

# 100,000-Megohm-Input Meter Indicates Static Electricity

*Ultrasensitive picoammeter/electrometer expands your measurement world to one-trillionth of an ampere and a trillion ohms*

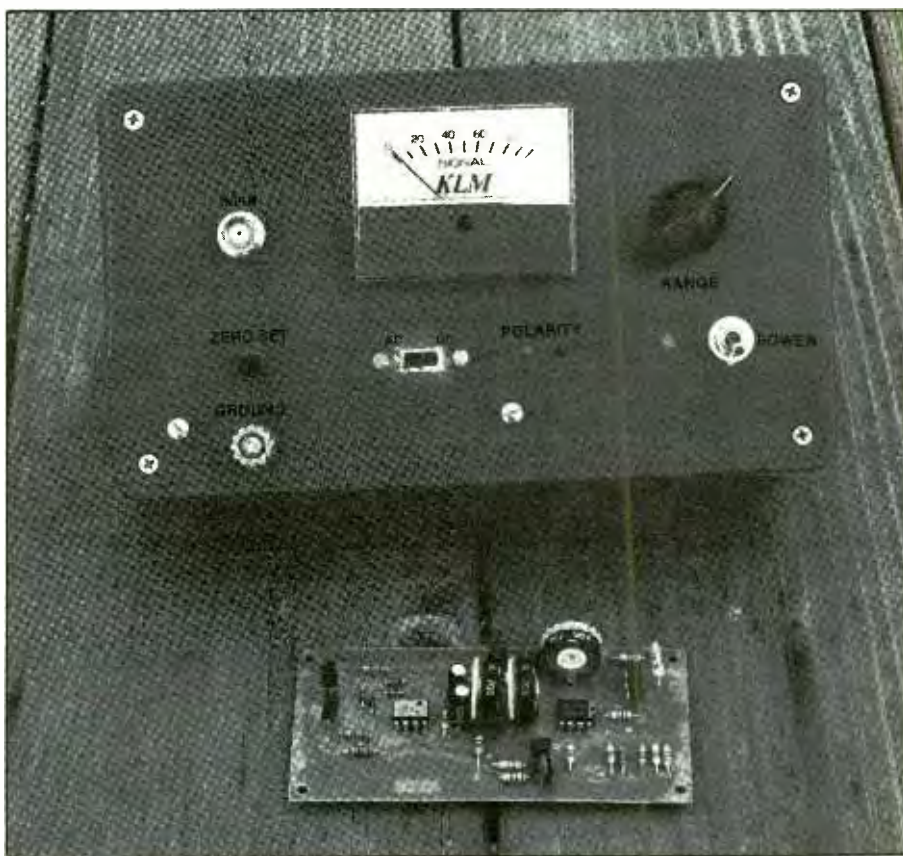
By Rudolf F. Graf  
& William Sheets

Typical volt-ohm-milliammeters, even 10-megohm FET VOMs, are useless when it comes to measuring minute electric charges or very-high-impedance sources such as ionization gauges, Geiger-Muller tubes, MOSFET gates, electrostatic devices, and comparable devices. They always place too high a load on the circuit. To make such measurements, you're usually forced to use an expensive laboratory instrument. Now there is a \$50-or-so alternative you can build to obtain relative indications, as follows.

Our inexpensive electrometer-type voltage/current meter employs no unfamiliar assembly techniques or difficult-to-find components. It uses basic printed-circuit wiring and a commonly available 1-mA analog meter movement (you may also use your DVM or an old tuning meter as a relative level indicator), among other readily available components. Yet, its sensitivity is so great that it can even detect a person's movement in a room, let alone the relative level of static electricity at your work station!

## About the Circuit

Shown schematically in Fig. 1 is a basic electrometer amplifier that has an input impedance of about 100,000 megohms. MOSFET-input opera-



tional amplifier *IC1* serves as a variable-gain dc amplifier. In this circuit, *R1*, *R2* and *R3* provide dc returns for the input circuit of the op amp, while *C1* and *R4* provide static protection for the IC.

A voltage divider made up of *R5* through *R8* and tap-selectable by the rotary switch provides gains of 1, 3.3, 10 and 33 times so that a +1-volt output swing is available with 1, 0.3,

0.1 and 0.03 volts ac or dc at the op amp's input. *BALANCE* control *R21* is included in the circuit to allow the zero point to be set.

The inverting (-) input of the op amp is kept at a voltage that is very close to the potential of the ac or dc input signal on the op amp's noninverting (+) input. Note that a "Guard" surrounds the components and conductors between INPUT jack

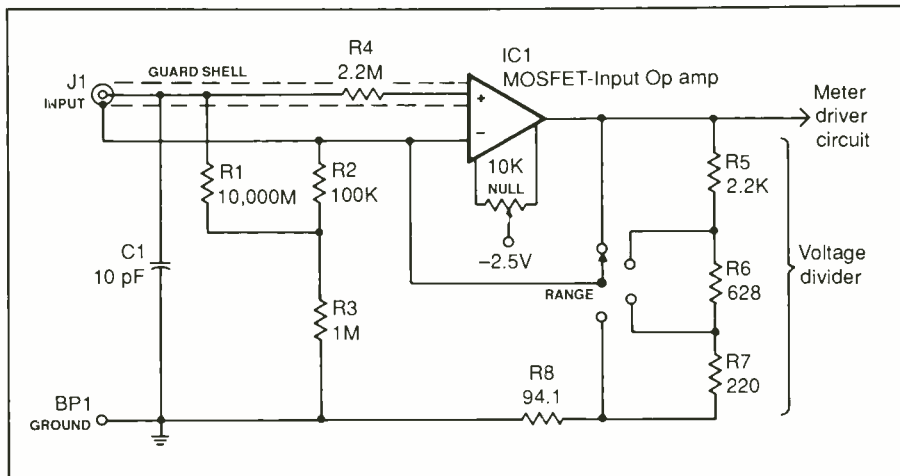


Fig. 1. The basic electrometer circuit uses a MOSFET-input operational amplifier and a special input network to minimize loading down a circuit under test.

functions of  $S1$  and  $R5$  through  $R8$  are exactly the same as in the previous circuit.

Note here that  $R6$  and  $R8$  each consist of two separate resistors, labeled  $R6A/R6B$  and  $R8A/R8B$ , respectively. The reason for these parallel-resistor arrangements is that single precision resistors of the values needed in these two instances do not exist and, therefore, must be obtained by appropriate parallel combinations of available values. In these two cases, the values required are 628 and 94.1 ohms for  $R6$  and  $R8$ , respectively.

After undergoing amplification by  $IC1$ , the signal at the pin 6 output is coupled back to the pin 2 inverting input of the op amp through RANGE switch  $S1$ . Independent of the setting of this switch, the amplified pin 6 output of  $IC1$  should always be between 0 and +1 volt. Test point  $TP1$  on the output line provides a means for connecting a voltmeter into the circuit to externally monitor, via a pin jack or other device, the voltage at this point during calibration.

Transistors  $Q1$  and  $Q2$  and their associated components serve as simple voltage regulators that supply a "stiff" +2.5 volts to  $IC1$  from the power supply made up of batteries  $B1$  and  $B2$ , without the need for zener diodes and inefficient shunt regulator circuits. The result of this powering arrangement is minimal drain on the battery supply.

Resistor  $R12$  couples the pin 6 output from  $IC1$  to the pin 4 input of  $IC2$ , which functions as the meter circuit's rectifier/driver circuit. Switch  $S2$  permits selection of either ac or dc for measurement purposes. In the DC position,  $C6$  and  $C7$  restrict the circuit's frequency response and reduce noise pickup. Diodes  $D1$  through  $D4$  make up a bridge rectifier for 0-to-1-milliamper meter movement  $M1$ . Capacitor  $C8$  shunts ac signals to bypass  $M1$ .

Since  $D1$  through  $D4$  are in the feedback path, nonlinearities of the

$J1$  and the + input of  $IC1$ . This "Guard" is *not* a mesh shield; rather, it represents a shield formed by the copper conductor pattern on the printed-circuit board on which the project's circuitry is assembled. Because the potential difference between the inverting and noninverting inputs to the op amp is very small, equal to the output of the amplifier divided by the open-loop gain (typically more than 1,000 times), leakage across the surface of the pc board as a result of dirt, humidity, etc., is minimized by this "guarding" arrangement.

Guarding is a technique commonly used for measuring very high resistances and very small currents and capacitances, and where undesired or stray effects may mask quantities to be measured. It generally makes use of a voltage or current or another signal to cancel out the unwanted effects. Several examples of the guarding technique are illustrated in Fig. 2. Note that guarding is used for *shielding* purposes only; the guard must *not* be connected to circuit ground!

Returning to Fig. 1, the output of the op amp goes to a metering circuit that gives an indication of the magnitude of the parameter being measured. Potentials of up to 1 volt peak

of positive or negative polarity can be measured by this circuit. Use of an ac metering scheme allows ac voltages to be measured by this circuit.

Input resistor  $R1$  is a special device that has a value of 100,000 megohms. It is returned to the junction between  $R2$  and  $R3$  so that about 90 percent of the input voltage applied via  $J1$  appears at the junction. This arrangement has the effect of raising the apparent resistance of the electrometer's input by a factor of ten times, effectively to 1,000 megohms.

Some dc stability is sacrificed by the input-network arrangement shown in Fig. 1. If the value of  $R2$  is reduced to 10,000 ohms, 1,000,000 megohms can be obtained, although doing this would cause troublesome drift in the operating point. Therefore, for most purposes, 100,000 megohms is sufficient. By using the most sensitive range (0.03V) in the metering circuit, input currents of 0.1 picoampere (0.1 micro-micro ampere) are detectable with acceptable stability.

Shown in Fig. 3 is the schematic diagram of the entire electrometer circuit, including its dual-polarity battery-type power supply. As in the Fig. 1 circuit,  $IC1$  is a MOSFET-input op amp. Input to the project is applied through  $J1$  across  $R1$  to the + input terminal at pin 3 of  $IC1$ . The

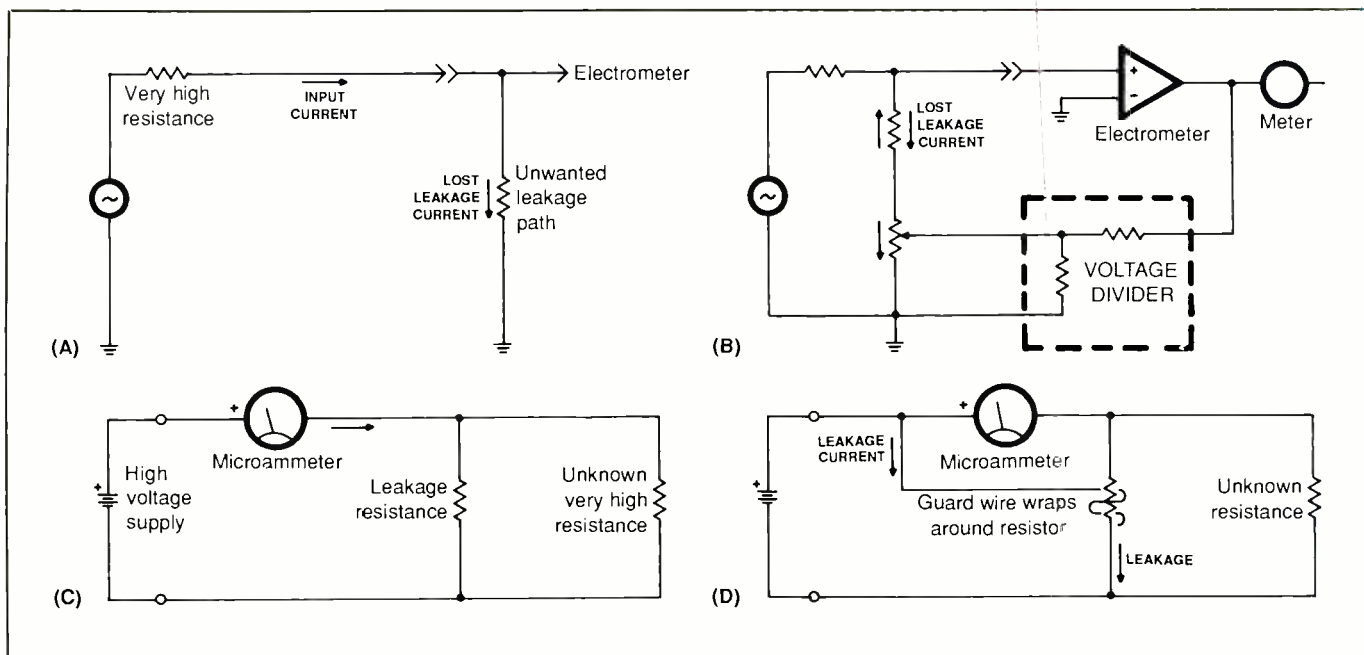


Fig. 2. Unguarded (A) and guarded (B) systems. In (B), a portion of the electrometer's output is tapped off and used to cancel the leakage path. High-resistance measurements with unguarded (C) and guarded (D) setups. Microamme-

ter in (C) indicates sum of currents through an unknown resistance and leakage along the surface, while microammeter in (D) shows resistor current, as leakage current bypasses the meter.

diodes are compensated for and *M1* will indicate the absolute average dc value of the input signal applied to pin 3 of *IC2* on its linear scale.

AC CAL and DC CAL controls *R9* and *R10*, with *R11*, provide the means for calibrating the ac and dc functions, according to the position to which *S2* is set. These controls must be set so that 1 volt ac or dc, as indicated on the meter connected between *TP1* and circuit ground, will cause full-scale deflection on *M1*.

The output of *IC2* also drives *Q3* and *Q4*, through *R17*. If *IC1*'s output is positive, *Q3* conducts and lights red light-emitting diode *LED1*, indicating a positive (+) input voltage. Conversely, a negative input voltage will cause *Q4* to conduct and light green *LED2*. The *LED1/LED2* arrangement glows alternately red and green for ac inputs.

BALANCE control *R21* is used to null *IC1* to set *M1*'s pointer to its 0 index.

Power is applied to and disabled

from the circuit via POWER switch *S3*. Drain on the battery supply is about 10 to 15 milliamperes. Yellow light-emitting diode *LED3* is an optional power-on indicator that has nothing to do with circuit operation. This LED and current-limiting resistor *R20* can be eliminated if you wish to save on component cost or/and battery drain.

### Construction

Due to the stability requirements for this project's circuitry, printed-circuit construction is mandatory. You can etch and drill your own pc board using the actual-size artwork shown in Fig. 4 (use only G10 epoxy-fiberglass pc blank) or purchase a ready-to-wire, silk-screened pc board from the source given in the Note at the end of the Parts List. Before beginning to wire the board, thoroughly clean it with isopropyl alcohol and, if possible, acetone to remove all dirt, grease, etc. (If you are using a silk-screened board, do *not* clean the

screened side with acetone or allow acetone to get on it; if you do, the screened legends will wash off.) These are volatile materials; so work in a well-ventilated location and away from open flames!

Begin wiring the board by installing and soldering into place the resistors, followed by the capacitors, diodes, transistors and, finally, the integrated circuits, as illustrated in Fig. 5. Make absolutely certain that the diodes and electrolytic capacitors are properly oriented before soldering their leads to the copper pads on the bottom of the board. Clip away all excess component lead lengths. Similarly, make sure the ICs are plugged into the holes in the proper locations and that they are properly oriented before soldering their pins to the pads.

Prepare suitable-length wires for BP1, J1, both holes for all LEDs, M1+, M1-, S1,1 through S1,5, S2,1 through S2,6 (note that there is no hole for S2,4, which is not used), S3,1 through S3,4, and TP1. If you are us-



ing stranded hookup wire, strip ¼ inch of insulation from both ends, tightly twist together the fine wires and sparingly tin with solder. Plug one end of each wire into the indicated holes and solder into place.

Carefully check all soldering. Reflow the solder on any suspicious connection. Also, use solder wick or a vacuum-type desoldering tool to remove any solder bridges you might have created between closely spaced pads and/or traces. When you are sure your soldering is okay, clean the bottom of the board with flux remover or isopropyl alcohol.

This extremely sensitive project must be housed inside either an all-metal enclosure or a foil-lined plastic project box. The first thing to do is drill the mounting holes for the circuit-board assembly through the floor of the enclosure.

Next, machine the enclosure as needed for mounting *B1*, *J1*, *LED1* through *LED3*, *S1* through *S3*, and a pin jack (for connection to *TP1*) on the front panel. A suggested layout is shown in the lead photo. When suitable holes have been made, temporarily mount the circuit-board assembly in place, with the adjustment shaft of *R21* facing toward the front panel, using ½-inch spacers and 4-40 × ¼-inch machine screws and nuts. Determine exactly where on the front panel the hole for this trimmer control's shaft must be drilled and mark that location. Remove the circuit board assembly and then drill the hole in the marked location.

The four-cell holders for *B1* and *B2* should be mounted on the rear wall of the enclosure. To accomplish this, drill the holes according to the pattern on the holders. This done, mount the holders on the rear wall. Then remount the circuit-board assembly in its location with the same hardware you previously used.

Mount rotary RANGE switch *S1* in its hole in the front panel, making the hardware only finger tight. Place a pointer-type knob on the switch's

## Background

For most electronics work, the loading effect of a VOM is not a critical factor. However, when it is necessary to measure minute charges or sources that have very high impedance, they will not suffice.

Of course, it is possible to use electrostatic instruments that are voltage operated without drawing any current from the circuit or source being measured. Unfortunately, though, these devices are suitable for only relatively high voltages (beyond about 50 to 100 volts). One such device, invented more than a century ago, is the electrostatic repulsion. In the electrostatic repulsion, two very light metallic leaves made of gold foil are suspended from a wire. A charge placed on the wire causes the gold leaves to repel each other by a given amount. It is theoretically possible, but hardly practical, to calibrate such an instrument.

Invention of the vacuum tube made it possible to use the tube as an amplifier in which the grid theoretically draws no current. Tubes for this application must be operated at very low voltages to avoid causing unwanted electrons from collecting on the grid and interfering with the measurement. This type of device can detect and measure very small currents, down to a picoampere (micro-micro or 10<sup>-12</sup> ampere). A disadvantage is that commercial electrometers are priced beyond the means of most home experimenters and many professional service shops.

The metal-oxide field-effect transistor (MOSFET), conceived in the 1920s by a man named Lilienthal, finally became a practical reality in the 1960s. The MOSFET modulates the surface conductivity of a semiconductor with an electric field,

applied via a gate electrode. In theory, and quite close in practice, the MOSFET's gate draws no current because it is insulated from the semiconductor structure. The MOSFET has become a basic building block of modern electronics and is the heart of VLSI (very-large-scale integrated-circuit) devices.

The MOSFET has the potential of being an ideal device for electrometer applications. Though early MOSFETs were unstable and noisy, the modern MOSFET-input operational amplifier has overcome most of the problems. MOSFET-input op amps now make it possible to measure very small electrical charges and currents and to use these signals to control very large currents. Individual power MOSFET devices can now switch 10 to 30 amperes at 100 volts or more while being controlled by megohm-level impedance sources, an ability not presently possible with bipolar devices.

The project presented in the main article takes advantage of a commonly available, inexpensive MOSFET-input op amp, the CA3420, to produce a low-cost picoammeter/electrometer instrument that can measure currents as low as 1 picoampere and resistances as high as 1M megohm.

Now just about anyone who is interested in electronics, whether as a hobby or as a career, can have this type of instrument without having to spend many hundreds or even thousands of dollars for a similar commercial instrument. With it, one can now seriously check the relative level of static electricity that might damage an electronic or computer component, the effectiveness of insulation, determine the static-charge polarity of different materials, and other tasks beyond the capability of common test instruments.

shaft and, without allowing the switch itself to move, rotate the knob through all four positions. As you do this, observe where the index on the knob points for the first and last positions. If these are not symmetrical, readjust the positioning of the switch

until they are. You may have to remove the knob to do this.

Once the RANGE switch is properly positioned, tighten its hardware and replace the knob on the shaft. Once again, rotate the knob through all four positions. This time, make a

Fig. 3. The diagram of the complete electrometer, including metering circuit and AA-cell dc power supply.

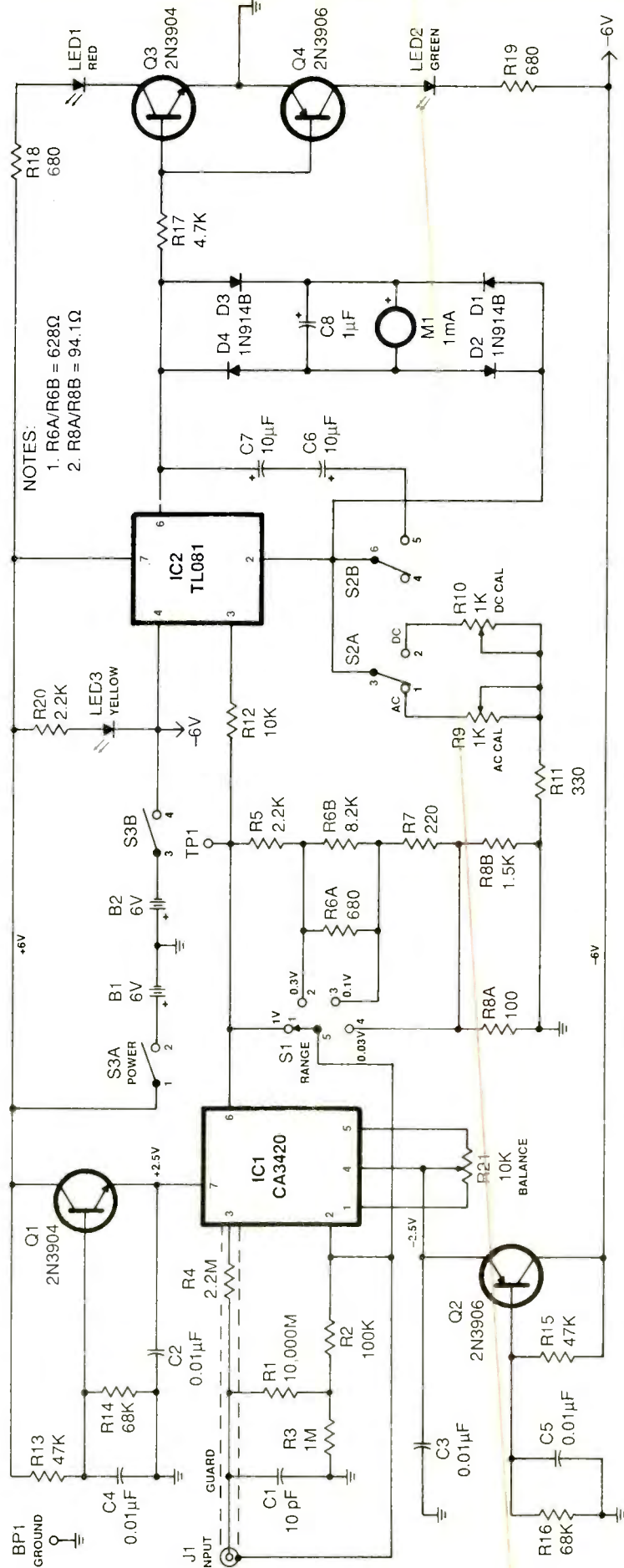
light pencil mark at the location where the knob index stops to indicate where to put the range legends for the switch. Remove the knob.

Now label the front panel according to the legends detailed in Fig. 3. If you use a dry-transfer lettering kit for this, wrap the shaft of the rotary switch in masking tape. Then spray at least two *very light* coats of clear acrylic over the entire front panel to protect the lettering. Be sure to allow each coat to completely dry before spraying on the next.

When the acrylic spray has completely dried, mount the pin and banana jack, BNC connector, meter movement and switches in their respective holes in the front panel.

Referring to both Fig. 3 and Fig. 5, connect and solder the free ends of the appropriate wires to the indicated lugs on the switches and pin jack. Do the same for the wires coming from the J1 CENTER and BP1 holes. Locate the free end of the M1 + wire and connect and solder it to the + terminal on M1. Do the same with the free end of the M1 - wire and - terminal on M1.

Now locate the wires coming from the LED1 through LED3 holes and slip over each a 1-inch length of small-diameter heat-shrinkable or plastic tubing. Cut the cathode leads of all three LEDs to a length of 1/2 inch and form a small hook in each. Crimp the free end of the LED1 K wire to the cathode lead of LED1 and solder the connection. Do the same with the LED2 K and LED3 K wires and the cathode leads of LED2 and LED3, respectively. Then repeat the procedure with the anode wires (not identified in Fig. 5) and anode leads of each LED in turn. When this is done, push the tubing up over the connections to fully insulate them and



NOTES:  
 1. R6A/R6B = 628Ω  
 2. R8A/R8B = 94.1Ω

## PARTS LIST

### Semiconductors

D1 thru D4—1N914B silicon switching diode  
 IC1—CA3420 MOSFET-input operational amplifier (RCA)  
 IC2—TL081 operational amplifier (Motorola or Texas Instruments)  
 LED1—Red light-emitting diode  
 LED2—Green light-emitting diode  
 LED3—Yellow light-emitting diode (optional—see text)  
 Q1, Q3—2N3904 or ECG123A silicon npn transistor  
 Q2, Q4—2N3906 or ECG159 silicon pnp transistor

### Capacitors

C1—10-pF, 10% silver mica (do not substitute)  
 C2 thru C5—0.01- $\mu$ F, 50-volt disc  
 C6, C7—10- $\mu$ F, 16-volt electrolytic  
 C8—1- $\mu$ F, 50-volt electrolytic

### Resistors ( $\frac{1}{4}$ -watt, 10% tolerance)

R1—10,000 megohms  
 R4—2.2 megohms  
 R11—330 ohms  
 R12—10,000 ohms  
 R13, R15—47,000 ohms

R14, R16—68,000 ohms  
 R17—4,700 ohms  
 R18, R19—680 ohms  
 R20—2,200 ohms (needed only if LED3 is used)  
 R2—100,000 ohms, 5% tolerance  
 R3—1 megohm, 5% tolerance  
 R5—2,200 ohms, 1% tolerance  
 R6A/R6B—628 ohms, 1% tolerance (680 and 8,200 ohms, both 1% tolerance, in parallel; matched resistor pairs are supplied in kit—see text)  
 R7—220 ohms, 1% tolerance  
 R8A/R8B—94.1 ohms, 1% tolerance (100 and 1,500 ohms, both 1% tolerance, in parallel; matched resistor pairs are supplied in kit,—see text)  
 R9, R10—1,000-ohm upright pc-type trimmer potentiometer  
 R21—10,000-ohm upright pc-type trimmer potentiometer with shaft

### Miscellaneous

B1, B2—Eight AA cells  
 BP1—banana jack (preferably black)  
 J1—Female panel-mount BNC connector

M1—0-to-1-mA meter movement  
 S1—4-position, 1-pole nonshorting rotary switch  
 S2, S3—Dpdt slide or toggle switch  
 TP1—Pin jack (see text)

Printed-circuit board; suitable enclosure (see text); two AA cell holders (4 cells each); pointer-type knob for S1; material for making test cable for J1 (UG-88 or similar male BNC connector, good-quality RG-58U coaxial cable, etc.—see text); materials for making ground cable for BP1 (banana plug, test-lead cable, etc.—see text); small-diameter heat-shrinkable or plastic tubing for LEDs; labeling kit; suitable machine hardware; hookup wire; solder; etc.

**Note:** The following items are available from North Country Radio, P.O. Box 53, Wykagyl Station, NY 10804: All components, including etched, drilled and silk-screened pc board, C8 and R10 but *not* LED 3 or any items under Miscellaneous, \$37.50 plus \$2.50 P&H; pc board only, \$10.00, plus \$2.50 P&H. New York residents, please add state sales tax.

shrink into place. This done, plug the domed cases of the LEDs into their respective front-panel holes.

Prepare two wires of sufficient length to reach from S3 to the battery holders. Crimp and solder one end of each wire to the indicated lugs on the switch and the other ends to the indicated lugs on the battery holders. Crimp but do not solder the free end of the wire coming from the GND hole on the board to the + lug on the holder for B2. Finally crimp and solder a short length of hookup wire between the - lug on the B1 and + lug on the B2 holders. Check battery polarity before proceeding.

If you are using a plastic enclosure for your project, make certain that you fully line it with aluminum foil before mounting any components in place. Also, make sure you do not ground the shell of INPUT connector J1; this is a guard—*not* a ground

connection. If you are using a metal enclosure, use insulating hardware to mount this BNC connector on the panel. Keep the wiring to J1 as short as possible and as far away from other wires.

To use this instrument, you need a pair of input cables, one to connect from the INPUT BNC connector to the point of interest in and the other to connect from the GROUND banana jack to ground in the circuit under investigation. Both should be no longer than 36 inches.

Start with the input lead. As illustrated in Fig. 6, to make this lead you need a male BNC connector that mates with J1 and a length of good-quality RG-58U coaxial cable. Prepare one end of this cable by removing  $1\frac{1}{4}$  inch of outer plastic jacket. Then carefully trim away  $\frac{3}{8}$  inch of the exposed shield mesh. Next, strip  $\frac{1}{4}$  inch of insulation from the inner

conductor. If this conductor is made up of stranded wire, tightly twist together the wires and sparingly tin them with solder. Use heat judiciously to prevent the inner insulation from melting and causing the inner conductor and shield to short to each other.

This end of the cable can be finished in any of several ways. For example, you can terminate it in a pointed probe, a ball connector or leave it as is.

If you use a probe, solder to the inner conductor about a 1-inch length of bare solid hookup wire. Use a probe whose handle can accommodate the coaxial cable. Use only a *plastic* probe—not a fiber one! Slide the cable into the handle until the wire exits the hole at the point end. Then wrap the wire around the neck of the probe tip and screw on the retaining ring. Use a similar arrange-



ment if you use a ball-type connector. To use the cable as is, slip a 2-inch length of heat-shrinkable tubing over the prepared end and position it so that it completely covers the mesh shield and only partially covers the insulator for the inner conductor. Shrink the tubing solidly into place. When you are done,  $\frac{1}{8}$  inch of the inner insulation and all of the exposed inner conductor should be visible.

Prepare the other end of the coaxial cable as detailed with the instructions supplied with the BNC connector. Install this connector on the cable end exactly as detailed by the manufacturer. If no instructions are supplied, prepare the cable end and secure it as you normally would for any other BNC connector.

Preparation of the ground cable is much simpler. All you need for this cable are a length of stranded wire, preferably the type used for test-instrument cables, and a banana plug. Remove  $\frac{3}{8}$  inch of insulation from both ends, tightly twist together the fine wires and sparingly tin with solder. Terminate one end in the banana plug by the usual means and the other with a small insulated alligator clip or ball-type connector.

### Checkout & Calibration

With no AA cells installed in the battery holders, perform the following resistance check. First, clip the common lead of your ohmmeter to either the - lug on the B1 holder or the + lug on the B2 holder and leave it there. Then touch the ohmmeter's "hot" probe to first pin 7 and then pin 4 of IC2. In both cases, you should obtain a meter reading of more than 300 ohms. If your readings are less than 300 ohms, try reversing the connections of the ohmmeter. Whichever way you connect the ohmmeter probes, the higher reading should exceed 300 ohms. If you do not obtain the proper readings, recheck all wiring, component orientations and values or part num-

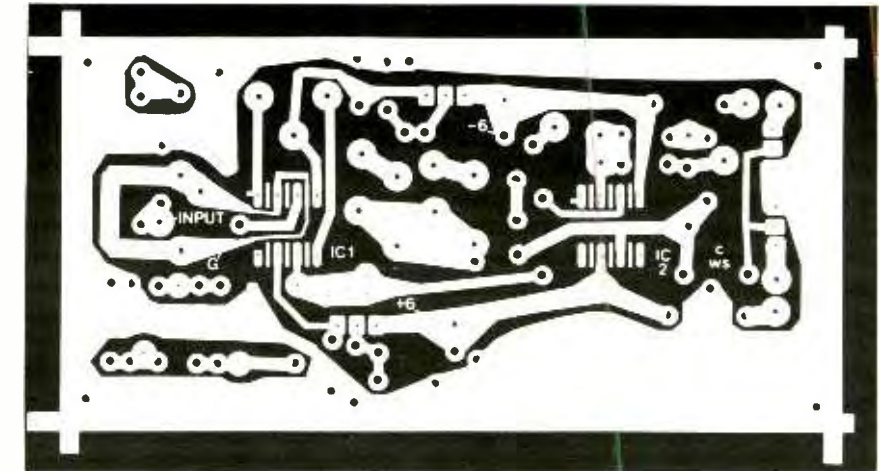


Fig. 4. The actual-size etching-and-drilling guide for the printed-circuit board to be used in this project.

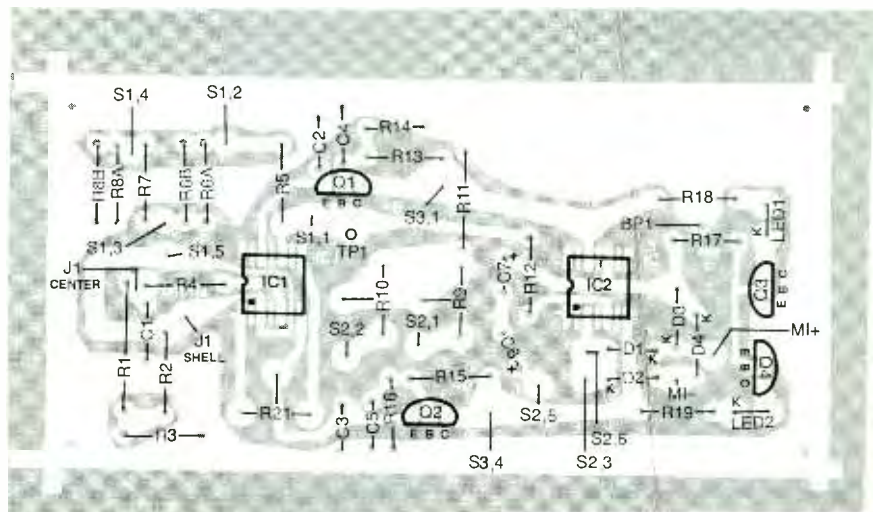


Fig. 5. The wiring diagram for the pc board.

bers. Do not proceed until the problem has been rectified.

When you are satisfied that everything is okay, set POWER switch S1 to OFF and install the AA cells in the battery holders. Make sure each cell is installed in the correct orientation.

Then set S1 to ON and immediately check to see if the yellow LED is on. You may also notice at this point that either the red or the green LED or both alternately are on as well.

If everything appears to be okay up to this point, use a dc voltmeter

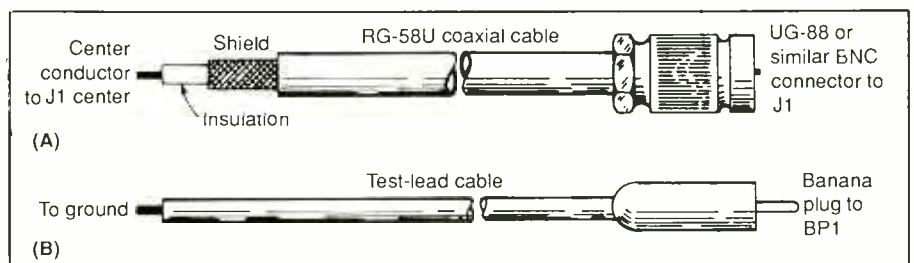


Fig. 6. Fabrication details for the two test leads required by the electrometer.

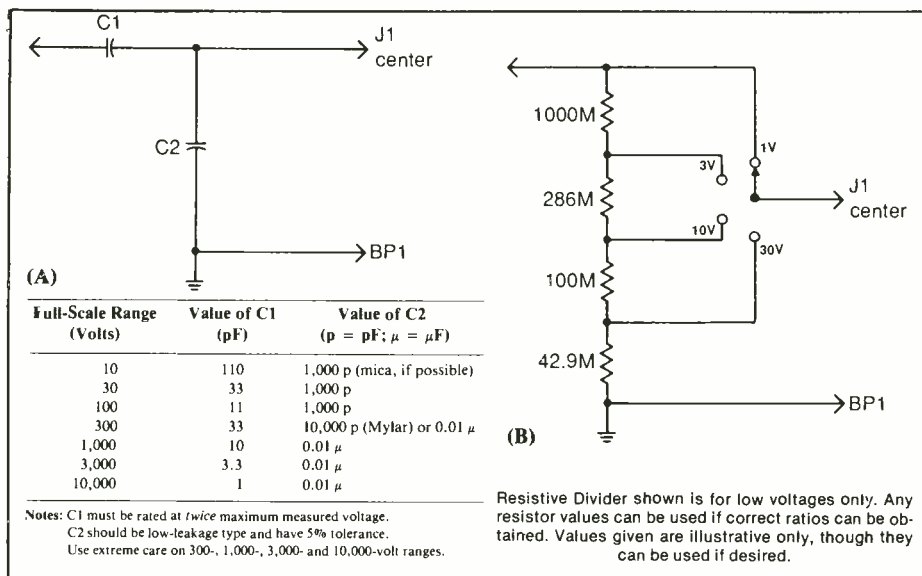


Fig. 7. Examples of external capacitive (A) and resistive (B) voltage dividers that can extend the project's measuring range.

(or multimeter set to dc volts) to verify the following:

- IC1 pin 7: +2 to +3 volts
- IC1 pin 4: -2 to -3 volts
- IC1 pin 6: -1 to +1 volt (may vary)
- IC2 pin 7: +6 volts
- IC2 pin 4: -6 volts

These voltage checks should be made with the meter's common probe connected at all times to a convenient circuit-ground point. If you do not obtain one or more of these voltage readings at the indicated points, power down the project, remove the cells from the battery holders, and rectify the problem.

Next, temporarily connect a wire between the R1/R4/C1 junction and circuit-ground trace on the circuit-board assembly. Set the RANGE switch to 1V and adjust the setting of the BALANCE control for a null reading on the meter. If the meter's pointer will not adjust to the null (zero) point, power down and, once again check your construction work. If you find no wiring or installation fault, check out IC1 and IC2.

Set S1 to DC and check to see if the BALANCE control will null the meter in each setting of the RANGE switch.

Note that on one side of the null setting the red LED should be on and on the other side the green LED should be on. If you do not obtain these indications, check IC2, Q3, Q4, LED1 and LED2.

Next, set S1 to 1V and apply an exact +1-volt dc source to the center conductor of INPUT connector J1

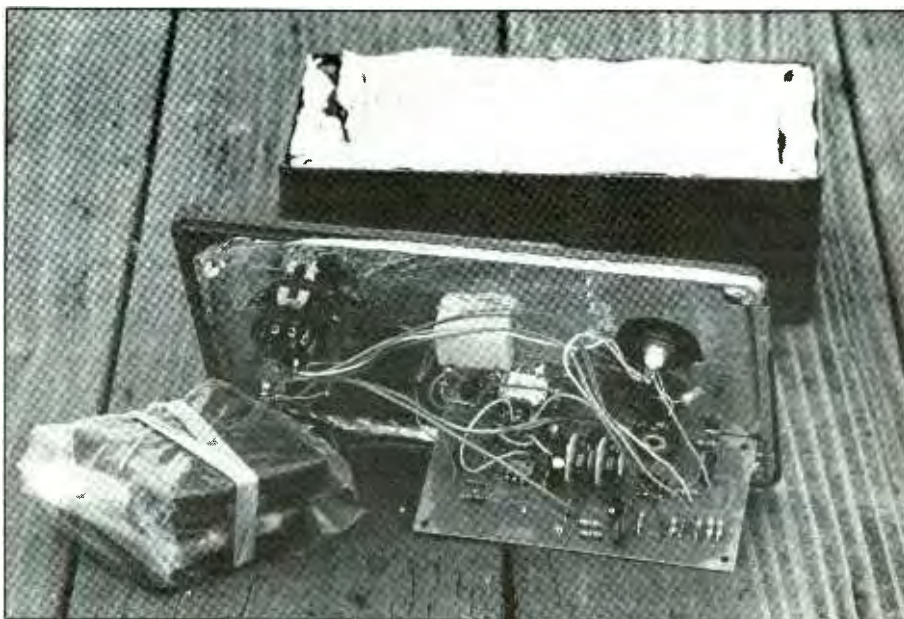
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and BP1 GROUND. Do not connect the shell of J1 to anything for this test. Adjust the setting of R10 for a full-scale meter pointer deflection. Now apply a 1-volt rms ac signal (60 Hz is okay) in place of the dc signal and adjust the setting of R9 for full-scale meter pointer deflection. Your instrument is now calibrated. Mount the front panel in place to complete construction.

### Using the Project

You will find this instrument to be extremely sensitive, even if you use an unwound paper clip instead of an antenna or input cable. To measure potentials greater than 1 volt ac or dc, you must use an external voltage divider. You can make such a divider with either high-value resistors or capacitors, the latter being preferable. Do not attempt to directly measure potentials that exceed 1 volt; if you do, IC1 may be damaged. Also, do not touch the input cable to objects that are charged to a high voltage. In some cases, it may be advisable to connect the ground cable to an earth ground like a cold-water pipe.

Simple voltage dividers that can be



This prototype of the finished project is housed inside a plastic box. Note that aluminum foil on all interior surfaces of the enclosure provides the required shielding.



## 100,000-Megohm-Input Meter (from page 31)

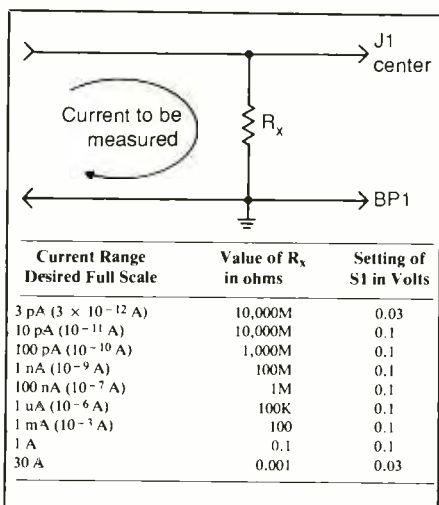


Fig. 8. The setup for making current measurements with the project.

used with this project are shown in Fig. 7. The capacitive divider illustrated in (A) has the advantage of drawing no steady dc current from the circuit under test. However, with the input resistance to the project at *J1* being finite, the dc voltage across *C2* in Fig. 7(A) will gradually drop even if input voltage to *C1* is kept constant. Therefore, you must make sure that *C1* and *C2* are discharged before reading the voltage and immediately take the reading after connecting *C1* to the unknown voltage source.

The project has about 12 picofarads of input capacitance. This should be taken into account when making ac measurements. The electrometer's frequency response is about 10 Hz to 10 kHz, allowing it to be used for making low-level audio measurements. However, keep in mind that the project's capacitive input impedance is a limiting factor at very-high impedances. Bear in mind that 1 picofarad of capacitance is a 159-megohm reactance at 1,000 Hz. Therefore, at very-high impedance, this is not a negligible consideration.

Figure 8 illustrates the setup for making current measurements with the electrometer. It also details what settings to use for various cur-

rent/resistance values. When measuring currents, be sure to connect the instrument exactly as shown.

When measuring static-electricity charges, it is perhaps best to do so by proximity, using an "antenna" made from a straightened paper clip plugged into the center contact of the INPUT connector. Do *not* make a direct electrical connection to the antenna or a cable plugged into the INPUT jack when making static-charge tests. If the charge is too high, it will overload the electrometer and possibly even damage the MOSFET input to the op amp.

If you wish, you can perform a number of interesting experiments in electrostatics and high-impedance phenomena with this instrument that are impossible to do with general-purpose instruments. Its positive- and negative-scope provisions can identify the polarity of a static charge, for example. **ME**



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