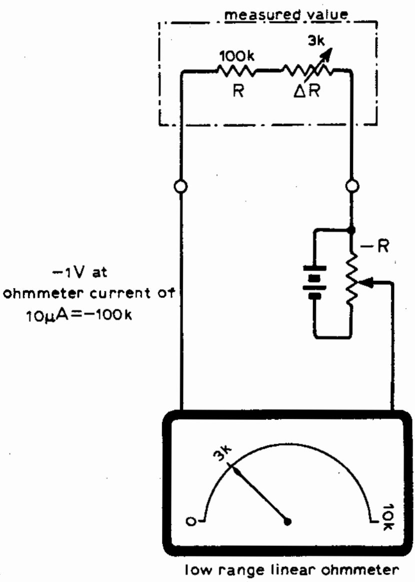
Cancellation by negative resistance provides alternative to Wheatstone bridge

When a small resistance variation must be measured in the presence of a large fixed resistance, the Wheatstone bridge technique is usually used. A better way, which eliminates balancing and/or output voltage signals which are a non-linear function of resistance change, is the use of a linear ohmmeter and negative resistance cancellation of the high fixed resistance value. A linear ohmmeter produces a constant current at its terminals; this allows the use of a potential as a negative resistance because the fixed current holds the Q-point of the battery or source of potential at some constant negative resistance value. Then the ohmmeter may be used on a low range (on which it would be pegged without the bucking voltage) to show the small resistance value change.



In the example shown, a battery and low-resistance potentiometer is used as a variable voltage source to produce the negative resistance value to cancel 100 kΩ of the unknown's total value, allowing the variation value of 3 kΩ to be read on the 10 kΩ range of the linear ohmmeter.

The linear ohmmeter may be any commercial instrument, such as the digital instruments available with resistance measuring ranges.

David R. Schaller,
Milwaukee,
Wisconsin

Test Adapters

A series of adapters, using a multimeter as their indicating device, saves space and money

By **ROBERT F. SCOTT**
TECHNICAL EDITOR

NOT so many years ago a service technician could tackle any radio or audio repair job with a tube checker and multimeter. The multimeter alone was enough to see him through a service call to a local factory or theater. Now, with TV, hi-fi audio, intercoms, transistorized equipment and electronic industrial controls—much of which must be serviced on the spot—a technician in the field may need a vtvm, battery and transistor testers and an ac ammeter. For audio servicing he may need a calibrated attenuator (microvolter) to obtain extremely low outputs from his af generator and an audio wattmeter for checking amplifiers and allied equipment.

Adding these to the normal shop complement of service equipment is a financial drain on many technicians. And the bulk puts a premium on space in the service truck.

One way to lick the space problem and reduce the financial outlay has been presented by Simpson with a new line of seven Add-A-Tester adapters for the famous 260 multimeters and the recently introduced model 270. The Add-A-Testers include an audio wattmeter, dc vtvm, audio microvolt attenuator, ac ammeter, and also temperature, battery and transistor testers. Each adapter measures 5-5/16 x 4-⅜ x 3-7/16 inches, and plugs into the bottom of the 260 or 270 vom as shown in the photograph. Adapter weight ranges from 12 ounces for the transistor tester to 2 pounds for the vtvm and ac ammeter.

The model 260 is a popular multimeter that has been made in three versions. The series I cannot be used with the Add-A-Testers. It is identified by its flat, square-cornered panel. The Series II has a raised panel with rounded corners, uses pin jacks and has a 100-μa dc range. The series III looks a lot like the series II and is distinguished by its 50-μa dc range and banana jacks.

Inexpensive adapter case kits are available for using the series II and III 260's and the 270's produced prior to June 1, 1959. Adapter case kit model 401 is optional. It consists of a modified instrument case that permits latching the Add-A-Testers securely to the underside of the multitester. The 402 case kit for the series II 260's consists of a modified case and parts necessary for adding a 50-μa dc range. This kit is necessary when using the series II instruments with the vtvm and temperature, transistor and battery testers requiring the basic 50-μa movement.

The Add-A-Tester adapters have four banana plugs arranged along the top rear so they mate with jacks on the 260/270 multimeter. Four extra pin type plugs are supplied with each adapter so they can be used with series II 260's. All adapters have a switch (or special position on the function or range switch) that permits the multimeter to be used for its normal functions without detaching the adapter.

Model 650 transistor tester

The 650 Add-A-Tester provides beta and I_{CO} measurements on general-purpose low- and medium-power germanium transistors. Power transistors and silicon junction types are checked by interpolation. Beta ranges are 0 to 10, 50 and 250 and the I_{CO} range is 0 to 100 μa.

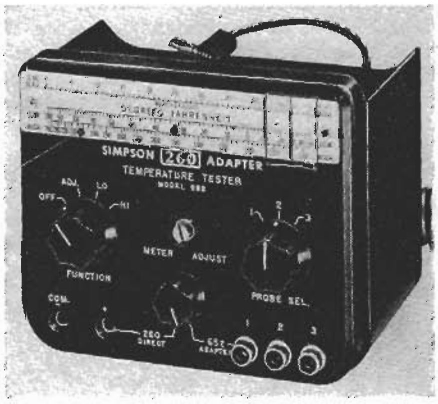
The circuit of the 650 transistor tester (Fig. 1) is essentially a bridge that balances when collector current is 1 ma. The BAT ADJ control sets the voltage applied to the bridge for optimum accuracy. In the initial setup, it is set so the meter reads 25 on the 50-volt dc range. The ZERO ADJ control varies the base to provide 1-ma collector current and balance the bridge.

The basic bridge circuit for measuring beta is shown in Fig. 2. When the BETA switch is in the 250, 50 or 10 positions, predetermined values of resistance are switched into the base circuit, thus changing the base current and unbalancing the bridge. Beta is read directly from the scale corresponding to the setting of the BETA switch.

The transistor tester uses the 50-μa movement of the 260/270. In use, the transistor is plugged in and the FUNCTION switch is thrown to NPN or PNP, depending on the transistor being tested. The BETA switch is set at BAT and the BAT ADJ control is set so the meter reads half-scale on the 50-volt

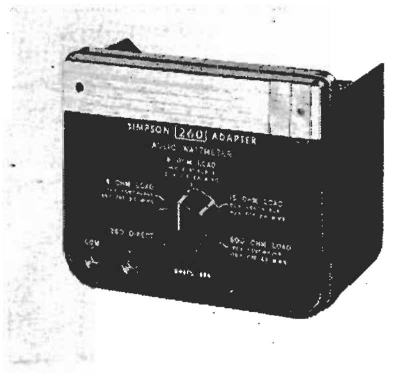
Model 260 multimeter and 650 transistor-tester adapter.

Model 651 dc vtvm adapter.

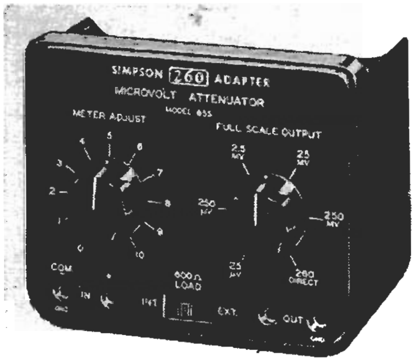


Model 652 temperature-tester adapter.

Ac ammeter adapter model 653.



Audio-wattmeter adapter model 654.



Model 655 microvolt-attenuator adapter.

Model 656 battery-tester adapter.

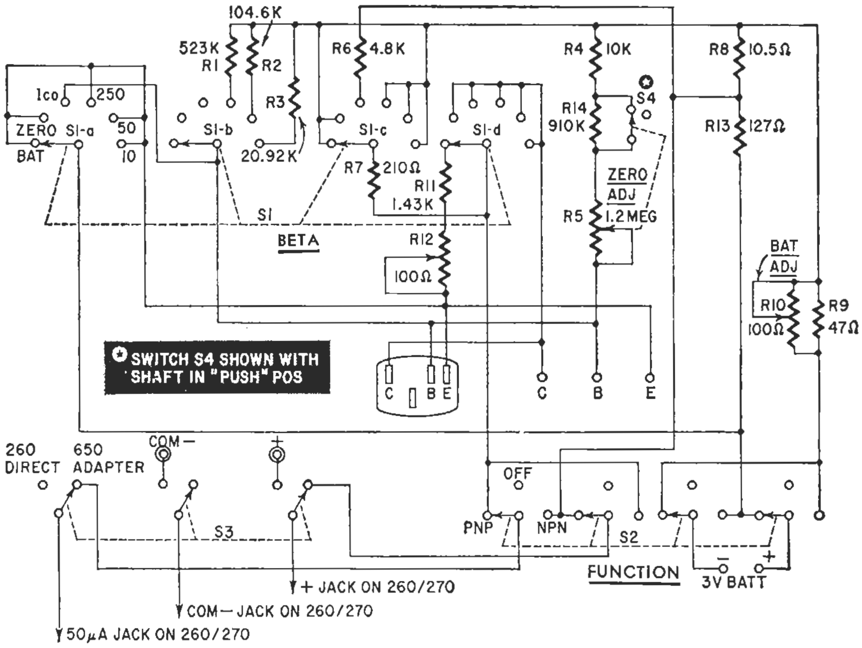


Fig. 1—Circuit of transistor-tester adapter, model 650. All adapters using 50-μa meter range have plug on short lead to connect to 50-μa jack on meter.

dc scale of the meter. The BETA switch is then set to ZERO and the ZERO ADJ control R5 is varied until the meter reads zero indicating bridge balance.

(The ZERO ADJ control is a combination pot, R5, and push-pull switch, S4. When pushed in, R14 is shorted out. The initial setup is made with the control pushed in. If the meter does not zero, the control is pulled out and the operation repeated.) If the meter still does not zero, the transistor is defective or has high leakage and must be checked as a power transistor.

When the BETA switch is advanced to I_{co}, the emitter circuit is opened and the meter reads collector current. Read the 0–10 scale on the meter and multiply by 10 for leakage in μa. Full scale is 100 μa. Compare this reading to the transistor data sheet. It should be equal to or less than the manufacturer's data.

Throwing the BETA switch to 250, 50 or 10 causes the meter to indicate beta directly on the corresponding scale of the 260/270.

Silicon transistors are checked like germanium types but the beta reading obtained must be multiplied by 1.16 for accurate evaluation.

Power transistors have high values of I_{co}, so it is not always possible to zero the meter with the ZERO ADJ control. In this case, the control is set for the lowest reading. The BETA switch is then thrown to 250 and the first reading is subtracted from the second. The difference is the beta of the transistor. When I_{co} is more than 100 μa, it is measured by switching the 260/270 to the 0–1 or 0–10–ma range and reading I_{co} on the corresponding scale.

Model 651 dc vtvm

This Add-A-Tester converts the 260/270 multimeter into a completely portable dc vtvm that meets the needs of the modern radio and electronics service technician. Its sensitivity (0.5 volt full scale on the lowest range) makes it especially useful in checking transistor circuitry and agc measurements. Its 10 full-scale ranges are 0–0.5, –1, –2.5, –5, –10, –25, –50, –100, –250 and 0–500 volts dc with an input resistance of 11 megohms. A FUNCTION switch turns the instrument on and off and selects polarity of the dc probe.

The vtvm uses a bridge type circuit with a triode-connected 1AG4 subminiature pentode. The self-contained power supply consists of two Eveready 413 30-volt B-batteries and two Mallory ZM-9 1.34-volt mercury cells in parallel for the filament supply.

The complete circuit of the 651 is shown in Fig. 3, a bridge-circuit analogy in Fig. 4. The battery voltages are equal in adjacent arms of the bridge so it is balanced and the meter reads zero when the filament–plate resistance of the tube equals the value of R17.

Voltages to be measured are applied to the grid of the tube. This unbalances the bridge and the value of the applied voltage is read directly on the meter scale specified for the setting of the 651's range selector switch. When using the 651 with the 260 multimeter, the accuracy is ±3% full scale and ±5% of the reading. With the 270 multimeter, the accuracies are 2% and 4% respectively.

The FUNCTION selecter should be set for the polarity of the voltage being measured. It is connected so the positive "side" of the voltage being measured is connected to the grid of the tube. The ZERO ADJ control should be set on each voltage range. It is adjusted so the meter pointer is exactly over the zero

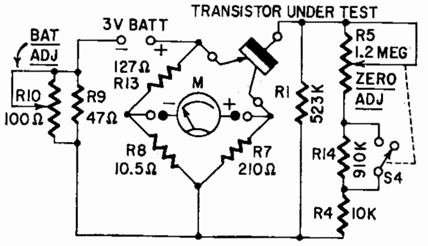
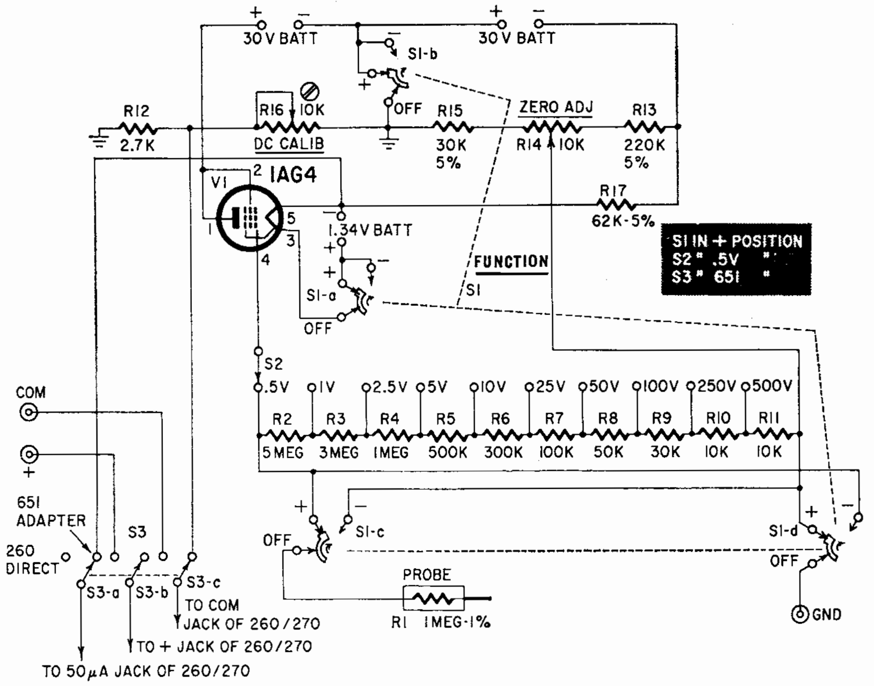


Fig. 2—Equivalent circuit of transistor tester with switch in Beta 250 position.

Fig. 3—Schematic of model 651 dc vtvm.



line with the dc probe connected to the ground terminal.

Model 652 temperature tester

This is a self-powered instrument for measuring temperatures from −50° to +250°F in two ranges. The low range goes up to 100°, the high from 100° to 250°F. Accuracy ranges from ±2° to ±4°, depending on the temperatures covered. The model 652 handles up to three temperature probes and comes with one probe with a 15-foot lead. Other probes are available with 30-, 50-, 100- and 150-foot leads.

The temperature tester is a battery-powered bridge with a thermistor probe in one arm. The probe is placed in the location where temperature is to be measured. The circuit is shown in Fig. 5. The bridge uses the 50-μa movement of the 260/270 with readings taken on the 50-volt dc scale. A slide rule across the top of the 652 converts the meter readings to temperature.

The FUNCTION switch is marked OFF, ADJ, LO and HI. It turns the instrument on and off, sets up the bridge for balancing and selects the temperature range. In the ADJ position, the battery is connected across the bridge with the probe disconnected. The METER ADJ control (R3) is set so the meter reads 25. This is half-scale when set on the 50-volt range.

When measuring temperature, the thermistor probe is substituted for R9 and calibrate pot R11. Bridge sensitivity is changed for the two ranges by varying the resistances of the three arms. On the LO range, R1 is shorted out for measurements up to 100°. R2 and R12 are short-circuited for measuring temperatures ranging between 100° and 250° on the HI range.

The meter pointer deflects off scale on the right if the temperature is below −50°F and off scale on the left if it is above 100°F on the LO range. If the pointer deflects off scale to the left on the HI range, the temperature is above 250° and the probe must be removed from the high-temperature area to prevent damaging it.

Ac ammeter model 653

This instrument measures alternating currents in ranges of 0–0.25, –1, –2.5, –12.5 and 0–25 amps with frequency response essentially flat from 50 to 3,000 cycles to cover power-frequency requirements of military and commercial supplies. Insulation is for 600 volts rms maximum.

The ac ammeter (Fig. 6) is a current transformer with a tapped primary and a secondary loaded by a precision resistor. The primary is inserted in series with the circuit being metered. Current in the primary induces a proportional current in the secondary and the 4-ohm load resistor. The current in the primary circuit is obtained by taking a reading on the 2.5-volt ac scale of the 260/270 and multiplying it by the factor indicated above the range binding post used.

Model 654 audio wattmeter

The wattmeter is designed for use in installing and servicing audio equipment. It provides noninductive 4-, 8-, 16- and 600-ohm loads for circuits being metered. Frequency response is flat from dc to 20 kc. Maximum wattages (with ambient temperature of 77°F) are 50 watts continuous and 100 watts for 2½ minutes with 4- and 16-ohm loads and 25 watts continuous and 50 watts for 2½ minutes with 8- or 600-ohm loads.

The circuit diagram of the 654 audio wattmeter is in Fig. 7. The "+" and "−" INPUT terminals on the 654 are connected directly to the corresponding terminals on the 260/270 multimeter. When the five-position LOAD SELECTOR is in the 260 DIRECT position, the test leads are connected to the multimeter so it can be used for any of its normal functions without detaching the adapter. In the other four positions of the LOAD SELECTOR, one or more of the internal load resistors are bridged across the INPUT terminals and the 260/270.

When the 654 is being used, the normal equipment load—speakers, phones,

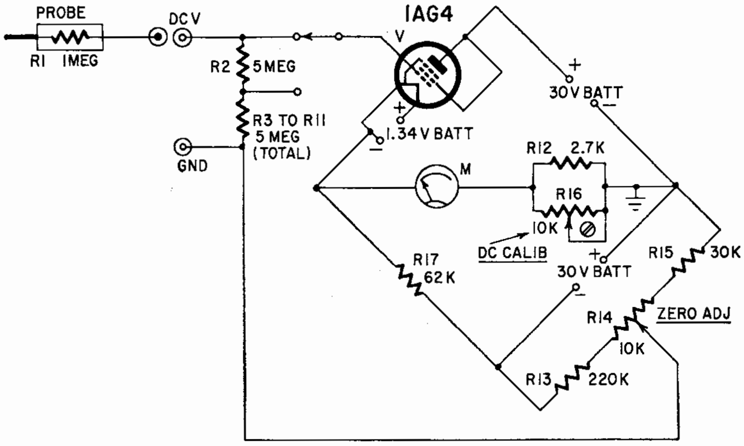


Fig. 4—Bridge circuit of 651 dc vtvm.

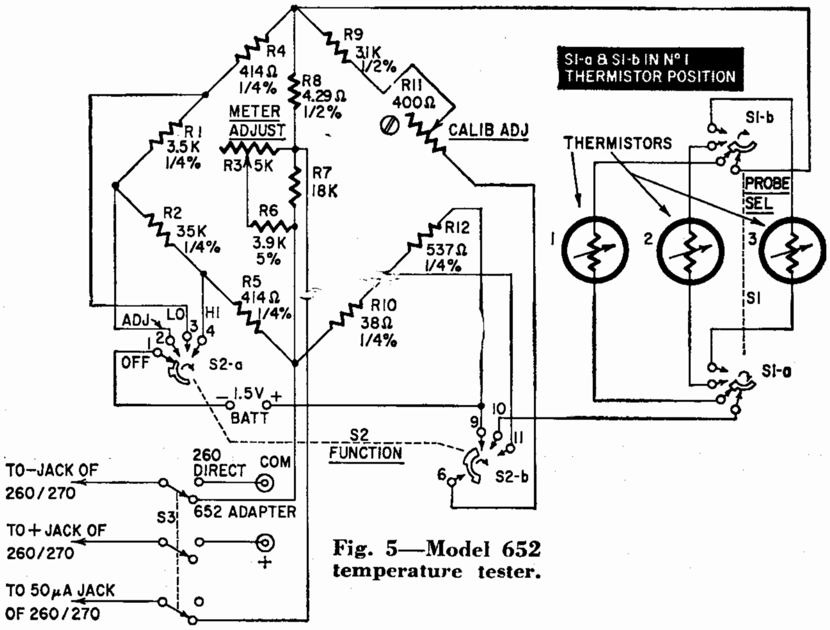


Fig. 5—Model 652 temperature tester.

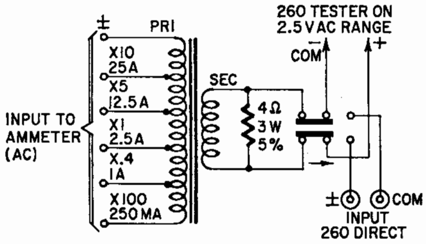


Fig. 6—Ac ammeter, model 653.

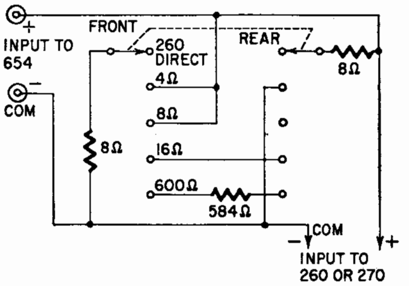


Fig. 7—Audio wattmeter model 654. Load-selector switch selects various load-resistor combinations.

lines, etc.—is removed from the output of the circuit or equipment being metered. The LOAD SELECTOR is set to the impedance matching the nominal circuit load. An audio voltage is fed into the unit being tested and the wattmeter measures the voltage across its load resistors on one of its ac voltage ranges. An attached slide rule converts the voltage reading to watts.

655 microvolt attenuator

This instrument provides calibrated low-level outputs ranging from 25 μv to 250 mv from a 2.5-volt ac or dc source. Its frequency response, essentially flat from 0 to 20 kc, makes it an excellent source of precise low voltages. It consists of an input level control—METER ADJ—and a five-position 600-ohm ladder attenuator. Each section of the ladder reduces the signal 20 db or to one-tenth of its input level. The input impedance is 2,000 ohms. An internal 600-ohm load resistor can be switched in or out, depending on the resistance or impedance of the external load circuit.

The input voltage is applied across the 2,000-ohm METER ADJ control and the 260/270 multimeter measures the voltage applied to the ladder attenuator (Fig. 8). When the ladder's input is exactly 2.5 volts, the microvolter's output is 25 μv, 250 μv, 2.5 mv, 25 mv or 250 mv, depending on the range selector switch—marked FULL-SCALE OUTPUT. When the input to the microvolter is greater than 2.5 volts—maximum input is 33 volts—the output is equal to the meter reading multiplied by the attenuation factor corresponding to the range setting.

The 600-ohm internal load resistor is used when the microvolter's output is connected to a circuit with an input impedance of 60,000 ohms or higher. When the impedance is less than 60,000 ohms but greater than 600 ohms, the 600Ω LOAD switch is thrown to OUT. An

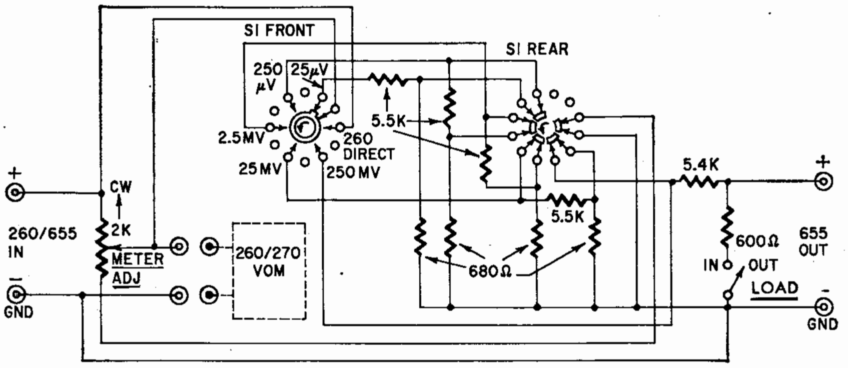


Fig. 8—Model 655 microvolter schematic.

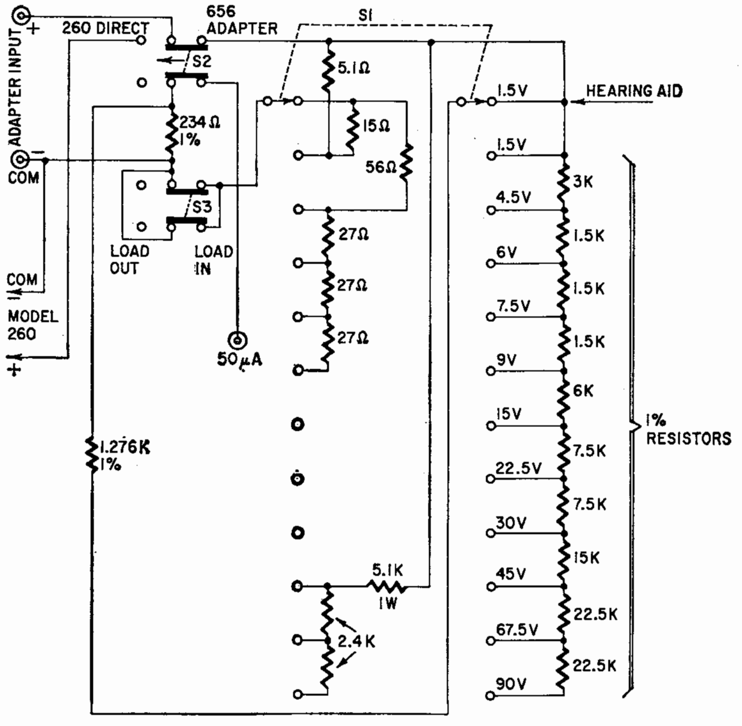


Fig. 9—Model 656 battery tester. Batteries checked under recommended load.

external resistor is shunted across the circuit so the load on the microvolter appears as 600 ohms. The value of the external shunt resistor R_x equals $600 \times R/600 - R$, where R is the input resistance (or impedance) of the circuit being supplied.

When the input resistance (or impedance) of the external circuit is less than 600 ohms, the 655's internal load resistor is switched out and a resistance sufficient to bring the load impedance up to 600 ohms is inserted in series with one of the output leads. Voltage across the external circuit's input is proportional to the 655's output or $R \times E_o/600$, where R is the resistance of the load and E_o is the output voltage of the microvolt attenuator.

Battery tester model 656

This instrument tests, under suitable load, the batteries most commonly used in radio, hearing-aid and industrial service. The adapter has 12 voltage ranges. One for small 1.5-volt hearing-aid batteries and 1.5-, 4.5-, 6-, 7.5-, 9-, 15-, 22.5-, 30-, 45-, 67.5- and 90-volt ranges for A- and B-batteries.

The 656 (Fig. 9) has a slide switch which, when in the LOAD IN position, shunts the battery under test with the manufacturers' recommended load. In the LOAD OUT position, the shunt is disconnected and the battery can be tested under normal in-circuit operating conditions. The metering circuit draws a maximum of 1 ma.

The 656 uses the 50-μa movement of the 260/270. The multitester is set up for measurements on the 50-volt dc range and readings are made on that scale. A slide rule with three basic scales is mounted across the top of the adapter's case. The top is calibrated 0 to 50, the middle is marked BAD-WEAK-GOOD (for radio and hearing-aid batteries and all B-batteries). The bottom scale is calibrated from 0 to 110% (of the selector voltage range).

In testing a battery, the adapter's range-selector switch is set to the battery's terminal voltage and the meter is read on the 50-volt dc scale. The hairline on the slide rule is placed over the meter reading on the top scale and the battery condition and percent of rated voltage are read on the middle and bottom scales of the rule. Actual battery voltage is found by multiplying the range-selector setting by the indicated percentage. END

AMATEUR CONVENTION

The Hudson Amateur Radio Council is holding its first annual convention at the Statler-Hilton Hotel in New York City. It will open at 10 am Saturday, Oct. 15 and close at 7 pm with a banquet. There will be technical talks, meetings, manufacturers' exhibits and prizes. The convention is being run entirely by the amateur clubs of the New York area and everyone within commuting distance is invited. For information write HARC Convention, PO Box 971, New Rochelle, N. Y.

CAPACITOR TEST BOX FINDS INTERMITTENTS

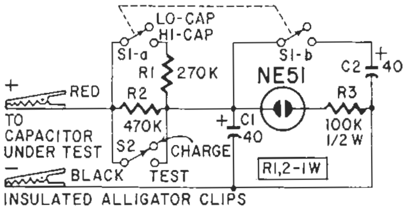
By JAMES A. FRED

IT'S hard to locate an intermittent electrolytic with in-circuit tests. If you try shunting the suspected unit with a good electrolytic, the charging current may temporarily heal the bad one. Then when you remove the test capacitor the set appears to work normally and you still don't know what's wrong.

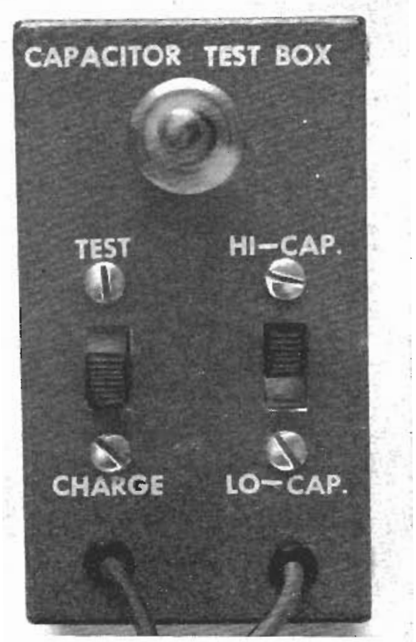
After running into this problem a couple of times, I decided to build an electrolytic test box that would pick up bad capacitors without healing them. The unit I devised is shown in the diagram and photos.

A neon lamp and its series current-limiting resistor are connected across a test capacitor. The lamp lights when the capacitor is charged. Charging resistors are switched in and out of the circuit by S2, the CHARGE-TEST switch. Switch S1 gives you either a 40-μf test capacitor (LO-CAP) or connects two 40-μf units in parallel to form an 80-μf unit (HI-CAP). At the same time, another section of S1 changes the value of the charging resistor—either R2 by itself (for 40 μf) or R2 and R1 in parallel (for 80 μf).

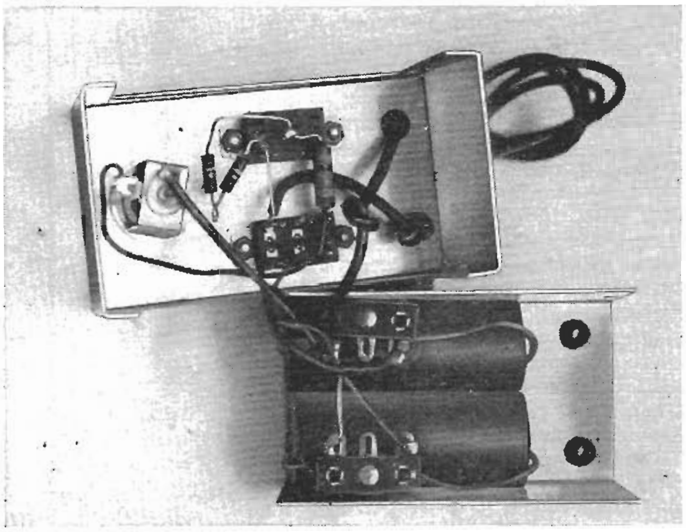
Using the checker is easy. Just set S1 for high or low—40 or 80 μf and S2 to CHARGE. Then connect the tester to the capacitor under test with its insulated test clips—of course, you have already turned on the defective radio, hi-fi or TV. Wait for the neon lamp to light. Now slide S2 to the TEST position. If the capacitor under test is bad, the fault should vanish. If the fault remains, obviously the capacitor is good. Before going on to the next electrolytic, discharge the checker by shorting the red and black test leads. END



Circuit of simple test unit.



Completed electrolytic tester.



Parts layout inside checker.

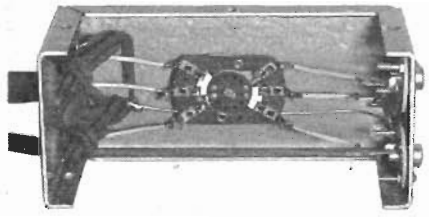
AUDIO COMPARATOR

By J. E. PUGH, JR.

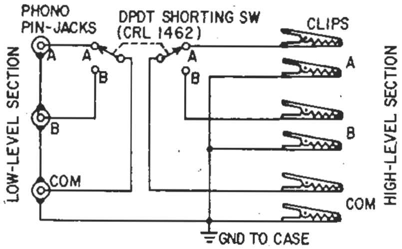
THIS simple, inexpensive instrument can be used to make rapid comparison tests on hi-fi tuners, phonographs, microphones, amplifiers, ac and dc voltage levels, the phasing of multi-speaker installations, or nearly any other use where it is desirable to compare levels or quality. It is useful in hi-fi sales and service and public address work. In addition, it can be used for switching between two or more turntables at dances or get-togethers.

A dpdt shorting type switch (Centralab 1462 or equivalent) is used in this model for comparing any two similar components. This will take care of most applications but, if you want to compare a larger number of units, use a two-pole switch with more positions and a correspondingly greater number of connectors.

The completed unit, ready to use.



Inside view of Comparator shows simple construction.



Circuit of the Audio Comparator.

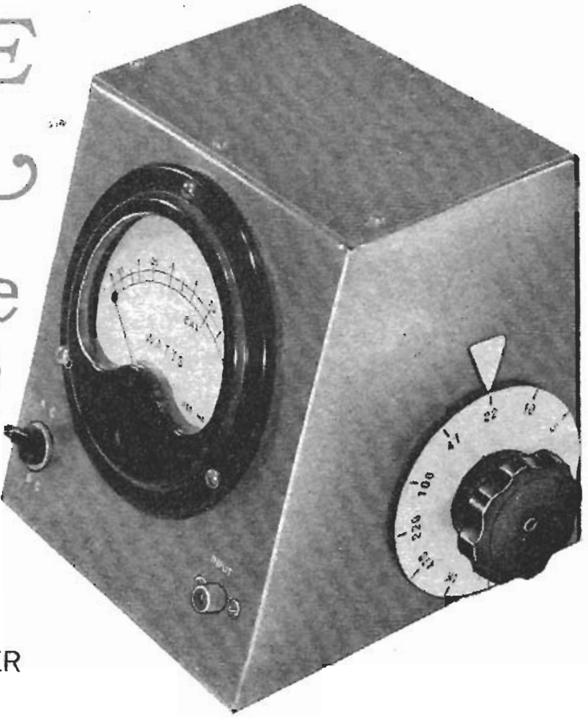
Phono pin jacks are used on the low-level section to minimize hum and noise pickup. This section of the comparator is used where the signal level is low, such as at the input of an amplifier. The high-level section uses 5-foot lamp cords terminated in Mueller type 45 clips. It is used for tests on amplifier output and speaker systems.

The parts are mounted in a 2¼ x 2¼ x 5-inch aluminum box. Accessories include two 3-foot mike cables terminated with phono pin plugs and two 25-foot lamp-cord clip leads.

To compare high-impedance, low-level components such as microphones, phonographs or tuners connect one unit to jack A, the other to jack B and the indicator to the common jack. Amplifiers are compared by connecting the input and output of each amplifier to the corresponding A and B channels. Apply the input signal to the common jack and the speaker to the common clip lead. Compare speaker quality by connecting one unit to clip lead A, the other to clip lead B, and the amplifier output to the common clip lead.

Check speaker phasing by connecting the A and B clip leads to their voice coils and a type-C or -D flashlight cell with a 5.6-ohm resistor in series to Common. Switch between speakers to see that their cones move in the same direction for correct phasing. If this test is to be made often, such as when making PA installations, install the battery and resistor in the box and use a spst toggle switch to connect it between ground and the high-level switch arm when needed. END

UNIQUE POWER & Impedance METER



READ MAXIMUM OUTPUT OF AMPLIFIERS, SIGNAL GENERATORS AND LOW-POWER TRANSMITTERS

BY ROY HARTKOPF

MEASURING VOLTAGE, current or resistance is relatively easy; all you need is a VOM or VTVM. However, when it comes to measuring power, most experimenters run into trouble. One difficulty is that two independent variables must be measured at the same time: either voltage and current, voltage and resistance, or current and resistance. This may not be too difficult, but if you want to measure *maximum* output power of an amplifier, signal generator, or low-power transmitter, the problem is complicated by the fact that, when making the measurement, the load impedance must match the output impedance of the device being tested.

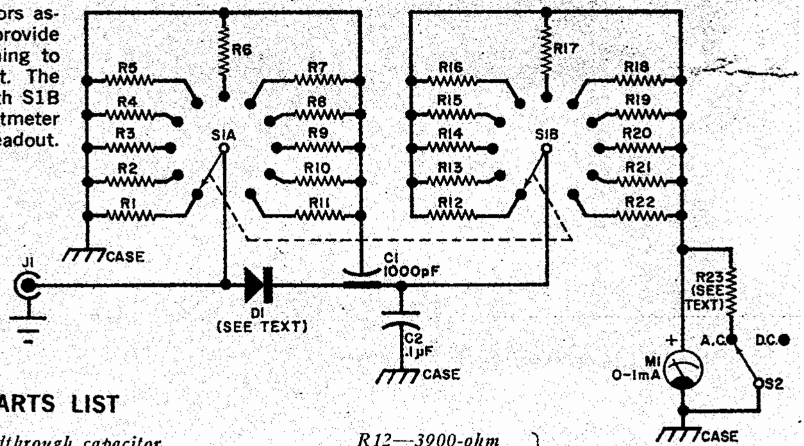
The "Power and Impedance Meter" described here is a low-cost, signal-powered instrument that measures power output from a few milliwatts to 3 watts and simultaneously (and automatically) matches the output impedance from 4.7 to 10,000 ohms. What is more, the meter has a frequency range from d.c. to about 150 MHz! It has no power supply or semiconductor circuitry; and does not require alignment or maintenance.

The power meter is very easy to use: simply connect it to the output to be measured and rotate a single switch until a meter calibrated in watts indicates a maximum value. This is the maximum power output and the switch position indicates the approximate output impedance of the circuit being tested. The test set can be modified easily to indicate output impedance almost exactly.

Construction. The Power and Impedance Meter is constructed in an enclosed metal case to prevent excessive radiation when the test set is used with a low-power transmitter. A sloping front panel is convenient but any other shape is satisfactory.

The load resistors associated with switch *S1A* (*R1* through *R11* in Fig. 1) should be 2-watt, non-inductive units whose tolerances are chosen for the amount of reading accuracy desired, keeping in mind that the ultimate accuracy depends on the meter movement itself. The ohmic values of the resistors shown in the Parts List were selected to cover most loading cases.

Fig. 1. The resistors associated with S1A provide impedance matching to circuit under test. The resistors used with S1B make up a voltmeter using M1 as the readout.



PARTS LIST

C1—1000-pF, feedthrough capacitor
C2—0.1-µF capacitor
D1—Germanium rectifier diode (see text)
J1—Phono jack or other coaxial fitting
M1—0-1-mA meter
R1—4.7-ohm
R2—10-ohm
R3—22-ohm
R4—47-ohm
R5—100-ohm
R6—220-ohm
R7—470-ohm
R8—1000-ohm
R9—2200-ohm
R10—4700-ohm
R11—10,000-ohm

These resistors 2-watt non-inductive

R12—3900-ohm
R13—5600-ohm
R14—8200-ohm
R15—12,000-ohm
R16—18,000-ohm
R17—27,000-ohm
R18—39,000-ohm
R19—56,000-ohm
R20—82,000-ohm
R21—120,000-ohm
R22—180,000-ohm
R23—see text

These resistors ½-watt

S1—3-pole, 11-position rotary switch (see text)
S2—S.p.s.t. switch
Misc.—tin-plated shield material, metal enclosure, large knob with pointer, hookup wire, solder, hardware, etc.

The switch can be assembled outside the case. Although only two 11-position decks are required, the author used a three-deck switch with the third one serving as support for one end of the meter resistors (*R12* through *R22*). Disassemble the switch and make up a U-shaped, tin-plated metal shield that covers the front deck of the switch (see photo). The front end of the shield is clamped (and grounded to the chassis) with the switch mounting hardware. Drill holes in the rear of the shield for the rear leads of the load resistors (which are soldered to the shield). The front leads of the load resistors are soldered to the appropriate terminals on the front deck of *S1*. Resistors *R12* through *R22* are mounted between the center and rear decks of the switch. Remove the rotor segment of the rear deck to prevent accidental shorting of resistors.

Drill a hole in the corner of the shield that will be closest to input jack *J1*. This hole should be capable of accepting feedthrough capacitor *C1*, which is soldered to the shield. One end of *C1* is used as a support for diode *D1*. Capacitor *C2* is then soldered in position, and the completed switch assembly is mounted in the chassis. Mount switch *S2* and input receptacle *J1* on the panel.

Almost any diode will suffice for *D1*, but there are two factors which must be considered. With three watts (d.c.) across a 10,000-ohm load, there are 173 volts across the diode. With the same power and impedance, the a.c. voltage is about 250 volts peak. All germanium signal diodes will fail at this voltage level. At the other extreme, 30 mW across a 5-ohm load produces less than half a volt across the diode, which is below the threshold of conduction for a high-voltage silicon diode. In practice, these two extremes are seldom encountered, and the author has found that a germanium rectifier having a 120-volt PIV rating will suffice for almost all conditions.

To calibrate the meter scale for indicating power in watts, gently remove the meter-face protective covering, and recalibrate the scale in accordance with Table I. When this is done, mount the meter in the case.

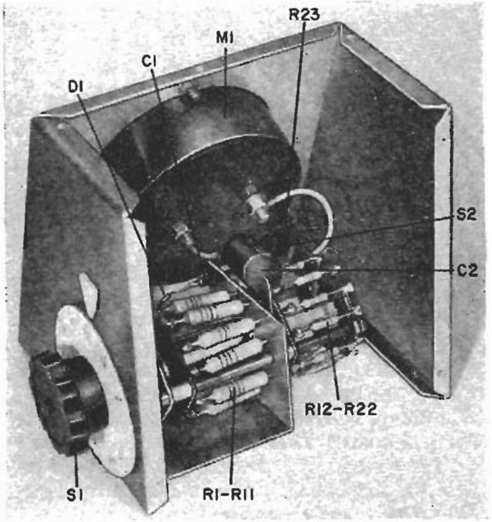
Because the r.m.s. value of an a.c. signal (assuming it is a sine wave) is only 0.707 of the peak value, it is necessary to have a shunt resistor in parallel with the meter during a.c. measurements. Since meters vary considerably in their internal resistance, the choice of this shunt resistor *R23* must be made to suit the meter you are using. To do this, connect a high-voltage supply and a potentiometer with a resistance of several thousand ohms in series with the meter. Adjust the potentiometer until the meter indicates exactly full scale (3 watts). Then connect various values of resistors across the meter terminals until the meter reads 1.5 watts (the CAL position on the scale).

TABLE I—METER CALIBRATION

WATTS	mA
3	1.0
2.5	0.91
2	0.82
1.5 (CAL)	0.707
1	0.57
0.75	0.5
0.5	0.41
0.25	0.29
0.1	0.185
0.05	0.13
0.01	0.057

Since the meter now indicates peak, rather than r.m.s., power, it cannot be expected to give exact results for inputs that are not sine waves. However, this method is used in most VTVM's and has proved to be quite satisfactory in practice, particularly at very high frequencies. Once *R23* has been selected, wire the test set in accordance with Fig. 1.

Operation. Connect input receptacle *J1* to the amplifier, signal generator, or low-power transmitter to be tested. Set *S2* to the AC position, and turn on the system. Rotate *S1* until the meter indicates the highest power output and read the switch position. For example, if the test set indicates maximum power of 1.5 watts at 470 ohms, you know that the device under test has an output impedance of 470 ohms (or close to it) and an output of 1.5 watts. If, on the other hand, you find that the meter indicates 0.5 watts in both the 220- and 470-ohm positions, the correct impedance is about 350 ohms and the power output is a little over one watt.



Mount the resistors, shield, C1, and D1 before installing the switch in the chassis. Grounding, through switch mounting hardware, must be tight!

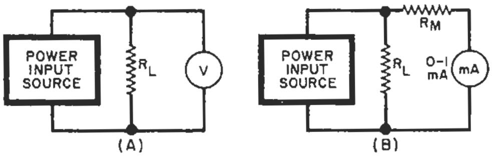


Fig. 2. Power measuring methods. (A) shows basic approach to measuring power, while (B) illustrates the method used in the Power and Impedance Meter.

Calibration Method. The Power and Impedance Meter uses the E^2/R approach to measuring power. The basic circuit is shown in Fig. 2(a). The power dissipated by R_L is E^2/R. Thus if R_L is 100 ohms and the voltmeter indicates 5 volts, the power is $5^2/100$ or ¼ watt. Because power is proportional to the square of the meter deflection, the scale is nonlinear. As an example, if the desired full-scale indication is 2 watts, then the 1-watt indication mark is $1/\sqrt{2}$ or 0.707 of full scale.

Assume that the meter in Fig. 2(a) indicated 10 volts full scale. With a 100-ohm resistor, the power is 1 watt. If the resistor is changed to 500 ohms, the

(*Continued on page* 110)

BREAKTHROUGH

IN ELECTRONICS CALCULATING

Still plodding through math and electronics problems the slow pencil-and-paper way? Smash the paperwork barrier with this new Electronics Slide Rule.

Even if you've never used a slide rule before, you can whiz through resonant frequency calculations and inductive or capacitive reactance problems. You can find reciprocals for resistance formulas instantly. You can even locate tricky decimal points in a jiffy.

You can also work regular math problems in a flash: multiplication...division...square roots...logarithms...trigonometry.

Anyone can use this sturdy 12-inch, all-metal slide rule. We show you how with our complete 4-lesson instruction course. Slide rule, course, and handsome leather carrying case deliberately priced low as our way of making friends with men in Electronics. FREE booklet gives full details. Mail coupon below today.

MAIL THIS COUPON FOR FREE BOOKLET

CIE Cleveland Institute of Electronics
1776 East 17th Street, Cleveland, Ohio 44114

Please send me your FREE booklet describing the Electronics Slide Rule and 4-lesson instruction course. Also FREE if I act at once—a handy pocket-sized Electronics Data Guide.

Name (PLEASE PRINT)
Address
City
State Zip
PE-151

CIRCLE NO. 14 ON READER SERVICE PAGE

Live Better Electronically With

LAFAYETTE
RADIO ELECTRONICS

1969 Catalog 690 FREE!

Now OFF PRESS
BETTER THAN EVER
Over 500 Pages

Stereo Hi-Fi • Citizens Band • Ham Gear • Tape Recorders • Test Equipment • TV and Radio Tubes and Parts • Cameras • Auto Accessories • Musical Instruments • Tools • Books

Featuring Everything in Electronics for
• HOME • INDUSTRY • LABORATORY
from the "World's Hi-Fi & Electronics Center"

LAFAYETTE Radio ELECTRONICS
Dept. 35128 P.O. Box 10
Syosset, L.I., N.Y. 11791

Send me the FREE 1969 catalog 690. 35128
Name
Address
City
State Zip

CIRCLE NO. 26 ON READER SERVICE PAGE

POWER METER

(*Continued from page* 69)

power at 10 volts is $10^2/500$ or ⅕ watt. As a result, if the voltmeter were calibrated in watts, it would give the proper indication only with one particular value of load resistor.

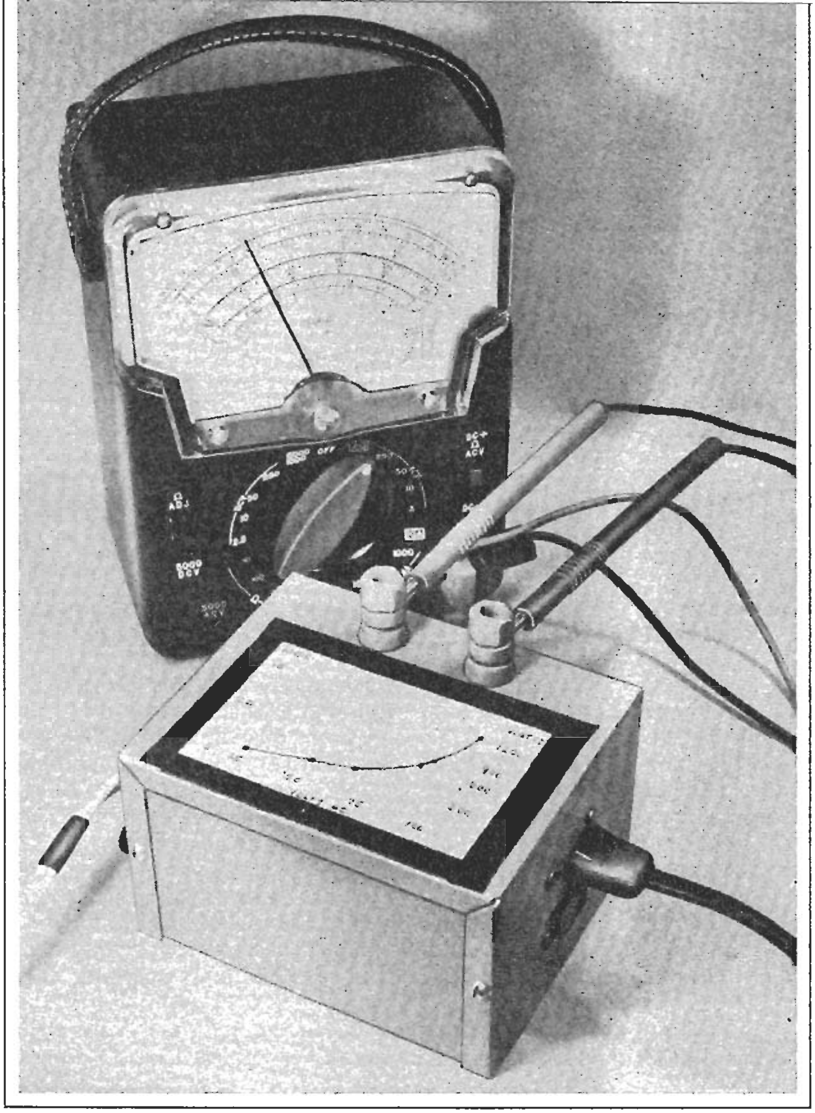
The solution to the problem is to forget about voltage measurements and concentrate on the amount of current required to produce a full-scale meter deflection. With a 1-mA meter movement, all we have to do is arrange for 1 mA to flow through the meter whenever we want the meter to indicate full scale (1 watt, 3 watts, etc.). A simplified circuit for doing this is shown in Fig. 2(b).

For a full-scale meter deflection of 3 watts and with a load resistor of 100 ohms, the voltage across R_L would be W × R or 17.32 volts. To make a 1-mA meter indicate full scale, the total resistance in the meter circuit (R_M plus meter movement resistance) will have to be 17,320 ohms. Similarly, if the load resistor is 500 ohms, the voltage across it is 38.73 volts and the meter-circuit resistance must be 38,730 ohms.

TABLE II—METER RESISTOR VALUES

R_L (ohms)	E (volts)	R_M (calculated) (kohms)	R_M (used) (kohms)
4.7	3.742	3.7	3.9
10	5.48	5.5	5.6
22	8.12	8.1	8.2
37	11.87	11.8	12
100	17.32	17.3	18
220	26.67	25.7	27
470	37.42	37.4	39
1000	54.8	54.8	56
2200	81.2	81.2	82
4700	118.7	118.7	120
10 k	173.2	173.2	180

The values used to determine R_M for the Power and Impedance Meter are given in Table II. Note that in every case, the calculated value of R_M is close enough to a standard resistance value that it is not necessary to use special resistors. The use of 3 watts as the full-scale deflection makes possible this happy circumstance. Since the meter, in this case, had an internal resistance of only 100 ohms, its resistance was ignored. —30—



Measure A.C. Amps & Watts with Your VOM

BY NEIL JOHNSON

YOU CAN USE ANY FILAMENT TRANSFORMER IN MAKING LOW-COST 1200-WATT ADAPTER

FEW EXPERIMENTERS have facilities to measure the wattage or alternating current drawn by a piece of electrical or electronic equipment. The question of how many watts a certain piece of gear draws during operation goes unanswered. The main reason for this situation is that a broad-range a.c. ammeter or wattmeter is expensive.

However, most experimenters own a multimeter—VOM or VTVM. With the

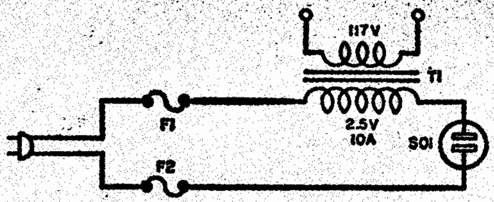


Fig. 1. Don't let simplicity of circuit fool you; it does a good job. Almost any filament transformer can be used as explained in text.

PARTS LIST

F1, F2—10-ampere fuse
SO1—A.C. outlet
T1—Filament transformer: primary, 117 volts; secondary 2.5 volts, 10 amperes (Allied Radio 54 B 3711 or similar—see text)
Misc.—A.C. line cord with plug, feedthrough grommet, binding posts (2), fuse holders (2), suitable chassis, test jig—see text

HOW IT WORKS

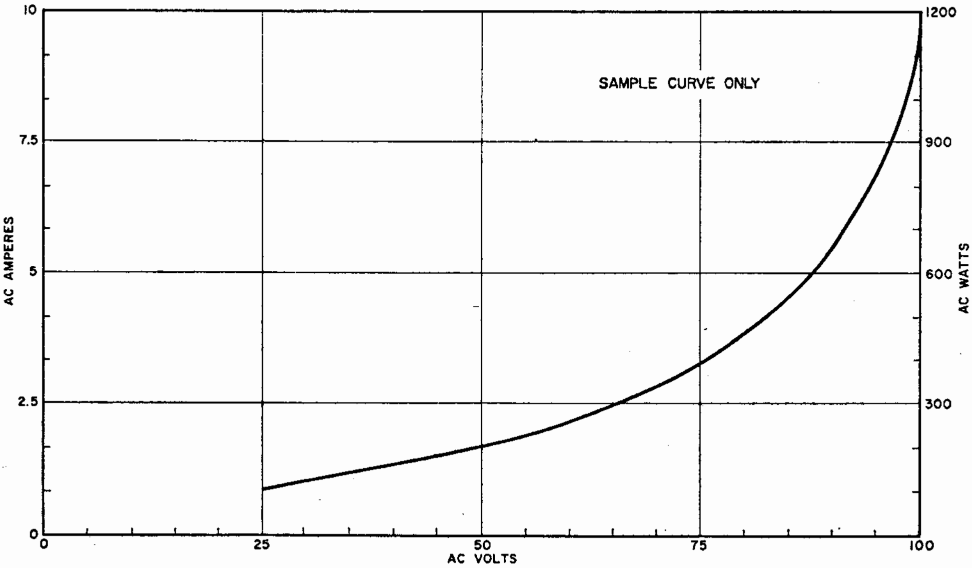
The heart of the adapter is a conventional filament transformer hooked up "backward." When a piece of gear is plugged into *SO1*, current proportional to the wattage of the load will be drawn through the low-resistance, low-voltage winding. This will induce in the 117-volt winding of the transformer a voltage that can be easily measured. The higher the voltage, the greater the current being drawn by the load.

There is a bonus with this type of current measurement. As the load applied to *SO1* is increased, there will come a point where the transformer core will saturate. This effect produces nonlinear output readings with the result that a larger meter scale differential exists between currents at the low end of the scale, and smaller at the high end. For example, a 1-ampere change at the 2-ampere point will move the multimeter needle a greater distance than a 1-ampere change at the 8-ampere point. This is desirable because, in the first case, the change is a significant 50%, while in the second case, the change is only 12½%. In essence, this is a form of "expanded scale" metering.

addition of a low-cost filament transformer, and a few other parts, you can convert your VOM into an a.c. ammeter or wattmeter. The ammeter adapter to be described here will enable your VOM to measure from an ampere, or so, to over 10 amperes a.c., or from a couple of watts to over 1000 watts.

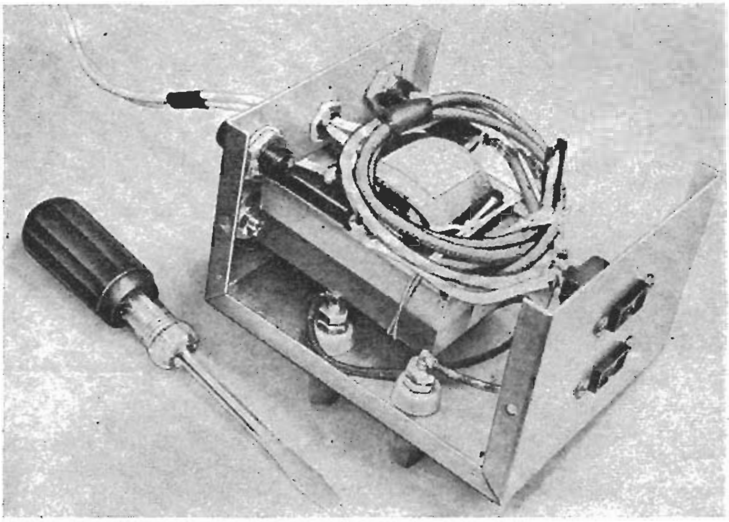
Construction. Although the transformer specified in the Parts List for the adapter has a 2.5-volt, 10-ampere secondary winding, you can use almost any filament transformer you happen to have at hand provided that the low-voltage winding can carry the current range you want to measure. For example, a 5-volt, 6-ampere filament transformer can be used if the load current being measured does not exceed six amperes (at 117-volt nominal line voltage, this amounts to about 702 watts). The only requirement, other than current-carrying capability, is that the filament winding have a low

Fig. 2. Actual-size graph that can be copied (without the sample curve) and glued to your metal cabinet. The calibration curve for the transformer you use can then be plotted and drawn in for future reference.



voltage rating so as not to introduce an excessive voltage drop and distort the true wattage reading.

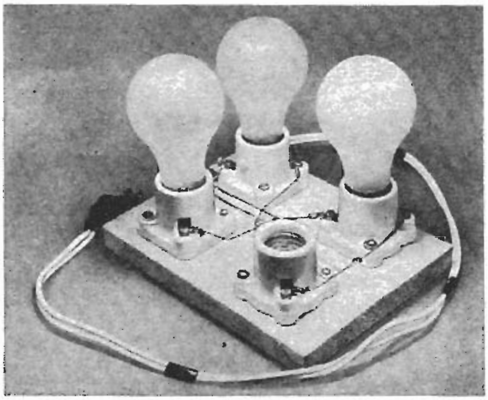
The schematic in Fig. 1 and the photo show one method of construction. (Almost any method will do.) Transformer *T1* is mounted within the metal box, the two input fuses (*F1* and *F2*) and a.c. line cord protrude from one end, while the a.c. outlet (*SO1*) is mounted on the other end. The multimeter binding posts, and the meter calibration graph, are affixed to the top of the box.



In the author's version, the filment transformer, two fuse holders, and the line cord grommet are on one wall, the output binding posts are on the middle wall, while a pair of a.c. sockets are mounted on the third chassis wall. Layout is not critical; any other will do as well.

Calibration. Temporarily make up a test jig consisting of four conventional electrical screw-in candelabra lamp sockets. Wire these sockets in parallel to a length of ordinary lamp wire terminated with a conventional electrical plug. Mate this plug with *SO1* on the ammeter adapter, then connect your VOM (set to its highest a.c. range) to the binding posts. Plug the adapter into the power line.

Bulbs of various wattages are used to create a wide load variation. Be careful of exposed line wiring.



Start the calibration by inserting a low-wattage lamp into one of the sockets on the test jig. Adjust the VOM a.c. range switch until an easy-to-read indication is found on the meter scale. Record this value and the wattage of the bulb. Various wattage lamps, or combinations of lamps, can be inserted into the sockets of the test jig to produce a range of wattages.

As necessary, change the a.c. voltage range switch on the VOM. The wattages that produce the meter indications should be recorded. If electrical appliances are used for the very high wattages, remove the test jig plug from the adapter, and insert the appliance plug. These appliances usually have a nameplate calling out their wattages.

Calibration Curve. After a sufficient number of readings have been recorded, make up a calibration curve as shown in the graph (Fig. 2). To convert wattage

(*Continued on page* 100)

MEASURE A.C. AMPS & WATTS

(*Continued from page* 63)

to amperes, divide the recorded wattage value by the line voltage. For example, if you have 600 watts on a 120-volt line: 600/120 = 5 amperes.

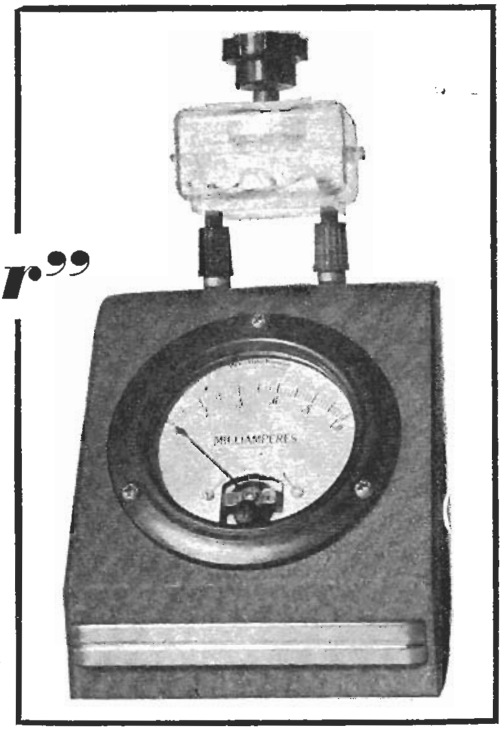
With respect to a.c. loads that are predominantly inductive—such as electric motors—the adapter will indicate volt-amperes, not watts. This phenomenon is common to all types of a.c. ammeters. To convert volt-amperes to true watts, multiply by the power factor of the device under test. If the power factor is unknown, use 0.8 as an average value.

Always start voltage measurements with the VOM set to its highest a.c. range, as the starting currents of some devices, particularly electric motors, can be very high. The resultant high voltage surge may damage the meter. —30—

Throw Together A "Quintupler"

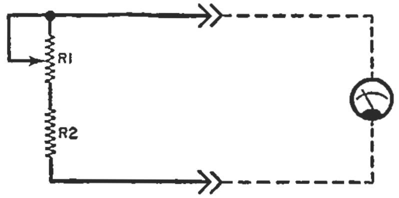
SHUNT UPS RANGE OF YOUR MILLIAMMETER

BY FRANK H. TOOKER



HOW OFTEN has the pointer of your milliammeter been deflected off scale because the current through the meter was slightly too high? What did you do? Change meters or give up because you didn't have a suitable meter at hand? If your measurements can tolerate a modest inaccuracy, you need a "Quintupler."

The "Quintupler" is nothing more than a simple variable shunt that you temporarily place across the milliammeter. The shunt is made up of two resistances: a potentiometer (*R1*) equal to, or slightly greater in value than, the internal resistance of the meter movement; and a fixed resistor (*R2*) with a value of about 10-15% of the potentiometer's resistance.



Values of potentiometer R1 and resistor R2 depend on the internal resistance of the meter movement.

For example, if the meter has an internal resistance of 100 ohms, the potentiometer should also be 100 ohms, and the resistor between 10 and 15 ohms.

The following discussion assumes that your meter is a 0-to-1 mA unit; however, the same procedure applies to all current-measuring meters. Before using the variable shunt, adjust the current amplitude through the meter movement only for full-scale deflection. Plug the shunt into the meter's inputs, leaving the power connected. Now adjust the potentiometer so that the meter pointer deflects to 0.5 mA to obtain an *X2* range. For the *X3*, *X4*, and *X5* ranges, adjust the potentiometer so that the meter pointer deflects to 0.33 mA, 0.25 mA, and 0.20 mA, respectively. The *X1* range is obtained with the variable shunt out of the circuit. Record pot position for each range.

This setup allows you to measure up to 5-mA current amplitudes with only a 0-to-1 mA meter movement. Using a greater than five times multiplication factor for any given meter movement is not recommended since beyond this point the adjustment of the potentiometer is too critical. -30-

Expanded Scale
AC Voltmeter

Danny Ruttenberg

Expanded scale voltmeters — meters that "expand" a given range of voltage to cover the whole meter face — are not new. These specialized instruments are widely used for accurate monitoring and measurements of critical voltages. Most popular by far are those that are designed to monitor powerline voltage.

Normally designed to read 90 to 135 volts, they give clear indication of line voltage fluctuations. Covering the full scale of an expanded-scale meter, this 90 to 135 volt scale would occupy only 25% of a comparable meter that commences readings at zero. Hence, readings on an expanded scale unit can be four times as accurate and sensitive.

Most commercial expanded-scale meters use mechanical zero-suppression, and are comparatively expensive. While very useful to any ham or serviceman, their high cost has inhibited their general use.

The design described below, is, to my knowledge, the first attempt at expanding a meter scale electronically. Using a standard 0-1 ma meter and inexpensive parts, its cost is less than one third of comparable commercial units.

D1 is an inexpensive silicon rectifier rated at 500 ma., 130 v rms. D2 is a zener diode. The potentiometer is set up as a voltage divider across the power line. As long as the voltage applied to the two diodes back to back is below D2's Zener voltage, current will not flow in either direction. When the applied voltage rises above D2's Zener voltage, D2 will conduct in both directions, D1 only in the forward direction. The result is, that current commences to flow through the meter, producing deflection. Once D2 starts to conduct, it has no control over the amount of current flowing through it, so current is limited by the potentiometer, and above D2's Zener voltage, is proportional to line voltage.

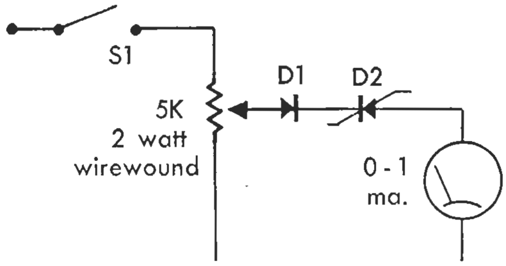


Figure 1

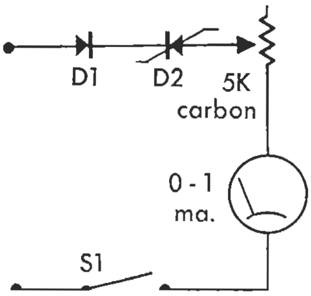


Figure 2

Fig. 1 This simple expanded scale circuit makes it possible to monitor voltage with much better accuracy than using a standard meter.

Fig. 2 With A Zener diode of exact value, the circuit will draw much less current.

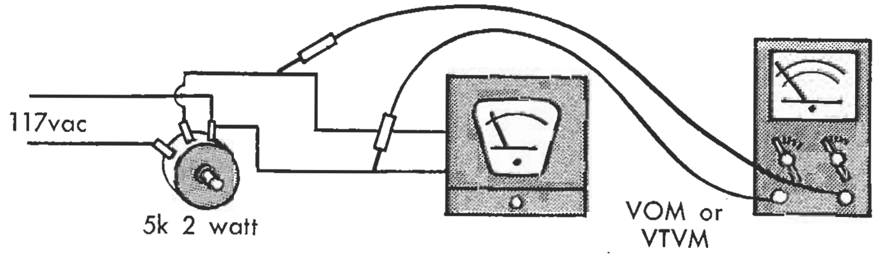


Fig. 3 Calibration is simple; accuracy limited only by the accuracy of the meter used.

As you can see in the photograph, my meter starts to read at 95 volts AC, but this does not necessarily mean that D2's Zener voltage must be 95 volts. Actually, any Zener diode rated at 25 to 95 volts could be used. Using a 25 volt Zener diode, as I did, it is clear that the potentiometer is used to set the point at which the meter will start to read. Once the circuit is wired, it is only necessary to set it so that voltage at the arm of the potentiometer is 25 volts when applied voltage is 95 volts. With a 5000 ohm potentiometer, full scale reading will be approximately 120 volts AC.

It will be necessary to alter the scale of the meter you are to use to read properly. This operation, while delicate, is easier than it seems. Remove the meter from it's case, and dismount the dial plate by removing the two retaining screws. Flip it over, and give the back of the plate a coat of flat white paint. After it is dry, remount the dial plate, white side up. Now hook the meter into the circuit, and, while applying calibrating voltages, (more about that later), make scratch marks with a pin or other sharp instrument at 5 volt intervals. Remove the dial plate and, using india ink or soft pencil, clearly mark voltages and calibration points. Then remount the dial plate, reassemble the meter.

Calibrating voltages: Of course, your line voltage is quite reliable at 117 volts, so there's one calibration point. For voltages down to 95 volts, it is only necessary to place another 5000 ohm, 2 watt wirewound potentiometer in series with the voltmeter circuit. Adjustment of this pot will give a continuously variable voltage down to 50 volts. Use a good AC VOM or VTVM for calibration, connecting as in fig. 3. Now, set the potentiometer

continued on page 39

Ex Scale *cont'd from page 29*

in the circuit for minimum voltage, apply 95 volts to the circuit, and slowly rotate the potentiometer until the meter produces a slight reading. Leave it at this point, and increase input voltage 5 volts at a time (using the outboard potentiometer), marking the scale as you go.

If it happens that you do have a 95 volt Zener diode, use the circuit in fig. 2. It's main advantage is that, whereas the circuit in fig. 1 continually draws 20 ma. from the power line, this one does not. In fact, it draws only 1 ma. at full scale deflection. Operation, is the same, except that, since D2 is of the proper Zener voltage, the potentiometer is not necessary. Still, there must be a current limiting device. For this purpose, use a 5000 ohm carbon control as shown, and adjust it for full scale deflection at 125 volts input to the circuit.

A.C. LINE VOLTAGE MONITOR

By CHARLES D. GEILKER
Research Associate
Warner & Swasey Observatory

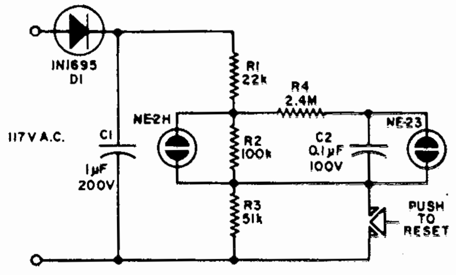
IN situations where electronic equipment must be left operating unattended for long periods of time, it is often desirable to have some check on whether low supply voltage, or even outright power failure has occurred in the interval since the equipment was last serviced.

In the voltage monitor circuit shown in Fig. 1, the NE-2H lamp has a higher d.c. striking voltage than the NE-23 although they maintain the same voltage level once the lamps have fired. In the circuit, *D*1 and *C*1 form a simple half-wave rectifier which places 150 volts across the resistance divider string, *R*1, *R*2, and *R*3. When the line voltage is turned on, the voltage drop across *R*2 is insufficient to fire the NE-2H; however, it does exceed the 65-volt firing level of the NE-23, and the NE-23 blinks since a relaxation oscillator is formed by *R*4 and *C*2.

Momentarily depressing the reset switch shorts out *R*3 and fires the NE-2H. Now the maintaining voltage of the NE-23 drops and the blinking stops. Should a power failure occur, or the line voltage drop below 100 volts, the NE-2H goes out and the NE-23 will signal the fact by blinking until it is reset again.

*R*1 sets the "blink threshold" for low line voltage. Thus, increasing the value of *R*1 from 22,000 ohms to 26,000 ohms raises the threshold from 100 to 105 volts. In addition, some NE-2H's are polarity sensitive and may require that the leads be transposed for proper operation. Ordinary 5% resistors work satisfactorily throughout the circuit. ▲

Fig. 1. Blinking NE-23 signals power failure.



Voltage-regulator IC biases expanded scale meter

by Alan D. Wilcox
University of Virginia, Charlottesville, Va.

To monitor the state of charge of a standby storage-battery system, only voltages between 12 and 15 volts need to be read. A conventional test meter reading 0 to 15 V full scale will suffice, but readings can more easily be observed when the voltmeter has an expanded scale that reads from a minimum of 10 V to a maximum of 15 V.

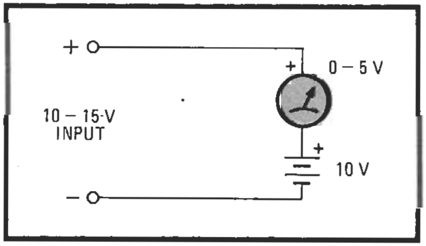
One such expanded-scale circuit is shown in the figure. The battery provides a 10-V bias to the meter so that when a voltage source of 10 to 15 V is applied to the combination, the meter shows the difference of 0 to 5 V. But this arrangement is unsatisfactory, both because it must have a battery for operation and because its accuracy depends on the battery having a potential of exactly 10 V.

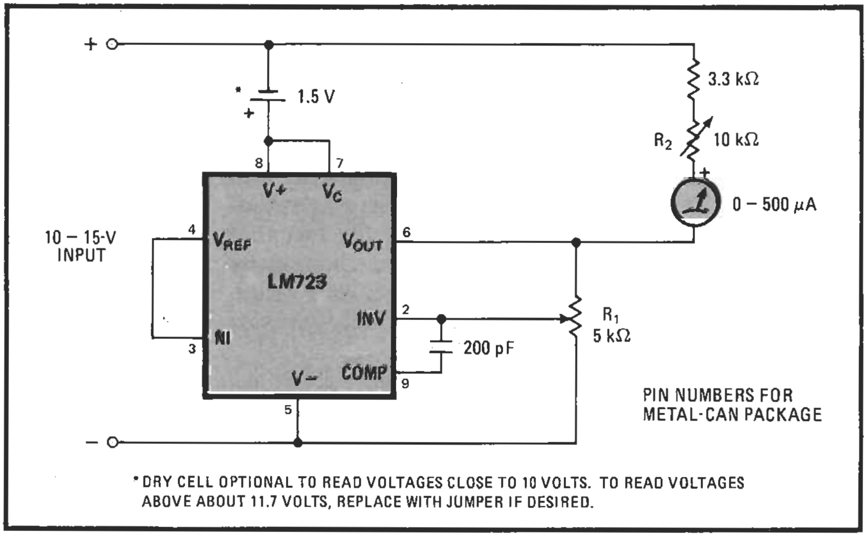
There is a better way. Since the voltage to be monitored will be above 12 V, a National Semiconductor LM723 voltage regulator can be used as shown in the figure to provide a stable 10-V bias. A 500-microampere meter and series resistor R_2 constitute the 0-to-5-V voltmeter. If the battery voltage should drop below about 11.7 V, regulation falls off, but this inaccuracy can be corrected by using a 1.5-V dry cell if readings below 12 V are necessary. The dry cell does not affect the accuracy of the meter calibration—it simply extends the reading range down to about 10.2 V.

The unit draws about 3 milliamperes and can be used continuously across the storage-battery system. The entire circuit can be constructed on a small circuit board and mounted on the terminal posts of the 500-μA meter.

The circuit is calibrated by applying 15 V to the input and adjusting R_1 for 10 V at the output of the 723. Then, R_2 is set for a full-scale reading on the meter. For the 500-μA meter, 200 μA corresponds to 12 V, 300 μA to 13 V, etc. Normal battery voltage reads near center scale, and small deviations can be seen at a glance. ☐

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.



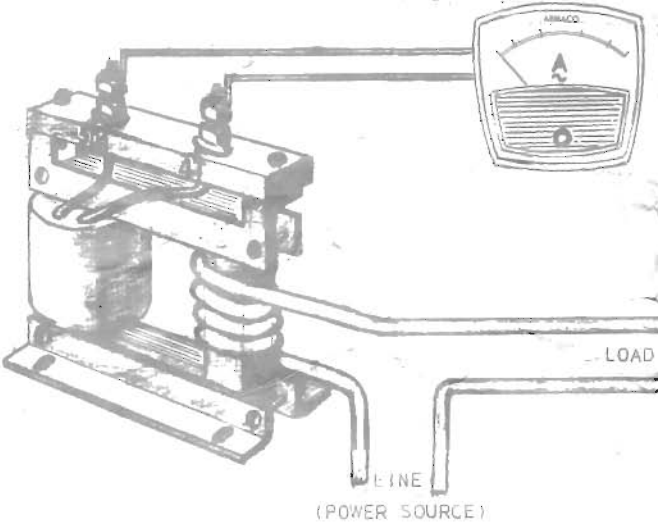


The right idea. This circuit displays very precise readings of 0 for 10-v input, 100 for 11-v input, and so on up to 500 for 15-v input. Adjustment of R_1 and R_2 calibrates it accurately. Circuit shown in inset also displays voltage in the 10–15-v range but requires a battery of exactly 10 v for accurate reading. Note that the 1.5-v dry cell used in the main circuit does not affect its calibration and is not necessary for readings above 11.7 v.

INSTRUCTIONS
FOR
ARMACO
ALTERNATING CURRENT AMMETERS

An AC ammeter requires terminals and interior components large enough to carry the current passing through the meter. For larger currents the meter would become too large to conveniently mount in a panel. For this reason all ARMACO UM2 meters for reading AC current of 25 amperes and above are provided with a current transformer to step down to a maximum reading of 5 amperes. Even though the meter reads only 5 amperes AC full scale deflection, it is scaled to indicate the actual current flowing through the primary of the current transformer. The current transformer provided with the meter will be marked to show the number of turns required for correct indication. For example, the 25 ampere model requires eight turns, and is marked "8T" on the transformer. Use #14 wire to connect the meter to the transformer terminals.

R. MACK & CO. LTD.
Quality Electronic Components



ACCURATE MILLIAMMETERS ON A BUDGET

How to modify surplus-type meters to obtain high accuracy.

BY DAVID CORBIN

Buying an ammeter with built-in shunts to measure currents from milliamperes to hundreds of amperes can be an expensive proposition. It is much less costly to obtain a basic 1-mA movement and add the shunts you need to create the necessary ranges. This can be done by using the table supplied here. It tells you what shunt values are required for a given milliammeter movement with a 1-mA full-scale swing.

About Accuracy. Depending on the movement you choose and how much you pay for it, basic accuracy will be between 1% and 5% full-scale. The accuracy figure is loosely based on both repeatability and scale precision. Bear in mind that the accuracy of large panel meters is generally no better than 1% full-scale. What these movements offer for the high prices they command are ruggedness, long life, temperature compensation, magnetic shielding, and high breakdown voltage, all of which may be important in some applications. Where the application is not critical, you can choose a small $3.50 to $6.00 panel meter and get more than adequate results.

When you look at accuracy figures for basic meter movements, be sure you understand the meaning of the figures. Since a current-measuring meter is placed in series with the source and load, it should have the lowest possible resistance for maximum sensitivity. The meter's resistance is a part of the circuit and affects the overall flow of current.

Let us assume that you have two meters, one with a 50-ohm resistance and the other with a 100-ohm resistance. If you were to insert the 100-ohm meter into a circuit with 100 ohms resistance in which the actual current flow is 1 mA, the meter would indicate 0.5 mA. Substituting the 50-ohm meter would yield a 0.67-mA reading. The readings obtained are the actual currents flowing in the circuit *while the meters are in the circuit* and they are within 1% of the actual current. (Of course, if you remove the meters, the current in the circuit would again become 1 mA.) The discrepancies are the result of the fact that the meters add their own resistance to the circuit and reduce the overall current flow.

If the meters had zero resistance (impossible to achieve in practice), they would not affect the flow of current. In this case, both meters would indicate 1 mA. It is obvious then that, in the world of real measurements, you must take into account the effect the meter has on the circuit that is being tested.

Custom Tailoring. Since the voltage it takes to swing the milliammeter's pointer to full-scale is the product of full-scale current times coil resistance, it is easy to design circuits and make reference charts for choosing shunt and series-shunt combinations. It is amazing how small a voltage is required for a full-scale pointer swing on a typical 1-mA movement. For example, a 50-ohm, 1-mA movement requires 1 mA × 50 ohms, or 50 mV (0.050 V) full-scale.

The problem is that many low-cost meter movements are provided with no specifications other than the scale markings. You cannot measure the coil resistance with an ohmmeter because the test voltage is much too high and can damage the movement or burn out the meter's coil. The best way to check milliammeter movements is with a simple meter calibration circuit like that shown in Fig. 1. For this, you will need a good standard multimeter capable of indicating current to 1 mA full-scale. (Even a $6 basic movement will do if its coil resistance is specified.)

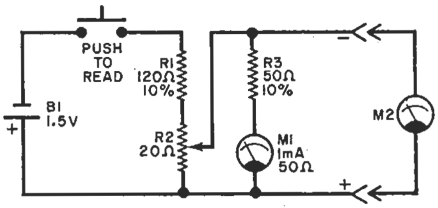


Fig. 1. Here is a simple meter calibration circuit you can use to check meter movements.

The meter calibrator shown in Fig. 1 uses a 50-ohm movement. This movement indicates half of the voltage dropped across tested movement *M1*. The total reading from *M2* is read as 0 to 0.1 volt or as 0 to 100 ohms. Potentiometer *R2* is adjusted for a full-scale reading on *M1*.

Once you know coil resistance R_M and full-scale voltage E_M, as indicated on *M2*, you can calculate the shunts needed to increase the basic movement's range. The formula for this is $R_S = E_M/(I_D - I_M)$ where R_S is the shunt resistance in ohms and I_D and I_M are the design and movement's full-scale currents in amperes. However, to avoid having to perform the mathematics, you can refer instead to the table, which gives the values of the shunt resistors needed for various 1-mA meter movements for a variety of full-scale ranges. The resistances in the table are rounded off to three places in most cases. It isn't necessary to be too accurate in shunt-resistor selection because of the limitations resulting from the built-in errors of the basic meter movement itself.

About the best possible accuracy you will be able to obtain, no matter how precise the values of the shunt resistors, will be 1% of the full-scale reading. The resistors you use will not normally be better than 1% to 5%, and the meter movement itself cannot be interpreted to better than 1% accuracy even if it is the best available.

The 1-mA movement will probably be calibrated in 10 major divisions, with five minor divisions between each. This works out to 0.1-mA major and 0.02-mA minor steps when only the basic measuring range of the movement is considered. When multiplied by the shunt factor for a 50-mA full-scale reading, the major steps are each 5 mA and the minor steps are each 1 mA. However, without an antiparallax mirror backing on the movement and other refinements, one minor division is about the limit of what you can interpret on any reading.

Thus, a 1-mA error is possible in the reading and 0.5 mA in the meter's basic accuracy. In terms of a shunt, assuming a 50-ohm movement, this is like using a 1-ohm resistor instead of the required 1.02 ohms. In fact, the difference of 0.5 mA caused by the movement itself would be the same as an error of from 1.0098884 to 1.0309278 ohms instead of the exact 1.0204081 ohms required.

SHUNTS NEEDED FOR VARIOUS MOVEMENT RESISTANCES AND FULL-SCALE CURRENT

	Shunt (ohms)				
Movement (ohms)	12.5	25	50	75	100
Current (mA)					
5	3.13	6.25	12.5	18.75	25.0
10	1.39	2.78	5.56	8.33	11.1
25	0.52	1.04	2.08	3.13	4.17
50	0.26	0.51	1.02	1.53	2.04
75	0.17	0.34	0.68	1.01	1.35
100	0.13	0.25	0.51	0.76	1.01
150	0.08	0.17	0.34	0.50	0.67
200	0.06	0.13	0.25	0.38	0.50
500	0.025	0.05	0.10	0.15	0.20
1000	0.0125	0.025	0.05	0.075	0.10
10,000	0.00125	0.0025	0.005	0.0075	0.01

This simply points out the limit of accuracy to be expected with *any* moving-coil type of meter. Needless to say, the home-built metering circuit can be as accurate as the best commercial analog meters.

To avoid having to wind special resistors, you can use combinations of standard resistor values to make the required shunts because the precision required for good results will not be excessive. The formula for determining the value of the parallel resistor needed for a given shunt value and given one resistor of known value is $R_U = R_S R_K/(R_K - R_S)$, where R_U is the resistance to be found, R_S is the desired shunt resistance, and R_K is the value of the known resistor. To obtain a good many values with odd decimal endings, a fractional value resistor can be used in series with a standard larger value resistor. Of course, the accuracy will suffer when the possible errors of the resistor values are added to the circuit. However, if you use 1% and 5% tolerance resistors and the scale multiplication is large, the amount of overall error will be in the same range as the limits of the meter movement itself and will not have much effect on the accuracy of the reading.

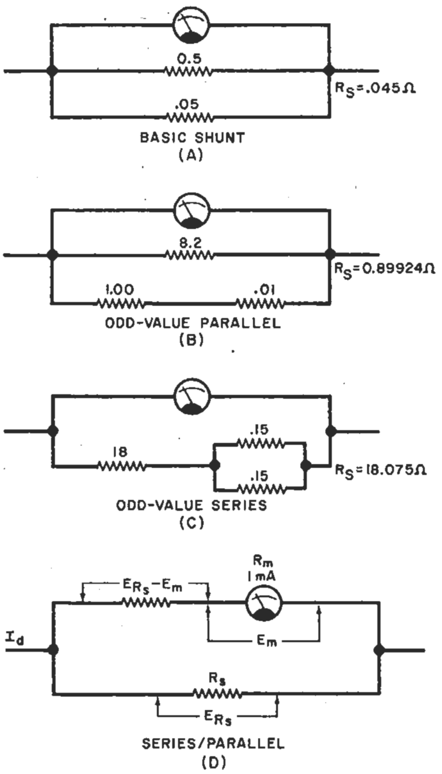


Fig. 2. Various configurations for using shunts with meters.

The power that is generated in the shunt must be handled without excessive heating of the shunt or the values of the shunt resistors will change. By using resistors with 50% greater heat dissipation (power rating) than is actually required, you will not exceed safe limits. Even with a 10-ampere shunt, the current is not large enough to generate much heat in a 0.01-ohm load. The power generated will be 1 watt, so a 2-watt resistor will be more than adequate. Smaller currents develop correspondingly lower power in the shunts. The formula for calculating the power rating of the shunt resistors is $P = 1.5E_M (I_D - 0.001)$, where P is the power in watts, E_M is full-scale meter voltage in volts, and 0.001 is the value of the 1-mA meter movement's full-scale current.

To measure higher currents without having to resort to very small values of resistors and resistor combinations for the shunts, a dropping resistor can be placed in series with the meter movement. (Various configurations of shunt circuits are shown in Fig. 2. The Fig. 2D circuit illustrates the resistor placed in series with the meter movement.) If you know the value required for shunt resistor R_S, the formula for determining the value of dropping resistor R_D is $R_D = [R_S(I_D - 0.001) - E_M]/0.001$, where R_D is in ohms, I_D is in amperes, and 0.001 is the full-range current of the meter movement. To find R_S when the total drop is specified, use the formula $R_S = E_{RS} / (I_D - 0.001)$. Then $R_D = (E_{RS} - E_M) /0.001$.

The Fig. 2D circuit can be used when a certain voltage drop is required in a metering circuit and it is different from the drop that would result from using a standard shunt circuit. It is also handy for avoiding small values of resistance, but the pitfall is excessive power loss through the shunt when measuring high currents.

The power in the shunt is calculated by subtracting 1 mA from the design current (I_D) and multiplying this times the voltage drop across the shunt, which is the same as the total circuit drop. Almost any value of resistance can be used for the shunt, but the power rating will go up in direct proportion to the resistance for any given current measurement. The biggest advantage will be in the avoidance of odd-value shunt resistors that cannot readily be obtained by connecting resistors in parallel or series-parallel configurations.

Multirange general-purpose meters can be made by using a combination of simple shunt and series-shunt networks and a multi-position switch. The lower ranges, where shunts are obtainable in close-to-standard values, can have the shunts switched directly across the meter movement.

Summing Up. The design of current-measuring circuits in which a standard 1-mA meter movement is used is applicable to even the most limited budget and available test equipment. It provides accurate current monitoring in up to four decade ranges at a typical cost of less than $15. A single-value monitor circuit can be installed in a project for less than $9, and it will provide an accuracy of between 1% and 5% full-scale, depending on the care taken during the design stages. The problem of finding and stocking a variety of current meters is solved by keeping one or two milliammeter movements handy and making up a few standard shunt circuits to use with them as described here. ◇

Ohms per volt

A question of voltmeter manufacture

by "Cathode Ray"

Having to keep up an appearance of infallibility is one of the stresses of youth that cause many to die young. But those that escape it, or with maturity learn better, enjoy not adding loss of face to the discomforts of old age. Thus, instead of being upset by receiving a letter from Mr A. J. Sargent pointing out a slip in my treatise on magnetism in the January 1973 issue I was happy to see in it an excuse for further chat.

The said slip had nothing to do with magnetism, so would not have occurred if I'd stuck to the point. It was a slightly faulty buzz from a particularly energetic bee escaping from my well-stocked bonnet. Its motive force was the practice of voltmeter makers of specifying the current load of their products in ohms per volt. My correspondent pointed out to me that it was the reciprocal of current that was so specified. He tactfully refrained from adding "Fancy Cathode Ray forgetting Ohm's Law!".

Well of course he was perfectly right, and although I doubt if anyone was misled by my error, and it was only the generally accepted kind of sloppiness of speech we use in reckoning petrol consumption in miles per gallon, I really ought always to practise what I preach and use my words carefully.

This particular side swipe comes out at the slightest pretext (such as an article on magnetism) because I hope some day to provoke a voltmeter maker into explaining why he specifies the current load of his meters not only reciprocally but also clumsily in ohms per volt. One doesn't ask for a 13 volts-per-ohm plug, suitable for a 240 amp-ohms power supply.

It is in fact an even clumsier practice than at first appears, for in full it has to read "ohms per volt of full-scale reading". So if you want to know how much current is leaking away through your 20,000 ohms per volt voltmeter (to impress you the makers always say 20,000Ω, not 20kΩ) when it is reading, say, 195V on the 300-V range, you have to divide 195 by 300 times 20,000; and if you concentrate on it sufficiently you get 32.5μA as the answer. Personally I think it would be a lot easier if below the voltage scales there was a voltmeter leakage (or load) scale, 0 to 50μA, in grey to be distinct from the volt scales and less conspicuous, but there whenever you wanted it. The deflection that indicated the voltage would at the same time show the voltmeter current.

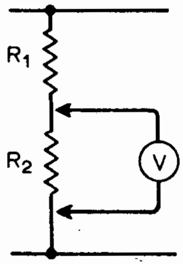
If you did want to know the voltmeter resistance on any range you would simply divide that range (in volts) by the 50μA or whatever full-scale current was shown on that particular instrument. In our example, on the 300-V range it would be 300/50, which (as the current is in μA) is 6MΩ.

Most voltmeters use the same current on all ranges, hence the simplicity of specifying that figure. As for the exceptions that are complicated by more than one full-scale current, note that equally they have more than one ohms-per-volt of full-scale voltage. I'm still waiting to hear why the makers prefer to work in the latter involved terms. M. G. Scroggie, who is very much at one with me in such matters, has been waiting at least 12 years, since the question was first put bluntly in *Radio & Electronic Laboratory Handbook*, 7th edition, and again in the 8th.

What we really want to know, of course, is neither the current nor the resistance. We want to know the voltage between A and B before we connected the voltmeter to those two points. Being very accommodating we would settle for the drop in voltage due to the connecting; it is easy enough to add this to the indicated voltage to give the true reading (subject of course to the possible meter error; and if you haven't studied the relevant British Standard, BS 89, you'd be surprised to see how large that could be. For example, if the reading at 0°C on a portable multi-range moving-coil instrument with a 3in scale was 30V on the 100-V range, the true reading within the tolerances allowed in the Industrial Grade—previously called British Standard First Grade—could be anything from 24.75 and 35.25V. So there would be no sense in logging it to several places of decimals!).

Unfortunately the load error, which is extra, depends on the impedance of the circuit to which the voltmeter is connected. If that is hundreds of times less than the voltmeter resistance then you have little to worry about. But we rarely know what it is, and (especially in circuits subject to feedback) may not even be able to make a reliable guess at the order of magnitude.

One particular but often occurring case is the potential divider (see Figure). Let's suppose it is connected across a relatively low-resistance d.c. source. That puts R_1 and R_2 practically in parallel, so far as the resistance in series with the voltage source and the voltmeter V is concerned. If you have any hesitation about accepting that statement, study of the theorem ascribed to Thévenin (by the French) and Helmholtz (by the Germans) is indicated. Note that this effective source resistance is the same regardless of whether one is measuring the voltage across R_1 and R_2. It is equal to $R_1R_2/(R_1+R_2)$. Call it R_s. The drop in voltage in it due to V is of course I_vR_s, where I_v is the current taken by the voltmeter, read off the scale which the voltmeter manufacturing industry will be rushing to insert when it has finished reading this article. (Oh yes?) So we just add I_vR_s to the voltage reading.



Current load with a potential divider.

If we haven't a clue what the source resistance is, or alternatively have but can't be bothered to perform the above simple calculation or tap it out on the pocket computer, we can get a correction by shunting V by a resistance equal to the resistance of V. Doing this will reduce the reading. This drop is the correction we should add to the first reading. If it is more than about 10% then the correction itself is appreciably inaccurate and we should get a higher-resistance voltmeter.

The late Bainbridge-Bell described a method in which a multi-range voltmeter itself is used to provide an alternative resistance. A reading is obtained on two ranges, the ratio of the higher voltmeter resistance to the lower being m. In most instruments it is the same as the ratio of full-scale readings. Then if V_1 and V_2 are the readings on the upper and lower ranges respectively, the corrected voltage is

$$\frac{(m-1)V_1V_2}{mV_2-V_1}$$

A disadvantage of this method is that readings which come low on the scale are less accurate. Both these altered-resistance in

of circuits it may be helpful to remember that the base-to-emitter voltage is fairly constant at about 0.55–0.6V for silicon and 0.16–0.2V for germanium.

These methods of correction can be used for a.v. provided also that the a.v. voltmeter is not used on a non-linear part of its range (most of them include a rectifier). And if the circuit is reactive the correction is likely to be very inaccurate. Remember too that a.v. voltmeters are in general less accurate than d.v.

Another curious thing about the habits of meter makers is that although their most popular products measure current as well as voltage (for which they specify voltmeter ohms per volt of full-scale reading) rarely if ever do they act logically by specifying the ammeter in siemens per ampere of full-scale reading. Again, I wonder why, and hope an answer may be forthcoming. Now that the voltages in most electronic circuits are so much lower than they used to be, the voltage lost in the meter when measuring current is correspondingly more significant and ought to be allowed for, or at least allowable for by those who want to do so. But the information is not given. Of course the S/A of f.s.r. form of supplying it is logical only in the context of the illogical Ω/V of f.s.r. which I've been busy deploring. The sensible way would be to have an unobtrusive voltage-drop scale for use when reading current.

I have no doubt that if any instrument makers are taking a blind bit of notice of my constructive criticisms they will be already asking their dictating machines to take a letter pointing out that there are already too many scales to have to find room for on their multi-range test meters, and adopting my suggestions would only make confusion worse confounded. (I don't think on second thoughts they would phrase it just like that.) Perhaps so, but now that a branch of industrial endeavour dignified by the name of ergonomics has been introduced why not use it? If however even this resource fails, at least may we have the full-scale voltmeter current and ammeter voltage included in the specifications in place of the ohms-per-volt rubbish?

MARCH 1974 ISSUE

The issue number on the spine of the March 1974 issue was incorrectly printed as 1461. It should have been 1459, as correctly printed on the contents page. We apologize to readers, librarians and others to whom this error may have caused inconvenience.

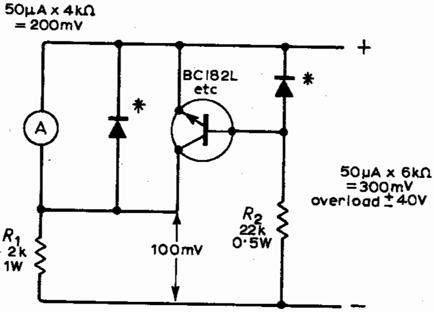
TEST JACK ADAPTER

Have you ever bought a new meter or other piece of test equipment only to discover that none of your standard ¾-inch spaced test plugs will fit the jacks on it? If you can't or don't want to modify your new piece of gear by slotting the test jack mounting holes, consider this simple adapter you can make to rectify the situation. All you need are a pair of banana jacks, a pair of noninsulated banana jacks, and a 1¼-inch (3.81-cm) square piece of ⅛-inch (3.2-mm) thick plexiglass or bakelite. Round the corners of the plastic and drill two holes at opposite corners for the jacks, spaced ¾-inch (1.9-cm) apart. Then carefully measure the spacing between the test jacks on the new equipment and drill holes for the plugs in the plastic square to match this spacing. Assemble and wire the plugs and jacks and you're all set.—*Donald R. Hicke, San Diego, CA.*

Meter protection circuit

Design of the protection circuit shown is as follows (though values shown should suit most movements).

- Establish V_F for the basic meter movement ($R_C \times I_{FSD}$). If < 350mV circuit can be used as it stands. If 350mV $< V_F < 700$mV two diodes must be used in series in both positions, and if 700mV $< V_F < 1$V three diodes should be used. As a check to ensure the circuit does not affect the accuracy of the meter, apply a voltage to the circuit to give f.s.d., remove the transistor emitter, and diode cathodes. Needle position should not alter.



* see text

- Decide maximum voltage drop that can be tolerated across R_1 ($I_{FSD} \times R_1$), and hence choose a value of R_1.

- Effective resistance of the movement will be $R_C + R_1$, which must be used in calculating shunts or multipliers for use with the meter.

- Maximum forward and reverse voltage that the circuit will tolerate will then be $R_1 \times 200$mA. If the reverse voltage will never exceed 5V, base diode can be omitted.

On an overload, which would normally result in a little "clink" as the needle entwines the stop, the needle runs off the scale in either direction in a controlled way, and gently presses itself against the stop.

C. Shenton,
Weston-super-Mare,
Somerset.

Measuring picoamperes with extreme accuracy

by William D. Kraengel Jr.
Valley Stream, N. Y.

The accuracy of the simple measuring technique proposed by Battes ["Measuring small currents with an ordinary voltmeter," *Electronics*, Feb. 15, 1973, p. 118] can be greatly improved, to such an extent that nanoampere and even picoampere currents can be precisely determined. The basic technique remains unchanged: a voltmeter is still made to measure the potential developed across its own input resistor. But the results become more useful and precise when the original equation used to determine current is modified to compensate for the error caused by inserting the resistance in series with the circuit under test. Otherwise, the error in determining the actual current can be significant because the original equation is based on circuit assumptions that hold true only in certain cases.

As indicated in the figure, when the voltmeter's input resistance, R_{in}, is regarded as a calibrated current shunt, the test current, I_t, is calculated from:

$$I_t = V_m/R_{in} \qquad (1)$$

where V_m is the voltmeter's displayed reading. This is the equation for the approximate current as derived in the original article.

This current value approximates the true load current:

$$I_L = E_s/R_L \qquad (2)$$

where E_s is the source voltage and R_L is the sum of the source and circuit-load resistances. This equation holds true only if R_{in} is very low, since:

$$I_t = E_s/(R_L + R_{in}) \qquad (3)$$

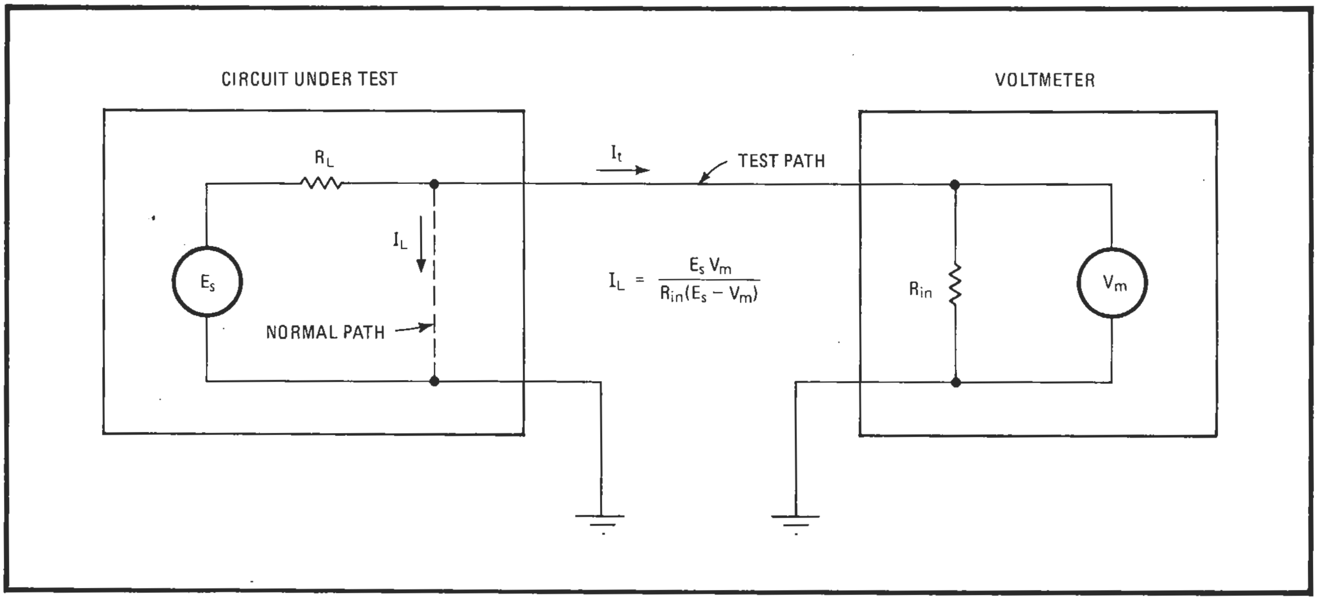
Thus the general equation for determining the true load current may be had by setting Eq. 1 equal to Eq. 2, solving for R_L, and substituting for R_L in Eq. 2 to yield:

$$I_L = E_s V_m/R_{in}(E_s - V_m) \qquad (4)$$

Consider the case where a digital multimeter with an R_{in} of 10 megohms measures V_m = 181.8 millivolts for an E_s = 2 volts and R_L = 100 MΩ. The test current calculated from Eq. 1 is 18.2 nanoamperes, whereas the value of I_L from Eq. 4 is 20 nA, the actual value. Thus a measurement error of about 10% is avoided.

Ac test current can be determined as well by simply replacing R_{in} with the voltmeter's input impedance, Z_{in}, in Eq. 4. The impedance must of course be known for every frequency of interest.

Though it is true that even currents in the picoampere range can be calculated, it must be noted that modern digital multimeters have input-bias currents on the order of 10 to 100 pA. This consideration alone invalidates the technique for measuring currents in that range. ☐



Accurate. Nanoampere currents can be precisely determined by measuring the potential developed across a voltmeter's own input resistance for a given test configuration and substituting the value into the redeveloped equation [*Electronics*, Feb. 15, 1973, p. 118]. Currents in the picoampere range can be found, too, provided they are well above the 10–100-pA input-bias value of the digital voltmeter.

MAKE YOUR VTVM A MEGGER TOO

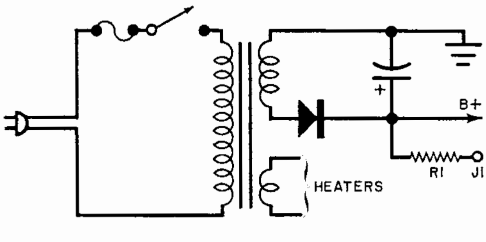
MEASURE UP TO 50,000 MEGOHMS

BY JAMES CHILDS AND JOHN ESKRIDGE

BUILT RIGHT into your VTVM is a megger that can measure extremely high resistances (to 50,000 megohms). To make use of this megger function, all you have to do to the basic meter is add a resistor and a pin or banana jack. The modification simply provides a convenient voltage source for measuring very high resistances; it does not interfere with the normal operation of your meter.

The megger modification comes in handy for all sorts of jobs. It greatly simplifies the detection of leakage in non-electrolytic capacitors, between coil and transformer windings, and between conductors of transmission lines.

The filtered d.c. for the megger is obtained from the positive side of the filter capacitor, through load resistor *R1* which is also used as a current limiter, in your VTVM as shown in the schematic diagram. Load resistor *R1* is the megger modification resistor that must be added to the VTVM's circuit. Its value must be calculated on the basis that it will pass no more than 1 mA if the ground lead of the meter is accidentally shorted to *J1* (the pin or banana jack that is used in the modification). This value is usually between 50,000 and 75,000 ohms, depending on the amplitude of the B+ voltage in your particular meter and derived by Ohm's Law ($R1 = B+/0.001$).



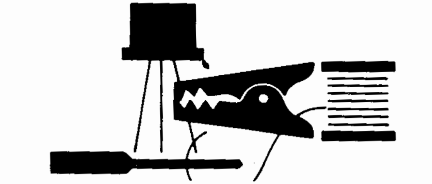
Two small parts, R1 and J1, are all that have to be added to basic VTVM to provide megger function.

The first step in measuring an unknown resistance is to measure the source voltage at *J1* with the positive d.c. probe of the meter. Then unknown resistor *Rx* is placed between *J1* and the probe to provide a circuit from B+ through *Rx* and into the input of the meter. At this point, the meter is measuring the voltage drop across input impedance *Rm* of the meter, which is typically 11 megohms.

If *Rm* and its voltage drop *Em* are known, you can calculate total current *It*. The voltage drop across *Rx* can be calculated by subtracting meter voltage *Em* from source voltage *Es* to obtain *Ex*, the voltage dropped across the resistance being measured.

With total current through and the voltage drop across *Rx* known, calculate the value of *Rx* by using Ohm's Law ($Rx = Ex/Ix$), or from the equation: $Rx = [Rm\,(Es - Em)]/Em$.

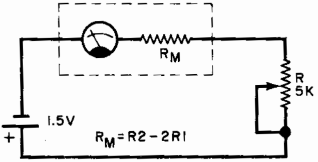
Most VTVM's have unregulated power supplies, but since the resistances being measured are very high, the loading effect on the power supplies will be negligible. Also, since current through *Rx* is very low, the voltage drop across the current-limiting resistor, *R1*, can be ignored. -30-



Tips & Techniques

DETERMINING METER RESISTANCE

Most of us, at one time or another, have had to determine the internal resistance of a meter. This circuit shows one method of getting an accurate measurement. Resistor *R_M* represents the internal resistance (unknown), and *R* is a 5000-ohm potentiometer (almost any one will do). The 1.5-volt battery should be a fresh flashlight cell. After breadboarding the circuit, adjust *R* for full scale deflection of the meter. Then remove *R* and measure its resistance. Record the value as *R1*. Next, put *R* back in the circuit, but this time adjust it for one-half scale deflection. Then remove *R* and measure its resistance, and record it as *R2*. Finally use the equation $R_M = R2 - 2R1$ to determine the unknown resistance.—*Ralph C. Born, Jr.*



TEST METER CIRCUITS

Gotta a need to do some measurin? Here are seven circuits to help you. From Ray Marston.

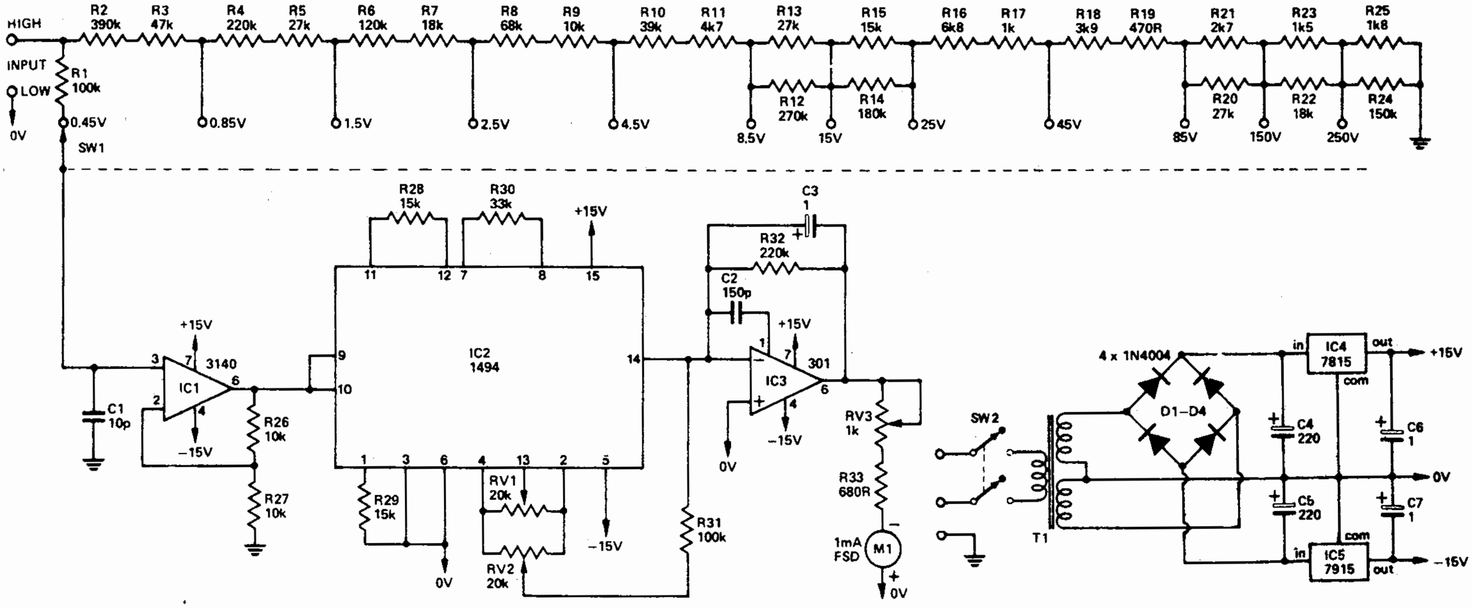


Fig. 1. A true RMS voltmeter. The input voltage is divided by the input network such that the input IC1 is 0.47 volts (DC or RMS) for full scale deflection. IC1 provides buffering and a gain of two.

Squaring of the output of IC1 is done by IC2 (1494), a four quadrant multiplier, which gives a current output proportional to the product of the voltages at its two inputs (pin 9 and 10). As we are feeding the same signal into both inputs the result is the square function.

The output of this IC is a current which is converted to a voltage by IC3 which also provides the averaging network (C3, R32). Its output drives the meter whose scale is a square root function.

Adjustments are provided for the input offset of IC2 (RV1) output offset (RV2) and overall calibration (RV3).

As the power requirement of all the ICs is ±15 V we use a line power supply and three-terminal regulators. Current drain is about 15 mA on both supplies.

BY FAR the most important thing a hobbyist or technician needs to know is what's going on inside a circuit. Such data is usually obtained from a test meter of some sort. This month we present several circuits that measure different useful quantities.

Figure 1 shows a true RMS voltmeter. Such a meter is useful whenever one encounters complex waveforms or has to make power measurement with the latter. Ordinary AC voltmeters will give RMS readings for sine waves on specially calibrated scales. These readings, however, will not be correct for square waves or any other shape you'd care to name. The circuit shown electronically calculates the actual RMS value of the waveform under test.

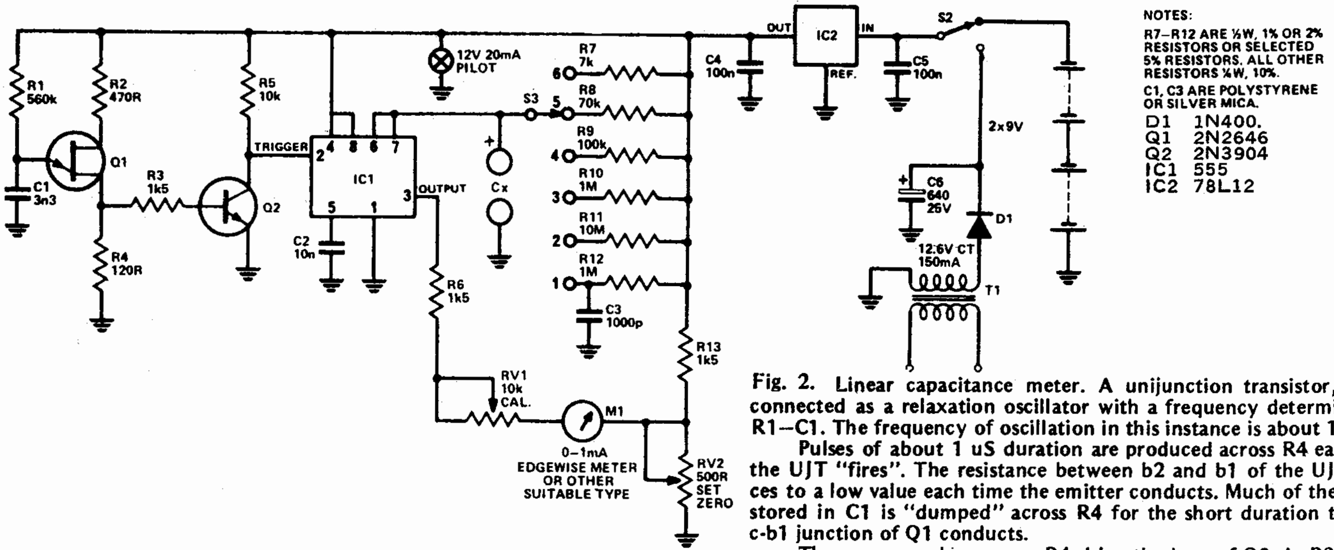
If you have a large quantity of unmarked or doubtful capacitors then the capacitance meter in Figure 2 should be useful. This particular version permits operation from AC or batteries.

The measurement of phase relationships between two AC signals is important when one wishes to determine phase shifts in a circuit, a load's power factor and so on. The circuit has two outputs. One is intended for use with a meter (0-1mA should be adequate), and the other can be connected to a chart recorder and gives a output from -180° to +180°.

Figure 4 shows a linear scale ohmeter. What more can we say? (Before you answer that read the caption).

Nowadays, most frequency measurements are made on digital frequency counters. However, for audio applications the job can be done quite effectively by the analogue frequency meter in figure 5. The circuit can give a full scale reading of 100kHz with an accuracy that is limited by its range resistors and the meter used.

Figure 6 shows a sequential logic tester. Essentially this circuit does nothing more than provide a series of clean pulses to a digital circuit. With it, you can monitor a circuit's action at a greatly reduced rate. Figure 7 shows a simple logic probe that can be used with virtually any type of logic and can detect pulses as narrow as 500ns.



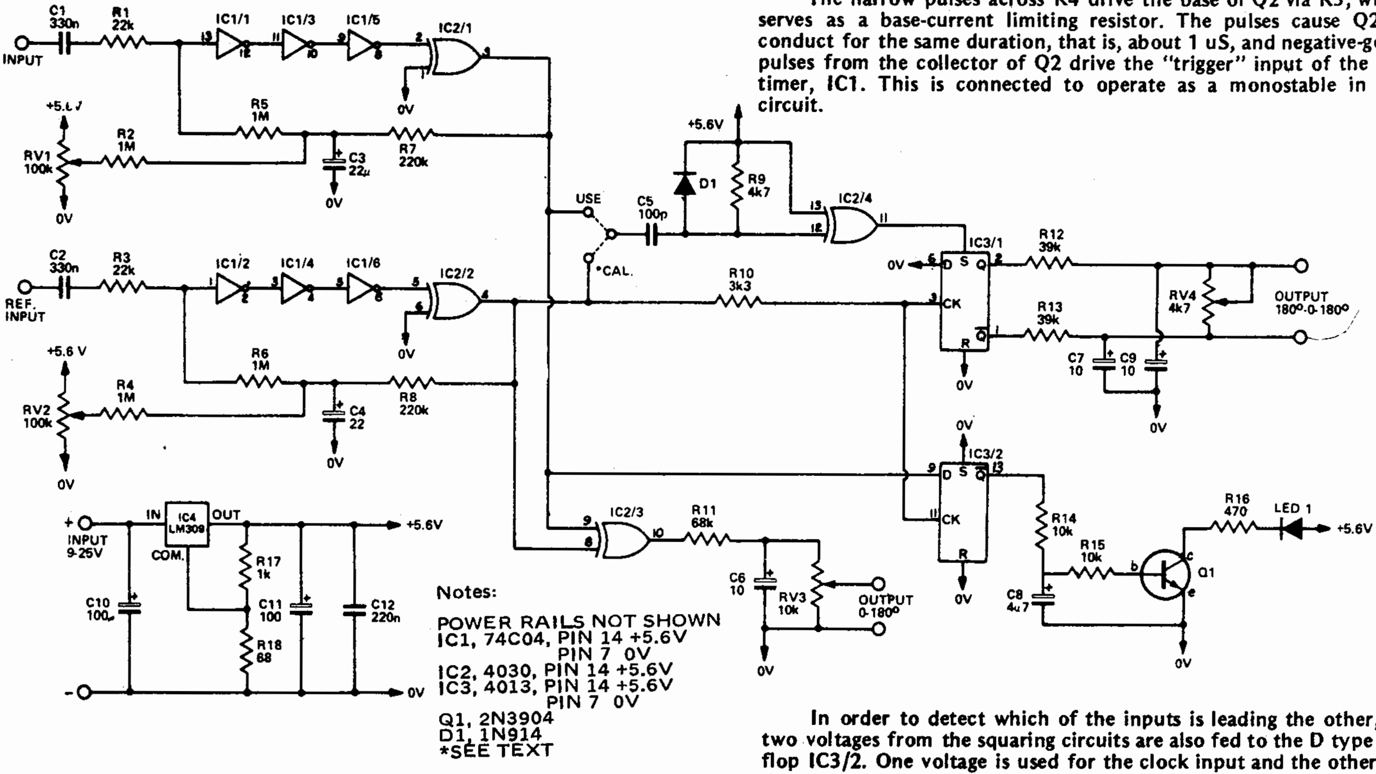
NOTES:
R7–R12 ARE ½W, 1% OR 2% RESISTORS OR SELECTED 5% RESISTORS. ALL OTHER RESISTORS ¼W, 10%.
C1, C3 ARE POLYSTYRENE OR SILVER MICA.

D1	1N400.
Q1	2N2646
Q2	2N3904
IC1	555
IC2	78L12

Fig. 2. Linear capacitance meter. A unijunction transistor, Q1, is connected as a relaxation oscillator with a frequency determined by R1–C1. The frequency of oscillation in this instance is about 1 kHz.

Pulses of about 1 uS duration are produced across R4 each time the UJT "fires". The resistance between b2 and b1 of the UJT reduces to a low value each time the emitter conducts. Much of the charge stored in C1 is "dumped" across R4 for the short duration that the c-b1 junction of Q1 conducts.

The narrow pulses across R4 drive the base of Q2 via R3, which serves as a base-current limiting resistor. The pulses cause Q2 to conduct for the same duration, that is, about 1 uS, and negative-going pulses from the collector of Q2 drive the "trigger" input of the 555 timer, IC1. This is connected to operate as a monostable in this circuit.



Notes:
POWER RAILS NOT SHOWN
IC1, 74C04, PIN 14 +5.6V
PIN 7 0V
IC2, 4030, PIN 14 +5.6V
IC3, 4013, PIN 14 +5.6V
PIN 7 0V
Q1, 2N3904
D1, 1N914
*SEE TEXT

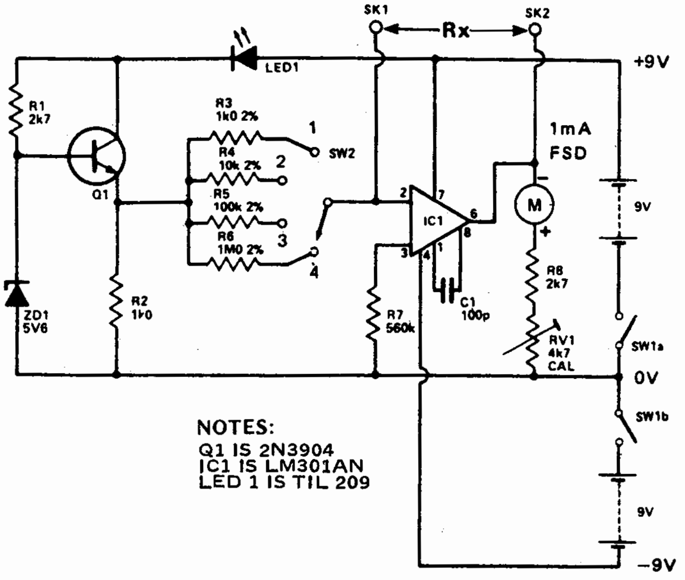
Fig. 3. Phase meter circuit. The two inputs are first squared. For example the reference input is amplified by gates IC1/2, IC1/4 and IC1/6 and then applied to IC2/2, one of the spare EX.OR gates whose other input is grounded. This conveniently behaves as a Schmitt trigger type of bistable circuit. The average of the output of this gate is formed by R8 and C4, and this is inserted via R6 as the DC level at gate IC1/2.

This produces two important consequences. Firstly it forces the output of IC2/2 to a symmetrical 180° on/180° off condition which is kept stable by almost complete DC feedback. And secondly, because we now have a true squaring circuit rather than a zero-crossing detector, all errors due to even-order harmonic distortion are cancelled. R4 and RV2 are used to adjust for input offset and set the exact 180° condition.

IC gates IC1/1, IC1/3, IC1/5 and IC2/1 process the signal from the other channel in an identical manner, and the two squared outputs are fed to gate IC2/3 which is the gate that forms the EX.OR of them. Its output is filtered by R11 and C6 and a voltage proportional to the phase difference of the inputs may be taken from across C6. RV3 is used to set this to a convenient value — for instance it may be set to 180 mV for a 180° phase difference and read it on a digital multimeter.

In order to detect which of the inputs is leading the other, the two voltages from the squaring circuits are also fed to the D type flip-flop IC3/2. One voltage is used for the clock input and the other as a data input. This type of flip-flop is really a data latch, and whatever voltage is present at the D input at the moment when the clock voltage changes from low to high is held until the next clock pulse. Thus if the D input stays low until after the clock input goes high, the output Q will always remain low showing that the D input lags the clock input. The complementary output Q will be high and this is used to turn on the transistor and LED indicating this lag condition. Since any noise arriving at the clock input can cause spurious resetting of the flip-flop, it is preferable to use a clean voltage to drive it. This is why this channel has been designated the reference. Noise on the other channel is almost completely ignored.

These then are the basic EX.OR functional parts of the phase-meter, and this would leave one flip-flop unused. In fact it turns out that there are two functions that these gates can usefully perform. First, for setting up the input squaring circuits: if the flip-flop is slaved to the squaring circuit, the exact 180° condition can be set when the complementary outputs Q and Q have equal average values. Secondly these gates can be arranged to turn the flip-flop on and off to give a conventional phase meter circuit output. While this does not give as accurate a reading, it does give one which is of opposite polarity for leading and lagging voltages and which can therefore be recorded graphically and unambiguously on an instrument such as a chart recorder. This is therefore designated the recorder output.



NOTES:
Q1 IS 2N3904
IC1 IS LM301AN
LED 1 IS TIL 209

Fig. 4. (Above). Linear ohm-meter circuit. The circuit is divided into two parts: a reference voltage generator and a readout unit that indicates the value of the resistor under test. The reference voltage generator section of the circuit comprises zener diode ZD1, transistor Q1, and resistors R1 and R2. The action of these components is such that a stable reference of about 5 V is developed across R2. This reference voltage is fed to the op-amp resistance-indicating circuit via range resistors R3 to R6.

The op-amp is wired as an inverting DC amplifier, with the 1 mA meter and R8-RV1 forming a voltmeter across its output, and with the op-amp gain determined by the relative values of ranging resistors R3 to R6 and by the negative feedback resistor Rx. RV1 is adjusted so that the meter reads full scale when Rx has the same value as the selected range resistor. Under this condition the op-amp circuit has a voltage gain of precisely unity. Since the values of the reference voltage and the ranging resistors are fixed, the reading of the meter is directly proportional to the value of Rx, and the circuit thus functions as a linear-scale ohm-meter and has a full scale value equal to the value of the selected range resistor.

NOTES:
D1,2 ARE 1N4001
IC1 IS 741
IC2 IS 555

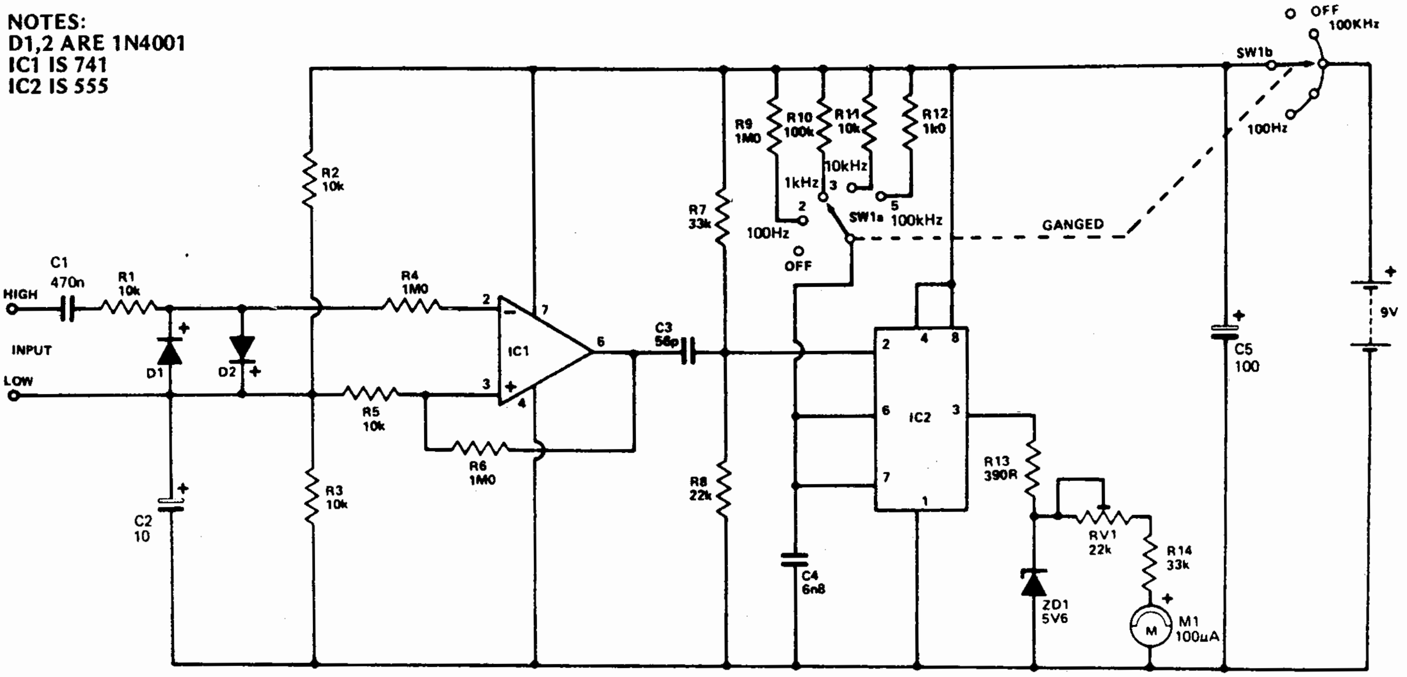


Fig. 5. Linear frequency meter. The circuit consists of an op-amp operated as a Schmitt trigger to amplify and square the input signal, followed by a 555 timer wired as a monostable, giving a short output pulse of fixed width for each cycle of input signal. This pulse drives a moving-coil meter, the reading being an average of the pulse amplitude, which is proportional to the pulse frequency. As the pulse frequency is directly related to the input frequency, the meter reading is directly proportional to the input frequency.

The input signal is coupled into IC1 via C1, which provides DC blocking. Protection from overload caused by high amplitude input signals is provided by a diode clipper consisting of D1, D2 and R1. The diodes are connected in an inverse-parallel arrangement so that both positive and negative peaks, above the diode forward conduction voltage, are clipped.

The output of IC1 is a train of square waves at the same frequency as the input. The output of IC1 is differentiated to provide short trigger pulses for the 555 timer, IC2. The differentiating network consists of C3, R7 and R8. This network is arranged to provide a trigger pulse that is always shorter than the output pulse of the 555. Capacitor C3 is selected to give the shortest possible pulse to the 555 consistent with reliable triggering.

The output of the 555 monostable will be a pulse of fixed width, determined by the range resistors, R9 to R12, and capacitor C4. The ranges are arranged to give a 75% output duty cycle at frequencies of 100 Hz, 1 kHz, 10 kHz and 100 kHz on the input.

The output pulse from the 555 is clipped at 5V6 by a zener diode, ZD1, to avoid inaccuracies caused by falling battery voltage (as the battery ages). The meter responds to the average value of the clipped pulses. As the frequency increases, the duty cycle (on/off ratio) of the pulse train increases, increasing the average voltage and thus the meter current in direct proportion. Thus the reading on the meter will be linearly related to frequency.

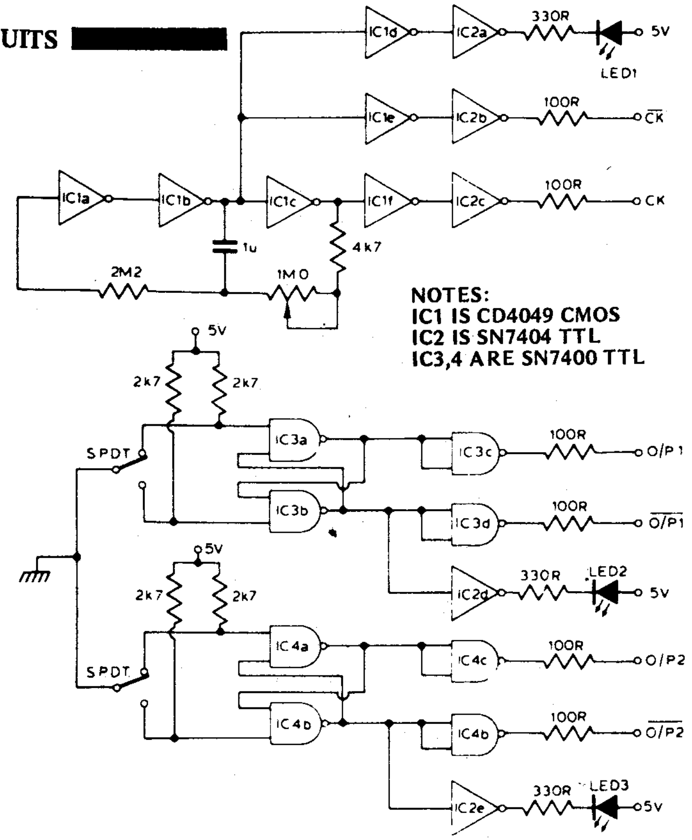


Fig. 6. (Above). Sequential Logic Tester. Anyone testing a sequential logic circuit requires input pulses free of contact bounce. This unit does this, providing two switched, jitter-free outputs and a 'slow' variable speed clock. The complements of these signals are also provided.

The components shown give the clock a frequency range of 1-200 Hz. The clock's buffered output will drive up to two TTL inputs.

The 100R resistors on all outputs provide some measure of accidental short circuit protection.

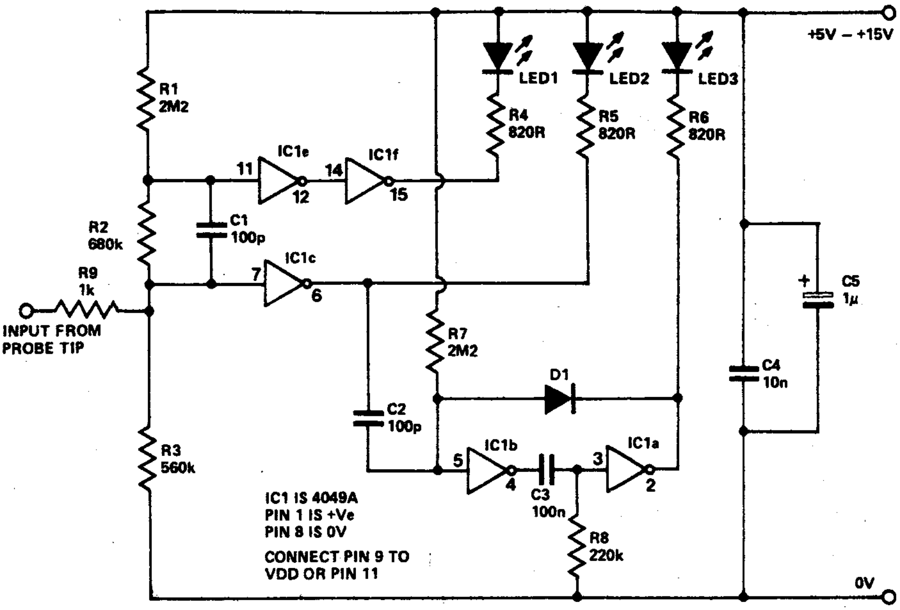


Fig. 7. Logic Probe. Anyone working with digital circuits must have someway of detecting pulses. This circuit can follow a pulse train at speeds up to 1.5 MHz. and can detect pulses down to 500ns wide.

When the circuit is presented with a HIGH pulse, inverters IC1e and f turn LED 1 on. In the LOW state, IC1c turns LED 2 on. IC1b and a and their associated components form a monostable that is used to turn LED 3 on in the presence of momentary pulses. R1 is used to isolate the probe's input and C4 and C5 are used to decouple the circuit from the supply line. Construction is non-critical but make sure you tie pin 9 (the input of the unused inverter) to Vdd, Vss or pin 11.

Microammeter

by Owen Bishop

THIS circuit adapts any ordinary voltmeter to measure currents in the microamp range. You can also use it with a multimeter, switched to a voltage-measuring range. The lowest current range on a typical multimeter is 0 - 250 uA, but with this circuit, the range can be as small as 0 - 1 uA. Of course, if you have a FET multimeter, you will probably not need this circuit, as it is likely to be built in to your meter already.

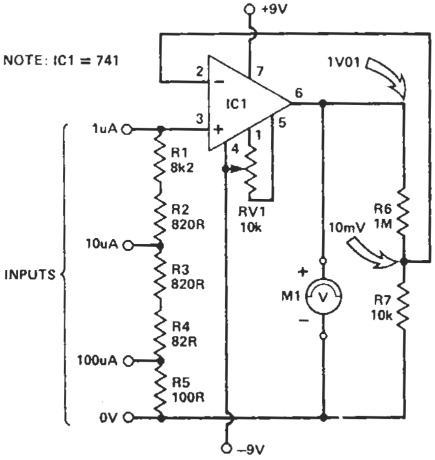
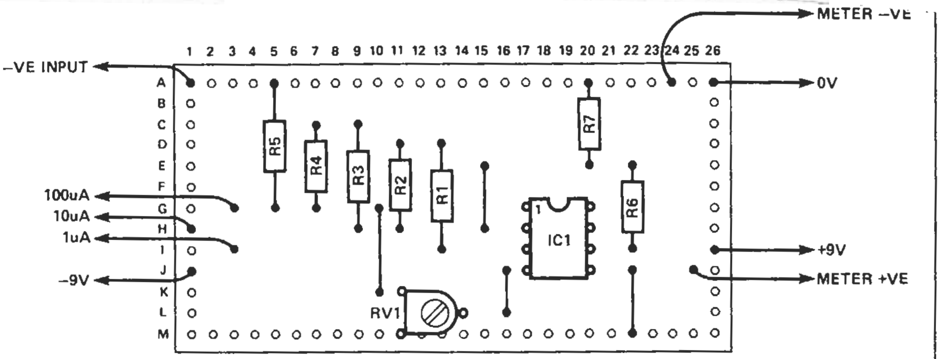
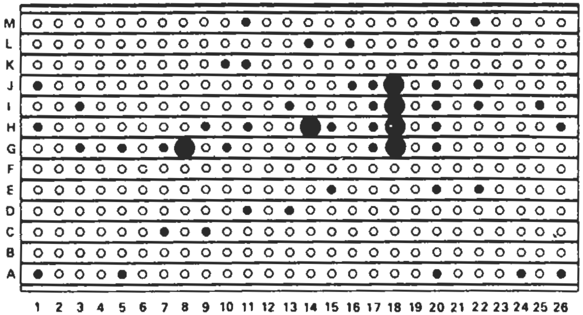


Fig. 1. The Microammeter circuit.



Veroboard component overlay and track-side view.



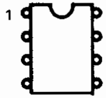
Setting up

To set up the circuit, connect the voltmeter as shown in Figure 2. This should, preferably be a 1 V FSD panel meter or a multimeter switched to the 1V DC range, but a 2 V or 3 V meter will do almost as well.

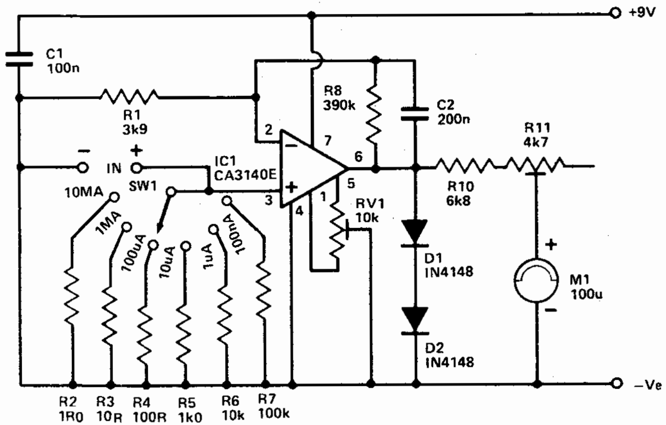
Now switch on the power; the meter will show a reading of some kind. Join the 1 uA input socket to the junction of R6 and R7, using a test-lead; this connects the two inputs of the op-amp together. The reading on the meter should be 0 V, but if not, adjust the offset null potentiometer (RV1) until the needle of the meter comes to rest at zero. The temporary lead may now be removed, and the circuit is ready for use.

Designer Circuits

NANOAMP METER



CA3140E
TOP VIEW



R1 TO R7 ARE CLOSE TOLERANCE TYPES

It is not possible to accurately measure currents of a few microamps. or less using an ordinary panel meter or multimeter. In order to make such measurements it is necessary to use an active circuit such as the one shown here. It can be built as a self-contained unit or used as part of an instrument requiring a highly sensitive current meter. The sensitivity is from 100 nA to 10 mA. FSD in six ranges; the higher ranges being included to permit calibration, and because many multimeters have very few low current ranges.

M1 is connected in a 1 V FSD voltmeter circuit which also uses R10 and R11. The latter is adjusted to give the unit the correct sensitivity. IC1 is an Op Amp connected in the non-inverting mode and having a DC voltage gain of about 100 times (set by feedback network R8-R1). C2 reduces the AC gain to only about unity so as to improve stability and immunity to stray pick-up. The non-inverting input of the IC1 is biased to the 0 V rail by whichever of the range resistors (R2-R7) is selected by SW1. In theory this gives zero output voltage and no meter deflection, but in practice it is necessary to compensate for small offset voltages using offset null control, RV1.

If an input current is connected to the unit, a voltage will be developed across the selected range resistor, this voltage being amplified to produce a positive meter deflection. With R2 switched into circuit, 10mA is needed to give full scale deflection of M1, since 10mA will cause 10mV to be developed across R2 (E=I x R, = 0.01 A x 1 ohm, = 0.01 V or 10 mV), and this will be amplifier one hundred fold by IC1 to give one volt at the output. On successive ranges the range resistor is raised by a factor of ten, reducing by a factor of ten the current required at the input to develop 10mV and give full scale deflection of M1.

This arrangement relies on the amplifier having a very high input impedance so that it does not drop a significant amount of input current, and this is achieved by using a FET input op amp having a typical input resistance of 1.5 million meg ohms. D1 and D2 prevent the output voltage of IC1 from exceeding more than about 1.3 volts, and they thus protect M1 against overloads.

When adjusting RV1 start with its slider at the pin 5 end of the track (there should be a strong deflection of M1), and then back it off just far enough to zero the meter, and no further.