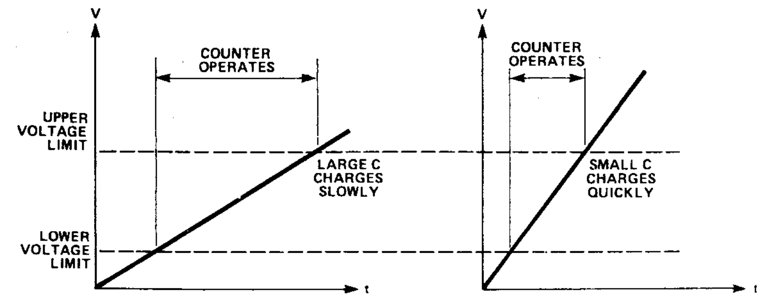


Fig. 1. Charging time between voltage limits is proportional to capacitance under constant current conditions.

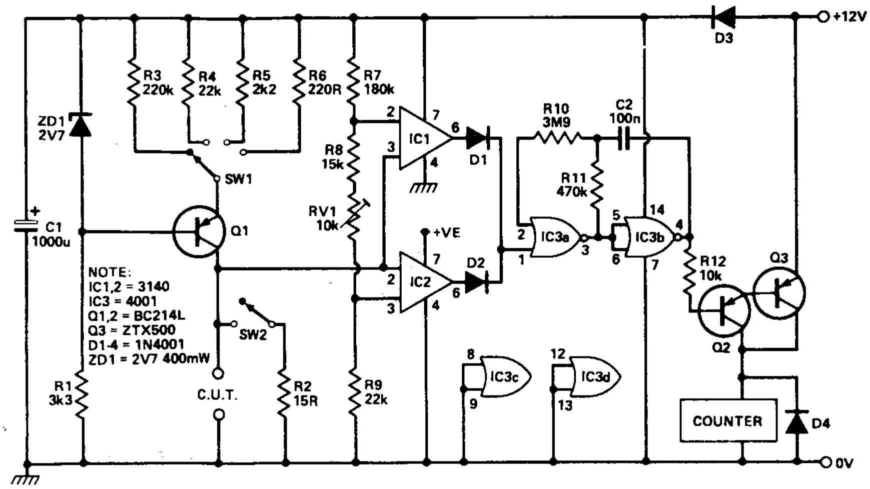


Fig. 2. The circuit diagram of the Millifaradometer.

Circuit Description

The circuitry around Q1 **(Fig. 3)** forms a constant current source with the current being selected by SW1. The capacitor under test is connected to the terminals marked CUT. SW2 and R2 remove any initial charge on the capacitor. When SW2 is opened the capacitor charges at a constant current and its voltage increases linearly with time. Since the relationship is CV = It, for a given current, the voltage will rise between two limits over a time determined by the value of the capacitor.

IC1, IC2 and associated components form a window comparator whose output goes low when the voltage across CUT lies within certain limits. The limits can be adjusted by RV1, providing a means of calibration. The window comparator gates the astable built around IC3 which counts at the rate of approximately 10Hz, driving the counter via Q2 and Q3 as long as it is gated on.

D3 and C1 decouple the supply to the sensitive parts of the circuit and protect them from the interference generated by the counter. D4 suppresses the spikes generated by the counter. Figure 3 shows the voltages at various parts of the circuit during a measurement cycle.

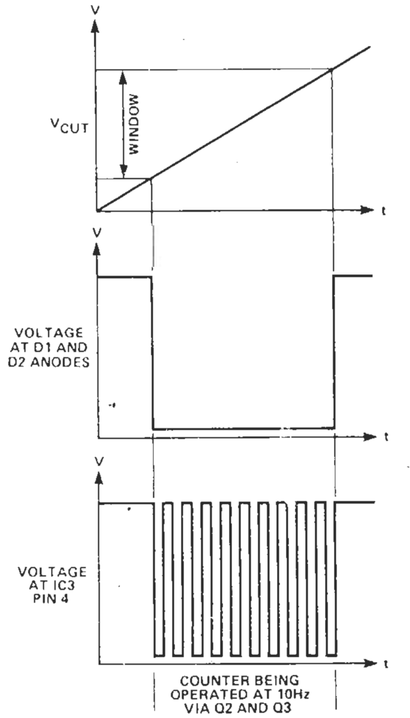


Fig. 3. Voltages at key points in the circuit.

Construction

The printed circuit overlay is shown in **Fig. 4** and is mounted using two of the mounting posts in the case, drilled 3mm. The board is drilled 3.5mm and 3mm set screws are used. Another 3mm set screw, with nut and spacer is inserted just above IC1.

Take care to mount polarized components and semiconductors correctly, and solder in the semiconductors last. Component values are not critical but if R3 to R6 are close tolerance so much the better. Electrolytics have large tolerances which vary with age and temperature, so extreme accuracy is unnecessary.

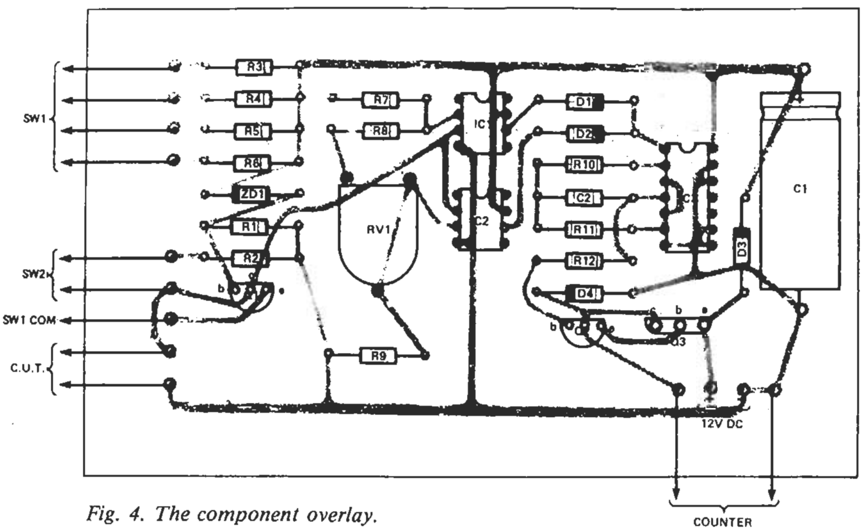


Fig. 4. The component overlay.

-Flying leads are used to connect the instrument to the bench power supply or 12V battery.

Setting Up

Find a capacitor between 10 and 20 uF. If possible, measure it accurately on a piece of commercial equipment. Reset the counter to zero and connect the capacitor. With SW1 on the X1 range switch SW2 to test. The counter should operate. Note the reading and repeat the procedure adjusting RV1 to give consistently accurate results. With large value capacitors there is a delay before counting begins while the bottom of the window is reached.

Parts List

Resistors (All ¼w 5% carbon film)	
R1	3k3
R2	15R
R3	220k
R4, 9	22k
R5	2k2
R6	220R
R7	180k
R8	15k
R10	3M9
R11	470k
R12	10k
RV1	10k horizontal skeleton preset
Capacitors	
C1	0*u* 16V electrolytic
C2	100n polyester
Semiconductors	
IC1, 2	3140
IC3	4001
Q1, Q2	2N5087
Q3	2N4401
D1 to 4	1N4001
ZD1	2V7 400mW zener diode
Miscellaneous	
SW1	Single-pole 4 way rotary switch
SW2	SPST toggle switch

Counter, 12V, 10 impulses per second with reset; case (console type); PCB; terminals; pointer knob; red and black 4mm plugs; connecting wire; set screw; nuts, washers, transfer. For the counter, try getting one surplus. If this is a no-go, Electro Sonic Cat. #G0-875-106-3 should be ok. Electro Sonic, 1100 Gordon Baker Rd., Willowdale, Ont., M2H 3B3 (416) 494-1555.

In Use

If in doubt about the value of a capacitor, set the range switch to a high range. The counter may count a couple of times or fail to count at all, which will indicate that a lower range is required. Starting on a low range may mean watching the counter for an excessive time until it stops. When counting finishes, simply add the number of zeros indicated by the range switch and that is the value of the capacitor.

To test another capacitor, switch the test switch up, replace the tested capacitor with the one to be tested, zero the counter and select a likely range. Then switch the test switch to test and watch.

After finding the value of a capacitor (bearing the +50%/-20% tolerance in mind) it is frequently possible to find the voltage rating by referring to catalogues, as these often give data including the physical size of capacitors.

The Millifaradometer can also be used to check electrolytics in faulty equipment. It should be remembered that a capacitor which is very leaky will charge slowly and seem to have a large value because of the current shunted through its own internal resistance. Capacitors which behave in this way should have their leakage checked with a multimeter set on resistance.

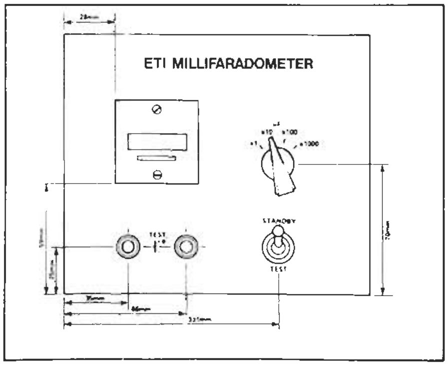
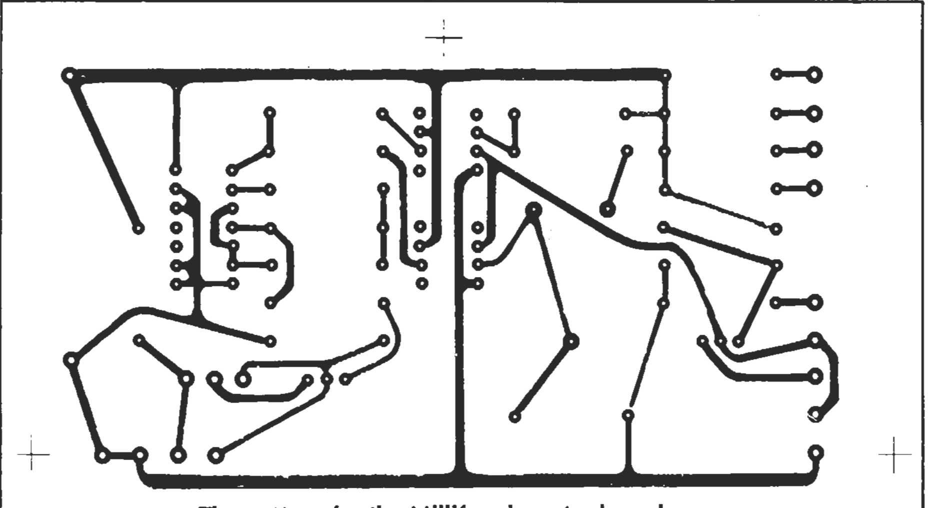


Fig. 5. Front panel layout of the ETI Millifaradometer.



The pattern for the Millifaradometer board.

How It Works

The Millifaradometer consists of four basic sections.

a) A constant current generator based on Q1 and associated components.

b) A window comparator built around IC1 and IC2.

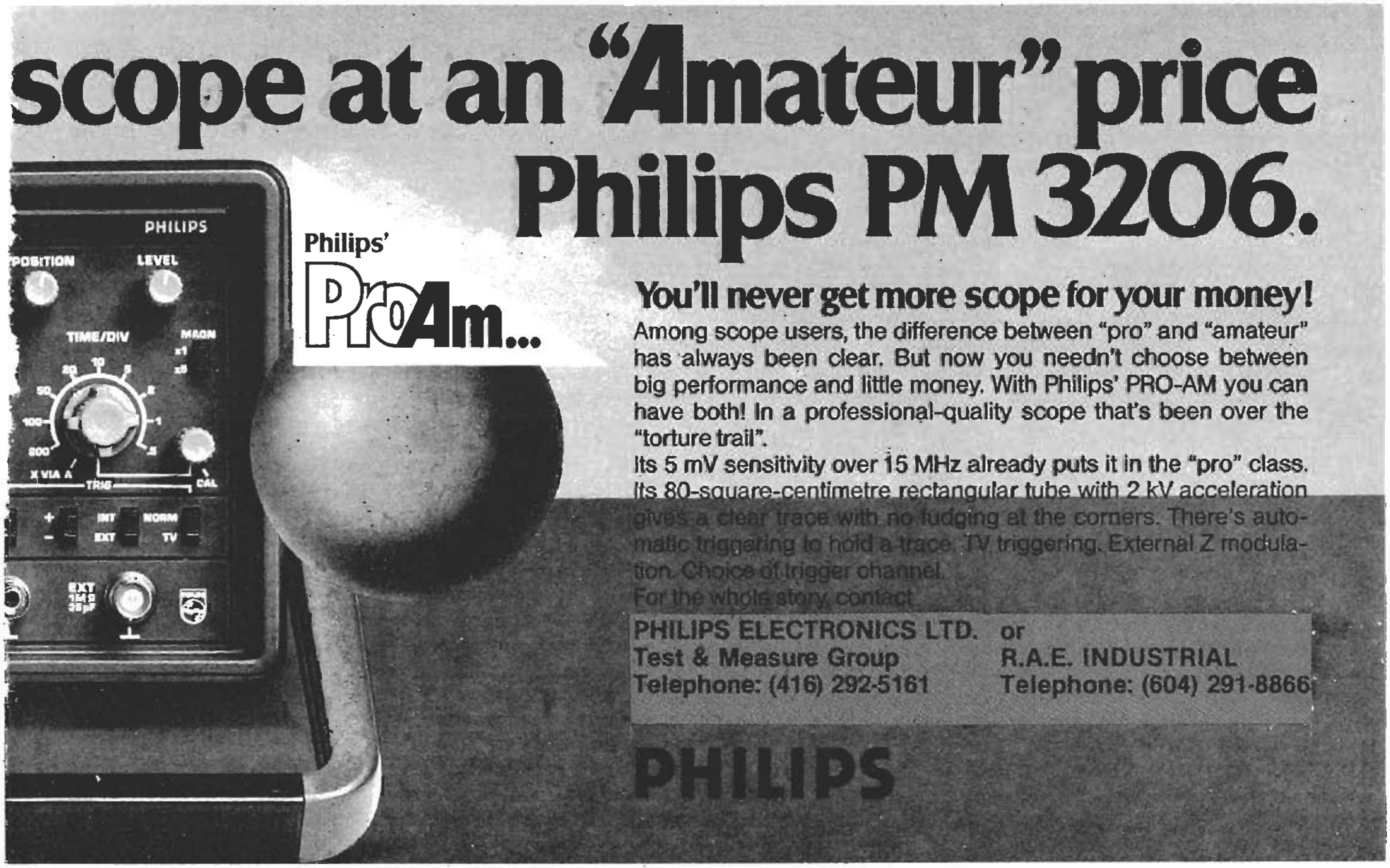
c) A gated astable multivibrator around IC3a and IC3b.

d) A counter and driver transistors Q2 and Q3.

With SW2 closed, the capacitor to be measured is connected across the terminals marked CUT. The switch and 15R resistor ensure that the capacitor is discharged at the outset. When SW2 is opened the capacitor charges up via Q1, and the voltage increases linearly at a rate dependent on the current and size of the capacitor.

When the bottom of the window (set by the divider chain R7, R8, R9, RV1) is reached, the output of the window comparator goes low, gating on the astable multivibrator IC3a and b. This runs at approximately 10Hz and drives the counter via Q2 and Q3. After a time, determined by the value of the charging current, the size of capacitor and the width of the window (set by RV1), the output from the comparator goes high and the counter stops.

The charging currents and window width are so arranged that on range 1 the voltage across a capacitor of 10uF will change by 1V/s and during this time the counter will count to 10. A capacitor of 20uF will take twice as long and count to 20 in 2 seconds on range 1. On the X 1000 range a capacitor of 47,000uF will take 4.7 seconds to change its charge by 1V and the counter will register 47. ■



NEW IDEAS

Use your scope as a capacitance

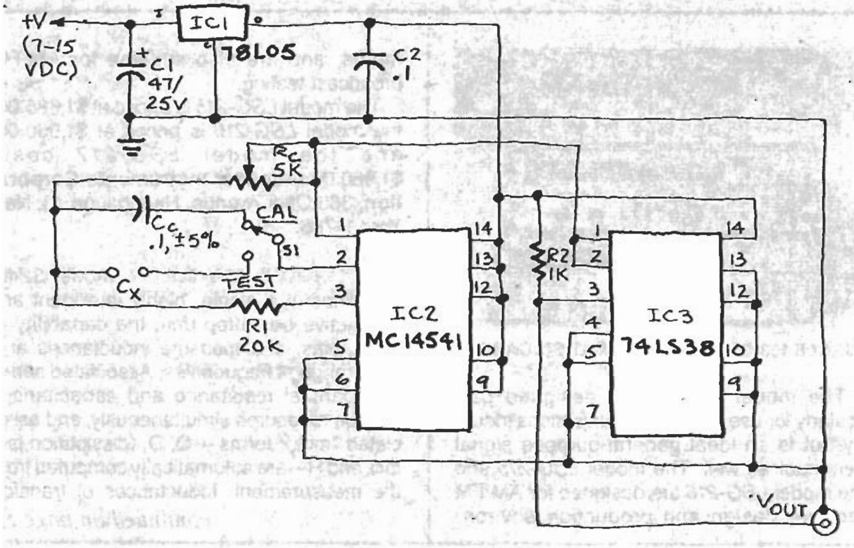


FIG. 1

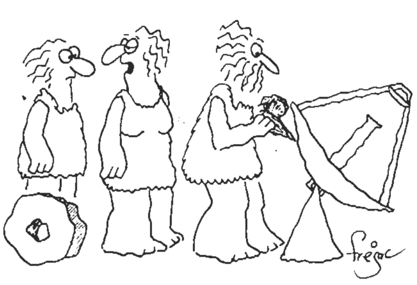
THIS MONTH WE'LL TAKE A LOOK AT A handy little circuit that allows your oscilloscope to be used as a precision capacitance meter. Basically, the device is an R-C oscillator and a wave shaper. Figure 1 shows the schematic for that circuit. As you can see, it consists of three IC's along with some resistors and capacitors.

The circuit shown is powered by a 7- to 15-volt DC supply. (A 9-volt transistor battery works just fine.) The supply consists of IC1 (a 78L05 voltage regulator) and two filter capacitors. Next, look at the oscillator/shaper circuit; that circuit consists of IC2 (a MC14541 oscillator/timer) and IC3 (a 74LS38 quad NAND buffer) along with some resistors and capacitors. There are several IC's that might have been used but those were chosen because of their availability.

To calibrate the device, first connect your scope to V_{OUT}. Then put the CAL/TEST switch to the calibrate position and adjust the 5-kilohm potentiometer R_C until a 1-millisecond cycle is generated. That's it; easy, isn't it? The next step is to try it out using a known-valued capacitor.

To find the value of the capacitor, simply connect the component leads to the points labeled C_X in the schematic. With the scope still connected to V_{OUT}, set the scope's attenuation to (typically) 2 volts. Now, adjust the sweep of the scope until you see 3 cycles or so on the screen. At that point, measure the time between two identical points on the trace (one complete cycle) and multiply that value by 100. That calculated value is the capacitance value in microfarads. It should be pretty close to the specified value of the capacitor. If so, you can how find the value of an unknown capacitor.

The precision of the device, as well as the value of the smallest capacitor it can measure, is limited by the scope and the calibration capacitor C_C. Typically, the device can be calibrated to 2% or better without difficulty by using a capacitor good to 1% or better. Those capacitors are generally more expensive, but we're sure you'll find that they're worth it.—*Jeff C. Verive*



"First Ogg invented the wheel, then he discovered fire. Now he's trying to build a receiving dish for satellite TV."

BUILD THIS

LC METER

This month we show you how to build the inductance/capacitance meter, and show you how to get the most out of using it.

NEIL W. HECKT

Part 2

LAST TIME WE EXPLAINED the theory behind the LC meter. Now we build and align the meter so that you'll have a very accurate instrument to add to your lab.

Construction

The instrument is assembled on a double-sided printed-circuit board for which templates are provided in PC Service. Alternately, a PC board having plated-through holes is available from the source given in the Parts List.

The component placement is shown in Fig. 3. Note that the four display drivers, IC8–IC11, are mounted under the liquid-crystal display (DSP1). The display must be mounted about ½ inch off the PC board if it is to be reasonably close to the front panel of the specified Pactec *HPL-9VB* cabinet. Three layers of low-profile 40 pin IC socket-halves plugged together will provide the clearance. On the other hand, both the kit and the finished unit specified in the Parts List contain some Samtec 0.56-inch sockets.

If S1, S2, and S3 are ITT's Cannon-type switches, they mount directly on the PC board. However, the switches supplied with the kit are from a different manufacturer and it is necessary to mount them off the PC board in such a manner that less than 1/32-inch of the longer leads protrude through the board on the solder side. In either case, the correct mounting so the push-button switches will fit through the holes in the cabinet is for the center line of the switch shafts to be 11/32 inch above the component side of the PC board. (Note: The switches in the kit are supplied pre-installed.)

The PC board provides for two 4-pole double-throw switches and one 2-pole double-throw switch. The extra contacts aren't used.

The LM7805 voltage regulator, IC12, lies flat on the board and must have a small piece of plastic electrical tape between it and the PC board to prevent shorting the case of the regulator to the circuit traces. Of course a standard mica insulator can also be used. Heat is not a problem as the unit draws only 17 mA.

Binding posts BP1 and BP2 are mounted in a somewhat unusual way directly to the PC board. Drill clearance holes for two 8-32 screws at the two binding-post locations shown in Fig. 3. Pass the screws through from the bottom of the board and secure ¾-inch 8-32 metal spacers at each location. When the cabinet is assembled, BP1 and BP2 are passed through the cabinet cover into the spacers, making the electrical connections and securing the cabinet.

The completed unit, with the cover removed, is shown in Fig. 4. Notice that no binding posts are shown. Instead, there are threaded spacers in the binding-post locations on the PC board. When the cover is installed the

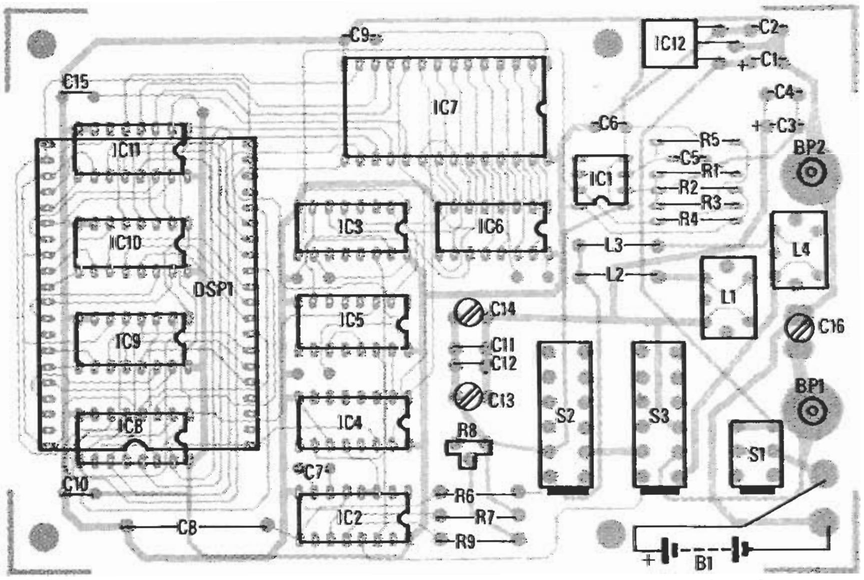


FIG. 3—THE PARTS LAYOUT for the PC board. Four integrated circuits, IC8–IC11, are located directly under the display module (DSP1). Binding posts BP1 and BP2 mount through the enclosure to spacers on the PC board.

binding posts pass through the cover and are screwed into the spacers; thereby securing the cover while providing electrical connections to the meter.

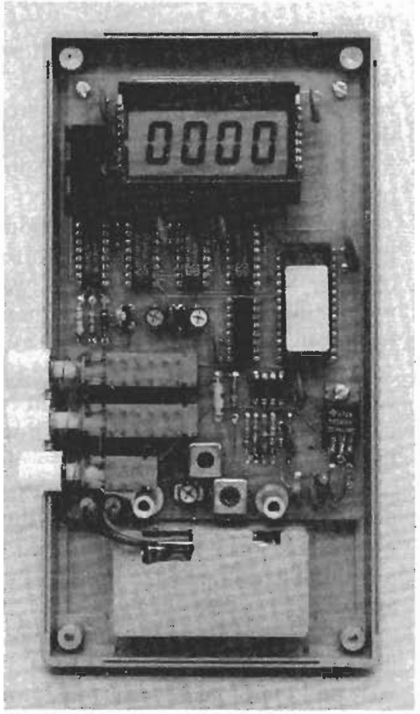


FIG. 4—THE COMPLETED METER. Five IC's are installed on the PC board directly under the display module, which is raised off the board approximately ½ inch so it will be flush with the enclosure's window. The battery is in a separate compartment that is moulded into the bottom of the enclosure.

PARTS LIST

All resistors ¼-watt, 5%, unless otherwise noted.

R1, R2, R7—100,000 ohms
R3, R5—47,000 ohms
R4—1000 ohms
R6—1 Megohm
R8—25,000 ohms, trimmer potentiometer, 0.1″ × .2″ spacing
R9—4700 ohms

Capacitors

C1, C3—10 µF, 10 volts, tantalum
C2, C4, C5, C9, C10, C15—0.1 µF, 50 volt, ceramic disc
C6—not used
C7—1500 pF, 100 volt, Mylar
C8—2.2 µF, polystyrene (Panasonic *ECQ-1225KZ*)
C11, C12—330 pF, polystyrene or propolyne
*C13—12–70 pF, trimmer capacitor (Mouser *ME242-1270*)
*C14, C16—3–10 pF, trimmer capacitor (Mouser *ME242-2710*)

Semiconductors

IC1—LM311N
IC2—CD4046
IC3—CD4520
IC4—CD4020
IC5—CD4022
IC6—CD4040
IC7—27C256 special programmed EPROM (see ordering note below)
IC8—CD4054
IC9–IC11—CD4056
IC12—LM7805CT
†DSP1—four digit LCD display, AND *FE0202*

Inductors

*L1—39 µH, variable inductor (Toko *154ANS-T1016Z*)
*L2—33 µH (J. W. Miller *8230-56*)
*L3—0.39 µH (J. W. Miller *8230-10*)
*L4—0.33 µH, variable inductor (Toko *BTKXNS-T1047Z*)

Other components

B1—9-volt battery
*BP1, BP2—5-way binding post with 8-32 thread
*S1, S2, S3—DPDT alternate action switch (ITT Schadow *51281*)
*3—pushbuttons for S1–S3
†2—LCD sockets
*2—8-32 × ¾-inch threaded spacer with mounting hardware
*2—8-32 screws and star washers
*1—battery terminal clip †1—socket for DSP1, Samtec *ESQ-120-12-T-S*
1—enclosure, Pactec *HPL-9VB*

Note: The following parts and kits are available from Almost All Digital Electronics, 5211 117th St. SE, Bellevue, WA 98006.

A complete kit containing all components in the parts list with the exception of the EPROM, display kit, enclosure, and the PC board: $69.95. A kit of hard-to-locate parts consisting of those indicated in the parts list with the * symbol: $29.95. The programmed EPROM: $19.95. The display kit consisting of those parts indicated in the parts list with a † symbol: $14.95. The enclosure, with all holes machined and a front panel decal: $19.95. The PC board with plated-through holes: $19.95

A complete semi-kit (the switches are mounted and soldered) consisting of all of the above and a "standard" capacitor for calibration: $149.95.

The completely assembled, tested, and calibrated unit: $169.95. Add $5 for shipping and handling per total order. Washington residents must add 8% sales tax.

Alignment

All that's needed to align the unit is a frequency counter and a capacitor of approximately 68,000 pF who's value is known to an accuracy of at least 1%. That capacitor is much larger than the 705-pF standard capacitor in the tank circuit, making the standard capacitor insignificant when adjusting the standard 70.5-µH inductor.

Ignore the display during the initial alignment because it might be doing some pretty wild things if the PLL is not in lock. (That particular adjustment will be made after the oscillator alignment.) Connect the frequency counter to pin 14 of IC3. The frequency at that location is the oscillator frequency/16.

First calculate the oscillator frequency when your known capacitor will be in the circuit:

$$f2 = 1/(2 \times \pi \times \sqrt{(70.5E\text{-}6 \times (C_k + 705)E\text{-}12)})/16$$

where C_K is your known capacitor in pF. (*f*2 should be about 4500 Hz.)

Connect C_K across the test jacks, depress C_X switch S3, and adjust L1 to obtain the calculated frequency ±10 Hz. Release S3 and set coarse-adjustment C13 (12–70 pF) and fine-adjustment C14 (3–10 pF) to obtain a frequency of 44,582Hz ±100 Hz. You may want to repeat the entire procedure several times because there is some interaction between the adjustment of L1 and the capacitors.

Finally, set R8 to the center of the adjustment range that produces 0000 on the display. The lock range is fairly large so the adjustment isn't critical. The center of the range will provide the best long-term stability rather than any immediate benefit.

The 9-volt battery-terminal clip cannot be installed until the PC board is installed in the cabinet because the clip cannot fit through the opening to the cabinet's battery compartment. Alternately, you can cut away part of the battery compartment's wall so the clip can then slide through into the compartment.

Final adjustment

After final assembly, the only remaining operation is to adjust the zero-trimmers for the binding posts. Use a non-metallic alignment tool for the adjustments.

With nothing connected to the binding posts, depress switch S3 and adjust C16 for a 0.00 pF reading. The adjustment will be somewhat tricky because the 3–10 pF trimmer capacitor is very tiny and has only a ½-turn range.

Next, place a piece of braided solder wick (which is about as close to zero inductance as you can get) across the binding posts and depress switch S2. Adjust inductor L4 for a reading of 0.00.

Note: The C16-adjustment reading is hard to maintain because the effect of your hand's capacitance is well within the range of the instrument. Rather than habitually make the zero adjustment, or when using test leads, we suggest you measure the open circuit capacitance and/or short-circuit inductance as described above— including test leads if any, and subtract those values from the final reading. The range of the zero adjustments is too small to compensate for test leads anyway.

The offset drift of the zero adjustments is usually only ±0.01–0.02 µH, and therefore becomes insignificant (1% to 2%) when measuring components with values greater than 1 µH or 10 pF.

Accuracy

Using 31 inductors ranging in value from 0.1 µH to 6800 µH, and 35 capacitors ranging from 2.7 pF to 0.1 µF, the average error for inductance measurements, compared to the measurements of a 1-MHz digital *HP4275A* laboratory-type LCR bridge was 1.58%. Percentages for values below 0.1 µH lose meaning because the 0.01-µH resolution would cause a minimum percentage error of 10%, degrading to 100% at 0.01 µH.

The average error for capacitors was 0.78%. Percentages for values below 1.0 pF lose meaning because the 0.10-pF resolution would cause a minimum percentage error of 10%, degrading to 100% at 0.10 pF

When the same components were measured on an *HP4274A* digital LCR bridge, at 100 kHz the average error between the two laboratory instruments was 10.17% for inductors and 7.12% for capacitors. **R-E**

Digital Capacitance Meter

Part 2—A valuable addition to your workbench that lets you check the value of unmarked and suspected capacitors.

BILL WILSON AND BILL OWEN*

CAPACITOR VALUES FROM 1 pF TO 9,999 μF are easily measured using this digital capacitance meter. A quartz timebase, precision resistors and a premium IC timer yield 1% ± count accuracy. Story begins in the September issue.

Construction

The *model CM-1000* is constructed using two double-sided plated-through glass-epoxy PC boards. The display board contains a complete four-digit counter and requires only power, ground, clock input, latch enable, and three decimal point connections. This arrangement greatly simplifies the building, testing and interfacing of the display and main counter boards. The remaining circuitry with the exception of the fuse and line cord is installed on the main counter board. The POWER/RANGE switch module solders directly to the main counter board eliminating almost all of the point-to-point wiring. The electronics assembly bolts in place in the custom black anodized heavy-gauge aluminum enclosure. The front panel is cut out for the pushbutton switch module and has a window with a high contrast lens for the LED digits. The front panel controls are labeled with a two-color silk screen. The instrument top is extended forward to protect the LED digits from direct overhead light and the instrument bottom has a tilt stand for angled viewing. Four machine screws recessed in each side allow easy removal of instrument covers. An exploded view of the meter assembly is in Fig. 3.

Begin construction with the two PC boards. Figures 4 and 5 are foil patterns for the bottom and top sides of the master board while Fig. 6 shows the component layout. Similarly, Figs. 7 and 8 are foil patterns for the display board while Fig. 9 shows parts placement. All components, with the exception of the POWER/RANGE switch and trimmer capacitor C2, mount on the component screened side of the PC board. Refer to Figs. 5 and 6 for component placement. Use a 20- to 25-watt small-tipped soldering pencil and small diameter solder. Be careful not to force solder through the plated-through holes as shorts can result from solder pools on the component side of the PC board. Do not install the IC's at this time.

The POWER/RANGE switch assembly is installed using No. 4 1/16-inch-thick fiber washers next to the PC board. See Fig. 3 for assembly details. Assemble the front and rear panels and side rails using hardware provided. Set the assembled PC boards in place on the chassis. The main counter board bolts to the side rails at four locations. When the two PC boards are aligned there are eight mating pairs of foil fingers that will be soldered to connect the two boards. Place a 1-inch piece of excess component lead in the hold in the third finger from each end of the display board. With the component lead wires centered in the display board as shown, solder to the foil finger and bend each side of both wires down to align with

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*Product Engineers, Optoelectronics, Inc.

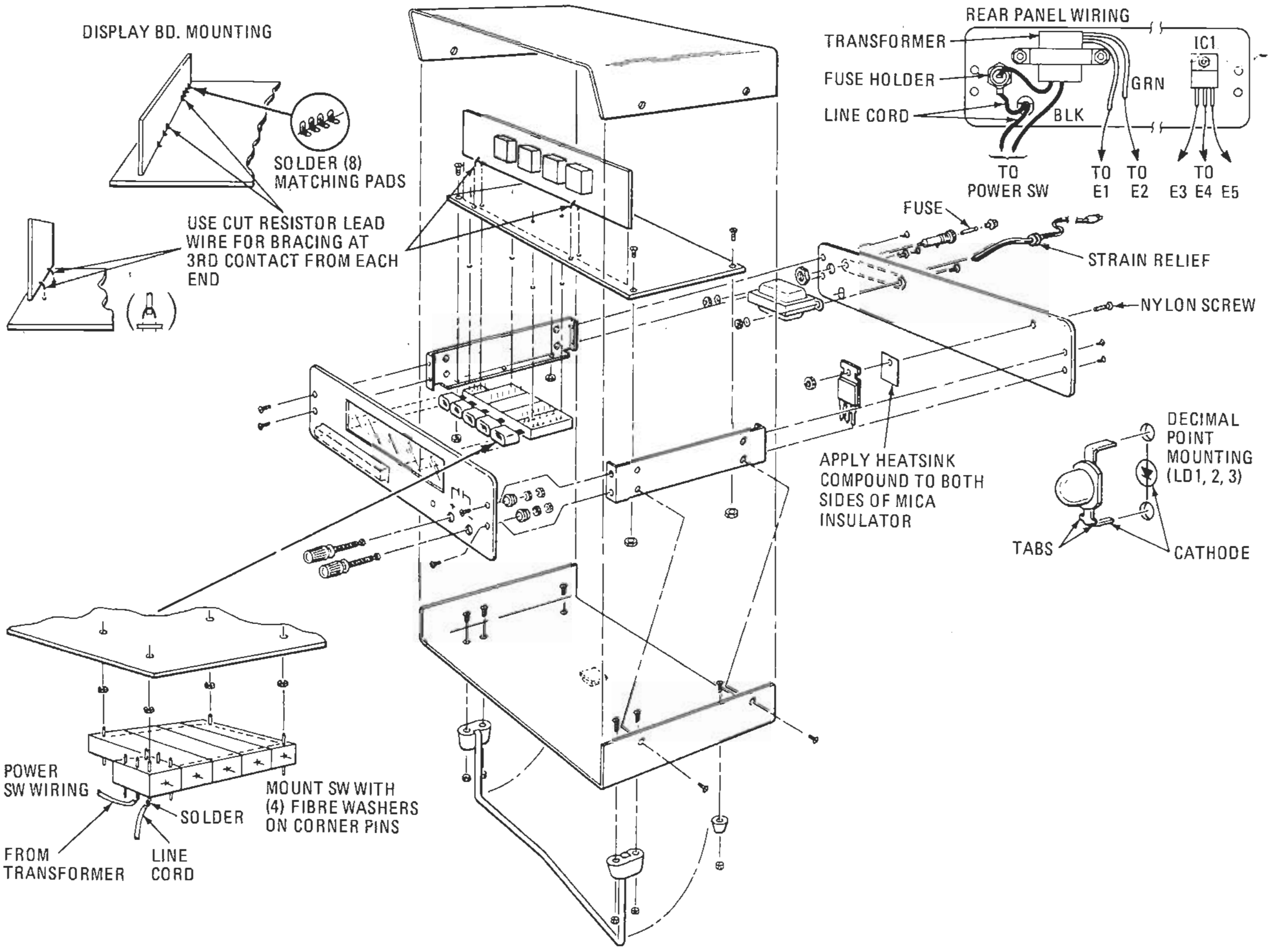


FIG. 3—EXPLODED VIEW of the model CM-1000 digital capacitance meter. Parts are as supplied in the kit. Use this as a guide if you build your meter from scratch.

PARTS LIST

Resistors are 10%, ¼ watt unless otherwise noted

R1—243,000 ohms, metal film, 0.25%, ⅛ watt
R2—11,300 ohms, metal film, 0.25%, ⅛ watt
R3—2430 ohms, metal film, 1%, ⅛ watt
R4—220 ohms, 5%
R5, R8, R21—100 ohms, carbon potentiometer, 1 watt
R6—243 ohms, metal film, 1%, ⅛ watt
R7—33 ohms, 5%
R9, R11—10,000 ohms
R10—3300 ohms
R12, R14—330 ohms
R13—6.8 megohms
R15—8.2 megohms
R16—180 ohms
R17-R19—2200 ohms
R20—1000 ohms
R22—11 megohms
R23-R26—100 ohms
R27, R28—4700 ohms
C1—47 pF NPO disc
C2—15-60 pF, ceramic trimmer
C3, C13, C19, C23—0.47 μF, 50 volts
C4, C5—3.3 μF tantalum
C6—.001 μF
C7, C8, C9, C11, C12, C14, C17, C20, C27, C28—0.1 μF
C10—.01 μF
C18—.02 μF
C21—3300 μF, 16 volts, electrolytic
C22—220 μF, 25 volts, electrolytic
C24—33 pF NPO disc
C25—8.2 pF NPO disc
C26—470 pF disc
D1-D4—1N4002 silicon rectifier diode
IC1—556 dual timer
IC2-IC4, IC12, IC14, IC16, IC18—74LS90 decade counter/divider
IC5—74LS73 flip-flop
IC6—4001 quad NOR gate
IC7—74LS04 hex inverter
IC8, IC9—74LS00 quad 2-input NAND gate
IC10—SE555 precision timer
IC11—voltage regulator, 7805
IC13, IC15, IC17, IC19—4511 BCD to 7-segment decoder/driver
DIS1-DIS4—MAN-6680 7-segment LED display
XTAL1—quartz crystal, 3.579 MHz
S1-S5—5-gang SPST pushbutton switch
T1—power transformer, 117 VAC primary, 10 VAC secondary
J1, J2—insulated banana jack
F1—120-volt, 125-mA fuse
Miscellaneous: PC boards, 1 8-pin IC socket, 4 16-pin IC sockets, 14 14-pin IC sockets, line cord, hardware

The following parts are available from Optoelectronics, Inc., 5821 N.E. 14 Avenue, Fort Lauderdale, FL 33334.

CM-1000K Complete Kit	$129.95
CM-1000WT Factory Wired & Tested	179.95
CM-1000 PC Boards Only	24.95
P-1000K Cap. Counter Probe Kit	3.95
P-1000 Assembled Probe	6.95

Add 5% shipping, handling and insurance, for foreign orders add 10%. Florida residents add 4% State Sales Tax.

holes in the main counter board. Insert the wire ends in their respective locations on the main counter board and push the display board down until the foil finger pairs touch. Check alignment to see that the display board is at right angles to the counter board and that the foil fingers are perfectly aligned. Solder the wires to the main counter board and after rechecking alignment solder the matching foil fingers together.

Feed 6 feet of the AC line cord through the back panel and secure using plastic strain relief. Mount the transformer, fuse holder, using hardware provided on the back panel where indicated. Wire one side of the AC line through the power switch to the transformer primary as shown. The other side of the AC line runs to the other side of the transformer primary through the fuse holder.

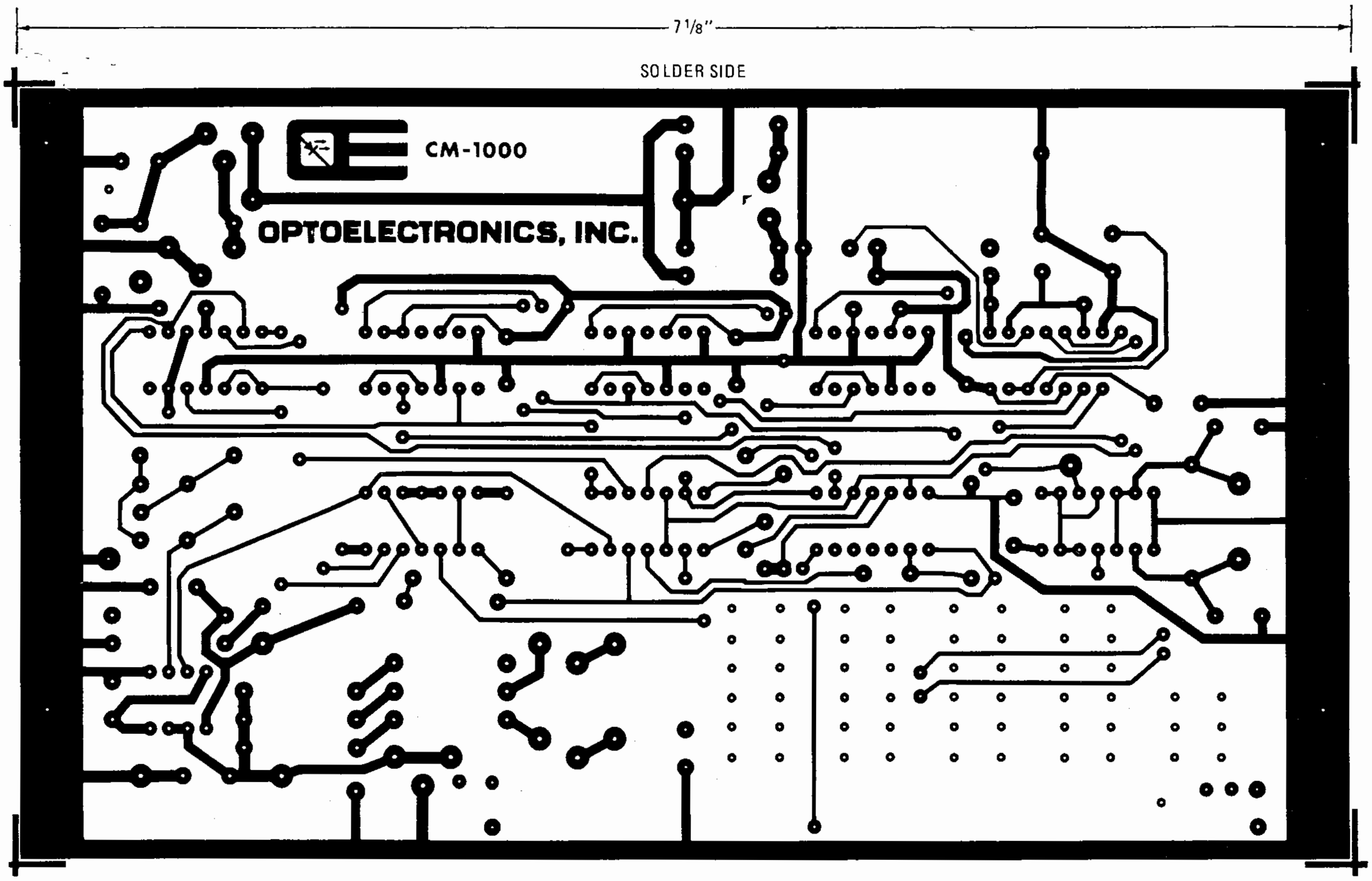


FIG. 4—**FOIL PATTERN** for the bottom (solder) side of the main board.

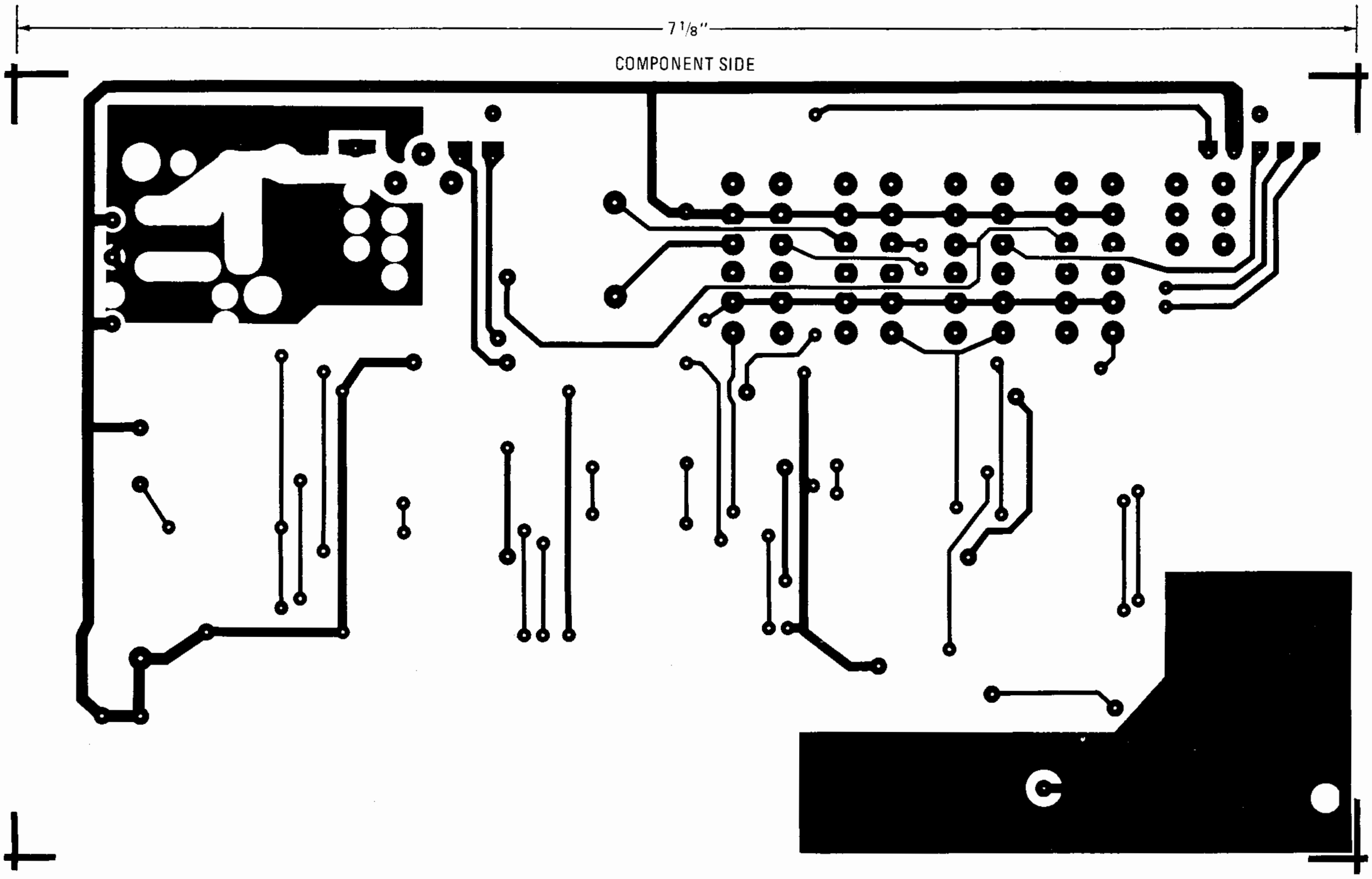


FIG. 5—**COMPONENT-SIDE** foil pattern. Board supplied in kit has plated-through holes. Compensate for lack of hole plating if you make your own boards.

Before installing IC's into sockets, perform a simple test by plugging in the AC power cord and depressing one of the range switches. Connect a voltmeter between the negative input terminal on the front panel and test point 1 (TP1). It should be possible to measure 5 volts DC by adjusting R21. If the voltage checks, then install all IC's in their sockets making sure that the notch on the IC is aligned with the outline on the printed-circuit board.

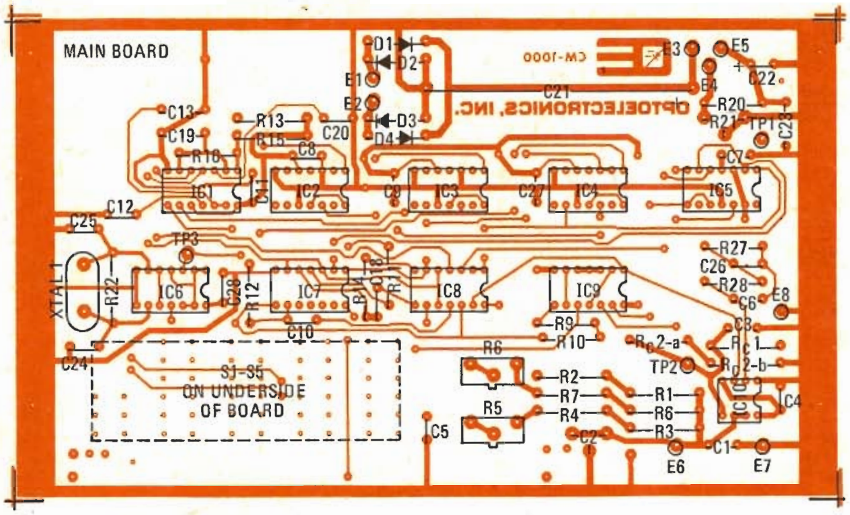
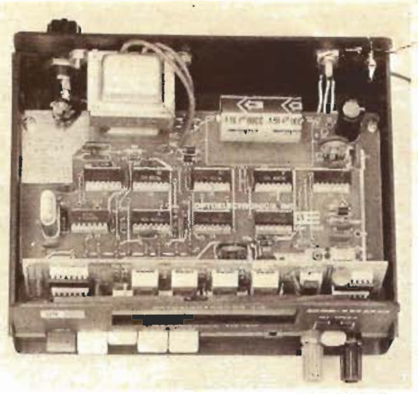


FIG. 6—COMPONENT LAYOUT for the main board. Trimmer capacitor C2 is mounted on underside of board. See text on R_c1 and R_c2.



INTERIOR VIEW of the Optoelectronics model CM-1000 digital capacitance meter.

Calibration

With IC's installed, reapply power and adjust TP1 for +5 volts referenced to ground. Depress the R1/PF switch and use a small bladed screwdriver to turn the ZERO ADJUST control (trimmer capacitor C2) until a reading of 0001 is observed. Continue to turn the control until the "1" turns to "0." **Do not adjust any further.**

The next step requires the use of an accurately known capacitor. The parts kit includes a calibrated capacitor with its value marked on the package. Connect this capacitor across the input terminals and depress the R3/μF switch. Adjust trimmer R5 to produce a reading equal to the value given.

Use a low-leakage capacitor between 10 and 22 μF to calibrate range **R4/μF** with trimmer R8 by comparing its reading to that observed on the previously calibrated R3/μF range. **R-E**

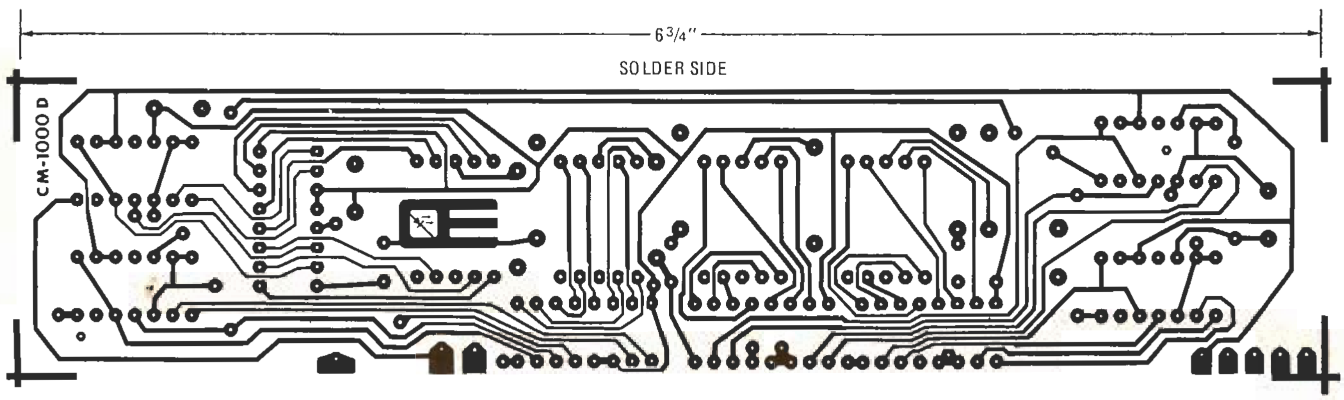


FIG. 7—BACK SIDE OF DISPLAY PANEL is etched with this foil pattern.

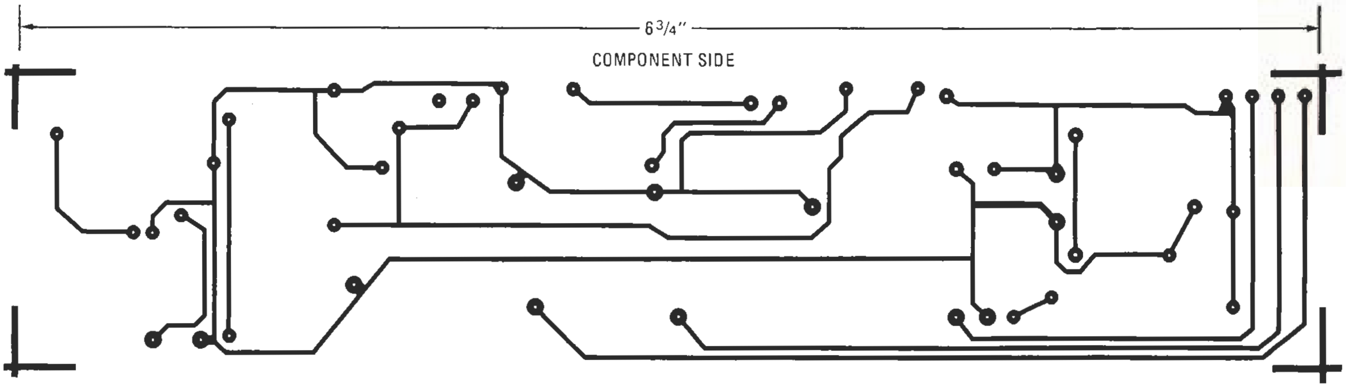


FIG. 8—FOIL PATTERN for the component (front) side of the display PC board.

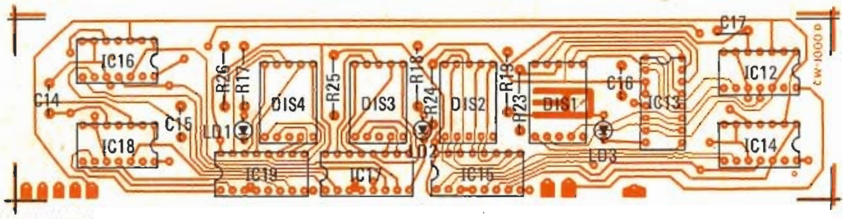


FIG. 9—DISPLAY BOARD components are laid out as shown. Decade counters and driver IC's are on board along with the LED displays and a few capacitors and resistors.

CAPACITANCE-METER ERRORS

In the capacitance-meter article in the July 1989 issue of **Radio-Electronics**, Fig. 3 shows pin 7 of IC3 (the 555 astable) connected to R13 or R14 via switch S3-b, with both potentiometers grounded. Figure 1 in the sidebar on page 40 shows pin 7 connected to the collector of an internal NPN transistor. Also, pin 7 of IC1 and IC2 (the 555 monostables) is tied to +5V. Even if a 555 astable could function with pin 7 grounded, your schematic shows pin 2 tied to pin 4. Checking on a breadboard shows that there's *no way* for a 555 to function with pins 4 and/or 7 grounded.
RICHARD P. MARQUISS
Wheaton, MD

You're right. The bottom terminals of R13 and R14 (connected to switch S3-b in Fig. 3 on page 39), and pin 4 of IC3 should be tied to +5V, not ground. However, pin 6 is correctly connected to C6. Although wrong in the schematic, the PC board and Parts-Placement diagram are correct.

We also found several errors in the sidebar on pages 40–41 that you didn't notice. The two "PRESENT/ABSENT" labels in the upper left-hand corner of Fig. 1 in the

OOOOPS!

There are errors in the schematic of the digital capacitance meter on page 38 of the December 1977 issue. Capacitor C3 is .001 μF as in the parts list; not .01 μF. The number 6 pins of displays DIS1, DIS3 and DIS4 should go to R42, R43 and R44, respectively, instead of to the points indicated in the diagram.