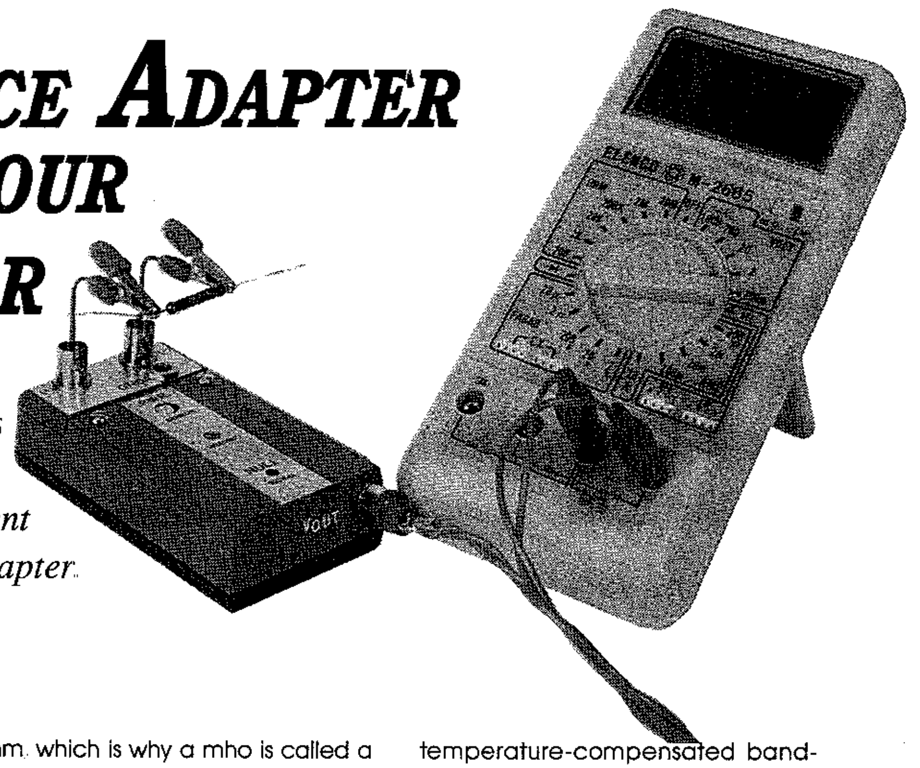
BUILD A CONDUCTANCE ADAPTER FOR YOUR MULTIMETER



Extend your digital multimeter's range dramatically to include resistance in gigohms and current in picoamps with this simple adapter.

KIP CAMPISI

Have you ever tried to make an accurate, stable measurement on a resistor with a value over 10 megohms? Are you in need of an instrument to measure very low leakage currents in insulators or semiconductors? Both of those tasks become trivial with the Conductance Adapter discussed in this article.

If you have access to a 4-½-digit multimeter, you can use the Conductance Adapter to measure a 1-gigohm resistor—that's right, 1 *billion* ohms—with a resolution of 1%, and to measure currents down to 10 *pico*amps. You can also use a 3-½-digit multimeter; however, the resolution obviously will be reduced. You can either use the built-in temperature-compensated 1.000-volt reference or use an external voltage reference of your choice. The circuit is extremely stable, and does not suffer from noise like a standard ohmmeter working at high impedances.

Measuring Conductance. Because working with a large conductance value is easier than working with a small resistance value, measuring conductance rather than resistance is much more convenient when the current flowing through a device being measured becomes very small. Conductance is measured in *mhos*. A mho is the reciprocal of the resistance unit ohm, which is why a mho is called a mho: it is "ohm" spelled backwards.

The Conductance Adapter is so sensitive that precautions have to be taken to get an accurate measurement. Ordinary test probe leads just lying on the bench or across each other will show significant leakage currents due to their less than perfect insulation, which acts like a conductor at the extremely low currents needed to measure high resistances. The same can be said for printed-circuit board material, flux residue, and most plastics and other materials used as insulators. The only two insulators that can be trusted in the picoamp range are air and Teflon, which will both be used in the mechanical and electrical construction of the Adapter.

Incidentally, there is a new name for the mho, the *siemen*. Note that 1 mho equals 1 siemen. There is no change in definition of the unit—only its name. Since the abbreviation for siemen, "S", is easily confused with that for seconds, "s", we will use the older term in this article.

How It Works. The schematic diagram in Fig. 1 shows how simple the circuit actually is. A 1.000-volt reference is buffered by IC1, a TLC271, and is connected to J1 for use when measuring conductance. The voltage reference is derived from IC3, a 1.25-volt temperature-compensated bandgap reference. The current drop developed by the component under test at J1 and J2 is converted by IC2 to an output voltage that can be displayed on a digital voltmeter. The output voltage is limited to a maximum of 2.0 volts and a minimum of 1.0 volt. With the inverting input of IC2 at "virtual ground", that means the maximum input current that can be measured is −2.0 microamps.

In reading the conductance of an unknown resistor (labeled "R_x" in Fig. 1), −1.0 volt is applied to J1, with J2 being at virtual ground. Based on the maximum input current that can be converted by IC2, the smallest resistance that can be measured is 500,000 ohms. The values chosen for the circuit generate a conductance reading of 1.0 micromho-per-volt, or 1.0 nanomho-per-millivolt output. A 1.0-million-ohm resistor will have a conductance of 1.0 micromho, or 1000 nanomhos. A 1.0-billion-ohm resistor would be equal to 1.0 nanomho.

The current-to-voltage conversion is set by R10, which gives an output of 1-volt-per-microamp, or 1-millivolt-per-nanoamp. The unit you select for R10 should have as high a tolerance as you can find. Standard 5% units will not do—the lowest tolerance you should use for R10 is 1%. That value is easily purchased from various mail-

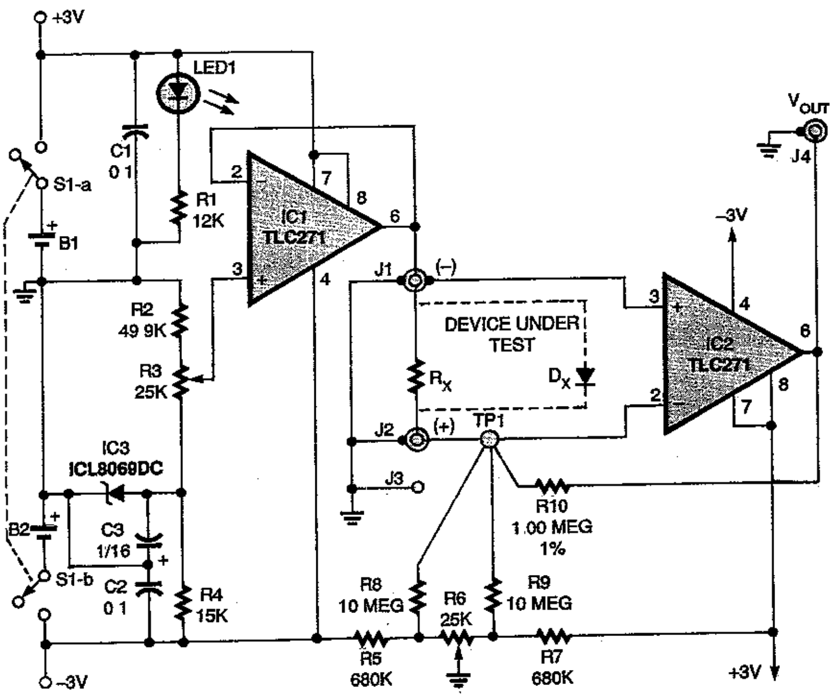


Fig. 1. The schematic diagram for the Conductance Adapter shows how simple a circuit is needed to accurately measure very high resistances and very low currents.

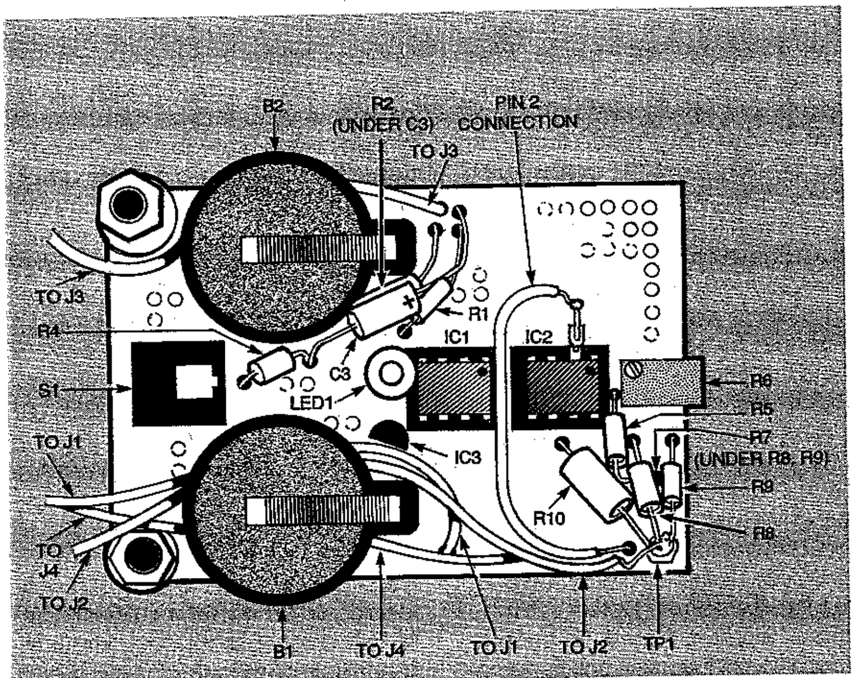


Fig. 2. Here is the top side of the Conductance Adapter. Because of the circuit's sensitivity to very high resistances, only Teflon-insulated wires should be used or the Adapter will not work properly.

order firms. For best accuracy, a 0.1% tolerance resistor is desirable. Unfortunately, a tolerance that tight is difficult to locate.

Power Supply. The ±3-volt power for the Conductance Adapter is supplied by two 3-volt lithium "coin"-type batteries installed right on the board in suitable holders. Since the total current draw for the Conductance Adapter is less than 150 microamps, the batteries should last a very long time. A "super-bright" LED is used for LED1, with the current through LED1 limited by R1. In order to keep current

PARTS LIST FOR THE CONDUCTANCE ADAPTER

SEMICONDUCTORS

IC1, IC2—TLC271 CMOS operational-amplifier (Mouser 511-TS271CN)
IC3—ICL8069 Band-Gap Reference integrated circuit (Mouser 570-ICL8069 DCZR)
LED1—Red LED, super-bright, T1 case (Mouser 509-EBR3368S)

RESISTORS

(All resistors are ¼-watt, 5% units unless otherwise noted.)
R1—12,000-ohm
R2—49,900-ohm, ¼-watt, 1%, metal film
R3, R6—25,000-ohm, multi-turn trimpot, cermet
R4—15,000-ohm
R5, R7—680,000-ohm
R8, R9—10-megohm
R10—1.00-megohm, ¼-watt, 1% or better, metal film (see text)

CAPACITORS

C1, C2—0.1µF, ceramic disc
C3—1.0µF, 16WVDC, solid tantalum

ADDITIONAL PARTS AND MATERIALS

S1—DPDT push-on/push-off or toggle switch
TP1—Teflon-insulated stand-off (Johnson STD-1, STD-2, or similar)
J1, J2—Teflon-insulated BNC jack (Pomona 4160)
J3—Banana jack
J4—RCA-style jack
B1, B2—CR2032 3-volt lithium batteries
Printed-circuit board (Radio Shack 276-150 or similar), 3/8- to 1/2-inch threaded spacers, screws, 22-gauge Teflon-insulated wire, enclosure, 14-gauge solid bus wire, alligator clips, 8-pin IC sockets, breakaway socket, battery holders, RCA-style plug

NOTE: All of the semiconductors, batteries, and battery holders are available through Mouser Electronics, Tel: 800-346-6873. Teflon-insulated BNC jacks and plugs are available from ITT Pomona, 1500 East 9th Street, Pomona, CA 91766-3835, Tel 1-800-ITT-POMONA. Teflon insulated wire, standoffs, and all passive components are available from Johnson Shop Products, P.O. Box 2843, Cupertino, CA 95015, Tel: 408-257-8614.

consumption to a minimum, LED1 is set to only put out a modest (but still discernible) glow.

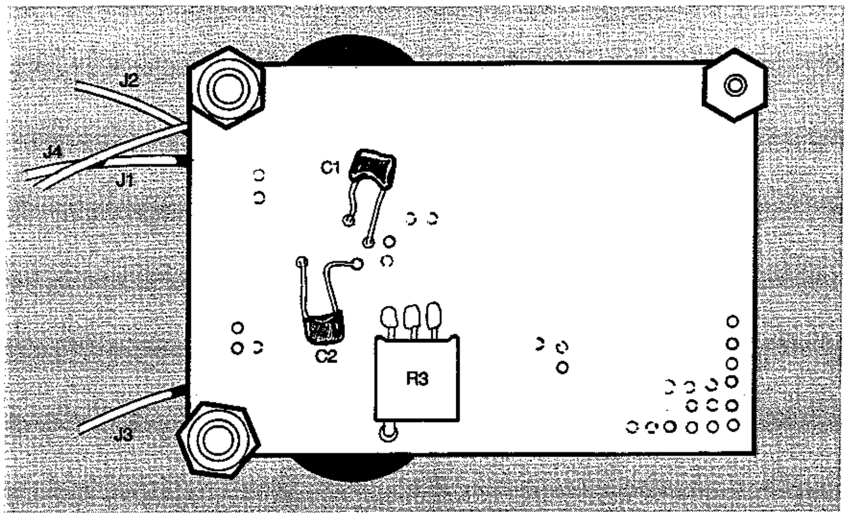


Fig. 3 Here is the bottom side of the Conductance Adapter. If you use a slightly larger board, these components can be placed on the top side along with the rest of the components.

Construction. The Conductance Adapter was built on standard perforated construction board. The actual placement of the parts is not critical, but if you want to follow the parts placement used in the prototype, that information is shown in the photographs of Fig. 2 (the component side) and Fig. 3 (the solder side). The balance of this article will assume that your board will resemble the author's prototype.

The board should be cut to fit the enclosure before starting construction. The board shown in Figs. 2 and 3 measures 1-7/8 inch × 2-3/4 inch.

Begin by installing the battery holders, the two 8-pin IC sockets, and potentiometer R6. You have the option of either mounting S1 on the board, or panel-mounting a slide or toggle switch on the case. Capacitors C1 and C2, along with resistor R3, are mounted on the underside of the board as shown in Fig. 3, but you may mount those components on top if you prefer.

Locate and install a Teflon-insulated standoff which has a solder terminal on its top near R6; that standoff will serve as TP1. Attach one end of resistors R8, R9, and R10 to TP1 with a mechanical crimp—**do not** solder them yet. Connect the other ends of those resistors to the appropriate locations as shown in Fig. 1, keeping the component bodies from touching the board. Attach two Teflon-insulated wires to TP1, then solder the joint. Make one wire long enough to reach J2, and the other long enough to reach pin 2 of IC2. Install one pin from a break-away type SIP socket on the wire for pin 2 of IC2. That socket pin will later be connected to pin 2 of IC2. Finish the board by installing the remaining components and make all of the interconnects on the board. Be sure to use Teflon-coated wires for insulated wires, and leave the lengths long enough to reach the panel-mounted components.

The case can be any convenient hand-held enclosure that will hold the entire circuit. Locate and install the four jacks and power switch. Drill clearance holes to mount the board and for LED1 and the adjustment screw of R6. If you have mounted S1 on the board instead, drill a hole for the push-button to protrude. Make sure that you use Teflon-insulated BNC jacks for J1 and J2.

Connect the board to the panel components and install IC1 in its socket. Install IC2 as follows: Carefully bend pin 2 out and away from its package so that it is at right angles to the rest of the pins. Install IC2 in its socket and slip the socket pin from the lead going to TP1 onto pin 2. That isolates pin 2 from all leakage paths. Inspect all of your connections and install the board in the enclosure with 3/8- to 1/2-inch spacers and screws.

Test Leads. Special attention must be given to both the input and output leads used on the adapter. Coaxial cable is NOT recommended for those leads, as the capacitance of the cable can cause oscillation at the outputs of IC1 and IC2. Prepare an output cable by twisting together a pair of foot-long Teflon-insulated wires. Attach one end of the twisted-wire pair to an RCA plug, and the other end to plugs that match your DMM's input sockets.

The input leads can be made similarly, using twisted pairs terminated in Teflon insulated BNC plugs. An easier method is to attach a single wire to a 1-inch length of 14-gauge bus wire. Pulling a conductor out of some 14-gauge Romex-type house wiring from a home-improvement center or hardware store will work fine for that. The 14-gauge wire will easily slide into the center of the BNC jack. If you need to, you can plug a separate ground lead into J3, but be sure to use only Teflon-insulated wire for all of your cables, and don't allow the component under test (or the hooks or clips used to connect it) to touch any medium except air. A simple but effective test jig can be made from two pieces of 14-gauge bus wire, about 2- to 3-inches long, with a small alligator clip soldered to one end of each and inserted into the BNC jacks. That arrangement works well when testing components such as resistors or diodes individually.

Calibration. To calibrate the Adapter, connect a DVM between J1 & J2 (the input jacks), turn on the Adapter's power, and adjust R3 (CAL) for a reading of exactly −1.0000 volts. Now connect the output from J4 (the RCA-style jack) to the DVM and adjust R6 (NULL) for a reading of 0.00 millivolts. Check the "null" reading occasionally—temperature drift may cause it to shift 10 to 20 microvolts.

Operation. The advantage to using the Conductance Adapter in measuring high impedances rather than an ohmmeter is that the Adapter applies a constant voltage to the device under test and then reads the resulting current. That is opposite to how an ohmmeter does the same task. Because of that, the Conductance Adapter has much better noise suppression. When using the Adapter,

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BUILD THE PCDRILL

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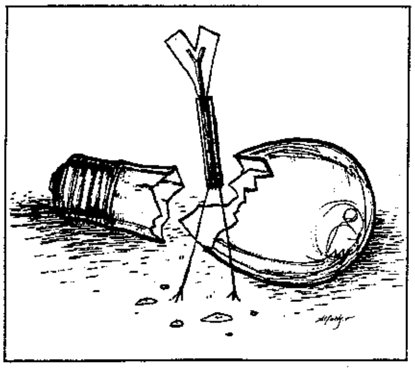
the compiled version (Look for PCDRILL.ZIP on the Gernsback FTP site —ftp gernsback.com/pub/EN)

Select each of the first four options in turn The table and the drill should move in the selected direction. The test program moves the table and caddy in "slow motion." but real applications (like the one that will be presented next time) produce quicker and smoother movement If either motor stalls and the table or drill does not move, the associated guide is probably jamming against the track Adjust the guide and try again Repeat the process until both table and caddy move smoothly throughout the entire range of travel.

Several tweaks can improve the performance of PCDrill For instance, apply paste wax to all moving wooden surfaces, including the drill caddy sides and drill slides. All moving metal surfaces should get a thin coat of light oil That includes the driver nuts, threaded rods, and aluminum angle tracks. Those lubrication efforts will decrease friction and make for smoother operation.

Next time we'll align PCDrill, and introduce the application program and all of its functions We'll also look at the application's data file and explain each of its entries, including the Speed entry that maximizes speed of movement We'll also provide details for building a 5.75-volt power supply from scratch, and use PCDrill to fabricate its own PC board. To round things out, we'll provide an AC wiring option that allows you to energize the drill only during actual drilling, as opposed to having the drill run continuously. See you then. Ω



CONDUCTANCE ADAPTER

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keep the input leads short to avoid 60-Hz line pickup. Although the ICs used in the Conductance Adapter are ESD protected, you should avoid letting any static discharges into J1 or J2.

Connect a 1-megohm resistor to J1 and J2 and the output on a DVM will be 1.000 volts, which is equal to 1.00 micromho or 1000 nanomhos. A 300-megohm resistor will read 3.33 millivolts, which is equal to 3.33 nanomhos A diode (shown as D_x in Fig. 1) might show a reading of 2.55 millivolts when reverse biased That is equal to a leakage current of 2.55 nanoamps Leakages can be measured down to 10 picoamps. If you need a voltage greater than −1.00 volt for your tests, do not make any connection to J1. Apply an external voltage between the ground jack (J3) and the free lead of the device being tested Do not let any voltages applied to J2 exceed 3 volts, or IC2 will be destroyed Ω

USING THE NE602

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If the signal is an SSB signal, then the LO is set at a frequency of 2.5- to 2.8-kHz higher or lower than the IF, depending on whether you want to demodulate an upper-sideband (USB) or lower-sideband (LSB) signal.

The input signal circuit in Fig. 15 uses a 455-kHz IF transformer of the sort used for transistor radios (see Digi-Key or Mouser catalogs for suitable types) The transformer that you want to use for T1 is the type that has a resonant secondary with a tapped inductance The LO circuit uses the same type of transformer as the input, but configured as a Hartley oscillator.

The output signal is at audio frequencies, and is filtered by an R-C network The audio output is balanced, so it should be fed to a differential audio amplifier such as an op-amp.

NE602 "Universal" Project Board. We've included a printed circuit pattern for a "universal" project board based on the NE602 The on-board circuitry (Fig 16) is limited to the DC power connection, which is regulated by a three-terminal IC voltage regulator. All other functions can be set by you to make any project that you want There are a large number of multi-pad stand-alone connections for various components depending on the circuit that you want to make, as well as positions for three six-pin standard shielded coils of the sort manufactured by Toko and sold by Digi-Key You can also use these same holes for mounting home-brew toroid inductors Figure 17 shows the parts placement of the universal project board The universal NE602 board can be bought from FAR Circuits, 18N640 Field Court, Dundee, IL, 60118 for $4 plus $1.50 shipping for every four boards ordered (*i.e.* 1 to 4 boards shipped for $1.50) IL residents will have to add appropriate sales tax.

Now you've seen how well-behaved the NE602 is Here is an RF chip that will function in a variety of applications from receivers, to converters, to oscillators, to signal generators With the universal project board, the task of testing a new design based on the NE602 becomes "duck soup." Ω